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LIST OF PLATES.

ERRATA.

Paper II., page 22, lines 9 and 10, *for* θ *read* ϑ.

Line 12, *for* $\frac{T_1}{6}\,\frac{4T_2}{10}$ *read* $\frac{T_1}{6}+\frac{4T_2}{10}$.

Page 24, line 27, *for* 3 inches *read* 3 feet, *for* 2 inches *read* 2 feet.

CORRECTION.

SURFACE WELLS AND THEIR YIELD.

BY CAPT. L. H. CLOSE, R.E.

The following should be substituted for *Fig.* 8 on page 28 of the above pamphlet :—

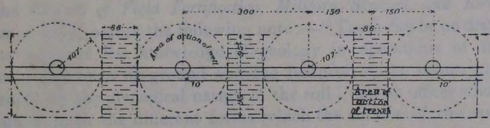


Fig. 8.

(*See also Plate II. at end*).

be considered complete unless it contained some amount of geo-logical information." Again, in Lord Wolseley's *Soldier's Pocket Book*, reference is made at a later date to the value of some amount of geological knowledge to the soldier.

I may, therefore, take it as admitted by all competent authorities that some acquaintance with the leading principles of geology is of decided advantage, not only to the military engineer, who has to construct earthworks of different kinds, but also to those military officers who have to make reconnaissance surveys. Indeed, it is useful to almost anybody who has anything to do with groundwork. I may accordingly confine myself this evening to the endeavour to show some of the special ways in which such a knowledge comes in.

As you are all no doubt aware, geology deals with the nature and structure of the rocks forming the crust or superficial coating of the earth. And it takes into account not only the materials of which such rocks are composed, but likewise their relations to one another, their relative ages, the disturbances they have undergone, and the extent to which they have been worn away by the action of rivers and atmospheric agencies. It is due to the effects of subterranean movements and to the wearing power of atmospheric agencies that the surface of the earth has assumed its present form and contours; and the reason for the existence of such can only be discovered through geological investigation.

I must assume, in the first place, that you are aware that the rocks of the earth's crust are divisible into two great divisions, according to whether they have been laid down as sediment from water, or thrust up from the interior in a molten or plastic condition. To the former class, which includes such common rocks as sandstone, clay, and limestone, is applied the name of *sedimentary*, and to the latter, as represented by granite and basalt, that of *plutonic*.

Plutonic rocks are met with in solid masses, structurally more or less similar from the surface to such depths as we are enabled to penetrate, and, therefore, presenting few further features of interest to the engineer, who knows that when he comes to them he has to deal with the same intractable material throughout.

Very different is the case with the sedimentary rocks, which, although originally laid down in water, have now been upraised so as to form a very large proportion of the dry land of the earth. These form layers, or strata, superimposed one over the other; and although, as in the case of the chalk in this neighbourhood, they may be composed of the same kind of rock for a very great thickness, sooner or later they are underlain or overlain by beds of different mineralogical composition and hardness. Moreover, although originally deposited in an approximately horizontal plane, they have in most cases been more or less disturbed or tilted, while much of them has been worn away by the action of rivers and rain from extensive areas of the earth's surface. It thus comes about that bold cliffs or escarpments have been formed along certain definite lines, while in adjacent districts plains of softer rocks have been exposed to view by the removal of the beds by which they were formerly overlain.

Here, then, we are face to face with one very important fact, namely, that the contours in a country composed of disturbed sedimentary rocks are coincident with the geological boundaries, as is well exemplified in this neighbourhood. And the importance of a due recognition of this fact to members of the military profession can scarcely be overstated. For it must be borne in mind that a geological formation forming a line of escarpment must, *ipso facto*, be of a different composition from the beds forming the plain at its foot, the former being always harder than the latter. And how important such a feature is in regard to the construction of roads and the passage of troops across country, I need not remind a professional audience.

If, then, a contoured map of a new country were laid before you, you would at once be able to say where some, at least, of the geological formations came to an end to be replaced by others ; and if such map were also coloured geologically, you would have further important information as to the nature of such country, and its practicability or impracticability for military purposes, if only you could read the meaning of such colouring.

There are, however, several ways of arriving at a more or less exact conclusion as to the capacities and products of a country of this nature. The professional geologist would first of all set about discovering fossils in one or more of the constituent beds, by means of which he would at once be able to identify the relative ages of such beds ; for each period of the earth's history had its own particular kind of animals and plants, by the remains of which the period to which any series of rocks belonged may be determined.

But this kind of knowledge is not possessed, nor indeed is it absolutely essential to every military engineer. Much may be done with far less complete information. And here I must take it for granted that gentlemen in this room are acquainted with the appearance and nature of some of the commoner kinds of sedimentary rocks, such as limestone, sandstone, clay, and slate. Hence without any more information as to their age, except that the higher beds must necessarily be newer than those by which they are underlain, the mineralogical composition of the various strata may be roughly determined.

The next thing to find out is the "lie," or inclination of the different beds. And here I must call attention to the necessity of familiarity with a few technical terms. First of all we have the *dip*, or inclination which a bed forms with the horizontal, and the point of the compass to which such dip inclines. Care must, however, be taken to see from what direction we are looking at the beds, as the dip when viewed from the outcrop may appear horizontal, when it is really inclined. At right angles to the dip is the *strike*, or longitudinal extent of the strata, as displayed in the map of England; such strike coinciding with their line of escarpment or outcrop. When strata are raised in a saddle-shaped line of elevation, the strike of such saddle is known as an *anticlinal* axis; and conversely, when they form a trough, the name of *synclinal* axis is applied to their line of strike. The stretching of the strata in such an anticlinal line renders them easily worn away, and accordingly such *anticlinals* are frequently denuded into valleys. On the other hand, synclinals, which originally formed a trough, have been compressed, and consequently resist wear. Hence synclinal hills are not unfrequently the final result of denuding agencies.

Now let us turn to the practical importance of a knowledge of their features. In hills where the strata are *horizontal*, that is, without any perceptible dip, it will be evident that if the edge or outcrop of any particular bed be found on one side, it will occur at the same level on the other. And that when such bed is hard and affords a good metal, a road may easily be carried round the level on the contour of that particular bed. On the other hand, it will be likewise evident that if we take the road across the hill it will traverse the edges of the various beds in ascending series, and in the reverse order in descending. And it will thus be manifest that if the beds consist of an alternation of hard and soft rocks, the better course for the road would be round the hill.

Again, suppose the strata exposed on the side of the hill be dipping towards its interior, or in other words to form an escarpment, the outcrop of one of the harder layers would be equally available for a line of road along the hill, and would indeed be better for this purpose than in the former case, as the drainage would be good. Moreover, there would be no danger of the overlying beds slipping on those below, so that blasting or excavating might be safely resorted to.

On the other hand, the road could not be carried round the other side of the hill, for not only would the particular stratum be found at a lower contour, but it would be dipping *away* from the centre of the hill, so that there would be great danger of the overlying beds slipping, while the road would be rendered rotten by the drainage flowing over it. When taking a road along a valley, it will therefore be evident that the side in which the rocks dip away from the valley should be selected for operations.

These observations apply with equal force as regards the selection of sites for building in rocky districts. In cases where the rocks above dip towards the building site, great care should be exercised that they are not underlain by a bed of clay, on which they would be likely to slip in very wet seasons. Sometimes the edge of the cliff may be concealed by débris, and then it is important that geological observations should be made on the same line of strata at a distance where they are freely exposed.

And here it may be mentioned that having fixed the position of one prominent bed of rock along a scarped hill, it will be unnecessary, in a geological reconnaissance, to ascend the hills every mile or so, as it may be taken for granted that the same features will continue right along the strike.

In another type of hills the strata of the two sides will be found to dip towards one another, this being the remnant of an original synclinal trough to which allusion has already been made. As regards roads, the observations made on hills with the beds on one side dipping towards their centre will apply also in this case, but to both sides of the hill. Moreover, the trough-shape, or, still better, the basin-shape, as is sometimes the case, causes all the water that falls on the strata to percolate towards the centre of the hill, when it descends until stopped by an impervious stratum. And it is, therefore, evident that there is every chance of finding water in such situations. Indeed, in the old days, hills of this type almost always formed the sites of hill-forts, as was exemplified by Schamyl's last stronghold in Daghestan.

Precisely opposite to synclinal hills are anticlinal hills, where the strata form a saddle, and where, of course, it would be futile to attempt to find water. Nevertheless, the want of knowledge of these most elementary features in geology has permitted of well-sinking in such situations, as was exemplified some years ago by a boring in the chalk of Portsdown Hill.

In the foregoing observations attention has been chiefly directed to the importance of dip in practical geology ; but when speaking of the carrying of roads along a hillside on a particular bed, it will be understood that we are following on the line of strike. And a few words may now be said as to the important part played by that feature. Firstly, as regards roads, it will be obvious that by following the strike much less difficulty will be experienced in construction than by running across the same, when not only are hills and valleys encountered, but rocks of different composition are met with, some of which may be exceedingly bad for carrying the materials of a road. This fact seems to have been well known to the ancient Romans in this country as the result of practical experience, since many of their roads follow the line of the hills. Apart from the physica difficulties of another course, it is also advisable to remember that when a good stratum for a road has been discovered, that is to say, one that will not only afford a good foundation, but will likewise supply material for metal, and building materials for bridges, etc., it is from all points of view advisable to follow the strike of that particular formation. Of course, in selecting a line for a road, the engineer would prefer to find a rock not too hard to be easily excavated, and also sufficiently firm to afford a solid floor for his metal. And while the line of a synclinal trough would obviously be the worst, the crown of an anticlinal axis would clearly be the ideal.

Many of these remarks will apply also in the case of canals, where, however, the line of a synclinal would be much superior to that of an anticlinal. An even better line would, however, be a clay flat at the foot of an escarpment of limestone or sandstone rock, since springs would be almost certain to flow along such a line; two essential features in canal construction being an impervious formation for the bed of the channel itself, and the accession of a supply of water from feeding-springs during its course.

In regard to the construction of trenches, an acquaintance with the direction of the strike and dip of the rocks to be operated upon is also of the highest importance. By this means alone can it be determined where soft and easily worked beds are to be met with, and likewise where hard impracticable rocks come in. In cases where the strike of the strata runs towards the position of the place to be sapped, the relative position of the hard and soft rocks can, of course, be determined from the immediate front. If, on the other hand, the strike runs transversely to the position, the relations of the beds can be made out from some more or less distant point on one side or the other.

An instance in illustration of the above is stated by Sir E. Hamley to have occurred during the siege of Sebastopol. At the commencement of operations the French found themselves in soft ground, which could be dug out like garden soil; whereas the English trenches were dug in hard rock, mingled with flints. And a geological map will show that Sebastopol stands on the line of division between soft tertiary and hard cretaceous rocks, a feature which ought, of course, to have been taken into account when planning operations, but which seems to have been totally neglected.

In the selection of sites for forts, synclinal hills are to be preferred to anticlinals, on account of the facility for obtaining water already alluded to, and also because of their steeply scarped sides.

For camping grounds, as you are well aware, the two most essential features are good water and good drainage. And whether the water supply be derived from a river, or from wells, it is equally important to see that it be not contaminated by the drainage. In this connection the lie of the rocks is all important. And if the camp be situated on high ground on the outcrops of tilted strata, care must be taken not to tap the same strata in the low grounds where they flatten out and become horizontal. Theoretically, gravel and sand form the best strata on which to camp; but if, as is not unfrequently the case, a gravel bed occupies a hollow, and is underlain by a stratum, or "pan" of clay, it may form the very worst site. In a wet season, at least, the base of such a gravel bed is full of water, and any sudden fall of rain may render the whole basin saturated, and thus reduce the camp to the condition of a quagmire. If such sites be selected, the only thing to do is to pierce through the underlying clay pan, in order to afford the contained water a means of escape; then the ground will become perfectly safe, and suitable for the purpose required.

The mention of water in this connection leads naturally on to the important subject of water supply, and well-boring and sinking. In this subject, which is one of considerable difficulty to realize fully, geological knowledge is of prime importance, and for want of it ludicrous mistakes have frequently been made. It may be stated in the first place that all rocks of a porous nature are generally saturated with water at a variable depth below the surface of the earth, and that owing to capillary attraction such stored water rises in the hills very considerably above the level of the valleys beneath, the height of such stored water varying, of course, with the amount of rainfall. But it is not only porous and permeable rocks, such as chalk and sandstone, that become thus saturated with water. A hard impermeable limestone, such as the Kentish rag of Maidstone, if interpenetrated by a number of fissures and joints, or having a few sandy beds interstratified, is capable of becoming as good a water-bearer as a porous rock. But, especially in the case of tilted rocks, which are those with which we have generally to deal, one, or rather two, essential conditions must obtain. Firstly, the pervious water-bearing stratum must be underlain by an impervious clay bed to prevent the water from escaping below ; while, secondly, it must be covered or overlain by an equally impervious stratum to prevent leakage from above. Such tilted strata form, as a rule, portions of synclinal and anticlinal folds, and it is, of course, in the synclinals that the water accumulates. But the amount of water contained in such pervious water-stratum depends largely on the nature of the exposed surface of such stratum. If the exposed surface forms the side of a cliff, in which only a very small area of the rock can act as a collecting ground, then, of course, the supply of water is limited. If, on the other hand, the exposed collecting area is large, and more or less flat, then the conditions are of the most favourable type, and the stratum will become supersaturated with water. Such a condition of things exists in this district, where the country in the neighbourhood of Maidstone forms the great collecting area for the deep water supply of the London basin. The water-bearing stratum is the one technically known as the lower greensand, consisting locally of the rocks termed the Aylesford sands and the subjacent Kentish rag ; the Weald clay, which underlies the whole formation, stopping leakage from below, as does the superincumbent gault clay of Burwell above.

As the same series of strata are met with in the reverse order on the other side of London in the Chiltern Hills, it was naturally assumed that the London basin formed a perfect synclinal trough, as does that of Paris, and consequently that if a bore were put down to tap the lower greensand in London, the water would rise to the level of the surface, or above—in fact, nearly to the level of the outcrop of such beds. As a matter of fact, such rise does, or rather did, occur in the basin, but, as was shown by Meux's boring in Tottenham Court Road, it was due to the lower greensand ending abruptly against a ridge of impervious older rocks, which effectually prevented the water from penetrating further. A true artesian well is sunk in a synclinal basin, and when other causes do not interpose, the water will rise, as already said, nearly to the level of the outcrop of the strata from which it is derived.

A fault or dislocation of the strata in a synclinal basin will, however, produce a natural artesian well, causing the water to rise up along the side of the fissure and to flow out on the surface. The great Boxwell spring in Gloucestershire, which discharges 2,000,000 gallons a day, is an example of this. It brings up to the surface the waters collected in the oolitic limestones of the Cheltenham district, which are prevented from escaping below by the underlying impervious lias clay. Faults are, indeed, so important both in well sinking and mining, as well as in all kinds of earthworks, that a few minutes must be devoted to their consideration. They are dislocations of strata, where one set of beds has been lowered down against another part of the same set. There may, however, be faults forming a set of steps. Very frequently, where a fault occurs, the edges of the beds that have dropped down are turned up against the mass alongside of which they have fallen by dragging against it in their descent.

It will be obvious that it would be perfectly idle to bore for water in vertical strata; and also that a full knowledge of the dip and relations of the strata of any particular district are absolutely essential before any well-sinking or boring operations can be undertaken with any definite hope of success.

In a synclinal basin artesian wells may be bored into a number of water-bearing strata lying one below the other. But it must be remembered that if we are getting a good supply of water from one bed, the putting down a bore into a lower one may very frequently drain the former, or, as the well-diggers say, let the bottom out of the well. It will further be obvious that to whatever depths permeable beds in a basin descend, the water will follow until stopped by their thinning out, a fault, or some other cause; so that the permeable beds will become completely saturated below the lowest level of escape. But, as already said, the resistance of the rocks to the passage of water, together with capillary attraction, combine so to raise the level of the water in the hills that they contain a large bulk above the lowest escape level. The further away from the valleys, the higher will this level of storage water become. When this storage water stands at its normal level, it escapes at the foot of the hills as permanent springs; but when it is above the average level, it gives rise to those intermittent springs known as *bourns.* Lines of escarpment are therefore safe places to search for water.

In all the foregoing observations I have merely talked about the alternation of permeable and impermeable beds as the conditions to be noticed in regard to water supply. And in fact such can be observed with fair ease by any person of average intelligence without any knowledge of geology, properly so called. But there is another aspect of the case when geological knowledge in its highest sense must be called in. In the upper secondary rocks of England there are three distinct beds consisting of blue clay, frequently so alike in hand-specimens that it would often be very difficult to say from which beds they were taken. But these three beds have very different situations in the geological series, the first, or London clay, being above the chalk; the second, or gault, below the chalk; and the third, or Wealden, below the lower greensand, which itself underlies the gault. And it is obvious that in any operations for the purpose of obtaining water it is essential to be aware on which of these three clay beds the engineer is located. As an instance of this, the case may be cited of a civil engineer who put down borings (1) in the London clay near London, (2) in the gault near Redhill, and (3) in the Weald clay near Maidstone, under the impression that he was all the time in one and the same stratum! In the one case he would have had to bore 400 feet, in the second 100 feet, and in the third 600 feet.

Now how is this discrimination to be effected? In some cases it may of course be determined by means of the superposition of the different beds. But very often this method is impracticable, and even when available does not tell us the exact age of the different formations. This can only be done by means of fossils, or the imbedded remains of animals and plants. As already briefly mentioned, every stratum has its own particular series of fossils, by which it can always be recognized, in spite of the variations which occur locally in its mineral composition. Fossils, in fact, may be likened to the styles characterizing different architectural periods; with the difference, however, that whereas architectural styles fix the absolute date, fossils give only relative dates. From the study of fossils it has been found practicable to form a classified series of geological formations. And from these it is easy to fix the horizon of any stratified formation in any part of the world. In the case referred to, the London clay contains estuarine fossils not very widely different from the types of life found on the warmer coasts at the present day; those of the gault are marine creatures of quite a different type; while in the Wealden we meet with remains of fresh-water and land animals, the latter including the gigantic reptiles known as *Iguanodon*. It cannot be denied that it is best for the practical engineer to be acquainted with the leading types of fossils characteristic of each particular bed by himself. But if this be found impracticable, the fossils themselves can be identified in a museum or by an expert, and the ages of the beds to be dealt with thus definitely fixed.

It is not only, however, in respect to water-supply that the identification of strata by means of their imbedded fossils is so important. It is equally so with regard to the search for coal and other minerals. In Europe the greater part of the workable coal is found in rocks of the so-called carboniferous period; and it is therefore of little or no use searching in beds of other ages. The whole series of carboniferous strata, of which the coal-measures form the top, are overlain by a series of red beds known as the permian and trias, and are underlain by a second very similar series termed the Devonian. Consequently, while the former may be profitably bored in the hope of coming on coal, it is obviously useless to sink shafts in the latter. From a want of geological knowledge much time and money have been spent in such futile efforts.

But it is by no means certain that coal will always be found beneath the permian and trias. For these, as a rule, overlie the carboniferous in what is termed an unconformable manner. That is to say, the latter had been tilted and denuded before the former were deposited upon them, so that it is only in certain places we come upon the true coal-measures. The carboniferous rocks also themselves often unconformably overlie the older rocks; and gaults play an important part in bringing the workable coal into an accessible position.

The one definite means of ascertaining whether we are in the true coal-measures is the nature of the fossil plants brought up in the core cut by the borer. These are for the most part quite different from the plants of later epochs, consisting of gigantic club-mosses, or lycopods (*Lepidodendron*), sigillarias, horsetails, and ferns. It was by obtaining such plants that the deep-seated coal at Dover was ascertained to belong to the carboniferous period, and was therefore likely to prove of commercial value.

Careful observations of the strata have shown that in various parts of the Continent beds much newer than the permian and trias unconformably overlie the coal-measures in certain districts. And this led to the conclusion that the latter might be found beneath the cretaceous rocks of the south-east of England; a theoretical conclusion which has been fully justified by experiment. It is of the greatest importance to determine the anticlinals and synclinals in such deep-seated beds in order to know where to sink shafts with the best hope of finding workable coal. And here it may be mentioned that the great difficulty is to determine the direction of the dip, the cores brought up by the borer showing the angle with great accuracy, but giving no clue as to the point of the compass to which it inclines.

In other parts of the world, notably India, the chief beds of workable coal are found in deposits of newer age than the carboniferous, chiefly the trias and jura; and if you have to search for coal in that country, you have first to make yourself acquainted with the characteristic fossil plants of the Gondwana series, as the formation is called, on finding which you will be sure that you are on the right horizon. This is essential, since coal is also found in certain Indian tertiary strata, but mostly in such thin seams and pockets as to be of little or no commercial value.

Another aspect where geology is of the highest importance to the military engineer is connected with the supply of building materials, under which heading may be included building-stones, brick-clays, roofing-slates, sand, and lime. Here it is of the first importance that rocks presenting a superficial resemblance should not be mistaken for one another, *e.g.*, white quartzite for statuary marble; or altered limestone for granite. Pyrite, too, has often been mistaken for gold.

Another important point is to realize that the mineralogical composition of strata is not constant in different countries, the chalk being represented in India by a red sandstone. If therefore we find a good building-stone in a particular stratum of one country, the odds are very great against its occurring in the same stratum in a distant one.

When the surface of a country is so covered up by superficial deposits that the nature of the subjacent rocks is not apparent, the soil itself will generally give an inkling as to the composition of the latter, from which it is of course derived. In the top soil a sandy nature will betoken sandstone rocks below, while a marly character indicates limestone. By digging down some distance into such soil fragments of the subjacent rocks themselves will generally be met with in greater or less profusion.

In regard to building-stones, the chief points to ascertain are whether they will wear well in the climate to which they are to be exposed, whether they are easy to work, and whether their position in the quarry is such as to repay the cost of working. On such questions it often depends whether stone or brick is to be the material employed. In countries where there are numerous old buildings, the rate of wear of the materials may be easily ascertained. In the absence of these, natural rock-faces and escarpments may be consulted. Where these weather into smooth faces, without tendency to disintegrate into thin flakes and split up, they may be considered to indicate a good building-stone. It is of prime importance that the stones are laid in their original bedding-planes, as it is obvious that if they are not laid horizontally, especially in the case of copings, they will be much more liable to disintegrate. Moreover, when first quarried, stones contain a considerable quantity of water, and it is therefore advisable that they should be worked into shape while in this comparatively soft condition, although they should not be used till fully hardened by drying.

In regard to the facility of working rocks, the presence and number of the so-called joint-planes should be taken into consideration. If there are two of these crossing one another, more or less, nearly at right angles to the bedding-planes and to each other, the rock will be of the best type for quarrying. And it should be worked along one face of the vertical joints and the bedding-planes. It is the absence of such joints that renders granite such an intractable material to quarry.

The best kinds of building-stones are limestones (magnesian or otherwise) and fine-grained sandstones. Compact limestones, such as the mountain limestone of the carboniferous series, are, however, too solid to work well, generally breaking with what is called a conchoidal fracture. They are, therefore, better employed for lime than for building-stones. The best types of limestones are those displaying the so-called oolitic structure, due to the concreting of carbonate of lime in concentric layers round minute grains of sand or other nuclei. These form the most perfect kind of freestone; but it is essential that the oolitic structure should be comparatively fine, as in the Bath-stone, since, if larger, and passing into a pea-grit, it renders the stone more or less liable to disintegrate. Many limestones, it may be mentioned, as the chalk, are largely composed of the remains of minute marine animals, and all limestones are, indeed, ultimately of organic origin. The presence of such organisms does not, as a rule, in any way detract from the utility of the stone as a building material.

Next to limestone comes sandstone, which, as its name implies, is formed of grains of sand of various size cemented together by silicious, ferruginous, or calcareous matter. When altered by heat, such sandstone becomes converted into quartz-rock, or quartzite, which is frequently less fitted for building than ordinary sandstone. For such purposes sandstone should be fine-grained and thick-bedded, like that of Cheshire, when it forms as perfect a freestone as limestone. The coarser kinds, or grits, are more suited to other purposes, such as millstones. Certain grits, or coarse sandstones, are used in stoves; and it is important to ascertain that these are pure, which may be done by testing in the fire. If they contain limestone, they will be converted into lime and split.

Thin-bedded, or flaggy limestones, are chiefly employed for paving; and these, like building-stones, may be found in formations of any age, those of the Yorkshire oolites being largely used in this country.

Plutonic, or igneous rocks, are of less general value as building stones, owing to the difficulty of extracting them from the quarry, as well as in subsequent working. They have, however, the advantage of great durability, and also of being capable of being laid in any position, owing to the absence of bedding-planes. In addition to this feature, plutonic rocks may always be recognized by their crystalline structure. Sometimes, as in the case of granite and gneiss, this crystalline structure is fully apparent to the naked eye; but even when the rock is fine-grained, and apparently homogeneous, like basalt and pitchstone, it can always be revealed by thin microscopic sections. In India the basalt of the Deccan has been largely used on the G.I.P. for the construction of bridges and stations; but any that shows a red colour should be rejected, as being liable to perish, owing to the presence of an undue amount of iron.

Before leaving plutonic rocks it is essential to mention how important it is to the surveyor and telegraphist to be able to recognize the appearance of volcanic rocks in the field, even at a distance. The former, if he approach too close, will have his compass deflected, while serious disturbances will result to field cables if laid on such rocks. Apart from cones, volcanic rocks are generally recognizable as forming extensive flat table-lands, like those of the Deccan, or by their intrusion in the form of dykes among stratified rocks, like the whinsill in the north of England.

The uses of granite as a building material are too well known to require special mention; but, as an instance of the importance of geological observations in a new country before undertaking constructive works, it may be noted that granite was exported from England for Government House, St. John's, Newfoundland, where the whole country is composed of that material.

As regards sources of lime, it is only necessary to recall the observations as to the necessity of guarding against mistaking altered limestone for granite, or statuary marble for white quartzite or felspar. When no limestone is to be found in a country, the shore, if in the tropics, should be searched for the presence of coral reefs, or, if in temperate climates, for shell-banks.

With a few brief remarks on slate for roofing purposes, I may bring my observations to a close. True slate, in place of dividing along the original planes of bedding, cleaves in new planes produced by pressure and heat at any angle to the latter, the bedding-planes being frequently shown by layers of different colours running across the cleavage-planes. It is only true cleaved slate which splits into the extremely fine and perfectly flat plates with which we are all familiar. Slate possessing this property of cleavage is of comparatively rare occurrence, and it can only be met with in rocks which have been subjected to a considerable amount of heat and pressure. Obviously, therefore, it would be idle to look for such slates in rocks of a loose and incoherent nature, such as those composing most of the tertiary strata of this country. There are, however, other so-called slates, such as those of Stonesfield, in Oxfordshire, which are really shales or thin flags, since they split into plates of more less marked thinness, concident with the bedding-planes. They are never so thin or so flat as true cleaved slates, although they often give a more picturesque appearance to a roof.

PAPER II.

SOME FIELD SUSPENSION BRIDGES.

By Lieutenant L. W. S. Oldham, R.E.

This subject has been discussed at considerable length in previous volumes of these papers; but of such pre-eminent usefulness is this class of bridge, and at the same time capable of assuming such infinite variety of form, that perhaps there may be points of interest in the following brief notes:—

During nearly four years at Gilgit it fell to my lot to build or superintend the building of fourteen suspension bridges of from 100 feet to 500 feet span. There were thus exceptional opportunities for testing the practical value of various modifications in design and construction suggested by previous writers.

Among these is the use of a double set of cables supporting alternate slings, as a method of preventing undulation.

The substitution of inverted catenary guy ropes below the bridge for ordinary wind-guys, etc., etc.

The three bridges to which reference is made below are:—

1. The Gilgit bridge over the river of that name. Length 520 feet in one span of 368 feet, and a half span of 152 feet.

2. Tashôt bridge over the Hunza river. One span 304 feet

3. Chamogah bridge over the Gilgit river just above its junction with the Indus. One span 432 feet.

Service Conditions.—The general conditions under which these bridges were built, approximate to those met with on active service.

The entire absence of material on the spot. The difficulties of transport by pack animals for 450 miles of mountain roads from the nearest railways to site of work. The scarcity of labour, and the imperative necessity of getting the work done somehow, are all characteristic features of field engineering.

Time was not so rigorously limited as is usually the case on service. But on the other hand the want of funds was an abiding difficulty; and passes closed by snow for nine months in the year severely penalized any want of foresight.

Gilgit Bridge.

Site.—The best site that offered was not a good one, and necessitated a bridge of great length. *Plate* I. is a general view of the completed bridge from a photograph. *Plate* II. gives a section of the river bed, and the bridge in elevation.

It will be seen that the river at summer flood level has a width of about 350 feet.

The channel, however, which the stream has cut is 500 feet wide, with vertical sides about 20 feet above ordinary flood level.

It was decided to take the bridge across at this level from bank to bank with a central pier and frame as shown in the plate.

The reason for allowing so large a water way was that extraordinary floods occur at uncertain intervals. They are caused by a side glacier in the Ashkuman valley, some 70 miles above Gilgit, which in its advance blocks the bed of the river, forming a temporary lake.

Sometimes the pent up water gradually cuts a new outlet, in which case no damage is done. At other times the ice-dam fails suddenly from the pressure behind, and a devastating flood down the whole Gilgit valley is the result.

The bridge was designed and the pier built by Captain Fowler, D.S.O., R.E., in 1894. Work was, however, interrupted on it for a long time owing to the Chitral Expedition. The completion of the bridge thus fell to me at a later date.

Pier.—The pier, 23 feet in height, is solidly built of dry stone masonry; large blocks of undressed stone bound together with string courses and binders of timber.

Design.—The design was adopted as being the most economical distribution of the frame timbers available, these being unobtainable except at a great expenditure of labour and money.

It will be seen that the points of support are of very unequal height. The two half-spans on either side of the pier frame are symmetrical, each being 152 feet, while the remaining half-span is 216 feet.

Cables. When first built the only cables to hand were two steel cables $4\frac{1}{2}$ inches in circumference, with a breaking strain of 70 tons. Later were added on each side one 3-inch steel cable, breaking strain about 25 tons, two 2-inch steel ropes, breaking strain about 12 tons.

Traffic.—Traffic was regulated by a sentry on the bridge, and was strictly limited to 50 men or 10 pack animals at any one time.

Construction.—The details of construction present no features of particular interest, except perhaps the erection of the frame on the central pier.

There was no space on the top of the pier to put the frame together *in situ.* It had therefore to be hoisted bodily into its place. A derrick was first erected on the pier, its footing clear of the space to be occupied by the frame sill. Guy ropes, foot ropes, etc., were duly attached, the main guy being a steel rope across the river, connected by a tackle to an anchorage in the far bank. The frame, which had been put together at the foot of the pier, was slung to the derrick by two 6-inch cables made fast round the uprights, passed through snatch blocks attached to the top of the derrick, and thence to two powerful tackles. At a crucial moment when the frame had just reached the top of the pier one of these cables parted. Though it looked sound enough, it must have deteriorated considerably to break under the strain; however, thanks to preventer ropes and timbers no damage was done, and eventually the frame rested securely in its destined position.

The rest of the construction proceeded in the usual manner, and calls for no comment.

Stiffness.—The great difficulty with a light bridge of any great span is to secure the necessary stiffness. When first put up the handrail was of the ordinary post and rail type. The undulation was, however, so great in even a moderate wind that to stand near the centre of the bridge was to be reminded most unpleasantly of the deck of a channel packet in a gale.

The substitution of a light lattice girder, or rather of a handrail with lattice braces, was a marked improvement. The form used is simplicity itself, and necessitated no additional labour or iron work, questions of primary importance under the circumstances (see *Plate* II.).

The vertical catenary guy ropes below the roadway were added two years later, and were a great success. Upon these I shall have some remarks to make below.

Slings.—When first built the slings were of telegraph wire. These, however, required such constant readjustment that light wire rope was afterwards substituted, secured with thimbles and clips. Diagonals were also added at the same time.

Abutments.—The roadway was free over the central pier, and over the shore transoms at each abutment, the road-bearers being kept in place by iron straps, which, however, allowed free movement longitudinally.

Tashôt Bridge.

Site.—The Hunza river runs through a narrow gorge, here about 300 feet wide, and with perpendicular cliffs on either side. The bridge was built to replace a light temporary structure of telegraph wire, erected some years before, which was totally wrecked by a tremendous storm early in 1897.

The frames remained standing, and the cables were not damaged; but the roadway, which was secured with telegraph wire binding, spikes and nails, was torn away, and chesses were recovered several hundred yards *up* stream, where they had been carried by the wind.

The site was therefore one where the efficacy of arrangements for withstanding wind pressure would be severely tested; and to these I shall confine my remarks.

The new bridge had a span of 320 feet.

The weight of roadway was about 120 lbs. to the running foot. It was secured throughout with bolts and screws, and was at a height of 60 feet above ordinary flood level. The cables, 20 feet apart at points of support, were brought together to about 10 feet at the centre, adding much to the stiffness of the bridge.

Instead of wind-guys I adopted a suggestion made in a previous paper by Captain Capper, R.E., and substituted inverted catenary cables below the roadway, with slings to each transom.

The catenary had a dip or rather rise of one-twelfth. The ends of the cables were secured to jumpers leaded into the rock on either side of the centre line of the bridge.

This arrangement seemed in every way satisfactory; the bridge was a marvel of stiffness.

It was possible, though of course strictly prohibited, to gallop across on horseback without causing any inconvenient oscillation. This, with a roadway weighing only 120 lbs. to the foot run, is worthy of note.

The mistake made was not providing horizontal wind-guys in addition. The next hurricane that some months later swept up the valley demonstrated this practically. Though, fortunately, the damage done was not very serious, it was sufficient to show in practice what in a recent letter to the *R.E. Journal* Lieutenant Carey, R.E., has worked out in theory:—That where no horizontal wind-guys are provided, a catenary guy rope below the roadway is itself subject during a gale to very severe strain, and also causes a great additional strain in the main cables of the bridge.

The strain of course varies inversely as the splay of the guy ropes. The example quoted below is of a medium splay.

Bridge 320 feet span, as described above, with catenary guy ropes below the roadway, but no horizontal wind-guys.

W = weight of roadway per foot run = 120 lbs.

P = wind pressure per running foot of the bridge.

Slope of main cable slings ... ... $\frac{6}{1}$.

Slope of guy rope slings ... ... $\frac{2}{1}$.

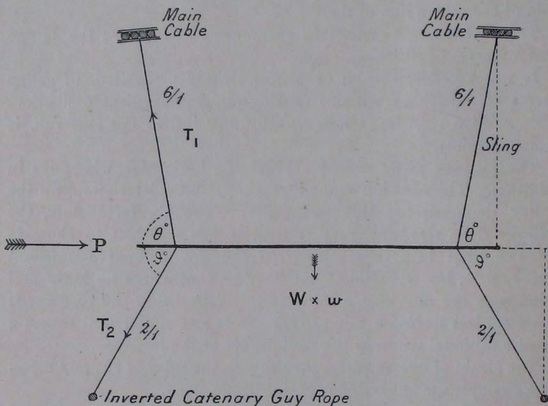
T_1 = tension due to wind pressure in main cable per foot run of bridge.

T_2 = tension due to wind pressure in lower slings per foot run of bridge.

The area of resistance to a wind blowing at right angles to the roadway is 2 square feet per foot run of roadway.

With a wind pressure of 60 lbs. per square foot—

$$P = 120 \text{ lbs.}$$



Neglecting all loads except the wind pressure and resolving horizontally and vertically.

$$P = T_1 \cos \theta + T_2 \cos \vartheta.$$

$$T_1 \sin \theta = T_2 \sin \vartheta.$$

$$\cos \theta = \tfrac{1}{6} \text{ about.}$$

$$\sin \theta = 1 \quad ,,$$

$$\cos \theta = \cdot 4.$$

$$\sin \theta = \cdot 9.$$

$$P = 120.$$

$$\left.\begin{aligned} 120 &= \frac{T_1}{6} \; \frac{4\,T_2}{10}. \\ T_1 &= \frac{9\,T_2}{10}. \end{aligned}\right\}$$

$$\left.\begin{aligned} T_1 &= 196. \\ T_2 &= 218. \end{aligned}\right\}$$

That is, the tension due to wind pressure alone per foot run of he roadway is

In the guy ropes	218 lbs.
In the main cables	196 lbs.

More than three times the strain due to the permanent load on the bridge; a strain moreover from which the main cables can be entirely freed by the use of horizontal wind guys.

The obvious conclusion is, I think, that while guy ropes, preferably catenaries, below the roadway are of the utmost utility to secure stiffness in light bridges, horizontal wind guys are essential in exposed situations.

Chamogah Bridge.

Site.—The channel is here 400 feet wide, with perpendicular cliffs on either side. The bridge was carried across at a height of about 40 feet above ordinary summer flood level in one span of 432 feet (see *Plate* IV.).

Approaches.—On both banks the approaches had to be blasted out of the solid rock.

Of necessity they were indirect; but in a country where wheeled traffic is unknown this does not signify.

On the left bank no frame was required; while on the right bank a low pier and 20-foot timber frame carried the cables.

Cables.—These consisted of 24 $1\frac{1}{2}$-inch ropes of patent plough steel, with a breaking strain of 9 tons for each rope. That is, 12 ropes on each side, and a total breaking strain of 216 tons.

The 12 ropes on each side were arranged in 2 cables of 6 ropes each. These were kept perfectly separate throughout between the points of support. The slings carrying the roadway were attached alternately to either cable.

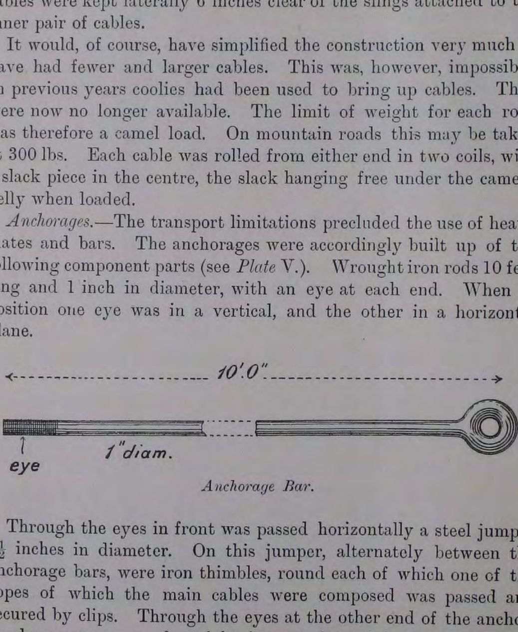
The idea was borrowed from a paper in a previous volume of this series descriptive of a suspension bridge in Iceland.

The theory is that the roadway being supported by two perfectly distinct pairs of cables, the undulations set up in one pair of cables by a live load on the bridge will be neutralized when the load is transferred at the next bay to the other pair of cables. The wave is thus polarized almost as soon as initiated by a following wave at half wave distance.

The experiment had been tried with success at Tashôt, except that the two sets of slings were apt to ride. To prevent this in the present case, the outer cable on each side was carried throughout a foot above the inner one. Also the slings attached to the outer cables were kept laterally 6 inches clear of the slings attached to the inner pair of cables.

It would, of course, have simplified the construction very much to have had fewer and larger cables. This was, however, impossible. In previous years coolies had been used to bring up cables. They were now no longer available. The limit of weight for each rope was therefore a camel load. On mountain roads this may be taken at 300 lbs. Each cable was rolled from either end in two coils, with a slack piece in the centre, the slack hanging free under the camel's belly when loaded.

Anchorages.—The transport limitations precluded the use of heavy plates and bars. The anchorages were accordingly built up of the following component parts (see *Plate* V.). Wrought iron rods 10 feet long and 1 inch in diameter, with an eye at each end. When in position one eye was in a vertical, and the other in a horizontal plane.



Anchorage Bar.

Through the eyes in front was passed horizontally a steel jumper $1\frac{1}{2}$ inches in diameter. On this jumper, alternately between the anchorage bars, were iron thimbles, round each of which one of the ropes of which the main cables were composed was passed and secured by clips. Through the eyes at the other end of the anchorage bars were a row of upright jumpers from 3 feet to 4 feet long, embedded in the masonry, with two iron plates $3'' \times 2'' \times \frac{1}{4}''$ in front to distribute the strain (see *Plate* V.).

Construction.—While the approaches, anchorages, and pier were being blasted out and built up, the carpenters were busy putting together the frames, scarfing the road-bearers, and preparing the rest of the woodwork.

Frames.—The design of frame is shown in *Plate* VI. It is a convenient form when the approach to the bridge is indirect. It is also convenient for the double cable arrangement just described.

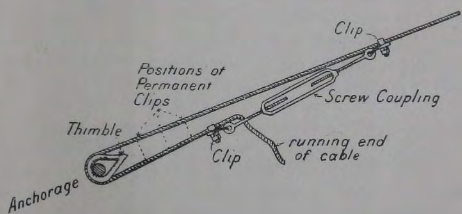
As soon as the anchorages were built in, and the frames in position, an overhead rope was got across, and by its help the ropes of the main cables.

These were secured to the left bank anchorage, and arrangements made at the right bank anchorage for their adjustment.

With so large a number of ropes the difficulty of getting them all equally strained was considerable.

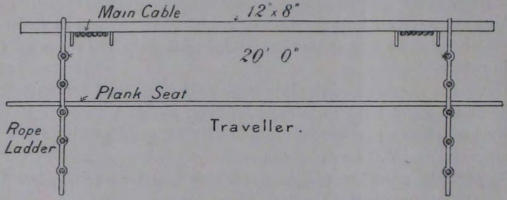
On previous occasions different methods had been tried; but the most satisfactory proved the following :—

The ropes were got across singly, made fast at one anchorage, and pulled up approximately to the required dip, the running end of each rope being passed round the other anchorage, and attached temporarily to its own standing part by a screw coupling (see sketch).

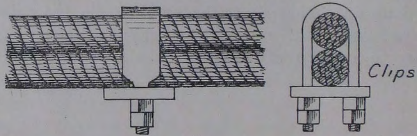


The couplings used were of the ordinary telegraph pattern, with right and left-handed screws. The lightness of these small ropes adds very much to the difficulty of getting them evenly strained. A heavy cable falls of its own weight into a parabola; but a light wire rope which has been tightly coiled for camel transport hangs in all sorts of shapes between the supports when unloaded. To straighten out the ropes, therefore, and to enable them to be evenly strained, a "traveller" composed of a couple of solid timbers and two rope ladders (*vide* sketch) was got out in the centre of the span.

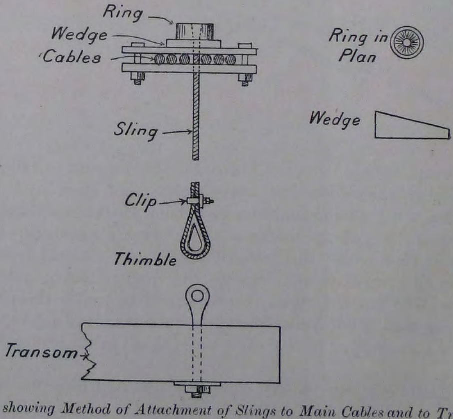
An intelligent man on each side of it shouted directions as to which ropes required to be tautened, and this was done at the anchorage by means of the screw couplings.



The ropes were then made fast at the anchorage by means of clips



The couplings were, however, allowed to remain, and the work of fixing the slings carrying the transoms was proceeded with from the other end of the bridge.



Sketch showing Method of Attachment of Slings to Main Cables and to Transom.

By working from one end in fixing the slings kinks in any of the ropes were pulled out.

The necessary adjustment at the anchorage was effected by removing the clips of that particular rope, and making the adjustment required by means of the screw coupling; the slips were then replaced.

The weight on the cable up to this point was only that of the transoms and a few road-bearers and loose chesses. The latter can, if necessary, be removed while the adjustments are being made. Finally, when the ropes of the main cables are all evenly strained, the screw couplings are removed and the roadway completed.

Roadway.—The roadway is 7 feet wide, and is carried by four road-bearers, the outer ones being scarfed.

The handrail is lattice-braced for stiffness (*Plate* IV.).

Wind-guys.—The wind-guys are horizontal catenaries, as shown in *Plate* VI. Lateral oscillation is thereby reduced to a minimum, and the roadway is subjected to far less strain in a gale than is the case with direct wind-guys attached at intervals.

In this case the chords are continuous between the up stream and down stream catenary wind-guys. They pass below the roadway, and are secured to the transoms by staples (see *Plate* VI.).

Of necessity all the measurements and fittings had to be done on shore. When ready the ropes were launched. The four ends of the wind-guys were secured to holdfasts of jumpers leaded into the rock, strained taut by means of powerful screw couplings, and made fast, the couplings being then removed.

Guy Ropes.—Below the roadway are the inverted catenary guy ropes previously found so invaluable to stiffen the bridge.

PAPER III.

THE EVOLUTION OF THE DEFENCE.

By Colonel M. H. G. Goldie, R.E.

An endeavour was made to show in a former paper* that it ought to be possible to construct serviceable field defences, in spite of the great power and accuracy of modern artillery and musketry fire. In the same paper it was shown that field defences, applied on a certain definite system, were found of convincing utility, both in attack and defence, in certain battles of times more or less recent.

That exposition must be looked on, however, only as introductory. It referred only to one system of defence, though an enquiry into the true present value of the various systems of defence remains to be undertaken. It attempted no explanation of the real meaning of defence, though only when that fundamental principle is clearly understood can it be seen that there is probably but one path to defensive victory. It gave no hint of the connection between modern weapons and defensive action, though all history prepares us for such a connection. And, finally, it dealt but passingly with what is, after all, the ultimate criterion of value of any defensive system, the great moral factor.

It is quite unnecessary to prove now that defence to be successful must be active. Many writers, Napoleon among others, have laid this down as an axiom. Here, therefore, this axiom will be made the basis of all further argument. There is one way, and only one way, in which defence becomes active; and that is by counter-

* "Tactical Employment of Field Defences." Paper V., Vol. XXIV., *R.E.P.P.*, 1898.

attack. It is conceivable that a force on the defensive might sit down motionless and hammer away doggedly, in the hope of wearing out the assailant before finally passing to the offensive. Such a course has been tried; but it will be proved in these pages that it never has succeeded, and never can succeed. There is thus no alternative but counter-attack. Hence it may be assumed that the relation between defence and counter-attack is permanent. Every great defence has been conducted with counter-attack for its chief object; every great defence must always be so conducted.

But the connection between the weapons in use and the conduct of defence is not similarly permanent. In the passage of time immense improvements have been made in the gun and the firearm. A mode of defence almost necessary in the case of the musket may not be the mode of defence best adapted to take full advantage of the extraordinary power of the breech-loader.

If then we would ascertain the present value of the different systems of defence, we must first estimate the extent to which each system lends itself to the great fundamental idea of all defence—counter-attack. We must then enquire which defensive system it is that affords the most improved weapons the fullest opportunity of doing their work. It is not often, in modern times at all events, that an action has been fought on a plain, nor on smooth, glacis-like slopes. Hence in all cases it must be supposed that the systems are brought to their trial on ground of average irregularity, with woods, villages, and farmsteads more or less scattered over it. A system put to the tests thus far mentioned may meet with approval; but these tests are insufficient. Unless a defensive system imply such action as shall keep alive the offensive spirit in the troops, and shall encourage local commanders in unhesitatingly accepting responsibility, that system must necessarily be condemned.

It is the object of this investigation to test the different defensive systems, and to discover that system which best fulfils the conditions above described.

In order that there may be no doubt whatever as to the meaning of the terms employed, it is essential to give a precise definition of what is here understood by counter-attack.

There is no doubt that a clear distinction is not always drawn between counter-attack and what is usually called the general advance; and yet the idea involved in one mode of action is quite different from the idea involved in the other. If the general-in-chief on the defensive has thoroughly grasped the situation, the general advance will not take place until the action has reached a certain phase, that is to say, not until the power of the assailant is felt to be exhausted. At Waterloo the Duke of Wellington ordered the general advance; but by that time the Prussians had overcome Napoleon's flank defence, the attack of the Imperial Guard was shattered, and the French cavalry practically destroyed. The power of his assailant was felt by the Duke to be exhausted. It is an object of counter-attack not to take advantage of exhaustion, but to bring about exhaustion.

We say an object of counter-attack because that is not the only object. Counter-attack is of two kinds—the great organized counter-attack and the minor, local, improvised counter-attack. The object of these two kinds of attack is essentially different.

We shall first endeavour to prove that the object of all great organized counter-attack is, and always has been, to bring about the exhaustion of the assailant. To accomplish this it will be necessary to show, in each case adduced, that the power of the assailant was, prior to the great counter-attacks, by no means exhausted; and that on the completion of these attacks either the assailant's power was exhausted, or, if not, then the defence, having no further resource, failed. Of such importance is this point in the study of defence, no apology is offered for treating it at some length.

A detailed description of the Battle of Rivoli was given in the former paper. It will suffice, therefore, to say here that the Austrians advanced in six columns, of which three were separated from each other and from the remainder by great natural features, while three, advancing in the centre, preserved in some degree their connection. What then was Bonaparte's action? Receiving the attack of the Austrian right central column, he flung his troops against the other two, and by that means succeeded in stopping temporarily the whole Austrian central attack. That done, Bonaparte flew with great fury on Quasdanowich, who was advancing in all haste through the defile of Osteria Dugana and driving before him a small French force which had been intrenched at the head of the defile. Quasdanowich being routed, Bonaparte turned again on the Austrian centre which had meantime resumed its advance, and put it to flight. The Austrian right column had by this time penetrated far to the French rear; here, however, it was assailed by a detached force supported by a strong reserve, and practically destroyed. There can be no question that in this action the Austrians advanced boldly enough to the attack, and were so advancing when the counter-attacks above described, three north and one south of Rivoli, were directed against them. There is also no question that at the conclusion of those attacks the power of the Austrians was exhausted. There can be no difficulty then in describing as great counter-attacks these four French attacks, which had for their object, and attained as their result, the exhaustion of the Austrian power of action.

At Austerlitz the Russian attack was still in full vigour at that precise moment when Napoleon launched the great counter-attack which cut the allied army in two. There can be no doubt that by the time the great counter-attack was fairly over, the allies had nothing to think of but retreat.

Laon, fought in 1814, furnishes an excellent illustration of what is meant by the great counter-attack. Utilizing the villages of Clacy, Semilly, and Ardon, Blucher disposed his right so as completely to occupy Napoleon. Marmont advanced against the Prussian centre and left, which was concealed in a heavy mass behind the rocks of Laon. Upon Marmont Blucher fell with superior forces and destroyed him. No resource was then left to Napoleon but rapid retreat.

At Neerwinden, in 1793, Dumouriez suffered a severe defeat. It was his intention to hold the Austrian right, 18,000 strong, by false attacks, while with superior forces he assailed the Austrian left, composed of 21,000 men. The Austrian left held its own; seeing which, the Prince de Coburg ordered a great counter-attack on his right. This attack swept before it the French left, and compelled the retreat of the whole force. At the moment this attack was launched the French had no thought of losing the day; had it failed it is not improbable they would have been victorious.

When Laudon attacked Frederic at Liegnitz, he was himself attacked, and in a measure surprised, though he had hoped to surprise the King. Until the King's counter-attack began to make itself felt, the Prussian troops at many points were desperately on the defensive. A defeat would have been ruin to them, but counter-attack compelled Laudon to retreat.

In the Battle of Fleurus, presently to be described, we shall find Kléber's great counter-attacks a very important feature. One of these attacks made in great strength with a part of the reserve, and well supported by artillery, completely stopped the advance of the Austrian right under Latour; a second caused the retreat of Kaunitz on the left centre. But the Austrian commander here broke off the fight.

At Auerstedt a great attack by Davoust drove back the Prussians, who till then had been entirely on the offensive; the Prussians could then do no more. Sauroren was a fight well worthy of Wellington's genius. Clausel, being sent by Soult to outflank the British left, became separated from the French centre. At once Wellington seized his chance and attacked. The 6th Division in front, the 4th Division on his left, and a Portuguese brigade on his right almost surrounded Clausel; this and some determined advances by the 27th and 48th Regiments placed it beyond Soult's power to continue the attack. It is, therefore, plain that here counter-attack on a great scale effected exactly what has been above described as its *rôle*. In no battle does this appear more clearly than in that at the Lisaine, described in the previous paper. The attack of Keller, on the morning of the third day, was made when the French were still far from beaten. This is proved by the fact that Cremer twice beat Keller off. Still, Keller's attack really effected its object, for Cremer never advanced again; on the contrary, the whole French army retreated.

When Laudon led forward the great Austrian Reserve at Kunersdorf, the repeated violent attacks of Frederic had fairly beaten the Russians. Had the King been able to overthrow Laudon, he would have gained a tremendous victory. It has been said the Prussian troops were too exhausted to do much, but that they were not then beaten is clear; for as the Austrian Reserve advanced, Finck was still attacking the Elsbuch, and the Duke of Wurtemburg hurried to his assistance at the head of the cavalry. These leaders defeated, the Prussians had no fight left in them.

It has occasionally happened that the great counter-attack has been used in battle, leaving the general result indecisive. The most remarkable instance of this occurred at Eylan. On this occasion Napoleon attacked incessantly as corps after corps arrived; only by this means could he hope to maintain himself. The Russians made four great counter-attacks, of which the first destroyed Augereau; the second pierced the French centre, and was only finally beaten off by the bodyguard; the third compelled the retirement of Davoust; and the fourth stopped the advance of Ney. By this time fortunately night had fallen, for the French were completely exhausted, showing that the Russian attacks had successfully accomplished their work; they left the Russians, however, equally exhausted, and hence no decisive result was obtained.

It may also be shown that the failure of a great counter-attack may, in certain circumstances, lead to a result tactically indecisive. This was the case at Vionville in 1870, where a French attack, which assumed great proportions, and threatened the most serious consequences, was brought to a stand by desperate cavalry charges, and to a complete end by the opportune arrival of a part of the German Xth Corps. Alvensleben's numerical strength was not, however, sufficient to enable him to take advantage of his partial success; he contented himself with his great strategical gain.

We come now to a set of cases where the defeat of the counter-attack has implied the overthrow of the defence. This was eminently the case at Breslau, already described in detail. The last Prussian counter-attack was here organized by the Duc de Beverne himself, and nevertheless failed, though a previous great cavalry attack by Ziethen had completely stopped Nadasti's advance against the Prussian left. With the failure of Beverne's attack all Prussian efforts ceased, and in the night they retreated.

Toulouse is another very clear instance, for here everything turned on the success or failure of Soult's last great enterprise against Beresford. Full of promise, for Beresford was then executing a difficult flank march within reach of the French artillery, it completely miscarried; and with that miscarriage died out all hope of a French victory.

The Battle of Mosskirch was fought in 1800 by the French under the command of Moreau, against the Austrians under Kray. It consisted of a series of turning movements, met by many Austrian counter-attacks, not one of which succeeded, unless indeed we except the first, by which the village of Helidorf was carried. The second, though well supported by artillery, was stopped by the opportune arrival of a French division under Delmas. The third, made with diminished vehemence, was repulsed by divisions Bastoul and Delmas. The fourth and last, met with similar activity, put an end to all Austrian resistance. Among French victories Mosskirch accordingly takes a high place.

The desperate attempts of Fuad Pasha at Philippopolis, in 1878, to draw the Russians to his left by heavy attacks, in the hope of opening a way of escape on his right, are not necessarily to be classed as counter-attacks; for the Russians closing round had hemmed him in with his back to the mountains, and hence his efforts may be compared with those of Bazaine to escape from Metz, or Osman Pasha from Plevna.

In the Appendices at the end of this paper are given the results of one hundred modern battles. Fifteen times only in these was the defence successful. While enumerating instances of successful great counter-attack we have just named no less than nine of these fifteen battles, a total of three-fifths; of such importance to the defence is the success of great counter-attack. It will readily be understood how needful it is to understand exactly why these counter-attacks succeeded, and why others failed. And this more especially as the defensive victory gained, in the six battles not as yet named, was the result in each case of an exceptional cause.

At Waterloo and Gettysburg the assailant was crushed by superior numbers; at Rossbach and Fredericksburg the attack made defied every recognized principle; at Kolin, Frederic's orders were completely misunderstood, and the impossible attempted, and at Vimiero, Junot made separate, disconnected attacks, with inferior forces, against a commander who knew how to crush each in turn, using his forces in combination.

From the nature of the case an abrupt drop would not be expected from the use of great counter-attack to the use of minor counter-attack, each for its own specific end. On the contrary, to such an extent has minor counter-attack, sometimes in a single effort, sometimes in a succession of efforts, replaced the great counter-attack that to give every known instance of the former as a substitute for the latter would amount to describing in detail almost every battle that has been fought. Yet very rarely in all those battles has the minor attack, used as a substitute, had any real effect on the result of the contest.

Towards the end of Kolin, when Daun had lost all courage, a thoroughly well-timed attack by a small Saxon detachment put the Prussians to rout; but the Prussians at that time were already in a desperate plight. At Busaco, Cameron, of the 9th Regiment, assailed and drove off a portion of Reynier's attack, but he was unable to do more than thus save the situation for the moment. At Albuera a most brilliant counter-attack by the Fusilier Brigade saved the British force from defeat; but only that, for the condition of that force at the end of the fight was such it could not have gone on. At Chancellorsville, Pleasanton so handled his batteries as to make what might be called a minor counter-attack, and he certainly stopped the Confederate flank attack for a time; while later on an infantry counter-attack compelled the same Confederate force to come to a halt for the night. But this had no ultimate influence on the battle, which went against the Federals. At

Spicheren an attack by Laveaucoupet, made with troops from the reserve, almost met with success, and might have been entitled had it done so to rank with the greater counter-attacks; but it dwindled away to nothing, unsupported by the French commander, and must be classed with substitutes for great counter-attack.

There are doubtless other cases of similar minor attack on a trifling scale attaining a momentary success; but against these are to be set the hundreds upon hundreds of instances of the most complete failure. And hence it is that misapplied counter-attack is one of the chief reasons why the history of defence is such dismal reading.

When a smaller force has for its task, or takes upon itself as its task, to hold as nearly as possible where it stands a force of strength so superior it cannot be tactically defeated, how does the smaller force proceed? The Battles of Colombey and Vionville supply the answer to this question. The smaller force cannot under such circumstances merely observe the larger force, for that would not prevent the larger force moving as it might choose, and the object of the smaller force is to stop any movement. Accordingly von der Goltz at Colombey and von Alvensleben at Vionville at once attacked the enemy, who was in each case very considerably the stronger, and continued to make such a series of ceaseless attacks as forced the enemy to develope more and more of his strength.

Now this is the most important object of the minor counter-attack. By no other means can an inferior force compel a much superior force to stand to its ground. It is probable that as regards a force on the offensive this fact is thoroughly recognized. There is no difficulty, indeed, in drawing instances from military history which tend to confirm that opinion. Take the case of Arcola, presently to be described. The frequent attacks of Massena, made along the causeway in the direction of Porcil, could have had no other object but to hold fast at Porcil the Austrian division placed there. The attacks of Hill, Picton, and the Spaniards round the French position at Toulouse were intended to prevent Soult withdrawing sufficient forces for stopping the flank march of Beresford, to whom the real attack was entrusted. The efforts of the weak Imperial Guard to force the bridges at Boffalora, Ponte Nuovo, and Ponte Vecchio sufficed to hold along the Grand Canal, at Magenta, vastly superior Austrian forces, and gave McMahon an opportunity of turning the Austrian right. So the attacks made by Sherman, costly as they were, on the Confederate intrenchments at

Kenesaw occupied the attention of Johnston, whose position was meanwhile turned.

Coming to later times, there is to be gathered from the Battle of Königgrätz a clear idea of the meaning of minor counter-attack. Throughout this day the first Prussian army fought to hold to its front along the Bistritz the bulk of the Austrian forces. In the wood of Maslowed, from 8.30 a.m. to 11 a.m., 14 Prussian battalions with 24 guns found employment for 40 Austrian battalions and a numerous artillery. Between 11 a.m. and 3 p.m. the same Prussian force was holding in play no less than 51 Austrian battalions. This result was only achieved by constant minor attack, in which sometimes one force, sometimes the other, gained ground. At Wörth the Germans attacked McMahon on both flanks; they were not, therefore, idle in front; on the contrary, the attacks made here had a very definite object—to prevent the French withdrawing troops to stem the advance against their right. It will presently be seen that the same idea pervaded the German plan at Le Mans. The Xth Corps assailed and partly outflanked the French right; every effort was made, therefore, to prevent the accumulation of French forces against the Xth. With this object the IIIrd Corps attacked the intrenchments in their front, and the IXth Corps, while masking, attacked the heights of Auvours. There is something in common between the Battles of St. Quentin and Nivelles. In both cases the field was cut in two by a river; but while the Nivelles is generally fordable the Somme is not. Nevertheless, in both cases the real attack was made along the two banks of the river, while the left of the enemy was hotly pressed and his right contained. At St. Quentin the German containing force carried out its rather difficult duty by incessant aggression, sometimes on a larger, sometimes on a smaller scale; and it distinctly succeeded, though at one time von Manteuffel found it necessary to withdraw from it a considerable detachment for the support of his real attack.

These illustrations show how active must be that force which aids the general attack by containing superior forces of the enemy. It is not so easy to find instances of a containing force by similar activity aiding, not the attack, but the defence, though, as already stated, examples are innumerable of minor counter-attack made as a poor and treacherous substitute for the greater. That such an instance may be accepted as valid there must be indubitable effort on the part of the defender to contain by active measures, but only to contain, on a part of his front the greatest possible force of the assailant. The Battle of Neerwinden, already mentioned, appears to answer to this description; for here the Austrian left, 21,000 strong, undoubtedly occupied 30,000 of the enemy, while on their right 18,000 men fell upon 15,000. Every partial advance made by the Austrians on their left served to draw Dumouriez more deeply into the great re-entrant, whence he could not easily issue to succour his broken left. Laon, also already mentioned, may likewise be accepted as illustrative. For Blucher, attacked by Marmont on his left and by Napoleon on his right, prepared to fall in great strength on the former, while he at the same time kept the latter continually occupied. Now here the old Prussian general had Napoleon to deal with, and it must redound to his credit that all his measures succeeded; for it must have needed courage to withdraw troops from before Napoleon that the destruction of Marmont might be more complete; and it must have needed great activity and firmness to hold Napoleon where he stood while the destruction of Marmont was in progress.

In the Battle of Loigny, fought in December, 1870, the Germans once assembled became the assailants; but at the beginning of the action the Ist Bavarian Corps, fighting to contain the enemy, was distinctly on the defensive. This corps the French endeavoured to overwhelm on the line Beauvilliers-Château Goury, while at the same time attempts were made to stop the advance of the 17th and 22nd German Divisions. The task of the latter two divisions was not very easy, but the 17th succeeded in continually advancing. To inflict a heavy defeat on the French was much desired; it was therefore the object of the Bavarians to hold the enemy fast, if possible, until help came. This they succeeded in doing by means of an active defence, during which the 3rd Bavarian Brigade carried out a counter-attack that completely demoralized the French 2nd Division. Such an effort, made at such a time, was in entire accord with the true spirit of minor counter-attack.

Thus with some certainty the following conclusions are reached:—

1. Organized counter-attack carried out, though not very frequently, on a great scale has been the cause of the greater number of defensive victories. It follows that counter-attack of this nature is the great object of a true defensive system.

2. Minor counter-attack, generally improvised, has been carried out extensively as a substitute for great counter-attack; but only in rare cases has it led to a decisive result. Therefore such an em-

ployment of counter-attack stands self-condemned. This conclusion is in accordance with the opinion of modern writers. For instance, Boguslauski says: "Partial counter-strokes on isolated parts of a battle-field, such as the French made frequently and with great bravery at Sedan, can only have a momentary effect."

3. Minor counter-attacks as the necessary weapon of a containing force are well understood, and have been often used where the containing force has formed part of an army on the offensive; but where the containing force has formed part of an army acting defensively, this equally essential use of the minor counter-attack appears to have been very uncommon. Yet it is clear that by this means the assailant may be made to suffer in two ways. First, a large proportion of his force is thus occupied and compelled to stand its ground. Second, worn down by repeated attacks the assailant is rather forced to call up reinforcements than enabled to detach troops to strengthen his real attack. Hence minor attack on this system contributes largely, if indirectly, to the ultimate issue of the battle.

