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CORRIGENDA.

Paper III., Page 62, 5th Paragraph, after Spearmans.—*For* "to make a road for the 12-pr. naval guns" *read* "to assist in getting up the 12-pr. naval guns, the road for which had been made during the day by the 17th Company, R.E."

PAPER I.

GRAPHIC SOLUTION OF ENGINEERING PROBLEMS.

By Lieut.-Colonel J. H. C. Harrison, late R.E.

It may be thought that the title I have chosen is too comprehensive, and that it is impossible within the space of one, or perhaps two, lectures to even glance at the multifarious subjects included under the head of civil engineering. To this I reply that it is not my intention to deal with any one of these subjects in detail, and we shall, indeed, be able to do little more in the time allotted than consider the general question of the stability of structures. But in doing this I hope to be able to establish the value of the polar diagram, and to show that anyone who possesses an adequate acquaintance with its varied applications possesses an instrument of extensive use for the general solution of civil engineering problems.

Graphic methods have, within quite recent years, become much developed, and attained to an importance such as was never before contemplated. They appeal to the eye, and are intelligible to the ordinary intellect.

It has, indeed, been aptly said that these methods would seem to be peculiarly adapted to the requirements of the civil engineer, for his "designs are geometric conceptions, within which forces statically combined act along geometric lines, so that it is natural that he strives to follow a train of geometric thought."

By quoting this passage, however, I do not wish to be thought to advocate the employment of graphic methods to the exclusion of analytic, for there is no doubt that the simple problems of most ordinary occurrence are most easily solved by the application of formulæ. But the graphic method may be regarded as valuable as an education for the solution of problems *not* of ordinary occurrence, and as a key to the analytic method, which in its symbolic form is often obscure. There are, for instance, certain problems (such as cases of unsymmetrically loaded fixed and continuous beams, tunnels, and underground cellars, the solution of which by analytic methods would be only possible at the hands of an accomplished mathematician), which lend themselves readily to graphic treatment.

I ought, perhaps, to say that I lay no claim myself to any special knowledge of *graphics*, but that, having had the experience of many years' teaching of applied mechanics to the students of the Government C.E. College at Roorkee, in the N.W. Provinces of India, during which, perhaps, I may be said to have devoted some attention to these graphic methods, I venture to hope that what I am about to say may be of some assistance to my younger brother officers who are now for the first time commencing the study of this subject.

The creation and development of the graphic method is, I believe, commonly attributed to Professor Culmann, of Zürich, about 1860. From Switzerland it passed into Germany, Austria, Italy, Russia, and Denmark, in each of which countries it was readily assimilated and taught in the schools, where the way had been prepared for it by a study of the works of Carnot, Poncelet, Möbius (extending over the period from about 1803 to 1858), and other geometricians.

But in 1858 Professor Rankine, in his *Manual of Applied Mechanics*, propounded a theorem regarding the "Equilibrium of Impressed Forces in a Polygonal Frame," which would seem to have contained the whole principle of the graphic method, but which appears to have remained unappreciated—in England at any rate—and comparatively barren of results.

In what I am about to say I shall take Professor Rankine's manual as the basis of my remarks.

In the time allotted, however, it will be impossible, as I have already hinted, to do more than glance at the principles involved, leaving the important subject of fixed and continuous beams, involving a consideration of Professor Mohr's graphic interpretation of the equation to the elastic line, and the question of earth pressure in its interesting bearing on foundations—especially well foundations—altogether untouched.

I would ask your indulgence in regard to the difficulty of making my subject interesting in a lecture, a difficulty arising, perhaps, out of its argumentative nature and the necessity of keeping the eye, ear, and mind continually on the alert. I have, in consequence, used my best endeavours to reduce the diagrams to a minimum, and suppress details so far as it is possible to do so.

The problems we shall deal with are all *dynamical*, that is, involve the consideration of *force*, the influence of which is, as we all know, invariably *active* as regards the matter acted on, that is, tends towards its motion in either a positive or negative sense. We shall, however, confine ourselves to statical problems only, that is, to those in which this active influence is effectually resisted. This, however, should in no way detract from the comprehensiveness of some of the methods employed. For instance, the graphical equivalents of the expressions Σmx and Σmx^2 would be the same whether the element of *time* were taken into account or not, that is, whether one of the symbols, x say, were employed to represent merely so many lineal units, or to stand for a velocity or acceleration, the other symbol being taken to mean the number of mass units involved. In the former case the expression Σmx would obviously stand for the sum of the moments of the system of material particles m about a given straight line; in the latter for the sum of the momenta or quantity of motion of such a system in motion. Similarly, the expression Σmx^2 would, in the former case, stand for the sum of the moments of inertia of the stationary system about a given axis; in the latter for the aggregate kinetic energy of the moving one. We may, indeed, still further generalize and say that the graphical equivalent of the expression Σmx, as hereinafter explained, affords a general construction for the summation of pairs of quantities of any kind whatever, provided only that each of the two elements of the several pairs contains quantities all of one kind. So likewise for the expression Σmx^2.

These considerations, however, lead us somewhat beyond the scope of these lectures, which embrace the graphical solution of civil engineering problems only. Before proceeding further, however, it will be well to assure ourselves that we are unanimous in regard to the preliminaries of our subject.

First, then, as to *Design*. The design of structures may be said to be the art of arranging the material of which they are composed

Material structures are continuously loaded by their own weights; they may be additionally loaded either by detached or continuous loads. Professor Rankine, however, on p. 131 of his *Applied Mechanics*, points out that "the mode of distribution of the intensity of the load upon a given piece of a structure affects its strength and stiffness only. So far as its *stability alone* is concerned, it is sufficient to know the magnitude and position of the *resultant* of that load, which . . . may then be treated as a single force." It may be added that, by still further supposing these several resultant loads to be entirely and proportionately distributed at the joints, the case may be reduced to that of a polygonal frame loaded *at the joints only*.

Having thus run through the preliminaries of our subject, I shall now enunciate and explain the general theorem regarding polygonal frames given on p. 140 of Professor Rankine's *Applied Mechanics*, which, since it so obviously depends on the principle of the triangle or polygon of forces, needs no proof. I shall hope to be able to show that this construction not only affords a means of measuring the direct stresses developed in the pieces of *all framed* structures subjected to the action of any system of applied loads whatsoever, but also of testing the stability of *all* structures, whether framed or not, and whether employed in spanning an interval or not. It also enables the magnitude and line of action of the resultant of the total applied load, or of the resultant of any part of the system of applied loads, to be determined, and affords a graphic representation of the curve of bending moments at successive sections of the structure; and it may also be readily made to furnish the value of the moment of any one, or of any number, of the applied loads about any chosen section of the structure. It also enables the centre of mass and the moments of inertia about a given axis of a system of material particles in one plane, or the centre of action of a given system of parallel forces acting on such a material system, to be ascertained. And, lastly, a construction geometrically similar, but made in regard to a given plane curve, enables the differentiated and integrated forms of that curve to be drawn.

In the explanatory diagrams I have employed the method of lettering devised by Mr. Bow, which, for the benefit of those unacquainted with it, may be briefly described as follows :—

To each of the enclosures, called *pens*, whether partially or entirely closed, into which the diagram is divided up by the lines of action of the forces a letter is allotted, and the force acting along the intersection of two pens, is distinguished by the two letters allotted to the pens concerned.

Thus, in *Figs.* 2 and 3 force AB acts along intersection of open pens A and B, and PB along that of closed pen P and open pen B, and so on.

The theorem is the following :—

"*If lines radiating from a point be drawn parallel to the lines of resistance of the bars of a polygonal frame, then the sides of any polygon whose angles lie in those radiating lines will represent a system of forces which, being applied to the joints of the frame, will balance each other, each such force being applied to the joint between the bars whose lines of resistance are parallel to the pair of radiating lines that enclose the side of the polygon of forces representing the force in question. Also, the lengths of the radiating lines will represent the stresses along the bars to whose lines of resistance they are respectively parallel.*"

Thus, suppose the radiating lines, otherwise called vectors, *pa*, *pb*, *pc*..., etc., of *Fig.* 1 to be drawn parallel to the lines of resistance of the bars of the polygonal frames ABCD..., etc., shown in *Figs.* 2 and 3, of which *Fig.* 3 shows an inverted form of the frame shown in *Fig.* 2, then will the sides of *any* polygon, such as *abcd*..., etc., whose angles lie *in* those radiating lines, represent a system of forces which, applied to the joints of the frame, will balance each other, each such force being applied to the joint between the bars whose lines of resistance are parallel to the pair of radiating lines that enclose the side of the polygon of forces representing the force in question. Thus, force AB (*Figs.* 2 and 3), represented by *ab* (*Fig.* 1), is applied at joint PAB (*Figs.* 2 and 3), and is balanced by the resistance in bars PA and PB, because these latter are represented respectively in direction and magnitude by the vectors *pa* and *pb* of *Fig.* 1, which enclose the side *ab*. Similarly, force DE of *Figs.* 2 and 3, corresponding to *de* of polygon *abcd*... of *Fig.* 1, acts at joint where bars PD and PE (*Figs.* 2 and 3) meet, and is balanced by the stresses in the bars, whose lines of resistance are parallel to the vectors *pd* and *pe* of *Fig.* 1, and so for any other force.