When a certain mode of action has been adopted sufficiently often to prove that its efficacy has been acknowledged, and yet, when two centuries of military history are consulted, is found to have been adopted really only now and then, it is natural to ask if there be not some almost insuperable difficulty in carrying out that mode of action. As this applies precisely both to great counter-attack and to minor attack used as the weapon of a containing force, it is necessary to discover, if possible, the cause of difficulty in their execution.

On this point von der Goltz, in a recent work, makes the following remarks. He says: "Tactical counter-strokes on the battle-field, except in the most simple form, by an advance straight to the front after beating off an attack, demand great ability in the handling of troops, such as Napoleon had. At Austerlitz he gave an example thereof worthy of imitation, but such examples are rare." And again: "With the same troops counter-strokes against one part of the enemy's line, and then against another part, together with tactical movements on inner lines, are scarcely ever possible, because the opponents are too near each other; such a force would find itself not merely between two opponents, but between two fires." And once more: "The picture of a force on the defensive, crouching watchfully in its place until it has spied out a mistake made by the enemy, then to fall on him at once, seems most excellent but seldom works out in reality. An army cannot leap like a tiger with the speed of thought on its prey. Time is needed, first of all, to discover and realize the opportunity, then to form a decision, next to send orders to the troops, and lastly to put these in motion in the required direction. Thus a lapse of time is accounted for during which most probably the attacking force, as it continues the general movement, will have left behind it the defender's opportunity."

These quotations show fairly in a few words why small counter-attacks have almost always failed as substitutes for great counter-attacks properly organized. Time is needed to organize great counter-attacks, and on the field of battle there never has been time. Hence there has been, as a rule, no resource but a straightforward attack, made on the spur of the moment with such troops as happen to be at hand, without any organization, rarely with the support of artillery fire, and therefore on an unimportant scale, and in the least telling direction. Such efforts have almost always been very easily repulsed by fresh troops brought up by the assailant in support; because, as the attack is on a small scale, so it needs but a relatively small number of troops to destroy its efficacy. To put this still more shortly, counter-attacks have almost always been weak and numerous because the defending commander has so rarely the power of organizing anything better.

What then has been the cause of this common want of power? The answer is plain; want of clear foreknowledge, ignorance where the assailant's blow may be expected, and therefore inability to dispose the troops except on the simplest of all plans, at so many thousands per mile. But there are certain victories which great counter-attack claims as its own. These victories are Rivoli, Austerlitz, Laon, Neerwinden, Liegnitz, Fleurus, Auerstedt, Sauroren, Lisaine, Kunersdorf. Enough has been already said to prove that in almost all these cases the defender had ample time to make the most careful preparations. Every move of Alvinzi's was known to Bonaparte at Rivoli; the measures of Bonaparte prove it. Napoleon's foreknowledge at Austerlitz is proverbial. Blucher's dispositions at Laon, considering he was then fighting Napoleon, preclude the idea of chance. Neerwinden was a simple battle; the Austrians had but to advance a wing. At Liegnitz, Laudon was in no strength. At Fleurus, the French army stood on a great semicircle with reserves massed at a central point ready for any emergency. The Prussian generalship at Auerstedt was so indifferent, Davoust was able to do almost as he pleased. Sauroren very much resembled Salamanca, the difference being that at the former battle Wellington did not immediately, though he did after a time, assume the offensive, while at the latter he assumed and retained the offensive the moment Marmont's error stood revealed; in both cases he had the element time in his favour. At the Lisaine, von Werder so placed his great reserves that he was ready for any emergency; yet here also ample time was given to set the reserve in motion. The Russian resistance at Kunersdorf, once the direction of the King's attack was evident, gave Laudon all the time he required to bring up a great reserve standing in a central position.

To these instances may be added that of Toulouse, for Soult had ample time to form his great reserve, and clear indications where to use it. His failure was not in conception, but in execution, and this latter failure was, under the circumstances, inexcusable.

The failures of great counter-attack at Breslau, Mosskirch, and Philippopolis, if that battle be included, are equally important, for in none of these cases is there any evidence of timely, careful organization. The same remark applies to the indecisive results obtained at Eylau and Vionville.

It follows that the one essential to successful great counter-attack is careful organization, for which there is time only when the defender has a clear idea where he is likely to be attacked.

All this does not apply to the minor attacks of a containing force forming part of an army on the defensive. Of such attacks von der Goltz says nothing. Such a containing force must make its attacks in precisely the same way as any other containing force. Instances will be given presently of forces on the defensive contained by artillery fire alone; but such instances are not instructive. Much more to the purpose is it to examine such actions as Loigny and St. Quentin, where both opponents were full of life and energy. Here the Germans, employing all three arms, held superior forces to their ground by continued attacks. These attacks were instituted and carried out by local commanders as circumstances allowed. It is difficult to see how they could be carried out in any other way. Their object is not to bring about directly the total defeat of the enemy, but by compelling him to fight to pin him down where he is, just as the German IIIrd Corps, aided by a part of the Xth, pinned down the whole French army at Vionville.

Minor counter-attacks of this nature, made with this object, have almost always been frontal. Yet there is no doubt an intelligent and energetic local commander, thoroughly acquainted with the nature of his task, and determined to carry it through, will find the means of sometimes taking the enemy in flank, and inflicting upon him fearful loss. The action of Nachod, fought in the war of 1866, furnishes two instances of counter-attack carried out in this intelligent and brilliant manner. The Prussian advanced guard, composed of $6\frac{1}{2}$ battalions, 8 squadrons, and 12 guns, had been attacked by 14 Austrian battalions, and forced to yield ground. After this a part of Rosenzweig's brigade attacked the Prussian centre; it was met by two battalions, one of which assailed it in front, the other on its right flank, and drove it back with great loss. When the Prussian Vth Corps at last reached the field, it was unable to advance against the fire of 80 pieces of Austrian artillery. The Austrians therefore resumed the offensive. One of their attacks was made by 5 battalions against the village Wyokow, $1\frac{1}{2}$ battalions of this force taking part by a flank movement from the north. This flanking movement was met by 1 battalion in front, while half a battalion took it in flank. The Austrian movement was easily repulsed, and their attack failed.

We are now in a position to test the value of the different defensive systems, as respects their utility in favouring the employment of counter-attack; for the criterion to be applied is established. That criterion is the extent to which each system aids the defender in forming an opinion where the enemy's real attack is likely to be made, and thus enables him to mass his troops where he would most wish to find them when the attack is in progress.

In the Appendices are given the names and some particulars of one hundred battles fought in the XVIIIth and XIXth centuries. As some very familar names do not appear in these lists it is desirable to give the general considerations which led to the inclusion of certain battles in preference to others. Those general considerations are the following :—

I. Battles are included in which the numbers of men engaged were very great; as Wagram, Leipsic, Solferino, Königgrätz, Gravelotte.

II. In which the result was especially decisive; as Rossbach, Jena, Waterloo, Aladja-Dagh, Vittoria, Blenheim.

III. In which remarkable generalship was displayed; as Austerlitz, Salamanca, Sauroren, Ramillies, Leuthen.

IV. In which the struggle was well maintained; as Malplaquet, Albuera, Borodino, Kunersdorf, Gettysburg, Spotsylvania, Essling.

V. Which contain features of particular interest; for example, all those battles thus far mentioned in these pages.

VI. Which were fought by commanders of renown.

All the battles included in the lists were fought by trained European armies, with the exception of those belonging to the American War of Secession, and to the Sikh War. The Sikh army being well armed and trained, and also skilled in intrenching, its chief battles against our own troops seemed worthy of a place in the chosen hundred.

All battles, such as Sedan, which at bottom imply efforts to break through an investment, are excluded from the lists; also battles, such as Inkerman and Balaclava, which, though glorious episodes, allowed no room for the display of skill; and, finally, a number of battles in which the men engaged were not trained soldiers.

It will be observed that the number of lists is three. In such a matter it is not possible to be very precise, yet little difficulty was found, except in two or three cases, in placing these battles in their respective lists.

The first list contains the names of nineteen battles. The force on the defensive in all these battles occupied a position which, including the flanks, was wholly fortified; or was naturally extremely difficult of access at all points; or partly one and partly the other. Among these nineteen battles is to be found no instance in which the defence was successful, though in two cases the result of the contest is marked "Indecisive." A battle is indecisive when, though the assailant is compelled to abandon the attempt to gain his end by one means, he is immediately ready to attempt gaining it by another, as was the plight of the Federals at Spotsylvania and Cold Harbour; or when, though the assailant is exhausted, the defender is equally exhausted, but not compelled to retreat, as at Eylau, Albuera, and Antietam; or, when one force drawing off the other is unable to interfere, as at Talavera, Corunna, Colombey, and Vionville. The indecisive Battle of Busaco answers most nearly to the first of these definitions.

The second list contains the names of sixty-four battles. In all these cases the position defended was nowhere fortified, or if fortified, then so slightly or in such a manner that the result in no way depended on the presence or absence of fortifications; also the whole position, including the flanks, was easily accessible, or accessible with no great difficulty, in the absence of natural obstacles. It will be noticed that villages have not been reckoned as fortifications, even when prepared for defence, for reasons to be hereafter explained. In the battles of this class the defence was ten times successful, while seven actions, all referred to above, were indecisive. Leaving the indecisive actions out of account, the proportion of defensive victories is ten in fifty-seven, or nearly one in six.

The third list contains the names of seventeen battles. Here the defended position was always so occupied that, including the flanks, a part of it was very difficult of access, owing to field defences or by nature, or partly owing to the one cause, partly owing to the other; and this portion of the position might be called the defensive zone. The other part of the position was easy of access, in the absence of field defences and natural difficulties—the offensive zone. In these battles the victory fell five times to the defence, and one action, already referred to, was indecisive. If this last action be left out of account, the proportion of defensive victories is five in sixteen, or nearly one in three.

It is believed that the hundred battles named in these lists comprise practically all those fought in the past two centuries, which are important to the subject under discussion. Likewise, that the division of these battles among three lists gives, with a certain degree of roughness, a sufficiently near view of the truth. To each of these lists has been allotted one particular, definite system of defence. It may consequently be asserted that in each one of these battles, either the first, or the second, or the third system of defence was adopted; and that no fourth system of defence ever has been adopted.

What has been here called the first system of defence is now to be examined. Positions occupied for defence on this system have been wholly protected, front and flanks. The protection where natural might have been a marsh, as on the right flank at Creveldt; a deep stream, as on the left and part of the front at Torgau; a range of heights, as at Le Mans; or a stretch of country in which deployment was impossible, as at Creveldt and Le Mans. The field defences used in this system consisted sometimes of continuous lines, as at Spotsylvania and Kenesaw; or of lines of redoubts, sometimes connected and sometimes unconnected by trenches, as at Malplaquet, Nivelles, and Shipka. So long as the field of battle is arranged on the whole defensively, and shows no clear offensive zone where great counter-attack might be made, the system of defence adopted is here held to be the first.

In a defensive system of this precise nature there are three great defects. To the defending commander his position appears almost unassailable ; hence he is over-confident and becomes careless ; does not cause his cavalry to be sufficiently active, nor his outposts properly alert. This over-confidence and consequent carelessness can be traced in the details of Creveldt, Nivelles, Chancellorsville, Kenesaw, and Shipka.

As it is the object here of the defender to make his position at all points as strong as possible, it follows that the degree of strength everywhere approaches uniformity. If a certain point be judged to fall in strength below the standard of the whole line, that point is at once strengthened. To the defender then, ultimately, all his position looks alike ; he may know his adversary will think differently, but how precisely his adversary will think and decide he does not know. So that for two reasons an equal distribution of troops along the line is called for—First, because works of equal strength seem to demand defence by equal numbers ; and second, because the uncertainty where the attack will come makes it necessary to be equally strong at all points. Great difficulty has always been experienced, in battles fought under this system, in distinguishing at first between real and false attacks ; this was so in a marked degree at Creveldt, Nivelles, Kenesaw. It follows that there has always been almost fatal delay in concentrating and moving to the really endangered point the troops needed to save it.

For the same reason, ignorance of what may be expected, there has never been a real chance, on this system, of organizing a great counter-attack. If a glance be cast over Appendix I. it will be noticed how varied, in all the battles therein named, the mode of attack has been. Against all this variety the defender has had nothing to pit except absolute ignorance or mere guess-work. He never in any instance knew where to post his reserves so that at the crisis, when a great counter-attack carried out on the instant might have saved the day, those reserves should be just where wanted. In the series of battles there are but two, the counter-attacks in which deserve to be mentioned. The first of these is Breslau, where Ziethen's great cavalry attack did, as already mentioned, stop Nadasti's effort against the Prussian left. But this was almost wholly a cavalry attack, which, though successful and of immense utility, is not what would now be understood as an organized counter-attack. Also the plan of attack at Breslau cannot be reckoned a masterpiece, as it consisted of four separate parts in no way related to each other. The second is Borodino, where the

Russian defence was marked by great activity. Different reasons have been assigned for Napoleon's unusual conduct of this battle. Without entering into detail it may be said that he attacked the Russians at their strongest points; that owing to the great loss of time thus caused he gave them an opportunity, which was utilized, of drawing to their left the whole of the troops from their unassailed, uncontained right; and that the Russians obtained in this way at least the chance of organizing, late in the day, a great counter-attack. This, in the confusion of one of the most desperate battles in history, they never thoroughly succeeded in doing, and all their efforts were foiled.

Brought to the required touchstone, this defensive system evidently fails, and it would be unnecessary to say anything more about it were it not that a tendency to wholesale intrenching is still observable at field manœuvres. A system thus practised might be carried into war, where as yet it has never succeeded, except in that one minor instance in 1877, often quoted to prove how ill-considered it is possible for an attack to be. Therefore to show still more plainly under what difficulties defence on this system labours, three illustrations will be drawn from the battles mentioned in Appendix I.

Creveldt has the unique distinction of exemplifying all three defects above mentioned. For the French commander relied absolutely on his defences, and neglected his outposts; he failed entirely in massing his troops to meet the attacks he could not foresee; and, with the exception of a small cavalry skirmish, he could set in motion no counter-attack at all. Nivelles illustrates the enormous power conferred by this system on the assailant, of choosing his point of attack and concealing the preparation of his means. If ever this mode of defence had a great chance of success, it was at Le Mans. The defenders were to the assailants as three to one, were brave men fighting for the highest cause, were aware a victory was of the greatest consequence and demanded any sacrifice, and were not ill-led. The country in their front was of such a nature that the enemy was almost certain to attack at all points in small bodies, thus eliminating one of the most fatal defects of the system.

Creveldt (see *Plate* I.) was fought on the 23rd June, 1758, by the allies, under Duke Ferdinand of Brunswick, against the French, on the defensive, under the Count de Clermont.

The French stood behind the Landwehr, a high, thick wall with a broad and deep ditch on each side. This dyke was passable at only a few points, such as Stöken and Hükesmed. The roads leading to those points were bordered by trees, and wound through gardens and fields surrounded by hedges and ditches. The right was covered by a great marsh; the only access to the left was through woods, by narrow roads, crossing numerous brooks. The only advanced posts were at Creveldt and Anradt.

The only country in front of the position sufficiently open for the action of artillery was that about Creveldt, the remainder, towards Anradt, being a succession of bush-covered heaths. From this point, therefore, Spoerken, who commanded 16 battalions and 20 squadrons, with a numerous artillery, was ordered to maintain a lively cannonade. Oberg, with 6 battalions and 6 squadrons, was ordered to move from St. Antonius very slowly on Hükesmed and Stöken. While the attention of the French was occupied by these two corps, the Duke, who had surveyed the whole country from the church tower of St. Antonius, moved a force of 16 battalions, 28 squadrons, with artillery, in four columns on Anradt. This march was absolutely concealed from the enemy, but very difficult. It occupied many hours, though the distance to be covered was insignificant; for in some places the breadth of front was limited to eight paces, and at some points, such as Borselsbaum, the advance is said to have been made in single file. For the guns it was necessary to cut roads.

The Comte de Clermont appears to have been fully occupied with arrangements to meet the advance of Oberg against Hükesmed and Stöken and a now anticipated attack from Creveldt, when suddenly he heard with astonishment that his outposts were driven in at Anradt, a proof that he allowed himself to be surprised. And now came the proof that his dispositions were not calculated to meet the Duke's attack. Either because he could do no better, or because he still doubted how events were thickening, he moved towards Anradt only 15 battalions and 30 squadrons. This force very nearly equalled in strength that brought up by the Duke; yet such is the effect of irresolution when opposed to decision, the Duke was never really stopped, except by difficulties of the ground. In three hours he had crossed the stream south of Stöken, passed the wood, and broken in on the French left. Oberg now crossed the Landwehr and connected with the Duke's left, so that their united forces swept the French position.

As it was here found impossible to post a force which should stop the allied advance, it is not to be expected time or opportunity could be found for that much harder task, the organization of a great counter-attack. And so, forming his troops as best he could, de Clermont retreated as he might.

Nivelle (*Plate* II.) was one of Wellington's finest strokes. For months Soult had been engaged fortifying the Nivelle position, which on the day of the battle was thus occupied. On the left stood d'Erlon in two lines strongly intrenched. In the first line stood two brigades, left on the rocks of Mondarain, right at the forge of Urdax, on the Nivelle. The rest of d'Erlon's two divisions occupied the second line some miles in rear of the first. The chief works of this line were four redoubts, each for 500 men, thrown up behind a ravine. The left of this line was in rear of the centre of the first, the right on the Nivelle, at the bridge of Amotz.

Resting on the Nivelle, Clauzel's main line continued that of d'Erlon to Ascain, also on the river, which here made a wide sweep in Clauzel's rear. This line was strongly fortified with redoubts and abattis, and was held by two divisions Clauzel, and one division d'Erlon. In front of the left were the St. Barbe and other redoubts. The smaller Rhune, well fortified, was occupied by a brigade—it formed an advanced work on the right.

Beyond Ascain the intrenched camp of Serres was held by rather more than one division. Vilatte occupied a ridge crossing the gorges of Olette and Jolimont. Reille held the right, strongly fortified behind inundations. These latter forces combined amounted to 40,000 men. Foy, who was on Soult's left, had instructions to fall on the British right in case of attack.

The Nivelle above Amotz was fordable; hence Wellington designed to pass the first French line, and attack the second at the Nivelle, so as to turn both Clauzel and d'Erlon at their point of junction. The following were his dispositions:—Foy and d'Erlon's first line together numbered 12,000 men. To hold these in check were allotted 6,000 men, including four battalions opposite the Mondarain rocks watching Foy. This left Hill 20,000 men and 9 guns to deal with 5,000 in d'Erlon's second line. Beresford assembled 24,000 men, with artillery, composed of the 3rd, 4th, and 7th Divisions, and Giron's Corps, at the greater Rhune, Zugaramundi, and the Puerto di Echellar, to attack 10,000 men under Clauzel. Alten, with the Light Division and Longa's Corps, 8,000 men, was to concentrate at the greater Rhune, and attack towards Ascain, so that he had to deal with about 3,000 of the enemy. Thus on this side, while 6,000 men occupied 12,000, a force of 52,000 men was available to attack 18,000.

Freyre assembled 9,000 men and 6 guns at Fort Calvaire and towards Jolimont to prevent the detaching of support from Serres. Hope had 19,000 men and 54 guns, composed of the 1st and 5th Divisions, 2 brigades cavalry, and 3 additional brigades infantry, opposite Reille. Thus on this side 28,000 men contained about 40,000.

A combination such as this required not only great care in arrangement and exactness in execution so that the parts might fit, but concealment from the enemy lest he might interrupt. There was no interruption. As a preliminary the smaller Rhune had to be stormed; this outwork was inaccessible in front, but could be got at from the flanks. So perfect was the ignorance of the French, the necessary positions were gained without their knowledge, and after a sharp struggle the smaller Rhune fell. The redoubt St. Barbe and its neighbours gave little trouble.

After a difficult night march Hill reached the required positions at 7 a.m. The gorge of Urdax and Amhoa were quickly cleared, and d'Erlon's second line attacked at 11 a.m. The 6th Division turned the ravine and, wheeling to the right, cleared the nearest redoubt; the other divisions then in succession cleared the remaining redoubts, and the French retreated over the river. Meanwhile to the left of the 6th, Beresford's 3rd Division pushed in at Amotz and, supported by the other divisions, cut d'Erlon from Clauzel, thus uniting Hill and Beresford. The whole of Clauzel's left now retreated, his right alone endeavouring to make a stand. This failing before the advance of Alten, the retreat became general and disorderly. At the approach of dark three divisions were firmly established in rear of Soult's right.

In front of Reille the advanced positions of the Sans Culottes and Bon Secours were rapidly taken, and the Nassau Redoubt assailed, a false attack being maintained until Clauzel retired. Reille then withdrew, covered by Vilatte.

The French loss amounted to 4,265 men, 51 guns, and their great fortified position; that of the British to 2,694 men.

So surely was the weak point of this position, invisible to Soult, detected by Wellington, and a mass of men thrown upon it irresistible by any dispositions Soult then had it in his power to make.

A part of the so-called Battle of Le Mans (*Plate* III.) was fought north of the Huisne. This part may here be neglected, as it had but little to do with the main action. Confining attention to the great French position, the right rested on the Sarthe at Arnage, and then ran along the Chemin aux Bœufs to Yvré station This front was protected by emplacements, shelter trenches in tiers, and road barricades at Arnage, Les Mortes Aures, to the east of Pontlieue, and at Le Tertre, and was occupied by four divisions. The left was on the Auvours Heights, found under the circumstances of the case to be assailable only with difficulty. Here were two divisions.

The circumstances were peculiar, owing to nature of the country, the inclemency of the weather, and the shortness of daylight. So close was the country no cavalry could act, artillery could not find positions, and infantry could scarcely deploy. Snow lying deep marching was very difficult, and much marching had to be done as owing to the bad weather the troops could not bivouac. Little time was, therefore, available each day for fighting, pushing ahead, and definitely gaining ground. As the assailant acted against such difficulties, the position of the defender, well intrenched or aided by hedges, hollow ways, and steep slopes, was strong, but uniformly strong. It seemed probable that in such country the assailant would be compelled to attack in small bodies at all points; and if this were so, the situation was relieved of one of the chief dangers inherent in this system of defence.

On the 10th January, 1871, the IXth and Xth German Corps being still at some distance, the IIIrd Corps pushed on alone, captured advanced posts at Parigné l'Evêque, Les Guettes Farm, Changé, Champagné, etc., in spite of French counter-attacks, and made 5,000 prisoners. This was a serious matter for the French. It proved them vigilant; but such costly defeats must have seriously lowered their *morale*, while improving the spirits of the Germans.

Next day the IXth Corps came up opposite the heights of Auvours, captured Villiers and a few farms, and covered the right of the IIIrd. That corps penetrated to the Chemin aux Bœufs, capturing Le Tertre; it also took, but lost again, Les Arches Chateau. Here the French made many minor counter-attacks, and fairly held their own, though at night they were in close contact with the enemy from Les Arches, through Le Tertre to the Parigné-Pontlieue road. Here the IIIrd Corps was in contact with the 14th Cavalry Brigade of the Xth Corps. That corps had passed Mulsanne in the morning and, advancing solidly through very close and difficult country, captured by night Les Mortes Aures, La Tuilerie, and Les Epinettes. This was the overpowering attack Chanzy could not foresee; the chance to which perhaps his idea that he must be attacked everywhere had blinded him.

It was resolved that on the 12th the Xth Corps should continue its advance, aided by the left of the IIIrd, while the Auvours Heights and the rest of the position was contained. The French made one serious effort to retake Le Tertre, but abandoned it as the pressure of the Xth Corps made itself heavily felt. One thousand prisoners were lost in an effort to recapture Les Epinettes. Retreat then became general, Le Mans was taken, and the French army almost entirely broken up.

The second defensive system is that in which fortification has not been employed, nor natural features relied on. A few words of explanation are necessary to show why certain battles are reckoned as belonging to this category, though slight fieldworks and natural obstacles were present in front of the position.

The obstacle at Kolin was a rather marshy stream, but it did not, it is thought, hinder the advance of the Prussians in any marked degree. The great line of Russian intrenchments at Kunersdorf did not, owing to the direction of the King's attack, play any part in the battle ; the short line of flanking intrenchment was captured by the Prussians as easily as though it had no existence. The real obstacle here was the Kuhgrund. But it had never been expected that the King would attack over the Kuhgrund, a long steep-sided hollow of the existence of which he had no knowledge. Thus the Kuhgrund, as an obstacle, was not a factor that determined the dispositions of the allies ; it was not the cause why they were able to make their great counter-attack. Remove the Austrian reserve from the field ; would the Kuhgrund then have stopped the King ? Assuredly not. For this reason Kunersdorf, like Kolin, a victory for the defence, has been placed to the credit of the second system rather than to the credit of the third.

The main French intrenchments at Rivoli were hardly at all used. The intrenchments on the right flank were defended, but their length was very insignificant, so that they can hardly be reckoned as amounting to a true defensive zone. The great numerical strength of the forces engaged gives the Battle of Essling considerable importance. In this contest the villages Essling and Aspern were the scenes of desperate fighting. Looking, however, to the nature of the struggle as a whole, it was judged that this battle could not be accepted as one fought on the third defensive system.

The only other battles requiring mention are Busaco, Alma, and

Spicheren. At Busaco the British force stood on a ridge, the slopes of which were steep; yet the steepness of the slopes does not appear to have materially hindered the French advance. The redoubt in front of the British at Alma was certainly a bone of contention, but it cannot be said to have constituted for the Russians anything like a defensive zone. The intrenchments at Spicheren almost entirely served to cover the French retreat.

No commander is more likely to be watchful than he whose troops are not intrenched. Occasionally troops not intrenched have had to pay dearly for carelessness, as they had at Weissenberg and Beaumont; but these were very exceptional cases, a surprise being regarded as a greater disgrace than a defeat. This watchfulness, extending from the commander to the troops, and thus leading to discovery of the enemy's movements, is itself a cause why the commander, owing to early intelligence, has often found himself in a position to forecast events.

But suppose the contrary, and suppose also that one commander has occupied a simple position unintrenched, while another has occupied a position wholly intrenched, then in what respect is the former better situated than the latter as regards the power to predict where he is likely to be attacked? It would appear at first sight as though both commanders were in precisely the same case, the one perplexed by just the same doubts as the other, both compelled to prepare an equal resistance everywhere, since the point at which attack may be pressed hardest is a mystery which only time can solve.

But there is a difference. The commander who has thoroughly fortified his position has created something, in the efficacy of which he firmly believes. Should he discover a flaw in his armour he repairs it, perfecting his defences until if there be a flaw he does not see it. The commander who does not fortify has created nothing; he has taken up a position such as it is. He has no reason for self-deception; if there be a flaw, he sees it but leaves it alone. There is probably no such thing in nature as a position of absolutely uniform strength, even where nature is least abrupt. Why did not Ney carry out precisely Napoleon's early orders at Waterloo, where the position taken up by the Duke of Wellington was such that it is usual enough to speak of "the plains of Waterloo?" Because, he said, the slight depressions he would be obliged to cross were then too heavy in mud. That slight change in the execution of an order made an important difference.

An unfortified position has practically never been an uniformly strong position, and so much a commander must certainly see and know. It is natural that this knowledge should lead to abandonment of uniformity in allotting troops for defence. This can be tested, for the general disposition of troops on the defensive is noted in the Appendices. The information on which this column of the Appendices has been filled has been sometimes full and clear, sometimes of such a nature that it has been possible only to make an inference. The result of a comparison between the dispositions made in the first system and the dispositions made in the second is that in the latter case there has been a much less tendency to uniformity along the position. If then in many instances commanders have massed their troops more strongly at some points than at others, it is reasonable to infer they must have had clear ideas where they expected attack. Yet for each case in which a defender was attacked as he expected may be quoted another in which attack came not as anticipated. The strength of a position and the disposition of troops in it may be misjudged; but, apart from this, reasons may urge an assailant which none but the greatest commander could fathom. For instance, he might take a tactical risk to gain a strategical advantage. Of this nature was the Russian attack at Austerlitz, and that of Napoleon at Waterloo.

Where the dispositions of the defender at all approach uniformity, there is one cause which in a number of cases has decided the point of strongest attack, and this, for want of a better word, must be called chance. Suppose two great lines of combatants, one of which is seeking an opening at which to thrust in the wedge. A division trained to more than average thoroughness, or animated by an ardour beyond the common; or another division at some distant part of the field, favoured by slight accidents of the ground which would escape any but the most vigilant eye; or the sudden determination to concentrate every gun on some joint in the defence where a first-rate artillery commander caught a glimpse of wavering; any of these chances might decide what till then no man in the field foresaw.

It will probably be judged then that while the commander who does not fortify escapes temptations which appear to the commander who does fortify an imperious demand, yet the former has, from a variety of causes, little advantage over the latter when he comes to ask himself where he expects to be attacked, or, if he have an advantage, it lies in his own genius.

The second defensive system suffers from the disadvantage that it is extravagant of troops. In the majority of cases the length of front defended by one division has not been far from unequal to the length of front defended by another. Hence when the crisis has come at some one part of the field, there have always been at other parts of the field many bodies of troops with no opportunity of ever firing a shot. In this sense a want of economy may be also charged against the first system. But suppose now the defender, abandoning the idea of rigidly allotting his troops at so many thousands to a mile, forms a first line sufficiently strong, as he supposes, to beat back the first tentative efforts of the assailant, and posts a few very strong reserves at considerable intervals. Within easy reach of each reserve there is only a certain definite part of the first line. There must then be fractions of that first line which must, whatever happens, rely for a considerable time on their own powers of resistance. As any one of these fractions may turn out to be the assailant's chief goal, all must alike from the beginning be proportionately strengthened. At everyone of the fractions not seriously attacked this extra support is so much waste, a draught on the reserves by which the result of the main struggle is to be determined. Why should not these fractions be fortified, so that the original first line might hold them, and the necessity be thus avoided of sending them extra troops ?

Sixty-four battles are named in Appendix II. as fought on this system, or two out of three in the complete hundred. This simple fact is a recommendation which must appear of some weight. Therefore, instead of relating in detail the course of any one battle, it will be more interesting to analyze the enumeration of successes and defeats in the appendix, and thus obtain a clearer notion of the true value of the system.

Ten victories were won by the defence under the following heads :—By great counter-attack seven, namely, Kunersdorf, Liegnitz, Neerwinden, Rivoli, Austerlitz, Auerstedt, and Laon ; in one the attack completely miscarried, namely, Kolin ; in one an ill-conducted attack was destroyed by a stroke of generalship, namely, at Rossbach ; and in one the assailant was overpowered by superior numbers, namely, at Waterloo. It must also be remarked that at Liegnitz the assailant, Laudon, was numerically weak and partly taken by surprise ; and that at Rivoli the Austrian generalship, at Austerlitz the Russian, and at Auerstedt the Prussian, were all particularly bad. It follows that, when put to a fair trial, the value of the system as a cause of victories is even less than at first sight might appear.

Seven times the result of the battle was indecisive. This has been already adverted to; and here it will only be added that, as a matter of fact, at Eylau and Antietam the defender retreated, and at Corunna embarked; at Colombey and Vionville the strategical object of the numerically weak assailant was gained. At Albuera the defender was wholly exhausted; and at Busaco, after two wholly unsupported attacks, Massena drew off his forces, and immediately turned Wellington's left. In none of these battles, therefore, did the second defensive system prove its superiority.

The battles fought on the first defensive system contained but one fought by the Duke of Wellington, and in that he assumed the offensive. Appendix II. contains the names of six of Wellington's battles, in four of which he attacked: at Vittoria and Orthez without qualification; at Salamanca, as soon as he perceived Marmont's fatal error; and at Sauroren, on the second day, his great counter-attack having succeeded. At Busaco and Waterloo, and on the first day of Sauroren, he was defending, and on each occasion beat off his assailant. These might appear veritable triumphs for this defensive system but for one mitigating cause. The French tactics were no match for the tactics of Wellington. The French advancing in column were met by the fire of British troops in line. To this fire the column could hardly reply, and thus before it had time to deploy it was practically destroyed. The counter-attack then took the form of a charge, which rapidly ended the business. But this is impossible now. Against modern infantry fire no troops could advance in column; they would not attempt it. Troops in line will not again have troops in column to contend against; line will meet line. And this again implies a certain discount in estimating the true value of the system under consideration. Favoured though this system has been by numerous commanders, we cannot honestly conclude that it yields much of promise. Indubitably it possesses advantages over the first system, for it tends to make the commander and the troops careful and watchful, and it does not in the same degree tie down the commander to a rigid system of uniformity. Yet unless he possess true genius he has the same difficulty in fathoming the designs of his adversary, and, therefore, cannot tell how to set about organizing a great counter-attack. If we appeal to reason, the prospect of a successful defence on this system seems small; if we appeal to history, such is the uncertainty of war, the chances rise, chiefly owing to extraordinary errors in the combinations of assailants, almost to one in six.

We now come to the third defensive system, in which the position, including the flanks, is divided into offensive and defensive zones. The latter are fortified or protected by natural obstacles, such as a marsh, a ravine, or a difficult stream.

Much has been written concerning the advantages of attack and defence respectively. It is unnecessary to repeat here the old arguments, but a view of the question, which is perhaps novel, will be given here, as it is hoped thus to reach a conclusion which has an important bearing on the defensive problem.

The greatest commanders have seldom resolved to act defensively except for the most cogent reason. Napoleon was on the defensive at Rivoli; but this was unavoidable, because at the moment when he joined the army the Austrians were already advancing; and the manner of that advance was such that the truest wisdom lay in allowing its continuance. At Marengo numerical weakness compelled the French to stand at first on the defensive; but on the arrival of Desaix the tables were at once turned. At Austerlitz the, for themselves, unfortunate precipitancy of the Russians was a parallel to the Austrian extravagance at Rivoli. Essling was a desperate effort to maintain a footing on the northern bank of the Danube; Leipsic an equally desperate struggle against vastly superior numbers; Brienne and Arcis were expiring efforts made against foes who had become innumerable.

Frederic the Great was for the first time on the defensive at Rossbach, but his defence amounted in reality to a violent attack. At Hochkirch he was surprised. At Liegnitz he found himself reduced to almost his last biscuit, and surrounded by vastly superior forces of the enemy; he was only too happy then when the impetuous Laudon attacked him unsupported, and thus left open the road to Breslau.

On no occasion did Marlborough wait to be attacked.

Considering the character usually attributed to Wellington he assumed the offensive pretty often. At Salamanca, Vittoria, on the second day of Sauroren, at Nivelle, Orthez, Toulouse, as well as in many minor combats, he attacked and defeated his enemy. At Talavera he defended because he could not trust the Spaniards. Busaco has been called by Napier "a political battle," which Wellington would not, under ordinary circumstances, have fought at all. Considering what had happened at Ligny, and the doubtful composition of his own army, Wellington could hardly have been expected to fight offensively at Waterloo.

Among generals whose fame stands lower, Duke Ferdinand of Brunswick was only once actually attacked, by the Duke of Broglio, at Minden; but at the same battle Duke Ferdinand assailed and defeated the French on the other wing. Creveldt, Minden, Wilhelmsthal were his chief offensive victories.

This general desire to assume an offensive *rôle*, so strong in all confident commanders, proves their feeling of superiority. But it must not be forgotten that in almost every case of actual contest there has been a marked difference between the talents and characters of the opposing leaders. Frederic had most frequently to deal with such slow and cautious men as Braun and Daun. Marlborough never, Napoleon seldom, in his earlier days at all events, was matched with equal brains and equal force of character. In the presence of Massena, Wellington was always most careful, as he himself allowed; but he launched out against Soult or King Joseph.

Still, allowing that leaders have sometimes felt their spirits overcrow'd, and that such humility has led, and might again lead, to a capitulation, such as that of General Mack at Ulm, it seems fair to assume that the acceptance of battle in a defensive position implies generally the recognition of defective means. Such a defect must in argument be represented by inferiority in numbers, since, in a supposed case, the abilities of the leaders, the *morale* of the troops, and the antecedents of the campaign are unknown quantities which must be ignored; while the weapons used must, as a matter of course, be presumed the same on both sides.

It will be noticed that in each of the appendices the list of battles is divided into three parts. One of these parts is headed (A), *Muskets*, the musket having been the weapon in use when the battles under this heading were fought. The second part is headed, for a similar reason, (B), *Rifles*, and the third part (C), *Breech-loaders*. As the progress of invention led to successive improvements in weapons, opinion was freely expressed at each stage that the defensive gained an overpowering advantage. It is now necessary to test the grounds of this opinion.

Appendix I. gives ten battles fought with muskets, every one of which was a defeat for the force on the defensive. Appendix II. names forty-nine battles as fought with the same weapon; of which ten were victories for the defence and four were indecisive.

Appendix III., in a similar way, gives twelve battles, in which the defence was victorious twice, while one battle was indecisive. On the whole, out of seventy-one battles here named as fought with muskets, in fifty-four the attacking force was victorious, in twelve the force on the defensive, and five were indecisive. But in these five indecisive battles, namely, Eylau, Corunna, Busaco, Albuera, and Talavera, since the attack was actually beaten off, there is sufficient ground for attributing the musketry superiority to the defence. Hence the successes of the attack are to those of the defence as 54 to 17, or rather more than 3 to 1.

The rifle was introduced. The defender was now able to strike down his adversary at a much greater distance, that is, the zone of danger was now considerably increased; moreover, firing had become much more accurate, though rapidity of fire probably remained unaltered. But the assailant was in like case; he could open fire much earlier, and plant his shots more truly. There was, however, between the new powers of the defender and those of the assailant this important difference. The assailant was still compelled to halt and stand up in order to load. The defender was under no such necessity; hence the target presented by the assailant to the defender was much greater than the target presented by the defender to the assailant. The invention of the muzzle-loading rifle was therefore a real benefit to defence.

In Appendix I. six battles are shown as fought with rifles; of these, four were defeats for the defence, and two were indecisive. Appendix II. gives only four battles fought with rifles, of which three were defeats for the defence, and one was indecisive. Appendix III. names three such battles, of which one was a defeat, two were victories for the defence. On the whole, of thirteen battles, in eight the attacking force was victorious, in two the force on the defensive, and three battles were indecisive. The three indecisive battles were Spotsylvania, Cold Harbour, and Antietam. In the two former the attacking force must be held to have been beaten off; but at Antietam this was not so clearly the case, though Lee in the evening expressed himself determined to continue the action. Therefore the victories of the assailant to those of the defenders may be put at 9 to 4, or $2\frac{1}{4}$ to 1.

Then came the breech-loader. The range of the rifle being now very materially increased, the danger zone was correspondingly broadened. But in addition to this, as the accuracy of fire had become still greater, and its rapidity much greater, the zone of danger had become far more difficult to cross. But the assailant could also to a great extent reckon on these advantages; and he had one more which gave him back much that the rifle had cost him. He could load while prone on the earth, or, if he preferred it, as he ran forward. The target offered to the defender was thus materially reduced. Hence it is a very doubtful question if the breech-loader was, as many supposed, a real advantage to the defence. It is quite as likely that this invention has actually been more advantageous to the assailant.

In Appendix I. three battles, all defeats for the defence, are shown as fought with breech-loaders; in Appendix II. eleven battles, all defeats for the defence, except two which were indecisive; and in Appendix III. two battles, one a defeat, and one a victory for the defence. Here then is a record of sixteen battles fought with breech-loaders, of which the attack won thirteen, the defence one, and of which two were indecisive, namely, Colombey and Vionville. If, as before, these indecisive battles be allowed to the defence, the ratio of defensive defeats is to that of defensive victories as 13 to 3, or $4\frac{1}{3}$ to 1. Thus, in one hundred battles of modern times we find the defence much less successful with the breech-loader than it was with the rifle, and even less so than it was with the musket.

It may be very truly said that in these three periods, while the numbers of battles fought with rifles and breech-loaders were nearly equal, the number fought with muskets was more than two-thirds of the complete series. This cannot be helped. The musket period covered nearly a century and a-half. It is also true that this period was illustrated by the victories of the greatest military leaders, who shone more brightly in attack than in defence; that the rifle period included the American War of Secession, when defensive fighting was rather in vogue; and that the breech-loader period includes the Franco-German War, when the forces on the defensive were not, as a rule, well led, and when the superiority of the German artillery, overbalancing the superiority of the chassepot, contributed very materially to the success of the attack. If all these facts could be allowed for, they would no doubt modify the figures given above. The allowance cannot be made, but the analysis leaves us this important result—that the desire to attack, shown to be so strong in the breasts of the greatest leaders, has no way diminished, in spite of improvements in arms; on the contrary, not only is the attack still favoured, but it is carried out with at least the old success, and perhaps even with more.

But has any modification been introduced in the general plan of attack? The general mode of attack in each of the one hundred battles enumerated in the Appendices is therein given. In the battles of the first period the number of instances in which attempts were made against the flanks or rear was, roughly speaking, about three in every seven; in the battles of the second period six in thirteen; and in the battles of the third period ten in sixteen. Judged from this point of view, there would appear to have been a growth of caution, simultaneously with the improvements in weapons, an increasing tendency to substitute the less direct for the more direct method of attack. This tendency would appear to have become more pronounced with the introduction of the breech-loader. If the attack of villages be considered, we shall reach the same conclusion. In former times hesitation was never shown in attacking a village directly; since the introduction of the breech-loader, it has become a general rule to attack a village by the flanks; this was noticeably the case in the Franco-German War. This conclusion, that while the attack in general has never lost its favour, the indirect method of attack has become more common, is a conclusion of the utmost importance, if fully warranted.

It is certain that, since the introduction of the breech-loader, it has become more costly than it used to be to carry by frontal attack a strongly occupied position. It is to be anticipated therefore that any improvements in the breech-loader will increase this costliness, and therefore also increase the tendency to indirect attack. Since 1878 the breech-loader has been much improved, and the magazine added; it therefore seems reasonable to suppose that to carry by frontal attack a still strongly held position would now be very costly.

On the following data then (1), that it would now be very costly work carrying a position still strongly held by frontal attack; (2), that therefore an increased tendency to the indirect attack of such positions may be expected; (3), and that the adoption of the defensive will still imply numerical inferiority—on these data the third defensive system will be examined, with reference to the extent to which it favours the organization of great counter-attack.

In this system the front, including the flanks, has been formed of strong defensive zones and open offensive zones. Illustrations of this method of defence will be given presently, but it will conduce to clearness to define such a position as it might be formed at the present time.

As already stated at the beginning of this paper, the country to be defended is not to be supposed a plain simple ridge. Almost every ridge has spurs running out to the front at various angles, and is cut into by depressions taking various directions. Woods, farmsteads, and possibly villages may exist in rear of the position, within the position, or in front of it.

Villages in the line of advance, even when off the direct line of road, have always exercised a considerable drawing power on the forces of the assailant. There is possibly no single instance in military history of a village in such a situation having been left under observation only. There is in fact a sufficient reason why a village occupied by the defender cannot well be passed. If a village in front of a position can be brought under the artillery fire of the assailant, and is not under the artillery fire of the defender, then the latter cannot continue to occupy the village, and in such a case the task of the assailant is obviously a very easy one. A village subject to capture in this manner is a disadvantage to the defender, and a great defect in his position.

This defect is not an uncommon one, and has occurred even in carefully chosen positions. Thus the farmstead of Hougoumont was a defect in Wellington's position at Waterloo. The loss of this post would have had a bad moral effect on the whole British force, out of all proportion to the bad effect on the French army of failure to capture it. For the attack on Hougoumont had not as its end the capture of the farm, but to compel Wellington, in his determination to hold it, to draw thither reinforcements, and so weaken his left, the point at which Napoleon aimed his real effort. In this object Napoleon in a great measure succeeded, for at one time the British left centre was actually in great peril. In a similar way the whole strength of the Prussians, at the Battle of Ligny, was exhausted by the defence of the villages Ligny and St. Amand, so that when they could be no longer defended no further resistance could be made to Napoleon's great attack in the centre.

It is because villages have so often been no friends to the defence that, in the absence of definite information of additional intrenchments, they have not been held in this paper to constitute true defensive zones.

But could we suppose a village in front of a position, or just within the position, so placed as to be concealed from the artillery fire of the assailant, or masked therefrom by a fold of the ground, or by the interposition of a belt of trees, then such a village might be made the nucleus of a very strong defensive zone, especially if well flanked by the fire of some of the defender's guns.

It would of course be necessary that the village should be put in a perfect state of defence, that intrenchments should be thrown up so as to bring into the firing line an adequate number of rifles, and that the garrison should have for their own fire a sufficiently clear field. The cost of carrying such a position by the direct attack of infantry alone would be very great.

In the absence of a village, a wood suitably placed might answer the purpose. The attack of a wood has always been one of the most dangerous operations of war. An ill-placed wood, like an ill-placed village, is a great disadvantage to the defence, but if small and suitably placed, the wood, put in a thorough state of defence, may be made the kernel of a strong defensive zone. "Woods properly held on the defensive zone are of great value," says Home, "enabling the front of the army holding them to be extended. A wood of very great extent cannot be so treated."

Or a defensive zone may be created, by the construction of a proper system of field defences, with this great advantage—that in choice of position there is here great latitude.

Supposing then one or more such defensive zones, not exposed or but little exposed to direct artillery fire, to have been carefully prepared, the defender possesses this certain knowledge—that if the enemy's infantry endeavour seriously to carry these positions, it will be forced to submit to very heavy loss, with a great probability of failure ; that endeavours to carry such positions by direct assault are less probable than endeavours to turn them ; that the remainder of the position, though all strongly held, is open, and therefore may apparently be attacked with, to the assailant, better prospects of success than is offered by direct assaults in the defensive zone.

Therefore the defender has it in his power to economize in men in the defensive zones, thereby increasing the strength of the great reserves, with which he purposes to attack in the offensive zones.

This general sketch may serve as an explanation of what defence on the third system is supposed to mean, and may enable us to test more exactly the value of the system.

The drawing power of villages has been mentioned, but there is nothing strange in the idea of a force on the defensive exercising that power over the force on the offensive as a whole. On this point von der Goltz says: "The power of the defender to draw the attacker after him is naturally the greater the less the superiority of the attacker in numbers, etc. It must always be possible for a defender only slightly the weaker to draw the attacker after him wheresoever he chooses, so long as the theatre of war affords him play room." This is the more forcible since now armies no longer manœuvre to the same extent as formerly ; the objective of the force on the offensive almost always is the army of the enemy wherever found. Thus, though the force on the offensive is said to have the initiative, there are certainly powers of which the defender need not be deprived.

Says von der Goltz : "If the position occupied be such that before reaching it the attacker must cross obstacles which can be passed only at certain points, as a river where he is restricted to bridges, the defender has the advantage of knowing beforehand on what points he must concentrate his fire. Moreover, the movements of the attacker are in such a case compulsory, and the defender can picture to himself what to expect. . . . An apparent weakness, as at Austerlitz on the right flank, may be advantageous, because it induces the enemy to advance in a direction easily perceived. In fact it is convenient that a part of the front be naturally strong ; because, as a rule, one must suppose the defender the weaker of two opponents, and if he would certainly gain the upper hand on one part of the field, he must be sparing of his troops in occupying the other part."

The correct interpretation of the third defensive system is not, as is often stated, the economy of troops at one point to gain in numerical strength at another ; it is more than that. As put by von der Goltz, it implies the creation of very strong points, in attacking which the enemy could hardly hope for success, and where therefore economy is possible ; and parts of "apparent weakness" inviting attack, where the defender has massed his heaviest reserves for sudden counter-attack on a great scale in favourable directions.

In Appendix III. are given the names of seventeen battles, five of which were victories for the defence, and of which one was indecisive. In all these battles the position, including the flank, was partly strong by nature or was artificially made so ; while at the other part of the position there was no natural obstacle, and if field defences were made, still the difference in strength between the two parts of the position was great and obvious.

Now at first sight this definition might seem very nearly to correspond to the description which has just been given of a position prepared for defence on the third system. For here there might appear to be the "strong points" and the parts of "apparent weakness" inviting attack, just stated to be the modern interpretation of the terms defensive and offensive zones. Yet this in reality is not so. It will presently be shown that until the rifle began to be used, a defence on the third system, as now understood, though it might of course have been conceived, could hardly have been executed. Hence the illustrations we have of this defence, prior to Magenta, are imperfect; in each case the form was there, but the form was not animated by the spirit. Take Talavera as an instance. Here the Duke of Wellington put the Spaniards behind parapets; but was that to make a strong defensive zone? Probably not. It was more likely in the hope the Spaniards might be thus induced to stand by him. If then in those days a defence on the third system was so only in form, it seems probable that for troops armed with the musket the second defensive system was more suitable. As a matter of fact, out of forty-nine battles shown in the Appendices as fought on the second defensive system with the musket, thirty-five were victories for the assailant, or five in every seven; out of twelve battles shown as fought on the third defensive system with the musket, nine were victories for the assailant, or three in every four; a much higher proportion. When we come to the battles fought with the rifle and breech-loader, this proportion is reversed, being twelve victories in fifteen battles fought on the second, and two victories in five battles fought on the third, defensive system. This difference is striking, though the number of battles, on which the latter comparison is founded, is too small to make the result convincing of itself. The result may, however, become convincing when its reason is presently explained.

In order to arrive at that explanation a few of the battles fought on this system of defence will now be followed in detail. By this means we may be able at the same time to ascertain if commanders, in choosing points of attack, appear to have been influenced by the unequal strength of the parts of the defender's position; and possibly to form an opinion as to the true cause which governed the defender in strengthening some parts of his position, and not other parts.

Of all the hundred battles named in the Appendices the earliest fought was Blenheim. In this battle (*Plate* IV.) the French, 56,000 strong, under Marshal Tallard, were drawn up behind the river Nebel, the right resting on the Danube, here 300 feet broad and nowhere fordable. The left reached the wooded hills above

Lutzingen, so that the front covered about three miles. From Oberglauh to Blenheim the Nebel is very marshy, but especially so below Unterglauh, where in many parts the stream cannot be passed. Towards the Danube the points of crossing are confined to a few places near the mills. Such were the natural obstacles. The village of Blenheim was prepared for defence, and protected by abattis and barricades. Thus on the right flank, protected by the Danube, and at the centre, owing to the marsh, the position was much stronger than on the open left. Though on the right the passage of the Nebel was easy, the village of Blenheim formed here a serious obstacle. Whether designedly or not, the position was stronger at one part than at the other.

Marshal Tallard posted all the infantry of the right wing in and about Blenheim. On the extreme left 18 battalions of infantry formed a sort of oblique flank, between which and the village of Oberglauh stood a few battalions. Oberglauh was occupied by an infantry picket, and behind the village stood 30 battalions under Marsin. All the remainder of the line was occupied by cavalry. Between Blenheim and the Danube was a brigade of dismounted dragoons; to the left of Blenheim were 8 squadrons of *gens d'armes*, between whom and Oberglauh were 50 squadrons, and in front of Lutzingen the remainder of the cavalry. From this distribution it may be inferred that the French commander expected attack on his left, and also opposite Blenheim, but certainly not in the centre; and if that were so, he must have considered the marshy Nebel impossible to cross. There is no evidence in this of an adequate conception of defence on the third system.

The allies numbered 52,000 men and 52 guns. After carefully reconnoitring, the Duke of Marlborough ordered an attack on Blenheim, and Prince Eugene was directed to attack Marsin in front and on his left. This answered Tallard's expectations, and no doubt served to put him off his guard. But meantime the Duke, who neglected nothing, had directed a careful examination of the Nebel, and found it no such obstacle as Marshal Tallard had supposed. A sufficient number of fascines having been made, causeways were formed, by means of which at its least formidable points the difficulties of the marsh were overcome. There was no lack of pontoons; hence it was found possible to throw a bridge across the river above the village of Unterglauh, and four below it. The stone bridge having been also repaired, no less than six passages over the river were provided where a single passage had been deemed impossible.

Eugeñe's attack on Marsin was not interfered with, but that on Blenheim, which promised to be very costly, was reduced to a demonstration. Meantime four lines had been drawn up in the centre ready to cross the river. These lines consisted respectively of 17 battalions, 36 squadrons, 35 squadrons, and 11 battalions. By 3 o'clock the passage of the river was complete, the Duke was able to advance, and by 5 o'clock he had cut the French in two. It need hardly be said that the advance was in this case made against the point of least resistance. This point had been doubtless recognized by the Duke, for in those days it was possible to reconnoitre close up to an enemy. And no doubt as soon as he saw that which would, if it were possible to be done, make his task a simple one, he resolved to ascertain that which the French commander might certainly have ascertained before him.

Unfortunately for Marshal Tallard he could not quit his position, for the Nebel barred the way; in no way therefore could he interfere with the Duke's passage, except by an enfilading fire of artillery, which caused loss, but not a very serious loss. Long before troops from Blenheim could be brought up in sufficient numbers to interfere with the British advance the passage had been thoroughly made good, and the French centre was pierced. Nor could Marsin lend any important aid. Eugene had attacked with his accustomed vigour, and, fighting with varying success, turned the French left, and forced it beyond Lutzingen. Thus Marshal Tallard, abandoned to his own resources, found the fire of his scarce formed infantry overpowered, saw his cavalry and infantry melt into a crowd of fugitives, and was himself taken. Meantime the French left was also routed. Then Blenheim, in which was still a strong garrison augmented by crowds of fugitives, was attacked and surrounded. This was one of those cases where a village proved no friend to the troops defending it; for every man in Blenheim was either killed or taken, though it cannot be said the village was any impediment in the way of the attack.

Now here, it is to be observed, there was no great counter-attack. At first it was impossible to make one, for the Nebel, which the French could not pass, flowed between them and the British. When the latter force was over the river it was too late to attack them in force. This is the important feature of the battle from our present point of view; not merely that no great counter-attack took place, but that, from the nature of the situation, the possibility of making one was almost precluded.

The Duke of Marlborough's great victory of Ramillies, fought the 23rd May, 1706, offers similar points of interest. The French army (*Plate* V.), numbering 62,000, was drawn up to westward of the Little Gete. The right of the position was covered by the Mehaigne, at Tavieres; thence the front curved round, concave to the enemy, through Ramillies and Offuz to Autre Eglise. All the course of the Little Gete is a morass, and hence the French left was very difficult of access. Thus the difference in natural strength between the two parts of the position, from Tavieres to Ramillies, and from Ramillies to Autre Eglise, was strongly marked, and the more so as no attempt was made to strengthen the right by means of fortification. Thus here again the natural features of the ground, in the absence of field defences on the right, pointed to a defence on the third system.

One brigade of French infantry stood at Tavieres on the river Mehaigne. Twenty battalions were posted about Ramillies, where also there was a considerable number of guns. All the remainder of the infantry was formed in two lines, from Ramillies by Offuz to Autre Eglise. The tomb of Ottomund is the highest point in this district; it was not occupied, and in front of it stood only 100 squadrons, filling the space between Tavieres and Ramillies.

It follows from this distribution of troops that Villeroy, the French commander, felt perfectly sure of attack on his left alone, that is, in the space between Ramillies and Autre Eglise covered by the Little Gete. There is therefore no evidence here of a deliberate intention to leave a part of the front so apparently weak as to invite attack, for where the front was weak there was not a single infantry soldier.

The Duke of Marlborough began the battle by moving the bulk of his forces to the heights of Foulz, as though it were his object to cross the Gete, and attack the French left. Confirmed in his hopes, and therefore the more readily deceived, Villeroy rapidly piled up troops in rear of his left, drawing them for that purpose from the centre. As soon as he perceived that this movement had been thoroughly established, Marlborough proceeded to carry out his real design.

The French army formed, as has been shown, an arc, of which the chord was within Marlborough's power; for his troops set in motion from his own right, having a shorter distance to march, were able to pass Ramillies before the French left wing, moving by the circuitous route of Offuz, could hope to overtake them. But more than this; as the Little Gete has hills on both banks, it was possible for Marlborough to conceal his flank march from Villeroy, and this gave the British a considerable start.

Leaving in front of the French left at Foulz a sufficient force to continue an active demonstration, Marlborough retired his second line behind the shelter of his hills. As soon as this line was withdrawn completely out of sight of the French it filed off to the left, and a great attack was begun, having as objective the tomb of Ottomund. There is no doubt, therefore, that in this battle the great English commander drove straight at the weakest part of the defender's line.

Every detail was thought out by Marlborough, and all eventualities provided for. Tavieres was attacked and carried; 12 infantry battalions were directed against Ramillies; in rear of these attacks the heads of the great force moved across from Foulz marched on the tomb of Ottomund; a special cavalry force was told off to delay the march of any reinforcements moved across from the French left.

As the day wore on Villeroy at last discovered he had been deceived. At once he made endeavours to move troops from his left to the centre, but the cavalry told off to interfere with this attempt successfully performed its task. Meantime, in a series of great cavalry charges, the hundred squadrons of the French army were overthrown, the great infantry attack occupied the tomb of Ottomund, twenty additional battalions drawn from the British right completed the capture of Ramillies, and Marlborough, now facing to his right, enfiladed the whole French position.

Villeroy, as a last resource, endeavoured then to form a fresh line of battle between Offuz and Geest à Gerompont. But now Marlborough, continually drawing troops along the chord from his right, pushed forward from Ramillies and the tomb of Ottomund, and the new French line gave way.

Meantime the British right had found means to struggle across the morass of the Little Gete. Having succeeded then in rolling up the remains of the French left, these troops joined in the pursuit, which rapidly become a rout, hotly pressed by the cavalry.

In this battle the French lost 15,000 men, 80 standards, and all their artillery and baggage. The allies, who were numerically rather inferior to the French, lost 4,633 men.

As at Blenheim, there was no great counter-attack. No troops had been posted in a position from which a great counter-attack could be made; for it was impossible for such a movement to have been attempted across the Gete.

Kesselsdorf, fought on the 15th December, 1745, was not interesting in its details; perhaps, therefore, the following summary will suffice. The Prussian left and Austro-Saxon right were separated by a deep ravine neither could pass; the Saxons on the left, about Kesselsdorf, which was put in a state of defence, were easily assailable. Thus the position was much stronger at one part than at the other.

Rutowski, who commanded the Austro-Saxons, posted 16,000 behind the ravine, 19,000 about Kesselsdorf; but the right wing neither moved nor fired a shot, so that there is no evidence to show what Rutowski's design may have been. Dessauer attacked at Kesselsdorf, where alone attack was possible. The Saxons made a counter-attack, but it was unsupported, and therefore failed.

We come now to Lowositz, the first battle of the Seven Years' War, of date 1st October, 1756. This battle has been compared to Ramillies, though it is difficult to see why. The attack at Lowositz, both in conception and execution, was far below that at Ramillies, nor had it a similar object nor method. Moreover Braun's disposition of his troops was totally different from that of Villeroy.

The whole of the Austrian left and centre (*Plate* VI.) was covered by a stream with boggy banks, and forming lakes at intervals. From Salowitz to Lowositz the stream is in a deep bottom, and this can be crossed only at one small stone bridge. Lowositz was slightly fortified, and before it some small redoubts had been thrown up. Thus the left and centre could not be immediately assailed; the right, however, was not nearly so strong. Hence this battle comes under the third system.

On the long frontal slope of the Lobosch-berg there is finally a steep drop towards Lowositz, in front of which are many vineyards separated by stone walls. Here, about K, the Austrian commander had placed thousands of Croats, supported by some battalions of Hungarian infantry. The cavalry of the right wing was forward to the left of Lowositz, near N. In and about Lowositz, Braun had placed his best infantry and a numerous artillery, a strong battery being formed near the redoubts. The remainder of Braun's force, which was in all composed of 52 battalions, 72 squadrons, and 98 guns, was between Salowitz and Lowositz, so that the wings were separated by the brook. From these dispositions it would appear Braun rather anticipated attack on his right, but sought to strengthen that part by artificial means.

The Prussian army, composed of 26 battalions, 56 squadrons, and 102 guns, stood at I I, the right of the infantry being between Radostitz and the Homolka-berg. The latter hill, where a heavy battery was placed, commands the country as far as Salowitz. The left was on the Lobosch-berg. Up to noon the day was foggy, in the early morning it being impossible to see a hundred yards. As the fog partially cleared, the cavalry at N and the redoubts and battery near Lowositz became visible, but nothing else, and the King thought he might have to do only with a rear guard. Certain movements he had heard in the enemy's camp during the night strengthened this idea. To clear matters up he sent forward a dragoon regiment and some squadrons to attack the enemy's cavalry. The encounter took place at Q; the enemy were driven back, but the pursuit being carried too far, the Prussians came under a hot artillery fire from Lowositz and Salowitz, and were compelled to fall back with heavy loss.

The fog now lifting, the whole Austrian army was disclosed drawn up in position. "After carefully reconnoitring," says Tempelhof, "the King judged the enemy's right flank the weaker on many grounds, but especially because it was commanded from the Lobosch-berg." The truth is it was impossible to attack anywhere else, as will appear from the following account of the battle.

The King first advanced to the line Lobosch-berg-Homolka-berg, and the left wing, sufficiently strengthened, was despatched, under cover of a well-served artillery fire, towards Lowositz. The Croats, though supported by some of the best Austrian infantry sent forward from the right wing, were driven back, and a counter-attack attempted by Lascy being repulsed, fell back on Lowositz.

The Prussian advance was now for a time suspended, so that fresh artillery might be brought up to the Lobosch-berg, and to allow of the restoration of order which had been lost in fighting in the uneven and intricate ground before Lowositz. Then the advance was resumed as close as possible to the Elbe, so as to avoid the fire of the great Austrian battery.

Meantime the Prussian right continued to occupy the Homolka-berg, remaining in observation of the enemy's left and centre, which for their part attempted nothing, standing motionless behind the swampy brook. From this it is clear the attack of the Prussians could not have been attempted at Salowitz, nor between that village and Lowositz.

With only one bridge at his disposal it was difficult for Braun to draw troops to his right from the left; he had, therefore, no resource but to throw the whole of his right into Lowositz. Here the fight was long and obstinate, but eventually the advantage passed to the Prussians, who were greatly aided by their artillery on the Loboschberg. The village being set on fire, and the Austrians being much crowded and in disorder, a retirement became necessary. This was rather hurriedly carried out, covered by the cavalry.

No great counter-attack was attempted; it could not in such a situation have been done; though when Braun saw his right was defeated, he ordered his left to advance through Salowitz and attack the Prussian right. Only a small number of the infantry succeeded in passing the village, and these could not form under the heavy artillery fire from the Homolka-berg, which is only a few hundred paces from the dyke, over which lay the single passage across the boggy brook. The small force which had crossed retired in confusion. "The only object of Braun in this," says Tempelhof, "must have been to draw the attention of the enemy to that side and gain time to prepare his retreat."

Braun did effect his retreat in good order, and succeeded in taking up a fresh position, which the King did not immediately attack. The Duke of Bevern was, however, detached with a strong force of infantry and cavalry by Tschiskowitz to threaten the Austrian left; whereupon Braun withdrew over the river Eger, and the object of the King was attained.

The Austrian loss amounted to 2,984, the Prussian to 3,308.

The Battle of Prague is too well known to need any detailed description here. What will presently be said of Fleurus includes pretty nearly all that might be said of Prague, except this—that since at Prague the Austrian right formed a crochet, that alone pretty well insured defeat.

Hochkirch was a surprise; it is not, therefore, necessary to attempt any deductions as to the motives of the two commanders.

At Fleurus (*Plate* VII.), fought the 26th June, 1794, Jourdan on the defensive defeated the Prince de Cobourg. The French position formed round Charleroi, which had just been taken, a semicircle of no less than 18 miles in extent, the left and right both resting on the Sambre. Although many woods and villages were scattered over the interior of the position, there were no natural features of sufficient importance to prevent attack at any point. As, therefore, the right of the position from Heppignies, almost as far as the

Sambre, was strongly intrenched, this defence is clearly an illustration of the third system.

The distribution of troops was as follows:—On the right divisions Marceau and Meyer, 16,478 men occupied the ground from the Sambre to Campenaire, with advanced posts at Baulet, Wansersée, and Velaine. Lefebvre prolonged to Wagné with 8,815 men, having an advanced post at Fleurus; and division Championnet thence to Heppignies, 9,088 men, with advanced posts at Mellet and St. Fiacre. Before Gosselies and Thuméon was division Morlot, 8,578 strong. Montaigu commanded the left, 8,358 strong; its right was at Piéton, left at the woods of Monceaux and Forchies. The following troops were in reserve:—At Ransart, 11,064 men under Hatry; at Gosselies and Jumet, 2,713 cavalry under Dubois, and 9,969 infantry under Kléber; at Fontaine l'Evêque, Lernes, and Vespe, 5,904 men under Daurier. If Daurier be considered rather as forming the extreme left of the French line, we thus have 34,381 men intrenched on a front of about five miles; 22,840 men not intrenched holding a long line thirteen miles in total length; and a great central reserve, in two nearly equal masses, numbering in all 23,746 men. This cannot be considered a disposition proving that the French commander, Jourdan, deliberately left his front from Heppignies westward to the Sambre unfortified, so as to invite there an attack he hoped to overwhelm. Moreover, the enormous length of front scantily occupied entirely precludes such an idea.

The dispositions for attack were as follows:—On the right three columns, directed by the Prince of Orange and Latour, attacked Fontaine l'Evêque, the wood of Monceaux, and Traségnies. These columns numbered 20,000 men. Quasdanowich, with 11,400 men, moved against Frasnes, Mellet, and Gosselies. De Kaunitz, with 8,800, marched by Mellet and Fleurus on Heppignies. The Archduke Charles, rather weaker, moved on Fleurus. Beaulieu, with 17,000 men, attacked on the Archduke's left, moving on the wood of Lambusart along the Sambre. Thus the attacks, many in number, were made literally half round the compass, had no particular connection with each other, and were separated, as to the extremes, by more than twelve miles, all the intervening country being occupied by the enemy. It is needless to say anything more of such a design, except that almost any species of defence might have been made good against it.

On the Austrian right wing the Duke of Orange attacked Daurier ineffectively; he then attempted a flank movement, Daurier having meantime been joined by the left brigade of Montaigu; in the result the Duke had to retire on Forchies, and so quitted the field. Latour passed the Piéton and advanced in echelon from the right on Traségnies. After a long cannonade he forced Montaigu to retreat on Marchienne, except the brigade which joined Daurier. Latour then occupied the wood of Monceaux and cannonaded Marchienne. After this he heard of the Duke of Orange's retirement.

Probably these long cannonadings gave Jourdan time to despatch Kléber to the Piéton. The counter-attack was strongly supported by artillery. Kléber attacked the wood of Monceaux, turned Latour's left, and, supported by two regiments of cavalry, drove him back on Forchies. Thus Latour also was disposed of.

Quasdanowich deployed in advance of la Cense de Grandchamp. An attempt was made by Morlot to stop him by menacing his flanks, but Quasdanowich turned the tables by attacking Morlot's right, and the latter retired on Gosselies. Quasdanowich was still advancing when he received orders to break off the fight.

The left of Championnet rested on a great redoubt, armed with 18 heavy pieces and commanding the plain between Fleurus and Mellet. He was attacked by Kaunitz, who, after driving in the outposts, had deployed towards St. Fiacre. The French resisted obstinately, making a cavalry counter-attack from Wagné, which, however, was repulsed. Kaunitz later on sought to turn the French left when, in consequence of a false report of Lefebvre's retreat, the redoubt and intrenchments were abandoned in Championnet's retirement. Jourdan upon this brought up 6 battalions and 6 squadrons of Kléber's command, and directed Championnet to advance. The Austrians were driven back, but just then Kaunitz had received orders that the retirement was general.

The Archduke Charles appears to have effected little.

Beaulieu, sweeping away the French advanced posts, and having carried Marceau's intrenchments, drove a large part of his corps across the Sambre. Lefebvre then detached 3 battalions and Hatry also furnished three to enable Marceau to make good his defence; but Lefebvre himself retired to his intrenchments by echelon. A hot contest then began for the possession of the village of Lambusart, and Hatry was ordered to succour Lefebvre because Beaulieu was endeavouring to turn the village. A murderous combat ensued; but the village remained in French possession. About this time Beaulieu received retiring orders.

The Prince de Cobourg had originally hoped to succour Charleroi, and ordered a retirement on hearing the place had already fallen. Still, it is probable he could have done no more than he did, attacking on such a plan. The chief success of the defence was due to a great counter-attack; but this was rendered possible by the very nature of the attack.

The Austrian position and distribution of troops at Arcola (*Plate* VIII.) corresponded almost exactly to those of Villeroy at Ramillies, but a variety was introduced by Bonaparte in the method of attack. The Duke of Marlborough discovered quickly the weak point of his adversary, thrust himself in there in heavy mass, and inflicted an overwhelming defeat with no great loss to his own army. Bonaparte was three days at Arcola, two of which he spent hammering at the strongest Austrian gates; not till the third day did he take advantage of the Austrian weak point. This method was naturally very costly to the French, while the defeat of the Austrians was not nearly so crushing as that of the French at Ramillies.

The Austrian right was at Porcil, near Caldiero, left at Arcola; but owing to the position of the French forces at and south of Ronco, the left bank of the Alpon as far as its junction with the Adige must be considered a necessary part of the Austrian position. The ground between the Alpon and Adige is lower than the rivers, and is impracticable except on the causeways; one of these leads from Ronco to Arcola and St. Bonnifaccio, another from Ronco by Porcil to Caldiero, where it joins the Verona-Vicenza road. The wooden bridge at Arcola was then narrow and high; it had been barricaded and protected by artillery; the neighbouring houses were also loopholed.

Thus from Porcil round to Arcola the Austrian position was almost impregnable, for a small number of troops might easily have held the causeways. South of Arcola, in the absence of opposition, there was nothing to prevent the passage of the Adige or the Alpon; hence this part of the position, as long as it was undefended, was quite open to attack. This constitutes the resemblance between the Ramillies and Arcola positions.

Six Austrian battalions were at Porcil, 14 battalions and 22 squadrons at St. Bonnifaccio and Arcola, a strong detachment holding the bridge. There were no Austrian troops south of Arcola. Thus in the distribution of troops the resemblance to Ramillies was complete.

Massena, with 9,540 men, and Augereau, with 8,340 were about Ronco. On the 15th November the former was directed along the

Porcil, the latter along the Arcola causeway. Massena succeeded in forcing back the Porcil detachment, but as darkness approached considered it necessary to retire on Ronco. Augereau could do nothing at Arcola, for the strong reinforcements brought up by the Austrians repulsed every attack. Meantime Bonaparte detached Guyeux towards Albaredo, with orders to cross the Adige, and move along the left bank. The crossing was easily enough effected, but nothing more could be done, as the daylight was by that time gone. Therefore Bonaparte broke off the action, and ordered all his forces to recross the Adige, except the 12th and 75th Demi-Brigades left to guard the bridge at Ronco. The Austrians retained all their posts from Porcil to Arcola.

Next day the French, having recrossed the Adige in the morning, met the Austrians advancing towards the bridge at Ronco on both the causeways. The Austrians were forced back, and then, except for one or two incidents, there was a pause in the battle. One of these incidents was an attempted advance by the Austrians along the right bank of the Alpon, south of St. Bonnifaccio; this, however, was easily stopped. Another incident was an attempt by Bonaparte, which on that day remained incomplete, to cross the Alpon over a trestle bridge. Night coming on, the French retired as before, leaving only a guard on the left bank of the Adige.

The shortness of the November days may have induced Bonaparte to attempt at first a *coup de main*. Two days thus lost roused him, and his measures were now very different. On the third morning, the advancing Austrians having been again driven back along the causeways, the following dispositions were made. The French 32nd Demi-Brigade was posted in the wood at the confluence of the rivers; the 18th Light was posted at Ronco bridge; the 18th of the Line moved on Porcil, the 75th on Arcola. The trestle bridge having been completed, Augereau crossed the Alpon, near the junction with the Adige.

The 75th, heavily attacked on the Arcola causeway, was forced back towards the wood, hotly pursued by the Austrians. But now the 18th Line, advancing from Ronco bridge, supported the 75th; the 18th of the Line, returning along the causeway from Bionde, fell on the Austrian rear; and the 32nd, moving out of the wood, took them in flank. Attacked on all sides save one, the Austrians were thrown into the marsh, and lost two or three thousand prisoners.

Meantime Augereau, having crossed the Alpon, found himself stuck in a morass, and for a long time was unable to deploy. If the statement of Jomini is to be believed, Bonaparte withdrew attention from Augereau in his difficulties by causing Lieut. Herculus, with only 25 guides, to cross the Adige and advance towards St. Gregorio with a loud sounding of many trumpets. What seems more credible, two battalions called up from the south did now at this crisis reach St. Gregorio; and this might have served to give Augereau time for deployment. At all events the Austrians now began to retire, so that Massena got across the Alpon at Arcola, and Augereau extricated himself from the marsh. The Austrians made good their retreat, but lost 8,000 men.

Thus Bonaparte, after vain attempts to capture the Austrian stronghold, succeeded when he attacked them where they were weak.

It will readily be seen how impossible it was for the Austrians to make a great counter-attack. South of Arcola they had no troops. For the rest they had, as it were, two narrow doors. In at those doors the French could not enter, but out of those doors the Austrians could not issue.

Of Vimiero, the next name in Appendix III., but little need be said. A part of the British line stood opposite a deep ravine, but the centre and extreme left were assailable. Numerically weak, Junot attempted both attacks, giving Wellington time to beat off one attack and then move the same troops, concealed by the ground, to beat off the other. Had Wellington been left to himself he might have raised Vimiero to the rank of Rivoli; but he was not left to himself, and Junot comfortably escaped. It seems improbable that Wellington deliberately left two openings to invite attack, for that would have been to expect Junot to divide his inferior force into two widely separated parts, each of which could be met and repulsed by one concentrated force, as actually happened.

At Talavera, Wellington thoroughly fortified his right, and placed there the Spaniards, who were very shaky, under an untrustworthy leader. He placed the British on the left in the open, hoping no doubt they would sustain the main attack; as they did, for the French almost ignored the Spaniards, who nevertheless in great part fled, carrying wild confusion to the rear. The battle, therefore, properly enters the third defensive system as regards position, but not as regards execution. It was not probable the Spaniards would quit their protective works to make a great counter-attack; nor did they. At liberty to bring to bear on the British portion of the

Duke's line the whole weight of their superior numbers, the French gave him no opportunity of making anywhere a great counter-attack. Probably had the French made their attacks with more skill the battle might not have been indecisive. It is inferred then that though the British commander did desire to be attacked, as he was, on his left, this was not because he saw his way to inflicting on the French there a staggering blow, but merely because he did not trust the Spaniards.

Soult, though he defended almost round the compass at Toulouse, avoided Jourdan's great extension of front at Fleurus, and by carefully-arranged field defences he reduced the weakness of the salients, so that he was at least well situated for the execution of a great counter-attack by means of his central reserve. Yet it seems improbable that he intended, by leaving his right flank open, deliberately to invite attack there; for if he did he must have reckoned on his adversary committing a palpable fault.

It was shown in the former paper, where this battle was described in detail, that Wellington could reach Soult's right only by making a flank march, and to make a flank march under the very eyes and noses of a practised force has always been accounted a fault that should be dearly paid for. Why then, since the fault was committed, did Soult fail to take advantage of it? He was not thoroughly ready, though he had ample time.

Only here and at Fleurus did a force armed with the musket, defending on the third system, obtain a real opportunity of making a great counter-attack. In both cases the line of defence was in the form of a convex arc, and the reserve making the attack was centrally placed. At Fleurus the attempt succeeded because the columns of the assailant were too widely separated to act in combination. At Toulouse the attempt failed, possibly because Soult scarcely supposed he would have the chance he was offered, and therefore prepared for it too late.

The Sikhs were great intrenchers, sometimes turning the use of the spade to very good account. At Sobraon (*Plate* IX.), fought the 10th February, 1846, they had thrown up very extensive works, both flanks resting on the river Sutlej. These works consisted of lofty parapets with deep ditches, in several lines, armed with guns of heavy calibre. The centre of this position could hardly be assailed, so stupendous were here the intrenchments; on the left the works were less formidable, and on the right considerably so, in spite of the flanking fire of some batteries constructed on the opposite bank of the river. This want of uniformity in the strength of the Sikh line existed, but there is nothing to show the want was due to a fixed purpose.

The British were formed for attack at 2 a.m., but so thick at that hour was the fog, all action was postponed till after dawn. Then for two hours a cannonade was maintained; but the Sikh guns were not silenced, and British ammunition began to run short.

Sir Robert Dick was then ordered at 9 a.m. to move forward on the left. The advance of Dick's first line against the enemy's right, by far his weakest point, was covered by the fire of the batteries of Horsford, Fordyce, and Lane. When it arrived within 300 yards of the position a rush forward was made, and the first line of intrenchments occupied, not a shot having been fired, except by the flank companies against the Sikh batteries beyond the river. As in spite of this fire the batteries continued to enfilade the attack, it was necessary to advance the second line, the 10th and 80th Regiments being told off to silence the batteries, which they effectually did. By this advance the Sikhs were driven towards the centre of their line, and endeavoured to bring up supports from the left. On this side, however, Smith now advanced, and after two attempts succeeded in carrying the intrenchments, though the ground at this part was much broken, and the parapet difficult to climb.

In the centre Gilbert's division advanced, but had twice to fall back on account of the extremely high intrenchments. The third attempt succeeded, but it was made considerably to the left.

The Sikhs now retreated across the bridge of boats which here gave passage over the Sutlej. In the confusion the bridge gave way, so that the total Sikh loss amounted to 10,000 men and 67 guns. The British lost 320 killed, including Sir Robert Dick, and 2,063 wounded. The action was over by noon.

It is very clear that the true attack was here made against the weakest part of the position, and that no counter-attack was possible.

We now come to the period of the rifle, during which were fought three great battles belonging to the third defensive system, namely, Magenta, Fredericksburg, and Gettysburg. At Magenta, already described in detail in the former paper, the Austrians covered a part of their front by the very easily defended Grand Canal, the right flank remaining perfectly open. It is as certain as anything can be that in this the Austrian commander had no deep-laid design. The French made their main attack against the Austrian right, but without skill; for which reason it was certainly in the power of the Austrians to have made a great and successful counter-attack. None, however, was attempted.

It is only necessary to say of Fredericksburg that the principal Federal attack, over ground thoroughly searched by artillery fire, against a strongly held line of intrenchments, or what amounted to that, was a useless waste of life.

At Gettysburg the Federal left was strong by nature, the right was defended by breastworks, the centre was open. No design is apparent in this. Lee appears to have wished to draw the Federals to the flanks and then pierce the centre by a great attack. For this he was far too weak numerically, and his attacks were not sufficiently knit together.

Since the introduction of the breech-loader two great battles have been fought on this system, Gravelotte and Lisaine, both described in the previous paper. That Bazaine might, had he so willed it, have saved his army at Gravelotte by a great counter-attack on his right has been very often demonstrated. No one will need to be reminded that in this battle the German real attack was made in the French offensive zone; but here Bazaine had omitted to post a reserve.

At Lisaine, von Werder acted very differently. Parts only of his front were fortified or naturally protected; the right was quite *en l'air*. Though expecting attack chiefly on his left von Werder, like a good general, formed heavy reserves available at all points. When then the chief French attack was made against the open right, a great counter-attack in that quarter successfully ended the battle.

This investigation shows that of twelve battles fought with the musket, the force on the defensive occupying a position of which one part was much stronger than the other, none shows clearly that the defending commander did designedly leave a part of his position apparently weak, so as to induce attack where a thoroughly organized counter-attack was prepared for it. In two cases only was there a great counter-attack. In both of them the line of defence was a convex arc, at Fleurus a very considerable arc, which the enemy attacked without attempting to concentrate his forces. It seems improbable that Soult counted on Wellington making a flagrant error at Toulouse; and more improbable that, having counted on it, he would nevertheless be found unready when the error was made. Except, then, in two accidental cases, there was in these battles no counter-attack; and it seems very nearly impossible this should have been otherwise.

The effective range of the musket was limited to 200 or 250 yards. Up to that limit attacking troops could advance without loss, except from artillery fire, and then a good rush carried them to the defender's lines; such a rush as Sir Robert Dick's division made at Sobraon. But if a determined assailant got that far the odds were very heavy that the defender lost his position at that particular point. To prevent this catastrophe an obstacle was used, but it had to be such an obstacle as sufficed of itself to keep the assailant out; nothing short of that was of much use. At Blenheim this obstacle was the marshy Nebel; at Ramillies the still more marshy Gete; at Lowositz a muddy stream; at Arcola a swamp; at Kesselsdorf a ravine; and so forth.

But such an obstacle, an obstacle the assailant could not cross under the defender's fire, equally served to keep in the defenders and bar them from any advance. Thus, though the defender never dared to deplete his defensive zone of troops and so economize, the assailant was perfectly safe in leaving at this part of the field a comparatively small number of troops to amuse the defenders, or sometimes even in ignoring the defensive zone altogether; for in neither case was the defending force able, on account of its own great protective obstacle, to move out against the flank of the assailants marching on to the part of the front left open. At Lowositz, by artillery fire alone, the breaking out of Braun's left wing was prevented; at Arcola a few battalions on the causeways produced the same result; at Ramillies a small force left opposite Autre Eglise kept for some time nearly the whole of Villeroy's army idle; at Kesselsdorf and Talavera the defensive zone was left practically ignored.

But having this power the assailant was at liberty to throw nearly the whole of his forces against the open part of the position, and the defender could do nothing to prevent him. On every occasion where the weapon was the musket, and where the plan of attack was not demonstrably bad, this was exactly what happened.

To meet these very superior forces the defender could employ only such troops as he himself happened to have in the offensive zone, and these, under such circumstances, never sufficed for a really great counter-attack. Attempts were sometimes made to draw over in a desperate hurry part of the force standing useless behind the great obstacle; but these attempts seldom saved the day. At

Kesselsdorf, Lowositz, Prague, Arcola, Talavera, no such attempts were made ; at Blenheim, Toulouse, Sobraon, they were made without any success ; at Ramillies a very simple precautionary measure rendered the attempt nugatory.

But when the rifle came into use, more especially the far-ranging, accurate, rapidly firing breech-loader, the necessity for the great physical obstacle entirely vanished. At great distances the assailant began to suffer loss ; as the distance diminished his losses increased ; he could no longer approach, without enduring very serious loss, near enough to the position to take it with a rush. The true obstacle had become sustained, well-directed infantry and artillery fire. The slight firing trench served not to keep the assailant out, and therefore to hem the defender in, but merely to reduce the size of the target offered by the defender's body to the assailant's aim.

It followed that the assailant could no longer afford to ignore the troops posted in the defensive zone, for to do that would have been to offer a flank to a body of troops which could in a moment dash to the attack over its insignificant parapet. Neither was it now possible, as formerly, to contain the troops posted in the defensive zone by a mere show of force. To keep those troops pinned down where they were it was necessary to oppose to their fire at least an equal fire ; and this, considering the difference in the size of the respective targets, implied the employment by the assailant, at this part of the field, of a body of troops numerically much superior. Greatly did this detract from the assailant's power to attack elsewhere. What a small number of troops were left over for the turning movement at Gravelotte, and for the turning movement at the Lisaine !

Therefore it is argued that the division of the field of battle into two parts, one much stronger than the other, brought to the defender in the days of the musket no real advantage, but that when the musket vanished the disadvantage of this position vanished with it. It then became possible for the defender to make a true division of his field, and a corresponding disposition of his troops, with a clear, definite object, the organization of a great counter-attack.

For if we consider the five great battles—there were only five—fought, since the rifle was introduced, on this system, we shall find that in four of them the assailant made his chief attack in the offensive zone, while in the fifth, the only occasion where he attacked directly a well-prepared, stoutly-held defensive front, he paid a terrible price and lost the battle. No doubt at this battle, Fredericksburg, the ground over which the Federals advanced was thoroughly searched by artillery fire, and swept by a hail of bullets from the wall of the Telegraph road. But that is a condition always to be secured when a defensive front is designed. Gravelotte and the Lisaine likewise showed how costly frontal attacks must be on defensive fronts held by steady troops.

Therefore it is concluded that the first defensive system stands self-condemned; that the second system, though much superior in some ways, is extravagant of men, and does little to help the defender to a knowledge of what he may expect; that the third does help the defender to this knowledge, helping him, in the days of the musket, only too well, for it showed him exactly where he would be beaten; and that now the third system is economical of troops, helps the defender in forming a conclusion as to the probable course of events, and guides him in so disposing his troops as to have them at hand for the great counter-attack.

We now come to the most difficult par of this problem, the determination of the extent to which the second and third systems respectively bring out the power of the latest modern weapons.

To do this it is first necessary to give a more complete, though still quite a general, idea of what may be a possible distribution of troops suggested by this system of defence.

Most probably the general-in-chief would first desire to find suitable positions for his artillery. If this cannot be done, a successful defence becomes impossible. The positions found must be such that the artillery can perform three great duties. First, it must be able thoroughly to search the ground in front and on the flanks of the defensive zones. Second, it must be able to support the minor counter-attacks made in those zones. Only by this means can the troops there posted hold in front of them heavy forces of the enemy, and sufficiently reduce the balance of force left to him for decisive action elsewhere. Third, it must be able to support in the most efficacious way the great counter-attacks. Without such support these attacks must fail.

But as the artillery could not carry out these duties if it were always a target for the enemy's guns, it is equally important that the ground in front should afford the enemy no advantageous positions for his own artillery. To yield him this would be to grant more than the defence can afford. To see without being seen, to take every advantage and yield none, must be a cardinal principle.

Next comes the business of choosing the localities for defensive zones. Some ground is better suited for defensive, some for offensive action. The absolute necessities have been already stated. The lines to be held must be concealed or masked from the fire of the enemy's artillery; the front occupied must suffice for a considerable number of rifles, and the clear field of fire to the front and flanks must be ample; the supports and reserves should not be exposed to fire.

These zones cannot be chosen without reference to the artillery positions, in which possibly modifications may become necessary to ensure the infantry the aid of their own artillery.

There can be little difficulty in apportioning the troops allotted to the defensive zones. They must have their own reserves, whose all-important duty it is to carry out the local counter-attacks.

It is to be presumed the offensive zones will also have their firing lines and supports for very obvious reasons, the chief one of which is that time must always be required to set in motion the main reserves. Their actual distribution must depend on the accidents of the ground.

Of the main reserves it may be said with some certainty that they should be in masses, and perfectly concealed from the enemy's view. Possibly this latter fact may in some cases settle their first positions.

But if there be a choice, it is suggested they might be well placed if in rear of the wings of the defensive zones; for then in the event of the great efforts of the enemy being made in the offensive zones, they can, by marching straight forward, strike the assailant obliquely. To do this suddenly and unexpectedly would be the defender's aim.

No great counter-attack could be carried to completeness without the action of cavalry. No doubt a considerable fraction of this arm will be employed in obtaining, what is of the utmost importance to the defending commander, information; and a portion must, of course, be occupied frustrating the attempts of the enemy's cavalry. But the defender's task cannot be performed unless he keep posted in good positions sufficient bodies of horse to finish what is begun by the great counter-attack of infantry, supported by artillery.

The defender has still two arms, the mounted infantry and his machine guns, required for special duties. What these are will be suggested later on.

In this idea the flanks of the general position are included as a part of the whole. But it should perhaps be stated that in posting the main reserves it is contemplated that to them shall belong the duty of actively meeting a turning movement. Therefore some of these reserves must be posted accordingly.

Two factors there are which never change in war, the men who fight, and the ground they fight on. One factor is always changing, the weapon. That the defender may be enabled to take full advantage of the wonderful powers of his weapon he must be so placed that his weapon alone defends him, because then he can advance at will in any direction should the fire of the enemy slacken. But the assailant has also arms of precision ; he, too, can hurl in a tremendous storm of missiles, and he hurls them against a steady target. Therefore, as man has remained unchanged, while the means of putting him out of action have become much more effective, it is necessary to refuse the enemy the power of using his weapon to full advantage. This may be to some extent done by making the target of the assailant as small as possible, that is, by taking advantage of the ground.

If then we would estimate the extent to which one defensive system surpasses another in enabling an army in position to reap the benefit of arms of precision, we have to consider first the power of the weapon, and second the smallness of the target offered by the defender. A third item, the present increased tendency to turning movements, would probably on the whole affect both systems alike.

Let it be supposed then that a force on the defensive has taken up a position, not perhaps precisely in the manner already described, still somewhat on those principles. And let it be supposed that an assailing force has approached the position with the one object of crushing the defender where he stands. Assume that the advanced forces and posts, if there be any, have already cleared the front, so that the contest is now to be settled by the two main bodies.

It is to be presumed the attacking commander will at first see little in his front, except perhaps a line of guns, and that he will advance his line to draw the defender's fire. Let it be supposed then that the contest has reached this stage when the two forces are more or less engaged all along the line. For the sake of simplicity, let it be also supposed that the defender's position comprises, including the flanks, only two zones, one offensive and one defensive. It will be understood that in such a case one of the two flanks must be, owing to natural features, difficult to turn, as was the French left flank at Gravelotte, or the German left flank at the Lisaine, or the Austrian right flank at Lowositz, or the British right flank at Talavera, or Soult's right flank at Nivelle, and so on in a vast number of cases.

That being so, we shall suppose that the defending commander has become aware, from various indications, that the assailant is massing his forces preparatory to a determined attack in the offensive zone. The point now to be examined is not the suitability to such a state of affairs of the distribution of troops just suggested, for every commander would have to settle that for himself in each separate case, but the extent to which troops partly in a fortified defensive zone, and partly in an open offensive zone, as compared with troops on a front nowhere fortified, and everywhere more or less assailable, benefit by the power of their own weapons, and rob the enemy of the power of his.

The number of troops on the defensive being in both cases the same, we may call that number anything we please, and shall suppose it to be some number A + B, of which the part A has been allotted to the defensive zone, and the part B to the offensive zone, the third defensive system being employed. Then if the force A perform its duty it holds in its front a certain considerable number of the enemy's troops; and it has been shown that A can do this in virtue of the immense power of modern rifles, and for no other reason. The number of the enemy's troops A can hold in front measures the extent to which the defender benefits by the power of the modern weapon. The extent to which A in his intrenchments suffers loss measures the deprivation of that power to which the enemy has to submit.

If, now, we suppose the defender nowhere fortified, we may put it that the assailant has chosen some part of the field at which to drive home his great attack, and that he is containing all the rest of the line. What then is the state of the case along that part of the defender's line which is contained, the length of which we shall assume roughly equal to the length of front defended by A ?

To produce the same result the number of the enemy's troops held in its front by the contained line should be the number held in a similar way by the force A; otherwise the assailant's great attack would be stronger against the front of the second system than against the offensive zone of the third. But to effect this a much stronger force will be necessary on the contained line of the second system than in the defensive zone of the third, that is, than the force A; for though an unfortified force has nearly the same power of rifle as a fortified force, it offers a much greater target, and therefore suffers much greater losses; so the number of its rifles is more rapidly reduced. Let then the contained force on the second defensive system be represented by A + C. Although the force A + C will at first be much stronger in rifle fire than the force A, yet shortly, owing to its much greater losses, it will find itself able to do no more than A.

But it now follows that the force left over to meet the great attack of the assailant is not B, but only B – C. Either then a force equal to C must be added to the defending army, or that army must be content to meet its opponent's great attack, under precisely similar circumstances, with weaker forces. Thus the strength of the force C is the measure of the economy due to the adoption of the third defensive system. But that economy arises from the employment of intrenchments; and it is the modern rifle which renders the use of these simple intrenchments possible and sufficient, as has been already shown. Hence the third defensive system gets as much more out of the modern rifle than the second system as would be represented by an actual additional force. But this only applies as long as the great attack is made in the offensive zone.

Let it be next supposed that the assailant resolves to make his main effort in the defensive zone, the offensive zone being contained. Then since the troops in the offensive zone are in the open, they are, in that zone, in precisely the same condition as the troops in the contained part of a front under the second system; and therefore there is no economy in the offensive zone due to the employment of one system or the other. But in the defensive zone the main attack is directed in the one case against troops fortified, and in the other case against troops not fortified. There must be some economy of troops in the former case; that is, the third defensive system is here also the more economical. But this economy is not essentially due to the rifle; it might arise even in the case of the musket. Thus Picton was beaten off with heavy loss when he attacked Soult's fortified flank at Toulouse.

It is concluded that in what has been, and probably will continue to be, the more usual mode of attack the third defensive system gets more out of the modern rifle than the second system does; while in the rarer form of attack both systems are in this respect on a par.

A great attack made against the defensive zone has been called the rarer form, because it should be possible to make a defensive zone almost impregnable as regards frontal attack, and an attack in flank seems exposed to some danger.

In the case supposed, that is to say, a single defensive and a single offensive zone, the defender would probably have established two great reserves, one in rear of the right of the defensive zone, one in the offensive zone well on the right flank; a disposition of the reserves somewhat similar to that adopted at the Lisaine, and often proposed as one Bazaine might well have adopted at Gravelotte.

These reserves could not be moved until the defender knew for certain in which zone the main attack was being pressed. Once he had that knowledge the defending commander has merely to order his reserves to advance.

But the flank of the assailant's main attack would be covered by his own containing force; consequently before that flank can be struck the containing force must be in some way disposed of. If that were done, the reserve posted in the offensive zone, moving forward obliquely, would strike the flank of the great attack, while the reserve in the defensive zone, moving straight forward, would strike its head. Such a combined movement is possible on the field of battle, because it can be directed on the spot by a single mind; and has often been successfully carried out, as at Salamanca, Vittoria, Nivelle, Le Mans, in attack; Sauroren, in defence.

The containing force is, it is to be presumed, about a match for the contained force. The sudden appearance of a fresh force on the flank of the containing force might then make it possible for the contained force to take the offensive, and clear the ground for the advance of the reserve. It is suggested that the great mobility of the mounted infantry fits it to perform the *rôle* of that fresh force. For it might advance very rapidly from a concealed position, take up a flanking position, and suddenly open an enfilading fire. Machine guns, being also able to travel with great rapidity, might be of great assistance here.

A battle has occasionally been noticed in many respects similar to some previous battle, yet no one probably would like to undertake beforehand the description of a battle, given the fullest detail of the whole scene of action, and everything else that might be arbitrarily fixed. So that the above suggestions of possible movements are merely intended to imply that if reserves were posted suitably to meet a probable attack in the offensive zone, they would not be altogether badly placed to meet the much less probable case of an attack in the defensive zone; and that the defender would usually have means by which he could gain the time necessary for the movements of his reserves, and for clearing the way for their action. If he were wholly without those means, then he would still be worse off under the second defensive system than he would under the third, because none of his troops being intrenched they could not hold out so long.

It might be asked why object to the defender's troops in the firing line of the offensive zone being intrenched? There would be no objection if it were not a moral certainty that then the whole front would become one great defensive front, with no offensive zone at all; and thus the defence would descend to that of the first system, which has never scored a victory. But this need not happen, it might be suggested, if the ground were stronger by nature at one part of the position than at the other, as indeed, was the case at Gravelotte. It might so happen, it might be that nature so demarcated the field as to make the presence of a few firing trenches in the offensive zone unobjectionable; it might then be mere pedantry to object. And it might be further urged that if, against probability, the assailant choose to contain the offensive zone, then intrenchments would be of great value to the force defending there. It might be added the containing force would itself probably intrench, and so be enabled to economize. And this brings the one answer to all these doubts: let the intrenchments be made by the defender in the offensive zone when they are found to be necessary, but not till then.

Finally, these ideas apply only to the contest of unequal forces, when one force, owing to numerical weakness, is compelled to adopt the defensive. When two armies, not unequal in strength, engage, they would probably settle the matter in a totally different way.

The solution here proposed of the defensive problem makes everything subordinate to the necessity of organizing counter-attack on a great scale. Solutions have also been attempted, adopting nominally the third system, in which great counter-attack, though mentioned, is not the most important feature. As Captain Deguise, a Belgian officer, has worked out the subject in great detail, a brief description will be given of his proposals, as illustrative of these alternative methods.

It is the idea of Deguise that above all things, and before anything else can be done, the sting of the attack must be plucked out. Acting on this idea he supposes that the whole defensive line must be prepared for a stiff-necked defence, which shall last until the enemy begins to give signs of having had enough. Then counter-attack, which hitherto had been local, and having for an object to prevent the withdrawal of the enemy's troops from some parts for massing in front of others, is to be carried out on a great scale, as great a scale, that is, as the defender's numerical strength allows, by means of special reserves.

But this is not great counter-attack at all; it is merely another name for a general advance of the whole army, to convert a repulse of the enemy into a decisive victory after the enemy's power to advance has been knocked out of him. And that reduction of power Deguise proposes to effect solely by minor counter-attack. But it has been already shown from history that that can hardly be done.

Deguise declares himself a pronounced opponent of uniformity in fortifying the front of a position. He accordingly divides the position to be defended into two parts, or, in cases where the front is of great length, into series, each of which has two parts, one part reserved for defensive, the other part for defensive-offensive fighting. Both parts are to be fortified by redoubts, each capable of defence by one or two companies (250 or 500 men), the redoubts being connected by shelter trenches. In the defensive zone these redoubts are 500 to 600 yards apart, and in the defensive-offensive zone from 800 to 900 yards apart.

It is claimed for these redoubts that they characteristically draw to themselves the fire of the enemy, that they can be more easily defended than the same length of mere shelter trench, and, therefore, are economical of troops. Hence the closer together the redoubts the greater the economy of men; and it follows that by this means troops are economized in the defensive zone, where the ground is more favourable to defensive than to offensive fighting. In the defensive-offensive zone the redoubts are partly intended to render possible a stiff defence, but also to serve as *points d'appui*, in case the local counter-attacks here made should miscarry.

It is not proposed that the defence shall be entirely passive, even in the defensive zone. On the contrary, the regimental and other reserves posted at this part of the field have as their duties, in addition to feeding the fight, to execute minor attacks with the intention of holding the enemy, and, in case the enemy should succeed in breaking through, to act against his flanks.

To each unit in the defensive-offensive zone is assigned a somewhat shorter breadth of front than in the defensive zone. Consequently here, where the ground is supposed to be more favourable for offensive action, there is a stronger balance of troops available to carry out that offensive action at the moment when the position is assaulted.

The army reserves are intended to act on the flanks, and to make what is erroneously called the final counter-attack, when the whole force passes to the offensive.

The defensive process is here accomplished in a tolerably simple way. A very destructive infantry fire is directed on the enemy from all parts of the line by intrenched troops, aided by local counter-attacks, much stronger and more frequent in the defensive-offensive than in the defensive zone, made by local reserves. This tremendous fire is maintained until the forces of the enemy are sufficiently thinned and his fire sufficiently beaten down to warrant a general advance. The passage from the defensive to the offensive, always found so difficult, is here rendered easy by the maintenance in the troops of the offensive spirit, due to constant minor counter-attack.

This appears simple; but it appears also as though the defender were here fighting the whole tough part of the battle with only a fraction of his forces, while the enemy uses the whole of his. For the whole of the defender's army reserves remain quiescent until the enemy is practically beaten, and then they are set in motion to complete the *déroute*.

But to maintain for a considerable time a destructive fire along the whole front of a position would demand the employment of very great numbers, for the object is to produce a decisive effect on the enemy; and the fire must be maintained at its hottest until it has produced that effect. During the whole of this period the defenders are likewise under fire, both from artillery and infantry, and, on the supposition that the defenders continue to thin off the assailants, the defenders are themselves being thinned off, and their numbers must be maintained. Hence it seems more than probable the army reserves would themselves be used up.

But are these suppositions in accordance with true tactical ideas? Will the attacking commander continue to send up his men to be thinned off in this manner? Seldom, in all military history, have attacks been made thus. In the earlier stages of the battle, no doubt, the enemy's troops will appear all along the line, but only to fight over a great part of it a containing action. Against some parts attacks in great force will be driven, not by troops drawn from elsewhere, but by troops who have not yet been under fire. It is not clear by what inspiration the defender is enabled to foresee where these parts will be, nor how he is to be prepared with sufficient forces at the right spot and the right moment to meet those attacks.

In a word, this mode of defence is not a defence on the third system; it is merely the first uniform system in a very thin disguise.

Captain Deguise makes very little reference to artillery. It is not clear how he proposes the artillery of the defence is to be used so as to assist the infantry. Counter-attack, great or small, not fully supported by artillery fire has always been barren of results. The situation of the enemy's artillery is, as has been stated, just as important a matter to the defence as the use of his own. Yet it would seem Deguise must have forgotten what the artillery of the assailant would be doing when he advocated such an unlimited use of redoubts.

Certainly when Deguise wrote, the howitzer field battery had hardly been introduced, and the effect of a high-explosive shell bursting in a confined situation was a thing unknown. To be tenable now a redoubt must be not merely storm-proof; its existence, or at all events its situation, must be unknown to the enemy's gunners. In any ordinary position it is not likely that an endless string of redoubts could be constructed fulfilling these conditions. If, with this object, they were placed behind the crest-line of a long ridge, their very restricted field of fire would render them perfectly useless, and defeat the object with which they were thrown up.

There is still a use for the redoubt on the battle-field. Though we could never expect conditions of ground admitting of the use of a long string of redoubts, it is reasonable to anticipate the possibility of constructing a few which shall fulfil the required conditions. It is always possible that at some part the defensive line might be overpowered and momentarily driven back; in such a case *points d'appui* firmly held would be of undoubted use. It has been already said that a defensible village or a small wood suitably placed might form the nucleus of a defensive zone. For many reasons well-designed redoubts would be even preferable.

It has been concluded that troops disposed on what has been called, for shortness, the third defensive system have an advantage over troops wholly fortified or not fortified at all, since they can on that system be more readily organized for the execution of great counter-attack, and derive greater benefit from the power of modern weapons. There remains the moral question—Does this method of disposing troops tend to reduce or to increase the initiative of subordinate commanders?

It is admitted that in these days of accurate, long-range rifles troops once sent forward are very soon quite beyond the control of the commander who despatched them. This fact carries two consequences, one of which is that as much initiative as possible becomes desirable in the actual leader of those troops. The unexpected may at any moment be upon him; he must then have the strength of will to do instantly the right thing, cost what it may. The commander who gave the leader his orders is far in rear, in a position he cannot quit, whence he can send orders to the different corps to ensure co-operation, and despatch special troops on particular service as necessary. Circumstances may be no longer exactly what they were when the leader received his orders. He must rely entirely on himself; he must adapt his action at once to the spirit of his orders, and, as it were, pull the thing through somehow. This is so absolutely necessary that any system which interfered with the self-reliance, boldness, and fertility of resource of the subordinate leaders must be radically wrong.

Suppose, as an extreme case, a general-in-chief to have under his command corps, divisional, and brigade leaders absolutely incapable of carrying out an order, except with perfect literal fidelity. Then no system of attack or defence could be conceived by the brain of man which should avoid the necessity of a stream of aides-de-camp, despatched every two minutes in all directions with revised orders. But even if the general-in-chief noticed every single change—which is physically impossible on a wide field of battle—the duty of the aides-de-camp is equally impossible. For most likely it would take an aide two minutes to reach the brigadier, and by that time it would have become necessary to despatch a fresh aide with a revised order. Such a stream of aides-de-camp is just what must be avoided. The brigadiers must do without revised orders; they must be capable of acting in their absence.

Does the third system of defence tend to make brigadiers expect the stream of aides-de-camp? A subordinate who is always given a definite task, and is left to carry it out in his own way, grows accustomed, if he is worthy of employment, to acting for himself. Everyone must be familiar with systems in ordinary public life which encourage this mode of action and of making men, and with others which do not. The soldier is no exception. The essence of the thing is a clear definite duty set without one word as to how it is to be done. He who does not know or will not think how the thing is to be done must be set to find out. When everyone has found out, then only is an army thoroughly trained.

It is pretty clear that in the defensive zone the subordinate commander has a definite task to perform. It is his business by energy, agility, and audacity at one moment, and by perseverance and stubbornness at others, to keep in front of him, out of the main fight, the greatest possible number of the enemy. The measure of his success is the amount of relief he affords his comrades, at all other parts of the field, by forcing the assailant to divert into the defensive zone troops not originally intended to fight there. This object is marked out for him with perfect clearness, and gives ample scope for the exercise of the highest qualities.

The commanders in the offensive zone, whose troops are earliest engaged with the enemy, would also have very definite duties. Without the aid of field defences they have, as much as possible, to hinder the enemy, and prevent him gaining any ground from which his great attack might be launched with advantage, and also to compel him to show his hand by his early massing of troops.

During the earlier stages of the battle the commander of one of the great reserves to be presently used in counter-attack is probably ascertaining for himself the precise nature of the command he is sure in the course of time to receive. Once that command has come, it may be an order for counter-attack to the flank, or for attack obliquely, or for attack straight to the front; that matters not, the duty is as precise, as clearly defined, as separated from every other duty, as is the duty of this commander's comrade in the defensive zone.

This third defensive system, then, absolutely requires that distinct duties shall be allotted to the various commanders; and when that requirement is neglected the whole system goes by the board, and disaster follows. At Gravelotte, for instance, Bazaine, having placed the Imperial Guard in reserve, sent a part of it to the 2nd Corps and a part of it to the 3rd. Against this breaking up and frittering away of his command Bourbaki demurred. The Guard should have been used, under its own commander, as one huge powerful engine for great counter-attack on the right. Left with but a fraction of his command, Bourbaki—nothing is more evident—lost all initiative, advanced, hesitated, halted, and finally merely covered a retreat, amid the jeers of those he might have saved.

And now for the second point. The general-in-chief is responsible for failure or success, but he is compelled to hand over to subordinates the working out of the parts of his scheme. Therefore it is all the more necessary he should think out thoroughly beforehand all the details of his defence which can be foreseen and appear demanded by local circumstances. At the Lisaine, von Werder had to defend a wide front with a small force, but he was opposed to an enemy very strong in numbers, though of inferior quality. He worked out the problem thus :—A number of points were fortified and prepared for defence ; a few advance parties were thrown out ; large artillery positions were formed ; two great reserves were suitably posted. These reserves were used certainly as required, but were always maintained at their full strength. This alone enabled von Werder to meet the crisis when it came on his right.

But the posting of troops in this way is not a simple matter ; it results from a host of considerations. The condition of the enemy, the composition of his force, his means of supply, the ground available to him for artillery positions, the roads he can use, at what parts the enemy's march will be impeded by natural difficulties, where he can move easily and rapidly ; all these and other factors influence the commander in determining his dispositions. As the first steps taken are now more important than ever, the commander cannot think out the problem too carefully. Will all that care on his part and early attention to detail reappear as a hindrance to the initiative of subordinate commanders ? If so, the effect must be produced unconsciously, because they know nothing of the exact reasons leading to this or that decision. That is, the effect, if produced at all, reaches them through the character and temperament of the general-in-chief. Is there anything, then, in this particular system of defence tending to make a commander unusually anxious and fidgetty, and inclined to interfere with or usurp the commands of those subordinate to him ?

The simple answer is that the same early attention to detail would now have to be given by the commander on any other system of defence. So that in this respect all possible systems stand on the same footing. Only it may be said that the commander will be least anxious, and least likely to interfere with his subordinates, who carries out that system which he has practised in peace time, and in which he thoroughly believes.

The extent to which this system of defence encourages the offensive spirit in the troops is tolerably plain. When we read military history nothing seems more striking than the exhausted condition of both forces after a vigorously fought engagement. Rarely has the victorious force, even when it has acted consistently on the offensive, been in a condition to undertake pursuit. Exceptional cases there have been, of course, where the lack of pursuit was not due to the exhaustion of the victors. Thus, at Vittoria, where Wellington totally defeated King Joseph, there was no pursuit; but here the British troops took to plundering. At Salamanca there was no pursuit, owing to a tactical error. Yet what has usually prevented pursuit has been exhaustion. When troops on the defensive have beaten off the enemy they have not as a rule been able to do more. At Cold Harbour, Lee inflicted great loss on the Federals, but he did not further interfere with them; so that the Federal army was able to draw off, cross the James river, and at once begin the campaign which ended in Lee's ruin. So also at Spotsylvania; Grant was again and again repulsed, but he remained in a condition to move at his leisure on his southward march. There were, in fact, in the hundred battles here discussed only three in which a defensive victory was followed up by a great pursuit; and of these three one was Waterloo, where the Prussians did what the British could hardly have done.

It is fairly clear then that the offensive spirit most survives and overrides exhaustion where the action of the troops has been continuously offensive throughout the day, though even in that case, as has been said, the balance of remaining energy has not been very great.

The task to be performed in a defensive zone demands offensive action, continuous though local; in no other way would it be possible to force the enemy to bring up fresh troops diverted from the offensive zone. In the offensive zone itself the whole idea of the defence is by counter-attack. There is nothing then in the system to injure the offensive spirit of the troops; on the contrary, from beginning to end offensive action is required.

We arrive then at the general conclusion that, of all possible systems of defence, that system is on all points most advantageous which we have called, for shortness, the third. But it would appear this system demands, if success is to be attained by it, an uncommon degree of training in the officers, if not in the troops as well.

Owing to his multifarious duties the general-in-chief may only have time to oversee generally the choice and preparation of the position he has to defend. Within the limits allowed by strategical considerations there may be considerable choice of ground available to the defender. No one by the light of nature could say, within a reasonable time, which position out of several offered the greatest advantages, or the fewest disadvantages. It requires some training of eye and mind so to understand ground as to be able to perceive whether from the positions available for artillery the whole of the front can be thoroughly swept, and if this can be done without fear of undue annoyance from the guns of the assailant. And possibly even more careful training to be able to judge the adaptability of the ground to good defensive zones, and if the offensive and defensive zones bear to each other a due proportion. If these points can, beyond doubt, be settled favourably, the officer who is choosing the position must be able to assure the commander of many things—that the troops can see without being seen, and can readily reach their posts ; that the reserves can be massed in perfect concealment, and can move rapidly in any direction ; that the cavalry can be posted behind cover, where the ground is suitable for their action ; and that the flanks, if not naturally protected, can be defended by counter-attack ; besides all the ordinary points common to all systems alike.

But great knowledge and training are necessary to him who would choose a defensive zone. It is essential that it should be most difficult for the enemy's gunners to get the range of the intrenchments ; and yet from those intrenchments the defenders must have a clear field of fire, while the ground in front must be swept by the defender's artillery fire. It is almost impossible to find ground combining these conditions without yielding at least some advantages to the enemy. Judgment, which comes from training, consists in making those advantages indecisive.

And then when the defensive zone has been chosen it is needful to know what to do with it. An error in siting the redoubts, or in putting a small wood into a state of defence, might have fatal consequences, or at least might make the defence extremely costly.

It would probably be of no great utility to study one or two very accessible positions, especially once they had become familiar topics of conversation. Novelty is the implement. A report drawn up after careful study of new ground, discussed on the spot by representatives of all arms, each from his own point of view, in the presence of military students of all branches of the service, might be a contribution to the great end. Many such studies, always of new ground, conducted in this way might build up an education, which should be the property of a considerable number of officers. Possibly the training required might be obtained in some other way, but that it must be obtained by hard work and well-directed effort is at all events clear.

It may not perhaps be readily granted that it is desirable troops should have always a precise idea what it is they are going to do; but as to the officers there can be no question. It has been often said that in the strain of battle no more should be expected of the average man than that which by practice has become his second nature. If then officers are thoroughly trained in the difficult art of carrying out minor counter-attacks in a defensive zone, they are more likely in battle to take the right step than if they suddenly find themselves in a position which bears no relation to anything they have ever practised in time of peace.

Even the troops, it might be imagined, would be more easily led, would obey with greater alacrity, would go forward more readily, if it were firmly impressed on their minds that their small performance was an essential part of a great whole, a part so essential that if it were not thoroughly carried out the scheme of defence would fall in pieces, or be made good only at fearful cost to their comrades. How could this idea become familiar to them if first suggested in battle?

But there is a more pressing fear, the fear that for want of familiarity the troops might mistake the whole idea of defence, might conceive the holding of earthworks to be an ultimate object, not, as it is, merely a means to a much greater end. To get troops to quit cover when bullets are flying must surely be more difficult when those troops have not been accustomed to use and, as a matter of course, to quit cover at peace manœuvres and training than it would if that process were the only way they knew. But to learn to use and quit the protection of earthworks the troops must make the earthworks; and this, not for the practice of making them, which is a small matter, but for practice in first using and then advancing from them, which is a very great matter. And where are the troops most likely to take in the true meaning of the intrenchments, and of the advance from them? Not surely where they are thrown up rather as samples; but where the training ground is a defensive position, and every detail is carried out as it would be in the actual field.

APPENDIX I.

Position, including Flanks, wholly Fortified; or Naturally very Difficult of Access at all Points; or partly one and partly the other.

Battle.	Date.	Disposition of Defending Troops.	General mode of Attack.	Victory for	
		(A). *Muskets.*			
1. Malplaquet	11 9 09	Practically uniform.	In centre; left flank turned, right contained.	Attack.	
2. Breslau ...	22 11 57	Uniform	At four points ...	Attack ...	Great cavalry counter-attack.
3. Creveldt ...	23 6 58	Uniform	Against left flank; front contained.	Attack.	
4. Torgau ...	3 11 60	Uniform	On right flank and rear; also on left.	Attack ...	False attack on left converted to real.
5. Freiburg ...	29 10 62	Uniform	Left turned ...	Attack.	
6. Jemmapes	6 9 92	Uniform	Crochet enveloped.	Attack.	
7. Borodino ...	7 9 12	Left stronger ...	Left and centre	Attack ...	Defence given time to support left from right.
8. Bautzen ...	$\frac{20}{21}$ 5 13	Uniform	Right turned; left assailed; centre contained.	Attack.	
9. Nivelle ...	10 11 13	40,000 on right, 18,000 on left.	28,000 contain right, 50,000 assail left.	Attack.	
10. Ferozeshah	21 12 45	Uniform	Parallel lines ...	Attack.	
		(B). *Rifles.*			
11. Chancellorsville.	2 5 63	Uniform	Right turned; front contained.	Attack.	
12. Chickamauga.	$\frac{18}{20}$ 9 63	Uniform	Left and right centre.	Attack ...	Right centre was attacked when denuded to support left.
13. Chattanooga.	27 11 63	Uniform	On centre when denuded to support wings.	Attack.	

Appendix I.—*Continued.*

Position, including Flanks, wholly Fortified; or Naturally very Difficult of Access at all Points; or partly one and partly the other.

Battle.	Date.	Disposition of Defending Troops.	General mode of Attack.	Victory for	
		(B). *Rifles—continued.*			
14. Spotsylvania.	12 5 64	Uniform	Frontal	Indecisive.	
15. Cold Harbour.	1 6 64	Uniform	Frontal	Indecisive.	
16. Kenesaw ...	27 6 64	Uniform	Position turned; front contained.	Attack.	
		(C). *Breech-loaders.*			
17. Le Mans ...	$\frac{10}{12}$ 1 71	Right stronger	Right turned; front contained.	Attack.	
18. Aladja Dagh.	15 10 77	Uniform	Front and rear ...	Attack.	
19. Shipka ...	9 1 78	Uniform	Rear; front contained.	Attack.	

Note.—Uniform here means roughly so, and not necessarily in continuous lines.

APPENDIX II.

Position nowhere, or very slightly, Fortified; including Flanks, everywhere Accessible, in the absence of Natural Obstacles.

Battle.	Date.	Disposition of Defending Troops.	General mode of Attack.	Victory for	
			(A). *Muskets.*		
20. Oudenarde	11 7 08	Uniform	Right turned; left contained.	Attack.	
21. Chotusitz	17 5 42	Uniform	Parallel lines ...	Attack.	
22. Hohen-friedburg.	4 6 45	Defenders crushed as they moved on to the field.		Attack.	
23. Soor	30 9 45	Uniform	Suggestion of oblique attack.	Attack.	
24. Kolin ...	14 6 57	Uniform	Flank march ...	Defence ...	Attack quite miscarried.
25. Rossbach...	5 11 57	Fought on march.	Attempted flank march.	Defence.	
26. Leuthen ...	5 12 57	Uniform	Left flank; right contained.	Attack.	
27. Zorndorf ..	25 8 58	In an oblong...	Narrow face assailed.	Attack.	
28. Minden ...	1 8 59	Never fully drawn up.	Against left ...	Attack ...	Right wing of defenders attacked.
29. Kunersdorf	12 8 59	Across original position; great reserve formed.	Left flank (original).	Defence ...	Great counter-attack succeeds.
30. Liegnitz ...	15 8 60	Uniform	Frontal	Defence ...	Counter-attack succeeds.
31. Wilhelmsthal.	24 6 62	Uniform	Enveloping in masses.	Attack.	
32. Neerwinden.	18 3 93	Left stronger...	Into re-entrant...	Defence ...	Great counter-attack on right succeeds.
33. Montenotte	12 4 96	Uniform	Enveloping ...	Attack ...	Combined movement.
34. Castiglione	5 8 96	Uniform	Front and rear ...	Attack.	
35. Wurzbourg	3 9 96	Uniform	General	Attack.	
36. Rivoli ...	14 1 97	Wholly counter-attack.	In six columns ...	Defence ...	Four counter-attacks successful.

APPENDIX II.—*Continued.*

Position nowhere, or very slightly, Fortified; including Flanks, everywhere Accessible, in the absence of Natural Obstacles.

Battle.	Date.	Disposition of Defending Troops.	General mode of Attack.	Victory for	
			(A). *Muskets—continued.*		
37. Novi... ...	15 8 99	Uniform	General	Attack.	
38. Mosskirch	5 5 00	Uniform; reserves massed.	Turning movements.	Attack ...	Counter - attack failed.
39. Marengo ...	14 6 00	I. Uniform. II. On the march.	General	Both attacks.	A battle in two parts.
40. Hohenlinden.	3 12 00	On the march	On columns debouching from the forest, and against left flank.	Attack.	
41. Austerlitz	2 12 05	Left and centre stronger.	Right flank ...	Defence ...	Great counter-attack succeeds.
42. Jena	14 10 06	Uniform	General	Attack.	
43. Auerstedt	14 10 06	Arrive successively.	General	Defence ...	Great counter-attack succeeds.
44. Eylau ...	8 2 07	Uniform	Successively ...	Indecisive.	
45. Friedland	14 6 07	Wings separated by lake and stream.	Left crushed ...	Attack.	
46. Corunna ...	16 1 09	Uniform; two strong reserves.	In three columns	Indecisive	Defender embarked.
47. Eckmuhl...	22 4 09	Uniform	Combined movement.	Attack.	
48. Essling ...	21/22 5 09	Chiefly in two villages.	Villages	Attack.	
49. Wagram ...	6 7 09	Uniform	Left and centre...	Attack ...	Counter-stroke fails.
50. Busaco ...	27 9 10	Uniform	Two unsupported attacks.	Indecisive	Massena then turned Wellington's left.
51. Barosa ...	5 3 11	Uniform	Parallel lines ...	Attack.	
52. Albuera ...	16 5 11	Right stronger	Against right ...	Indecisive	Brilliant counter-attack succeeded, but defender exhausted
53. Salamanca	22 7 12	At first massed uniformly.	Detaches to outflank right.	Attack ...	Wellington assumes offensive

APPENDIX II.—*Continued.*

Position nowhere, or very slightly, Fortified; including Flanks, everywhere Accessible, in the absence of Natural Obstacles.

Battle.	Date.	Disposition of Defending Troops.	General mode of Attack.	Victory for	
		(A). *Muskets—continued.*			
54. Lutzen ...	2 5 13	Rencontre ...	Rencontre	Attack.	
55. Vittoria ...	21 6 13	Centre and left stronger.	Enveloping ...	Attack.	
56. Sauroren...	28/30 7 13	I. In two lines. II. Uniformly.	I. Detaches to outflank left. II. General.	Ultimately attack.	Wellington surrounds left attack, then assumes offensive.
57. Gross Beeren.	23 8 13	Separate masses.	Successively ...	Attack.	
58. Dresden ...	26/27 8 13	Left weak ...	On both wings ...	Attack.	
59. Dennewitz	6 9 13	Uniform	Flank attack ...	Attack.	
60. Leipsic ...	16/19 10 13	I. The French defend on the attack on the lines.	attack on the N., S. II. Great French—parallel	Attack.	
61. Hanau ...	30 10 13	Uniform	Parallel lines ...	Attack.	
62. Brienne ...	2 2 14	Crochet	General	Attack.	
63. Orthez ...	27 2 14	Massed in centre.	On both flanks, then suddenly in centre.	Attack.	
64. Laon ...	9 3 14	Right uniform; centre and left in concealed masses.	Against right and left.	Defence ...	Great counter-attack on left succeeds.
65. Arcis ...	20 3 14	Uniform	General	Attack ...	Defender weak numerically.
66 Ligny ...	16 6 15	Uniform	Right attacked, then centre, when denuded to support right.	Attack.	
67. Waterloo...	18 6 15	Uniform	Against centre; denuded to support right.	Defence ...	Napoleon overpowered by arrival of Prussians.
68. Chillianwallah.	13 1 49	Uniform	Parallel lines ...	Attack ...	Attack loses touch in traversing jungle.

Appendix II.—*Continued.*

Position nowhere, or very slightly, Fortified; including Flanks, everywhere Accessible, in the absence of Natural Obstacles.

Battle.	Date.	Disposition of Defending Troops.	General mode of Attack.	Victory for	
			(B). *Rifles.*		
69. Alma ...	20 9 54	Right stronger	Stronger against left.	Attack ...	Attack on redoubt indecisive.
70. Solferino...	24 6 59	Uniform	Stronger against right.	Attack.	
71. Antietam...	17 9 62	Left stronger...	Against both flanks.	Indecisive	Defender retreated.
72. Opoquon...	19 9 64	Uniform	Frontal; by cavalry against left.	Attack.	
			(C). *Breech-loaders.*		
73. Nachod ...	27 6 66	Uniform twice	General twice ...	Both attacks.	Alternate attacks, as at Marengo.
74. Skalitz ...	28 6 66	Left massed; centre and right uniform.	Three successive columns.	Attack.	
75. Königgrätz	3 7 66	Uniform	Front contained; right flank attacked; left obliquely.	Attack.	
76. Worth ...	6 8 70	Uniform	Enveloping ...	Attack ...	Breastworks unimportant.
77. Spicheren	6 8 70	Uniform	Piecemeal	Attack ...	Field defences covered retreat.
78. Colombey	14 8 70	Rear guard supported.	Containing... ...	Indecisive	Tactically.
79. Vionville ...	16 8 70	Uniform	Containing... ...	Indecisive	Tactically.
80. Loigny ...	2 12 70	Both sides attacked.	Turning movements.	Attack.	
81. Beaugency	$\frac{8}{10}$ 12 70	Uniform	Chiefly against centre and left (turning).	Attack.	
82. St. Quentin	19 1 71	Uniform	Divided by Somme, along which attacks made; right contained.	Attack.	
83. Philippopolis.	$\frac{15}{17}$ 1 78	In three successive positions.	Enveloping ...	Attack ...	Fuad's four counter-attacks, though heavy, failed.

Uniform has here the same meaning as in Appendix I.

APPENDIX III.

Position, including Flanks, partly Difficult of Access, as Fortified or by Nature (Defensive Zone); partly Easy of Access, as Unfortified or by Nature (Offensive Zone).

Battle.	Date.	Disposition of Defending Troops.	General mode of Attack.	Victory for	
			(A). *Muskets.*		
84. Blenheim	13 8 04	Massed on wings, cavalry in centre.	In centre; left assailed; right contained.	Attack.	
85. Ramillies	23 5 06	Massed on left, cavalry on right.	Against right; left contained.	Attack.	
86. Kesselsdorf	15 12 45	Left stronger...	Against left ...	Attack ...	Right unassailable
87. Lowositz...	1 10 56	Right stronger	Against right ...	Attack ...	Left unassailable.
88. Prague ...	18 5 57	Crochet	Crochet broken...	Attack.	
89. Hochkirch	14 8 58	Nearly uniform	Right flank; front contained.	Attack ...	A surprise.
90. Fleurus ...	20 6 94	Right stronger; great central reserves.	All round the semicircle.	Defence ...	Great counter-attack succeeds.
91. Arcola ...	$\frac{15}{17}$ 11 96	Massed on right and centre.	I. Against right and centre. II. Left.	Attack.	
92. Vimiero ...	21 8 08	Left weak ...	Centre and left...	Defence ...	Defender allowed time to crush attack on centre and then on left with same troops.
93. Talavera ...	$\frac{27}{28}$ 7 09	Right fortified	Against left and left flank.	Indecisive	Attacks ill-planned.
94. Toulouse...	10 4 14	Uniform; central reserve.	Against right; left and centre contained.	Attack ...	Great counter-attack fails.
95. Sobraon ...	10 2 46	Uniform	Against weak part of intrenchments.	Attack.	

Appendix III.—*Continued.*

Position, including Flanks, partly Difficult of Access, as Fortified or by Nature (Defensive Zone); partly Easy of Access, as Unfortified or by Nature (Offensive Zone).

Battle.	Date.	Disposition of Defending Troops.	General mode of Attack.	Victory for	
		(B). *Rifles.*			
96. Magenta ...	4 6 59	Stronger on canal.	Against open flank.	Attack.	
97. Fredericksburg.	13 12 62	Left fortified; right massed.	Against left ...	Defence.	
98. Gettysburg	$\frac{1}{3}$ 7 63	Flanks fortified; or difficult.	Against flanks, then against centre.	Defence...	Assailant weak numerically.
		(C). *Breech-loaders.*			
99. Gravelotte	18 8 70	Uniform, reserve massed on left.	Front contained; right flank turned.	Attack ...	Left fortified.
100. Lisaine ...	$\frac{15}{17}$ 1 71	Points fortified; two great artillery positions; two strong reserves.	Front contained; turning movement against right.	Defence...	Great counter-attack effective.

Uniform has here the same meaning as in Appendix I.
Throughout the terms right and left refer to Defender.

PAPER IV.

THE PERMANENT WAY OF RAILWAYS.

LECTURE BY JAMES C. INGLIS, ESQ., M. INST. C.E.

THE subject of to-night's lecture is a very wide one, but, unlike many of the engineering questions discussed here, it is free from any great complexity of design or practice. The permanent way of any railway can be understood at a glance by the least technical person, and yet, curiously, it is a subject which has been surrounded by an atmosphere of discussion from the earliest times in railway history. This apparent anomaly is due to the extremely varying conditions of its use, and to the widely different conclusions which observers and improvers draw from the effects of wear and tear.

Much has been discovered about permanent way since George Stephenson laid a section of the London and North Western Railway on granite blocks; and since Brunel, on the Great Western Railway, provided piles to support each rail joint in his first longitudinal road —which, by the way, had a rail weighing 45 lbs. per yard, and, strange to say, was provided with a skew joint.

Immediately the speed and weight of trains began to be increased on railways proper, as distinct from tramways, the conditions governing the construction of the road bed commenced to be differentiated, and it was soon generally found and admitted that while a rigid road bed had been quite serviceable for tramway purposes (both goods and passenger), a more elastic and uniformly yielding bed was necessary for higher speeds and weights.

Incidentally it may be mentioned as an instance of the very earliest ideas of permanent way, which are fast disappearing and passing into history, that some 15 years since, during the conversion of a rather long length of the Plymouth and Dartmoor Railway (or Tramway) into a portion of the Princetown Railway, a quantity of cast-iron fish-bellied rails, each about 3 feet long, carried on chairs and attached to granite blocks by means of wooden treenails and iron spikes in the centre, were removed. This line was constructed in 1840, and had been used for the transit of granite blocks, in great quantity and at times of excessive weight, from the quarries at Tor Royal; but notwithstanding the great age of the line, at those places where it had been properly maintained the original rails were in very fair condition and workable as a tramway for the conveyance of heavy loads at low speed; as a railway it was quite out of the question.

One other illustration. The longitudinal road designed by Brunel, which was universally adopted for the Great Western Railway and for other lines now forming part of that system. There are still some 600 miles of this type of way in existence, but it is rapidly being superseded by cross-sleeper road owing to the fact that while it was found amply efficient for the requirements of the broad gauge, it could not continuously withstand the increased strain of narrow gauge working, thereby involving a higher expenditure for maintenance, while being a less satisfactory running road.

There is now an absolute concensus of opinion as to the superiority of cross-sleepers for supporting the rails of railways of less than (say) 5 feet gauge. But apart from this change of views in railway engineering circles as to the design of permanent way, the alteration in practice is due in no small degree to the reduction in price of steel rails, a large quantity having been purchased a few years since by the Great Western Railway Company for £3 14s. 6d. per ton, while that company is now obtaining rigidly inspected steel rails capable of passing the standard tests prescribed for £5 12s. 6d. per ton.