The polygons ABCD... of *Figs.* 2 and 3 may be aptly termed *equilibrium polygons;* they are also known as *link* and *funicular polygons.* The polygon *abcd...ka* of *Fig.* 1 is known as the *polygon of external loads.*

The theorem just enunciated may be otherwise stated thus :—

"If the series of straight lines radiating from a point, and above referred to, be given, then will the corresponding equilibrium polygon remain unchanged however the inclinations of the forces acting at the joints of the frame, that is, at the angles of the polygon, be changed, provided only that the magnitudes of the forces be such that the angles of the polygon of external loads lie always on those radiating lines, or, if the magnitudes be given, that the magnitudes and inclinations together be such as to fulfil this condition."

Thus, given the radiating lines of *Fig.* 1 and the equilibrium polygons ABCDE... of *Figs.* 2 and 3, the latter will remain unchanged however the inclinations of the forces acting at the angles be changed, provided only that the *magnitudes* of the several forces vary in such a manner that the angles of the polygons of external loads lie always *on* those radiating lines.

A diagram such as that represented in *Fig.* 1, composed of radiating lines and external applied loads, is usually known as a *force* or *stress* diagram. It is, in fact, a diagram of the *summation of vectors.*

If the applied loads be all parallel, as represented by red lines in *Figs.* 2 and 3, then will the line of loads of the stress diagram be as shown by the red line of *Fig.* 1.

Regarding the given forces AB, BC, CD... as a system of external loads applied at the joints of the frame ABCD...JK (*Figs.* 2 and 3), and *kq*, *qa* (*Fig.* 1) as the resistances at the respective points of support QAP and PKQ (*Figs.* 2 and 3), it will be observed that this system of external applied loads and corresponding resistances balances, since the magnitudes and directions of the several forces may be represented by the sides of the closed polygon *abcd...jka* (*Fig.* 1), taken in order, and may all be conceived to act together simultaneously at a single point, viz., the centre of action of the system.

If, now, the directions of the forces acting at the angles of the equilibrium polygons of *Figs.* 2 and 3 be examined, it will be observed that the pieces of the curved portion immediately supporting the applied loads are, in the case of the frame shown in *Fig.* 2, thrown into *compressive* strain, the single straight piece PQ, which may be regarded as the *closing piece* of the equilibrium polygon, alone being in tensile strain, whereas the corresponding pieces of *Fig.* 3—which shows, as I have explained, an inverted form of the polygon of *Fig.* 2, with the same forces AB, BC, CD... applied in the same direction and at the same joints as in *Fig.* 2—are thrown into *tensile* strain, and the closing piece PQ into compressive strain. The stress diagram of *Fig.* 1 serves, it will be seen, to determine the *magnitudes* of the stresses in the several bars in *both* cases, but the *nature* or *sense* or *direction* of these stresses becomes reversed in the two cases, the tensions in the pieces of *Fig.* 3 changing into the compressions of those of the frame shown in *Fig.* 2, and *vice versâ*. The polygon of external loads is clearly the same in both cases, ak (*Fig.* 1) representing the total resultant load both in direction and magnitude, and ka the total resultant resistance, of which the portion kq', in conjunction with $q'q$, acts at the point of support PKQ, and $q'a$, in conjunction with qq', at PAQ. Further, in accordance with the theorem just enunciated, since the total resultant load ak is balanced by the forces kp, pa in the triangle of forces pak (*Fig.* 1), if the extreme sides PA and PK of the equilibrium polygons of *Figs.* 2 and 3 be produced to meet in χ, and through χ a straight line $\chi\kappa$ be drawn parallel to ak of *Fig.* 1 to meet the side PQ (*Figs.* 2 and 3) in κ, then (since the point χ may be regarded for the purpose in view as an imaginary joint) $\chi\kappa$ will represent the line of action of the total resultant load, and pass in consequence through the centre of action of the whole system.

It is, moreover, evident, by taking moments about the point κ, that the side PQ is divided at κ in the inverse ratio of the magnitudes of the resistances at the points of support resolved parallel to the total resultant load, so that

$$(\mathrm{APQ})\,\kappa : \kappa\,(\mathrm{PKQ}) :: kq'\ (\textit{Fig. } 1) : q'a.$$

We can from these results at once deduce a method of determining the position of the centre of action of a system of parallel forces acting in a plane.

Suppose a series of such forces to act at the points M_1, M_2, M_3, M_4, and M_5 (*Fig.* 14), all lying in one plane. Conceive a straight line in the direction of the force to pass through each centre of force, and suppose these lines to be revolved up into the plane of the points. Then the line of action of the resultant of the system may be determined by means of a force diagram and equilibrium polygon in the manner already explained and illustrated in *Figs.* 15 and 18.

Again, by supposing the same forces to be revolved through any convenient angle, while their points of action remain unchanged, we can obtain a second force and a second equilibrium polygon, and so also the line of action of a second resultant, likewise passing through the centre of action of the system (as in *Figs.* 17 and 18). The point G (*Fig.* 14), in which these two lines of resultant action intersect, will clearly be the centre of action of the system.

This method, in its application to material particles, is equivalent to a graphic application of the well-known rule for finding the centre of gravity of an irregular figure :—

"Cut the figure, drawn to a large scale, out in cardboard, and suspend it in two positions by a fine thread; the point in which the directions of the two lines of thread intersect corresponds with the centre of gravity of the figure"—for the lengths M_1, M_2, M_3... of *Fig.* 18 may all be taken proportional to the areas of portions of an irregular plane figure, which have all been reduced to the same base length.

If the forces are supposed to be revolved through a right angle (as in the figures referred to), it will be unnecessary to describe a second force polygon, the one first described being utilized by laying the edge of a set square along its stress lines, and so obtaining a second series of stress lines perpendicular to the first (*Figs.* 18 and 20).

Now, just as the magnitude and line of action of the total resultant load are determined by means of the stress diagram and equilibrium polygon, so also may the magnitude and line of action of the resultant of any portion of the system of applied loads be ascertained.

For instance, if pq (*Fig.* 1) be produced to meet the polygon of external loads in q'', and aq'' and $q''k$ be joined, as shown in yellow lines, then will aq'' represent in magnitude and direction the resultant applied load which is balanced by the lines of resistance which are parallel to pa and $q''p$ (*Fig.* 1); and $q''k$ that balanced by resistances parallel to pq'' and kp. The line of action of pq'' may be determined as follows :—

From the stress diagram and equilibrium polygon together (*Figs.* 1, 2, and 3) it is evident that the line of action of pq'' (or $q''p$) lies between the sides PE and PF of *Figs.* 2 and 3, and is a tangent to the imaginary curve describable within the equilibrium polygon in the same way that all the other sides of that polygon are. Hence, since the direction of pq'' is parallel to that of the closing side

PQ, and the stress diagram shows that all the other vectors are inclined to it, it follows that the point of contact with the imaginary curve of the line of resistance which is parallel to pq'' must be one of maximum curvature, that is, of maximum ordinate.

Let this line of action of pq'' be drawn in (as shown in yellow lines, *Figs.* 2 and 3), then, by producing the extreme sides of the equilibrium polygon PA and PK to meet it (produced both ways), and drawing through the points of intesection straight lines parallel respectively to aq'' and $q''k$, the lines of action of these resultant loads are determined, as shown in yellow lines in *Figs.* 2 and 3.

The lines of action of the resultant loads acting on the two portions into which the frame is divided by the line of action of the total resultant load $\chi\kappa$ may be determined in a similar manner.

The magnitude and line of action of any other combination of the applied loads, as, for instance, of DE, EF...HJ, as shown in yellow lines in *Figs.* 1, 2, and 3, may be determined in a precisely similar manner. Of course, if the applied loads be all parallel, so also will the resultant total or partial loads be, as shown by red lines.

Obviously, if the two components aq'' and $q''k$, above referred to, be resolved, at the points in which the extreme sides of the polygon (PA and PK) are met, in two directions parallel respectively to PQ and to the resistance at the corresponding point of support; the former component will in each case be equal to qq'' in magnitude, but will act in opposite directions either side the point of contact, in consequence cancelling each other, and the latter component will be equal to the resistance at the corresponding point of support. Hence the theorem :—

If a plane, containing the maximum ordinate parallel to the line of action of the total resultant load acting on a frame, be supposed to cut the plane of the frame perpendicularly, it will divide the structure into two parts such that the resultant load on each is equal to the resistance at the corresponding point of support.

In the case of symmetric loading, clearly this maximum ordinate lies *in* the line of action of the total resultant load.

It is evident that, by means of the stress diagram and equilibrium polygon, a graphic representation of the shearing force, being the resultant of the external forces acting on either side of a section, can be at once obtained. This is illustrated in *Figs.* 10 and 12.

It is also evident that if the resistances at the points of support are constrained to lie in certain directions, as in *Figs.* 2 and 3, the polygon of external loads must be closed by straight lines drawn parallel to those directions, and that if they be not so constrained they will act parallel to the total resultant load.

Let us now examine a little more closely the position we have arrived at.

The theorem first enunciated treats of *polygonal frames*, and the term *frame* is defined by Professor Rankine as "a structure composed of bars, rods, links, or cords attached together or supported by joints of the *first class*, the centre of resistance being at the centre of each joint, and the line of resistance consequently a polygon whose angles are at the centres of the joints" (Rankine's *Applied Mechanics*, p. 132).

The term *frame*, then, includes a *single polygonal frame* only (not two frames braced together), and the joints being of the first class, the lines of action and reaction in the pieces must coincide.

Now lines of resistance and equilibrium polygons are all mere conceptions, and we may as readily conceive them drawn for structures whose actual joints are of the second class as for those having joints of the first class, the difference clearly being that whereas in the latter case only *one single imaginary polygon* is possible under the given conditions (viz., that one whose angles lie *at* the centres of the actual joints), in the former the number of imaginary figures is within the given limits of resistance area, limitless, the condition to be fulfilled in the case of second class joints being that the angles of each polygon must lie on the corresponding load lines (*vide Figs.* 11 and 12).

Granted, then, that the theorem is applicable to structures having joints of the second equally with those having joints of the first class, and we arrive at the following position, viz. :—

Fig. 3 may be taken as representative of the line of resistance or of active stress of structures, concave on the upper side, the pieces of which immediately supporting the load or loads are entirely subjected to tensile strain, that is : —

Class I.—The general case of the suspension bridge, including examples of cables and ropes suspended across intervals for bridging or other purposes, and of beams of uniform strength, whose webs are carved on the under side, such as inverted bowstring girders, etc.

Fig. 2 may be regarded as representative of the line of resistance or of active stress of structures concave on the under side, whose supporting pieces are thrown into compressive strain only, that is :—

Class II.—The general case of the arch, including braced structures such as the triangular truss, bowstring girder, etc., and beams of uniform strength and uniform flange width and thickness, whose webs are curved on the upper side.

Under this heading come structures of uncemented blockwork generally, to which class the masonry arch belongs, the material of which is incapable of resisting a tensile strain—such, for instance, as buttresses, retaining walls, tall chimneys, etc. Any portion of the frame shown in *Fig.* 2, as (P) GHJK, might, for instance, be taken to represent the resultant line of active thrust of the loads PG, GH, HJ, and JK on the blocks shown by thin black lines in *Fig.* 6, producing ultimately the thrust PK on the bottom bed-joint surface, which must, therefore, exert an equal and opposite resistance to meet it. The portion of the stress diagram (*Fig.* 1) which refers to *Fig.* 6 is shown separately in *Fig.* 7, and it will be noticed that in this case the polygon of external loads is *pghjkp*, and that the pole *p* coincides with an angle of the polygon—is, in fact, a point *in* the polygon of external loads. It will also be observed that the line of resistance is, in these cases of second class joints, not coincident with the line of active thrust. It is shown in blue in *Fig.* 6, the line of active stress being shown in thick black line. This absence of coincidence of action and reaction will be referred to later.

The intermediate case is that in which the direction of the supporting pieces are all parallel to that of the closing piece, the pole being taken at an infinite distance from the load line of the stress diagram, as in *Fig.* 13, the stress diagram of which is shown in *Fig.* 13A, the closing piece, corresponding with PQ of *Figs.* 2 and 3, being shown in blue. That is :—

Class III.—The case of parallel flanged girders or beams, including braced structures, such as Warren and Whipple-Murphy girders, and beams of uniform width and strength with parallel flanges, the upper and lower longitudinal fibres or flanges of which are subjected respectively to stress of opposite kind.

Cantilevers may belong to either Class III. or Classes I. and II. combined. Balconies of wood and iron and structures of cemented blockwork would belong to the former, cranes of iron framework to the latter. It should, moreover, be noted that in those structures of Class III. which do not span an interval, the position of the fibres subjected to tensile and compressive strain respectively become reversed as compared with pieces similarly situated (in regard to the load) of structures that span an interval—the former being thrown into tensile strain above and compressive below the neutral surface, and the latter *vice versâ* (see *Figs.* 23 to 25).

It should be observed that in suspension and arch structures (Classes I. and II.) the closing piece PQ of the equilibrium polygon is afforded by external agency—in the former by means of the anchoring chain, in the latter by the abutments—and that, therefore, in order to reduce all classes to similar conditions, we must suppose imaginary and weightless pieces to take the place of the chain or abutment—in the suspension structure a weightless compression bar, in the arch a weightless tie rod. In this way the closing piece, whether imaginary or real, of all classes is furnished by the structure itself.

Returning now to the three conditions of equilibrium of a structure to which I referred at the commencement of this lecture, it will be seen that, in order to ascertain whether the first condition is fulfilled, a polygon of external loads, similar to that shown in *Fig.* 1, must be described and closed by straight lines drawn parallel to the directions in which the resistances at the points of support act (as *kq*, *qa*, *Fig.* 1), and it must then be ascertained whether the structure is capable of furnishing the resistances so determined.

In order to ascertain whether the second condition of equilibrium is fulfilled, a suitable pole must be selected, as in *Fig.* 1, and a stress diagram and equilibrium polygon described and closed, as in the examples shown in *Figs.* 1 to 3, and the effect of such resultant stresses on the structure examined.

Each of the three conditions enjoins that the system of forces concerned must *balance*, that is, must fulfil the three conditions of equilibrium of a system of forces acting in a plane on a rigid body. The first two of these latter conditions, having reference to the direction and magnitude of the forces, are tested by the correct closing of the stress diagram; the third, which, I shall show you, has reference to moments, by the correct closing of the equilibrium or moment polygon.

It follows that, for the mere purpose of testing the stability of a structure of Class III. and describing its moment polygon, a pole may be selected at a convenient and measurable distance from the load line, although for the measurement of the actual stresses in the pieces it must lie at an infinite distance, as already explained.

In the case of structures having joints of the first class, the single equilibrium polygon, possible under the given conditions, may be at once drawn after one trial polygon has been completed, in a manner to be explained presently.

But in the case of structures having joints of the second class, although, as has been already pointed out, it is sufficient, in order merely to examine the *stability* of a structure, to take into account the *resultants* only of the loads acting between the joints, yet the polygons so obtained do not represent the actual lines of action or resistance, the loads being, as a matter of fact, always more or less continuous. When the distribution of the load is taken into account, the polygons merge into the curves to which the sides of the polygons are tangents; the lines of action and reaction then coincide, and the equilibrium polygon becomes the *curve* of resistance or stress.

Thus, the polygons of *Figs.* 2 to 3 become the curves indicated by green lines, the vectors of *Fig.* 1 being in the direction of the tangents of the curves of *Figs.* 2 and 3 at the corresponding points.

The green curve of *Fig.* 3 exhibits the figure which a perfectly flexible, weightless, and inextensible string would assume were it acted on by the continuous loading shown by the green curve of *Fig.* 1, while the curve of *Fig.* 2 represents a resultant line of resistance such as would occur in a continuously loaded arch structure. The analogy between the funicular curve of Class I. and the linear arch of Class II. is thus apparent. The curve of resistance will, in any case, be a *catenary*, which may be generally defined as the figure which a uniform, flexible, and weightless rope or chain assumes when acted on by any system of loads whatsoever. If the load be distributed uniformly along a horizontal line and transmitted to the rope or chain, the catenary assumes the form of a *parabola*; if the rope be heavy and loaded with its own weight only, the curve becomes the *common catenary*; these are all special forms of the genus *catenary*.