In England and Scotland a bull-head rail with chairs, keys, and cross-sleepers is used generally for all main lines and most branches, while in Ireland there is a distinct preponderance of the flat-bottomed Vignoles rail, attached to the sleepers by fangs or clips. In this connection the lecturer noticed a curious development when in Ireland last year. On the Great Southern and Western Railway, where a Vignoles rail is the standard section, cast-iron chairs, or bed-plates, attached to the sleepers by bolts, were being used. This is the only case which has come under his observation of chairs being employed with the Vignoles rail, although he has seen small bed-plates introduced below the joint in the course of maintenance, to prevent the rail being forced into the sleeper at this point.

In America the Vignoles rail is used universally; and on the Continent, with the exception of one or two French railways, this kind of rail is generally employed.

That the supporters of the bull-head rail are convinced of the superiority of this type is evinced by the strong passive resistance offered to any departure therefrom in spite of the continual adverse criticism of the bull-head railroad by the supporters of the Vignoles rail.

The lecturer proposes to describe the present mode of constructing permanent way on the Great Western Railway, and in doing so, as the points arise, to make some comparison with the permanent way of other railways, at the same time stating a few of the results of his maintenance experience, and of such experiments as he has had carried out from time to time.

The whole of the Great Western lines are divided into three classes, viz.:—

(1). Main lines.

(2). Secondary main lines and heavy branches.

(3). Light branches.

For the first two of these classes it is now the practice to employ rails weighing 95 lbs. per yard, and 44 feet 6 inches long. Until a very recent period the standard rail was 32 feet in length, and the reasons for departing from this section will be dealt with presently.

If we examine carefully the effects of wear and tear upon express roads we shall see in as strong relief as can be brought out the various actions which tend towards the deterioration or failure of the road, and this knowledge can be applied to lines where there is no express running, and is believed to afford the safest guide in designing a road which shall be as free as possible from the known weak features of permanent way, because the dominating principle of all permanent way is that it must be altogether as mechanically sound as the locomotives and carriages which run thereon.

RAILS.

Commencing with rails. As observed in the opening remarks, the price of steel having been so greatly reduced, the almost universal use of steel rails has resulted. Unquestionably the introduction of steel for rails has been of immense advantage to the railway companies, and may be said to have largely saved the situation in the later conditions of express travelling.

The difficulty which had to be met in iron rails was the great tendency to scale or strip off owing to imperfect welding, this weakness arising from the process of manufacture, and applying more particularly perhaps to rails for which a different quality of material was used for the running face from the remainder of the rail. But numerous instances have been recorded of long lives of iron rails on the Great Western Railway under fairly heavy traffic, comparing favourably with many steel rails much more recently laid, manufactured by the Bessemer process.

Owing probably to the non-development of knowledge of this (the Bessemer) process, the earliest steel rails used were generally manufactured by the Open Hearth system, and these have almost invariably proved of a very satisfactory quality, as *Fig.* 1 and the following particulars of rails laid near Swindon in the year 1878 will show :—

Bull-Head Rail.

Laid in 1878 on the Gloucester branch, near $80\frac{1}{4}$ M.P.
Taken up in 1898.

Original weight	84 lbs. per yard.
Weight when taken up	80·64 lbs. per yard.
Loss per yard	3·36 lbs. or 4 per cent.
Number of trains per day in 1898 ...	82.

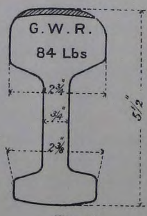


Fig. 1.

The steel for the present standard rail is made by the Bessemer process, and is most satisfactory both as regards strength and wearing capability, but very careful inspection is necessary during the various stages of manufacture.

The double-head rail was the first section adopted with the cross-sleeper, chaired road. The theory of the use of this rail was that it might be turned top for bottom every two or three years, thus equalizing the wear on both members until the limit of life was reached. This practice of turning rails used to be most common, but has of recent years fallen into general disfavour on account of the fact (apart from the decided opposition of the Board of Trade to the principle) that rails allowed to remain long in one position disclose when tested in the opposite position a great loss of strength, much more than that due to the wearing of the top surface. This deterioration is known as "hammer-hardening." It is fair, however, to remark that had the original period for turning been adhered to, viz., every two or three years, the evil would never have reached the extent to which it can be proved to have done. The lecturer has a specimen of a rail broken in the road which shows the peculiar cracks running transversely to the direction of the rail, which have been the subject of Mr. Kircaldy's recent paper delivered at the Institute of Civil Engineers.

Following the double-head section came the bull-head, which, as we now understand it, simply means making the head of the rail as much more massive than the foot as would be represented by the loss of metal due to wear which might fairly be calculated upon in the section of rail. Bearing upon this, *Figs.* 2 and 3 are of interest; these are cross-sections of old Great Western rails, the one,

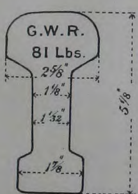


Fig. 2.

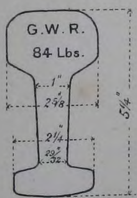


Fig. 3.

weighing 81 lbs. per yard, used on the Shrewsbury and Birmingham line in 1861; and the other, the standard section on the Great

Western system in 1876, weighing 84 lbs. per yard. These sections are peculiar, and both contain features which, although differently worked out, can be observed in the bull-head rails of to-day; and with regard to the web, they present a feature which is now being discussed, viz., whether the thickness of the web of the present up-to-date sections is quite what it ought to be to withstand the molecular stresses induced by unequal cooling. This point will be remarked on later.

Turning from these old sections, *Figs.* 4 to 7 show cross-sections of the Great Western 95-lb. rail, rolled in 44-foot 6-inch lengths; of the London and North Western Company's rail, 103½ lbs. per yard, and 60 feet in length; of the Midland rail, weighing 100 lbs. per yard, rolled in 36-foot lengths; and the standard 100-lb. American section. All these rails are the latest types used for express traffic.

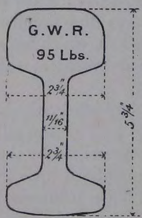


Fig. 4.

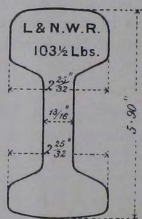


Fig. 5.

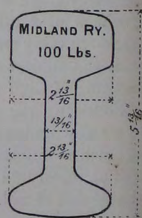


Fig. 6.

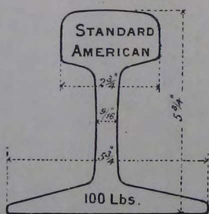


Fig. 7.

As an indication of the points considered in designing a new rail, the following were the changes made upon the previous section when the 95-lb. rail was introduced on the Great Western Railway :—

Width of rail increased.
Flatter top provided.
Undercutting of the bull-head abolished, and straight sides substituted.
The bottom member enlarged and flattened.

Dealing with these considerations—

(i.). *Width of Rail increased.*—This is an important point in a cross-sleeper road, giving it more lateral rigidity. There had from time to time been indications that with the previous standard rail the margin of efficient lateral rigidity was not sufficiently far off from every-day possibilities. The increased strength in this respect is considered one of the most important advantages which the permanent way has secured, by the more general adoption of the heavier section.

(ii.). *Flatter Top.*—This allows a greater length of rolling contact, and so reduces the destructive hammering action by the engine and carriages on the top surface, further tending to reduce wear.

(iii.). *Undercutting of Bull-head.*—The original intention of this feature was to ensure clean wear, thus obviating any possibility of a shoulder, as the metal was removed from the top and sides. However, it had the disadvantage of involving a widening of the gauge of the top of the rail as it wore down.

(iv.). *Enlargement and Flattening of Bottom Member.*—The early bull-head rails were furnished with by far too light a bottom member. For manufacturing reasons, if the size of the bull-head of the rail is increased, so also must the bottom, to prevent undue twisting after rolling, and to reduce the molecular stresses resulting from unequal contraction.

As to the flattening of the base, it must be borne in mind that the bottom member of the rail has as much to carry as the top, and an ample base is therefore a necessity to prevent "nicking." A rail with a flat-bottom member is also on the whole more satisfactory for the manufacture of points and crossings, which are invariably made from the same section as the rail in general use.

Comparing the Great Western rail with that of the London and North Western (*Figs.* 4 and 5), the difference between the respective

95-lb. and $103\frac{1}{2}$-lb. sections entirely arises from the thickness of the web, a point already noted. Undoubtedly the thickening of the web is a movement in the direction of safety; but so long as manufacturers experience no difficulty in rolling and straightening the thinner web rail, and while engineers find no tendency to fractures arising from internal molecular stresses, the point is, in the lecturer's opinion, not one of the first importance.

American practice favours a square-headed rail, as the cross-section of the 100 lbs. per yard association rail shows, and in this country there is on some lines a tendency to approach that section of head. This American standard section is the result of many enquiries by experts in the manufacture of rails, and also by railway engineers, and the particular radius adopted for the top corners was largely based upon the cross-section of rails which had worn showing the same radius. *Fig.* 8 will show that, for instance, with the Great Western standard, the radius of the rail approximates to that of the tyre running upon it.

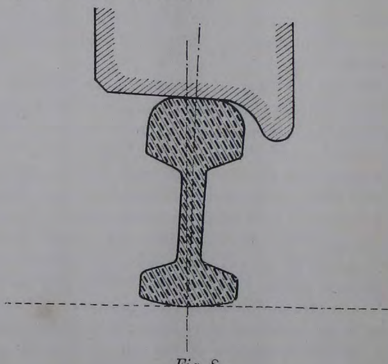


Fig. 8.

This figure (8) also shows the relative position of a locomotive wheel tyre when in a central position on the road, and it will be observed that with a 4-foot $8\frac{1}{2}$-inch gauge there is a clearance of $\frac{3}{8}$ inch for "play" on each side of the centre line. This clearance explains the practice which is adopted on the Great Western Railway of laying the line exactly to gauge, making no allowance for curves, except those which are exceedingly sharp, and which practice undoubtedly has a tendency to secure smoother running than the older one of laying the road exactly to gauge on straight lines, and from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch wide on curves.

One word in passing about tyres. The worst enemy to station yards and junctions is a hollow tyre, *i.e.*, a tyre with a groove worn by running, as illustrated by *Fig.* 9. Such wheels when travelling over crossings necessarily bump the road on the back of the "tread," and so beat the fittings to premature disruption.

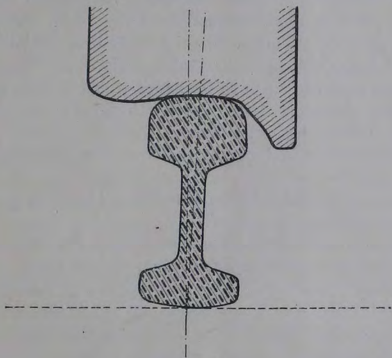


Fig. 9.

The alteration in the standard length of the Great Western rail from 32 feet to 44 feet 6 inches was prompted by the desire for fewer joints, and consequently less labour in keeping them tight, more particularly in tunnels. The argument used against the adoption of the longer length was the greater loss which would result if a rail failed; this objection is met, however, by the extreme scarcity of fractures with the heavy section, and by the adoption of closer sleepering.

The additional cost of laying was also urged, but this contention is altogether mythical, seeing that in any case a large gang is employed for re-laying, and it is found that the cost is no greater whether the rails are 32 feet or 44 feet 6 inches long, or even 60 feet, as the additional length merely involves the employment of a greater number of men in carrying and adjusting the rail at the moment of laying.

Forty-five feet may be taken as the maximum length which the English mills prefer to roll in large quantities; and it is found that this length can be properly straightened after rolling, a very important matter for good running.

Chairs.

Upon the adoption of a new rail a new chair is an obvious necessity; consequently when considering the design of the bull-head rail, prior to the introduction of the 95-lb. section, a new chair was designed. This chair weighs $46\frac{3}{4}$ lbs., is $7\frac{1}{2}$ inches wide across the base, and $1\frac{3}{4}$ inches thick underneath the rail. The thickness was decided upon as the result of experience, and after a long series of falling tests, and is thought to be the lowest practicable under severe conditions.

The changes made in designing the new chair compared with the previous one were:—

(*a*). Key jaw lengthened from 4 inches to $4\frac{3}{4}$ inches.

(*b*). Base enlarged.

(*c*). Serrations provided on the underside of the base.

Fig. 10 will clearly illustrate the points mentioned.

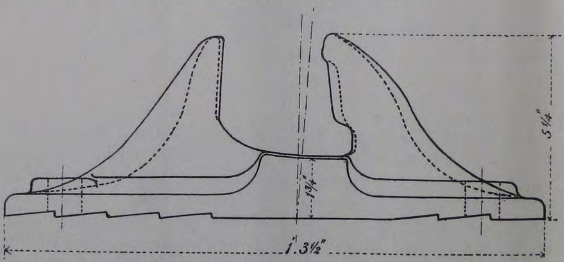


Fig. 10.

Expansion and Contraction.

In laying the road provision has to be made for expansion and contraction through a range of 70 degrees Fahrenheit; this is done by using a series of stops varying according to the temperature of the atmosphere. These stops, known as expansion gauges, are introduced between the ends of the rails at the time of laying, and are allowed to remain in the joints until they are properly "fished" up, and the road slewed into its proper line and "topped."

Sleepers.

Turning now to sleepers. The dimensions of those used upon the Great Western system are $9' \times 10'' \times 5''$, and they are creosoted before being put into the road. Indeed, this class of sleeper is almost generally used, and the demand is now so great that it is a standard item in the market.

As is well known, practically all the sleepers used on English railways come from the Baltic, and it would be unnecessary to give an account of the points to pay attention to in their selection and employment. It is, however, most desirable to stack the sleepers for one year after their arrival in England. Of course th is only an arbitrary period, as in busy seasons and in exceptional cases when the work is urgent many sleepers have to be creosoted and put into the road, although they may only have been stacked six months.

The number of sleepers laid per mile of railway on the Great Western system (and indeed on a large number of other railways) has changed from time to time as circumstances demanded. Up till about three years since twelve sleepers invariably spaced a 32-foot rail, thus providing a total bearing surface of 8·43 square feet per lineal yard of road; but on the Metropolitan lines of the company, where the trains follow one another exceedingly rapidly, it was found that, under the exacting conditions, this number was insufficient, and additional bearing area was provided by substituting $9' \times 12'' \times 6''$ sleepers for the $9' \times 10'' \times 5''$. This change from twelve $10'' \times 5''$ ordinary sleepers to twelve $12'' \times 6''$ special sleepers increased the bearing area 20 per cent. at an additional cost of £180 per mile. Such an expensive remedy could only be applied to the busy lines and not to the ordinary lines of the company, but the defect thus remedied pointed to a weakness in the general design of the permanent way, more especially as it had already been noticed that in certain parts of the system where the formation is soft, although the rails, sleepers, and fittings were good, and the ballast consisted of broken stone, it was impossible to maintain a smooth running surface in wet weather.

The lecturer particularly noticed the bad condition of one part of the line, and although the inspector in charge was an experienced one, his power of maintaining first-class road was for the time doubted. But, experimentally, it was eventually decided to lay a length of road with 13 sleepers to the 32-foot rail alongside another length which had just been completed to the old standard of 12 sleepers per rail. The difference due to the introduction of the thirteenth sleeper was remarkable, and whereas it had been impossible to maintain a good road at the place during the winter, it has become quite a normal task; and, moreover, a reduction in the number of men requisite to maintain the line has been brought about.

The result of these observations was a decision to increase the number of sleepers to thirteen $10'' \times 5''$ to the 32-foot rail. These are laid with a space between centres of 2 feet 1 inch at the joints, 2 feet 3 inches between the first and second sleepers, and 2 feet $6\frac{1}{2}$ inches in other parts of the rail.

In addition to the effect upon the road, there is the important consideration that the introduction of an extra sleeper reduces the girder length of the rail from 2 feet $9\frac{1}{2}$ inches to 2 feet $6\frac{1}{2}$ inches, thereby relieving the body of the rail from considerable unnecessary stresses developed by a longer span between the chairs.

It thus appears that the intensity of the pressure of the sleepers is an important point in securing a road which will, as has been shown, require a minimum amount of labour for maintenance, and at the same time present a good running surface.

The cost of thirteen $10'' \times 5''$ sleepers, with chairs, fangs, and keys complete, is about £5 5s.; and the cost of twelve $12'' \times 6''$ sleepers with identical fittings amounts to about £6 15s. The difference is due to the increased cost of the larger timber, as a $10'' \times 5''$ sleeper can be purchased for (say) 3s. 4d., while a $12'' \times 6''$ sleeper of the same length would cost (say) 6s. 1d.

Cost per Sleeper.	s.	d.
Clean sleeper	3	4·00
Creosote		7·53
Coal, stores, etc.		1·10
Wages		1·08
	4	1·71
Adzing and boring		·49
Chairing		1·38
Chairs	2	3·13
Bolts	1	7·93
	8	2·64

The wearing effect upon the sleepers due to the action of the traffic is greater than that of natural decay, and the extent to which these actions combined determine the life of the road depends upon a variety of causes—careless maintenance being a never-failing one. This extreme wearing can only take place when slackness is allowed to exist for a long period, and can be entirely prevented by keeping the chair securely fastened to the sleeper during the whole of its life. Considerable lengths of permanent way have been known to fail from non-observance of this precaution alone.

Another cause in determining the life of a sleeper is the enlarging of the spike or treenail holes, due to the actions of decay and vibration; but this also can be obviated by the fittings being kept tight continuously.

On the Great Western Railway the practice has been adopted of adzing and boring the clean sleepers after they have been duly seasoned, but before they are creosoted. By this means, when in the creosoting cylinder, the creosote has access not only to the surface of the sleeper, but to the surfaces of the bolt holes, and can thus spread around the holes for the depth of the sleeper, thereby strengthening it considerably at its weakest point, viz., under the chair. The abundant supply of creosote likewise prevents the rapid decay of the bolts.

Plate I. shows the extent to which creosote is absorbed by sleepers; and it may be surprising to some to find that so little penetrates the harder wood of the sleeper, although when being creosoted the sleepers (which have previously been thoroughly dried) are subjected to a pressure of about 100 lbs. to the square inch for a period of from $1\frac{1}{2}$ to 4 hours, in a cylinder exhausted of air.

On all lines there is a decided tendency to "spread," and in new lines laid to gauge this is frequently noted, thereby showing that the chairs and bolts have at times to resist a considerable shearing force. In view of this fact, and to avoid the breakages of the rails, which frequently occurred, the diameter of the bolts used on the Great Western system was increased from $\frac{3}{4}$ inch to $\frac{7}{8}$ inch, with satisfactory results; but doubtless on those lines where two spikes and two treenails are used for securing each chair the tendency to "spread" is met when the timber is fresh better than by two bolts or fangs, either $\frac{3}{4}$-inch or $\frac{7}{8}$-inch, as the sectional area of the four in the former case is greater than that of the two in the latter. On the Great Western Railway the difference has, however, been overcome by providing serrations on the underside of the base of the standard chair, and this arrangement offers resistance to shearing to a greater extent than any other device with which the lecturer is acquainted. But the lack of accurate workmanship in the casting of the chairs and the holes in them soon made it evident that the provision of serrations as described involved a difficulty which had not been foreseen; but this defect was in turn overcome by insisting upon the chairs being cast exactly to a standard pattern. Such accuracy could only be obtained by daily inspection during the process of manufacture, and by frequently gauging the castings, those varying more than (say) $\frac{1}{16}$ inch from the standard being rejected. Moreover, arrangements were made to ensure the accurate adzing and boring of the sleepers; and in this way it was possible after a time to get absolutely correct measurements between the jaws of the chairs when fixed upon the sleepers by the chairing machine.

Chairing Machinery.

Before proceeding to describe the process of chairing sleepers by machinery one instance might be given of bad hand-chairing which came under the lecturer's personal observation, and which had considerable influence in the decision to adopt the more modern method. A long length of new straight express line was laid in a chalk cutting; apparently it was in first-class condition, but, strange to say, express trains did not run as steadily on this new road, even after it had taken its bearing, as they did on other portions of the line.

To ascertain the cause the permanent way was minutely gauged, with the result that variations in gauge up to $\frac{1}{4}$-inch were discovered, proving that the platelayers had not been sufficiently careful in boring the bolt holes. These variations were quite sufficient to prevent the smooth running of trains, which was only obtained by re-laying the line with accurately chaired sleepers.

It is admitted that good platelayers do lay a road to perfection, but where, as on the Great Western Railway, some 200 miles of line have each year to be re-laid, generally under conditions unfavourable to minute accuracy, the practical result of hand-chairing is, in the lecturer's opinion, unsatisfactory.

Again, it must be remembered that with hand-chaired sleepers an extra force of men have frequently to be maintained for some time after the opening of a new piece of road for the purpose of tightening up the bolts as the trains seat the chairs on the sleepers.

Having these facts in mind, the chairing machine illustrated by *Plates* II., III. and IV. was devised.

When the adzed and bored sleeper has been placed into its proper position upon the machine, with the necessary chairs, hydraulic rams (each exerting 10 tons) press the chairs to the sleeper, and while this pressure is on, box spindles descend and engage the nuts of the bolts, screwing them up tightly to a point determined by friction pulleys.

The sleeper thus prepared, with chairs so accurately and firmly attached at the very commencement of its career, is protected as much as possible from deterioration during the earlier years of its life, when really most of the damage to permanent way takes place.

Rail Joint.

Another important point for consideration is the rail joint. On this detail much discussion has taken place and many experiments have been made, but it is not improbable that the final solution has yet to be found.

On investigation it is found that the greater number of rail fractures during a period of several years occurred near the ends. This fact is doubtless due to the tendency to slackness which exists at the joints, and to the consequent possibility of additional hammering as the vehicles pass from one rail to another. The weakness can be much diminished if care is taken to ensure the fishplates fitting accurately to the shoulder of the top and bottom members of the rail. *Plate* V. shows a fracture due to badly fitted and maintained joints; the seat which this loose maintenance has enabled the fishplate to make in the shoulder of the rail is very obvious, while it will be seen that the fishplate itself is also worn away. In no part of the permanent way is accuracy so advantageous as at the joints, and attention cannot be too strongly called to the rapid deterioration of all kinds of permanent way (more especially the fittings) from careless maintenance.

The fishplates must be rolled to true lines, holes bored in exact positions; while, similarly, the fishbolts must be well made, with truly parallel threads. Well-made fishbolts with parallel screw hold better than those tapered in the thread, but without rigid inspection a good bolt with perfect thread is not a natural output of a bolt factory. At one time spring washers were considerably used, but since the employment of a higher class of fishbolt their use has been discontinued.

There can be no doubt that the joint is the weakest point in the road longitudinally; records of fractures and the familiar jerking noise when travelling attest this; but by using heavy rails and fishplates of a good stout section, weighing (say) 31 lbs. per pair, and with sleepers 2 feet 1 inch apart, centre to centre at the joints, and men who understand packing the line, a good road can be obtained on any ordinary class of ballast, just the slightest pulsation being noticed when travelling over it. The life of any road which cannot be so maintained must be considerably reduced if the line is used for fast running.

Several experiments are being made with arrangements for the joint which bear upon the adjacent joint-sleepers, but obviously these cannot compete in cost with the ordinary fishplates, so that their superiority must be very pronounced ere they are brought into general use. For joint-plates bearing upon joint-sleepers the flat-bottomed or Vignoles rail presents considerable advantage over the bull-head rail, with its chairs closer to the joint. A joint-chair, receiving both ends of the rail, used to be the standard joint on the Great Northern Railway, but it was abandoned years since. Like many other devices, however, it is again cropping up (this time in conjunction with the fishplate), and is in experimental use on several railways; of some patterns the lecturer has heard good accounts.

A first principle, and one which inventors do not always keep in mind, is that permanent way fittings should have as few parts as possible. As a general example of the application of this axiom it may be pointed out that, in addition to the longer rails used, it is now the practice to make the wings of crossings quite long. At first sight it would seem that this is an awkward feature in the manufacture, but in practice it is not found so, more especially as the complicated fittings are now put together at the factory, and are simply laid into position on the ground. Formerly the practice was to order the crossings and lay them in on the ground according to the necessities of the site, or the views of the permanent way foreman carrying out the particular work.

In connection with the length of crossings, an important point is the provision of shoulders at the mitres of the points, as well as "joggles," so that in case of "creep" the tendency will be for the shoulder and "joggles" to push against the solid mass of metal, as opposed to the dragging action upon the bolts holding the point and the crossing together, which might otherwise be the case (see *Fig.* 11). From want of attention to this point many crossings have had to be renewed long before the expiration of their natural life. Of course the longer the wing rails, and the firmer the fastenings of the crossing to the timbers, the greater the tendency to stop "creep."

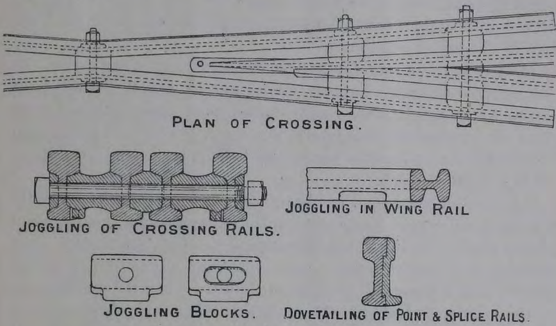


Fig. 11.

Perhaps all are not familiar with "creep" in rails, and a slight digression may be pardoned. "Creep" is a slow movement of the rails in the direction in which the trains, or the majority of the trains, travel, and is due obviously to the fact that the whole of the tractive force of the locomotive is expended in dragging the carriages over the rails. This drag on the rails is considerable, and it must be remembered that only the internal friction of the carriages and one or two slight losses, such as that due to wind, have to be deducted from the total drag to get the amount of this action in any one case. "Creep" is necessarily worse on newly laid roads in consequence of the ballast not sufficiently holding the sleepers. It seldom disappears altogether, but is greatly reduced as the road takes its bearing, and is well ballasted. "Creep" on a rising gradient, *i.e.*, in an upward direction, is not unusual.

Ballast.

Ballast is one of the most important factors in a good express road. The term "ballast" comprises two kinds, viz., "bottom" and "top." The "bottom" ballast is usually broken in pieces capable of being passed through a ring not exceeding six inches in diameter, while each piece of "top" ballast must be able to pass through a 2-inch ring.

In constructing a railway the general practice is to lay a layer of about 9 inches thick with "bottom" ballast, upon which is placed a 3-inch layer of "top" ballast, and upon this the sleepers are laid, and are ultimately "boxed" up with "top" ballast to at least the level of the top of the sleeper.

Broken stone or slag (by preference cold blast slag) makes the best possible ballast. Express roads laid in gravel ballast have proved to be much more easily shifted than lines ballasted with stone or slag, and for this reason the use of gravel ballast has been abandoned, except in cases where the ballast is "boxed" up above the top of the sleepers.

Much copper mine sand has been used in Cornwall (*i.e.*, gravelly sand from old copper workings); this sand is a coarse, heavy, clean gravel, slightly inclined to cementation on the top surface after exposure. It was invariably used with stone "bottom" ballast covered with 3 inches of "top," and the road "boxed" up half-way up the sleepers. Luxuriously smooth running was obtained with this ballast, far beyond any result with stone ballast, but its use had to be discontinued owing to the dust and dirt given off by it in dry weather. In the lecturer's opinion the satisfactory result to some extent arose from the self-wedging action of the sand when a train passed over the road.

Experiments with open, clean, free, river ballast (such as that from pits at Theale, near Reading, where there is a little fine sand) gave similarly smooth results when the ballast was placed over the sleepers up to one-half of the depth of the rail on the outside.

Administration.

No talk about permanent way would be complete without a few observations on the administration, discipline, and arrangements for maintaining the lines.

Express lines are mostly double; here and there are four lines. On an ordinary double line the permanent way gangs in normal circumstances, without many sidings, maintain a length of about $2\frac{1}{2}$ geographical miles. Each gang comprises a ganger, sub-ganger, and about three men. For every 10 to 15 gangs, depending upon the locality, position, and accessibility, an inspector is appointed, whose duty it is to see that the men skilfully and diligently perform their respective tasks ; and also to inspect periodically the roads, bridges, and structures on the line. Over 8 to 16 inspectors a divisional engineer is placed, the extent of whose division again depending upon the geographical position and accessibility of the lines. This completes the chain of arrangements for the maintenance of the lines, the divisional engineers being of course responsible to the head office.

In connection with each division there are bridge gangs, a bridge foreman, and re-laying gangs, as well as a complement of mechanics for carrying out any works which the permanent way men could not undertake. These men are located at a central depôt in the busier divisions, and, in the less busy divisions, in districts.

Questions as to the number of men required to maintain the lines naturally crop up frequently, and to deal with these, detailed returns of every gang, with full particulars of the railway, roads, and structures maintained, are kept in the head office ; on these returns particulars of any special features in connection with the line are noted. The returns are summarized and compared district by district, length by length, and by means of a diagram show in each inspector's district the number of men per running mile, as well as the total number of passenger and goods trains passing over the line. In this way not only can an accurate knowledge be obtained of the work performed by the various gangs, but healthy rivalry is established between the divisions, which is the only sure method of obtaining a uniform and economical manning of a large system of railway.

PAPER V.

THE DUTIES AND WORK OF A FIELD COMPANY, R.E., WITH A DIVISION FIGHTING ON THE OFFENSIVE.

BY COLONEL C. F. C. BERESFORD, R.E.

I TAKE as my text the well-known observation of Napoleon:—

"Those who neglect the support which the art of the engineer can give in the field gratuitously deprive themselves of a power and an auxiliary, never hurtful, always useful, and often indispensable. To maintain that victory falls to him who can advance and manœuvre, and that it is not requisite to work is to say what tends to produce error, and is false."

This should be read in conjunction with another maxim of Napoleon:—

"Field fortifications are always useful, never injurious, when they are rightly understood."

There is a wide-spread feeling among Royal Engineer officers, as expressed in numerous letters to the Corps Journal, and in an article entitled "The Fourth Arm" (contributed by Colonel Bell, V.C., to the *Journal of the Royal United Service Institution*), that the part to be taken by engineers on the battlefield has not received that recognition which is its due.

During recent years the work of the Corps has been rolling up like a snowball, which we almost dread may break in half from its own weight. We have been gathering up the teachings of science, and applying them to war in the shape of balloons, telegraphs, submarine mines, railways, fortress and field engineering.

Units to work all these have been carefully organized and trained, and have taken their well-recognized places in peace and war, except that in peace training there appears to be no provision for the right understanding of the field company on the day of battle.

Why should this be? Is it because there is apathy on the subject, and that the army at large has never seriously considered the intelligent use of field defences, or are we of the Engineers to blame for never having brought the subject into notice with sufficient persistency? If such be the case we should mend our ways forthwith, and my remarks to you to-day are made with this object in view, and in the hope of inducing some of my brother officers, better qualified for the task, to take it up.

You have only to read the reports on manœuvres in England to become aware of the fact that the tactical use of field engineering is neither seriously practised, or even well understood; not that its practice is so easy when the factor of time is so generally and, perhaps, unavoidably ignored at all peace operations.

I would ask anyone present if he can call to mind a case when a commander at manœuvres included in his dispositions for attack the serious use, intelligent or otherwise, of a field company, R.E.

As far as my own knowledge goes, I can only recollect it occurring at the late Irish manœuvres; and the fact that one of the generals took into account the tactical use of his engineers was commented upon to me by a distinguished authority on the art of war—an infantry officer—as unique in his experience.

I feel sure that many of my audience live in hope of one day joining a field company, and I know of no unit in the army that, having assumed its proper position, will have a better prospect of a great future, or be able to give its officers such opportunities of studying the art of war, and afford them so sure a path to distinction on active service.

A committee has lately been sitting at Aldershot to consider the training of engineer units. I have not heard whether the result of its labours have been promulgated, but one thing may be safely predicted, and that is, the efficiency desirable will only be obtained by a thorough knowledge of tactics by the officers and the constant exercise of the field company during peace time in conjunction with the other arms.

It would be quite beyond the scope of this lecture to do more than lightly touch upon some of the many and various questions that arise when we begin to discuss the subject of field defences, a subject which has been so fully dealt with by well-known authorities, and in the following list you would find ample food for reflection.

"*Précis*" *of Minor Tactics*, by the late Colonel Home, R.E. Chapter on Engineers.

"The Fourth Arm," by Colonel Bell, V.C., R.E., *Journal of Royal United Service Institution* for December, 1897.

Handbook of *Field Works*, by the late Colonel C. B. Brackenbury.

"Tactical Employment of Field Defences," by Colonel Goldie, R.E., in the *R.E. Professional Papers* for 1898.

"The Difficulties of the Tactical Defence, and How to Meet Them," by Major Mayne, R.E., *Journal of Royal United Service Institution*, September and October, 1896.

I think this list would offer to any officer new to the subject an excellent ground-work on which to base his study, without having to dive deeply into the abstruse reasoning of some writers on military tactics.

I will confine myself then to a rapid survey of the field company at home, and a horoscope of its fortune in war.

Field Company at Home.

The daily stage of duty run by a field company in peace time is more or less under the influence of bricks and mortar—the construction and maintenance of barracks—which duties, strange to say, awaken in the breasts of both military and civil critics a much keener interest than that aroused by the work for which military engineers were created. It touches them nearer home.

> "We build them nice barracks;
> They say they are bad.
> That our colonels are Methodist,
> Married or mad,"

sings the poet—a sweeping condemnation.

A civilian architect or engineer may fail—a Royal Engineer *never*.

We appreciate the compliment, as it places us only "a little lower than the angels"—somewhere in the same category as "Cæsar's wife"—and comfort ourselves with the remark of the late Captain May, of the Prussian Army, who said:—

"An engineer who is a good soldier and an indifferent architect will always be serviceable." In contradistinction, of course, to a good architect and indifferent soldier.

But for all that we must say a good word for the barrack work. It not only teaches the non-commissioned officers and men, and keeps them practised in their trades, but it teaches the officers self-reliance, organization, and the art of controlling and supervising large works and bodies of men. There are sermons in bricks and mortar as well as in stones, which, if we accept them in the right spirit, will have no small share in our preparation for the day of battle.

Field Company on Active Service.

Let us now suppose our field company has waved its last adieu to the "Incidental Item," and is fairly launched on a campaign as an integral part of an infantry division, and endeavour to sketch out its career on the march and in camp, and its destiny on the day of combat. Try and picture to our minds what the struggle might be, what share the field company could take in it; touch on the question as to whether the present organization and peace training give us what is wanted, and consider some suggestions for improving our methods of tactical instruction.

Tables I. and II. give you the composition of an infantry division and of a field company, R.E., at war strength.

TABLE I.

Composition of a Division of Infantry.

Divisional Staff.
2 Infantry Brigades, each of 4 Battalions.
1 Squadron Cavalry.
1 Brigade Division, R.F.A.
Ammunition Column.
Regimental Staff, Divisional Engineers. { Field Officer (C.R.E.), 1. Capt. or Sub. (Assist. C.R.E.), 1. N.C.O.'s and Men, 5.
1 Field Company, R.E.
Supply Column.
Field Hospital.

Total, 10,034 Men and 1,780 Horses.

TABLE II.

Field Company, R.E.

1 Major.
1 Captain.
4 Subalterns.
1 Medical Officer.

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2 Mounted Staff-Sergeants or Sergeants.
6 Dismounted Staff-Sergeants or Sergeants.
1 Shoeing Smith.
2 Buglers and Trumpeters.
48 Mounted Rank and File.
146 Dismounted Rank and File.

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13 Officers' Horses.
6 Public Riding Horses.
39 Draught Horses.
5 Pack Horses.

---

1 Maltese Cart for Medical Purposes.
4 Double Tool Carts.
3 Forage Carts.
1 Forge Wagon.
2 Pontoon Wagons.

We may take it that work for the company will begin as it puts foot on shore at the base of operations, supposing our army to be based on the sea. There may be piers to be built for discharging war material, huts to be erected, water supply to be organized, roads and bridges to be put in order, and many minor services to attend to.

Or the march up country may commence at once.

The duties of a field company on the march will depend on the natural features and resources of the country and the distance from the enemy, but will generally include road making, bridging, water supply, and any other work to facilitate the progress of the division.

The company's place on the march should be in front—partly with the advanced guard, and partly with the head of the main body, otherwise it cannot be in a position to render the most efficient service.

In camp, when out of touch of an enemy, water supply will be its chief care, or possibly the preparation of roads for a further advance; but as soon as a hostile country is reached, and outposts receive a greater importance, then will the defensive art of the engineer be looked for to assist at any special work requiring expert skill.

I say special work, because it must never be allowed that the infantry soldier is not quite capable of making his own defences when they are of an ordinary character.

And so the march goes on from day to day without calling for any exertion from the engineer beyond what he is equipped to carry out for dealing with the ordinary necessities of a march and the physical character of the surroundings.

When, however, the army, of which we may suppose our division to form a part, comes into touch with a hostile force, "then comes the tug-of-war," and then it is we should find the *rôle* of the engineer obtain a great development.

In his "*Précis*" *of Modern Tactics* Colonel Home has remarked:—

"It is often said that war is now so offensive in its character that in the field the use of earthworks is impossible, and, except in so far as the pioneer's duties are concerned, modern war finds no room for field engineers."

He then points out the fallacy of this creed, and shows by many examples the influence which field engineering has ever, and must ever have, when used intelligently.

To accomplish anything by brute force is always the simplest method, and saves time and trouble of thought, and exercise of intelligence; but then you must have the brute force in sufficient quantity, and even then the results do not always commend themselves to the human understanding.

Those who decry field defence in any form seem to me to do so in order to escape a difficulty, or rather, the difficulty of judging the proper time, place, and character of such works, upon which their whole utility depends. They shirk the question as too intricate, and assert that defences injure the *moral* of the soldier, and are merely the fads of the engineer nurtured in the bosom of permanent fortification.

Now experience has shown that inferior, undisciplined, or beaten troops are very difficult to retain or bring back into action if shelter exists close at hand; but the same danger does not exist for well-led and well-disciplined regiments, who have been taught to understand the proper use of all defence.

The expression "defensive operations" is always likely to be misunderstood. No general of the present day who has any views of crushing his opponent, or indeed of holding his own, will ever adopt a purely defensive attitude, and the conditions of modern war all point to the increased value of the offensive.

Entrenchments have at all periods of history been used, when intelligently constructed, as weapons of offence, and never to so great an extent or more intelligently than in the American War of 1861–5.

If you study the battles of that war you will find how time out of time the generals on both sides used fieldworks to cover their front while they engaged in a counter stroke or a flank attack.

Field engineering on the offensive was here put to its legitimate purpose, *i.e.*, to enable a smaller body of men, than would otherwise have been necessary, to hold on to a certain extent of ground, and by means of defences and local counter attacks to hold the enemy in front while he was being struck at on the flank.

This is the view of field defences which should be instilled into the soldier—That they are not places of refuge, but "pivots of manœuvre" to enable greater force to be given to the attack.

Trenches are made for tactics, and not tactics for trenches.

The word defence is used in its proper meaning by the pugilist, who speaks of "The noble art of self-defence." He does not mean by this that he stands in one spot with his arms across his face awaiting his adversary's onslaught, but that by using defensive operations with one hand he gives, or endeavours to give, the knock-out blow with the other.

The Attack.

Before organizing the field company for the combat we must have some idea of what we may expect this to be.

The battles fought by the British army against savage or semi-savage nationalities present so many different characteristics that it would be impossible to put forward a sealed pattern for our guide. The drill-book has accordingly given us a platform to start from by assuming that the typical battle is fought against a civilized opponent under the most advanced conditions of war.

It gives us the principles which have been evolved by the best authorities on military history, but distinctly forbids us to take the picture it presents as a standard to be servilely followed, directing us to consider the attack as a problem which cannot be treated under set conditions.

Let me refresh your memories by a brief sketch of the fight as set forth in the drill-book.

First, the screen of cavalry covering the advance, protecting from surprise, and reconnoitring the enemy.

The enemy in position with a force of cavalry, horse artillery, and infantry pushed to the front.

These must be driven back by our cavalry, guns, and mounted infantry, who find out all they can of the enemy, and then withdraw to the flanks as the latter shows up in greater force.

Our advance guard now approaches and takes up a strong position, holding its own as best it can, supported no doubt by a section or so of our field company.

The cavalry are now on the flank watching against counter attack.

The advance guard endeavours to draw the fire of the enemy, and make him disclose his position.

The general is making his reconnaissance accompanied, we hope, by the officer commanding the field company. And we further hope that all the other field company officers are employed on the same duty.

The general's plans are made, the infantry come up into a suitable position, and orders are given.

The artillery open the ball in order to beat down the defence and prepare the way for the infantry.

The infantry are launched into the battle in three bodies or lines—

1st. To develop the attack.

2nd. To support, reinforce, and complete it.

3rd. To confirm success, cover retreat, or meet any emergency.

The 1st line begin firing, possibly at 1,500 yards or over, but preferably hold their fire for medium ranges, 800 to 500 yards.

The troops begin to get mixed up, but the line fights its way on.

The 2nd line has been closing up until at about 500 yards from the position it joins the firing line, who are endeavouring to entrench themselves, we trust assisted by some of the field company.

The 2nd line carries the 1st line on to the final rush, assault, and victory—a success which, of course, is to be confirmed by the picks and shovels of the field company.

The 3rd line all this time has been taking up a good defensive position, and here again I dare say its comrades of the R.E. have been doing some useful work.

Having carefully read this picture of a battle in the drill-book, we should qualify the impression left on our minds by a study of one or two battles of modern times; and I don't think anyone can do better than to take *The Life of Stonewall Jackson*, by Colonel Henderson, for the purpose. There is a realism about his descriptions which brings very vividly before our minds the picture of the battlefield as it was, or may be, for men of our own race fighting very much as we may expect our soldiers to fight, and making an intelligent use of the art of the engineer.

With our minds thus prepared we should be in a position to discuss the question of the field company, R.E., and where it would come in on the day of battle.

Duties of the Officers.

A thorough reconnaissance of the ground at once suggests itself as the first duty for all the officers. In order to do the right thing at the right moment you must first of all know where you are, and what are the conditions which govern the case.

The senior R.E. officer should now ascertain the general's plans, and whether he has any orders to give as to the employment of the Engineers.

Here we at once come upon a certain difficulty.

It will be found in practice at peace manœuvres, or on active service, that the Staff are so occupied with their other work that they have neither the time nor the inclination to undertake so responsible a matter as legislation for engineer operations.

The same thing may be noticed in other armies, as at the Battle of Mars la Tour, when two of the companies of pioneers received no instruction for work, until at last they applied to be used as infantry in the attack, and were so used.

Now with an English division there is no R.E. officer on the Staff, so that the senior, who will be responsible for the work of the Engineers, will have to act largely on his own responsibility; and this I strongly would recommend him to do, and not to wait for orders that may never come.

He should, however, do all in his power to get into touch with the Staff, so that he may have a good knowledge of what is arranged, without having to hang about asking questions.

We will suppose him to have acquired all the necessary information.

He now knows his ground, and makes up his mind as to what measures he will take for meeting any eventuality, and arranges for the best distribution of his company, keeping in mind that it is desirable to break it up into smaller units according to the character of the ground and formation of the attack; but to keep in his own hand, if possible, the power of re-uniting it for any special work of importance—

Duties of the Company.

Assuming that our division has been sent forward to the attack, and that the country is one intersected by fences, streams, and roads, and dotted over with villages, woods, and homesteads; that we have hills to climb, marshes to cross, and bridges to defend.

The field company must be ready to—

Clear away obstacles requiring demolition.

Open up roads especially for artillery.

Make hasty repairs to bridges.

Lay down light bridges for infantry.

Prepare bridges for demolition.

Assist the infantry in putting villages, farms, woods, or other tactical points in a state of defence.

Or in opening up passages through villages, removing barricades, loopholing walls.

Follow up the fighting line and organize points of defence to strengthen the attack, check a reverse, or cover a retreat, and, in case of success, secure the position won. In Colonel Brackenbury's handbook on *Fieldworks*, Chapter X., on "Attack of Posts," he says, "Do not advance your column of attack until the obstacles are destroyed, or in a fair way to be so, and let this duty be allotted to a body which has nothing else to do."

In short, the work of the company will be to form a nucleus for the infantry working parties, and to carry out work requiring special appliances, all with the view of giving the attacking force a grip on the field of battle.

The idea that the whole of the field engineering during an engagement is to fall on the Sappers, and that the infantry have no part in it, is a mischievous idea for peace manœuvres, and an impossible idea for war. Unless the intention is to enormously increase the engineers with an army.

The engineers are there to direct their efforts to the principal points, to perform work of a technical nature, and to give unity and cohesion to the whole of the defensive or offensive engineering operations.

In a work by Capt. Gall entitled *Modern Tactics*, a book much used for promotion examinations I believe, the author, in his chapter on engineers, gives as his view that temporary independence for each arm in field engineering is indispensable, and that the infantry should be responsible for their own fieldworks during the attack, leaving the more solid work of heavy bridging and the like to the engineers.

The soundness of the principle on which Capt. Gall bases his views is undeniable; but it would scarcely be practicable to carry them out. The occupation of the infantry in attack is so absorbing that the proper preliminary measures for well-directed fieldworks would be lost to mind.

The case could, I think, be met by attaching an Engineer field company of suitable size to each brigade, and on active service reinforcing it by an officer and a detachment of infantry. This would tend to give the necessary coherence between the Engineers and the other troops.

The work of the engineers must be entirely subordinate to the tactical requirements, and they should not only be in touch with the Staff as to the plan of attack, but also with the commanders of divisions, brigades, and battalions as to the necessities of the moment.

A difficult *rôle* to play, and one which requires tact, forethought, and power of organization.

It has been remarked that the engineer arm, not only in the British, but also in continental armies, is apt to isolate itself and act independently, with the result that, from want of tactical knowledge, their work on the battlefield has sometimes been worthless, if not mischievous.

There is an undoubted truth in this which every engineer would do well to remember, and, as an example, I may quote the Battle of Königgrätz, where entrenchments were thrown up by the Engineers without reference to the divisional commanders, with the consequence that they were in the wrong places, and never occupied except by the enemy.

Organization and Equipment.

Having sketched thus briefly the position and duties of a field company, I come to the most important points for present consideration.

Is our field company's organization and equipment such that it could do itself justice in the field ?

Is its peace training sufficient to prepare it for its war duties; and, if not, how could it be improved ?

You see by Tables I. and II. the present war establishment of a company, and that a division has one such company attached to it. Is this sufficient ? A question very difficult to answer without a much larger experience of the company employed on its legitimate duties in the field.

My own feeling is that better results would be obtained by attaching a company of somewhat smaller size to each brigade, in addition to the divisional company, and I would even go farther and suggest that this organization should exist always at the larger stations in peace time, so that the company of Engineers belonging to a brigade should work, drill, and manœuvre with it, and also be responsible for the barrack repairs of that brigade.

The question of equipment resolves itself into the tools and material carried, and the means of carrying them.

The first is a matter of general experience, and presents no difficulty to an engineer, when he knows the class of work he is expected to carry out, and the number of men for whom he has to provide.

TABLE III.

Battalion of Infantry.

Tools.

Axes, Pick, $6\frac{1}{2}$lbs.	26
,, ,, $2\frac{3}{4}$lbs.	5
,, ,, Intrenching	128
Sandbags	20
Crowbars	12
Shovels, Intrenching	256
,, Light	8
,, Universal	25
Spades, N.P.	11

TABLE IV.

Tools and Stores.

Field Company, R.E.

Axes, Felling		43
,, Hand		26
Bill-hooks		47
Reaping-hooks		6
Axes, Pick		75
Sandbags		1000
Crowbars		10
Shovels, Universal		115
Spades		13
Galvanized Wire		lbs. 112
Guncotton	Wet	lbs. 372
	Dry Primers	lbs. 48 oz. 12
Detonators	No. 13	100
	No. 8	384
Fuze	Instantaneous	yards 200
	Safety	fathoms 128
Exploders, Dynamo, Electric		1
Tripod Pump		1
Hose		feet 300

Pack Animals.

4 for Technical Equipment, and
1 for Medical Panniers.

TABLE V.

Tool Cart.

Sandbags	316
Pickets, Tracing	60
Tapes, Tracing	3
Axes, Hand	6
,, Felling	11
,, Pick	17
Bars, Boring	3
,, Crow	2
,, Jumping	1
Dogs, Sawyers'	16

TABLE V.—*Continued.*

TOOL CART.—*Continued.*

Hammers ...		7
Hooks, Bill ...		11
,, Reaping ...		2
Saws, Cross-cut ...		1
,, Hand ...		4
Shovels, Universal ...		30
Spades ...		3
Rope, Tarred, $1\frac{1}{2}''$ ...	fathoms	113
Yarn, Spun ...	lbs.	33
Fuze { Instantaneous ...	yards	60
Fuze { Safety ...	yards	80
Guncotton { Primers ...		200
Guncotton { Wet Slabs ...	64 = lbs.	134
Detonators ...		120
Slow Match.		
Wire, Iron ...	lbs.	28

The present tool cart has its opponents and its advocates; and not having ever had the advantage of service with a field company, I don't feel in a position to offer an opinion, but would leave it to those who have had experience of it at manœuvres. I may, however, place before you the points for general consideration, as forming a part of the problem, which, I hope, will soon receive the attention it deserves.

Does the present cart fulfil its object? Is it strong and light, and capable of crossing a rough country?

Does it hold all the necessary tools in the most convenient way for distribution in the field?

Are the tools of the right sort, and in the right proportion and sufficient quantity?

Is there enough guncotton carried? Should the field company carry the heavier entrenching tools for the infantry and distribute them?

Is the pack equipment serviceable, and should it be increased?

All this has, I know, been thoroughly considered before now by the officers concerned, but hitherto there has scarcely been a sufficient basis to work upon, because the field company has not had opportunities at peace manœuvres of carrying out its duties for war.

And this brings me to the question of its training.

Training.

Not much fault can be found with its technical education ; indeed, the only question raised is whether this training is not of an unnecessarily high order for the work required in the field, and it has been often alleged that the ordinary pioneer would carry out the duties just as well. To this I cannot agree. All my experience goes to prove that the highly-trained man is worth half-a-dozen of the ordinary workman, put him to work at what you will.

But where is the tactical instruction gained ? I look to reports of manœuvres, but cannot trace it.

The difficulties to contend with at manœuvres seem to be—

1st. The necessity in many parts of England of obtaining a good water supply, coupled with the idea that too much hardship or roughing it for the soldier is prejudicial to recruiting.

This difficulty, I think, might be met by employing special workmen for the more elaborate water supply, thus releasing the field company, and also by providing each unit of the army with a pump and trough of its own.

2nd. The difficulty of obtaining permission to break ground, put ornamental villas into a state of defence, or demolish railway bridges.

3rd. The universal practice of ignoring time as a factor in tactical operations.

This again is influenced by the hardship of long hours and the recruiting question.

4th. The want of touch in their work between the Royal Engineers and the other branches of the service, and the consequent mutual ignorance of each other's duties.

Irish Manœuvres of 1899.

I now lay before you an account of some efforts we have lately made in Ireland to meet the difficulties mentioned, and under rather adverse circumstances to gain instruction in the duties of a field company.

I have already sent to the *R.E. Journal* an account of some of the work carried out at the Irish manœuvres, which took place between the 9th and 17th of August in the present year, and of which I now propose to give you a verbal description.

What was done by the R.E. is not put forward as a perfect model to follow, but as an example of one way of obtaining instruction in spite of the unrealities of mimic war.

The *Plate* shows the greater part of the manœuvre area, which was situated in Kilkenny and Queen's County, one of the most fertile and well cultivated districts in Ireland.

The country is very much enclosed and well wooded, except to the S. and S.W. of Durrow, where it assumes a more broken, open, and hilly character.

The whole area was a difficult one, especially for cavalry and artillery, and quite unlike what we are accustomed to at English manœuvres.

The numerous rivers and streams simplified the water supply to a great extent, but made a pontoon train a necessity for one of the opposing forces.

The general idea was that a Blue Force from Cork seeking to join a Blue Army from Galway was opposed by a Red Army from Dublin, which endeavoured to prevent the junction and to destroy the Cork Force.

The departure of the 7th Field Company, R.E., for South Africa rather upset our plans, so that our only resource was to organize provisional field companies.

The composition of these, as well as that of the two opposing forces, you can see on Tables VI. and VII.

TABLE VI.

R.E. at Irish Manœuvres, 1899.

Red Force.

C.R.E.

Bridging Train.	Officers.	N.C.O.'s & Men.	Horses
37th Co., R.E.	3	44	14
R.A.	1	15	22

2 Pontoon Wagons; 6 G.S. Wagons; 35 yards Bridging Material.

Provisional Field Co.	Officers.	N.C.O.'s & Men.	Horses.
R.E.	2	25	—
R.A.	—	6	10
Connaught Rangers	—	31	—

4 G.S. Wagons and 1 Water Cart.

TABLE VI.—*Continued.*

R.E. AT IRISH MANŒUVRES, 1899.—*Continued.*

Blue Force.

PROVISIONAL FIELD CO.	Officers.	N.C.O.'s & Men.	Horses.
R.E.	2	24	—
A.S.C.	—	8	12
2/East Yorks Regiment ..	1	31	—

5 G.S. Wagons and 1 Water Cart.

TABLE VII.

IRISH MANŒUVRES, 1899.

Composition of Opposing Forces.

Red.

Cavalry Brigade	1½ Regiments. 1 Battery R.H.A.
1st Infantry Brigade ...	4 Battalions.
2nd Infantry Brigade ...	4 Battalions.
Royal Engineers	Bridging Train. Provisional Field Company.
Brigade Division, R.A.	

Blue.

Cavalry Brigade	2 Regiments. 1 Battery R.H.A
Infantry Brigade	5 Battalions.
Brigade Division, R.A.	
Royal Engineers	Provisional Field Company.

In order to give as much reality as possible to the work, it was arranged by the direction of the Field Marshal Commanding that the R.E. were not to precede the other troops to the various camping grounds to make elaborate preparations, but were to keep in their proper places on the line of march, and act as they would do in war.

Directions to the following effect were issued to the R.E. :—

In order to gain instruction from the manœuvres, and in the absence of a field company, R.E., and opportunity for real work, the R.E. officers attached to the two forces will carry out the duties enumerated below :—

1. A thorough reconnaissance of the ground to be operated over.

2. To accompany the troops during all operations, and make themselves thoroughly acquainted with the course of action.

3. The preparation of schemes for any engineering work thought desirable on the supposition that a field company at war strength would be employed with each force, and with due regard to the time, tools, and material necessary for each work.

4. With the permission of an umpire to erect distinguishing flags to denote that posts were defended, bridges prepared for demolition, etc.

5. On the conclusion of each day's manœuvres to hand in reports, illustrated by rough sketches, of the work they had provided for.

Canvas screens were not to be carried to represent shelter trenches.

The following is a sketch of each day's operations, with notes on the part taken by the skeleton field companies, R.E. :—

In considering the work done by the Blue Engineers you must note that there were only two R.E. officers assisted by an infantry officer as acting engineer; and when the company is referred to, that this unit consisted of perhaps 10 sappers and 10 privates, while the sections were represented by 3 or 4 men, or possibly by only 1 non-commissioned officer or sapper.

At the commencement of the manœuvres the R.E. officer in command of Blue Engineers took great pains to instruct the non-commissioned officers and men in map reading, in drawing up schemes, and making reports. All this would generally be done by the section officers; but as these did not exist, the duty devolved on the men representing the sections, and was very creditably performed. On the 9th of August the opposing forces entered the manœuvre area, and the position at the close of the day was as follows :—

Red cavalry main body encamped at *Ballyroan* with outposts on the line *Oatlands House-Ballinakill.*

During the day they had reconnoitred the upper *Nore* and reported *Poorman's* and *Waterloo Bridges* as unoccupied, but had observed Blue cavalry at *Ballyragget* and *Attanagh*, and come into touch with them at *Watercastle Bridge;* they also discovered the main body of cavalry camping at *Durrow.*

The Blue cavalry during the day had blocked the bridges over the *Erkina River*, and reconnoitred towards the *Nore* and *Ballinakill*, but had found out nothing as to the position of the main body of Red's cavalry.

Blue cavalry camped at *Durrow* for the night.

The main armies had reached *Bert Bridge* and *Johnstown* respectively.

No tactical work was performed by the Engineers on this day.

10*th August.*—The Red cavalry occupy *Abbeyleix* and *Ballinakill* with scouting parties west and south. They failed to capture *Poorman's* and *Waterloo Bridges;* but one patrol pushed on to *Durrow*, till it was checked at one of the bridges by a section of the field company, R.E.

Blue cavalry concentrated $\frac{1}{2}$ mile west of *Knapton House*, and held the bridges over the *Nore* from *Waterloo Bridge* to *Kilbricken;* they also patrolled in the *Ballinakill* direction, but were driven back to *Durrow*.

The main Red force marched from *Bert Bridge* to *Ballyroan*.

Blue from *Johnstown* to *Durrow*.

The R.E. of the Red Force were solely employed on water supply. On the march they were at the *tail* of the column!

Blue Engineers were sent forward ahead of the advanced guard to secure the bridges at *Durrow*.

On the march they received an order from the senior R.E. officer to hurry on and take steps to defend the two bridges 1 mile N. of *Durrow*, *Tallyho Bridge*, and the cross roads about $\frac{1}{2}$ mile S.W. of *Moyne House*.

This is an example of an officer very properly taking the initiative, and shows that he thoroughly appreciated the tactical position. His action was entirely borne out by the subsequent orders of the Chief Staff Officer for the line of outposts, which exactly corresponded with the defended points.

The section not only put these points into a state of defence, but occupied them until relieved by the infantry outposts, and in one case checked the enemy's cavalry.

11*th August.*—Blue cavalry held the passages at *Poorman's* and *Waterloo Bridges* with detachments at *New Bridge* and *Watercastle*.

The main body, covered by the cavalry, marched *viâ Ballycolla*, and took up a position near *Ballygeehin House*.

The Red Force halted in *Abbeyleix*, and, being completely in the dark as to the movements of Blue, sent 2 battalions, a field battery, and subsequently a 3rd battalion to *Ballinakill*.

Another battalion went to *Poorman's Bridge*, and found it destroyed.

Matters now came to a standstill, so that the day's operations were practically over.

Although there was no engagement, the Director of the Manœuvres remarked that he never remembered an occasion when peace manœuvres represented more accurately the actual service conditions during the preliminary stages of a battle, the two forces being absolutely enveloped in ignorance of each other's movements.

The Engineers of the Red Force were little employed; a scheme for putting *Ballinakill* in a state of defence was, however, drawn up by one officer.

They marched in rear of the column, and were so placed when the troops were halted in *Abbeyleix.*

No attempt at reconnaissance seems to have been made, and when their services would have been of the greatest use in bridging, or repairing bridges, over the *Nore*, neither the pontoon train nor the field company were on the spot.

With the Blue Force it was different. The field company was with the advanced guard on the march to *Ballygeehin House*, while parties were detached to prepare *Gully* and *Waterloo Bridges* for demolition, put the posts there in a state of defence, and assist the cavalry to hold them.

The cavalry prepared *Watercastle Bridge* for demolition, and assisted the R.E. party at *Waterloo Bridge*, where by their combined action they drove off some of the enemy's cavalry.

This R.E. detachment then made for *Poorman's Bridge* to assist the cavalry there, and subsequently to re-join their company near *Gortnaclea House.*

Gully Bridge was prepared for demolition by another detachment

Meanwhile, with the concurrence of the O.C. of the advanced guard, it was arranged for the field company to secure the left flank of the main position.

This was done by two sections of the company preparing *Gortnaclea Bridge* for demolition and putting the surrounding ground in a state of defence.

Kilbricken and *New Bridges* were then similarly dealt with by the other two sections.

These measures practically made the position secure, and rendered the success of Blue pretty certain.

12th August.—The special idea had now to be changed, and Blue, supposed to have been driven across the *Erkina River*, broke the bridges.

Their orders (supposed to have been received from Cork) were to hold the ridge south of *Durrow* as long as possible and then retire, resting their right flank on the *Nore* and destroying the bridges.

Red's orders were to push Blue and destroy him.

Blue took up the position ordered with 3 battalions entrenched, supported by the brigade division of artillery on the right flank, and with a reserve of 2 battalions for a counter attack, the cavalry being on the left flank. The R.H.A. battery was posted on *Seskin Hill* to aid the counter stroke.

Tallyho Bridge was destroyed, and also that at *Ballyragget*, somewhat prematurely by orders of the O.C. cavalry at that point.

Red, being unable to cross the river in *Durrow Park* on account of the owner's objections, threw a bridge over the *Erkina* alongside the demolished bridge in the village.

Red then sent a battalion to *Caponellan Wood* to divert attention while he attacked the right flank of the position with 7 battalions, the attack being prepared by the field artillery from beyond the *Erkina*.

As the leading troops were gaining the crest of the ridge the attack was checked by the delivery of the counter stroke, and would probably have failed.

Meanwhile the Red Cavalry Brigade crossed the river at *Ballyconra Ford*, and pushed back the Blue cavalry almost to *Lisdowney*, thus threatening Blue's line of retreat.

The Engineer work was as follows :—Blue field company was ordered to send a party to destroy *Tallyho Bridge*, and then proceed to *Ballyragget* and prepare the bridge there for demolition. The remainder of the company were to assist at strengthening the position on the ridge.

The O.C.R.E., however, fully understanding the position of affairs, very properly took upon himself to send a section direct to *Ballyragget* in order to make sure of defending that point. The bridge here was quite capable of defence, but was destroyed by the section under orders from the cavalry commander.

The section, having carried out this order, marched to *Ballyconra Ford*, where it met the party from *Tallyho Bridge*, and together with half a squadron of cavalry they prepared for defence by loopholing walls, making clearings, and finally, under decision of an umpire, stopped the Red Cavalry Brigade for half an hour.

This had an important bearing on the day's operations.

The Red cavalry, however, eventually got over and pressed forward, threatening *Aharney Camp*, which was defended by the R.E. and infantry, who were at work on the water supply.

The Red Engineers threw a bridge over the river at *Durrow*, but appeared to have been unemployed during the remainder of the day.

The probability is that Red's attack would have failed; in that case they might have been thrown back on *Durrow* in confusion with only one point of passage over the river, and that under artillery fire at a range of about 2,500 yards; and yet no steps were taken to put *Durrow* into a state of defence or strengthen the post at "*The Brickfields*" so as to check pursuit.

14th August.—Blue was now ordered to evacuate the position of the 12th; retire southwards, trying to draw the Red Force down the right bank of the *Nore;* make a stand to check him near *Sweethill House;* then slip across the river at *Lismaine*, and so endeavour to march north and join their main army from *Galway.*

Red was ordered to press on and crush Blue without delay.

Blue accordingly retired under the protection of a line of outposts extending from *Ballykealy* cross roads to *Ballyconra.* The outposts as they retired formed a rear guard, while the cavalry secured the left flank.

A position was taken up N.W. of *Sweethill House.*

Red was somewhat slow in advancing, but finally threatened Blue's left flank at *Beechfield* and *Clone Houses*, and deployed for attack.

Blue, after an ineffective counter stroke, commenced to retire on *Lismaine*, and cease fire sounded.

Action of R.E.

The Red Engineers were apparently again unemployed.

The Blue field company was ordered early in the day to prepare *Lismaine Bridge* for demolition, fortify a position on the left bank to protect the baggage, and make roadways for the artillery to come into action.

When this was done half the company was sent to assist at the defence of the main position, which was hard pressed. They helped the infantry to loophole *Clone House*, and to place a cottage and some outhouses in a defensive state.

15th August.—The Blue Force, having been supposed to have escaped across the river, camped near *Ballyragget* on the night of the 14th.

The Red were at *Grange.*

The defeat of their main army being reported, Blue was ordered to re-cross the river and make for *Cork.*

The pontoon train was attached to Blue for the occasion.

The Red commander divided his force into three sections—

The northern section to watch the river from *Tallyho Bridge* to *Ballinaslee.*

The centre section from *Ballinaslee* to *Ballyconra.*

The southern section from *Ballyconra* to *Ballyragget.*

Blue cavalry crossed by the ford at *Ballyconra* and pushed on towards *Lisdowney.* There they encountered the head of the southern brigade, and were driven back to a point on the road about 1½ miles from *Lisdowney,* where Blue horse artillery were posted.

A bridge having been made at *Ballyconra,* the Blue infantry crossed, and pressed on towards *Lisdowney,* outflanking the Red brigade. Meanwhile 2 battalions of this brigade moved round and cut off Blue's communications with the bridge.

Red cavalry and R.H.A. went to *Brookfield House* to cut off Blue's escape in that direction. Red artillery were in action on *Seskin Hill.*

Three battalions from the centre brigade now moved down on Blue's right flank, and threatened to envelope it, when cease fire sounded.

Action of R.E.

The Blue field company assisted at the bridging operations at *Ballyconra.* There was a good deal of work required here to make the roadway to the bridge passable for artillery, as the approach was boggy.

Unfortunately the greater part of the company were cut off by the flanking movement of the Red brigade, and were put out of action.

A small party that had escaped occupied themselves at endeavouring to extemporize field observatories.

The Red field company were at *Lisdowney,* when their southern, brigade was driven back by the Blue advance with serious loss. There was a farm at this point which, if it had been put into a state of defence, might certainly have checked the enemy, but no steps were taken in the matter for at least half an hour, when the General himself coming up, ordered the work.

This was the closing day of the manœuvres proper, and I have endeavoured in the foregoing sketch to show what was done by a field company, skeleton though it was, what might have been done and what was left undone. As I have already said, I do not put this forward as a faultless example of the course we might follow at manœuvres, but I think it is possessed of germs which might be considerably developed at future peace operations so as to bring forth good fruit.

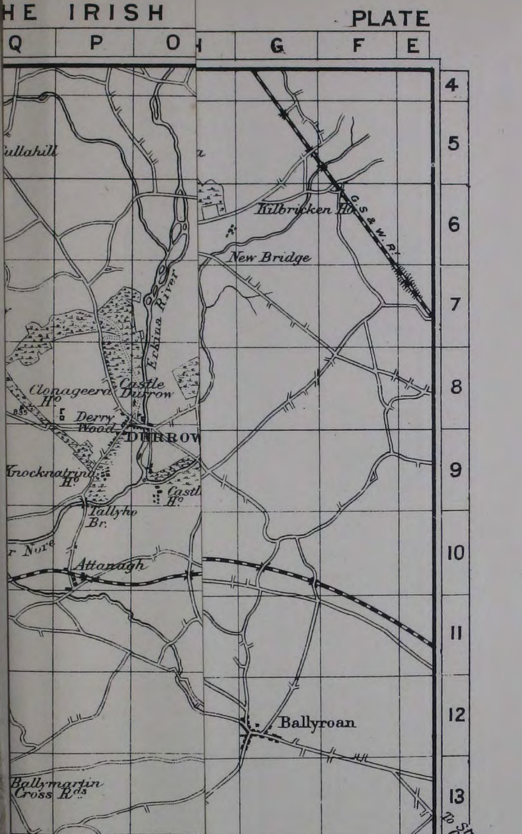
Concluding Remarks.

Before closing this lecture I wish to draw your attention to an admirable way of studying the work of Engineers in the field suggested by the late Captain R. da Costa Porter, and described by him in an article which you will find in Vol. XXI. of the *R.E. Professional Papers.*

He takes the Battle of Woerth as an example, and, having closely followed its details, works out a scheme showing what might have been done by the Engineers which was not done, and what effect this might have had on the final issue.

Any of you who feel inclined for the task should take some battle of which we have detailed account; imagine yourself in command of a field company, R.E., at war strength attached to a division, and work out step by step what action you would have taken with the men, tools, material, and transport at your disposal; draw up a narrative of this, with your deductions as to the influence your work would have had on the result of the battle.

And now for one word addressed especially to the more junior portion of my audience, who are on the threshold of their career. The welfare of the Corps is in your hands as the "trustees of futurity." Keep in mind that the art of war is your first study; that all your other work is subordinate to that—and never forget you are "Soldiers first and Engineers afterwards."



HE IRISH
PLATE
Q P O G F E
4 5 6 7 8 9 10 11 12 13 14 15
Cullahill
Kilbricken Ho.
G.S. & W. Ry.
New Bridge
Erkina River
Clonageera Ho.
Castle Durrow
835
Derry Wood
DURROW
Knocknatrina Ho.
Castle Ho.
Tallyho Br.
River Nore
Attanagh
Ballyroan
Ballymartin Cross Rds.
To Stradbally 6½ m.
P O G F E
Scale 1 Inch to a
5 4 3 2 1 0 1

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PAPER VI.

SUBAQUEOUS FOUNDATIONS FOR BRIDGES AND DOCKS.

A Lecture delivered at the Royal Engineers Institute, Chatham, by E. CRUTTWELL, M.INST.C.E., M.I.MECH.E., *7th December*, 1899.

THE present paper deals briefly with various methods of constructing foundations for bridges and dock-works when situated in water or in water-bearing formations.

The word "foundations" usually conveys the idea of preparing or excavating the ground for the purpose of obtaining a solid basis to build upon; but the term also includes other types of construction, which may be summarized under the head of "piled foundations."

Where the nature of the ground is favourable, such as in silt, sand, gravel, or clay, an economical pier, or abutment for a bridge, or a quay for a dock, may be made by driving piles at suitable intervals, and bracing them together above the level of the ground. Piles of fir timber, unless required for temporary purposes, are usually creosoted; but, for marine work, in situations exposed to the attack of worms, the best timber to adopt is greenheart.

Rolled iron or steel may also be driven as piles, and cheap constructions may often be made out of old railway metals.

Cast-iron screw-piles are used for piers of bridges when it is known that the ground through which they are to be screwed is free from large stones or boulders; but cast iron is not to be recommended unless the piles are secure against collision from vessels or other floating objects.

Piles, whether of timber or iron, should be braced in all directions, if possible from ground level upwards, at intervals of 10 feet, or at most 15 feet, from one set of bracings to the next. Where the depth of water in which the piles are driven exceeds about 10 or 15 feet at low tide, the bottom sets of bracings must be bolted up by divers. Such work is always expensive, and seldom so satisfactory as work done above the water level. In great depths of water, therefore, a piled foundation, except for temporary purposes, is usually undesirable.

Where piles are used for the front of a quay, they are usually tied with iron rods to a row of back piles driven from 6 to 10 feet apart, and about 20 or 30 feet away from the front row. Two, or perhaps three, tiers of tie-rods are often necessary. The front may be driven with sheet piles close together if there is much pressure from the filling of the quay to be resisted (see *Fig.* 1); or, where the pressure is not so great, the piles may be driven at intervals, with thinner sheet piles or planks interposed between or at the back of them (see *Fig.* 2).

If rubble stone or chalk are easily procurable, they may be formed into rough walling behind the piles, so as to relieve the piles of part of the earth pressure. The pressure is apt to be greatest where the range of tide is considerable, for in such cases there is at low water a mass of wet earth behind the piles tending to slip forward, with no counterbalancing weight of water in front of the quay to resist it. If the quay is to be used for the handling of heavy goods, or where railway sidings are to be laid alongside, it is generally advisable to carry the filling behind the piles right up to the level of the quay (*Fig.* 1); but, where the expected traffic on the quay is light, it may sometimes be more economical to reduce the pressure on the front piles by sloping the filling at the back, as shown in *Fig.* 2. In the latter case the quay space between the front piles and the top of slope is made good with planks supported on bearers resting upon the piles.

The greatest objection to the use of timber for permanent structures is that it is so liable to decay, especially at the parts situated between the wet and the dry, or at about the level of the water. The parts continually below, or those continually above the water do not decay nearly so quickly. The same may be said of iron and steel structures, although not to so great an extent as in the case of timber. For bridges, therefore, whenever enough money is available, those parts of the piers which are not accessible for painting will, as a general rule, be best constructed of masonry, brickwork, or concrete. The same applies to dock-works generally, although the extent of such works often renders it necessary on the score of expense to construct the quays of timber in the first place. In later years, when the necessary funds may be more conveniently raised than in the first instance, the timber quays can be replaced by more lasting materials. The possibility of reconstruction at a later date should be borne in mind when designing all structures of a more or less temporary character. The construction shown in *Fig.* 1, for instance, offers far greater facilities for putting in a new wall than that shown in *Fig.* 2. In the former case a trench for the new wall would be excavated at the back of the sheet piles—the piles acting as a cofferdam to exclude the water from the trench whilst excavating the foundation and building the wall. In the latter case a large quantity of new timbering would be necessary to exclude the water before the trench could be excavated.

The construction of concrete, brickwork, or masonry foundations will necessitate a certain amount of excavation, except, perhaps, in the case of a rocky bottom having no deposit of soft material above it—and even then the surface of the rock will often require levelling. Wherever possible, it is desirable to execute the final portions of the excavation and the building of the permanent work, whether of concrete, brickwork, or masonry, in the dry by excluding the water from the site of the foundation; but, under certain circumstances, where such a procedure would entail prohibitive expense, the lower portions of the foundations may be put in beneath the water. Due precautions must then be observed to prevent the cementing medium from being abstracted by the water. This can be best effected by the use of concrete deposited in bags or sacks, which are allowed to remain permanently in the work; or, where the water is not disturbed, by lowering the concrete through the water in a skip or box fitted with a moveable bottom, which opens downwards on a catch being released by the man in charge of the lowering gear.

Shallow foundations, when situated in tidal waters, may be put in "tide-work," although it is preferable to exclude the water entirely unless the cost of so doing is excessive. When tide-work is resorted to, the excavation (unless in rock or other material not liable to fall into the trench) is timbered in the ordinary way with poling-boards, runners, or sheet-piling, as the case may be; and the trench is pumped out at each tide as soon as the water falls below the top of the timbering. Care should be taken that no more of the excavation is bottomed up at each tide than can be completely covered over with the concrete, brickwork, or masonry of the permanent work, otherwise the ground will be disturbed by the incoming tide, and unequal settlement of the foundation will probably result. The permanent work should be protected before the tide comes in by covering it all over with sacks or matting weighted with stones or other heavy materials, so as to prevent their being disturbed by the inrush of the water. The work should be thoroughly cleaned and sprinkled with cement before resuming the succeeding layers or courses. A certain proportion of the cement is almost sure to be washed out by the incoming tide, so that it is advisable to mix the concrete or mortar stronger than where the work is executed in the dry. The cost of the extra cement and the increased cost of pumping will, as a rule, render it inexpedient to resort to tide-work except for shallow foundations extending only a few feet beneath low water level.

There are many ways of constructing deep foundations, the choice of which must be determined according to circumstances. Before a proper decision can be arrived at, the nature of the ground should be ascertained, if necessary by trial borings, or, in important works, by the sinking of a trial cylinder at or near to the site of the intended foundation. The cylinder may be of cast iron, or of wrought iron or steel, from 6 to 10 feet in diameter, and in segments of convenient height bolted together so as to be thoroughly water-tight. With cast iron the joints can be machined and fitted together with red lead; but with wrought iron or steel the joints, even if machined, will generally require a strip of indiarubber to make them water-tight. An example of a cast-iron joint is shown in *Fig.* 3, and a wrought-iron or steel joint with a strip of indiarubber in *Fig.* 4. The cylinder can be sunk through water-bearing strata by excavating the material from inside with machine grabs or dredgers, when its own weight will generally force it down. If not, weights must be added at the top, or pressure can be applied by hydraulic jacks somewhat as indicated in *Fig.* 5. In the event of boulders getting jammed beneath the cutting edge of the cylinder, and so preventing its descent, it may be necessary to remove the obstruction by divers. If clay or other impervious material be met with, the cylinder, when sunk sufficiently into it to resist the pressure of the water, can be pumped out, and the excavation can then be proceeded with by ordinary digging.

If clay is met with at a moderate depth—say about 40 feet below high water level—the cheapest way to put in the foundation will probably be to drive a cofferdam so as to enclose the site. The dam may consist of a single row of sheet piles where the ground is soft and of uniform consistency; but where stones or rough gravel are to be met with, the piles are apt to be deflected out of line, in which case it will be safer to drive a double row of piles and fill the intervening space with clay puddle.

The piles of a single dam are frequently grooved, and a wooden tongue about 2 inches square, nailed in the groove of one pile, slides in the adjoining groove, and so helps to keep the piles in line. If made an accurate fit, the tongue aids in making the joint water-tight; but there is a danger with tight-fitting tongues of splitting the piles. It is questionable whether in rough ground the tongues are an advantage; because, when the point of a pile is driven upon a stone or other obstruction, the pile may be deflected with such force as to cause it to split somewhat as indicated in *Fig.* 6.

In some parts of Russia, where round timber is very cheap, an excellent plan is adopted of adzing out the side of one pile to fit the natural curvature of the adjoining pile, as shown in *Fig.* 7. The piles are thus kept in line, and they are less liable to split than when tongued and grooved.

A single pile dam will frequently leak even when tongued and grooved, in which case the joints are caulked from the inside with oakum, like the seams of a ship. The caulking is done by gradually working down from the top, so as to keep pace with the lowering of the water when the pumps are set to work inside the dam. A single dam without tongues and grooves will require caulking at most of the joints. A double dam with properly rammed puddle should require neither caulking nor tongues, although often the tongues are put in as a precautionary measure.

The excavation within the dam is sometimes taken out right up to the sheet piles; but it is safer, especially in the case of deep foundations, to set the sheet piles back some distance from the excavation, and to drive strutting piles at intervals along the edge of the foundations. The strutting piles should be driven well below the bottom level of the intended excavation, but the sheet piles need not necessarily go so deep.

Fig. 8 shows the method adopted in putting in the foundation for one of the shore abutments of the Tower Bridge. A single row of sheet piles was driven 15 feet beyond the outer face of the excavation, and the strutting piles were driven at intervals of 9 feet. Before closing the dam, struts were inserted between the sheet piles and the strutting piles, and also between the strutting piles and the old river wall. The last-mentioned struts are dotted in *Fig.* 8. The foundations were 102 feet long by 80 feet wide. In order to avoid the risk of opening up such a large area all at once, the foundation of the abutment was executed in two portions. The back portion, behind the old river wall, was put in first, and the cofferdam was supported against it by inserting tiers of struts between the strutting piles and the work already built as the excavation of the front portion progressed downwards. The face of the trench next the cofferdam was secured with 3-inch deals driven as runners—the ground not being firm enough to admit of the use of poling boards. The bottom 12 feet of the excavation through the London clay was taken out in short lengths of 18 feet, in order to minimize the risk of a "blow" from the external pressure. The tiers of struts were removed after the permanent work had been brought up to their undersides. The lower setting of runners was withdrawn a foot at a time to keep pace with the concreting. The piles above the concrete were strutted back against the front footings of the abutment, as shown by the dotted lines in *Fig.* 8, in order to admit of the removal of the long struts extending to the back portion of the abutment. When the building had reached above the level of the foreshore up to the undersides of the upper tiers of struts, short timbers were inserted between the strutting piles and the face of the abutment so as to afford support to the piles of the dam. As soon as the work was brought up above the level of high water, a trench was sunk alongside the cofferdam, for the purpose of boring holes in the piles at a depth of 3 or 4 feet beneath the foreshore, so that the piles might be broken off at this level. The strutting piles were broken off in a similar manner level with the top of the concrete. It was considered that settlement of the foundation or of the neighbouring warehouses might possibly have ensued if the piles had been withdrawn entirely.

A double-piled dam with puddle between, as now being used for putting in some of the new quay walls at Middlesbrough Dock, is shown in *Fig.* 9. Here the excavation is taken out right up to the piles.

Fig. 10 shows how the old quay walls at Limehouse Dock have recently been deepened and strengthened by excavating and filling in concrete at the back of the old work, and utilizing the old sheet piles as a cofferdam. The excavation was taken out in lengths of about 15 feet at a time, and at least 30 feet was left undisturbed between any two lengths in progress simultaneously.

A difficult type of cofferdam is where the site consists of a rocky bottom without any overlying material into which the piles can be driven. Such a case occurs at the Falls of Connel, in Scotland, where a large bridge on the Callander and Oban Railway is now being constructed. The dams are made by fixing a single row of upright iron joists of H-section in holes bored in the rock about 6 feet apart. Horizontal planks 4 inches thick are laid in the grooves formed by the flanges of the joists (see *Fig.* 10A.) The junction between the lower planks and the rock is made good by throwing in sacks of cement concrete on both sides of the dam, and ramming them tight before the concrete has become set.

In the case of foundations extending to depths of 50 feet and more below high water level, it will often be cheaper and safer to employ cylinders or caissons of some sort, instead of the foregoing cofferdams. The cylinders and caissons are sunk to the necessary depths by removing the ground from inside them, either with machine grabs and dredgers, or by digging, or by a combination of both methods. The digging can be executed by divers if the bottom of the caisson is not entered sufficiently deep into clay or other impervious material to render it safe to pump out the water; but the grabs or dredgers will take out the bulk of the material, and the divers, as a rule, will only have to clear the cutting edge of the caisson by working the ground away from the edges towards the hole made by the grabs. The divers usually dig with ordinary tools, but in some kinds of soil, such as silt, sand, or fine gravel, it may sometimes be found advantageous to use a pneumatic or hydraulic jet for displacing the material round the sides of the cylinder or caisson. The jet is directed by the diver through a portable nozzle connected by a flexible tube with a compressor placed on the staging above.

If no clay is to be met with, and it is desired to put the foundation in in the dry, it will often be necessary to resort to pneumatic pressure in order to exclude the water from the cylinder or caisson. This process is slow and expensive, because the excavation has to be taken out, and the building materials—at any rate for the first few feet of the foundation—have to be entered in through air-locks, and the workmen must also pass in and out by the same means. The provision of the air-locks and the necessary air-tight decks or

The largest of them was 100 feet long by 60 feet wide by 115 feet high. The cribs were divided up into numerous pockets by cross partitions of timber. The outer and some of the middle pockets were weighted with gravel so as to aid the descent of the cribs. The cribs were sunk through a maximum thickness of about 60 feet of mud, silt, and sand, down to the gravel, which they reached at a maximum depth of about 135 feet below high water level. The sinking was executed entirely by dredgers or grabs working in the inner pockets. The latter were filled with concrete put in under water.

Another good example of American practice is found in the Blair-Crossing Bridge on the Missouri Valley and Blair Railway, as indicated in *Fig.* 14. Here the caissons were 54 feet long by 24 feet wide by 17 feet high. The sides were formed of single baulks of timber with two thicknesses of planks laid crossing one another on the outside of the timbers. The sides were supported with numerous timber struts placed across from one side to the other. A deck consisting of double timbers, and lined with planks on the underside, was constructed, so as to form an air-tight excavating chamber extending over the whole area of the caisson. Access to the excavating chamber was obtained by an iron cylindrical shaft provided with an air-lock. The ground beneath the caisson was loosened by directing hydraulic jets against it, and the loosened material was lifted by sand pumps through pipes passing up through the ceiling of the air-chamber. The sand pumps were on the ejector principle, by which a stream of water under pressure is forced down through a small pipe, and discharges as an annular jet in an upward direction into a suction pipe through which the sand or other material is drawn by the partial vacuum produced by the jet. The suction pipe can be fitted with a telescopic joint, or else with a flexible connection, so that the end containing the annular jet may be inserted in the material to be lifted. Gravel and stones as large as will enter the annular space may be lifted in this manner.

Timber caissons are useful where they have to be sunk in exposed situations, because they can be erected in convenient places elsewhere, and be afterwards floated into the required positions. A caisson built of materials which do not float can be floated if fitted with a deck, or with buoyancy compartments. If the caisson is not arranged with a deck for working under air pressure, a false bottom can be temporarily fitted, and be removed after the caisson has been floated into place. A caisson may also be suspended from pontoons whilst the floating operations are in progress.

If the caisson is to be erected at the site of the foundation, some sort of temporary staging is necessary to erect it upon, and to accommodate the machinery and other appliances used in sinking it. When the water is not too deep, the staging can be supported on timber piles, but in great depths a floating staging is usually employed. The latter, however, is objectionable owing to the constant changes both in the lateral and vertical positions of the staging.

An ingenious combination of floating and fixed staging was adopted in sinking the foundations for the piers of the new Tay Bridge, as indicated in *Fig.* 15. Several pontoons were braced together so as to form a platform, with two open spaces, or well-holes, to receive the pair of cylinders forming the pier. At each corner of the platform was a column, or leg, which could be moved up or down by hydraulic apparatus. The bases of the legs were splayed out so as to get a good hold on the silt and sand composing the bed of the Tay. The platform was floated into position with the legs lifted high enough to clear the ground. The legs were then lowered to the bottom, and at about high water the platform was secured to them by cotters, or pins. When the tide fell, the platform remained supported on the legs, and by means of hydraulic jacks was lifted to a convenient height above high water. The foundation cylinders were each 23 feet in diameter, of wrought iron lined with brickwork. They were bolted together in the well-holes, and were kept suspended from the platform until a sufficient number of lengths to reach the ground had been added, when they were lowered gradually by hydraulic jacks. The excavation inside the cylinders was taken out chiefly by machine grabs or dredgers; but where silty sand occurred, it was pumped up through 6-inch flexible hoses manipulated by divers. The concrete filling was lowered through the water in boxes with hinged bottoms. On the completion of a pier it was a quick and simple operation to set the platform afloat, and remove it, with its legs, to the next pier.

When large caissons have to be sunk in deep water or in exposed situations, it is generally less expensive to make them buoyant and to float them into position than to provide staging and lowering appliances for building them *in situ*. The method of sinking the caissons for the piers of the Hooghly "Jubilee" Bridge—the abutments of which have already been described—is a case in point. These caissons had to be pitched in 30 feet of water at low tide, and sunk through about 60 feet of silt before they reached a clay foundation. The caisson for each of the main piers was 66 feet long, with semi-circular ends, 25 feet wide, and 108 feet high. It had an outer skin of wrought iron, and was divided into three excavating wells by inner plating extending from top to bottom. Except for the rounded ends and the iron plating extending all the way up, the caisson was generally similar to the abutment caisson of the same bridge shown in *Fig.* 11. The spaces between the outer plating and the excavating wells served first as buoyancy chambers, but were ultimately filled in with concrete and brickwork. The caisson was built for a height of 16 feet above the cutting edge in a sheltered position, and was then floated out to the site of the pier. The plant for excavating and building was contained on pontoons moored alongside. The lower portions of the buoyancy chambers were filled with concrete, and 4-foot lengths of the caisson were added and backed with brickwork until the cutting-edge reached the bottom. The excavation was performed by specially constructed boring appliances, consisting of a hollow vertical shaft rotated by steam power, having radial cutters fixed to the lower end, which made holes in the ground from 10 to $14\frac{1}{2}$ feet in diameter. The excavated material was forced up the hollow shaft, and out into the river, by a hydraulic ejector. Whilst working in the silt the borings were made 10 feet in diameter, and they were usually kept about 10 feet in advance of the cutting-edge. The ground between the borings and the cutting-edge was forced into the bore-holes by the weight of the caisson, which was constantly increased as the sinking proceeded by filling up the buoyancy chambers with concrete. When clay was reached, the boring had to be enlarged to $14\frac{1}{2}$ feet before the caisson could be forced down. After entering a few feet into the clay, the water was partly pumped out of the caisson, and the loss of flotation thus effected enabled the cutting-edge to sink to a depth of 10 or 12 feet into the solid clay. The water pressure would probably have caused a "blow" if the caisson had been pumped out entirely, so the wells were concreted under water, as in the case of the abutments of the same bridge already described.

When the area of a foundation is very large, it is sometimes cheaper and safer to sink a number of comparatively small caissons rather than a single large one. *Figs.* 16 to 21 show how the two piers of the Tower Bridge were constructed. Here the base of the foundation measured 100 feet wide by 204 feet 6 inches long. The bed of the river was gravel for a foot or two from the surface, with London clay beneath. Parliament forbade the driving of a cofferdam into the bed of the Thames, so that the investigations of the engineer were narrowed down to a decision upon the best type of caisson to adopt. It was found cheapest to place comparatively small caissons at intervals around the middle portion of the pier, as shown in *Fig.* 16, to connect their adjoining ends together, to build the outer portion of the pier within them, and to utilize the permanent work thus built as a cofferdam for executing the middle portion of the pier.

Temporary staging was driven around and in the middle of the pier. The caissons were put together on platforms laid across from one staging to the other, as shown in *Fig.* 17. There were four caissons 28 feet square on each side of the pier, and two 35-foot triangular caissons at each end, making twelve caissons altogether. They were all spaced 2 feet 6 inches apart. The caissons consisted of a single skin of wrought iron, $\frac{1}{2}$ inch thick at the bottom, diminishing to $\frac{1}{4}$ inch at the top. The skin was strutted with timber frames from $3\frac{1}{2}$ to 4 feet apart, as shown in *Figs.* 16 and 17. The cutting edge was supported at intervals of 3 feet by iron joists placed vertically at the back of the two lowest timber frames. Four $2\frac{1}{4}$-inch lowering rods with long screws at their upper ends were attached near the corners and suspended the caisson from overhead beams, as shown in *Fig.* 17. The rods were in lengths of 8 feet, with eyes at each end, connected together by link-plates and pins. When the rods were in position, the screws were set up and the platform removed from beneath the caisson, which was then lowered by the screws until there was room to add another length to it beneath the beams. The lengths were from 10 to 12 feet high, and were jointed with indiarubber, as shown in *Fig.* 4. In fleeting the lowering rods, the weight of the caisson was taken temporarily by chains and hooks, which clipped the rods beneath the connecting link-plates. On reaching the bed of the river the ground was removed from the middle of the caisson by machine grabs, and divers worked the stuff from the edges towards the hole made by the grabs. Cast-iron blocks were stacked on the timber frames to weight the caisson down. A sluice was provided in one side of the caisson, so as to let the water in and out with the rise and fall of the tide. When the cutting-edge had reached 5 or 6 feet into the clay, the sluice was closed at about half ebb, the caisson was pumped out, and the remainder of the excavation performed by navvies digging in the dry. The tide was admitted again at about half flood, but was excluded altogether when the cutting-edge had penetrated about 12 feet into the clay. In order to spread the foundation, the clay was undercut to the extent of 5 feet beyond and 7 feet below the bottom of the caisson, as shown in *Fig.* 17. The sloping face of the undercutting was timbered with two settings of poling-boards strutted against the ground. This part of the digging had to be executed, and the timbering put in, very rapidly, so as to prevent the clay from falling in, and for this reason the undercutting of each caisson was taken out in three or four bays, one after the other, as shown in plan on *Fig.* 19. Each bay was concreted up before commencing the next. The lowering rods and beams were not removed until the concrete had been brought up a foot above the cutting-edge all round. The rods were very useful in controlling the descent of the caisson; for, by allowing one side or one corner to take the lead, the caisson was worked over bodily towards the opposite or highest side or corner, thus bringing it back to its correct position. The timber frames were removed one by one after the concrete had been filled up to the underside of each.

When the concrete of two adjoining caissons had been brought nearly up to the level of the river bed, the piles shown in *Fig.* 16 were driven for the purpose of excluding the water from the space between the caissons; but before this could be done it was necessary to insert additional struts (shaded dark in *Fig.* 16) to take the place of the diagonal struts which would cease to do their work as soon as the water pressure was removed from one end, whilst still remaining upon the other end. The ground between the caissons was dug out, and the space filled in with concrete up to the level of the concrete inside the caissons. The adjoining sides of the caissons were jointed close to the piles, as shown in *Fig.* 18. By removing the adjoining sides, two caissons were converted into one, and the brickwork and masonry of the pier were built through from one to the other. By repeating the process, the twelve caissons composing each pier were eventually all connected together, and the outer portion of the pier built so as to encircle the middle portion (see *Fig.* 16). By means of a sluice, the tide was permitted to ebb and flow within the middle portion until the encircling wall had been completed. The sluice was then closed, and the middle portion pumped out and excavated in the dry. The backs of the caissons were then taken away, and the concrete and brickwork filled in. In order thoroughly to incorporate the whole of the work, the various portions of the concrete were dovetailed together, and the brickwork throughout was racked back where possible, and indented wherever it was necessary to leave the faces vertical. The finished pier, or rather the lower part of it, is shown in *Figs.* 19, 20, and 21.

The Tower Bridge arrangement of caissons is equally applicable to the quay wall of a dock or the side walls of a lock entrance. In the latter case the side walls would be each constructed inside a row of caissons, and the invert would correspond with the middle portion of the pier described above. Caissons on this principle have been recently sunk at the new entrance locks of the Tyne and Middlesbrough Docks.

Pneumatic caissons were used for the main piers of the Forth Bridge. The four caissons at the South Queensferry Pier were sunk from 33 to 49 feet through silt and boulder clay until they reached their finished depths at from 71 to 89 feet below high water level. The two caissons at the Inchgarvie Pier were founded on rock, which they touched at 51 and 64 feet respectively below high water; but the rock was so steep that in order to get into it on the downhill side of the slope the caissons had to be sunk to depths of 64 and 72 feet below high water.

The lower portion of each caisson (see *Fig.* 22) was 70 feet in diameter, and in varying heights to suit the levels of the foundations. The upper portion, 24 feet high, diminished to a diameter of 60 feet at the top. Above this was a temporary caisson, 62 feet in diameter and 30 feet high, bolted on to the lower or permanent caisson. The latter consisted of a double skin of wrought-iron plate stiffened between with latticework. Within the inner skin, and at a height of 7 feet above the cutting-edge, was an air-tight deck of wrought-iron plate supported from above by iron girders. Three wrought-iron shafts, 3 feet 6 inches diameter, extended upwards from the deck, each fitted with an air-lock at the top. One lock was for the workmen, and the two others for removing the excavation and lowering the concrete.

The caissons were built on launching-ways in the first instance, and were afterwards floated out to the site. Cement concrete was filled between the outer and inner skins, and above the deck, in quantities sufficient to sink the caissons as required. Air-compressing engines were connected by pipes and flexible hose with the top of the workmen's shaft, down which the air was forced into the working chamber. The chamber was lighted by electricity; no less than 5 or 6 lights of 2,000 candle-power each being required.

The method of removing the mud and silt from the Queensferry caissons was as follows:—A sump was formed in the ground at the bottom of the air-shaft, into which water from an overhead tank was allowed to flow through a pipe regulated with a valve in any quantity desired. A discharge pipe, fitted with a valve and with a flexible hose at the bottom, communicated with the outside air. The flexible hose was manipulated by a man standing in the sump, who held it partly immersed in the diluted mud and silt. The compressed air in rushing through the discharge pipe carried the mud and silt with it, and discharged them outside the caisson above the level of the tide. This method was only applicable to the upper layers of soft material. When the boulder clay was reached it proved so hard that ordinary digging had but little effect, and machine spades worked by hydraulic rams and butted against the ceiling of the working chamber were specially constructed for excavating it.

In order to give the Inchgarvie caissons a level bearing upon the sloping surface of the rock, a series of supports for the cutting-edge were made by heaping up bags of sand and concrete wherever the surface was below the highest part (see *Fig.* 22). The rock beneath the caisson, and for a foot or so beyond it, was drilled, at first by ordinary hand jumpers, but afterwards rock drills driven by compressed air were used. The holes were charged with explosives which were fired by electricity after the men had withdrawn from the working chamber. The rock was also quarried wherever possible with crowbars and sledge hammers in the ordinary way.

The concrete was mixed on top and lowered through 18-inch tubes to the bottom of the caisson, whence it was shifted into place by hand, and gradually brought up until the working chamber was completely filled and packed tightly against the ceiling. The shafts and upper portions of the caissons were also filled in with concrete.

Instead of caissons, a diving-bell is sometimes used where the depth of the excavation is small, or where the ground does not require support. In such a case the excavation is commenced at the highest point, and gradually worked downwards until the edge of the diving-bell obtains a bearing all round upon the solid ground or rock. The concrete or masonry is then built up in layers—the diving-bell being raised as the work proceeds. Such a system is not expedient in the case of very large foundations, because either the diving-bell must be so large as to become unwieldy, or else it must be shifted about horizontally so as to cover the foundation bit by bit, thus entailing much trouble in bonding the bits together.

In conclusion, it may be stated that the foregoing examples are a few only of the many methods which have been and may be adopted in constructing subaqueous foundations. The subject has not been exhaustively treated—in fact, almost every case presents features peculiar to itself—but it is hoped that, so far as they go, the examples given may prove of some value.

PAPER VII.

BRIDGES ON BRANCH RAILWAYS.

A Lecture delivered by M. A. POLLARD-URQUHART, M. INST. C.E., 1*st February*, 1900.

IN the early days of railways bridges were not considered so necessary as they are now, level crossings being of frequent occurrence even on main lines, but now, owing to the increase of traffic, both on the railways and on the roads, bridges are required for general safety. In the case of light railways, where the speed is limited and the traffic small, bridges are less required, but for ordinary branch lines, worked at the usual rate of speed, bridges have to be provided for the public roads, and also in many cases for farm roads.

The average number of bridges to the mile on an ordinary branch line is about three, and it is, therefore, evident that by studying the cheapest effective style of bridge for the locality a considerable saving in first cost may be effected.

Three classes of bridges are met with :—

(1). Those carrying public roads across the railway.

(2). Those carrying accommodation roads across the railway; and

(3). Those carrying the railway across streams or watercourses.

1.—Public Road Bridges over the Railway.

Figs. 1 and 2 show a usual style for bridges of this description. *Fig.* 1 has box wings, that is, wing walls carried back at right angles to the face of the abutment, whilst in *Fig.* 2 the wing walls are splayed. The box wings are to be seen on a considerable number of public road bridges, and they certainly have the advantage of looking neat, and of being easy to design and build, but in point of cost they do not compare favourably with the splayed wings shown on *Fig.* 2. By designing the wings to end at a point where the slope of the road approach catches the slope of the railway cutting, the length and height of the wings are much reduced, and a structure of equal stability is securéd at a lower cost. The saving in masonry by using the type shown in *Fig.* 2 amounts to 43 cubic yards, which at 18s. per cubic yard amounts to over £38. There is, further, a saving in the length of the parapet of about 100 feet, or over 23 cubic yards, which at £2 represents £46, or a total saving in favour of design 2 of £84.

It is often the custom to use girders, with jack arches or patent trough flooring for carrying the road over the line, instead of an arch, but, except where the crossing is much on the skew, it is in most cases found to be much cheaper to use an arch.

Figs. 3 and 4 show comparative designs. The arch is constructed of 4 rings of brickwork, and has 4 feet of rise; the girders are 1 foot 6 inches deep, and the dead load of about 45 tons is distributed between them. Taking the price of the masonry at 18s. per cubic yard, the brick arches at 22s. per cubic yard, and the girders at £16 per ton, the cost of the arch design works out at £524, and of the girder design at £667, showing a saving of £143 in favour of the arch. In places where building labour and materials are scarce, saving of time in erecting the girders may occasionally counterbalance their extra cost.

In the case of double line bridges the saving is less, owing to the greater rise of the arch in the middle between the two lines of way necessitating a longer road approach.

The extra rise of the arch does not materially increase the building quantities, but in the case of a long road approach every foot of height increases the quantities of the bank and road metalling. As an instance of this, attention is drawn to *Fig.* 5, which] shows a double line bridge over the Forfar and Brechin Railway at Careston Station. The height of the road embankment is about 18 feet, necessitating at a gradient of 1 in 20 a length of approach of 360 feet on each side. The arch, as shown on dotted lines, requires 2 feet more of height, thus increasing the length of the approach by 40 feet on each side, the earthwork by over 2,000 cubic yards, and the road metalling by over 200 superficial yards, the extra cost coming to over £100.

A neat design for carrying a public road over a railway in deep cutting consists in building an arch on each side of the main arch, thus reducing the masonry in the wing walls. *Fig.* 6 shows an example of this. It was built on the East Fife Central Railway in a cutting 19 feet deep. At this depth the cost of the side arches about balanced the saving in the wing walls, but with a greater height of bridge the saving becomes more marked.

2.—Public Road Bridges under the Railway.

The span of these bridges usually varies from 20 to 35 feet on the square, and the general practice is to use girders to carry the railway. The reason for this is that no two roads come exactly the same width, or the same angle of skew, and girders are easier to proportion to these varying conditions. The style of superstructure most often used for single lines consists of two steel girders with cross girders resting on the lower flanges of the main girders, and the flooring consists of either buckled plates or 4-inch creosoted planking. The cost of such a bridge for a single line and over a 25-foot road works out at £487; and *Fig.* 7 shows a sketch of a bridge of this type, erected on the East Fife Central Railway. The span is 25 feet, the thickness of the abutment from 6 to 4 feet, and the weight of the steelwork 12 tons. The dead load is 36 tons, and the live load $61\frac{1}{2}$ tons, being at the rate of $2\frac{1}{2}$ tons per foot run. These weights give a stress in the centre of 60 tons on the flanges, and the girders are designed to carry this.

It frequently happens that it is a matter of importance to keep the distance between rail level and the surface of the road under the bridge as small as possible, so as to save excavation of the roadway; and to accomplish this various forms of steel flooring have been introduced in practice. Lindsay's troughing, and others of that description, are equivalent to increasing the number of cross girders until they almost touch; and by spreading the weight over several cross girders or troughs diminishing the strain on each one, and thus permitting them to be made shallower. In the bridge shown in *Fig.* 7 the distance from rail level to the underside of the main girders is 3 feet; but by using troughing, and by carrying the rail on a 7-inch running beam resting direct on the flooring, this distance can be reduced to 2 feet, and, if necessary, sleepers can be placed in trough. Comparing the superstructure of the bridge shown in *Fig.* 7, having a floor of cross girders and buckled plates, with the superstructure of a bridge having a floor of troughing, there is a saving of 14 cwt. in favour of the former. The saving in point of cost is not large; but in the case of ordinary cross girders and buckled plates the delays in delivery are got over, and it has always been found that troughing, especially in the case of skew bridges, is more difficult to erect.

3.—Bridges for Occupation Roads.

In the case of a farm road over a railway the style of bridge, of course, depends to a large extent on the acreage, the produce of which has to be led over it. The width of the roadway is generally from 12 feet to 15 feet, and the gradient of the approaches from 1 in 12 to 1 in 16.

A serviceable type of bridge over a single line of railway, and which will carry any weight that is likely to be taken over it, is shown in *Fig.* 8. The superstructure consists of steel joists 10 inches by 5 inches, with 4-inch creosoted planking, or concrete jack arches for the flooring. A thin layer of asphalte is spread on the planking, and the road metal is thus provided with a good foundation, and will not injure the timber. The cost of such a bridge, with splayed wing walls, timber floor, and wrought-iron parapet carried by the two outside joists, works out at £287. If concrete is used in the form of jack arches between the joists the cost would be slightly increased, owing to heavier joists being required to carry the extra weight. The difference in cost is not large if materials for concrete can easily be procured.

It is often the case, when an occupation bridge is not situated on the main haulage road to a farm, that the produce of a comparatively small acreage only has to be taken over it. In such a case as this a bridge built entirely of timber, as shown in *Fig.* 9, answers the purpose and effects a considerable saving, the cost of such a structure being only £198. Bridges of this type are only designed to carry light loads, such as ordinary farm carts and reaping machines, and are not meant to carry traction engines. If the timber is of good quality, and is kept well tarred, it will be many years before any renewals are required.

In carrying the railway over a farm road, if the road has to be lowered, it is a usual practice to use trough girders in order to save headway, these girders having to be very shallow, in order to clear the moving parts of the locomotive, and also to enable the platelayers to drive the chair spikes, and, therefore, only suitable for small spans, such as are met with in occupation bridges. *Fig.* 10 represents a bridge of this class recently erected on the East Fife Central Railway. It will be noticed that the rail level is only 1 foot 2 inches above the bottom of the girder, and in this particular case it enabled the necessary headway to be given without disturbing a large covered drain, which the line crossed at that point. These girders are proportioned to carry a rolling load of $3\frac{1}{2}$ tons per foot run, and weigh about 21 cwt. each. The cost of this bridge works out at £291.

4.—Bridges over Streams and Watercourses.

It is now proposed to give examples of the most suitable structures for carrying the railway over watercourses. *Fig.* 11 shows a viaduct consisting of 6 openings of 50 feet clear span, the distance between the centres of the piers being 55 feet, and the extreme height above the bed of the stream 60 feet. The abutments were constructed entirely of 7 to 1 concrete, and as owing to the shortness of the wings they would be, to a large extent, covered by the earthwork of the embankment, no special material was used for the facing. The piers were constructed with a brick face and concrete hearting. *Fig.* 12 gives a section of the girders and flooring, showing the method of construction; the brickwork casing consists of 18-inch and 9-inch work alternating, each thickness consisting of 9 courses. When 18 courses had been built, concrete was filled in, a reasonable time being allowed for the brickwork to set.

A 9-inch brick wall was built up the centre of the piers as the work progressed, which served to tie the side walls of the casing together. This method of construction has been most successful, no movement of any sort having taken place.

The stone and gravel for the concrete was got on the ground close by, and the bricks from works not far distant.

The superstructure consisted of lattice main girders placed 8 feet apart, with cross girders of ordinary $10'' \times 5''$ rolled iron joists, weighing 40 lbs. per foot run, on the top flange; the weight of each of the main girders was about 8 tons. The flooring consisted of 4-inch planking laid on the cross girders, and the rails were carried by longitudinal running beams 14 inches wide by 12 inches deep. In preparing the drawing for this viaduct, a design consisting of arches instead of girders was considered, but it was found the cost of the centres would be considerable, and owing to the low price of iron at that date, 1889, it was found better to use girders. This viaduct was erected over the River Eye, in Berwickshire, and cost £3,700, or rather less than £12 per foot run.

Fig. 13 shows a viaduct of 4 spans of 40 feet, at present in course of erection on the Gifford Light Railway in Haddingtonshire. In this case arches were found to be more economical than girders, owing to stone of good quality being procurable in the neighbourhood. The arches consist of 6 rings of brickwork built in cement, resting on springers of ashlar 2 feet 7 inches thick and 12 inches deep. The foundations are of 6 to 1 cement concrete, made from gravel taken from the bed of the stream. The height to rail level above the bed of the stream is 50 feet, and the length over all 194 feet.

The following are the quantities :—

Excavation	cub. yds.	526
Concrete in foundations	,,	359
Masonry in abutments, wings, and haunches	,,	680
Masonry in piers	,,	236
Brickwork in arches	,,	376
Masonry in parapets	,,	15
Ashlar in springers and cope...	cub. ft.	1463
Face work	sup. yds.	660

The cost of the viaduct when completed will be about £2,043. The total length is 194 feet, giving a cost per foot run of a little over £11.

An alternative design for this bridge (*Fig.* 16) was prepared, consisting of four openings of 40 feet clear width spanned by steel girders. Taking the same rate of prices as in the arch design, the cost works out to about £2,412, or over £12 per lineal foot, thus showing a considerable saving in favour of the first design. It will be noticed that in both cases the wing walls were kept as short as possible, the earthwork slope being arranged to nearly cover the high abutment.

Fig. 17 shows an elevation of the Tyne water bridge, at present being constructed on the Gifford Light Railway. It consists of three spans of 20 feet each. The River Tyne flows through the centre opening, the two side openings being made to give access to the intersected portion of the fields, and also to act as flood arches if necessary.

The abutments and wings are of snecked rubble, and the arches consist of five rings of brickwork. The wings are kept short so as to allow the toe of the earthwork slope to fall in front of the abutment to within 12 feet of the side of the pier, this being the width of roadway necessary for farmers' carts.

There were two alternative designs prepared for this bridge. *Fig.* 19 shows one with three spans crossed by girders instead of arches, and *Fig.* 21 a design for one span only, this latter being prepared with a view to avoiding the sinking of the foundations close to the river. The cost of the first of these designs works out to £1,006 ; of the second to £1,149, and of the third £1,400. The saving in favour of the arch is very marked, and as the piers and abutments are founded on strong clay, no serious settlement is likely to take place.

From the various examples given it will be seen that no two bridges are exactly alike, although as much as possible certain types have been adhered to. Every structure has to be designed to suit the locality, both for the class of materials available, and the class of labour to be got in the district. In some cases bridges have to be built in such a manner that when the line comes to be doubled only the superstructure has to be raised ; the method of doing this consists in sloping off parts of the abutment on the double line side to the line of the single railway earthwork embankment, the wing wall being constructed to stop at the foot of the single line slope. The foundations only for the wing walls are put in for the whole length.

In preparing designs for railway bridges, especially if stone is to be used, corners should be avoided as much as possible, and pilasters, except on the parapets, should be omitted, as people when they are travelling do not notice ornamental details.

In conclusion, the thanks of the lecturer are due to Mr. R. S. Cole, M.A., who prepared the slides, and assisted in the preparation of the lecture.

PAPER VIII.

ENGINEERS AND THEIR DUTIES.

FROM THE RUSSIAN, BY MAJOR J. E. EDMONDS, R.E.

NOTE.

THE title given to this paper by its author was "The Co-operation of Engineers and Infantry in War and in Peace Manœuvres." This appeared to be misleading, as only a small portion of it is devoted to combined work. The article may perhaps be assumed to be a lecture on Engineers for the information of the other branches of the service, just as Prince Kraft's *Letters on Artillery* were designed to diffuse a knowledge of the artillery arm.

CONTENTS.

Introduction.

General Organization of Field Engineer Troops in Peace and War.—In accordance with the *Regulations Concerning the Duties and Organization of the Field Engineer Troops*, published in "General Orders," in the *Military Bulletin*, No. 200, of 1894, the active engineer battalions are formed in time of peace into seven engineer brigades. On notification of the mobilization of the army, one battalion is assigned to each of the army corps, its commander, while continuing to carry out his regimental duties, performing also the work of corps engineer. In time of peace the engineer battalions are attached for two or three weeks annually to their corresponding army corps at the season of field operations or manœuvres.

The separation of the engineers from their army corps in time of peace, and their subordination to the independent commanders of the engineer brigades, was ordered with the object of introducing a more rigid system and more uniformity in the execution of the special work of engineer troops, which in this relation receive orders from and are controlled by the Engineer Committee of the Central Engineer Bureau.

In 1889 the nomination of the Inspector of Field Engineer Troops as a member of the Engineer Committee strengthened the real control and management of the instruction of the engineers in special work, and quickly led to the best results. At the present time the field engineer troops exhibit excellent technical capabilities, and will, it is to be hoped, show themselves of the greatest value in war.

The object of the present article is to make clear what is the *rôle* of the engineers attached to army corps, and the reciprocal assistance which the engineers and infantry ought to give each other.

The Most Important Duty of Engineers in Conjunction with Infantry—the Strengthening of a Position.—Amongst the numerous operations which the engineers may be called upon to execute in conjunction with infantry by far the most important is the strengthening of a position. The full explanation of the *rôle* of the engineers in this relation is the more necessary, as at present the strengthening of positions in the field is receiving exceptional attention.

The Importance of Entrenching on the Defensive.—The range and penetration of the small calibre magazine rifle and the high-explosive shells of the field artillery compel every unit which is forced by circumstances to remain on the defensive, instead of attacking, to entrench itself directly it arrives on a position, or, as it is said, to bury its fighting line in the ground. In this eventuality the party on the defensive, while lying hidden and having full power to direct a fire on the enemy advancing over the open, will be exposed to comparatively slight losses. If it neglects to entrench, it will suffer considerably to no purpose.

One of the Stages of the Attack.—If the time at the disposal of the defender enables him to construct not only trenches but fighting pivots, he strengthens considerably his chances of a complete success in the coming struggle; success, as we think, not only in the mere beating off of the attack, but in the thought of the pursuit of the enemy (when he shall have exhausted his strength on the position), and therefore his complete annihilation. In a word, under modern conditions the defensive must be regarded as one of the stages in the preparation of the attack by a numerically weaker side; and we add that this stage is most certain of success if the position has been properly prepared for defence.

Regimental Commanders Responsible for Hasty Defences. — In accordance with *Regulations for the Execution of Field Entrenchments*, 1891, the regimental leaders are responsible for the arrangement of the work in the hasty strengthening of a field position. This direction corresponds to the conditions (the large number of infantry and small proportion of engineers), and is thoroughly reasonable and right.

Organization Permits of an Engineer Company being Assigned to Each Infantry Division.—However, in the new organization of the field engineer troops each army corps receives a sapper battalion; a company can therefore be assigned to each infantry division. It is evident that the sappers, as specialists, will inevitably be called upon to assist in the strengthening of positions prepared by the infantry. In this relation sappers will be of the greatest use, if only they are properly made use of—the officers to reconnoitre and prepare schemes for the fortification of the position; the rank and file to instruct the infantry in the completion of the work, and in the construction and preparation for defence of pivots.

Troop Leaders should Accustom Themselves to make Use of Engineers.—It is, therefore, of the highest importance that troop leaders should accustom themselves in peace time to make proper use of the sappers in work undertaken in common with the infantry, so that in war many mistakes and muddles arising from want of knowledge may be avoided.

Troops must Entrench whenever they Halt for the Night.—It should also be laid down that every body of infantry must instinctively be accustomed to entrench its fighting line directly it takes up a position, that is, directly a march is over a position must be taken up, reconnaissances carried out, entrenchments made, and only after these precautions may the troops turn their attention to preparing their bivouac.

CHAPTER I.

The Duties of Engineers.—The Organization and Duties of the Sapper and Field Telegraph Companies of the Engineer Battalion.—Two Kinds of Work Carried Out by the Sappers Attached to Infantry Detachments.—The Orders Issued in the Warsaw District on the Combined Work of Sappers and Infantry.—The Necessity of Assigning Riding Horses to the Captains of Sapper Companies at Manœuvres.—The Necessity of Granting Money for Carrying Out Engineer Work at Manœuvres.—The Rights and Responsibilities of the Corps Engineer of an Army Corps not Operating Alone.—The Necessity for Agreement Between the Portions of the *Regulations for the Administration of an Army in the Field*, which affect the Corps Engineer, with the *Regulations for the Organization and Duties of Field Engineer Troops.*

Duties of Field Engineer Units as Laid Down.—The duties of the field engineer units are laid down in Section 3 of the *Regulations for the Organization and Duties of the Field Engineer Troops.* According to this section they are as follows:—(*a*). Fortification of positions. (*b*). Attack and defence of fortresses. (*c*). The construction of ordinary roads and the repair of railroads. (*d*). The construction of passages across every kind of obstacle, both with special equipment and with extemporized materials. (*e*). The diversion and destruction of railroads and other engineering works. (*f*). Demolitions. (*g*). The construction and maintenance of the field telegraph between the headquarters of the corps and divisions, and between detachments inside the divisions.

Composition of a Sapper Battalion and of Its Companies.—The normal composition of a sapper battalion, according to the regulations, is three sapper and one field telegraph companies. On mobilization a detachment of the field engineer park is attached to it. This carries engineer stores corresponding to the requirements of two infantry divisions, one cavalry division, and one sapper battalion. The first two companies have, in addition to the entrenching tools and demolition equipment, a light bridge train, by means of which a bridge 70 feet in length can be constructed. The bridge equipment of each company is carried on six three-horse carriages of a special pattern.

The Field Telegraph Company.—The field telegraph company of each battalion consists of two air-line and one cable sections. Each air-line section carries sufficient material to lay out a line 15 miles long. The cable section carries material for a line 21 miles long. Consequently the company can lay a line 51 miles long. Besides this, each of the three sections of the telegraph company carries equipment for two heliograph stations, so that the company can post six optical telegraph stations. Occasionally these stations are, with advantage, united under a separate "heliograph" command, as was done in the Warsaw manœuvres.

On arrival of its army corps in the theatre of war, the field telegraph company, as having strictly defined technical duties, is taken from the sapper battalion and divided into three sections, as above described, to maintain communication between the various headquarters.

The Field Companies.—The two first companies (with light bridge trains) take their places in the infantry divisions of their army corps, but the third remains, as a rule, with the staff of the corps, and is the only company of the sapper battalion which is left under the immediate control of its battalion commander (he is the corps engineer). The commanders of the companies attached to the infantry divisions naturally perform the duties of divisional engineers.

Division of Engineer Work.—We have already given a summary of the work required of the engineers; it divides itself into two groups:—

1. Exclusively Engineer Work.—*Those operations which are carried out exclusively, or nearly exclusively, by the sappers*—the construction and maintenance of telegraph lines, demolitions, passage of obstacles, field and temporary bridges, construction and repairs of ordinary carriage roads, and repair of railroads.

If it should happen in some of these operations that it is found necessary to call for artizans—carpenters and smiths—or for simple labourers—for constructing and repairing roads—from the infantry, nevertheless the work remains a purely engineer business. Its success, be it small or great, depends entirely on the sappers, or perhaps it would be more correct to say on the degree of training and preparation they have received in peace time, always supposing that the costly material for the work, or the means of immediately obtaining it, are to hand.

2. Work in Combination with Infantry.—*The second group is formed by the operations undertaken by the sappers in combination with whole units of the infantry*, in which the former appear only as guides. To this group belong the strengthening of positions and the attack and defence of fortresses. These operations are more complicated (as far as organization goes, though technically they are easier than Group 1), particularly the first. In the attack and defence of fortresses the *rôle* of the engineers is evidently a prominent one, as there must be trained men who can at once fulfil the demands created by the urgent necessities of a siege.

Causes of Ill-Success of Combined Work.—The complications, and often the ill-successes, of these combined operations at peace manœuvres are due on one side to the ignorance of the infantry commanders as regards the duties of engineers and a disinclination to fatigue their men by making them dig; on the other side, to the inability of the commander of the engineer company to orientate himself quickly under circumstances of which he has had no previous experience, perhaps to a want of courage on his part in insisting on his rights in the organization of combined work when there is a senior infantry officer present, and, finally, sometimes to the physical impossibility of carrying out his duties. For in peace time the commander of an engineer company (except the field telegraph) has no riding horse, and, having to make the march on foot with his men, is not in a condition at the end of it to carry out a reconnaissance of the position and prepare a scheme for fortifying it, as is in the majority of cases necessary.

Necessity for Practice in It.—It is evident, once the difficulty of organizing combined work is recognized, that every opportunity should be given the two arms to obtain experience at manœuvres and on the flying columns. This is done every year, but somehow or other the sapper work has not been of the use which one must and ought to expect from it.

Engineer Work often Mere Pretence.—On the march the sappers are, as a rule, assigned to the advanced guard, so that they may be in a position to repair the roads and bridges which the main body and trains have to traverse. But, as a rule, these repairs are merely fictional, as neither the commander of the advance guard nor the captain of the sapper company are provided with the means of obtaining the materials indispensable for such repairs (baulks, planks, and poles for repair of bridges, faggots for the repair of roads). Nevertheless, the repair of vicinal roads and bridges is very often necessary.

Suppose that a certain sum of money were assigned for this purpose. Even in this case the commander of the engineers would not always be in a position to carry out the indispensable repairs at once. Given the money, the materials themselves may not be on the spot. The search for them, the purchase and carriage to the spot required, demand a longer or shorter interval of time when every moment is of importance.

If there is a column of troops marching up towards the broken bridge in the expectation of finding the passage intact, and there are trees near, there is nothing else for the senior engineer present to do but to have these trees cut down and a bridge made with them.

Materials on Spot cannot be Used in Manœuvres as in War.—It is evident, even in time of peace, that the engineers must, under certain circumstances, decide to make use of the materials on the spot, but certainly in a more restricted manner than would be possible in time of war. To build a bridge in war time houses might have to be pulled down; in peace only trees and brushwood may be utilized. The damage done to private property under the circumstances should be paid for equally with that done by the passage of manœuvring troops.

Place of the Divisional Field Company on the March.—Now suppose that the advance guard marches on after some difficulty, but that one of the guns of the main body or a wagon of the trains breaks down a bridge. It must be repaired at once, but there is no one to do it, the sappers are with the advance guard. It is clear that the custom observed on flying columns of sending the whole sapper company with the advance guard is not a rational one. In carrying out marches it should be divided between the advance guard (half a company), main body (a section), and trains (a section).

Misuse of Engineers in Flying Columns.—As regards the utilization of sappers in combined work with the infantry, especially during the flying column season (when the bodies employed are less than a division), the state of things has, latterly, got worse and worse. The sappers are either forgotten, or employed to take the place in the ranks of a battalion of absent infantry companies, or, at the very best, when the general wishes to avoid the reproach of not understanding how to make use of engineers, the sappers are employed in digging shelter trenches and gun-pits on the selected position, although this is not their business, but that of the infantry. The general impression of the engineers gathered from work with the flying columns is that their presence forms a source of unnecessary embarrassment for the general, particularly in the solution of the question what to do with them.

Yet the regulations on the subject explain in a sufficiently detailed manner what the *rôle* of sappers attached to infantry should be. The instructions are given in the appendix of *Instructions for Field Service of Detachments of All Arms*, 1882.

Order on Combined Work in the Warsaw District.—The present commander of the Warsaw District, General-Adjutant Count Shuvalof, recognizing the normal state of things in the district entrusted to him when engineers and infantry had to work together, in Local General Orders, No. 70, of 9th June, 1895, gave directions for this combined work on mobile columns, manœuvres, and in war. This order, in the interest of the question under discussion, deserves to be quoted here in full :—

"General Order, No. 200, of 1894, published in the *Military Bulletin*, laid down the new organization of the field engineers. Among other things it had the object of bringing the engineers into closer contact with the other arms, and of giving them their due place in the attainment of the general object, the defeat of the enemy.

"In peace time, therefore, in operations undertaken in conjunction with other arms, it is indispensable for the development of the intention of the above quoted General Order to endeavour to lay down some sort of uniform system as to the work required of the engineers, so as to assure a regular and useful application of this far from numerically strong branch of the service.

"Up to the present, however, as far as can be discovered, during the mobile column season and manœuvres, a false direction has been given to activity of the engineers; either the sappers carried out work which, according to regulation, should have been done by the other arms, or they were used as simple infantry companies, or, finally, they were forgotten, and the sappers took part in the operations without being of the slightest use to themselves or to the rest of the troops.

"I, therefore, feel it necessary to point out to the commandants of detachments to which engineers are assigned at the time of mobile columns and manœuvres that they should be guided by para. 23 of *Instructions for Field Service of Detachments of All Arms*, 1882, and the *Regulations for the Employment of Engineers Attached to Detachments on Field Service*, which are annexed to them, from which the following may be quoted :—

(*a*). "*Duties of Senior Engineer.*—The senior engineer will take part in the reconnaissances of a position, and will be responsible for a report on the measures necessary for the attack or defence, as well as for drafting the orders for the engineers.

(*b*). "He will advise as to the construction of tactical pivots in the position, and take an executive share in the work carried out by the various arms in conjunction for completion and improvement of them.

(*c*). "He will advise on, and take an executive share in, the preparation of localities occupied with a defensive object (detached buildings, villages, woods) when this, under peace conditions, is possible.

(*d*). "He will carry out the construction of obstacles for the strengthening of tactical pivots and localities occupied for defensive purposes.

(*e*). "He will carry out the repairs of existing posts and vicinal roads on which the troops move.

(*f*). "He will construct provisional roads.

(*g*). "He will repair existing bridges, and construct new ones over dry ravines and over small streams.

(*h*). "He will make arrangements for the passage over large streams (by rafts, boats, etc.).

(*i*). "He will make preparations for the removal of artificial obstacles in the attack of an enemy's position, and take an executive share in their removal.

"In order that the engineers may be in a position to carry out all the above at minor and grand manœuvres, I direct:—

(*a*). "*Duties of Senior Officer.*—That officers commanding bodies of troops are to utilize the senior engineer with their detachment for the execution of reconnaissances, and are to make known to him their dispositions, orders, and the general distribution of their troops.

(*b*). "*Riding Horses.*—That at minor and grand manœuvres they are to assign riding horses from the cavalry to the commanders of engineer units of their detachments, and to give them mounted orderlies. Otherwise, having made a long march on foot, they will not be in a condition to execute their reconnaissances.

"As regards the provision of the money, indispensable for the purchase of materials, arrangements will be made later on by me."

Funds Provided.—In accordance with the representations of the Staff of the Warsaw District, the Headquarter Engineer Bureau placed a certain sum of money in 1895 and 1896 at the disposal of the divisional generals for the purchase of materials, and for the execution of indispensable engineer work at the manœuvres. The same staff obtained a decision that this money should be allotted annually.

Rights and Duties of the Corps and Divisional Engineers by Regulations.—In considering the combined work of engineers and infantry, it is necessary to examine the rights and duties of the senior engineer (corps engineer; he is also commander of the sapper battalion) and his assistants, the divisional engineers (commanders of the divisional engineer companies).

The rights and duties of the corps engineers of an army corps not operating alone* are defined in *Directions for the Administration of the Army in the Field*, pp. 805—812 (see *Military Bulletin*, No. 62, of 1890). He is made subordinate to the chief staff officer of the corps, and for his assistance makes the necessary calculations in the fortification of a position, for the construction and repair of roads and bridges and other work which can be executed by the men of the corps. He also assists the chief staff officer of the corps in all details referring to engineer work and by his own order directs the execution of work by units of the corps.

Alteration Suggested.—According to our judgment, routine would work better if the corps engineer had the right of personally reporting to the army corps commander, that is, was immediately subordinate to him.

According to the "Directions," the corps engineer has the rights of a regimental commander over the corps engineers, and also over engineers attached to the corps and the divisional engineers, unless they have special instructions. It is evident from the "Directions" that the only engineer troops likely to be attached to a corps, but not under the corps engineer as battalion commander, are the bridging battalions. It is desirable, in the interest of simplicity, that the bridging battalions should also be placed, for all purposes, under the corps engineer, so that all engineer movements can be dealt with in one order. In general, it appears useful to make the paragraphs of the "Directions," which treat of the rights and duties of the corps engineer, agree with *Regulations of the Organization and Duties of Field Engineer Troops*, which were published four years later.

It should also be arranged that all engineer companies not attached

* If the army corps is alone, the senior engineer has the powers of a chief engineer, p. 758.

to a division should be placed under the command of the corps engineer as their battalion commander. This step would have, at any rate, one advantage—that as the corps engineer is on the staff of the army corps and interested in the success of the work of all companies, he has full opportunity of learning of proposed movements of the units of the army corps and of proposed engineer works and he can warn the commanders of the telegraph and sapper companies in good time.

We should strive that the position in which the corps engineer is placed by the *Regulations for the Organization and Duties of Field Engineer Troops* may be entirely favourable for carrying out the duties required of him. Under his command in time of war are officers and N.C.O.'s who have served under him in peace time, on whose training he has expended many years. He knows their characters and capacities, and they know him. And this is one of the chief conditions of success in combined work.

CHAPTER II.

The Leading Principles in the Strengthening of a Position for an Obstinate Defence.—In Occupying a Defensive Position, an Active and not a Passive Defence is to be arranged for.—It is indispensable to secure the fullest scope for Artillery and Rifle Fire.—Sections for Passive and for Active Defence.—The Preparation of the Front for an Obstinate Defence.—The Recognition of Natural and Artificial Tactical Pivots.—Works to Facilitate the Operation of both Fire and Cold Steel.—Sectional Reserves to be Deployed on the Reverse Slopes, and no Shelters to be Constructed for them.—Measures for Strengthening Exposed Flanks.—The Necessity of the Timely Preparation of a Rear Position.—The Speedy and Timely Strengthening of the Main Position.—The Duties of the Corps and Divisional Engineers in the Fortification of the Position.—The Execution of the Reconnaissance and the Plan for the Fortification of the Position.—Orders for the Engineer Units.

How a Defensive Position should be Occupied.—Before examining the combined work of engineers and infantry in the fortification of a position let us consider how a body of troops should occupy a position taken up for a defensive battle.

Main Principles.—In the fortification of a position the following main principles should be borne in mind :—

1. Active and Passive Sections.—Every body of troops deploying on a position for action must, with very rare exceptions,

be prepared for an active, not a passive, defence, that is, for moving forward to the attack at every favourable opportunity. The result of this is that every defensive position must be divided into sections, some for active and some for passive defence.

As a matter of fact, the attacker does not carry out a serious attack on every part of the position, but only on some portions of it; against the remainder he demonstrates. *A defensive position, therefore, need not be occupied throughout with the same uniform strength.* The parts on which it seems most probable that the enemy will make his greatest efforts must be occupied in force (section of active defence); the parts which are less important, and which present stronger natural obstacles to the attack, may be held more weakly (section of passive defence). *By the comparative weakness of the troops in the passive sections must by no means be understood a less density of troops in the fighting line, but only a less strength in the sectional reserves.*

Thus, on these sections, from a battalion of four companies, not two but three may be put in the fighting line; from a regiment of four battalions, not two but three battalions. The intenseness of rifle fire in the passive sections will, therefore, be greater than in the active sections, so that—

(*a*). In the latter there will be comparative large intervals between the tactical pivots, field batteries, and shelter trenches, so that there may be no obstacle to the counter-attack of the main reserve placed behind these sections.