We are now in a position to enunciate the principle of projection by parallel rays of such polygons and curves as we have been considering. The principle is thus stated on p. 162 of Rankine's *Applied Mechanics* :—

"If a frame whose lines of resistance constitute a given figure be balanced under a system of external forces represented by a given system of lines, then will a frame whose lines of resistance constitute a figure which is a parallel projection of the original frame be balanced under a system of forces represented by the corresponding parallel projection of the given system of lines; and the lines representing the stresses along the bars of the new frame will be the corresponding parallel projections of the lines representing the stresses along the bars of the original frame."

If, for instance, the system of loads be parallel, and the plane of the frame be supposed to be revolved about the line of action of the total resultant load, and thence projected by parallel rays on to the plane of the paper, it is evident that the projection so obtained represents a frame loaded exactly similarly to the original frame, excepting only that the parallel loads will be nearer together and the span shorter compared to the frame depth. Otherwise considered, we may say that the scale of abscissæ measurements is hereby diminished, while that of ordinate measurements is retained unchanged, or it may be regarded as relatively increased.

If, further, the corresponding stress diagram be revolved about the line of total resultant load, and similarly projected, we shall obtain a projection of the stress diagram representing a system of forces which would severally balance if applied, as before, at the corresponding points of the projected frame, as the corresponding original forces were applied at the corresponding points of the original frame.

In a similar manner the frame or polygon might be revolved about the axis of abscissæ PQ with exactly similar results, provided the stress diagram is similarly revolved about *pq*.

It is evident, moreover, that this operation is inapplicable in the case of oblique loading, because the inclinations of the oblique loads would be relatively altered thereby.

Hence we may say that, in the case of parallel loading, the several equilibrium polygons or curves possible under given conditions may be regarded as representing one and the same polygon, only plotted differently; they may, in fact, be looked on as shadows or projections of some ideal polygon or curve existing in a plane inclined to that of the paper, and projected on to it.

And it is easy to show that in all cases this curve or polygon expresses the law of *variation of the bending moment* from section to section of the structure.

For, consider any section $\alpha\phi$ of the polygons shown in *Figs.* 2 and 3, taken in any direction. The shearing force, being the resultant of the applied loads on either side the section, is known from the stress diagram and equilibrium polygon, as already explained. Taking moments about the point δ, in which the equilibrium polygon or line of stress is cut by the section in question, we have—

$$\left.\begin{array}{l}\text{Moment of shearing force } (i.e., \\ \text{bending moment at any section})\end{array}\right\} = \text{moment of closing stress } pq.$$

But the closing stress pq is constant in value for every section of the same polygon. Hence the value of the bending moment varies with the length of the ordinate $\delta\phi$, that is, varies with the form of the equilibrium curve or polygon.

This result is an extremely important one, since it enables the bending moment at any section to be measured directly from the lineal and load scales already drawn.

In the case of parallel vertical loading, with closing side horizontal, which is that of most ordinary occurrence, the closing side of the stress diagram coincides with the pole distance, which is usually taken an even number of units, and some multiple of 10, so as to facilitate the operation. For obvious reasons, the pole distance should be measured on the same scale as that on which the line of loads, or its equivalent in the stress diagram, is measured (although for the mere measurement of the bending moment it would seem to be indifferent on which scale the pole distance and ordinate be measured, provided only that one be measured on one scale and the other on the other). For instance, in the method for finding the moments of inertia of a system of parallel loads about a given axis, which I am about to describe, the line in the second stress diagram corresponding to the line of loads in the first one is made up of a series of lengths measured off the lineal scale. The pole distance of this second stress diagram would, in consequence, be measured off that scale, whereas that of the first stress diagram would be measured off the scale of loads.

The following are the principles on which the polygons or curves are projected :—

I. The sides of the polygon, being tangents to the corresponding curve of bending moments, and the similar sides of any and all the projections, if produced, meet the axis of revolution, or line of intersection of the planes already referred to, in one and the same point.

II. Since the projecting of the ideal curve, already referred to, is equivalent to altering the scale of its abscissæ (or ordinates) while retaining that of its ordinates (or abscissæ), as already explained, if the figure of one projection be given and the new value of any one ordinate or abscissa, as the case may be, the new values of all the others are known by simple proportion.

For instance, the relations which the properties of the circle bear to those of the several conic sections afford a familiar illustration of the above principles.

Projections, as above described, are shown in *Figs.* 9 and 11.

Now this process of projection is specially useful in determining which of the many resistance curves possible within the limits of a second class joint is *the true one*, that is, *the* curved line along which the resistance actually *does* take place. In accordance with Moseley's principle of least resistance, which I shall quote for the benefit of those who have forgotten it, it must be that one along which the applied loads can be balanced by the material of which the structure is composed *with the least effort possible.*

The principle is thus stated and proved by Professor Rankine (*Applied Mechanics*, p. 215) :—

"If the forces which balance each other in or upon a given body or structure be distinguished into two systems, called respectively *active* and *passive*, then will the passive forces be the least which are capable of balancing the active forces, consistently with the physical condition of the body or structure.

"For the passive forces, being caused by the application of the active forces to the body or structure, will not increase after the active forces have been balanced by them, and will, therefore, not increase beyond the least amount capable of balancing the active forces."

Now, since the lengths of the several ordinates of the resistance curve are proportional to the magnitudes of the resisting couple required to balance the bending moments at the several sections of the structure, for any particular bending moment, the longer the ordinate the smaller the corresponding resisting force required to form the necessary couple; and, therefore, of all the curves possible under any given conditions, that one will clearly represent the curve of *least* resistance which, while falling within the prescribed limits of area resistance, *is the most concave of all with regard to the axis of abscissæ*, because the arm of that resisting couple will be the longest possible, and therefore the corresponding force the least possible under the given conditions. This principle, in conjunction with the method of projection just referred to, enables lines of least resistance, in the case of parallel loading, to be readily drawn in, as illustrated in *Figs.* 11 and 12, in which cases the plane of the ideal polygon is supposed to be revolved round the tangent at the highest point of the resistance area. Cases of oblique loading, including examples of underground cellars and tunnels, may be dealt with on first principles by the application of this principle of least resistance and of the method of drawing the line of action of partial loading already described. Time, however, forbids further discussion of this subject; suffice it to say that this problem admits of ready treatment by graphic methods.

It remains to show how the moments of the several applied loads at any section of the structure may be graphically represented—as at section $\alpha\phi$, for instance, of the closed curves shown in *Figs.* 2 and 3. Produce the sides of the polygon to meet the section $\alpha\phi$ in the points α, β, γ, δ, etc..

At the point PAQ we have the three forces *ap*, *pq* and *qa* (*Fig.* 1) in equilibrium; consequently any one of them may be regarded as the resultant of the other two. Hence at any point in the direction of AP (*Figs.* 2 and 3) we have

Moment of AQ = moment of PQ.

Therefore at α, in given section $\alpha\phi$, we have

Moment of AQ varies as length $\alpha\phi$.

Similarly, at point BAP (*Figs.* 2 and 3) the three forces *pa*, *ab* and *bp* (*Fig.* 1) are in equilibrium; therefore at any point in the direction of BP we have

Moment of AB = moment of PA.

Hence at β in given section $\alpha\phi$ we have

Moment of AB varies as length $\alpha\beta$.

In a similar manner it may be shown that the moment of the force BC varies as the length $\beta\gamma$ of $\alpha\phi$, and that of DC as $\gamma\delta$.

Cases of parallel loading, however, give much more satisfactory and exact results, for it will be observed that in the case of oblique loading the moments of the several loads are taken in regard to different points in the section $\alpha\phi$.

Suppose the moments of the parallel forces acting through the points M_1, M_2, M_3, M_4, M_5 (*Fig.* 14) about the straight line $G\gamma'$ be required. Describe the force and equilibrium polygons shown in *Figs.* 15 and 18, as already explained, and produce the directions of the equilibrium polygon to meet $G\gamma'$ in the points 2, 3, 4, and let x_1, x_2, x_3, x_4 and x_5 be the distances of M_1, M_2, M_3, M_4 and M_5 from the straight line $G\gamma'$.

Then for M_1 we have the triangle $gM_1 2$ of *Fig.* 15 similar to the triangle $M_1 p$ of *Fig.* 18. Let the pole distance of p measure π units.