(*b*). The defeat of the enemy's attack in the passive section may be accomplished mainly by rifle fire, the possibility of which under present conditions of range and penetration has been proved by military history (Plevna).

2. Full Development of Fire.—In deploying in the defensive position *it is imperative to make full use of the strong side of the defence, that is, to give the greatest possible development to gun and rifle fire.*

This means, with regard to rifle fire, that the company supports at once join the firing line, and that in a battalion of the first line at least two—better still, three—companies are able to use their rifles against the enemy when he attacks.

3. Division of the Work of Defence.—The work in the strengthening of a position falls on the following three groups:—

(*a*). The preparation of the front of the position for an obstinate defence.

(*b*). The removal of any cover from view and from fire available for the enemy.

(*c*). The removal of any obstacle to the free movement in every direction of the reserves.

The works under (*b*) and (*c*), as they facilitate the action both of fire and of cold steel, are not less important than those under (*a*), and it is much to be regretted that they are often forgotten in peace time, for this habit may be most injurious in war.

(*a*). Preparation of an Entrenched Line and Pivots.—*Value of Tactical Pivots.*—The preparation of the front of the position of an obstinate defence includes the construction of trenches for men and guns and the preparation of localities—natural defensive points (woods, villages, detached buildings)—and in their absence or unsuitability, the construction of field redoubts (closed, half closed, or open depending on the conditions). *Natural or artificial tactical pivots are indispensable for giving solidity and resisting power to a defensive position.* They make it possible to strike the enemy in front, flank, and rear; they provide not only cover for the defender, but present an obstacle (steep wedge-shaped ditch, wire entanglement), and should the enemy break through the intervals, they can be held until the reserves come up.

Tactical pivots must be organized both in the active and passive sections of the position. They are naturally indispensable on open flanks, and on the strategic key of the position.

The position of tactical pivots must be chosen so that they give a good field of view and of fire, and command the localities lying in front of the position. The defence of an artificial tactical pivot (field redoubt) is best undertaken by an infantry battalion, as one or two companies can occupy the redoubt, two or one company the trenches on its flanks, while the fourth company forms the exterior reserve.

The position of the tactical pivots and the spaces for the deployment of artillery must be selected at the time of the reconnaissance These points form the skeleton of the position, and the spaces between them are occupied by shelter trenches.

Selection of Position of Shelter Trenches.—The positions of the shelter trenches are chosen by infantry officers, who direct and carry out the work *without any assistance from the engineers.* [N.B.—Russian regulations do not favour the pushing out of infantry in front of the artillery. If it is necessary to protect the front of the guns, the artillery are withdrawn 600 to 800 paces behind the main line of pivots and trenches. The occupation of advance posts is considered unfavourable to counter-attack.]

Gun-Pits.—As regards the construction of gun-pits and epaulments, things are somewhat different. According to para. 26 of *Instructions for Intrenching*, 1891, "the positions of the guns are selected by the artillery officers. Each gun-pit requires 12 men with large shovels. *If the number of artillerymen available is insufficient* it is to be made up by the infantry."

In each field battery of eight guns eight pits are required. According to the above instructions these require 96 diggers, with the same number of large shovels; but each field battery only carries 32 large shovels!

Infantry must Assist in Construction.—It is, therefore, evident that the men of a battery are unable, with the means at their disposal, to construct gun-pits at all rapidly, and that each battery will require, in addition to its own 32 men, a working party of 64 infantrymen with large shovels. If the latter have only small shovels, then the number must be doubled, and it is better to do the work in two reliefs. As the gunners have also to construct shelters for their limber boxes, etc., it is better to reckon that each battery will require the help of a half-company of infantry with large shovels, and a whole company with small shovels. *These workmen should be sent from the regimental or divisional reserves, who do not require to make themselves cover.*

When large numbers of batteries are deployed together, the infantry working parties on one portion may be several companies, *e.g.*, for six batteries three companies with large shovels. In the interest of the success and good order of the work, it is advisable to detail an engineer officer to superintend it, and to give him a few sappers as assistants, say one to each two gun-pits. However, this is not always possible, as the engineers have to undertake the superintendence of the working parties preparing localities for defence, constructing tactical pivots, making artificial obstacles and improving the communications for the free movement of the reserves outside the position.

(*b*). Clearing Foreground.—In preparing the ground in front of the position so that it can be seen and fired into, it is imperative to clear away everything which would serve to conceal the advance of the enemy or give him cover. Trees and bushes must be cut down, tall grass and corn cut or trampled under foot, enclosures, hedges, and buildings demolished, and dykes and ditches brought under fire from the position.

Ranges to be Taken.—It is evident the amount of preparation which has to be done depends on the circumstances of the particular place. On level ground, without cover in front of the position, it will be insignificant; on broken country the reverse. While the work is being carried out, ranges from the position to the more prominent points in front should be found. It is also indispensable to take measures to impede the approach of the enemy to the position. With this object, fords and bridges across ditches and streams in front of it must be destroyed, and the roads (in defiles) broken up.

To be Carried Out by the Infantry.—All these operations must be carried out by the infantry alone, and for this purpose, in each section of the front occupied by a regiment, one, two or three companies, according to the dimensions of the work required, must be told off from the battalion or regimental reserve. The superintendence of the work should be given to a field officer of the regiment.

(*c*). COMMUNICATIONS.—In order to ensure freedom of movement to the reserves of the various sections of the fighting line (battalion, regimental, divisional) it is imperative to pay particular attention to the repair of roads, the security of bridges, the formation of passages through walls and hedges, the improvement of means of communication across hollows and ravines (and in the absence of means the construction of them), and the construction of passages across streams and swamps.

Artillery Communication to be Ensured First.—In arranging for the carrying out of these operations the measures to ensure the free movement of the artillery in every direction must be the first care. Infantry in this matter are less exacting, and it is not necessary to make special passages for them across ravines and hollows unless these have nearly vertical sides.

To be Carried Out under Superintendence of the Engineers.—These operations present a certain amount of difficulty, and should be carried out under the superintendence of the engineers. The necessary working parties can be detailed from the regimental or divisional reserve.

4. INVISIBILITY.—In order to hinder the enemy finding out the disposition of the troops in the position, and to put difficulties in the way of his "ranging," all parapets, whether of trenches or redoubts, must be masked, that is, the exterior must be made to harmonize with the surrounding ground.

With the same object, the parapets of tactical pivots should, if possible, be kept low, say at 3½ feet, with 4½ feet as a limit. The masking of works should be carried out by the working parties who construct them.

5. Action of the Reserves.—The line occupied by firing line, field batteries and tactical pivots forms the main position, and to hold it the defender must make use of every resource and his whole strength. The sectional reserves behind the line (regimental, divisional and corps) are told off for their duty—to drive the enemy out with the bayonet should he succeed in breaking through the line between the tactical pivots or in obtaining possession of one of them.

Battalion Reserve to be Covered by Trenches, other Reserves by the Ground.—This active *rôle* of the sectional reserves demands of them complete freedom of movement, and excludes their being employed on any particular position behind the main one. The battalion reserve is an exception, and is deployed in trenches, partly in the fighting line itself (when, for instance, the front companies are pushed out to protect artillery), partly behind it in the support trenches. As regards the regimental reserve (deployed about 600 paces from the fighting line), the divisional reserve (1,200—1,500 paces from it), and the army corps reserve (1,500—2,000 paces), they must get cover from the ground, and be ready any minute to move forward to a bayonet attack.

6. The Flanks.—*Withdraw Flank and Use a Defensive Pivot.*—Under the present conditions of rifle fire the frontal attack of a fortified position is certain to result in enormous losses, and the assailant has a better chance if he demonstrates on the front and makes a flank attack. In view of this it is imperative to pay particular attention to strengthening the exposed flanks of the position. One of the best ways of doing this is to draw back the flank and place in it a defensive pivot (about in line with regimental reserve), supporting this with shelter trenches, so as to be able to bring a heavy fire on the enemy while he is turning the position. To garrison this defensive pivot, with its trenches and exterior reserve, not less than a battalion should be detailed.

It goes without saying that this battalion is detached from the regimental reserve, and is attached to the fighting line. If the regiment occupying the flank of the line has one battalion in the front line and another in the above-mentioned flank redoubt, there will still be two battalions in the reserve.

7. Second Line of Defence.—However staunch the defender may be, it is still possible that the attacker may, on certain portions, penetrate into the position, particularly between the tactical pivots; may even capture one of them, and hold on to it, in spite of the counter-attack of the sectional reserves.

Should be Short.—On this account, in order to hinder the enemy from massing troops inside the position and acting against the rear of the troops still remaining on the position, and also in order, in case of need, to allow the troops of the fighting line to retire without molestation, it is useful to form a rear position for a small number of troops (say, one or two tactical pivots with position for artillery, and with well-marked lines of retreat for the retiring troops) on the line of the army corps reserves (1,500 to 2,000 paces from the firing line). When the army corps reserve moves forward to the counter-attack it ought to leave about one battalion to hold this line.

Marks Limit of Retreat.—The numbers of the defenders of this rear position being gradually increased by the retiring troops in case of the ill-success of the counter-attack, it may be of the greatest utility. But, *above all, it serves to indicate to the defending troops the point to which they should retreat, and beyond which they must not retire.* It also has a good effect on the troops, for they know there is support and a defensive position behind them.

Independently of this a rear position may stop a victorious enemy, limit his spreading from the gap he has made and even serve to change the fortune of the day, if the sectional reserves of the neighbouring section or the main reserves hurry up to assist.

Such rear positions may be usefully placed behind the position of each army corps, and also behind the exposed flank of a position.

8. Prepare Position Directly it is Reached before Reposing.—In the way warlike operations are conducted at the present moment—by rapid manœuvres and swift deployment for battle—*the defender must obtain full value from the time given him for strengthening a position.* If a body of troops on the march receives intelligence to-day that to-morrow morning it will be engaged in a defensive action, *directly it arrives* on the position it must think not of rest, but of the fight before it. *It must immediately occupy the position and prepare it for bayonet and rifle defence* (removal of obstacles to movement inside the position, clearing in front of the position, construction of cover for men and guns), and therefore it cannot rest.

Engineers to Work through the Night.—If all the above are completed by dusk—they will take, as a rule, between two to three hours—the sappers, with the help of a small working party, must complete the rest during the night (construction of tactical pivots, preparing localities of defence, and, if time and means permit, strengthening them by artificial obstacles and constructing blindages and shelters).

HASTY AND DELIBERATE DEFENCE.—The amount of work which the defender can do on the position depends on the time at his disposal. Roughly, it may be treated under two heads—the hasty and the deliberate defence.

The hasty defence is adopted when 1, 2, 4, up to 12 hours are available—when the troops arriving in their bivouacs one evening have the whole night at their disposal.

It is sometimes possible to fortify the position within view of the enemy, and even under fire, each soldier digging a shelter pit for himself. For the deliberate defence the defender has comparatively plenty of time—24 hours or more—but rarely over 36 hours (two nights and a day).

Deliberate Defence.—When it is possible to fortify deliberately, all the numerous operations mentioned earlier in the article can be carried out; field fortifications (redoubts) may have their full text-book profile; inside the parapet blindages and shelters may be constructed to protect the defenders from shrapnel, rifle bullets, and fragments of common shell; parados may be built to protect the defenders of the gorge from bullets which pass over the front parapet; the more important tactical points may be strengthened by obstacles.

Hasty Defence.—Under the most favourable conditions of a hasty defence of the position—when an evening and night are available—the greater part of the operations already mentioned may be carried out, but in a restricted measure. Thus, although the artificial tactical points constructed may have the form of redoubts, the profile must be reduced, and the front ditch reduced to a depth of 9 or even 7 feet (*sic*).

With energetic and skilled superintendence and under favourable circumstances, some of the tactical points may be strengthened by obstacles and even provided with blindages and shelters.

In the event of there being only a few hours available for the hasty defence, the work done must be limited to what is absolutely indispensable—the excavation of trenches for men and guns, the hasty preparation of localities suitable for defence and the execution of works to facilitate the action of rifle and bayonet. Where there are no natural tactical pivots they must be constructed as open works, with just a shelter trench profile. Sometimes such a pivot may be formed by connecting together a number of rifle pits; then, if time is available, it may be converted into a closed work by adding a gorge, the ditch may be deepened, and a parados, etc., constructed.

Works to be Progressive, and Ready for Use at any Moment.—In general, in carrying out a hasty defence the work must be arranged in such a way that the trenches and fortifications undertaken may be occupied at any moment after their commencement. On the other hand, they must be organized in such a way that should more time be available, they may be gradually improved without filling up ditches already dug or demolishing parapets already thrown up.

Deliberate Defence an Easier Matter than Hasty Defence, but of Rarer Occurrence.—It is evident that the deliberate strengthening of a position is a task more easily solved than its hasty preparation. To judge, however, from the campaigns of 1866 and 1870–71, the latter has more frequently to be carried out than the former. The combats at Trautenau, Nachod, Skalitz and Podol (in the war of 1866), and the Battles of Weissenberg, Wörth, Spicheren, Mars-la-Tour, and Beaumont, in 1870, were chance collisions. In the actions of Trautenau, Nachod, Mars-la-Tour, Beaumont, the defender had not even an hour to strengthen his position. Among the mass of examples of battles from chance collisions actions premeditated on both sides are of rare occurrence.

In general, considering the conditions of contemporary battles, one cannot help coming to the conclusion that, in future, chance collisions between portions of the hostile armies wil always lead to premeditated battles (deliberate strengthening of the position), which will decide the fate of the whole campaign.

Reconnaissance by Corps Engineer.—Orders for the Execution of Work.—The duty of the corps engineer when the army corps takes up a defensive position, whether for hasty or deliberate fortification, includes first of all the preliminary reconnaissance of the position in conjunction with the divisional engineers, staff and artillery officers. This reconnaissance must be carried out in such time that, before the arrival of the army corps on the position, the corps engineer can hand to the corps commander on the position itself the scheme of occupying it and the draft orders for the engineers and the instructions for the general carrying out of the work. The divisional engineers, in accordance with their orders and instructions, will make out the orders for their men, each for his own division. In these will appear—

(*a*). What work is to be done under the officers of the various units and what under the engineers.

(*b*). From what units the working parties for work under the engineers will be detailed.

(*c*). When and where the working parties parade and what tools they are to be provided with.

(*d*). If other tools than the portable entrenching tools are required and they are to be got from the wagons and requisitioned from the inhabitants, when and where they will be issued and when returned.

(*e*). What engineer officers are in charge of the works.

On the orders for the engineers, in combined work of infantry and engineer, depend the success of the undertaking; they are naturally given by the senior engineer officer on the spot and must be sufficient, full, clear, and short.

In the deliberate defence of a position the orders for the engineers will always be in writing. In the hasty defence written orders will be written if there is time; but, as a rule, there will only be time to give them verbally or in the form of simple memoranda.

CHAPTER III.

Repair and Construction of Roads and Bridges in Time of War.—The Duties of the Inspector and General of Communications in Maintaining Roads and Bridges in Full Repair.—The Classes of Bridges Constructed in Time of War.

FROM the very first day of mobilization the sappers have important duties to carry out as regards the demolition and repair of roads and bridges.

1. DEMOLITIONS MAY BE REQUIRED TO COVER MOBILIZATION.—If the plan of mobilization of any given army is formed with the idea that even on the very first day it must be prepared to defend itself, either because the enemy can mobilize more quickly or from some similar cause, the temporary or total demolition of any engineering works on railways that would compel the enemy to undertake their repair

before he could make use of the track must be carried out directly mobilization is ordered. These demolitions fall to the share of the sappers. It is, of course, understood that the works suitable for the purpose have already been fixed in peace time.

We must here add that, although the sappers have the task of destroying important engineering works requiring a large quantity of explosives for the demolition, the destruction of minor works may be undertaken by cavalry officers, who, as far as that goes, may be required to carry out important demolitions when on raids in rear of the enemy's communications.

Besides the destruction of railway bridges, under given strategic conditions, it may be imperative to destroy bridges on main and country roads, if they are likely to be of service to the enemy. The neglect to do this considerably facilitates the enemy's advance. The French sinned grievously by their failure to observe this principle in 1870–71.

Examples of Neglect to Destroy Bridges.—For example, the bridges across the Moselle at Novéant and Pont à Mousson were not destroyed by the French. This allowed the Prussians to continue their advance without waste of time and led to the Battle of Mars-la-Tour, which stopped the retreat of Bazaine's army on Verdon, and was one of the causes which forced that army to take the fatal step of shutting itself up in Metz.

A yet more striking example of the faults of the French in this matter was given at the Battle of Wörth, when they neglected to destroy the bridges over the Sauer at Gorsdorf, Wörth, Gunstedt and Durrenbach, all of which were under artillery and partly under rifle fire from the French position; a fire, however, which did not prevent the Prussians making use of these bridges in their attacks.

Engineers should be Attached to the Advance Cavalry.—We must remember that all the above-mentioned operations will be carried out by the sappers a great deal more advantageously if engineering works not in their own but the enemy's country can be destroyed. We strongly advise that engineer officers, with the necessary explosives on pack animals, should be attached to the cavalry regiments, which on declaration of war are hurried across the frontier to impede the enemy's mobilization.

2. Repair of Roads and Bridges for the Advance.—When the army advances the sappers belonging to the various army corps will have to repair the roads and bridges—(*a*), in their own; (*b*), in the enemy's territory.

The parts of a modern army massed on the frontier previous to advancing occupy a front of considerable length (from 150 to 200 miles). This dangerous but unavoidable dispersion is gradually decreased as the army advances towards the enemy, so that a large army on coming into contact with the enemy just previous to a battle does not occupy a front of more than 60 miles.

Having completed its strategic deployment, the army advances from its frontier towards the enemy by march; so that, although in accordance with the last paragraph the army gradually concentrates, the larger tactical units (army corps) must still march on many parallel roads.

Country Roads.—Only a very small proportion of the troops will march in main roads, where repairs to bridges and roads are not likely to be wanted; the greater part will have to trudge on country roads. On these, repairs to bridges and even to the road surface, will be constantly necessary. Besides this, all bridges will not be fit to carry guns, ammunition wagons and the heavy vehicles of the train, either from their construction or in consequence of their age.

Further, as is well known, country roads are not, as a rule, distinguished by their excellent state of repair. To render a rapid advance of an army, and particularly of the vehicles, possible, holes and ruts must be filled up, steep places improved and, if the road crosses marshy ground, heavy work must be done to allow of the passage of artillery and trains.

Bridges and roads in one's own territory which are told off for troops by the plan of campaign must be repaired in the time between the mobilization and the strategic deployment. The improvements are, of course, the business of the sappers, who must commence them at the same time as the mobilization begins.

Some Engineer Battalions must be kept at War Strength, so that they do not have to Wait to Mobilize.—Taking into account that all the above works—the earlier mentioned demolitions and also the preparations of the theatre of war—the deliberate fortification of localities, the fortification of already selected positions, etc.—we are forced to the conclusion that it is of the greatest importance to keep some sapper battalions at full war strength, so that no time is required for their mobilization.

When the sappers have completed the work of repairing roads and bridges in their own territory, directly the army advances they will have continuous heavy work in the hostile territory if the enemy retires without fighting, destroying not only railway bridges and tunnels, but also the bridges on the country roads. In order to permit of a rapid advance in pursuit of the enemy the sappers must work fast and continuously. The corps and divisional engineer companies in the advance guards and in first line will be detailed, but they may have to be assisted by working parties from the infantry, carpenters and smiths being selected for the purpose.

Orders must further be given that the work in the repair and construction of bridges and roads undertaken by the sappers, must not only be done to facilitate the advance, but also on cross-roads, so as to permit the reserves to move in every direction to the support of the front lines.

3. WHO IS TO ORDER THE PRELIMINARY DEMOLITIONS.—A little earlier in this paper we showed the necessity, under certain circumstances, of destroying railway bridges and tunnels, and even road bridges, in our own and in the enemy's country.

Who is to take the responsibility of giving the order for this most important action? We say important, because a bridge or tunnel destroyed at the wrong time or wrong place may do a very great injury to our army and, in consequence, do service to the enemy.

In accordance with the *Regulations for the Duties and Organization of Field Engineer Troops*, the sapper battalions, on which the duty of carrying out demolitions falls, are on mobilization assigned to the various corps, the sapper companies to the infantry divisions of the corps.

But neither the commander of an army corps forming part of an army nor, much less, the commander of an infantry division will take upon himself, in the majority of cases, the responsibility of carrying out such demolitions or of ordering the time and place of such demolitions. It is clear that such a question can only be decided by the staff of the army and only put into execution by order of one of the chiefs of the field staff.

In the *Regulations for the Field Staff of the Army in Time of War*, A.O. 62, of 1890, the executive functions in the construction, repair and renewal (and particularly the maintenance in good order) of bridges and strategic roads are placed in the hands of the I.G.F. (the Inspector of Engineers) and Director of Communications of each army (Eastern Frontier, Caucasian, etc.).

What the Inspector of Engineers is Responsible for.—According to para. 427 of the Regulations, the following are carried out under the orders and guidance of the Inspector of Engineers—(*a*), the more important field engineer operations in the fortification of positions, the construction of communications, etc., when directed by the Commander-in-Chief ; (*b*), the construction and repair, in the theatre of war, of main roads and crossings necessary for the carrying out of the operations ; (*c*), the telegraphic connection of the headquarters of the army corps and detachments by a system constructed by the Bureau of Field Telegraphs and Posts, as well as by the field telegraph companies.

According to para. 429 on the advance of the army, by arrangement of the Inspector of Engineers with the Director of Communications and with the consent of the Chief of the Staff, constructed and repaired lines of communications are handed over to the field road bureau. According to this, also, the Inspector of Engineers has to see that the pontoon battalions, field telegraph parks and the field telegraph companies detailed to accompany the army are not detained in the rear. To facilitate this he enters at once into relations with the Director of Communications, so as to have the field telegraph line replaced by temporary and permanent lines erected by the Bureau of Field Posts and Telegraphs.

In para. 430 the Inspector of Engineers, with the preliminary consent of the Chief of the Staff, if the latter thinks that the march of events permits it, may place the necessary material for the repair and demolition of railways and other means of inter-communication, and also telegraph material, at the disposal of the Director of Communications, detailing, if necessary, engineer troops and the necessary number of officers to superintend. Similarly, in case of need he will address the Director of Communications for help and for the means at the disposal of the latter.

What the Director of Communications is Responsible for.—By para. 315, in accordance with page 163 of these Regulations, the Director of Communications, in the district assigned to him, will form a complete plan for the construction of the communications of the army. This plan must include—(1), the direction and chief points of each road ; (2), measures for keeping all minor roads used in conjunction with main roads in the necessary state of repair ; (3), measures for construction and further development of the telegraph lines.

Summary.—From the above-quoted paragraphs of the Regulations it will be seen that to the Inspector of Engineers is assigned the ordering of the construction and repairs of roads, bridges and field telegraphs in the *rayon* of the action of the army, that is, from the headquarters of the army and the army corps to the advance guard. This during the advance of the army changes from day to day.

The Director of Communications is charged with keeping in repair the means of communication connecting the headquarters of the army and the army corps with the base.

Further from the frontier into the heart of our country the communications are administered by the Directors of Communications of the military districts.

Thus, according to the Regulations, when the work of the Inspector of Engineers ends that of the Director of Communications begins. Therefore, as the bridges and field telegraph lines built by the sappers and pontooneers belong to the gear carried with the army, and would be entirely used up during a long advance, the Director of Communications is ordered to replace them by temporary bridges and telegraph lines, connecting the latter to the State trunk lines.

It is evident that to attain any measure of success the Inspector of Engineers and the Director of Communications must work hand in hand.

Director of Communications to carry out Demolitions.—As far as concerns the demolition, in case of need, of bridges and other railway constructions, the Regulations give the order for carrying out of the work to the Director of Communications. Besides what has already been quoted this is evident from para. 316, which says, "To the duties of the Director of Communications belong throughout the whole war the ordering of measures for the maintenance of all roads used by the troops, as well as of all telegraphs in his *rayon* and, similarly, for the demolition of such roads and lines when the Commander-in-Chief judges it expedient.

Although the above-mentioned paragraphs only speak of lines of communication, *i.e.*, those in reach of the army, it is evident that the Director of Communications (in peace time the District Director of Communications) must collect and prepare material in peace time for the rapid demolition of bridges and railway constructions in the zone between the line of strategic deployment and the frontier.

Rear Guard Commanders may Order some Demolitions.—With reference to the destruction of bridges by parts of an army during retreat after a defeat, if special orders have not been issued, it becomes the duty of the commander of the rear guard to take measures for carrying out the necessary demolitions on roads with the object of hindering the enemy's pursuit.

The question of the destruction of railroads is more complicated and in case of an unsuccessful fight must be decided in good time by the staff of the army.

The Rights and Duties of the Inspector of Engineers and the Director of Communications Compared.—Comparing the rights and duties of the Inspector of Engineers and the Director of Communications in laying down regulations for the control of the army in the field, one must see that the Director of Communications, under the Commander-in-Chief of course, has at his disposal all the means for carrying out the duties which are assigned to him in rear of the army for renewing and repairing roads, bridges and telegraphs. For the immediate inspection and direction of the work he has special instruments—the Director of Field Roads, the Chief of the Field Post and Telegraphs, and their subordinates. The works are carried out in rear of and under cover of the field army and may be done under ordinary conditions either by volunteers or by working parties.

In a word, the Director of Communications is the one and sole director of the construction, repair and maintenance of roads and telegraphs connecting the army with its base.

The Inspector of Engineers is in a very different position with regard to the repair of roads and bridges in the theatre of operations of the army. According to the *Regulations for the Duties and Organization of Field Engineer Troops* (published in 1894, that is, four years after the *Regulations for the Conduct of the Army in the Field* appeared), directly mobilization is ordered all the sapper battalions are distributed among the army corps and consequently cease to be immediately under the control of the Inspector of Engineers. Further, he has no instruments for carrying out repairs to roads and bridges in the proposed theatre of operations. Under his immediate control are :—(*a*). The field telegraph companies, for maintaining telegraphic communication between the headquarter staff and the Imperial telegraph lines on the one side and with the staffs of the army corps on the other. These companies should, therefore, be completely withdrawn from the army corps and be solely under the Inspector of Engineers. (*b*). The pontoon battalions, which are available for the rapid throwing of bridges across rivers of great breadth. The construction of pontoon bridges available for the whole army (*e.g.*, Sistova-Chemnitza, 1877–78) is carried out under the Inspector of Engineers after consultation with the Chief of the Staff.

With regard to the repair of roads and bridges required by the various columns of the army, the immediate interference of the Inspector of Engineers in the work would probably do more harm than good. For the successful issue of the work it must be ordered by someone on the spot (the commander of the advance guard, the commander of the column) and carried out by the sappers with his detachment. If during a movement any given column comes across a broken bridge over a stream of small breadth, the commander of the sapper company can get up the bridging train, which follows his company, at once. If the material proves insufficient, some bays can be constructed of materials to be found on the spot and the infantry can assist the sappers by lending carpenters.

In the above cases the *rôle* of the Inspector of Engineers is solely that of channel between the army and the office of the Director of Communications for arranging that the hasty bridges built by the sappers are replaced by temporary bridges constructed under the orders of the Director of Communications.

Only in the case when there is important and lengthy work in bridge building (the renewal of railway bridges destroyed by the enemy) may the Inspector of Engineers co-operate with the Director of Communications, arranging for him to carry out the work with the military engineers of his bureau.

In constructing field telegraph communication in the theatre of operations of the army the Inspector of Engineers will play a more active *rôle*, directing the connection by the telegraph lines, of the headquarters on one side with the staffs of the army corps on the other, with temporary lines erected by order of the Director of Communications, which join on to the Imperial telegraphs.

A survey of the duties of the field telegraph companies and the pontoon battalions will be given later.

4. Bridges which the Sappers may be called on to Construct.—In time of war the sappers may be called upon to construct any of the following kinds of bridges:—(*a*). Field or hasty. (*b*). Temporary. (*c*). Pontoon.

(*a*). *Field Bridges.*—Field bridges are constructed in moments of necessity, sometimes even under fire. They are built of whatever materials can be found on the spot or near it—*the timber of houses, trees, brushwood. In making field bridges the principal point is rapidity* *of construction*, so that the movements of the troops are not delayed. Their solidity, in view of the nature of the materials of which they are built and the short time for which they are required, may be considerably less than that of temporary bridges, which are required to remain serviceable for a considerable length of time.

Field bridges have a definite purpose—to allow the troops constructing them to cross over obstacles. If it appears there is any necessity to maintain a field bridge for any length of time, it must be further strengthened and completed or a temporary bridge built in its place.

The rank and file of the sapper and pontoon battalions are practiced every year during the camping-out season in the construction of field bridges from the material to hand. The time taken to build them depends on the number of bays and the span, but may be reckoned at from 2 to 8 hours.

As an example of the construction of field bridges in time of war we will describe shortly two bridges which we ourselves built (*a*) during the Khiva Expedition in 1873, and (*b*) during the Russo-Turkish War, 1877–78, for the Rushchuk army across the Kara Lom.

Field Bridge Constructed in the Khiva Expedition, 1873.—During the advance from Mangit *viâ* Kyate to the capital of the Khiva Khanate the combined Orenburg-Mangit column, on arriving at the channel of the Klich-Niaz-Bey, found, instead of the pile bridge which had crossed it, only the burnt ends of the piles scarcely visible above the water.

The stream was 189 feet wide, with a rapid current of 4 feet a second. Bearing in mind the necessity of building a bridge quickly, the want of carpenters' tools and the small number of carpenters in the combined column (there were only one officer and four N.C.O.'s of the engineers and a Turkestan sapper company with it), it was resolved to dismiss the idea of making use of the remains of the piles by lengthening them and using them as abutments. The inflated goat's skin bridge equipment carried by the Orenburg column provided a 49—56-foot bridge. Materials for the rest of the bridge had to be found in the neighbourhood.

About three-quarters of a mile from the bivouac of the detachment grew a copse, in which there were very few trees as large as from 4 to 6 inches in diameter. What there were were immediately ordered to be cut down. Only necessity compelled the use of such materials, as the trees were very twisted and small and, eventually, on further consideration, it was decided they were useless.

A short distance from the copse was a cemetery, around which were a few farmhouses. After examining them we concluded that the joists and rafters, although not sufficient for the entire work, would do for transoms and road-bearers. The doors and gates would serve as ready-made superstructures for the roadway. Orders were consequently issued to pull down the buildings and prepare the materials for bridging and at the same time to cut saplings and brushwood. The brushwood, made into fascines, would with the saplings help to form the roadway.

By evening all the materials were concentrated at the place chosen for the bridge.

Considering the materials to hand, it was decided to build a bridge on three-legged trestles. The spans were from 7 to 10 feet, depending on the road-bearers available, in 20 bays, of which 5 belonged to the portable goat's skin bridge carried on camels, the rest having to be built.

The work lasted all night. The chesses of the portable bridge and the doors only sufficed to form a 84-foot roadway ; the rest was formed of fascines and saplings, the intervals being filled up with brushwood and sprinkled earth. At 5 a.m. the bridge was ready.

It must be admitted that the bridge collapsed badly and unexpectedly, in consequence of the small scantlings available. Soon after it was open to traffic one of the trestle transoms broke under a field gun. While it was being replaced traffic had to be suspended and special measures of precaution had afterwards to be taken to preserve the bridge. The guns and limbers were hauled over by the men and some of the shells were taken out of the boxes and carried over by hand. However, the passage went on uninterruptedly, though slowly, and the whole detachment got safely to the other side and continued its march.

Field Bridge Built in the Russo-Turkish War.—The Turks, in a raid from the fortress of Rushchuk, managed to burn the bridge over the Kara Lom at Ivan Chiftlik. The bridge was 70 feet long, and in view of the intention of blockading Rushchuk without delay and as closely as possible, the 3rd Company of the 7th Sapper Battalion was ordered, in the middle of January, 1878, to restore the bridge as quickly as possible. And here, as in the previous instance, the materials for the piers and baulks consisted of the trees growing in the vicinity ; but for the roadway, by order of the staff of the XII. Army Corps, planks and nails were brought up. This materially facilitated the work of building the bridge and gave it a certain solidity, especially as the trees available for the construction of the trestles were 12 inches in diameter.

The bridge was built in the course of 24 hours, as it was decided to work all night, lighting the operation by bonfires. In consequence of the exceptional rapidity of the current (8 feet a second) and the floating masses of ice, it was determined to make the trestles exceptionally heavy, so that they should not be carried away by the current. This circumstance and the unevenness of the bottom, made the work of placing the trestles correctly very difficult. Nevertheless, the bridge was finished about 6 a.m. and opened for traffic. The bridge stood well, not only to the end of the war, but all through the occupation and thus by a combination of circumstances fully replaced a "temporary" bridge.

(*b*). *Temporary Bridge.—Temporary bridges* are intended for the maintenance of communication for a considerable period and possess such solidity that they may be crossed by any vehicle used in the army.

These bridges are built of materials of considerable strength; they require for their construction comparatively considerable time, which increases or decreases with the length of the bridge.

For military temporary bridges the following methods of spanning the gaps between the piers are generally used:—Baulks, tension bridges and frame bridges.

The engineer committee pays special attention to giving the N.C.O.'s and men of the engineers practice in temporary bridges and issues annually instructions and orders for the expenditure on the construction of such bridges by every unit.

Time Required.—Practice in building temporary bridges in the 4th Sapper Brigade has shown that the construction of tension bridges with a span of from 35 to 56 feet requires 14 to 20 hours of uninterrupted work.

The construction of frame bridges with a span of from 35 to 49 feet requires 16 to 22 hours, because a great deal of time goes in smiths' work. A bridge of three spans, 157 feet long, with two intermediate pile piers with the spans closed by double-lock frames, requires 74 hours of uninterrupted work.

(*c*). *Pontoon Bridges.*—The bridges carried with the army are of two kinds—(1). Those assigned to every column of importance. (2). Those forming the reserve.

(1). The first kind of bridge is intended for the construction of bridges of small span, such as any column not less than a division may have need. These light bridges are assigned to the divisional engineer companies and go with them everywhere.

In the Russian army it has been determined to provide the first two companies of each engineer battalion with this kind of bridge, 70 feet of bridge for each company. In the German army the bridges are longer; each of the 62 divisional bridge parks has material for the construction of 140 feet of bridge.

(2). The second kind of bridge is designed for the construction of passages across rivers of some width, which will be required by the whole army. In the Russian army such bridges are carried in the pontoon park assigned to each of the eight pontoon battalions. These battalions in time of war are not divided up among the army corps, but remain at the disposition of the army staff, which disposes of them as required. Each pontoon battalion can make a bridge for the passage of all arms about 700 feet long.

In the German army there is no mobile reserve of bridging material, but besides the 62 divisional parks mentioned above there are 20 corps bridge parks, each with a bridge train for 399 feet.

In the French army there are several bridge parks—divisional, corps, and army.

(*a*). 38 divisional (advance guards) parks, each with bridging material for 98 feet.

(*b*). 19 corps parks, each with bridging material for 420 feet.

(*c*.). 5 army parks, each with bridging material for 840 feet.

We cannot help wishing that the third company of each of our sapper battalions should have a light bridge park. Were it so, by combining the bridge park of the three divisional companies each army corps would have at its disposal 210 feet of bridge in case of need.

CHAPTER IV.

The Character of the Work of the Telegraph Troops in Offensive Operations.—The Position of the Vehicles of the Telegraph Troops on the Line of March.—The Necessity of detailing Cavalry Protection for Erected Lines.—The Necessity of placing the Telegraph Troops of the Subordinate Armies under the Command of the Inspector of Engineers of the Whole Army.—Scheme of Telegraph Lines for Three Subordinate Armies under Command of a Commander-in-Chief.—The Work of the Telegraph Troops of the 10th and 15th Sapper Battalions in the Grand Manœuvres near Bielostok, 1898.

THE WORK OF THE TELEGRAPH TROOPS.—Let us examine the work of the telegraph troops.

We have already shown that (*a*) in accordance with para. 427 of the *Regulations for the Field Administration of Armies in Time of War* the Inspector of Engineers of the Army is responsible for the connection by field telegraph of the great headquarters of the army with the staffs of the army corps and of detachments and also with the telegraph net constructed by the Bureau of Field Posts and Telegraphs ; and (*b*) in accordance with para. 3 of the *Regulations for the Duties and Organization of Field Engineer Troops* the telegraph troops of the sapper battalions are detailed for the construction and maintenance of telegraphic communication between the staffs of the army corps and divisions and also between the detachments of the subordinate armies which may be in the region of operations of the divisions (*e.g.*, the portions of the army advance guards).

The Connection between an Army Corps Headquarters with Army Headquarters more important than with Divisional Headquarters.—Comparing the requirements of these two regulations, we come to the conclusion that it is the task of the telegraph troops of a subordinate army to connect the staffs of the army corps with the staff of that army, as well as to connect the staffs of the army corps with the staffs of the divisions. We cannot help recognizing that the connection of the two former staffs is far more necessary than the connection of the staff of the army corps with its divisions and advance guards. If there should be insufficient material to erect all these lines, then we must dispense with telegraph communications between the staffs of the divisions and the brigades and even with the staffs of the army corps, but it is imperative to keep connection between the last and the staff of the army.

An exceptionally serious, responsible and difficult task falls to the lot of the telegraph troops allotted to the subordinate armies in offensive operations ; (*a*), following behind its army corps and divisions they have to erect new lines daily ; (*b*), they have to be at the offices receiving and sending messages not only by day, but by night, which is the busiest time ; (*c*), on account of the limited amount of material, they have, at the same time as they are erecting new lines, to dismantle lines put up previously which lead to places which the army has left and then to pick up the army to erect fresh lines with the material thus made available.

Description of the Conditions under which Telegraph Troops work.—Captain Massenbach, of the Bavarian Military Telegraph Service, thus describes the conditions under which the telegraph troops have to work :—"No one who has not had the experience can imagine what a task it is to follow immediately after an advancing army . . . Three main difficulties present themselves—(*a*), want of space on the roads encumbered by vehicles, guns, and wagons, which makes the construction of telegraphic lines nearly impossible; (*b*), exhaustion of the *personnel*, who pass the night sending and receiving messages and the day in putting up and pulling down lines; and (*c*) damage to telegraph material, arising from continuous work." To the above must be added :—The damage to the lines done by hostile raids, by the inhabitants and by cattle, who easily knock over the light poles of the field telegraph.

Help from Infantry.—In this continuous work of the telegraph troops the infantry can only give a passive assistance, but a most important one if the commanders of the fighting troops allow the telegraph section with their wagons to follow immediately after the wagons of the first echelon of the advance guard. If this is not permitted, the telegraphists, as Captain Massenbach very truly says, will be seriously delayed in erecting lines and opening communication.

Help from Cavalry.—Help from the cavalry takes the form of guarding the already erected lines. A troop of cavalry with one officer might form a guard for two air line and one cable sections.

Enemy's Lines sometimes Available.—The work of telegraph troops in erecting field telegraph lines is sensibly facilitated if the enemy has not entirely destroyed his own post office lines. In this case all that has to be done is to repair the lines. The possibility of this happening was shown in the Franco-Prussian War, 1870–1. During this campaign the Prussians erected 6,500 miles of lines; out of this 4,950 miles were repaired French lines, and only 1,550 miles were specially erected military lines.

Captured Lines must be Protected.—In order to ensure the possibility of using the enemy's lines, it is indispensable that measures are taken to protect the telegraph in an occupied country. If clear categorical orders are not given to the army on this subject, the telegraph poles will soon be used up for fuel and the wire will be taken for various economic purposes.

All Telegraph Units should be under the Inspector of Engineers.—In the *rayon* of each army corps in the first line telegraphic communication will be constructed by the telegraph troop of the sapper battalion of the corps. In order to secure telegraphic communication in offensive operations between the staff of the army and the staff of the army corps, *it is indispensable that orders are given every day to the commanders of the telegraph troops, stating at what points they are to unite* *with each other and with the staff of the army.* In accordance with *Regulations for the Field Administration of Armies in War*, these orders should be given by the Inspector of Engineers of the Army ; in order, therefore, to avoid misunderstandings and to guarantee uninterrupted service of the telegraph, *the telegraph troops ought to be under the orders of the Inspector of Engineers of the Army and be taken from the control of the army corps and divisional commanders.*

Out of this arises the question : " Should the telegraph troops be placed immediately under the Inspector of Engineers or should they get their orders from him through the corps engineer ? " In the first case, the Inspector of Engineers would issue daily orders to the commander of each troop as to what lines he was to erect and what dismantle ; in the second case, the corps engineers would get their orders and pass them on to the commanders of the telegraph units.

Taking into consideration (*a*) that during an advance the commander of a telegraph troop ought to receive his daily orders in good time, and certainly not later than the hour when the bivouacs are broken up (5 or 6 a.m.), after which the unnecessary lines are dismantled ; (*b*), that each day, directly the advance commences and the consequent dismantling of lines occurs, the Inspector of Engineers is deprived of the possibility of communicating by telegraph with the majority of the telegraph troop commanders ; and (*c*) that during an advance in the vicinity of the enemy, and particularly when a collision is expected, neither the staff of the army nor the Inspector of Engineers can say where the various army corps and divisions will be on the following day.

But Orders given through the Corps Engineer.—The corps engineer, however, being on the corps staff will know earlier and it therefore seems more suitable for successful working that the orders of the Inspector of Engineers should be given to the telegraph troops through the medium of the corps engineer.

In this case the Inspector should inform the corps engineer daily (*a*) where the headquarters of the army will be next day and (*b*) where his lines should join on to those of the neighbouring corps, if the staff of each corps is not directly connected with headquarters, and direct him to communicate with it through the lines of the nearest corps. This will be more often than not the channel of communication.

Given these particulars, the corps engineer can get the other indispensable data (the headquarters of the corps and the divisions) from the corps staff and can inform the commander of the telegraph troop in good time of the connections he has to make.

Scheme for Telegraphic Communication between Three Armies.—We now present the scheme of telegraphic communication of three subordinate armies under a Commander-in-Chief. We assume that (*a*) the armies have completed their deployment and the grand headquarters are already in the enemy's country, about two or three marches from the frontier; (*b*), the first subordinate army consists of three army corps, the second of four and the third of five; and (*c*) two army corps of the 1st Army and three each of the 2nd and 3rd Armies are in the first line and the rest follow.

Under the above conditions it is of the first importance to maintain uninterrupted telegraphic communication :—

(1). Between the grand headquarters and the Government permanent telegraph lines in the rear of the army.

(2). Between the grand headquarters and the headquarters of the various armies and between the latter themselves.

(3). Between the army headquarters and the headquarters of the various corps comprising each army.

(4). Communications from the army corps headquarters to the divisions is most useful, also to the brigades if the last are employed as army advance guards. But if there is insufficient material, this telegraphic communication can be abandoned, as usually the distances between the smaller units are not very great and communication can easily be kept up between them by means of flying posts of cavalry.

[NOTE.—It is most desirable that the telegraph (or telephone) should be made use of on outpost duty and therefore it is convenient if the various portions of the advance guard can be connected with each other and with the main body. It is also desirable to employ the telegraph company on the battlefield. But it is to be understood that on outpost duty and on the battlefield the communication between minor staffs (*e.g.*, the divisional with the regimental) should be made by telephone, not telegraph, and the lines should be laid not by the telegraph troops, but by the infantry, the material being carried on their own wagons. As a consequence of the proved usefulness of these telephone lines, the equipment of the army with telephones and a small amount of thin wire is a matter of the near future.]

Connection with the Home Telegraph System.—In accordance with *Regulations for the Administration of Armies in the Field*, there is no one on the staff of the Commander-in-Chief dealing with the construction and maintenance of the permanent telegraph lines connecting the grand headquarters with the Imperial telegraph net.

Actually this duty falls to the General of Communications of the subordinate army, in the *rayon* of which the Commander-in-Chief happens to be. By his orders the Bureau of Field Posts and Telegraphs assigned to his command goes on continuously replacing by its own lines the lines of the field telegraph erected by the troops advancing with the army.

It is evident that this replacement is much facilitated and hastened if instead of constructing new lines the Bureau has only to repair the enemy's permanent lines.

However, when the army has advanced a considerable distance from the frontier, the duty of maintaining the permanent lines is taken from the General of Communications of the army and handed over partly to the General of Communications of the border district and partly to the governor appointed to control the conquered territory.

The work of maintaining uninterrupted telegraph communication between the Commander-in-Chief and the various armies, and between the latter, is the main duty of the General of Communications of each army and his Bureau of Field Posts and Telegraphs. As a rule, these telegraph lines are from their character to be reckoned as permanent and their durability is equal to that of the Imperial telegraph lines.

Independently, however, of the material for the construction of permanent lines, the General of Communications ought to have at his disposal light telegraph material, carried in wagons, of the quality usually supplied to the telegraph troops. It is indispensable that he should have the material in view of his daily duty of replacing the field telegraph line, so that the telegraph troops may dismantle their lines in good time and always be up at the front.

This kind of telegraph line, generally known as the Etappen telegraph, is used both in the French and German armies, and the issue of it to the General of Communications seems indispensable.

In the French army the *personnel* of not only the Etappen, but also the field telegraph, are formed on mobilization from the officials of the State telegraphs, with a cadre of officers and N.C.O.'s. In Russia it appears this arrangement would do for the Etappen telegraph, as it operates at some distance from the enemy, and the presence with it of a non-military element would not act injuriously on its efficiency.

Connection of Army Headquarters with the Army Corps and Divisions.—The connection by telegraph of the army headquarters with the corps headquarters and of the army corps headquarters with the divisional headquarters and the advance guards is the duty of the telegraph troops. Each troop has *matériel* and *personnel* for erecting 30 miles of air line and 21 of cable, in all 51 miles.

Work to be Expected of the Telegraph Troops.—Taking into consideration that this troop has daily and continuously for long periods—by day to erect new lines and dismantle old ones, by night to receive and despatch messages, we can only reckon on new lines of $\frac{1}{3}$ of the length of the available material being installed daily. This calculation is made on the assumption that every day one-third of the *personnel* will erect and work new lines, one-third will dismantle old ones and come up in rear, and one-third will rest. This rest is absolutely necessary for men and officers, as they are called on to work day and night.

It therefore appears that as at peace manœuvres lasting eight to ten days there are rest days, more work may be expected of the telegraph troops and we may reckon on their being able to lay out a half of their material, 24 to 27 miles.

In our example we assumed that in each subordinate army there were several army corps in second line during an advance. The telegraph troops of these corps will be detailed to connect the army headquarters with the corps headquarters ; as a rule it is sufficient to connect the army headquarters with one corps headquarters, as the various corps headquarters are connected together. The corps headquarters will, of course, have communication with their divisions.

Work of Air and Cable Sections.—Until contact with the enemy the air line sections will work alternately with the cable section. On collision being imminent, as it is indispensable that the telegraph should be pushed forward to the position of the senior officer at the front (corps commander, divisional general), it is preferable to use the cable section, as it is more mobile.

In Russia, as we have shown above, we have both air line and cable telegraph. In France a decided preference is given to the cable ; of the 34 miles of wire carried by the telegraph detachment, which corresponds to our troop, 30 are cable and only 4 miles uninsulated wire. In the German army, on the contrary, the preference is given to simple uninsulated wire.

Criticism of Dobruishin as to the Use of Air Lines on Poles.—In the very complete and interesting article by M. Dobruishin, *Telegraphs and Their Work in War* (*Vorjenny Sbornik*, 1895, No. 7), is given a scheme of telegraphs for an army of three army corps. The author reckons that for the construction of uninterrupted telegraphic communication between the army headquarters and the corps headquarters, only with marches of medium length, 12 miles, 99 to 120 miles of cable are required. This deduction is accompanied by the following unconsoling conclusion :—" No army can have such large resources at its disposal for fear of impeding its movements with a mass of vehicles."

However, in the same article the author gives details of the new organization of the engineers, from which it is not difficult to see that three corps, the number of which he is speaking, have three telegraph troops, with a sum total of 90 miles of air line and 63 miles of cable telegraph line.

The author rightly holds the opinion that " in offensive movements the cable line exclusively must be used." When an army is halted there is no great difficulty in installing communication between the army and the corps headquarters and either air line or cable can be used. But the construction of lines during the movements of the army is in a very different position. The posts indispensable for air lines can only be erected slowly and this precludes (?) their being used ; there is consequently only one method—the laying of a field cable.

We do not agree with the worthy author with regard to the slowness of erecting posts being so great as to exclude their use in offensive operations. Cable telegraph can be installed more quickly and more easily than air line, but the experience with air lines gained at grand manœuvres and at the schools of instruction shows under normal conditions (when there are no special obstacles to overcome) that air line on posts can be put up at the rate of about $2\frac{1}{4}$ miles an hour and that this pace is sufficient to keep up with an advancing army. It is only indispensable that during an advance measures are taken to remove any obstacles to the erection of a telegraph line.

Two of these obstacles are (*a*) difficulty of movement for the wagons of the telegraph troop on roads already occupied by men and vehicles ; (*b*), comparative slowness of movement of the wagons of the air line section on sandy by-roads and in muddy weather. The first obstacle is easily removed; the staff must order that the telegraph wagons detailed for laying a line follow the vehicles of the first echelon of the advance guard. The second obstacle may be got over by harnessing a fourth horse to the three-horsed telegraph wagons and for this purpose spare horses must be authorized.

WORK AT THE BIELOSTOK MANŒUVRES, 1898.—At the Imperial manœuvres near Bielostok in 1898 we had an opportunity of watching closely the work of the field telegraph of the Western army. For these manœuvres the telegraph troops of the 10th and 15th Sapper Battalions were utilized.

Mobilization.—Each was of full strength—two air line and one cable section. The *personnel* was made up to mobilization strength by means of the three telegraph troops of the 4th Sapper Brigade. For horsing the wagons through the manœuvres horses were hired. The contractors assembled the animals at the end stations of the railway where the telegraph troops arriving from Warsaw disembarked. The cable section of the 10th Sapper Battalion alone was completely equipped with army horses collected from various parts of the brigade.

Daily Orders.—By order of the Commander-in-Chief these troops were placed immediately under the orders of the Inspector of Engineers of the Army. The latter, after consultation with the Commander-in-Chief, issued orders daily by telegraph to the commanders of the telegraph troops on the following points:—(*a*). What lines to construct. (*b*). What lines to close. (*c*). At what point the field telegraph was to be connected with the permanent Imperial telegraph.

Intercommunication. — At manœuvres the tasks both of the Inspector of Engineers and of the General of Communications are considerably easier than in war time in the matter of maintaining uninterrupted communication between the staffs of the armies and the permanent telegraph lines. Actually the telegraph troops, when they had made the connection each day between the new positions of staffs of the army and the staffs of the army corps and divisions, always found themselves within easy distance of the permanent telegraph. They used as points of connection either the railway stations or the railway sidings, at which the officers of the field posts and telegraphs who followed up the army opened offices on the permanent line. In this manner it was practically unnecessary for the General of Communications to construct Etappen telegraph, and the Inspector of Engineers was relieved of the necessity of maintaining the first constructed lines of the field telegraph until they were replaced by lines of Etappen telegraph.

Daily Work.—The lines of field telegraph were constructed two days before the commencement of the manœuvres and connected the army staff with the staffs of the army corps, divisions and advance guards in the places of preliminary concentration for the manœuvres. Thus it happened that the telegraph troops during the whole of the manœuvres, except on the rest days, had daily to construct new lines, at the same time dismantling the old ones as they followed up the army. Even on the rest days they had to operate the lines put up the previous day. Once a telegraph station was opened it received and despatched messages until the army broke up bivouac (usually about 7 a.m.). Then the station was closed, the lines were taken up, and the wagons with the available plant moved forward with the advance guard to construct new lines to the indicated places.

Number of Messages.—During the ten days' operations of the field telegraph the following number of messages were received and despatched from the various offices which were opened :—(*a*). By the troop of the 10th Sapper Battalion—who provided one office at army headquarters—despatched 1,051 messages, received 1,117 ; (*b*), by the troop of the 15th Sapper Battalion, despatched 544, received 493.

Length of Line.—The length of line laid out each day by the two troops will be seen from the following table :—

Date.	Day of Manœuvres.	10th Troop.		15th Troop.		Total.		Grand Total.
		Air Line.	Cable.	Air Line.	Cable.	Air Line.	Cable.	Total Air and Cable.
Aug.		Miles.	Miles.	Miles.	Miles.	Miles.	Miles.	Miles.
16	—	22½		30	3	52½	3	55½
17	—	25½		30	3	55½	3	58½
18	1	7	16	2½	15	9½	31	40½
19	2	12	5⅓	13	8	25	13⅓	38⅓
20	3	12⅓	5	5	6	17⅓	11	28⅓
21	4	12⅓	5	5	6	17⅓	11	28⅓
22	5	5	4½	6	3¾	11	8¼	19¼
23	6	3¾	7¾	7½	7½	11¼	15¼	26½
24	7	6	10¾	7½	6	13½	16¼	30¼
25	8	4½	—	5	—	9½	—	9½
							Total	335 miles.

On inspection of the table we see :—

(*a*). The staffs at the points of preliminary concentration were connected by air lines, except for a short length of 3 miles of cable, which the 15th Troop were compelled to employ, as they had used up all their available bare wire. This arrangement was recommended by the Inspector of Engineers, so as to have both cable sections free on the first day of the manœuvres to lay wire as the troops advanced. On the first day, therefore, the greater part of the work was done by the cable sections ; they laid 31 miles out of $40\frac{1}{2}$. On subsequent days it was left to the judgment of the commander of the telegraph troop as to whether he would use the air line or cable. The commanders of the two troops agreed, in so far as they used cable for the more distant lines and bare wire for those nearer in. Thus on the second day of the manœuvres $13\frac{1}{2}$ miles of cable and 25 of air line were laid out ; on the third day 11 miles of cable and $17\frac{1}{3}$ of air line, etc.

(*b*). The greatest length of line laid out, $58\frac{1}{2}$ miles, was on the eve of the commencement of the manœuvres. On the first day the amount decreased to $40\frac{1}{2}$ miles, on the second to $38\frac{1}{3}$ miles, and the fifth day the total length was only $19\frac{1}{4}$. This is easily comprehensible, for as the army advanced and approached the enemy it gradually concentrated. The comparatively greater lengths used on the sixth and seventh days—$26\frac{1}{4}$ and $31\frac{1}{4}$ miles—is explained by the fact that in view of collision with the enemy the lines constructed on the previous day were not dismantled, but were prolonged from the places of bivouac to the scene of combat, so that the Commander-in-Chief could receive intelligence and send orders to his two army corps.

Rate of Work.—During the manœuvres the following rates of work were attained by the telegraph troops marching with the advancing troops :—(*a*). For air line, from $1\frac{1}{4}$ to $1\frac{3}{4}$ miles an hour ; and (*b*) for cable, $1\frac{3}{4}$ to $2\frac{1}{2}$ miles an hour ; the slower rate being reached when the cable was hung on trees growing near the road, so as to protect it from injury by wagons, etc.

Damage to Matériel.—Turning to the question of what damage was done to field telegraph lines by raids of the enemy, it must be admitted that *damage and injury were very frequently done to the lines and that therefore telegraph stores, and particularly cable, deteriorated rapidly*, although strict orders were given by the commanders of the military district that damage to the lines should be carried out without real injury to the stores.

In order that the obstacles under which the telegraph troops of the Southern army maintained uninterrupted communication between the various headquarters may be clearly understood, we give the following extracts from the reports of the commanders of the troops for one day :—

"*18th August.*—During the night, on the *** line, the enemy's raiders made nine breaks and twelve faults on the cable, cut off and carried away 385 feet of cable." (Report of Telegraph Troop of 10th Sapper Battalion).

"*18th August.*—On the *** line twenty faults were made ; the cable was cut in several places, and nearly 700 feet carried off." (Report of Telegraph Troop of 15th Sapper Battalion).

Damage of the stores of the telegraph troops, which are exceedingly costly, is an evil which it is imperative to combat and imperative to lessen.

Sad to say, we cannot hope to stop it altogether, as the raiders can avail themselves with impunity of the fact that it is impossible for the men of the telegraph troops to be able to report them by name.

Orders must be Given to Protect the Telegraph.—It occasionally happens that damage is done to the telegraph lines not by the enemy, but by vehicles of our own army. To ensure uninterrupted communication it is imperative to impress on the troops that they must protect their field telegraph, as it is of the utmost service.

CHAPTER V.

The Command of Engineer Railway Companies.—The Essential Principles of the Use of Railways in War.—Ordinary and War Traffic Management.—Military Traffic Management and Occasions for its Application.—The Utilization of Enemy's Railways in the Wars of 1870–1 and 1877–8.—Railway Troops and Railway Traffic Companies in Germany and France.—The Railway Battalion of the Russian Army.—The Necessity for Russia to Organize in Peace Time.—Traffic Companies from the *Personnel* of the Railways.—The Necessity of Providing the Russian Railway Battalion with Interrupted Practice in Peace Time and in Responsible Railway Management by Assigning to it the Administration of Some Small Branch Line.—Field Narrow Gauge Railways and their Use in War.—Field Railways with Steam Draft in Germany and Horse Draft in Austria.—Proposed Organization of Such Railways in Russia.

Importance of Railways.—We have already discussed the duties of engineers on the repair and construction of ordinary roads and bridges. But railroads, as well as ordinary roads, play an exceptionally important *rôle* in modern warfare in the preliminary, the auxiliary and even the main operations.

In view of this, it is a matter of the highest importance for a field army to possess the means of putting in order and of operating without undue delay railways captured from the enemy.

The Railway Section of a Field Company.—In accordance with para. i. of *Regulations for Specialist Portions of the Engineers*, 1896, the duty of constructing railroads is assigned to the field engineer troops. For carrying out this object each field company has among its specialists a railway section consisting of 20 men of various terms of service. In para. 25 of the *Instructions for the Specialist Portions of the Engineers*, 1894, it is laid down that this section should consist of (*a*) privates who have gone through the course of instruction at the sapper and demolition schools, (*b*), privates who have worked either on railways or with steam machinery and (*c*) carpenters, locksmiths and blacksmiths. The completion of the lower ranks of these sections by men of the above-named categories meets with no difficulties, except that men acquainted with steam machinery are seldom met with in the field companies.

Their Training.—The railway sections of the sapper battalions are trained every summer on the small model railway which is to be found in the park of every sapper brigade. In addition practical instruction is carried out on free portions of any railway near the sapper camp.

As far as possible the practical instruction is also carried out in the spring on railways near the headquarters of the battalion.

As a result of this instruction the railway sections are able to carry out the repair and demolition of railroads. As regards traction, the men are only shown the construction of a locomotive and are not trained to drive engines. With traffic management also they are practically unacquainted.

Their Use.—Taking into account that on mobilization the sapper companies are distributed among the infantry divisions and that in each company there are only 20 men with a knowledge of the construction and repair of railroads, it is impossible not to come to the conclusion that recourse to the services of the railway section of the sapper companies will only be made in case of dire necessity, and then only for the repair of small sections of destroyed or damaged permanent way; and they will be assisted by other engineers or infantry working parties. The men of the railway sections may also be employed in preparing trucks for the conveyance of troops.

This modest *rôle* of the railway sections is not difficult to explain, for the first specialist duty of the men is not railway work, they are before all sappers and, as such, have already specialist work. This *rôle* is besides clearly laid down in *Regulations for Specialist Portions of the Engineers.* For the working of railways in war and for the construction of new railways in war, there are special engineer troops—the railway battalions.

The Working of Railways in War. — Before examining the organization and duties of the railway battalions in war we shall give some general ideas on the working of railways in war.

Main Principles.—The practical experience of the use of railways in war during the second half of this century has given us certain principles. The most important of these are :—

(1). *On Mobilization Railways must come under the Military Authorities.*—On mobilization every railway of the empire, with its *personnel* and rolling stock, must come under the orders of the military authorities.

(2). *Two Categories—Peace and War Conditions.*—In such a case the railway lines may be divided into two categories—(*a*), those on and near the theatre of war; (*b*), those outside the theatre of war. The former must be worked under war conditions, the latter may maintain their ordinary organization.

(3). *Those under Civil and those under Military Management.*—The railroads worked under war conditions may be divided into two sections—(*a*), those worked by the peace time administration, which, however, is completely subordinate to Military Directors of Railway (civil administration under war conditions) and (*b*) those lines completely under military administration and worked by railway troops (military administration).

(4). *Complete Control of Military Trains.*—On railways with the ordinary peace administration the agents of the War Office control only the military trains, but under special circumstances may control the *personnel* and rolling stock.

(5). *All under One Head.—The management of all railways, both those under normal and those under war conditions, must be in the hands of one man.* This is imperative (*a*), so that military trains may always be able to travel right through without delay; (*b*), so that *personnel* and rolling stock may be shifted from one railway to another without friction, as the circumstances of the hour require.

(6). *Railways must be Watched in Peace Time.*—The Ministry of War must watch the railways in the military interest in peace time.

The objects of this are (*a*) to obtain a railway network which will correspond with the strategic requirements of the country; (*b*), to make timely preparations for a rapid change from peace to war conditions (mobilization of the railways) and (*c*) to prepare beforehand time tables for the movement of men and stores on mobilization for the strategic deployment.

(7). *Uniform System.*—It is imperative for the success of railway administration in war that in peace time all railways are organized uniformly on one system corresponding to their duties in war. This is particularly important with regard to traffic (uniform rules for traffic and signalling) and the construction and management of the locomotives.

(8). *Training in Rapid Repairs.*—To ensure the rapid repair and preparation for traffic of lines captured from the enemy it is imperative (*a*) to have in peace fully trained and reliable cadres for the formation of construction and traffic railway companies; (*b*), to form traffic sections in peace, independently of the railway troops, from the railway officials serving on the various railways and to collect them periodically for practical exercises and (*c*) to have in reserve in peace railway bridges and piers in numbered sections, so that they can rapidly be put together.

The System in Germany.—The railway system adopted in Germany satisfies in a great measure the above-mentioned elementary principles for railway management in war. In the German army the Director of Railways, who is a member of the field head-quarter staff and subordinate to the Inspector-General of Etappen and Railways, controls not only the railways in the theatre of war, but every railway line in the empire. Besides this, the management of troop trains on railways outside the theatre of war is the duty of the chief of the railway section of the general staff, who is immediately subordinate to the Director of Railways.

Military Management of Railways.—The military management of railway lines is of particular interest for us. We may divide railways into (*a*) those lines of our own or our allies, the management of which it is recognized must be wholly given over to the military authorities; (*b*), lines captured from the enemy; (*c*), lines built in war time.

(*a*). *Reinforce, but do not Remove, the Civilian Staff on our Own Lines.*—As a fundamental principle it is neither advantageous nor indispensable to change the civil *personnel* who have charge of a line in peace time for an exclusively military staff; the former have been trained to a recognized system by years of work in combination, are united in their interests and fully acquainted with idiosyncrasies of the line and its management.

As a general rule, the complete change of the railway *personnel* of a line should only be carried out under very special circumstances, but the strengthening of the *personnel* of any given line which may happen to be in the theatre of war, in order to meet and deal with particularly heavy traffic, is of frequent occurrence. For instance, in the war of 1877–8 the *personnel* of the Roumanian railways was reinforced by the men of our newly-formed railway battalions (first by the 3rd, and afterwards by the 2nd and 4th), who not only assisted in the general running of the lines, but in their up-keep and improvement.

(*b*). *The Enemy's Lines; how Repaired and Worked.*—Directly any territory is conquered from the enemy the railroads in it must be repaired and got into running order. In 1870–1 the Prussians had to work about 1,800 miles of French railway lines and employed on them about 25,000 men. However, the experience gained in this campaign led to the conviction that field railway troops formed at the moment of necessity in time of war are not always up to their work. As a result railway detachments were formed in Prussia, so as to serve as a nucleus for constructional and traffic companies on mobilization. Besides these detachments, Germany has now railway traffic troops formed from the *personnel* of the railways who are liable for military service.

These troops are called out periodically for practice in railway work under war conditions.

Some Turkish Lines in 1877–8 *worked by Turks after they were Captured.*—In the Russo-Turkish War of 1877–8, when the Russian army had completed its winter campaign in the Balkans, use was made of the Turkish railway line Sarambey-Constantinople (300 miles), and its branches Yamboli-Tirnovo-Semenli (61 miles) and Dadeagach-Kyleli-Burgas (66 miles). The Turks in retiring on Constantinople did not destroy the railway bridges across the Maritza (at Tirnovo-Semenli and at Kyleli-Burgas) and across the Arda (near Adrianople). They limited themselves to burning the rolling stock, damaging the telegraph and burning the wooden trestle bridge (about 44 yards long) near Germanli station. This bridge was re-built by an engineer company in a week.

Notwithstanding that there were three Russian railway battalions in Turkey, this railway was worked by the same *personnel* which had served under the Turkish management. Only some military police and technical surveillance were provided by the 3rd and 4th Battalions.

How the Line was Guarded.—According to the author of the article "Materials for the History of the 4th Railway Battalion" in the *Engineer Journal*, 1897, Nos. 6 and 7, the line was guarded in the following manner:—At all stations and intermediate posts, which were spaced about 6 miles apart, defensible posts for one to two N.C.O.'s and three to six privates were constructed. The duty of these detachments included:—(1). The surveillance of the employés, who were Bulgarians, Greeks, and Turks. (At first even the pointsmen, couplers, and guards of the trains had to be watched). (2). The guarding of the permanent way and particularly the bridges, embankments, etc.

It must be admitted that this is an exceptional example, and that in future it is hardly possible that our army will be able to utilize an enemy's railway and work it by the same *personnel* which runs it in peace time.

(*c*). *New Lines Built in War.*—The experience of 1870–71 and 1877–78 confirms the necessity of constructing new branches on railways even during the progress of the campaign.

Thus the Prussians built three branch lines.

1870–1.—(*a*). To avoid Metz, from Remilly to Pont-à-Mousson, 16 miles long, (*b*), to avoid the demolished tunnel at Nanteuil, 3 miles and (*c*) to avoid the demolished bridge de la Versine, 1 mile.

1877–8.—Our army in 1877 built two railway lines—(*a*), Bender-Galitz, a length of 171 miles, in 100 days; and (*b*) Fratesht-Chemnitza, a length of 50 miles, in 50 days. Both these lines were built not by the engineer troops, but by contractors. The explanation of this is that the work had to be carried out in the country of an ally, not of an enemy, and with the object of increasing the very insufficient railway communication of Roumania. In future we may expect that the construction of railway lines in an enemy's country and their management will be carried out exclusively by railway troops.

The Railway Troops of France and Germany.—The regular and rational solution of the question of the rapid repair and the immediate opening for traffic of railways in time of war, equally with that of the construction of new branches, is of the very greatest importance. Let us examine how this question is solved in Germany and in France, in the two empires which had notable practice in working railways for military purposes in 1870–1.

Germany.—In Germany in time of peace there are 21 railway companies. On mobilization each company is expanded into four companies, three constructional and one traffic, and there are therefore available 63 constructional and 21 traffic companies. Each traffic company has to work a section of line about 27 to 36 miles long. For the practical instruction of the men, Prussia has a military line Berlin-Juterbog about 27 miles long, which is managed altogether by the men of the railway regiment.

In war time the constructional companies are detailed to put in order damaged or demolished railroads and to construct new lines. The traffic companies prepare the enemy's lines for traffic directly they are captured.

It is proposed to divide captured lines into sections managed by the "Field Directors of Railways," each section containing about 270 miles of line. Under the orders of each of these directors are two railway traffic inspectors, dealing with about 135 miles each. In each inspection a captain carries out the duties of general manager, two lieutenants superintend the work, the 2nd lieutenants perform the duties of traffic managers and controllers of all trains and ordinary repairs. Individual railway officials are detailed as managers of shops, stores, telegraphs, etc.

Under the orders of each inspector are :—

(*a*). Railway traffic detachments for every 27 to 36 miles. These detachments are formed in peace time of railway employés as mentioned above and replace the railway traffic companies of the leading armies, leaving them available to repair and prepare for traffic any lines that may be captured.

(*b*). Gangs of workmen for loading and unloading warlike stores, supplies, etc.

France.—In the French army there is one railway regiment (the 5th Engineers) consisting of two four-company battalions. The practical instruction of these units is carried out at the railway park in Versailles, and on the State railway Orléans-Potay-Voves-Chatres, which is about 45 miles long.

Particular attention is paid in France to the formation in peace time of technical railway traffic detachments of the regular railway employés. These detachments are periodically mobilized for practical work. The *personnel* of these detachments work together at their special duties in peace and form a united body for analogous work in war, with the advantage that the seniors know the character and ability of their subordinates and these latter know their chiefs and each other. This guarantees success in such a complicated, important and responsible work as the management of a railway in war.

In the article "Railway Troops," by A. von Vendrich (in the *Vorjenny Sbornik*, No. 7, 1896), is inserted a translation of the regulations for the organization of these detachments and instructions for their control. From these are extracted the following details of their formation, instruction and management.

(1). The detachments for military communications form a corps having a permanent organization in war. It is responsible for the construction, repair and working of all railways, the service of which is not assured by the national railway companies. These detachments have their own hierarchy without any relation to the army.

(2). The *personnel* of the detachments is formed from the engineers first and second grade employés and the workmen of the six great railway companies and the State railways. The senior employés are obliged to serve three years in the detachment and have the privileges of "volunteers." The lower ranks are taken principally from those men liable for military service; they join willingly, as they escape all other military duty.

(3). From the *personnel* of the private and Government lines are formed nine detachments, each known by a number. With the exception of the 8th Detachment, which is mixed, each railway company provides a detachment.

(4). Each detachment is managed by a special administrative council, the president of which is the chief of the detachment and its members are the traffic managers, the road engineers, the mechanical engineers and the chief accountant, with a secretary. The chief of the detachment, who is generally a retired Engineer officer, has the rights of the commander of a corps and is immediately subordinate to the committee of military railroads. All the senior ranks of the detachment, as well as the chief of it, have the usual disciplinary powers.

(5). In peace the detachments, by order of the Minister of War, carry out inspections, reviews and musters for practice. When called out in peace time all ranks are paid.

(6). In war time all ranks wear a uniform. It is somewhat similar to that of the Engineers, but with the addition of a wheel and with lace on the sleeves and cap, depending on the rank in the railway service. The seniors also wear uniform on certain occasions in peace time.

(7). Each detachment is divided into three parts—service of traffic, service of permanent way and service of traction. Each service has its own *personnel*. Each detachment has a total of 1,273 men, by whose help it can work 180 miles of line.

Deductions from German and French Practice.—Examining the organization of the railway troops in Germany and France, our attention is drawn to the two following facts:—

(1). *Plenty of Practice.*—In both empires the railway troops are exercised in peace time and are responsible for the actual working of certain lines. This is most important, as it gives a guarantee that these troops will show themselves equal to the duties expected of them in war time. *It is imperative that such complicated and responsible work as the working of a railway in war should be taught practically by the actual management of a railway* and the instruction should be by no means limited to lines in an engineer park, where at the best of times there is hardly more than two or three miles.

(2). *Employés of the Railways used as Reserve.*—Independently of the railway troops—not only in France, but also in Germany, where there are on mobilization 84 railway companies—traffic detachments are formed in peace time from the *personnel* of the great railways. These detachments are of great use to the army in case of need—(*a*), they strengthen the *personnel* on the national lines on which there is more than usual traffic and (*b*) work lines taken from the enemy. There are actually in France nine traffic detachments, which hardly cost the War Office anything and are capable of working nearly 1,600 miles of lines.

Russian Railway Troops.—In the Russian army of to-day there are seven railway battalions—four regular (1st, 2nd, 3rd, 4th), two Trans-Caspian and one Central Asian. The last is stationed in the Priamur military district. The 1st Railway Battalion consists of 4 companies, 2 construction and 2 traffic. The remaining regular battalions (2nd, 3rd, and 4th) and the two Trans-Caspian have each 5 companies, 2 construction, 2 traffic and a depôt. On mobilization the depôt company, with the help of reservists, forms 1 battalion of 4 companies, 3 traffic and 1 construction.

Thus, if we allow that the two Trans-Caspian battalions, which in peace work the Trans-Caspian railway, are available, there will be in the European theatre of war (*a*) 12 construction and 12 traffic companies and (*b*) 5 construction and 15 traffic companies; in all 44 companies. Nothing has as yet been done towards forming railway detachments from the *personnel* of the railways.

Russian and German compared.—Comparing the Russian railway organization with the German we see that (*a*) in Germany the 21 railway companies of peace time become 84 companies in war, the constructional companies (63) being three times as numerous as the traffic companies (21). The explanation of this is that it is proposed to hand over the working of railways taken from the enemy to the detachments formed of the railway employés of the national lines. The regular engineer railway companies are only expected to prepare lines taken from the enemy for traffic. When they have put them in order they hand them over to the detachments. The repair of demolished railway lines, as well as the building of new branches, is, in the German army, carried out by the constructional companies. On the other hand, in the Russian army the 27 railway companies of peace time give on mobilization only 44 companies, 17 construction and 27 traffic. It is impossible to concede that these numbers are sufficient and it is imperative to take measures to increase them. It would appear that this could be done without increasing the number of peace battalions. Suppose on mobilization that each active railway company be divided into two companies, then the six battalions before mentioned would give 48 companies and with the depôt companies expanded into battalions as before, 68 companies, 29 construction and 39 traffic.

Besides this it is necessary to form military railway traffic detachments from the "personnel" of the national railways.

[NOTE i.—The formation of these detachments is facilitated by the present law, No. 26 of 1888, by virtue of which the rank and file of the reserve of the army serving voluntarily on the railways are not required to join their units on mobilization, but remain in the railway service; they come, if required, under the orders of the responsible commander of the station.]

The principle accepted in France should be rigidly maintained—that each detachment should be wholly formed from the *personnel* of one national railway company. In all the empires of Western Europe the railway national companies have this obligation imposed on them. It is imperative to introduce it into Russia. The

Ministry of Communications and the Ministry of War should be instructed to arrange it.

The realization of this measure will make it possible (*a*) to increase the number of construction companies by a corresponding decrease of the traffic companies; (*b*), to make available for the active army the two Trans-Caspian railway battalions, leaving the working of the Trans-Caspian railway in war to the before-mentioned railway detachment.

The Instruction of the Rank and File.—Turning to the question of the special instruction of the rank and file of the railway battalions in peace, it is evident that as the two Trans-Caspian battalions are actually responsible for the working of the Trans-Caspian railway, they enjoy a most excellent training, not only in traffic management, but also in maintenance of the permanent way, etc. The Central Asian battalion receives a similar training on the Siberian railway. It appears also that the construction companies of the 2nd, 3rd, and 4th Battalions as a railway brigade, independent of practice in the engineer park, are exercised nearly every year under the orders of the headquarter staff in the actual construction of new lines of railway, occasionally under nearly war conditions.

1890.—Thus in 1890 the 2nd and 4th Railway Battalions constructed the Kavertz-Lutzky branch of the South-Western Railway, seven miles long, under the superintendence of Lieut.-General Golovin.

1891.—In 1891 the 4th Railway Battalion built the fortress railway in Kronshtadt.

1893.—In 1893 experimental broad and narrow gauge lines were laid at Novogeorgievsk under the superintendence of Lieut.-General Bogoloobov.

1894.—In 1894 the following work was carried out:—the building of the railway at Libav, the Orano-Olitsky branch and the rapid construction of the Bielsky-Gainobsky branch of the South-Western Railway.

1895.—In 1895 the experimental construction of fortress lines at Sebastopol was carried out, and lastly

1896–7.—In 1896—1897 the experimental construction of field narrow gauge railway for steam draught at Looblin under the superintendence of Lieut.-General Bogoloobov.

Undoubtedly all these works were of the greatest use, acquainting both officers and men with the practical construction of railways; *but they do not give sufficient practice* in the working of a railway.

There was certainly some practice in this (particularly in the Looblin experiments), but it was far from sufficient, because it was a narrow gauge experimental line and not nearly all the traffic companies took part in it.

Continuous Practice in Working a Line is Necessary.—Therefore, in order that the rank and file of the traffic companies may be up to their work in war, it is imperative that we copy France and Germany and give the men continuous practice in the working of a line. For this object some particular branch of a railway should be handed over to the railway brigade, which should be made responsible for its proper working. A suitable loop line, with a small passenger and goods traffic, is the Prinarevsky railway (Malkin-Ostrolenka Lomka-Lapi, 111 miles long), with two ends (Malkin and Lapi), joining the Petersburg-Warsaw line.

War Conditions Desirable.—This, however, is not altogether sufficient; as the railway battalions in peace serve only as schools for the training of railway employés for carrying out railway service in war time, it is evidently *imperative to teach the officers and N.C.O.'s of these battalions the working of a railway under war conditions as well as peace, e.g.*, to manage heavy traffic, say 16 trains in 24 hours, which is about what would be expected in war, for a period of several days every year.

Bridging, Building.—It is also imperative to practice the rank and file of the construction companies in the erection of iron bridges of a fixed pattern, which should be prepared in numbers approximate to what will be required in war. In France, at the Versailles Engineer Park, there are about a hundred bays of iron bridge, each about 70 feet long. The railway construction companies are practised in turn in putting up and taking down a railway bridge with fixed abutments and piers and fastened together with screw bolts.

NARROW GAUGE RAILWAYS.—Independently of increase of broad gauge railways for strategic purposes at home and abroad, the question of the use of narrow gauge railways, with steam or horse draught, for an army in the field has been much discussed; such railways are generally known as field railways.

Advantages.—The chief advantage of these railways, as compared with broad gauge, is the rapidity with which they can be laid. On this quality depends the special claim made for field railways—that they may replace not only railroads but ordinary roads and may be built anywhere, where a country road is possible. For they render possible (*a*) a considerable reduction in the radius of the curves (40—35 yards), (*b*), the admission of considerably steeper gradients, 55 in 1,000, instead of 8 in 1,000 required on the broad gauge and (*c*) a decrease in the requirements in the strength of bridges, etc.

The small radii of the curves and the increased gradients make it possible to apply the railway to the actual surface of the ground without the necessity of constructing high embankments or deep cuttings.

The carrying power of field railways is not great, 300—700 tons per 24 hours.

The weight of each train of a field railway is not great (about 6½ tons of useful capacity), requiring small draught power and, therefore, only a small strain on the locomotive, which, on the 2-foot gauge, for instance, only weighs from 2½ to 3 tons. This decrease of strain on the locomotive is very important as regards the rapidity of building the line, for the less the weight of the locomotive the less the strain on the permanent way ; so that the ballast and all the sleepers, rails, etc., may be less solid. Similarly, the time required for building bridges may be much curtailed.

Use of Narrow Gauge Railways.—Narrow gauge railways find their use in war under the following circumstances :—

(1). *For Supply.*—For uniting the national railways with the nearest points of the enemy's system . . . for although all the neighbouring empires have extensive railway systems, on declaration of war the country which had at first to remain on the defensive would render unserviceable the sections of the line lying between the frontier and the line of strategic deployment (tunnels and bridges would be destroyed, part of the permanent way removed, embankments torn down).

On the advance of the army towards the frontier and beyond it, its supply would depend on A.S.C. transport. But this arrangement, as it depends on the quality of the roads, is not altogether reliable and very troublesome, especially as the distance between the field army and its points of concentration increase. If it is possible to construct several lines of field railway as the army advances, so that they are in a condition to bring up supplies every day and uninterruptedly, then the burning question of supply is very simply and surely solved.

(2). *For Diversion Lines.*—For the construction of loop lines (to avoid a fortress or some engineering work, *e.g.*, a tunnel which has been destroyed) and for connecting branches with the enemy's lines.

Usefulness Depends on Rapidity of Construction.—The usefulness of a branch railway made in war time depends mainly on the rapidity of its construction. The historical facts as regards the building of railways are as follows :—(*a*). The branch built by the Prussians in 1870 to avoid Metz, $15\frac{1}{2}$ miles long, took 35 days (little less than $\frac{1}{2}$ a mile a day) and was of hardly any use to the Prussians, as its completion was nearly synchronous with the surrender of the fortress ; (*b*), the line Frateshti-Chemnitza, built in 1877, 50 miles long, was constructed at the rate of slightly over a mile a day, but, in consequence of its late completion, did not entirely fulfil the hopes placed in it ; (*c*), the greatest success attained in railway building in war was on the line Bender-Galatz, in 1877 ; 171 miles were completed in 100 days.

If we reject exaggerations and accept the opinion of the commander of the Prussian railway regiment, Taubert, the mean rate of construction of a reliable narrow gauge railway for steam traffic is about $3\frac{3}{5}$ miles (6 kilomètres) per 24 hours, and that this result is amply sufficient to enable us to decide on principle what type of railway should be built in war.

(3). *For Ceinture Railways.*—In fortresses, for connecting the enceinte with the girdle forts and these with each other.

(4). *For Attack of Fortresses.*—In the attack of fortresses, for bringing up the siege park (and other material) from the end point of the railway to the artillery siege park and quarters of the blockading troops. This line will have the character of a ceinture railway all round the fortress attacked. It is evident that for constructing this line in time of war the stores collected in the frontier fortresses for laying fortress railway will be made use of.

(5). *For Temporary Lines.*—For the rapid transport of loads for comparatively short distances (*e.g.*, the arming of a position with siege or fortress artillery, the formation of depôts, etc.). This class of line, having merely to serve for a short time, may have the character of a light portable railway of the Decauville, Dolberg, or Tachtareb type.

Experiments with Narrow Gauge in Germany.—During the last seven years very serious experiments have been carried out in Germany in order to determine the details of the material for field railways with steam draught and, more particularly, practical data for their construction and working. The War Office has not grudged money for carrying out these experiments, as simultaneously with them and with the preparation of the materials for use in war, the railway troops have received most excellent training in the construction and working of the lines. In 1893 the experimental line Elzen Zelle, 42 miles long, was built; in 1895 the line Jenickendorf-Doburg, 57 miles; in 1896 the branch Broterode-Vernshausen, 9 miles; and, lastly, in 1897 the line Werder-Zinna-Buckarsdorf, 49 miles.

The success in building these experimental lines was varied, apart from the powers exhibited by them. Thus the Broterode-Vernshausen line was built by two railway companies in 37 days; as the length was only 9 miles this was poor, only $\frac{1}{4}$ mile a day; it should be mentioned the line was properly ballasted for its whole length.

Forty-Nine Miles Built in Eight Days.—The field railway Werder-Buckarsdorf was built by the men of the 16th Railway Company (*sic*). The aim in view in constructing it was to build 80 kilomètres (48 miles) in 8 days, and in the following 8 days to transport over it part of the artillery siege park (guns and platforms), 32 tons of supplies and the guard siege artillery regiment with its baggage and equipment. It was, therefore, necessary to build the line as quickly as possible, without detriment to its solidity, that it might be uninterruptedly used by heavy traffic from the very opening of the line. For keeping the permanent way in order the line was divided into sections of about 12 miles each.

The survey for the choice of route was carried out before the commencement of work by a special commission. According to the conditions, that no embankments were to be prepared and no depressions levelled up where it appeared possible to use the slopes without exceeding the limit of the gradient, the laying of 49 miles of the permanent way was accomplished in 9 days. There are no details as to how the traffic of the line was worked. This is much to be regretted, as in all probability the very rapid construction of the line to the detriment of its solidity must have affected its carrying power during the first days of its working.

Narrow Gauge Pattern Selected by Germany.—As a result of these experiments Germany selected field railways with steam draught; with 2-foot gauge; limit of gradient, 55 in 1,000; limiting radius of curves, 100 feet; weight of rails, 18 lbs. to the yard; rails in $16\frac{1}{3}$-foot lengths, with 8 metal sleepers (weight 385 lbs.); locomotives, three-axled, weight $7\frac{1}{2}$ tons, $2\frac{1}{2}$ tons on each axle; available carrying power of each wagon, 1,200 lbs.; traffic possibility of the line, 14 trains per 24 hours. The prepared material for the construction of field railways is stored at Thorn and Insterburg.

Austrian Horse Draught.—In Austria railway transport with horse draught finds favour. The lines are of the types (*a*) field (light) and (*b*) fortress. Gauge, 2 feet 4 inches; limiting radius of curves, 40 feet; steepest gradient, 1 in 100. In the field railway the rails are 9·9 lbs. per yard, in the fortress 11 to 13 lbs. per yard; wooden sleepers; rails fastened end to end by hooks on the Dolberg system. Two-axled wagons are used with a useful carrying power of 400 lbs. each; double wagons, carrying 800 lbs., are also made. It is calculated the maximum load (useful and dead) for each pair of horses used is 1,440 lbs. On the basis of experiments which have been made, it is expected to lay 9 miles in 24 hours. Distance between stations, 15 miles.

A train consists of 200 wagons with 100 horses. Such a train will carry 60,000 lbs., *i.e.*, the daily supply of two Austrian army corps. Traffic is only carried on by daylight, from 6 a.m. to 6 p.m. A train can only travel 30 miles a day; for the traffic of 60 miles of line 4 trains are required, 2 loaded and 2 empty. Loading and unloading is carried out at night.

The material for bridges is prepared in peace time, for the light railway wooden, for the fortress lines steel trestles and girders of the Eiffel type.

In Austria there is already the material for the construction of four field railways, each 60 to 65 miles long; it is stored at Olmutz, Kracow, Przemysl, and Stryi. The material of the fortress railway is kept at Kracow and Przemysl.

For the construction and working of each line one railway company is detailed, with a telegraph detachment and a landsturm working party.

Comparison of Steam and Horse Draught.—If the capabilities of the field railway with steam draught and horse draught are compared, it will be seen that the former has greater carrying power, but that the latter can be more quickly built. Premising that on a steam railway 15 trains can be despatched in each 24 hours and the useful load of each train is only 12,000 lbs. (10 wagons), 180,000 lbs. will be delivered every 24 hours instead of the 60,000 lbs. of the horse railway. Thus the carrying power of the steam line is three times as great as that of the horse line. But in solving the question of choice of type for field railways it must be borne in mind that when supplies and stores reach the end of the railway they have still to be distributed to the army, which will be scattered over a wide section and mostly at a long distance from the end station of the railway. Thus, considering the ordinary use of the field railway to replace A.S.C. transport with an army of five to six army corps, it would be better to have three horse lines than one steam line, as the troops would more easily and quickly receive the supplies intended for them. This advantage of the horse line is strengthened by the facility with which it is built, compared with the steam line, as its construction permits the greatest portability, considerably less preparation of the surface and much lighter bridges.

It appears, however, that for fortress railways, as well as those built in war as diversions or branches and ceinture railways round invested fortress had better be for steam draught on account of its greater carrying power.

Preparation of Narrow Gauge Railway that Russia should make.—Turning to the question of field railways as it affects Russia, we ought to have

Stores.—(1). In each of our three frontier military districts a few horse railway parks (about one park to two army corps), each park for 60 miles.

(2). To provide each frontier fortress with steam railway parks; as these parks can be used as already noted in offensive operations, the material may be somewhat greater in quantity than actually required for the needs of the fortress.

(3). Independently of steam railways each fortress should contain a small provision (6 to 9 miles) of light portable railway for transporting heavy weights in view of the necessity of having to rapidly arm a position.

Personnel.—(4). For the construction and working of fortress and field railways it is imperative to form in time of peace (*a*) in each frontier fortress a railway company of the higher establishment, which in war is mobilized in a 4-company battalion; (*b*), in each of the three frontier military districts a railway battalion of the following strength:—(1). Companies for the construction and working of horse railways, one company per two parks; (2), two railway companies—construction and traffic—trained in the construction and traffic of broad gauge railways.

This battalion should in peace be under the command of the

General of the District. On mobilization each company of this battalion should be expanded into two.

The inclusion in this battalion of construction and traffic companies is desirable, as much for the increase of railway troops, of which we have few, as for the fact that the construction and working of horse railways are so simple that if the newly-formed battalion were left to do this simple work only it might degenerate from an engineer into a mere transport unit.

CHAPTER VI.

Some Suggestions as Regards the Engineer Corps.

In conclusion of our article we will make a few suggestions :—

(1). *The Engineer Brigade Staff should not Demobilize on Mobilization.*—We have shown above that in accordance with the *Regulations for the Duties and Organization of the Field Engineer Troops* on mobilization the commander of an engineer company becomes divisional engineer, the commander of a battalion corps engineer.

It would seem desirable that the commander of the engineer brigade, as manager of the specialist instruction of the field engineer units in peace, should fill the position of Inspector of Engineers of an army. But in accordance with the principle laid down in the Regulations for the command of troops in the field, that the chiefs of the sections of the staff of the military districts occupy the posts of corresponding chiefs of sections in the field headquarters of the army, the C.R.E. of the district becomes Inspector of Engineers and the staff of the engineer brigade is broken up, exhibiting itself as the only unit of the army which demobilizes instead of mobilizing on mobilization.

In the interest of the arm it would appear better not to break up this staff, but to attach it as it stands to the staff of an army. The officers of the engineer brigade staff by years of common work are accustomed to work together without friction and would form a most useful nucleus for a new staff, *e.g.*, for the staff of the chief engineer of a siege corps, the staff of a corps engineer of a detached corps, the staff of the military governor of a captured province.

(2). *Suggestions as to the Officers.*—We have already seen the very various special trades in which the lower ranks of the field engineer troops must be trained. For successful training it is indispensable to have in the engineer battalions a very fully trained and reliable staff of officers. At present the engineers are mainly supplied with officers by the Nicholas Engineer School, the establishment of which has lately been considerably increased. However, the supply of officers from this school is still insufficient and the numbers are made up by candidates from the war schools, who are transferred without examination, after being in the school a year and receiving an "approved" certificate. Experience shows that about one-half of the officers enter the engineers thus by transfer.

The newly gazetted officers, not only those from the war schools, but those also from the Nicholas Engineer School, make themselves practically acquainted with the various special duties during the first year and, strictly speaking, only begin to be useful in second year of service; in the third year they can enter the Engineer Academy.

Too Frequent Changes.—The frequent change of officers in the engineer units is a great inconvenience in every way. Tradition, which is the very breath of a unit, is kept up by the officers; if the officers are frequently changed *esprit de corps* disappears. We allow that every officer does not go to the Academy,* but those who do not and remain with the various units, use every effort to get transferred to something, to the Guard, to the cadets' schools as instructors, to the Intendence, to the engineer units quartered at Petersburg; some even try to get into the cavalry.

Slow Promotion.—Deeply regretting the above state of things, it is imperative to explain its cause. The chief reason is that though there is more work in the engineers than in the other arms of the service (they have the same work as the infantry and in addition entrenchments, demolitions, telegraphs, railways, etc.), the promotion is exceptionally slow, notably slower than in the infantry. It is sufficient to say that in the present year, 1898, there are captains in the engineer battalions who entered the army in 1870.

How to Accelerate it.—It is most important to help the engineer officers and quicken their promotion. For this purpose it would seem best to take the following measures:—(*a*). To note the junior field officers of the engineer battalions and the commanders of detached engineer companies (fortress) as candidates for the com-

* Higher Engineer School.

mand of detached infantry battalions as well as of engineer units; (*b*), to introduce a fixed proportion, say 1 to 8, between the commands of engineer battalions given to guard and ordinary engineer field officers; (*c*), to nominate the commanders of engineer battalions to the command of fortress infantry regiments as well as of infantry regiments. It would be very useful if engineer officers exclusively were nominated to command fortress infantry regiments, as in war time the duties of these are almost analogous with those of engineer battalions.

(3). In order to improve the status of officers in the field engineer units, it is imperative to nominate to them officers of the highest military capacity. For this purpose it would seem well to take the two following measures:—

(*a*). To nominate to the command of engineer companies (and afterwards of battalions) officers of the general engineer staff who themselves wish this. Agreement with this solution is unavoidable, as in war officers of the engineer staff* will be undoubtedly included in the active army and will have to superintend the duties of engineer troops with which they have actually nothing to do in peace. This question has been discussed more than once in the military papers, for instance, in our issue in 1878, after the then recent striking experiences of the Russian-Turkish War.

For the practical solution of the above question it would seem possible to accept the same arrangement which obtains for officers of the general staff commanding companies and to lay down that the commander of an engineer company, in whose place an officer of the general engineer staff is commanding for a year, should retain the ration allowed and additional pay allotted to the captain of a company. This would give a well-deserved rest to an officer who had been commanding a company 18 or 19 years. He might during the time perform the duties of second in command of the engineer battalion.

An officer of the engineer staff who received a good report at the end of his time of command of a company might be noted as a candidate for chief of staff of an engineer brigade, and afterwards for the command of a battalion. It is, of course, understood that some fixed proportion must be kept for the field officer of the engineer battalions, so that they are not injured. In our opinion it might be laid down that of eight vacancies in the command of

* Permanent fortress building staff.

independent engineer units, one should be given to the staff officer of the engineers of the guard, one to the general engineer staff, and six to the field officers of the engineer battalions.

Right to Special Promotion of Staff College Graduates.—(*b*). It is to be regretted that officers who have passed the General Staff Academy and are doing duty with engineer troops, do not enjoy the right to accelerated promotion to field officer's rank, which is granted to officers who have passed the Nicholas Engineer Academy. According to a Regulation of 1869, 25 per cent. of the annual promotion to lieutenant-colonel are given to captains of the engineer units who have passed the Nicholas Engineer Academy and have completed four years as captains; besides this, these officers may, by a decision of the Minister of War, be promoted not only in the engineers, but into the infantry, particularly into the fortress regiments.

As in the engineer units captains on an average are promoted to lieutenant-colonel after about ten years' service in their rank, it is very essential, as much in the interest of justice as for the good of the service, to extend the right to officers who have done the two years course at the General Staff Academy; otherwise they will not remain with their units, to the unspeakable loss of the service.

(4). As we mentioned above, in the interest of the service it is desirable to give the corps engineer the right of personal interview with the army corps commander, in the presence of the Chief of the Staff, *i.e.*, to make him immediately subordinate to the army corps commander.

(5). In the frontier districts it is imperative to keep the engineer battalions at war strength; they have so much work to do from the very first day of mobilization that they will not have time to carry out their own mobilization.

PAPER IX.

LIGHT RAILWAYS, AND THE EFFECT OF RECENT LEGISLATION THEREON.

A Lecture delivered by COLONEL G. F. O. BOUGHEY, C.S.I., LATE R.E., *at the R.E. Institute* 30*th November*, 1899.

THE subject to which it is my privilege to ask your attention this evening is Light Railways, and the effect of recent legislation thereon.

What is a light railway? This is a question which has been put to me times without number in the course of the last three years, during which I have had the honour of being one of the Light Railway Commissioners, and since it admits of no concise and exact answer, I have had, when it has been put to me by the man in the street, considerable difficulty in parrying it in order to proceed on my way. Indeed, it is an attempt to answer this question, or rather to assist you in framing an answer for yourselves, that forms my justification for appearing before you this evening.

The railway system of this country is one of which, on the whole, we may be justly proud. Constructed in the most substantial manner, and worked with the aid of every appliance that can conduce to safety, a very remarkable degree of speed, safety, and efficiency has been attained. But this result has only been arrived at by considerable expenditure both in construction and working. This has rendered it impossible to serve districts without any large centres of population, the traffic from which could not possibly be expected to give a remunerative return on the outlay. There are still many districts in England where the cost of cartage to the nearest station varies from 5s. to 10s. per ton. This forms a heavy tax upon agricultural produce, and it led people to think that the system of constructing and working railways in this country was too inelastic, if the needs of these districts, which were being sorely left behind in the struggle for existence, could not be supplied.

The first attempt made by Parliament to deal with this matter was as far back as in the year 1868. In the Regulation of Railways Act, 1868, certain clauses were introduced to facilitate the construction of what were termed light railways. Here we come upon the first authoritative use of the term "Light Railway," and also upon the first definition of a "Light Railway"; for that Act, somewhat rashly perhaps, defined a "Light Railway" to be one upon which the speed might not exceed 25 miles an hour, and the axle load, or weight which could be brought upon the rails by any one pair of wheels, either of a locomotive or of a vehicle, might not exceed 8 tons.

Here I may perhaps say that I venture to think the use of the term "Light Railway" to designate lines of the class we are considering is unfortunate, as it seems likely to give rise to some misapprehension of their character. It is curious that among the many terms which are used upon the Continent of Europe to designate lines of this class there is not one which can properly be translated "Light Railway." They are termed *Chemins de fer vicinaux; chemins de fer d'intérêt local; chemins de fer affluents; chemins de fer secondaires; chemins de fer économiques; secundärbahnen; nebenbahnen; kleinbahnen;* and *localbahnen;* or local, feeder, secondary, cheap, or minor lines, but not light lines.

To return to the Act of 1868. The light railway provisions of this Act proved a failure, and only 11 lines with a total mileage of about 130 miles were constructed under these provisions. There were, no doubt, many reasons for this failure, but looking at the matter only from an engineering point of view, it is clear that if the first essential of a minimum capital outlay is to be complied with, the line must be as far as possible a surface line, with, in many cases, severe gradients and sharp curves. A very light locomotive cannot haul a remunerative load up very steep gradients at ordinary railway rates. The limit of 8 tons per axle was therefore very prejudicial to such lines, for on a gradient of 1 in 40, assuming a tractive force on the level of 10lb. per ton, and an insistent weight of 6 times the tractive force, a locomotive with 16 tons on 2 pairs of driving wheels coupled will only haul a gross load, including its own weight, of about 85 tons, and with 24 tons on 3 pairs of driving wheels coupled will similarly only haul a gross load of about 140 tons. In another way this limit of 8 tons per axle was prejudicial, for it required special locomotives to be obtained instead of allowing the line to be worked by some of the old locomotives of the main line. There seems to have been some idea that on a light railway the trains must be light. But even this object was not attained, for an engine with 24 tons on 3 pairs of wheels coupled would haul just the same load as one with the same weight on 2 pairs of wheels coupled, or 12 tons per axle. The only thing really gained by the regulation in question was that the rails might be a little lighter; but this at the best only resulted in a very trifling economy in the cost of construction.

So far, then, we have rather come upon a description of what is not a light railway than upon anything to help us in determining what is a light railway. But while so little was being done in England other European countries were not idle, and in Belgium alone, in recent years, no less than 1,000 miles of minor lines, mostly on the mètre gauge (3-foot 3⅜-inch), have been constructed at a cost, including rolling stock and all outlay, of rather less than £3,000 per mile, and are paying over 3 per cent. per annum on the whole of their capital. It is pointed out by Mr. Cole in a very useful book which he has recently published, entitled *Light Railways at Home and Abroad*, that we were better off than our neighbours when we had better railway accommodation than they. But the position is now reversed, and the result has been that farmers on the Continent have actually been able to undersell the British farmer in the London market. The pressure of this competition again drew attention to the subject in England, and it was felt that something more must be done to encourage the construction of light railways. This feeling was given expression to by Mr. Acworth, who very pertinently asked why, if light railways are useful to foreign farmers, must they be useless to English farmers? A conference was held at the Board of Trade at the end of 1894 and the beginning of 1895, at which the subject was thoroughly discussed, and a committee was appointed to report:—

(1). How far the usual requirements of the Board of Trade as to constructing and working new railways may fairly be relaxed, especially in the case of lines built through sparsely populated and agricultural districts.

(2). Whether additional legal facilities for obtaining powers to construct tram roads and light railways are necessary or desirable. The result was the passing of the Light Railways Act, 1896.

This Act, in the first place, greatly cheapened the procedure necessary for obtaining the authority for constructing a light railway by the appointment of three Commissioners, who were to hold a public inquiry on the spot in the case of every application for a light railway made to them. This greatly reduced the expense of obtaining the necessary authority, which, previously, could only be got by the costly process of obtaining a private Act of Parliament. Secondly. The Acts of Parliament, which were generally applicable to all railways, and in particular the enactments requiring the use of continuous automatic brakes on passenger trains, the inter-locking of points and signals, the provision of gates at level crossings, and other matters relating to the public safety, which were obligatory on all railways, were declared not to be applicable to light railways unless specially applied to them by the Order authorizing the line. Thirdly. Any county, borough, or district council was empowered to apply for authority to construct and work a light railway, or to advance money to a light railway company by way of shares or loans, and there was power to charge upon the rates any deficiency of interest on capital not provided from the profits of working. Fourthly. The Treasury was empowered, at its discretion, to make loans, or in special cases free grants of money, out of funds specially allotted for these purposes. Lastly. An Order made by the Commissioners was to have no effect until confirmed by the Board of Trade, who were specially charged with seeing to the safety of the public, and who were directed not to confirm an Order if by reason of its magnitude, or of its effect on the undertaking of an existing railway, the proposal ought, in their opinion, to be submitted to Parliament.

From this very general description of the principal provisions of the Act of 1896 it will be seen that, very wisely, no attempt was made to define a light railway. The only definition attempted was the negative one, that a line of considerable magnitude, or which competed with an existing railway, was not a light railway. But, subject to this, the Commissioners, and specially the Board of Trade, were left free to impose such conditions as they thought proper, particularly in the matter of public safety, and, in short, were left face to face with the question—What is a light railway?

The views of the Commissioners and of the Board of Trade as to what constitutes a light railway will be found in the various Orders authorizing the construction of light railways, of which a considerable number have now been issued and published, and can be purchased.

The first and principal point which differentiates a light railway from an ordinary railway is that light railways are essentially lines of limited speed. It is clear that a limitation of the maximum speed is the foundation for any economies that may be effected in the cost of construction, or in relaxing the precautions to be taken for the safe working of trains. When the maximum speed is limited, the cost of construction can be reduced to a minimum by making the line follow closely the surface of the ground by the use of sharp curves and severe gradients, which would not otherwise be permissible. The permanent way, too, may then be of a type which would not be up to the requirements of first-class lines of unlimited speed. In this way the cost of construction may be greatly lessened, and, similarly, the staff and appliances necessary for the safe working of trains few in number and of limited speed may be sensibly reduced. The Commissioners and the Board of Trade have accepted the maximum speed of 25 miles an hour prescribed for light railways by the Act of 1868, and in no case up to the present has a higher maximum speed been allowed than 25 miles an hour for a line of the standard 4-foot 8½-inch gauge, though in some cases a lower maximum has been laid down. On the Continent the maximum speed usually varies from 18 to 27 miles an hour. In France it is left to be determined by the Prefect.

The maximum speed being settled, the minimum radius of curves is governed by it. For lines of the standard gauge with a maximum speed of 25 miles an hour the Light Railway Orders issued prescribe a normal minimum radius of curves of 9 chains, or, say, 600 feet. Round curves of less radius than this, speed must be reduced to 10 miles an hour, and a guard rail must be provided inside the inner rail of the curve. It is usual to limit the maximum speed to 20 miles an hour on long inclines with gradients steeper than 1 in 50. On a line which was almost entirely curved, with hardly any straight portions, and with many curves of 600 feet radius, and many gradients of 1 in 50, the maximum speed allowed was 20 miles an hour.

The above figures are for lines of the standard gauge. An order has been issued for a line from Leek to Hartington, a portion of which, about 8 miles in length, is in a difficult country, and has a gauge of 2 feet 6 inches, with a ruling gradient of 1 in 40. For this line a maximum speed of 15 miles an hour has been prescribed and a minimum radius of curve of $4\frac{1}{2}$ chains, say, 300 feet, unless otherwise specially sanctioned by the Board of Trade, in which case the speed over curves of lesser radius is not to exceed 10 miles an hour.

The next point to be considered is as to the weight of rail to be adopted, and the weight it has to carry, that is, the maximum load that can be brought on to the rails by any one pair of wheels. Here, as everywhere, the maximum speed is the chief determining factor, for a lighter rail in proportion to the load can be allowed on lines with limited speed than on those with unlimited speed. The orders issued allow of 50-lb., 56-lb., 60-lb., and 70-lb. rails, with corresponding axle loads of 10, 12, 14, and 16 tons respectively. It is not desirable to have too light a rail, especially where there are sharp curves and gradients. The rail I would recommend for lines of the standard gauge, and for all but very special cases, is a 60-lb. flat-footed rail with a maximum axle load of 14 tons. This has the advantage of being within the limit of weight of a large proportion of the locomotives on existing lines, so that the branch line could be worked by locomotives from the main line without having to obtain special ones for the purpose. Old rails, which are still in good condition, but are no longer fit for the heavy weights and high speeds of main line traffic, may well be used on these lines. The supply of these at low rates is an important way in which main lines may assist light railways, and at the same time secure the construction of useful feeders to themselves.

I now come to the matter of crossing public roads. We have seen that the line must be as far as possible a surface line in order to carry out the condition of a minimum cost of construction. This is also necessary, because there must be frequent stations or goods sidings in order to serve the district properly. It is, therefore, unavoidable that many roads shall be crossed on the level. Main roads carrying a fair amount of traffic must, of course, be provided with gates and gatekeepers if they cannot be passed under or over the line by bridges. But if for the reasons already given, that is to say, either on the ground of economy, or in order to have a station at or near a main road, it is necessary to cross it at about the level of its surface, it is not in the interest of the locality to make a hump some 16 or 17 feet high in an otherwise fairly level road in order to carry it over the line by a bridge. It is better to have gates and a gatekeeper. The orders issued, recognizing that the number of trains on light railways are not likely to be numerous, provide that the gates shall be kept closed across the railway except when required to be opened for the passage of trains. The road traffic is thus unobstructed except for the passage of some six or eight trains daily, three or four in each direction, and trains cannot pass unless they see that the line is clear.

But there are many other roads of various classes, down to mere country lanes, on which the traffic is light, and which cannot be so fully protected. On the Continent of Europe, as a rule, such crossings are not guarded or protected in any way. If light railways in this country are to be constructed and worked economically, people will have to get accustomed to level crossings, and to look out for themselves as they do on the Continent, or, indeed, as everyone must do when merely crossing a street in a town. Parliament has granted to the Board of Trade full discretion as to what regulations affecting the public safety shall be applied to light railways, and by so doing appears to have recognized the principle that the same precautions are neither possible nor necessary in the case of light railways as for ordinary railways. The matter has been dealt with in the orders issued by requiring gates at certain specified roads, which include all the principal ones, and on roads of less importance, where the line is fenced, which in this country is generally the case, what is known as an American cattle pit, or cattle guard, is required to be provided. These are a novelty in England, but they have been successfully used in other countries, and even as near to us as in Ireland. They consist simply of a shallow open culvert some 4 feet wide, cut across the railway, and bridged over by the rails. In some cases they are covered with a grating of wood or angle iron set edgewise, which animals will not put their feet upon. Animals passing along the road are therefore prevented from leaving the road and straying upon the railway. The speed is ordered to be reduced to 10 miles an hour, or less if the Board of Trade so require, for 300 yards before passing over the crossing, and a notice board has to be put up on the road 50 yards on each side of the crossing. There is also power to the Board of Trade to require gates at any of these crossings if hereafter found necessary. With all these precautions there is no reasonable prospect of danger, and it is to be hoped that in time the public will be satisfied that they are sufficiently protected.

I have mentioned that orders have been issued for light railways of at least two different gauges, the standard gauge and a 2-foot 6-inch gauge, so I must say a word about gauge. But there is already a good deal of literature on the subject, and I have no desire to add to it. In Mr. Cole's book, which I have already alluded to, there is a whole chapter on the question of gauge. There is, or was, a very general impression that a light railway must be a narrow gauge line. This is not so, and I will endeavour to state shortly my own personal views on the subject of gauge as affecting light railways, and leave you to form your own opinions on the question. A light railway or branch line should be of the same gauge as the main line unless there are sufficient reasons to the contrary. But in a difficult country, where the sharp curves admissible on a 2-foot 6-inch gauge line would admit of a considerable saving in the cost of construction, and where there is a sufficient area to be served, and consequent length of line to make that saving important, and to justify the provision of special rolling stock, and specially where the branch leads direct into a market town so that a considerable proportion of the goods traffic will not need to be transhipped—in such cases, I think, the adoption of a 2-foot 6-inch gauge would be justifiable.

There is a strong feeling in England against a break of gauge which cannot be ignored, and I do not wish to underrate the cost and delay due to transhipment. But in the case I have mentioned I think there are sufficient reasons for encountering the disadvantages of a break of gauge. In such a case full advantage should be taken of the flexibility and economy of a very narrow gauge, and I have no hesitation in expressing my preference for a 2-foot 6-inch gauge where the standard gauge has to be departed from. Modern designs of locomotives and rolling stock enable a line of this gauge to carry a considerable traffic with good and economical train loads, as I think those of you will admit who saw the rolling stock for the Barsi light railway in India, which was exhibited at Leeds some three years ago. With no load brought upon the rails by any one pair of wheels greater than five tons, a locomotive with four pairs of wheels coupled, or 20 tons on the driving wheels, was capable of hauling, including its own weight, 750 tons on the level, or 110 tons on a gradient of 1 in 40, in bogie wagons of a gross weight, including tare and load of 20 tons each, and was going round curves of, I think, only 150 feet radius.

There is yet one more important point which the engineer must consider before he can proceed to lay out his line, and that is whether the line must be taken across country on land to be acquired for the purpose, or can be laid along the side of a road. Land in England is valuable, especially when required for a railway. A light railway can seldom do with less than an average width of one chain (66 feet) or 8 acres per mile, and this at £100 per acre comes to £800 per mile. Naturally, therefore, where there is a nice green along the side of a road, an engineer looks at it with longing eyes. There is at least one line in England which is laid on the side of the road. This is called the Wisbech and Upwell Tramway, but it is for all practical purposes a light railway, or branch of the Great Eastern Railway, about 5¾ miles in length. It is laid on the side of a very wide road in Cambridgeshire. It is a very interesting line of its kind, and does not appear to cause any practical inconvenience to the traffic on the road. Lines along the side of roads are more common in Ireland, where the exclusive use of a strip by the side of a road is allowable, provided that a width of not less than 18 feet of roadway is left untouched. The objections to the use of the side of a road are that this commonly involves bad gradients and sharp curves, which form a permanent increase to the cost of working, and it is often necessary to diverge from the road and acquire land in order to avoid them, or to pass behind a village. If the road is near a town, and the land along it is likely to be built upon, the presence of a railway on one side of the road would be prejudicial. And, lastly, the maximum speed would probably be reduced from 25 miles to 15 miles an hour, or less, when running on the side of a road. It is, therefore, only in exceptional cases of a very wide road with good gradients and curves that a light railway can appropriate a part of it for its exclusive use.

The engineer may now proceed to set out the line in accordance with the principles I have indicated, and in doing so it is only necessary for him to bear in mind this one additional point—that the line is not required to be a direct line from point to point, but rather a circuitous one, laid out so as to serve as many centres of traffic and population as possible. To sum up, I would say that the principles affecting the construction of a line as a light railway are as follows :—A light railway being one of limited speed, advantage should be taken of this to make it as far as possible a surface line with sharp curves and severe gradients. The weight of rail to be adopted must be suitable to the speed and the maximum axle load. The crossing of public roads on the level must be accepted. The gauge should ordinarily be the standard gauge of the country, but if it has to be departed from, a 2-foot 6-inch gauge should be adopted. The line should ordinarily run on land to be acquired for the purpose, but may run by the side of the road in exceptional cases where there is a strip of waste available for the exclusive use of the line. And, lastly, the line should be laid out so as to serve as many centres of traffic and population as possible, rather than in a direct course from point to point.

For actual details of construction I cannot do better than refer you to those laid down in France for lines of local interest in a decree of August, 1881. These regulations do not prescribe a maximum speed, which is left to be determined by the Prefect. They deal with three gauges — 4-foot 8½-inch, one mètre (3-foot 3⅜-inch), and three-quarter mètre, or 2-foot 6-inch, and prescribe standard dimensions for all these gauges on the following amongst other points :—

Rails.—60-lb. iron or 50-lb. steel for the 4-foot 8½-inch gauge. For other gauges weights to be prescribed.

Ballast.—14 inches deep. The width at top to be equal to the greatest width of vehicles.

Formation.—Width to be such as to give 3 feet on each side beyond the toe of slope of the ballast.

Curves.—Minimum radius :—

4-foot 8½-inch gauge ...	...	...	...	820 feet.
3-foot 3⅜-inch gauge ...	...	...	...	328 „
2-foot 6-inch gauge ...	...	...	...	164 „

Gradients.—Not to exceed 3 per cent. except in exceptional circumstances.

Straight or Level Portions between Opposite Curves and Gradients.—200 feet for the 4-foot 8½-inch gauge; 130 feet for smaller gauges.

Level Crossings.—Types of barriers to be determined by the Prefect. Gatekeepers' houses may be dispensed with at little frequented crossings.

Fencing.—Permission may be granted to dispense with fencing, except—

(*a*). In crossing inhabited places ;

(*b*). In parts contiguous to public roads ;

(*c*). For a length of 10 mètres (33 feet) on each side of level crossings and stations.

Standard dimensions for rolling stock and fixed structures are also prescribed.

From a report made by Colonel Addison on light railways in Italy I find that a classification has been drawn up giving four or five different types of secondary railways, fixing in each the gauge, the weight of rail, the maximum curvature and gradients, the maximum speed, the minimum width of formation, depth of ballast, etc. If a new line is proposed it is only necessary to select one of these types.

In India complete standard dimensions have been laid down for the 5-foot 6-inch and mètre gauges (3-foot $3\frac{3}{8}$-inch). The 4-foot $8\frac{1}{2}$-inch gauge is not in use in India.

A line having been constructed as a light railway, we have now to consider how it may be worked as a light railway. I have heard it said that the only thing about a light railway that is light is the traffic. From the nature of the case the traffic must be light, and these lines cannot be made to give any return on their outlay unless worked in the most economical manner. Here, again, speed is the ruling factor, and precautions which are necessary in the case of lines of unlimited speed with trains following one another at short intervals may safely be relaxed in the case of lines with few trains and restricted speed. The most important of these requirements are those which relate to the provision of continuous automatic brakes on passenger trains and the interlocking of points with signals.

As regards continuous automatic brakes, it appears from Mr. Cole's book on light railways that they are frequently dispensed with on the Continent when the speed does not exceed 18 to 25 miles an hour. Mr. Cole quotes from the proceedings of the International Railway Congress of 1892, a table showing the percentage of brake power to gross weight of train for speeds up to 24 miles an hour and on different gradients, recommended by the "Union des chemins de fer Allemands," and apparently, he says, adopted in Austria-Hungary. Mr. Cole's book also contains a valuable note by Mr. Hodson, Director of Construction, Indian State Railways, on the theory of brake power. In India I have been accustomed for many years to work long lines with considerable traffic without continuous brakes on passenger trains running at speeds considerably above 25 miles an hour, and it is only now, when speed and traffic are considerably increasing, that automatic brakes are being adopted in India, even on the main lines. A very light traffic can only be economically worked by mixed trains of passengers and goods. A very large proportion of the traffic in India is carried in mixed trains. The goods stock is of a good type, and is fitted with screw couplings. It is placed in front of the passenger vehicles for convenience of shunting at roadside stations, and consequently there are no continuous brakes, though mixed trains consisting of 30 vehicles and upwards are not uncommon. In England, however, the orders issued for light railways almost invariably require the use of continuous brakes on passenger trains.

Similar remarks apply to the interlocking of points and signals. Again referring to Mr. Cole's book I find that on German light lines there is power to dispense with fixed signals, and even with point indicators on facing points. In India I have long been accustomed to facing points unconnected with signals, and subject only to a restriction of speed over them to 10 miles an hour. The orders issued for light railways in England provide that at crossing stations there shall be a home signal for each direction at the entrance points, and that precautions shall be taken that no signals shall be lowered unless the points are in the proper position, and that two conflicting signals cannot be given.

Platforms may also be dispensed with if convenient means of access to the carriages are provided. This is an important item of economy in construction, for platforms, though convenient, are costly in the amount of underground work required, not only for themselves, but to raise all the station buildings to the same level. On the Continent they are frequently dispensed with even on main lines. In India, for new intermediate stations, I have often sloped the platform up from the rails at a slope of, say, 1 in 20, and set the permanent or temporary buildings far enough back from the rails, so that their floor should be high enough to enable a platform to be built hereafter if necessary.

Shelters and conveniences at stations must await the development of traffic. With such a platform as I have described trains can stop alongside every important road, and thus foster traffic as much as possible.

The use of special instruments for block signalling may be dispensed with, and replaced by a telephone. Or, though it does not appear to find favour in England, the Indian "Line clear system" might be adopted. In India a very considerable traffic is conducted under this system on single lines. It consists simply, under a code of regulations, in furnishing the driver with a copy of a telegram from the station ahead stating that the line is clear, and authorizing him to proceed. The orders for light railways in England provide that if the Board of Trade require electrical communication to be provided, it shall be provided in such manner as the Board may direct.

I now come to the question as to what would be the cost of constructing and working a light railway in the manner described, and what it may be expected to earn. In Belgium 1,000 miles of minor lines have been constructed at a cost, including rolling stock and all outlay, of rather less than £3,000 per mile. These are mostly on the mètre gauge (3-foot $3\frac{3}{8}$-inch), and as many of them appear to be laid on the roads, the cost of land is very small. They earn about £6 per mile per week. The working expenses are about 66 per cent., or £4 per mile per week. The net earnings of about £2 per mile per week give a return of over 3 per cent. per annum on the capital. In England a line on the standard gauge with no heavy works would probably cost about twice as much as the Belgian mètre gauge lines, or, say, £6,000 per mile. It is not unreasonable to assume that it will earn £10 per mile per week, and can be worked for 60 per cent., or £6 per mile per week, which would give a return of about $3\frac{1}{2}$ per cent. per annum on the capital.

As instances of what is being done in the United Kingdom, I may mention the Wisbech and Upwell line in Cambridgeshire and the Clogher Valley Railway in Ireland. The Wisbech and Upwell line is on the standard gauge, with a 50-lb. rail, and runs for the most part on the side of the road. The length of line constructed is $5\frac{3}{4}$ miles, with 2 miles of sidings, at a cost of rather more than £7,000 per mile of line, excluding sidings. The earnings are about £9, and the expenses about £7 per mile per week. The Clogher Valley Railway, 37 miles in length, 3-foot gauge, 45-lb. rail, runs also for the most part on the side of a road. It has cost about £3,500 per mile. It earns about £4 per mile per week, and though worked very economically, practically the whole of this is absorbed in working expenses.

The question of the rates to be charged for goods traffic on light railways is an important one. It does not follow that because a light railway is constructed at a much lower cost per mile, and is worked in a less expensive manner than a main line, it can carry goods at lower rates, or even at the same rates as a main line. If a branch costs, say, half as much per mile to construct as a main line, but cannot hope to deal with a quarter of the amount of traffic per mile carried by the main line, it cannot afford to carry its traffic at main line rates, at any rate until its traffic has developed to a considerable extent. Moreover, in many cases the saving in cost of construction is largely due to severe gradients and curves, which will add to the cost of working traffic over them. Consequently many of the orders issued contain a provision that the maximum rates for the carriage of goods may be 25 per cent. in excess of those on the adjoining main line, but with power to the Board of Trade to revise these rates at the end of the first five years. This seems a reasonable provision, and will still enable a light railway to effect an enormous saving on the cost of carting, which may be approximately put at 1s. per ton per mile.

So far I have only spoken of lines which, constructed like ordinary railways, take their own line across country, or appropriate to their exclusive use a strip alongside a road. But street railways also, at least in some cases, come under the definition of light railways. By street railways I mean what are commonly known in England as tramways, and in which the use of the road is shared jointly with the ordinary road traffic. Several orders have been issued for lines wholly or partly of this class, and you will probably have one here before long, as an order has been issued for a line of this class to serve Chatham and the surrounding districts. Tramways, for reasons which I need not now discuss, have never been popular in England, though in Europe and America they have been largely employed. The wonderful development in recent years of electric traction, which seems especially suitable for lines of this class, has drawn attention to this class of lines in England. Electric traction would in itself form a most interesting subject for a lecture. In America, with the rapidity characteristic of that great country, a magnificent system extending to some 15,000 miles of town and country roads has already sprung up, and Switzerland contains some interesting examples of the use of electric traction. Within the last few days I have read in the newspapers that Lord Charles Beresford told the members of the Institute of Mechanical Engineers that the traveller could go from the station to the city of Pekin by electric traction. You are not at present, therefore, quite as advanced in this respect here as at Pekin, but, as I have just said, it is likely that this reproach will be removed before long. In this country a small commencement has been made, and systems are already at work in Bristol, Middlesbrough, Dublin, the Isle of Man, and other places, and in several large towns the existing tramways are being converted and extended for electric traction. There are signs of a large development of electric traction for street railways in England, and it cannot be doubted that there is a great future in store for lines of this class.

The title of my lecture requires that I should say something in conclusion on the effects of recent legislation on light railways in England. As to this I cannot do better than refer you to the two reports, for the years 1897 and 1898 respectively, of the Proceedings of the Light Railway Commissioners and of the Board of Trade, which have been presented to Parliament by the Board of Trade in compliance with the Light Railways Act, 1896. These are published, and the report for the year 1899 will be presented to Parliament when it re-assembles, and will then be available to the public. I have prepared a tabular statement giving the statistics of light railways under the Act of 1896 up to a very recent date, and I will shortly summarize a few of the leading figures. We have seen that in the 28 years, from 1868, when Parliament first decided to encourage the construction of light railways, up to the passing of the Act of 1896, the mileage constructed was quite insignificant. In the matter of tramways, or, as I prefer to call them, street railways, England was far behind other countries. The few lines that existed were mostly worked by horses, a few were worked by steam, and electric traction was just beginning to be introduced. The horse and steam lines were in many cases anything but a commercial success.

The passing of the Light Railways Act, 1896, brought about a remarkable change in this state of things. The Light Railway Com missioners in their reports have separated the lines into two classes, which they call A and B, and which correspond with the two classes to which I have referred, namely, ordinary light railways or Class A, and street railways, or Class B. In the three years since the passing of the Act we have the following figures :—

CLASS A.—*Ordinary Light Railways.*

No. of lines applied for	110
Mileage	1,425 miles
Total of construction estimate, excluding rolling stock	£7,907,953

No. of lines approved by the Light Railway Commissioners	70
Mileage	$786\frac{1}{2}$ miles
Total of construction estimate, excluding rolling stock	£4,348,299

CLASS B.—*Street Railways.*

No. of lines applied for	105
Mileage	791 miles
Total of construction estimate, excluding electrical equipment and rolling stock	£6,371,026
No. of lines approved by the Light Railway Commissioners	46
Mileage	$225\frac{1}{2}$ miles
Total of construction estimate, excluding electrical equipment and rolling stock	£1,661,402

These are large figures, and show what a considerable impetus was given to the promotion of lines of both classes by the Act of 1896. Of course the raising of capital, acquisition of land, and construction of the line take time, and though several of the lines have surmounted their preliminary difficulties and are now under construction, it is too soon yet to form any opinion on their financial prospects, or the benefits they will confer on their respective districts.

The difficulty of raising the capital is, of course, in some cases great, and especially in the poorer districts. It is to be feared that in some cases this difficulty will prove insurmountable, even with such aid as is to be obtained from the State, and from local authorities. In most, if not all, European countries it is recognized that these lines cannot, at any rate for some time, earn a sufficient interest on their capital, and assistance is granted both by Imperial and local authorities. This usually takes the form of a contribution to the capital, or of an annual subsidy for a limited number of years. The most complete system is in Belgium, where a National society for local railways has been constituted. This society, which is practically a Government department, itself constructs and works the lines sanctioned, keeping separate accounts for each line sanctioned. At the end of 1897 it had a capital of nearly £4,000,000 sterling contributed in the following proportions :—

By the State	29·5	per cent.
By local authorities, *i.e.*, provinces and communes	67·8	„
By private persons...	2·7	„

The result may be considered most satisfactory. As already stated, nearly 1,000 miles were open for traffic, and earning over 3 per cent. on their capital.

In England the amount of assistance promised by Imperial and local authorities has, so far, been small. The Treasury have promised sums amounting in all to £121,000 to nine lines, and in the various orders provision has been made for local authorities either to make loans or take shares to a total amount not exceeding £109,100. In one case of an ordinary light railway, and in several cases of street railways, local authorities have themselves undertaken to raise the capital and construct and work the line. But taken as a whole, it is generally left to the promoters of a line to raise the capital, and the amount of assistance from Imperial and local authorities is very small. The experience of Belgium shows, I think, two things—Firstly, the extreme difficulty in raising the capital; and, secondly, that a moderate return on the capital may reasonably be expected. The amount of capital found in Belgium by private investors is insignificant, and far below what it should be. I venture to think that Imperial authorities, local authorities, and private investors might each contribute one-third of the capital. In the case of public authorities the sum might be limited to a maximum sum per mile, say, £2,000 to £2,500 per mile from each of the two classes of public authorities. And I think that the contribution from Imperial funds need not necessarily be a free grant, but might be entitled to rank for dividends after payment of a moderate dividend on the other capital.

The value of light railways as feeders to the main lines is great, and therefore some assistance may not unreasonably be looked for from main lines. The most practical form which this assistance would take is probably the provision of junction facilities without cost to the new line, which appears to be frequently done on the Continent; also the supply of serviceable old rails, and the working the line and supplying rolling stock on liberal terms. A branch line, even if of different gauge, can be worked better and cheaper by a main line than by a separate administration, and this plan offers the greatest advantages to the public, the branch line, and the main line.

Lastly, the experience of Belgium as to the direct return on capital is encouraging, though it emphasizes the need for a very low cost per mile, and for great economy in working. The indirect benefits conferred on the districts served by light railways make the matter one of vast importance. The demand for light railways has, as I have shown, been felt in England at least for the last 30 years; the Light Railways Act, 1896, has so far brought forth a very encouraging response, and with such improvements as experience may suggest, there is every reason to anticipate that great and lasting benefits will result from it.

The Light Railways Act, 1896.

Tabular Statement showing Applications separated under Class A and Class B up to the 18th November, 1899.

		Applications.			Approved.			Rejected.			Withdrawn.			Postponed.			Not dealt with.			Orders sent to the Board of Trade.		
		No.	Mileage.	Estimate.	No.	Mileage.	Estimate.	No.	Mileage.	Estimate.	No.	Mileage.	Estimate.	No.	Mileage.	Estimate.	No.	Mileage.	Estimate.	No.	Mileage.	Estimate.
	Class A.																					
I.	Dec., 1896...	19	231	875,672	12	115½	470,537	5	87½	329,105	1	9½		1	18½	76,030				11	107¾	571,663
II.	May, 1897...	20	230¼	1,264,791	16	195	1,068,905	2	14	42,730	2	19½	88,555							14	167¾	830,964
III.	Nov., 1897...	14	167	818,758	10	114¾	560,903	2	20½	130,094	2	25½	111,543							9	93¾	458,903
IV.	May, 1898...	17	301½	1,723,672	6	60¾	363,675	9	121¾	650,963	1	14¾	71,000				1	97	598,977	5	53	326,315
V.	Nov., 1898...	22	256	1,577,267	13	147¼	1,003,653	5	60¾	357,117	2	11½	58,537	1	7¾	69,254	1	4½	11,496	12	141¾	947,277
VI.	May, 1899...	18	238¾	1,647,793	13	153¼	880,626	2	37½	431,157	2	27¾	224,897				1	12¼	74,735	1	—	—
	Total......	110	1,425	7,907,953	70	786½	4,348,299	25	342	1,941,166	10	108½	554,532	2	26¼	145,284	3	113¾	685,208	52	564	3,135,122
	Class B.																					
I.	Dec., 1896..	9	76¾	469,577	5	39¾	236,412	3	20	137,559	1	12½	68,685							5	39¾	236,412
II.	May, 1897...	8	43	293,032	4	30½	177,071	1	2	11,228	3	10½	104,733							4	33	197,531
III.	Nov., 1897...	16	125½	966,021	6	26¼	200,545	6	60¼	403,918	4	28¼	223,839							6	27¼	223,982
IV.	May, 1898...	18	128¾	1,144,453	11	38¾	353,188	4	59	453,486	3	21¼	207,466							9	35¼	299,501
V.	Nov., 1898...	32	244	1,767,195	15	69	504,660	10	88½	702,783	6	55¾	345,491	1	7	56,340				7	32½	201,448
VI.	May, 1899...	22	173	1,730,748	5	21¼	189,526	2	28¾	331,776	1	14½	129,276				14	108½	1,080,170			
	Total.....	105	791	6,371,026	46	225½	1,661,402	26	258½	2,040,750	18	142¾	1,079,490	1	7	56,340	14	108½	1,080,170	31	167¾	1,158,874
	Grand Total	215	2,216	14,278,979	116	1,012	6,009,701	51	600½	3,981,916	23	251¼	1 634,022	3	33¼	201,624	17	222¼	1,765,378	83*	731¾	4,393,996

* Representing 86 Applications.