Then we have

$$g2 : M_1 \ (\textit{Fig. } 18) :: x_1 : \pi ;$$

$$\therefore \pi \times g2 = M_1 \times x_1 = \text{moment of } M_1.$$

And similarly—

$$\pi \times 2\gamma = M_2 \times x_2 = \text{moment of } M_2 ;$$

and so on.

π being, as before explained, taken some multiple of 10 on the load scale, and the lengths $g2$, 23... measured on the lineal scale, the moments of the several forces are thus known.

If now we denote the quantities x_1, x_2, x_3... generally by x, and M_1, M_2, M_3... generally by m, the sum of the quantities $\pi\ (g2 + 2\gamma + \gamma 3 + \ldots)$ may be denoted by the symbol Σmx. Hence the general rule.

If quantities x_1, x_2, x_3..., etc., all of the same kind, be laid off from one extremity of a straight line, and all in one direction so as to overlap, and the quantities m_1, m_2, m_3..., etc., all of one kind, be laid off consecutively, one after the other, from one extremity of a straight line drawn at right angles to the former one, then, regarding the latter as a line of loads and the former as the line cut by the directions of the parallel loads at the several distances x_1, x_2, x_3... from one extremity, we can, by means of a stress diagram and equilibrium polygon, obtain the value of the expression Σmx within any given limits.

Further, if the lengths representing the quantities M_1x_1, M_2x_2, M_3x_3..., etc., be regarded as a series of new parallel forces acting severally at the points of application of the original ones, and a new stress diagram and equilibrium polygon be described as before, then may the value of the expression Σmx^2 within any given limits be determined in a precisely similar manner to that in which Σmx was so. This is illustrated in *Figs.* 16, 19, and 20, in which $g'\gamma'$ (*Fig.* 16) would represent the moments of inertia of the given loads M_1, M_2, M_3... about axis $G\gamma'$, and $g''\gamma''$ (*Fig.* 19) those about axis $G\gamma''$.

Lastly, if the stress diagram and equilibrium polygon be examined, it will be observed that the former furnishes a series of tangents whereby the curve of the latter is described; so that the inclination α to the axis of abscissæ of the tangent at any point of that curve is given by the relation

$$\alpha = \tan^{-1}\{\text{shearing force} \div \text{polar distance}\}.$$

At any section BP or 2′2, for instance, between AB and BC of *Figs.* 11 and 12 the magnitude of the shearing force is *bd* (*Fig.* 12), and the pole distance being *pd*, we have (denoting the shearing force by F and pole distance by π)

$$\tan \alpha = \left(\frac{bd}{pd}\right) = \left(\frac{\mathrm{F}}{\pi}\right).$$

But when a curve is continuous, we know that the tangent of inclination to the axis of abscissæ of a tangent to the curve at any point is, in the limit, equal to the ratio of change in length of ordinate to that of abscissa at that point, and is known as the differential coefficient of the equation to the curve at that point.

Hence, when the curve of bending moments is continuous, we have generally, *with pole distance unity*—

$$\text{Shearing force at any section} \div 1 = \frac{\mathrm{F}}{1} = \tan \alpha = \frac{dy}{dx} = \frac{d\mathrm{M}}{dx},$$

or

$$\mathrm{M} = \int \mathrm{F}\,dx,$$

which we know to be the case from analytical considerations.

Hence the following rule:—In order to integrate a given curve, as 4′, 3′, 2′, 1′... (*Fig.* 12), it is only necessary to take a pole P (*Fig.* 12) and set off a distance P*d*, equal to unity and parallel to the axis of abscissæ, and to draw an indefinite straight line through *d* parallel to the axis of ordinates. Then mark off along this latter line distances, as *dr*, *da*, *db*, *dc*, etc., equal to the lengths of the corresponding ordinates at the several points 4, 3, 2, 1..., and then join the outer extremity of these lengths to P. Then will the vectors P*r*, P*a*, P*b*, P*c*... be parallel to the tangents of the required curve at the extremities of the ordinates drawn at the points 4, 3, 2, 1....

Obviously, if a pole distance greater than unity be employed, the resulting curve will be flatter, and the ordinates, in consequence, correspondingly shorter than they would be with unit pole distance, and they must in consequence be multiplied by the number of units contained in the pole distance. With pole distance π, the above relation would be $\mathrm{F} = \pi \dfrac{d\mathrm{M}}{dx}$.

We have thus indirectly arrived at a most valuable result, viz., a graphic method of integrating and differentiating a given curve, for the latter process is merely the inverse of the former. The importance of this, since the results of observations and experiments in physical and engineering science are, as a rule, more conveniently plotted graphically to scale at once than reduced to equations, needs no comment.

For instance, we know from analytical considerations that the deflection of a supported beam at the section at which the bending moment is measured by M is denoted by the expression

$$\frac{1}{\mathrm{EI}}\iint \mathrm{M}dx^2, \text{ or } \frac{1}{\mathrm{EI}}\iiint \mathrm{F}dx^3,$$

in which the symbols have their usual significance.

If this expression is dealt with graphically, we see that the curve of bending moments must be integrated twice, or the curve of shearing force *three* times, and if, in the latter case, pole distances of p, p' and p'' be used respectively, the maximum ordinate of the resultant curve must be multiplied by the numerical factor $p \times p' \times p'' \div \mathrm{E} \times \mathrm{I}$, ordinates being measured on the lineal scale, the pole p on the load scale, and p' and p'' on the lineal scale.

It is, moreover, easy to show that the ordinates of the integrated form of a given plane curve measure respectively the areas of certain portions of this latter curve.

Consider, for instance, the ordinates of the curve inscribable in the blue moment-polygon of *Fig.* 11, which is an integrated form of the shearing-force-curve of *Fig.* 12.

It is necessary first to deal with the corresponding polygons.

Commencing with ordinate aa', we have the triangle $a\rho a'$ of *Fig.* 11 similar to the triangle $r\mathrm{P}d$ of *Fig.* 12.

Hence $\qquad aa' : \rho a' :: rd : \mathrm{P}d \ (= \pi)$;

$\therefore \qquad aa' = (\rho a' \times rd) \div \pi =$ (area of rectangle 44′, *Fig.* 12) $\div \pi$.

In other words, the ordinate aa' of *Fig.* 11 contains the same number of lineal units as there are superficial units in $\frac{1}{\pi}$ (area of rectangle 44′ of *Fig.* 12).

Similarly—

ordinate $\beta\beta'$ (*Fig.* 11) = (area of rectangle 33′, *Fig.* 12) $\div \pi$;

$\therefore \qquad$ total ordinate at $\beta =$ (sum of areas 44′ + 33′) $\div \pi$.

So, also, total ordinate at γ (*Fig.* 11) = total area of stepped figure (*Fig.* 12) measured from RR up to that ordinate.

Hence, when the ordinates are taken infinitely near together, we obtain the relation between a given plane curve and its integrated form, which may be expressed as follows :—

The number of lineal units in a given ordinate of the integrated form is the same as the number of superficial units in the given curve measured up to that ordinate, divided by the number of lineal units in the pole distance.

I would invite your attention to the diagrams I have prepared.

Fig. 1 is the stress diagram of the equilibrium curves shown in *Figs.* 2 and 3, as already explained.

In *Fig.* 4 I have placed a portion of the polygon of *Fig.* 2 in a light iron crane, which, please observe, consists of *two* frames braced together. The portion taken from *Fig.* 2 I have coloured black ; the added frame I have coloured red ; and the bracing green. I have done this so that the corresponding lines of the stress diagram and equilibrium polygon may be readily perceived, and it will be observed that since the single applied load PQ is supported by *each* frame, *each* extremity of *pq* in the stress diagram becomes a pole, the external load at the joints of the frames being furnished by the resultant brace stresses at those points, shown by the broken red and black lines. The bending moment diagram I have shown with a full red and a full black line.

In *Fig.* 6 I have placed a portion of the polygon of *Fig.* 2 in a blockwork structure, as already explained.

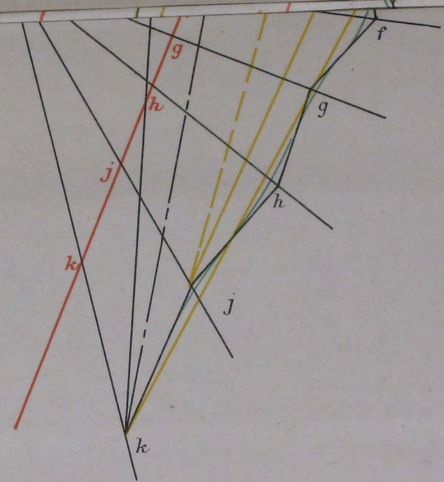
In *Fig.* 8 I have formed a hinged arch of two framed structures each similar to the crane of *Fig.* 4, and it will be observed that the stress diagram of the original black portion (viz., *pfghjk*) is similar in *Figs.* 5 and 10. The red frame of *Fig.* 8 is loaded with external vertical loads above as well as with the bracing below, and its stress diagram may, therefore, advantageously be compared with that of *Fig.* 4, the red frame of which latter is only loaded with the bracing.