PAPER X.

THE BIOLYSIS OF SEWAGE.

By W. D. Scott-Moncrieff, Esq., Fellow San. Inst.

In the last lecture an attempt was made to indicate certain lines of advance upon which practical sanitation as applied to domestic and public buildings is moving, in the direction of stronger materials and less complicated parts.

Certain methods which have been introduced recently for the purification of sewage by purely natural means, and without the use of chemicals, will now engage our attention. These are now generally known as bacterial processes, to which I have given the name "Biolysis."*

Before proceeding to explain these methods I must make a grateful acknowledgment of the facilities which have been afforded me by the War Department for dealing with the exceptionally strong sewage from the barracks at Caterham. I shall specially refer to this installation, as well as to what are known as the Ashtead experiments, which supplied the necessary data for the construction of the large installation.

* The terms bacterial or bacteriological, which are frequently used, do not suffice to convey the proper meaning, because the processes do not depend upon the work of micro-organisms alone, but also upon the action of substances produced by the life processes which occur in digestion. The breaking up of organic matter is mostly carried out by a combination of digestive and bacterial activity, and may, therefore, be spoken of more correctly as biolytic.

In trying to make the subject clear to you I am afraid this lecture must be more or less of the nature of a personal narrative of my experiences in advancing step by step towards a final solution of the problem, and there can be no better introduction than a reference to the monumental labours of Pasteur. It may be surprising to many of you that sewage should form the subject matter of such lofty labours as those of the great Frenchman. As a matter of fact, he did very little work directly upon its purification, but nearly all the knowledge he acquired and communicated on fermentation, and the part played by micro-organism in fermentative changes, bear directly upon the solution of the sewage problem and the conversion of the waste products of life to the uses of the living. The chemist had utterly failed by the aid of chemical processes to accomplish what these humble agents are continually doing to perfection, and the sewage problem remained unsolved until their functions had been investigated, and their beneficent processes applied.

That the task of discovering and utilizing these functions has been no easy one may be gathered from the fact that they had until quite recently escaped the notice of the most accomplished experts in the science of bacteriology, and this is borne out by the disparaging criticisms made in journals devoted to scientific subjects, which until quite recently jeered at the efforts of pioneers in biolysis as the labours of ignorance.

It is almost unnecessary for me to point out that the organic substances which occur in sewage from civilized communities must necessarily be of the most complicated description. There is not a vegetable substance, either wholesome and fitted for food or poisonous and fitted for medicine, but finds its way into the sewers of our towns. These substances represent nearly the entire range of combinations not only in the vegetable but in the animal kingdom as well, but the final result of a complete breaking down of these almost infinitely elaborated materials and their return to the inorganic form from which they were originally built up may be expressed in a single sentence. Their final mineralization takes the form in varying proportions of the following substances:—Nitric acid (HNO_3), sulphuric acid (H_2SO_4), phosphoric acid (H_3PO_4), carbonic acid (CO_2), and water (H_2O). The solution of the sewage problem is the solving of the riddle how these final and comparatively simple molecular forms can be attained without the aid of chemicals, by purely natural means, and on the largest scale without incurring undue expense, without creating a nuisance, and without danger to health.

One preliminary point with regard to the composition of sewage has not been sufficiently appreciated. It is made up of the waste products of life, diluted with water, which contains large quantities of dissolved oxygen, as much as 7 c.c. of free oxygen per litre being commonly present in ordinary tap water. It is well known that outfall sewage contains little or no dissolved oxygen, and the disappearance of the free oxygen in the tap water has therefore to be accounted for, either by supposing that it directly attacks the organic matter, and oxidizes it, or by some other explanation. Now we know that the dissolved oxygen in the water attacks complex organic substances very slowly, and that the disappearance of the free oxygen from the tap water is nearly wholly accounted for by the presence of vast numbers of organisms in the sewage and the sewers which use it up, and in doing so liquefy the solid organic substances contained in it. It was this obvious fact of the wonderful liquefaction which went on in the sewers of our great communities which first set me thinking that nature might be capable of purifying sewage without the aid of chemicals, and which started me upon lines of enquiry, which have closely occupied my time and my thoughts for more than seven years. There was no literature available at that time, not even the researches of Pasteur, or the great work of Warrington upon the nitrification of organic matter in the upper layers of cultivated soils, that could suggest any direct means of applying these investigations to the purification of ordinary sewage as a whole, and the well-known reports of the Massachusetts State Board of Health upon the bacterial action of different kinds of filters never dealt with the main part of the problem, the anærobic and ammonia changes, at all.

The building of the house in which I am now writing these lines afforded an opportunity for making experiments on a practical scale, and in 1891 I erected the apparatus which I shall now show to you for dealing with the sewage from my own household, which consisted of about 10 to 12 persons. The arrangement is shown on *Plate* IV., *Fig.* 1, and on *Plate* I., *Fig.* 1 being a plan, *Fig.* 2 a longitudinal, and *Fig.* 3 a transverse section of what has been since generally called a "Cultivation Tank." The tank is 2½ feet wide, 10 feet long, and about 3 feet deep at the deepest part. The entire sewage and waste water from the house, with the exception of the grease, which is kept back by a properly constructed grease trap, finds its way into one end of the tank at the point G. The liquid portion rises through a perforated grating E, and then through a layer of flints till it reaches the level of the outflow pipe H, which is about 2 inches below the level of the invert of the drain. The mean depth of the filtering material is about 14 inches, and the cubic space beneath the grating of the channel F is only about 5 cubic feet.

Now it is quite obvious that unless some very rapid liquefying process were at work this small area covered with the grating would very soon be choked up with the solid matter coming into it which is not strained back in any way, and without having actually seen the apparatus at work it seemed more likely that it should be clogged up in 24 hours than that it should go on working for months at a time without attention of any kind. The invariable results obtained from installations of these tanks, where an allowance of 3 to 4 cubic feet of flints is allowed for each inhabitant, has been that almost complete liquefaction of the solid organic matter goes on continuously, and that the sludge in every case is a negligible quantity.

Having got so far it now remained to be found out if the breaking up of the organic matter which took place in the "cultivation" tank was carried sufficiently far to allow of its being finally mineralized if suitable natural conditions were provided. I have already referred to the disappearance of the free oxygen contained in tap water in long lengths of sewers, but this, of course, could not be expected in a short length of 50 yards of drain coming from the house.

Pasteur had divided micro-organisms into two great groups or classes, the distinction being based upon the faculty of some to live in the presence of oxygen, and of others to live in its absence. These he called ærobic and anærobic, and he had pointed out that the changes which arise from fermentations produced by the anærobic varieties in the presence of common organic substances, such as those contained in sewage, were much more rapid and violent than those which occur among the fermentations from the life processes of the ærobic varieties.

The question was—were these organisms capable of dealing with the vast accumulations of organic matter which exist in the sewage of large towns? Of their vast numbers there could be no doubt, and it was well known that it was only possible to remove them either by large quantities of antiseptic preparations or by sterilization by heat. Even if the former method were resorted to, as in the case of the Hermite process, other organisms are continually ready to take the place of those destroyed, the bacillus subtilis, for instance, being widely distributed over the tropics as well as the temperate zones; and unless the most elaborate precautions were taken, which are not possible on such a gigantic scale, nature is always prepared to renew her attacks by the very same organisms that she originally had employed. If the vast quantities of organic matter contained in the sewage of a large town seemed to be in excess of the capacity of these natural forces to deal with, the difficulty seemed to disappear in the light of what was already known as to the prodigious and almost incredible capacity of these organisms to increase in numbers, and to encroach upon any amount of food which could possibly be supplied to them.

On the one hand, if the organisms were set to work upon the sewage of London, 67,583,000 gallons of sewage would have to be treated every year, and this yielded 2,021,000 tons of sludge in 1893. It seemed improbable on the face of it that the whole of this huge accumulation could be subjected to the elaborate process of chemical disruption by organisms, which in their simplest forms would require to number 25,000 to make up a procession 1 inch in length. On the other hand, Cohn had calculated that a single germ could increase, by simple fission, at such a rate that, if the conditions were absolutely favourable, their numbers at the end of the third day would reach the prodigious total of 4,772 billions, and that if this were estimated in weight, the mass arising from the single germ would weigh 7,500 tons. Even if their increase fell immeasurably short of the theoretical amount, the presence of organisms in vast numbers was sufficiently proved from observations in the laboratory at Ashtead, seeing that one cubic centimètre of the effluent from a "cultivation" tank contained as many as 3,562,000 micro-organisms, so that after all it appeared as if the vast amount of organic matter to be purified had its counterpart in the unlimited forces which nature could command for accomplishing the task.

The results of passing the sewage through the "cultivation" tank were easily estimated, and were roughly speaking as follows:— 1st. The solid organic particles in the sewage were thrown into solution, with the exception of a small amount of deposit, which is not easily analysed, and which partakes of the nature of peat or humus. 2nd. The compound nitrogenous organic substances such as albumen and urates were broken down to a great extent into nitrogen as free ammonia, and the carbon compounds such as starch and sugar into carbonic acid and water. Now all this was a step in the right direction because from an economic as well as a chemical standpoint nature did the work herself without requiring any attention, and without the aid of any chemicals. The effluent itself, however, which came over from this hydrolytic process was by no means an attractive one, and much time and labour was spent upon devising some means of improving it. I succeeded in making it clearer and less odourous by duplicating the "cultivation" tanks so as to keep one always ærated and rested in reserve; and this has been widely adopted, though not always with intelligence.

Returning to the sewage as it came from the drain, I have already pointed out that it would contain much more oxygen than in the case of long lengths of sewers, in which it is used up and totally disappears, but by the time it had gone through the "cultivation" tank the free oxygen had altogether vanished, and this showed, of course, that a great part of the tank had an active anærobic fermentation going on in it, and that any ærobic organisms must necessarily have their life processes confined to the near neighbourhood of the incoming sewage, where they would soon use up all the oxygen available. A vast number of these organisms certainly survived their passage through the tank, and when carefully nursed in the laboratory by being supplied with fresh nutritive gelatine, under the most favourable conditions as to temperature and oxygen, soon set to work and gave rise to the formation of colonies. Among other organisms B. Fluorescens Liquefaciens, B. Subtilis, B. Proteus vulgaris, B. Figurans, B. Luteus, B. Mycoides, B. Cladothrix were found; but in long established installations many of these seem to disappear, unable to survive in the struggle against anærobic organisms which establish themselves on the surfaces of the flints, and whose ferments are highly poisonous to the ærobic varieties.

Before long a more or less accidental opportunity occurred for estimating to what extent the breaking down of the organic matter had been carried in the "cultivation" tank, not only in terms of the chemical changes, which could be easily estimated, but in relation to the important question as to whether or not the changes were sufficient to allow of complete mineralization taking place under favourable conditions. The first attempts I made to carry on these further steps or stages in purification were in the direction of passing the effluent through shallow open earthenware channels filled with coke, or wide, shallow concreted channels filled with flints; but little was effected by them, and the increase of nitrates arising from the oxidation of the nitrogen as free ammonia, which came from the anærobic fermentation, was very small indeed. The opportunity I have referred to occurred from noting what happened when the effluent was passed into an almost stagnant but bacterially very active ditch forming a back water from a river. A fairly accurate estimate could be formed of the relation between the volume of water in the ditch and the volume of the effluent flowing into it by finding out the relative amounts of chlorine in the one and in the other, as shown in the analysis. From this it appeared that the dilution was about 3 of ditch or back water to 1 of effluent. When, however, the nitrogenous contamination was estimated there was a totally different relation, for instead of the reduction of unoxidized organic nitrogen being from 1 to 3, it was from 1 to $\frac{1}{7}$th in the albuminoid ammonia, and from 1 to $\frac{1}{20}$th in the free ammonia. This proved two things of great importance—1st. That the ditch or back water was a very active oxidizing agent. 2nd. That the organic matter coming over from the "cultivation" tank was in a condition highly susceptible to further oxidizing changes, and was in a much more unstable molecular condition than the raw sewage which had seriously polluted the stream when untreated. Instead of pollution occurring when the effluent flowed into the ditch it was a matter of common observation that it ran more clearly below than above the point of discharge.

This, of course, opened up a new light upon the whole process, and as the chemists would make no allowance for this change, which they did not seem much inclined to believe in, they still insisted upon estimating the merits or demerits of the effluent, not from what happened to it in the stream, but from its chemical composition as it escaped from the "cultivation" tank itself. All this happened in 1893–4, and nearly four more years were passed before a solution of the problem began to dawn upon me. I began then, on the bacteriological aspect of the riddle, to see what was obvious enough:—1st. That there must always be a mob of organisms coming over with the sewage. 2nd. That whether these survived or not, yet when the free oxygen was used up, the prevailing fermentation must be anærobic, and carried on by anærobic organisms. 3rd. That whatever intermediate conditions might be necessary, the last stages of nitrification or oxidizing of the hydrolized sewage must be carried on by nitrifying organisms.

4th. That the less they were interfered with by other organisms the better, if the best results were to be obtained. 5th. There was every reason to believe that the more completely the organic matter was mineralized, the more likely would these nitrifying organisms in the final stages be able to complete the process. I put the case as follows in a paper read before the Sanitary Congress at Birmingham last October:—

1st. The process of purification by biolysis is not instantaneous but gradual.

2nd. Dividing it into any convenient number of stages or periods, each of these must represent a different character of food supply.

3rd. No one kind of organism is capable of flourishing in all the different media or stages equally well.

In other words, the process working upon these data or axioms would have to consist—

(*a*). Of the disappearance of free oxygen in the tap water diluting the sewage, with equivalent changes due to the liquefying and breaking up of the organic compounds in the sewage.

(*b*). Of further hydrolytic changes due to anærobic fermentation by anærobic organisms in the "cultivation" tanks, more especially the breaking down of the organic nitrogen into nitrogen as free ammonia.

(*c*). A reversal of the anærobic conditions and the providing of some highly oxidizing apparatus, so arranged as to provide for the organisms best suited to each stage being to a certain extent isolated and protected, more especially those nitrifying organisms which brought the mineralization nearest to its final stage.

Working in that direction, I devised a very simple apparatus, which actually does provide the required conditions, and which produces a percentage of purification in terms of the relation of the oxidized to the unoxidized residual nitrogen of 96·7 as against 81·5 per cent. of the Thames at Hampton, a standard considered high enough by the good people of London for drinking purposes.

I constructed nine wooden boxes (*Plate* IV., *Fig.* 2) with perforated bottoms, each of them 2 feet long by 7 inches wide, by 7 inches deep, filled with coke about the size of beans. These boxes were arranged one over the other, with a clear space of 2 inches between each. The upper surface of the highest box gave an area of a little over 1 square foot of area, a small margin of half an inch, 7 inches instead of 6 being allowed as non-effective. By regulating the flow of hydraulized sewage as it came from the "cultivation" tank any given rate could be obtained per acre. This apparatus provided the condition already referred to of a series of colonies, each occupied by organisms best suited to the food supply of each successive tray, and the expectation was—1st. That the anærobic organisms in the liquid would be superseded by ærobic organisms which could produce first nitrites and then nitrates in the trays immediately beneath, and that the highly ærating arrangement of the clear air spaces between each tray would provide for the free growth of nitrifying organisms in the lowest trays or colonies. Putting on one side the chemical and bacterial results obtained, it is obvious that the efficiency of the apparatus as an ærating machine could be gauged by an estimation of the dissolved oxygen that was absorbed by the liquid as it passed through the various trays. This test is shown on the diagram, *Plate* II. The tap water which was originally employed for flushing purposes was known to contain about 7 c.c.'s per litre of dissolved oxygen, and the liquid from the "cultivation" tank contained none at all. It is evident then that the high oxidizing efficiency of the apparatus was beyond all question when it was discovered that 6 c.c.'s per litre of dissolved oxygen was regularly returned to the liquid by the time it had passed through the lowest tray; and it followed from this that the conditions were highly favourable to the growth of nitrifying organisms, which require a highly ærated liquid for their activity. The purification actually obtained, measured by the amount of organic nitrogen oxidized to nitrates by the life processes of the bacteria, is clearly shown on the same diagram (*Plate* II.). From this it will be seen that the liquid before coming on to the filters contained more than 12 parts per 100,000 of organic nitrogen, which was first converted into nitrogen as free ammonia in a condition easily capable of being oxidised to nitrates, and that the percentage of nitrification was as high as 96 per cent. The carbon changes which occurred were also most satisfactory, as shown in the following analysis by the late Sir Edward Franklin :—

ANALYSIS BY SIR E. FRANKLAND, F.R.S.

Ashtead Experiments.

February 10th, 1898.	Total Solid Matters	Organic Carbon.	Organic Nitrogen	Ammonia.	Nitrogen as Nitrates and Nitrites.	Total Combined Nitrogen	Chlorine.	Remarks.
Sample of Crude Sewage.	85·6	5·538	1·054	11·25	0	10·31	7·1	Foul Odour
Sample of Sewage Effluent.	79·3	·713	·111	·42	5·940	6·40	5·9	No Odour

The apparatus was started on the 25th of October, 1897, and after having been kept at work continuously night and day, samples were taken and analyzed by Dr. Rideal during the month of February following.

The peculiarity of the results obtained were, first, that the nitrification obtained was almost complete, the actual amount of nitrates (9 parts per 100,000), being three or four times higher than had been supposed to be possible. Another new feature brought out by the experiment was that while the process of nitrification had been generally believed to be a slow one, requiring longer time than the conversion of the organic nitrogen of the sewage to nitrogen as free ammonia, the change in this case only occupied about eight minutes. It also appeared that the process was capable of conserving nearly the whole of the original nitrogen in the sewage instead of dissipating it in gaseous forms, which was one of the most prominent features of other processes.

We have now to consider how far this high nitrification was of importance from three distinct points of view—1st, the effect from the standpoint of the purification of the liquid itself; 2nd, its effect upon other organic impurities with which it might be mixed in a stream or river; and, 3rd, the value of the nitrates themselves as a nourishment for plants.

Taking these in their order. 1st. The purification could be estimated from the most reliable standard possible by comparing the amounts of the oxidized to the unoxidized nitrogen in the effluent, and as the latter was only about two per cent., the purification might be regarded as very nearly approaching to perfection. 2nd. The presence of such a large absolute quantity of nitrates must have a great purifying action upon other organic polluting substances with which the effluent might be mixed, because the oxygen in the nitrates is available for the mineralization of unoxidized nitrogen, and this process may either be carried on by organisms which produce nitrates at the expense of the nitrites or as a further oxidizing process reverting to nitrites. The evidence of this process being one that is in active operation where even very slightly nitrified effluents are mixed with highly polluted waters is brought out clearly in a recent report by the experts employed to report upon the bacterial process for the Corporation of Manchester. In this case the effluent was mixed with equal quantities of the foul water of the ship canal.

Thus, 49 daily samples of the average daily filtrate, which on no occasion showed any signs of putrescence, were mixed daily with an equal bulk of ship canal water, which latter differed from the filtrate each day in being putrescible The result in mixture was found to be non-putrescent on 43 of the days, whilst on the remaining six days the experts record that the mixed sample was questionable.

It can readily be understood from these figures how valuable an effluent coming from a bacterial process, such as that obtained by the Ashtead experiments, would be when no less than nine parts per 100,000 were available. You must understand then that the effluent from a well-designed bacterial plant is not only incapable of putrefaction itself, but helps to prevent putrefaction in other foul liquids as well.

I have only to refer now to the third point, viz., the value of the nitrates obtained in the effluent as a nourishment for plants. This may be explained in a few words from the results obtained by Nobbe, who is a great authority upon what is known as the water culture of plants. The optimum required for their nourishment has been shown to be eight parts of nitric nitrogen per 100,000 of water, which is the exact figure obtained in the Ashtead experiments between the 8th and the 9th trays. It was evident, then, that from all three points of view, the purification of the sewage itself, the capacity of the effluent to act as a purifier, and the value of the nitrates obtained, the results were highly satisfactory, and it appeared certain that I was on the high road to a final solution of the problem in the best sense of the term.

I must now go into a further explanation of how these results were obtained. It is obvious that if the coke placed in the different trays was to be utilized as the vehicle for restoring oxygen to the sewage, it was necessary that full advantage should be taken of every portion of it, in other words, that the distribution of the liquid should be carried on as evenly as possible. It was also necessary to avoid any rapid passage taking place at particular points. The distributers in the experiments consisted of V-shaped channels suspended, as shown on *Plate* III., *Fig.* 1 and 2, upon small trunnions at each extremity, fixed at such points that when the liquid rose to a certain level a condition of unstable equilibrium was established, which was led to the tipping out of the contents at periods which were regulated by the time which was occupied in filling the "tippers." It seems at the first glance that it must be a difficult matter to establish the proper amount of food supply which should be given to micro-organisms at a single meal, and the best intervals that should occur between them, but with the output of nitrates as a test of the best amounts and intervals it was easy enough to find out from estimation by error. I found that in passing the hydrolized liquid through the trays beyond a rate of 1 gallon per foot per hour a very rapid falling away in the quality of the effluent followed, and that, on the other hand, passing it through very slowly did not give proportionate results. This can be readily understood when it is considered that only the very small margin of 2 per cent. or 3 per cent. of unnitrified nitrogen remained to be oxidized, and that cutting down the flow by 15 per cent. or 20 per cent. below the rate that gave these excellent results was not justified by an advantage which did not show more than one-half or one-quarter per cent. of additional nitrates. By running the flow at greatly varying rates the conclusion was reached that, in the case of the Ashtead conditions, at all events, the best all-round results were obtained when the liquid was discharged from each tipper at intervals of six minutes between each discharge, the tippers being 2 feet long, and distributing the sewage in lines 3 inches apart. This is at the rate of a little over 1,000,000 gallons per acre per 24 hours, but in the case of very strong sewage this rate of flow cannot be maintained so as to yield the same high percentage of nitrification. It also appears from the Ashtead experiments, confirmed by the experience obtained at Caterham, that only 3½ to 4 cubic feet of coke are required for the nitrification of 20 gallons per 24 hours of ordinary sewage. This compares favourably with installations where the Ashtead conditions are only partially realized, and which require as much as 9 cubic feet of coke to yield less than one-third of the nitrification, viz., about 3 parts per 100,000, not to speak of the loss of a large percentage of nitrogen in a gaseous form due to the mixed character of the organisms which carry on the work.

From the Ashtead experiments the following conclusions could be definitely arrived at :—

1. That subjecting micro-organisms to alternately ærobic and anærobic conditions after the sewage has been subjected to an anærobic fermentation could not possibly yield satisfactory results. The corollary from this conclusion is that all systems which depend upon the alternate filling and emptying of bacterial beds must necessarily be wrong in principle because these do subject the micro-organisms to alternately ærobic and anærobic conditions.

2. That it is necessary to carry on the supply of hydrolized sewage to the oxidizing organisms as regularly as possible, and that flooding and emptying a bed does not approximate to the optimum condition, but is a step in an opposite direction to the right one.

I shall now show how the results of the Ashtead experiments have been followed up in actual practice, more especially in the way of accurate distribution. The original "cultivation" tank used for the experiments was photographed, and is shown on *Plate* IV., *Fig.* 1, and the nitrifying boxes are shown on *Fig.* 2.

The chain pump on the left of *Fig.* 1 is used for discharging the contents of the "cultivation" tank at intervals of about two months upon a piece of ground $9' \times 9'$, which has taken the entire discharge of the last eight years without differing in appearance from ordinary garden soil. The small pump on the right was used for filling a tank fixed in the roof of the laboratory with hydrolized sewage for the purposes of experiment.

Turning now to *Plate* III., *Figs.* 1 and 2 show the tilters or tippers, which can be lifted off and on as they rock upon segmental bearings. *Figs.* 4 and 5 show the method of construction of the trays, which are formed into continuous horizontal grids or gratings, with inverted steel angle iron bars; and *Fig.* 3 shows an enlarged view of these angle irons, which it will be noticed are punched with semi-circular indentations along their edges, so as to prevent the sewage from running along their lower surfaces, the points of the indentations acting like the spokes of an umbrella, and forcing the sewage to drop regularly as it drips from one tray to another. All these details were the outcome of many failures to attain accurate results by other devices. Having secured accurate dripping, which is another term for taking full advantage of the biolytic conditions, the problem of regular supply was easy enough, because when the flow of the hydrolized sewage is properly regulated it is obvious that the tilters must take a certain time to fill before discharging their contents, and when this is regulated to six minutes between each discharge the experience of the Ashtead experiments could be repeated in actual practice with perfect accuracy.

I must now give a description of the installation at Caterham, which was constructed with the intention of embodying the Ashtead experimental apparatus upon a large scale, and of dealing with a much stronger sewage. The following were the official figures which were given to me of the amount of water used in the barracks, which is measured by meter.

Gallons per 24 hours	...	22,000
Persons	...	1,180
Horses	...	2

Occasionally a large additional number of persons has to be provided for, and the water at times has been cut down to about 15,000 gallons per 24 hours. This occurred on the two weeks when the analyses were taken, but was more than compensated for by the rainfall, which has not yet been separated from the foul water drains, and which is sometimes very heavy.

Although the sewage is exceptionally strong, about twice the foulness of that from average towns, it does not follow that a much larger provision must be made on that account for the anærobic fermentation. On the contrary, there is reason to believe that the fermentation of the stronger sewage is more rapid and violent than in the case of less polluted liquids; and it may well be that foul liquids containing a small amount of organic solids may yield such a feeble anærobic fermentation that they require a longer time to complete the necessary change to free ammonia than in the case of stronger sewage. This requires a separate series of experiments to determine, but, as a matter of fact, the provision made in the Caterham installation for the anærobic fermentation was only 3 cubic feet per person of flints in the "cultivation" tank, and this undoubtedly suffices for the production of the necessary ammonia change preceding nitrification, seeing that the oxidized results leave nothing further to be desired when the flow through the filters is at the rate of 400,000 gallons per acre per 24 hours.

In the plan and section of the Caterham "Cultivation Tank," *Plate* V., you will notice a chamber K filled with inverted glazed stoneware vessels or dishes M carried on T-iron bars batted in to the opposite sides of the tank. The object of this arrangement was to find out whether or not the anærobic change could be carried too far. It is obvious that the presence of large quantities of the gases arising from the anærobic fermentation all through the body of the hydrolized sewage on its way from the "cultivation" tank to the filters must greatly intensify the anærobic conditions, and be highly lethal to ærobic organisms which might have survived the anærobic conditions of the first fermentation. It was found that compound forms of ammonia had been brought about by this second subjection to an anærobic fermentation with the production of enzymes highly toxic to the organisms of nitrification. The object of the experiment was attained by the falling away of the nitrates to zero in the final effluent, apparently due to the excess of fermentation which had taken place among the inverted vessels. This information having been obtained, the liquid was taken direct from the "cultivation" tank, but fortunately there is another considerable installation which is still using a second chamber, and I hope that later on there may be a further opportunity of investigating this most interesting question of excessive septic change.

You must understand then that the sewage in the Caterham installation is treated in an exactly similar way to that at Ashtead, that is to say, it is brought down and into the restricting channel F (*Plate* V.) beneath the grating E and allowed to flow continuously upward through the flints in the "cultivation" tank till it escapes about the same level as the sewer invert A into the manhole or sunip B, and is carried away by perforated pipes laid near the upper surface of the flints (CC, *Plate* VI.) to be treated in the nitrifying trays.

Distribution.

Many experiments were carried on at great expense to discover improvements in the method of distribution over the surface of the top tray. Large tippers were tried, throwing their contents over perforated slabs, *Plate* V., *Fig.* 2*a*; revolving arms (Barker's mills), like those used in breweries, were also tried; but both were found to give very inaccurate results, and were abandoned. The device now employed depends upon the production of a head of liquid by its instantaneous discharge from a 20-gallon tipping trough into a long properly proportioned tank; but I am now reverting to the tippers as shown in *Plate* III., which have already been described.

The tippers have the advantage over perforated pipes that there are no small holes to clog up with the fibrous growths associated with all unnitrified sewage.

It will be noticed that the plan of the Caterham installation follows so closely on the lines of the one at Ashtead, which has already been fully explained, that no further description is necessary, and the same remarks apply to the nitrifying trays, which are constructed with perforated concrete slabs instead of the inverted angle irons as shown on *Plate* III.

The chemical and bacteriological results are fully given in the appendix containing Dr. Rideal's Report.

The results obtained in the effluents are so clearly set forth in the analysis that it is unnecessary to do more than refer you to the tables; but an interesting account was given in the *Engineer* last January of how their representative was impressed by the effect of the highly nitrified effluent upon the vegetation which was nourished by it. He says: "The effluent is caught in a basin at the bottom of the trays, from which it escapes a clear, colourless, fresh-smelling liquid, which passes down the side of a very poor, chalky-soiled slope of ground. The effect of the effluent on this soil is astonishing. The crops raised are luxurious in their growth. Flowers are particularly grateful for the nitrates, growing, as they do, to abnormal heights, being of extraordinarily dark-coloured foliage, and being covered in season, at which time we saw them, with a profusion of fine blossoms. It is certainly an object lesson to observe at one end of the installation the catch-pit, which receives the sewage from the barracks—a particularly strong sewage—and at the other end the clean-smelling liquid watering the poor soil, and causing it to produce flowers of unusual quality." This is a tribute to the capacity of nature to carry on the circle of life which I have attempted to describe to you; but before concluding I wish again to refer to Pasteur, without whose genius these results would have been much more difficult of attainment.

He was a man who combined within his own personality those qualities of intellect, of imagination, and of character which place him not in one of the niches of the Temple of Fame, but upon one of its highest pinnacles. When we consider the state of knowledge that preceded the work of Pasteur in the vast field where he was both discoverer and cultivator, and compare it with the state of knowledge at the time he died, it is difficult to realize that the great gap was not only filled in by the labours of a single man, but filled in such a way that almost all he did was like grain garnered for the benefit of the human race, which again has been sown in a springtime of prolific thought, to which his researches are as sunlight, and his ideas like rain. When some new fact has to be accounted for in the remote regions of microscopic life, it is to Pasteur's writings that we turn to have it explained.*

He made clear what was already obvious, but unnoted, that life as we know it is divided into two great streams, or functions, or objects, the one being building up and the other breaking down. We do not know why life is for ever rising to its apex in an individual form, recovering from the losses of its dead, and rising from its ashes, through reproduction to the renewal of youth and the return of Spring. We know nothing of the secrets of those occult forces which are never at rest, and which never lose their potential; but we do know, and Pasteur, more than any other man, made it clear to us, that all this infinite labour in building up the organic structures, upon which life in its infinite aspects depends, rests on the work of incalculable myriads of microscopic creatures, each possessed of life, which prepare the waste products of the living and the dead among the living, for the maintenance and support of life from its lowest to its highest forms. In the performance of these functions these creatures are more than beneficent; their functions may be looked upon as the very foundations upon which the superstructure of life reposes. A coral island is not more dependent for its existence upon the work of the organisms which built it up from the floor of the sea than the living man and the living worm are dependent on the life processes of the organisms which build up their bodies from the waste-heaps of death and decay. You can understand then how full of interest the sewage problem becomes when you know that it is nothing less than the invocation of these vast forces and processes which form the subject matter of biolysis or the bacterial purification of sewage by purely natural means.

* Fortunately for the English student, one of his most distinguished disciples has provided us with a text-book which at all salient points gathers and concentrates the light, so as to make the work of the great master coherent and intelligible, bringing together many scattered rays, and making everything plain. I refer to Professor Sims-Woodhead's text-book upon bacteriology, which is unique in its method and its scope. It is not only one of the most interesting, but the most readable of books. To its author I have been indebted for the most unstinted encouragement and help, given in a spirit of unselfishness and kindness, which, as well as from deeper sources, he has drawn from the lifelong example of the incomparable Pasteur.

APPENDIX I.

28, Victoria Street, Westminster, S.W.
November 16th, 1899.

To the Under-Secretary of State,
War Office, S.W.

"Works."

Sir,—As requested by Mr. Scott-Moncrieff, I have the honour to report upon the working of the bacterial installation at Caterham. The reference is contained in a letter from your Department of September 7th as follows :—

War Office, S.W.
September 7th, 1899.

W. D. Scott-Moncrieff, Esq.,
14, *Victoria Street, S.W.*

Sir,—With reference to your letter of the 18th ult. respecting bacterial installation at Caterham, I am directed by the Secretary of State for War to request that you will be good enough to give information on the following points :—

1st. The length of time the installation has been at work without any alteration being made.

2nd. The average analysis of the sewage and of the filtrate.

3rd. The method in which the installation is being managed.

I am, Sir,
Your obedient servant,
R. Thompson, for I.G.F.

On receipt of this letter, Mr. Scott-Moncrieff asked me to deal with the second point raised therein, and I visited the barrack outfall towards the end of September, and arranged for a series of samples to be taken for the week ending October 8th. The samples of raw sewage, cultivation tank effluent, and filtrate were collected proportional to the flow every half-hour for a period of 3 hours. This average sample was then sent to me for analysis, and similar three-hourly samples were taken twice every day for a period of a week, times being selected to ascertain the variation in the flow and quality of the sewage for the complete period of 24 hours. In this way I was able to ascertain the variation in flow and quality over two complete cycles of 24 hours, and the results I obtained are embodied in Chart 1 appended to this report.

It will be seen that although the installation was designed for a normal flow of 22,000 gallons (the official return per meter), that during the trial the flow varied from about 86,000 gallons to a rate of less than 5,000 gallons per 24 hours, as shown in *Plate* VII.

This maximum flow of 86,000 gallons occurs early in the morning between 6 and 9 a.m., and it then rapidly diminishes, so that during the remainder of the day the flow never exceeds 35,000 gallons. The volume discharged in gallons per 3 hours will be better seen in Table I., containing the analyses of the raw sewages during these periods, and although the half-hourly gaugings have shown this abnormal flow, in no period of 3 hours did the flow exceed the rate of 6,690 gallons per 3 hours, or 53,520 gallons per 24 hours. In the same table it will be seen that the sum of all the gaugings gave a mean flow of 15,886 gallons per day, so that although these abnormally high rates occurred for short periods, the average flow per day was considerably less than the official figures for which the works were designed to deal with. On drawing Mr. Scott-Moncrieff's attention to this discrepancy, he obtained from the barrack authorities the reading of the water meter during the period of trial (the week ending October 7th). This was 110,000, or a daily flow of 15,714, showing that if the gaugings can be relied upon the quantity of rain and ground water finding its way to the outfall amounted to 1,200 gallons for the week.

The time when this rainfall affects the flow of the sewage can be seen by following the lines of the first and second period flow in Chart 1, and it will be noticed that the variation in flow due to rainfall during this particular period was inappreciable compared with the great variation brought about by the method of discharging the latrines early in the morning, which seems to be greatly in excess of the sanitary necessities for flushing. I understand that during heavy rainfall the flow has been almost equal to the capacity of the 9-inch sewer itself.

I have suggested to Mr. Moncrieff that it would be desirable for him to ask the authorities in charge of the barracks to so regulate the flow that it may be more uniformly distributed over the 24 hours, as this would materially benefit the uniform working of the installation, and might lead to a considerable economy in the water consumption as well.

Mr. Moncrieff has made a suggestion in which I quite concur—that an overflow weir should be provided at the outfall before communicating with the cultivation tank, which should come into operation when the flow exceeds 55,000 gallons, or over three times the average flow during the week in question, as when the rate exceeds such an amount, although the cultivation tank can deal with the sewage at a rate many times the normal flow, the filters, being designed for a continuous flow of about 20,000 gallons, cannot do so. If the flow is made more uniform, the installation will then deal with the whole of the sewage satisfactorily.

A grating along the edge of the weir would prevent any fœcal matter or solids being carried away by any overflow which might arise, should the flow exceed this amount through neglect or exceptional flushing or rainfall.

I am informed that provision is now being made for the separation of the rain water from the sewage, so that the difficulties which arise through road detritus and sand passing into the cultivation tank will now be obviated. At the same time it is easy to remove such detritus from the bottom of the tank, and to utilize it upon the land without trouble; and I understand that the farmer is pleased to take it.

Purification Effected.

The process consists of two stages. In the first the organic solids are dissolved and converted for the most part into ammonia and carbonic acid. This takes place in the cultivation tank, and in Table II. the composition of the tank effluent is shown, referring to the same periods as those of the raw sewage.

The second stage in the purification consists in the conversion of the ammonia into oxidized forms of nitrogen and a further oxidation of the organic carbon ; and the average results obtained by the filters during the trial are given in Table III., and, as will be seen from it, the filters deal with about one-third of the total flow, or at the rate, roughly, of 330,000 gallons per acre per day. When the flow is regulated in the way suggested the filters will then be capable of dealing with the whole of the tank effluent, as during the trial they dealt with the sewage at the rate of 11,000 gallons per day, as, for example, on Monday, October 1st, from 3 to 6 p.m., that being the time when the cultivation tank contained a sufficient body of liquid to ensure the filters running at that rate. It is obvious that if the flow be made more uniform, it will be possible for the tank to always contain sufficient fluid to ensure the filters working at this rate.

It will be further noticed from this table that the efficiency of the filter is not appreciably affected by the passage of the sewage through it at the higher rate.

The average results of the 16 samples of raw sewage, tank effluent, and finished effluent are given in the following table :—

	Raw Sewage.	Tank Effluent.	Finished Effluent.
Chlorine	15·1	14·8	13·3
Oxygen consumed	14·97	9·25	2·71
Nitric nitrogen	—	—	9·0
Nitrous nitrogen	—	—	0·346
Organic nitrogen	4·0	2·7	0·67
Ammoniacal nitrogen ...	13·2	14·9	5·0
Total nitrogen	17·2	17·6	15·016

The percentage purification, as shown by the oxygen consumed and the organic nitrogen, is as follows :—

	Oxygen consumed.	Organic Nitrogen.
Raw sewage on tank effluent	40 p.c.	32·5 p.c.
Raw Sewage on finished effluent	82 p.c.	83 p.c.

The process has therefore been successful in destroying completely four-fifths of the total organic matter present in the raw sewage; but the chief feature in the process consists in the large quantity of nitric nitrogen in the finished effluent, amounting to no less than

61 per cent. of the total nitrogen left in the effluent. Effluents containing nitrates invariably are free from putrefaction, provided the amount is sufficient to supply enough oxygen to prevent any residual organic matter from putrefying; and in the effluent at Caterham this is the case.

It is therefore needless for me to say that on no occasion have I found any of the Caterham effluents to show any signs of putrefaction, even when incubated for some days.

The amount of free ammonia in the average filtrate during the experimental week was somewhat higher than I was led to expect, as with the production of such a large quantity of nitrate, showing that active nitrification was taking place, it seemed possible with slight modification to so further improve the effluent as to nitrify the small remaining amount of ammonia.

I therefore re-examined the installation on October 26th and 27th with a view to testing the efficiency of the different filters, and as the result of this supplementary investigation I found that three bays, known as A, B, and C, representing one-eighth of the total filtering area, were yielding effluents which were less completely nitrified than those from the remaining filters, and that it was owing to their diminished action that the average quality of the effluent was diminished. This difference is well shown in the analyses obtained on these two days. Thus the filters D and F, representing half the filtering capacity of the installation, gave an average of 2·5 parts ammoniacal nitrogen, no nitrites, and 27·95 of nitric nitrogen, whilst the beds, containing material of different quality and originally introduced for experimental purposes, yielded more than four times as much ammoniacal nitrogen, with a corresponding diminution in the quantity of nitrate, and the presence of nitrites showed that the oxidation was less complete.

I have therefore advised Mr. Moncrieff to remove the material from the beds A, B, and C, and to replace it by similar material to that which is giving such good results in the other filters; and when this slight alteration is made I expect an increase in the amount of nitric nitrogen from 9 to 12 and disappearance in great part of the nitrous nitrogen, with a reduction in the ammoniacal nitrogen from 5 to 2.

I may also add that determinations of the dissolved oxygen in the effluent shows that in the three beds, representing three-fourths of the total installation, the amount of dissolved oxygen varied from 4·7 c.c. per litre to 7·0, showing that the effluent not only contained the large amount of oxidized nitrogen already referred to, but a quantity of dissolved oxygen approximating to that met with in well-aerated river waters.

Bacterial Results.

It has recently been demonstrated by Dr. Houston in his examination of the intermittent filter-beds of the L.C.C. that the sewage organisms survive the filter. I therefore thought it would be of interest to the Department to specially examine the effluents from the filters at Caterham with a view to ascertaining whether the sewage organisms survived the oxidizing influence to which they were subjected in their passage through the nitrifying trays, and I found that the number of organisms capable of growing on carbolized gelatine surface plates, amongst which the bacterium Coli Communis is found, were reduced from 2,180,000 per c.c. to 100,000 in the filtrate from C, to 50,000 in that from D, and 80,000 in the filtrate from F; so that whilst the least efficient of the filters removed 95 per cent. of these organisms, the best filter D removes 98·5 per cent.

I further found that although the addition of ·0001 c.c. of the tank effluent to a broth tube, and incubated at blood heat for four days, produced indol, the same dilution of the filtrate from D gave no turbidity or indol, whilst the filtrates from C and F, although producing turbidity, also failed to give any indol reaction.

The survival of spores of B. Enteriditis is no less interesting, and may be best seen from the following table, where (+) indicates the presence of such spores and (–) their absence :—

	Tank Effluent.	Filtrates.		
		C.	D.	F.
·01 c.c. … … … …	+	+	–	+
·001 c.c. .. … …	+	+	–	–
·002 c.c. .. … …	+	+	–	+
·0001 c.c. … … …	–	–	–	–

The nitric nitrogen and the ammoniacal nitrogen present on November 10th, when the bacterial samples were collected, are shown in the following table :—

	Tank Effluent.	Filtrates.		
		C.	D.	F.
Nitric nitrogen	Nil.	5·48	11·6	10·96
Ammoniacal nitrogen	12·3	4·56	2·05	3·28

On the several occasions on which I visited the works I noticed no nuisance, and in my opinion the works, subject to the alterations I have communicated in this report, will deal efficiently with the present sewage from the barracks.

I have the honour to be, Sir,

Yours faithfully,

SAMUEL RIDEAL.

APPENDIX II.

Table I.

Raw Sewages.

Caterham Installation, Parts per 100,000.

No.	Date and Time.	Volume discharged gallons, per 3 hours.	Chlorine.	Oxygen consumed.	Kjeldahl N.	Am-moniacal N.	Organic N.	Total N.
1	Monday, Oct. 2nd, 9—12 a.m....	4,358	15·0	34·08	34·6	22·7	11·9	34·6
4	,, ,, 3—6 p.m. ...	1,491	16·0	20·72	13·2	11·5	1·7	13·2
7	Tuesday, Oct 3rd, 6—9 a.m.	5,450	15·6	20·76	33·0	26·3	6·7	33·0
10	,, ,, 12—3 p.m.......	1,702	19·4	16·56	14·8	11·5	3·3	14·8
13	Wednesday, Oct. 4th, 3—6 a.m.	434	6·4	3·52	10·0	7·7	2·3	10·0
16	,, ,, 9 a.m.—12 n.	2,529	12·4	16·16	12·4	8·4	4·0	12·4
19	Thursday, Oct. 5th, 12—3 a.m.	1,904	4·5	9·60	3·4	2·2	1·2	3·4
22	,, ,, 6—9 a.m....	6,690	9·5	10·24	13·4	9·7	3·7	13·4
25	,, ,, 9—12 p.m....	1,054	11·1	7·85	12·5	10·4	2·1	12·5
28	Friday, Oct. 6th, 3—6 a.m.	432	3·8	1·16	2·9	2·1	0·8	2·9
31	,, ,, 6—9 p.m.... .	888	19·6	18·72	24·6	17·8	6·8	24·6
34	Saturday, Oct. 7th, 12—3 a.m....	563	23·5	10·28	22·3	18·0	4·3	22·3
37	,, ,, 3—6 p.m....	1,751	12·4	24·80	12·4	10·4	2·0	12·4
40	,, ,, 9—12 p.m....	514	24·8	21·76	26·3	18·5	7·8	26·3
43	Sunday, Oct. 8th, 12—3 p.m. ...	1,535	23·3	12·16	18·2	16·6	1·6	18·2
46	,, ,, 6—9 p.m. ...	678	24·1	11·12	21·5	17·4	4·1	21·5
Average	....	15,886 galls. per day.	15·1	14·97	17·2	13·2	4·0	17·2
	Official Meters.							
	Water gaugings	Week ending Oct. 7	110,000=	15,714 g.p. day.				
		,, ,, ,, 14	109,000=	15,571 ,,				

Samuel Rideal

Table II.

Tank Effluents.

Caterham Installation, Parts per 100,000.

No.	Date and Time.	Chlorine.	Oxygen consumed.	Kjeldahl N.	Ammoniacal N.	Organic N.	Total N.
2	Monday, Oct. 2nd, 9—12 a.m.	13·0	9·38	18·2	16·5	1·7	18·2
5	,, ,, 3—6 p.m.	13·0	7·71	15·5	14·4	1·1	15·5
8	Tuesday, Oct. 3rd, 6—9 a.m.........	13·4	4·48	15·8	15·6	0·2	15·8
11	,, ,, 12—3 p.m.	12·8	9·52	18·2	17·4	0·8	18·2
14	Wednesday, Oct. 4th, 3—6 a.m. ...	18·4	6·48	18·6	16·5	2·1	18·6
17	,, ,, 9—12 a.m....	15·9	7·92	23·2	17·4	5·8	23·2
20	Thursday, Oct. 5th, 12—3 a.m. ...	10·4	8·96	11·8	7·8	4·0	11·8
23	,, ,, 6—9 a.m......	8·5	6·40	11·8	9·9	1·9	11·8
26	,, ,, 9—12 p.m. ...	15·2	10·16	16·5	11·4	5·1	16·5
29	Friday, Oct. 6th, 3—6 a m.	14·6	7·04	14·0	11·4	2·6	14·0
32	,, ,, 6—9 p.m.	15·8	13·92	16·5	14·4	2·1	16·5
35	Saturday, Oct. 7th, 12—3 a.m......	17·4	9·68	19·9	16·5	3·4	19·9
38	,, ,, 3—6 p.m.	19·4	16·64	22·3	17·3	5·0	22·3
41	,, ,, 9—12 p.m. ...	17·6	10·56	21·4	16·4	5·0	21·4
44	Sunday, Oct. 8th, 12—3 p.m.	15·2	11·20	21·4	18·6	2·8	21·4
47	,, ,, 6—9 p.m.........	16·8	8·00	18·2	18·1	0·1	18·2
Average	....	14·8	9·25	17·7	14·9	2·7	17·7

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Table III.

Finished Effluents.

Caterham Installation, Parts per 100,000.

No.	Date and Time.	Volume treated on 800 square feet of Filter.	Chlorine.	Oxygen consumed.	Nitric N.	Nitrous N.	Kjeldahl N.	Ammoniacal N.	Albuminoid N.	Organic N.	Total N.
3	Monday, Oct. 2nd, 9—12 a.m....	432	12·0	1·97	10·5	·244	3·2	2·8	·20	·4	13·944
6	,, ,, 3—6 p.m. ...	1,440	12·0	2·27	9·4	·286	5·8	3·8	·31	2·0	15·486
9	Tuesday, Oct. 3rd, 6—9 a.m. ...	1,085	14·0	2·47	7·0	·400	6·2	5·7	·30	·5	13·600
12	,, ,, 12—3 p.m....	720	13·4	2·30	7·0	·489	4·7	4·6	·30	·1	12·189
15	Wednesday, Oct. 4th, 3—6 a.m.	480	14·0	2·74	7·9	·500	6·4	5·4	·29	1·0	14·800
18	,, ,, 9—12 a.m.	744	14·5	2·63	8·6	·495	5·4	5·1	·22	·3	14·495
21	Thursday, Oct. 5th, 12—3 a.m.	566	12·0	2·83	8·0	·375	4·1	3·8	·24	·3	12·475
24	,, ,, 6—9 a.m.	720	11·0	3·22	8·1	·365	4·1	4·0	·25	·1	12·565
27	,, ,, 9—12 p.m.	618	12·1	2·96	7·0	·274	5·8	5·3	·19	·5	13·074
30	Friday, Oct. 6th, 3—6 a.m.	618	12·6	2·05	8·1	·280	5·3	4·7	·22	·6	13·680
33	,, ,, 6—9 p.m......	644	13·5	3·65	8·1	·365	6·8	6·4	·37	·4	15·265
36	Saturday, Oct 7th, 12—3 a.m. ...	592	14·0	3·26	11·2	·360	6·6	5·6	·25	1·0	18·160
39	,, ,, 3—6 p.m....	978	14·6	3·82	9·6	·218	7·4	6·7	·33	·7	17·218
42	,, ,, 9—12 p.m.	686	15·2	3·44	8·7	·272	6·6	6·2	·29	·4	15·572
45	Sunday, Oct. 8th, 12—3 p.m. ...	652	13·2	1·36	11·5	·325	6·6	4·4	·25	1·9	18·425
48	,, ,, 6—9 p.m. ...	635	14·8	2·4	13·5	·335	6·1	5·6	·22	·5	19·935
Average	....	$\frac{1}{3}$ million gallons per day per acre.	13·3	2·71	9·0	·346	5·7	5·0	·26	·67	15·055

Samuel Rideal.

APPENDIX III.

[Excerpt from Vol. XX., Part IV., of *The Journal of the Sanitary Institute.*]

"*High Nitrification in Sewage Filtrates,*" *by* W. D. SCOTT-MONCRIEFF. (FELLOW).

WHEN the story of the sewage problem in this country comes to be written, after its various phases have been foreshortened by the passage of time, certain features will come into prominence, which are at present regarded as of minor importance.

One of these will be the value of highly nitrified effluents as plant food.

Consciously or unconsciously, the vast every-day operations of nature, whether upon cultivated land or the open prairie or forest, have always been a great factor in directing the mind towards the true solution of the problem. The natural method by which organic nitrogen is mineralized to nitrogen as nitrates may be spoken of as the high road which completes a circle, and all chemical devices, however ingenious, as only *culs-de-sac* or wanderings to nowhere.

Fifty years ago Chadwick and his followers looked upon a well-managed sewage farm as a full and sufficient remedy for all the troubles of great communities in disposing of their sewage, and bright pictures were drawn of the profits that would accrue from the acres that were fattened by their schemes. A higher note was struck by Warrington in 1850 when he read his paper before the Chemical Society on "The adjustment of the relations between the Animal and Vegetable Kingdoms, by which the vital functions of both are permanently maintained." As years went on it was discovered that the average sewage farm did not provide for the adjustment of these relations, and this adjustment may be truly spoken of as the crux of the whole problem. Warrington saw the main point clearly, but he had no data to go upon sufficient to enable him to offer a practical remedy.

It would occupy far more time than is now placed at my disposal, and would be outside the scope of my present purpose, if I attempted to fill in the gap between the state of knowledge now and that which existed in 1850. What I wish to make clear is that the disappointment arising from the failure of sewage farms as sources of profit is now fully accounted for, and they are not justified and should not be reckoned in dealing with more advanced methods in which the relations between the animal and vegetable kingdoms have been thoroughly adjusted; in other words, and to put it quite clearly, the solution of the sewage problem on purely natural lines, as suggested by Warrington, if realized, must be profitable in the very nature of things, so long as men, and animals, and plants continue to be constituted as they are at present; and this for the simple reason that where the cost of the necessary conditions is moderate the work itself is carried out for nothing.

Looking at the question from a quite contemporary standpoint, there are one or two features of the problem, which have been brought into prominent notice within the last twelve months, which might be spoken of as coincidences if they had not the common bond arising from a general movement of scientific interest in a particular direction.

The first of these I shall mention is Sir William Crookes' Presidential address to the British Association at Bristol. The second a Paper by Mr. Daniel Pidgeon in the current number of the *Royal Agricultural Society Journal* upon the bacterial purification of sewage; and the third, which is quite a coincidence, a Paper by Mr. W. E. Bear on fruit farming in England, which immediately follows the previous Paper in the same journal.

In the first paper Sir William Crookes points out the urgent necessity which exists for restoring nitrogen to the soil, and estimates the loss arising from the wasted sewage of this country alone at £16,000,000 per annum. This sum would pay 3 per cent. on a capital expenditure of £320,000,000, and still provide £6,400,000 per annum for wages and depreciation.

In the second paper Mr. Pidgeon deals with the bacterial treatment of sewage in a most interesting and masterly *résumé* of the whole subject, and a clear perception of the ultimate lines which the progress of the system is certain to take in the direction of a high nitrification of the filtrates.

In the third paper Mr. Bear deals with the enormous present production of fruit under highly artificial conditions, and gives the return of grapes at an average of 12 tons per acre, or 14 tons from vines in full bearing, and of tomatoes at an average of 20 tons per acre, both crops to a great extent being grown upon the same acreage.

These apparently disjointed contributions may be connected as follows :—

1st. The enormous importance of nitrogen, as nitrates, for the nourishment of plants.

2nd. The capacity of the bacterial processes to produce and conserve nitrates as the mineralized equivalent of the organic nitrogen in sewage.

3rd. The marvellous productiveness of land under highly artificial conditions at present in vogue, which would be greatly increased if highly nitrified effluents were available.

The paper by the President of the British Association speaks for itself, and the figures he gives, even if greatly modified so as to cover only the amount of sewage which could be dealt with in practice, would still be sufficiently startling; but the point of most importance is that bacterial processes, if properly carried out, do realize these figures in terms of nitric nitrogen per gallon of sewage purified by this method. Ninety per cent. nitrification of the total nitrogen in the effluent can easily be obtained from ordinary sewage; and this, based upon the cost of nitrate of soda, works out to about £14,000,000 per annum for the sewage of the United Kingdom. It should be clearly understood by everyone interested in the biolytic purification of sewage that the failure to realize the promises of profit from sewage farms has no bearing upon the present state of the case, because when raw sewage has been broken down to nitric nitrogen, carbonic acid, and water, the problem of the final adjustment spoken of by Mr. Warrington has been quite as completely solved as the problem of purification. They are inseparable, and the one is the counterpart of the other. It is nature's method, and whatever she does is done to perfection when favourable conditions are provided.

The following is the standard solution adopted by Nobbe as a model plant food supplied in parts per 100,000 :—

Lime ...	16	Chlorine ...	21
Magnesia ...	3	Oxide of Iron ...	·5
Potash ...	31	Nitrogen ...	8·2
Phosphoric Acid ...	7		

Dr. Voelcker, in a letter to Mr. Pidgeon, speaks of this solution as "containing those constituents and the amounts of each which have been found to be requisite for plant growth, and the absence of any of which or the supply in markedly lesser quantity of which would produce deterioration, while the larger supply of any of which would not be attended by increased benefit."

To show how rapidly the bacterial purification of sewage approaches this standard solution in the all-important element of nitrogen, I reproduce Dr. Rideal's analysis of the Ashtead experiments, from which it will be seen that the nitric nitrogen figures are identical with those of the standard solution between the 8th and 9th trays.

It follows from these figures that in the bacterial purification of sewage it is not only purification in its best sense that is obtained, but also a supply of nitrogen ready prepared for plant food, which, if generally available, would postpone the pressure of population upon food supplies among civilized communities for an indefinite time.

At the present moment disappointment about the broken promises of profit in the past seems to make everyone look upon sewage only as a nuisance to be got rid of; but the adjustment referred to by Warrington in 1850 has lost none of its significance.

It is now certain that this adjustment is effected by bacterial processes when properly conducted, and profit must follow to the community if these highly nitrified effluents can be utilized without too much expense being incurred in obtaining them. As I have already said, when the conditions are once provided the work itself is done for nothing.

I would much like to see a start made in such a community as Worthing, where the filtrates could easily be passed on to the fruit growers.

Table showing successive stages of Mineralization by Nitrifying Organisms. Ashtead Experiments, February, 1898.

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
	Description of Samples.	Chlorine.	Free NH_3.	=N.	Albuminoid NH_3.	=N.	Oxygen consumed.	O. consumed minus O. required by Nitrous Nitrogen.	Nitrous Nitrogen.	=Oxygen required.	Nitric Nitrogen.	=Useful Oxygen N_2O_5 to N_2O.	Total Oxidized Nitrogen.	Available Oxygen useful, O. Nitrate=O. consumed.	Total Unoxidized N. (Kjeldahl).	Total Organic Nitrogen.	Total Inorganic Nitrogen.	Total Nitrogen of all kinds.
	Effluent from Cultivation Tank, taken 3 and 5 p.m.	9·0	12·5	10·30	1·50	1·23	9·843	9·843	Nil.	—	0·12	0·274	1·12	− 9·57	12·35	2·05	10·42	12·47
Colonies of Ærobic Nitrifying Organisms.	1. Effluent from First Tray	9·0	10·5	8·65	1·25	1·03	6·694	5·56	0·99	1·13	0·096	0·219	1·036	− 6·47	11·5	2·85	9·74	12·59
	2. Effluent from Second Tray	8·5	9·0	7·42	1·00	0·82	5·773	4·74	0·90	1·03	0·48	1·09	1·38	− 4·66	11·10	3·68	8·80	12·48
	3. Effluent from Third Tray	8·5	5·0	4·12	0·60	0·49	4·493	3·60	0·78	0·59	1·87	4·27	2 65	− 0·22	6·60	2·48	6·77	9·25
	4. Effluent from Fourth Tray	8·0	4·0	3·3	0·35	0·29	1·728	0·98	0·66	0·75	2·76	6·30	3·42	+ 4·58	5·15	1·85	6·72	8 57
	5. Effluent from Fifth Tray	7·75	1·5	1·24	0·15	0·12	1·28	0·73	0·48	0·55	4·68	10·70	5·16	+ 9·42	1·75	0·51	6·40	6·91
	6. Effluent from Sixth Tray	8·0	1·75	1·44	0·35	0·29	1·497	0·92	0·51	0·58	4·416	10·10	4·926	+ 8·61	2·25	0·81	6·37	7·18
	7. Effluent from Seventh Tray	7·5	0·35	0·29	0·30	0·25	0·755	0·755	Nil.	—	6·6	15·08	6·6	+14·33	0·85	0·56	6·89	7·45
	8. Effluent from Eighth Tray	7·5	0·20	0·165	0·65	0·53	0·397	0·397	Nil.	—	7·32	16·73	7·32	+16·34	1·03	0·865	7·48	8·35
	9. Effluent from Ninth Tray	7·5	0·25	0·206	0·60	0·49	0·589	0·589	Slight trace.	—	9·0	20·0	9·0	+20·1	0·60	0 394	9·21	9·60

[*This discussion also applies to the papers by* W. J. DIBDIN and GEORGE THUDICHUM, and Prof. A. BOSTOCK HILL and JOSEPH GARFIELD.]

Dr. ARTHUR ANGELL (Hants County Analyst) said he was now fully convinced that the only proper method of treating sewage was on biological lines. He discouraged the idea of producing a profit from the sludge, and as to filtration, expressed the opinion that there was nothing *per se* in the kind of material used. One point had not yet been touched upon, and they must not put their heads in a sack in regard to it. The methods of disposal of sewage by microbic agency are really processes of putrefaction, and at present, apparently, they knew of no way of preventing the formation of obnoxious gases in the tanks. He had not heard of anyone successfully collecting and managing thoses gases.

Mr. A. J. MARTIN (Exeter), referring to a remark of the previous speaker, said that the production of gas was a necessary accompaniment of the work of a septic tank. There was, however, no difficulty in rendering the gas innocuous. At Exeter a part of it was burnt and utilized for lighting the works at night. Another method, which combined the merits of simplicity and efficiency, consisted in allowing the gases to filter through the roof arches and the thick layer of soil covering the tanks. No better way of deodorizing these gases could well be devised. A great deal had been said with regard to the respective merits of different filtering materials. He joined issue with the reader of the paper on filtration through coal when he attributed the excellence of the results he had obtained to the nature of the material used. He (the speaker) was of opinion that these results were due rather to the skill and judgment which were used in grading the material than to the nature of the material itself. Too much stress could not be laid upon the importance of thoroughly mingling the effluent passing through a filter with air. Mr. Dibdin's method of first filling a filter with effluent and then discharging it, so that wherever the water went air should follow, was the best practical way of effecting this on a large scale. He regretted that Mr. Cameron was not present to hear the handsome acknowledgments which had been made of his work.

Dr. L. P. KINNICUT (Massachusetts) said a few words respecting the change which had come over the methods of sewage purification adopted in England during recent years, and adduced facts in regard to Massachusetts.

Lieutenant-Colonel A. S. JONES (Finchampstead) said Mr. Dibdin's paper supplied a good deal of information as to the progress which had been made in his experiments, and he was glad to know that they were being followed up. As to Dr. Hill's paper, he thought it was pretty well agreed that whether it was broken glass, coal, ballast, or anything else which was used, the main thing was the way in which it was put together. Everything depended on getting a sufficient space for the air to come in, and it was advisable to drain off the very last portion of the water by an air-pump, so as to bring in a fresh supply of air throughout the filter. As to Mr. Scott-Moncrieff's paper, he went back to the old notion of making a profit on the sludge, and there he was on the wrong line. "Sludge, like the poor," the Colonel added, "we shall always have with us." And he desired to express his regret that the Septic Tank Syndicate had been allowed to parade an advertisement—"No more sludge"—in the Congress Exhibition. Referring to Dr. Bostock Hill's paper, Colonel Jones remarked on the new name "resolving chamber" for the old cesspool, or "septic tank," as Mr. Cameron called it.

Mr. E. G. Mawbey (Leicester) observed that in Leicester they got on well for some time with a sewage farm, notwithstanding that the soil was clay; but as the town grew, the farm began to get overworked, and they came to the conclusion that they ought to clarify the sewage before putting it on the land. From experiments, which were carried out at Leicester for twelve months, they found that sewage could be clarified without chemicals. The question they then wanted to settle was which was the best way to do it, whether by open tanks, closed septic tanks, or ærobic beds. The resulting effluent was to go over a large area of pasture. They had been extremely successful in clarifying the sewage by the use of coarse grained ærobic beds, and then sending it on to pasture land. They had splendid effluents, and everything was going on well. His opinion was that the end of sewage farms had not arrived, but the farms could be used successfully in connection with biological treatment.

Bailie R. Anderson (Glasgow) said one point had been carefully avoided in the papers to which they had listened, and that was why the septic tank took no trade refuse or storm-water carrying road detritus. So far as the arrangement which he had seen at Exeter went, it was entirely for domestic sewage; also at Barrhead, where separate sewers had been laid for conveying the domestic sewage to the septic arrangement for the treatment of the sewage, and not, as he had been informed, for the whole refuse of the borough.

Mr. A. J. Martin: And storm-water.

Mr. J. Brierley (Southampton) said that what had been stated in regard to the absence of nitrates from the effluent brought to his mind the results of some analyses which he made ten or twelve years ago of samples of water taken from various points of the river Itchen. He found that there was a gradual increase of nitrates up to a certain point. At that point the water had to pass through a mill, and he there found that there was not only a considerable decrease of organic impurities, but also a considerable diminution of nitrates. It had struck him that the process of oxygenation to which the water was subjected on passing through the mill gave an increased activity to the ærobic microbes in the water, and led them to attack the nitrates. If that was the case, and the same thing happened in the filter-beds, when the quantity of nitrates was increased it would seem to show that the activity of the ærobic microbes was being lessened.

The PRESIDENT OF THE SECTION (Professor Percy Frankland), in a few general remarks, said the figures that had been given as to the capacity of the filter-beds corresponded very closely with what he had found himself. As to the disappearance of nitrogen, there had always been a general impression that the inter-action of the nitrites and ammonia salts affected the amount of total nitrogen ultimately found in the effluent. He had found that it did not injure the filter-beds to run storm-water through them. As to the most suitable materials for filter-beds, everyone had his fad. All were probably equally good, but much depended on the grain, and the way the beds were arranged; they could have all sorts of results from the same bed, according to the way in which they managed it, and that showed the advantage of having trained persons engaged in the work. A rumour had got abroad to the effect that the Massachusetts Board of Health had abandoned the biological treatment of sewage, but there was absolutely no foundation for that statement.

Mr. G. THUDICHUM (London) said, in reply to Mr. Anderson, that it was not necessary to exclude storm-water, as that gentleman had alleged.

Professor BOSTOCK HILL (Birmingham) agreed with the last speaker. He also explained that he did not write his paper with the view of advocating the universal use of coal filter-beds. He had simply stated that he had obtained a certain result in a practical way, and he quite agreed with those who said that the choice of material was not the main thing.