Observe, however, that the design of *Fig.* 8 is a bad one, the resistance curve passing outside the structure at once, and consequently causing the bracing to be unnecessarily stressed. *Fig.* 8*a* shows an improved design (taken from Ritter's *Iron Bridges and Roofs*), the rib being designed of the form of the equilibrium polygon, and the bracing, therefore, only called into play when a moving load passes over the bridge.

In *Fig.* 9 several projections of the equilibrium polygon are shown; that in red is the resistance line of the structures shown in *Figs.* 8*a* and 8*b*.

Figs. 11 and 12 show the design of a semi-circular masonry arch ring with superstructure. Three projections of the resistance line are shown, that in black being the line of least resistance. The corresponding stress diagrams are shown in same colours in *Fig.* 12. The imaginary joints, enabling the weight of the superstructure to be estimated, are shown in broken blue lines.

Figs. 13 and 14 show an example of a braced structure of Class III., the pole of the stress diagram being at an infinite distance from the load line.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PAPER II.

ELECTRO-PNEUMATIC SIGNALLING.

BY ERNEST DE M. MALAN, ESQ.

(Lecture delivered at the School of Military Engineering, Chatham, on March 28th, 1901).

THIRTY years ago this month the first lecture ever given on Railway Signalling was delivered before this school by Capt. Tyler, of your distinguished Corps, and the past is linked to the present not only in the subject matter of the lecture which your Commandant has invited me to give you, but also in the fact that I have the honour to serve in a civilian capacity the lecturer of thirty years ago, now become Sir Henry Tyler.

Railway signalling was then in its childhood, but it has since developed through the ever-increasing needs of railway traffic to a point where it would now be scarcely recognised by its forbears. Each notable accident has sharpened the wits of those interested in this art of speedily forwarding and safeguarding the thousands of trains engaged in daily transporting their human and other freight all over the surface of the globe. And in this country there has been added the constant pressure of the Board of Trade, whose inspecting officers are always R.E. officers; and this has resulted in a more or less unifying of the main principles of railway signalling, leaving, as is always dear to our British modes of thought, the details to be carried out by each railway company as it seems best to them. The semaphore signal, for instance, has now completely superseded all other forms, and in various other ways the task of a modern engine-driver, rushing along at over 60 miles an hour, has been much lightened and made less susceptible of error.

With the increase of traffic, however, the labour of a signalman in pulling over the levers, especially in busy stations, has increased in a greater ratio than the actual number of trains running, as the various modern safety appliances, which are now considered essential in all up-to-date installations, necessitate a much larger expenditure of muscular force on his part. This not only exhausts the man as regards the muscles actually employed, but also reacts on his brain, so that he is more liable to error and misunderstanding when working his electrical instruments. This has been met by shortening the hours of labour; but within the last 20 years so-called "power" systems have been introduced with the view of replacing the animal force of the signalman by some sort of mechanical power. As may be expected, these first arose in that land where as yet there are few established forms and customs to oppose new ideas, the United States of America, and it is a development of the earliest form of power signalling, viz., the electro-pneumatic system, of which I have the honour to speak to you to-night. Whatever the form of the power that may be used, be it air, water, or electricity, it is stored up and directed to the actual moving of the points and signals by the manipulation of diminutive levers requiring a minimum of effort to pull them over, no matter how far from the cabin the points or signals may be. The signalman is thus left fresh and fully alert to attend to the working of the electrical instruments and the actual conducting of the traffic, as well as to meet any sudden emergency which may arise.

Among the many advantages obtained by the introduction of "power" systems may be noted the following:—

1. Ease of operation.

2. Reduction of size of locking-frame.

3. Absence of movable rods and wires leading out from the cabin; the possibility, therefore, of placing the cabin where an ordinary cabin with a large "manually" worked frame could not possibly be located.

4. Absence of all rods and wires above ground, where they are ever a fruitful source of accident to shunters and others, so much so that the Royal Commission on Railway Accidents recently recommended their avoidance wherever possible.

5. By the absence of these moving rods and wires all difficulties due to changes of temperature are swept away.

6. The points and signals are always "exactly" worked, and an indication or repetition of the same is sent to the signalman,

preventing him from making any further movement of his levers until he has received such indication, thus extending the full advantages of the mechanical interlocking between the levers to the actual apparatus on the ground, and not limiting it to the levers alone, as is usual with those of the manual system.

7. Points and signals can be placed exactly where required, as the power can be carried to any distance desired.

8. A reduction in the number of cabins and in the staff required to work a given frame is often possible.

Each power system has its own peculiarities and advantages, but the above are the most notable of the advantages common to all.

Before entering into a full description of the electro-pneumatic system, a brief *résumé* of the birth-dates of the principal modern systems will be shown.

Origin of Railway Signalling.

System.		Date.	Introduced by.	Country.
		Block Signalling.		
Electric ...	First installation ...	1844... ...	Cook	England.
		Installations Worked from a Locking Frame.		
Manual ...	First Locking Frame	1856... ...	Saxby	England.
Pneumatic	Experimentally only	About 1883	Westinghouse ...	U. States.
Hydro-Pneumatic	First installation ...	1884... ...	,, ...	,,
Hydraulic	,, ,, ...	About 1888	Bianchi	Italy.
Electro-Pneumatic	,, ,, ...	1892... ...	Westinghouse ...	U. States.
Electric ...	,, ,, ...	About 1894	Siemens & Halske	Austria.
		Automatic Signalling.		
Electric ...	With Wire Circuit...	1867... ...	Hall	U. States.
,,	,, Track ,, ...	1871... ...	Pope	,,
Electro-Pneumatic	,, ,, ,, ...	1883... ...	Westinghouse ...	,,

Block signalling is the term employed to denote the employment in each signal cabin of special electrical instruments, by means of which certain definite signals can be exchanged between one signalman and another, so as to ensure at all times a constant space (called a block section, hence the name) between two consecutive trains. This does not in any way appeal directly to the drivers. It was first introduced on the Great Eastern Railway in 1844, being based on a book by Sir William Fothergill Cook, brought out two years previously.

Lock and block signalling, where the electrical block instruments are mechanically and electrically connected with the levers working the signals in such a way that no lever lowering the signal for the admission of a train into a section can be used without the permission of the signalman in advance, was first introduced about 1874.

The concentration of the levers working signals and points, and the mechanical interlocking of the same, so that no conflicting points or signals can be pulled over together, was first carried out in 1856 by Mr. J. Saxby.

Twenty-seven years later, that is, in 1883, Mr. George Westinghouse, of air-brake fame, applied compressed air to the working of points and signals. As regards the points, difficulties led him to abandon the experiments with air alone in favour of a system where, instead of having to fill and empty long lengths of controlling pipes with air at each desired movement of the points, the force was transmitted through a column of water from the locking-frame to the motors at the points, compressed air still remaining the actual motive power. This worked much quicker and more satisfactorily than the all-air system, and from 1884 several cabins were fitted in this way, many of which are still in use. In the last few years the all-air system as applied to both signals and points has been worked up by other minds, and some installations have been erected in America, and there will be one shortly in this country on the London & South Western Railway. In this system the valves admitting air to the motors are operated by diaphragms, actuated by air at a very low pressure. In 1892 Mr. Westinghouse brought out his electro-pneumatically worked points (signals having been thus worked for nine years previously), and since then no more hydro-pneumatic plants have been manufactured, as the advantages of electricity over other agents for controlling the valves and indicating the movement of the motors are considered to, by far, outweigh any other disadvantages which its adoption might be thought to entail.

In the United States and in Europe there are now a very large number of hydro and electro-pneumatic installations.

In 1884 Bianchi introduced the hydraulic system, where the motive and indicating force is water under pressure. This is largely used, especially in Southern Europe.

About 1894 Messrs. Siemens & Halske put up their first electric installation in Austria, and this system is to be found in several places in Northern Europe. Electro-motors through gearing work the points and signals, the pressure used being about 110 volts. The indication is of course also electrical. Messrs. Webb & Thompson, of the London & North Western Railway, have recently brought out a similar system of their own, where electro-motors are used to actuate the points and long-pull magnets (as already used for several years on the Liverpool Overhead Railway) for the signals, and this is being installed on their own line.

As items of historical interest, three dates in connection with automatic signalling, where the train itself actuates the signals without the intervention of any signalman, are here given. In the early days of this system, which, whether born in England or the United States, has certainly been practically developed in the latter country, treadles were used which were connected to one another or to the signals by overhead wires, but these have now been superseded by the so-called track-circuit system, where a current of electricity of feeble voltage circulates through the rails of a section, and, as will be explained more fully later on, the presence of a train in this section short circuits the current, which in turn affects the signal displayed. Electro-pneumatically worked signals were thus applied in 1883, and their use since then is constantly extending.

Having thus briefly enumerated the chief power systems, we will now turn to a closer consideration of the electro-pneumatic system of signalling. At this point I would say that, having passed so many years on or connected with railways, I find it difficult to remember that you are not all as familiar with the technical terms as I am, and if there are any points which I have not made clear to you, I trust that you will not hesitate to stop me and demand the necessary elucidation.

The three main principles on which electro-pneumatic signalling is based may be briefly summed up as follows :—

1. Points, including all locks and bars working in connection with the same, signals of all kinds and forms, scotch-blocks, gates, etc., etc., are operated by compressed air, acting through motors consisting of small cylinders and pistons.

2. The valves controlling the admission and exhaustion of the air to and from the motors are operated by electro-magnets, through which small electric currents circulate in certain positions of the levers in the locking-frame ; the said frame consisting of a series of such levers mechanically interlocked with one another (as is the case in all manual frames), and operating suitable electric switches.

3. The movement of all points, signals, etc., is indicated or repeated in the locking-frame in such a way that, should it be partially or wholly prevented, the lever and all others dependent on it are at once locked up, and so cannot be moved in a dangerous direction until the cause of such hindrance is removed.

To render these principles clear, the following figures, showing a signal circuit in three positions of the lever, are presented. It must be of course understood that these and all other diagrams exhibited show the principles underlying the various arrangements of the apparatus, and not the actual form in which these are carried out in practice.

Fig. 1 shows a signal lever in its normal position, that is, perpendicular. In this case it controls two opposing signals, and when moved to the right or forwards, the right-hand signal is lowered, and when moved to the left or backwards, the left-hand signal comes "off," as lowering is technically called. It will be noticed that in its normal condition no current is flowing through any of the circuits, the operating circuit being interrupted at contacts B and F, and the indicating circuit at LCB. As soon as the signalman lifts the latch of the lever preliminary to moving it he closes LCB, and a current flows from the battery through LCB, the electro-magnet I, and the two contacts at the signals, and so back to the battery, resulting in the energizing of the magnet I and the consequent lifting up of the lock, thus enabling the lever to be moved in the desired direction, provided of course that the mechanical interlocking, shown at ML, allows of the same. On the lever being pulled over to F, as shown in *Fig.* 2, you will notice that contact F is closed, and therefore a current flows through it from the battery to the motor of signal F, and thence back again to the battery. The valve of the motor is thereby operated, as will be explained more fully later on, and air is admitted to the motor, whereupon the signal comes "off" or to the clear position. As soon as the signal arm leaves its danger position, however, the contact at the arm is broken, and thus the indicating circuit is interrupted, and magnet I becomes de-energized, allowing the lock to drop as shown. The lock in this position permits of a partial return of the lever towards its normal position, but, as shown in *Fig.* 3, not sufficiently to release such mechanical locking as is operated by it, and which should remain effective until the signal is absolutely at danger. This partial movement of the lever, however, is sufficient to interrupt the controlling circuit, thereby de-energizing the magnet

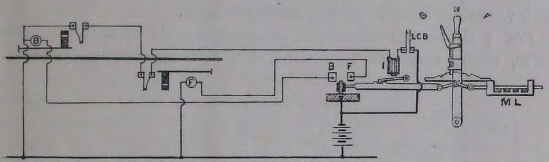


Fig. 1.

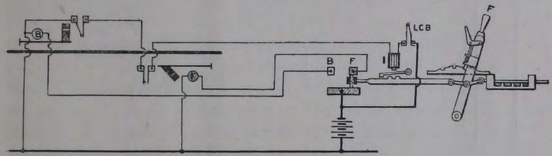


Fig. 2.

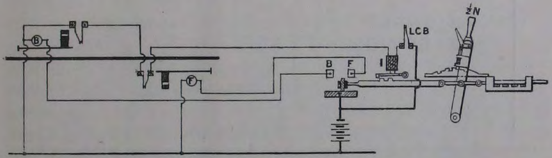


Fig. 3.

of the signal, whereupon the air escapes from the motor, thus allowing the signal arm to return to danger by gravity. Should it for any reason fail to do so, the indicating contact at the arm remains open, and therefore the lever operating the signal is prevented by the lock under magnet I from being returned to normal, and hence a change of route from the one governed by the deranged signal is prevented.

If, however, the signal duly returns to danger, then we have the position shown in *Fig.* 3, where the indicating circuit is closed at the signal and the magnet I is energized, thus permitting the complete return of the lever to its normal position. It will be seen that, besides forming a safe means of selecting and operating signals, this method also provides within itself the most effective form of interlocking between two opposing signals that can be devised, since no lever can assume two positions at one time.

Fig. 4 shows the method of selecting signals operated by one lever, where they are conflicting, but not necessarily opposing.

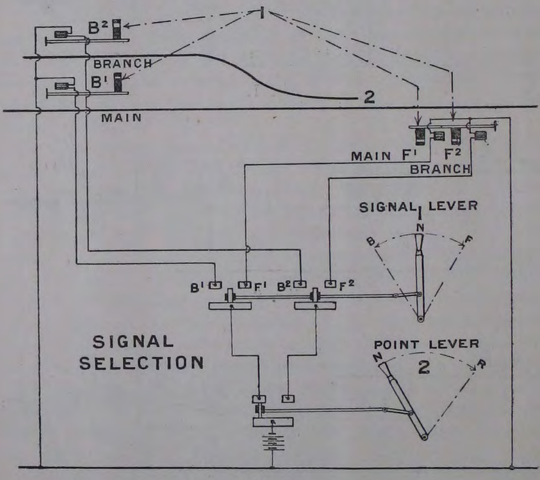


Fig. 4.

Thus F1 conflicts with F2, and in like manner B1 conflicts with B2, but the two B signals oppose the two F signals. Thus the selection between either of the B's and either of the F's is made by moving the lever backwards or forwards; conflicting signals, however, control the running from either one route to two (or more), as is the case with the F signals here, or from two or more routes to one route, as exemplified by the B signals. Conflicting signals therefore are differentiated by the different positions of one or more points (in the case shown it is one, No. 2), and advantage is taken of this to place the selecting contacts on the point lever. It will thus be seen that, in the normal position of the point lever as shown, a moving of the signal lever will result in the lowering of either B1 or F1, according as the signal lever is moved backwards or forwards. On the point lever being reversed, which, owing to the mechanical inter-locking, can take place only when the signal lever is in its central position, signals B2 or F2 alone can be operated. As will be shown later on, the point lever cannot assume either end position, in which alone it can close either of the signal selecting contacts, until the points are actually in the desired position, and therefore the signal is truly selected by the actual position of the points themselves. This is done therefore without the necessity of placing a selector at the points, where contacts are naturally much more liable to failure than when indoors, and this allows of the running of the signal controlling wires direct from the cabin to the signal, without the necessity of having to dodge all over the yard to the various points in the route to which the signal gives access, for, as I need hardly point out, it is not often that the selection of conflicting signals is as simple as here shown. In order not to unnecessarily complicate the diagram, the indicating circuit has been omitted, but it would include a circuit-breaker at every signal arm, all placed in series in one circuit, so that, unless all arms were at danger, the lever would be locked up.

By these methods of selecting opposing and conflicting signals it will be seen that a large economy in the number of signal levers is effected over what is necessary in ordinary manual signalling, where each signal arm usually requires a separate lever. This, of course, as well as the fact that the electro-pneumatic levers are spaced apart about half the distance of the manual levers, tends to make both frame and cabin very short and compact.

We will now turn to a consideration of the circuits for operating a pair of points. As in the signal circuits already studied, there are three diagrams, *Fig.* 5 showing the lever in its normal position, which in this case is slanting backwards. The controlling and indicating circuits are similar to those in the signal circuits, but as the points are moved in both directions by air, two controlling magnets and two indicating locks are requisite. In these diagrams all contacts through which a current is flowing are shown shaded, and in the normal position it will be seen that this is the case with contacts N and magnet N, so that thereby air has been admitted to the normal side of the piston actuating the points. The lever is always free to be pulled over up to its two-thirds position, where it is arrested by the lock of the indication magnet R1. In this

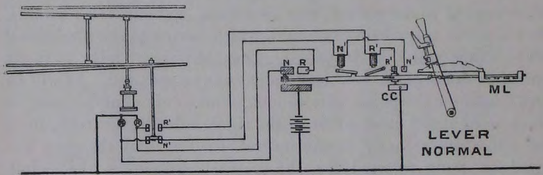


Fig. 5.

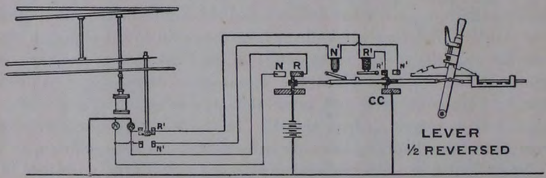


Fig 6.

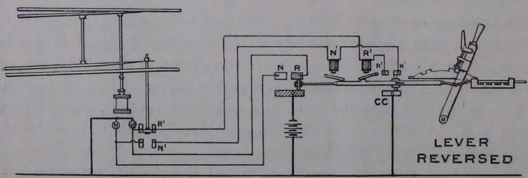


Fig. 7.

position, shown in *Fig.* 6, the contact N has been broken and R made, so that a current now flows through the R or reverse magnet of the motor, thus admitting air to the reverse side of the piston of the motor, and so reversing the points. Attached to these is the indicating switch N1, R1, and as the points come safely home in their new position, the contact is shifted from N1 to R1, and the current flowing to magnet R is tapped, a portion flowing through R1 to magnet R1, and thence through the contact R1 attached to the lever back to the battery. Lock R1 is thereby lifted, and the stroke of the lever may be now completed as shown in *Fig.* 7. Here you will notice that the circuit changer CC, which is actuated by means of a slot only in the very last portion of the stroke, has been shifted, so as to break the indicating circuit, and thus the magnet R1 becomes de-energized and the lock falls down. It is not until the last third of the stroke of the lever has been completed that the mechanical interlocking, ML, permits the moving of the signal lever, and therefore it is impossible that the latter be moved until the points are actually in their proper position, and the selecting of conflicting signals on the lever is as safe as if this were done at the points themselves. Should the motion of the points be hindered or entirely prevented, the indicator R1 would not be energized, and the lever would be prevented from completing its stroke. It is free, however, to be returned sufficiently to re-make contact N, and thus bring the points back to their original position, thus allowing of a stone or other obstruction being removed from the points without having to disconnect them from the motor.

Precisely the same conditions govern the return of the points and their lever to their normal position ; but the other pair of contacts N and N1 at the points, and the other indication magnet N1 engaging the lever, are called into play for this purpose.

Where two points are operated at the same time, as, for instance, at the two ends of an ordinary cross-over road, the point motors are connected up electrically in parallel and the indication circuits in series, so that the same voltage is retained for double points as for single ones, and any incomplete movement of any one of the points interrupts the indicating circuit, and so prevents the reversal of the lever.

I will now show you the actual manner in which the motors operate, though here again the drawings are somewhat diagrammatical in order to show the *modus operandi* quite clearly.

In *Fig.* 8 a standard signal motor is shown, and to give you some idea of its small dimensions, I may say that its diameter is 3 inches, and stroke 4 inches.

Compressed air from the main enters through the pipe on the left marked "AIR," and follows the arrow, so that the pin-valve chamber, PV, is constantly filled therewith. The valve itself is held up against its seat by the air pressure, and normally the cylinder remains open to the atmosphere through the exhaust port under the

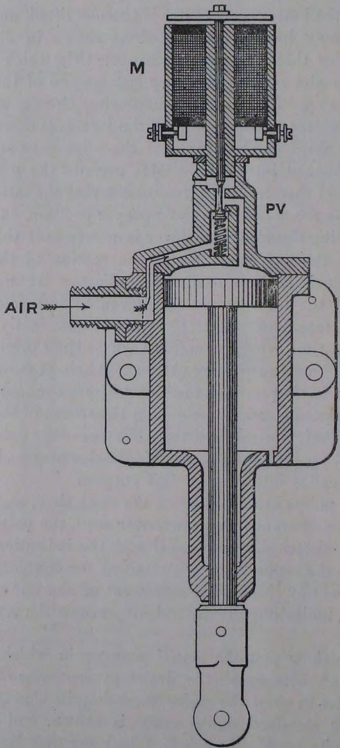


Fig. 8.

magnet. On this latter being energized by a current, the armature is attracted, taking with it the stem, thereby not only closing the exhaust port, but opening the pin-valve as well. The air now streams into the cylinder and pushes the piston downwards, whereby the signal is lowered, and remains so as long as the pin-valve is open. On the current being cut off by the return movement of the lever, or by the action of a passing train breaking the circuit through a treadle, the magnet becomes instantly de-energized, and the armature under the combined stimulus of the air pressure on the exhaust valve and the spring in the pin-valve rises, thus closing the pin-valve and cutting off the supply of air, and at the same time opening the exhaust. Under the action of suitable counter-weights, the piston is driven upwards, and the signal returns to danger. By properly proportioning the size of the exhaust port the exit of the air is choked, so that the movement of the signal arm, when returning to danger, is so cushioned that all violent striking of the stops is avoided, the action being somewhat similar to that of a pneumatic door-check. Were the signal returned to danger by air pressure, there would always be a risk of its remaining "off," owing to want of pressure, and the fundamental principle that the force returning a signal to danger must always be available, whether pipes or circuits are in order or not, would be violated.

Fig. 9 shows the application of a signal motor to a wooden signal post. The motor SM is in a cast-iron housing, and the piston-rod is connected to a counter-balance lever, which is joined to the signal arm by a rod in the usual manner. On the piston being pushed down by the air, the other end of the lever rises and pushes the arm off. On the current being interrupted, the counter-balance weight on the arm and on the lever both push the piston up again. Dotted behind the arm is shown the indicating contact for notifying to the cabin the position of the signal. At the foot of the post is the main air pipe MP, which runs through the whole yard, and from which a smaller pipe brings the air to the auxiliary reservoir AR. This reservoir serves to promptly supply the air to the motor, and to catch any moisture due to condensation of the air or any sediment contained in the pipe.

We now come to a point motor (*Fig.* 10), the most usual size of which in this country is 4 inches diameter, with 4 inches stroke. Here there are two pin-valves PV identical with that on the signal motor already described, but instead of these admitting air directly into the motor; they do so indirectly by means of the slide-valve SV, this method of working having certain practical advantages over the direct

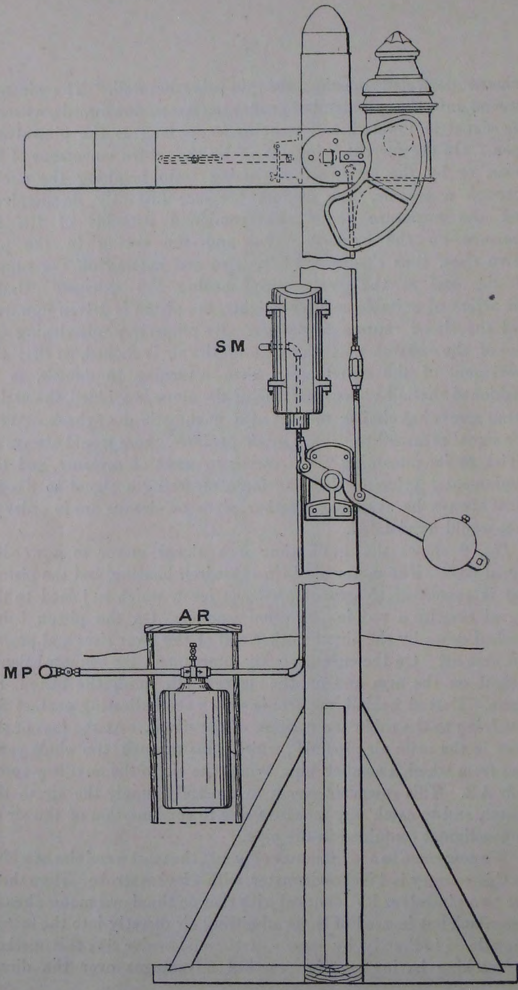


Fig. 9.

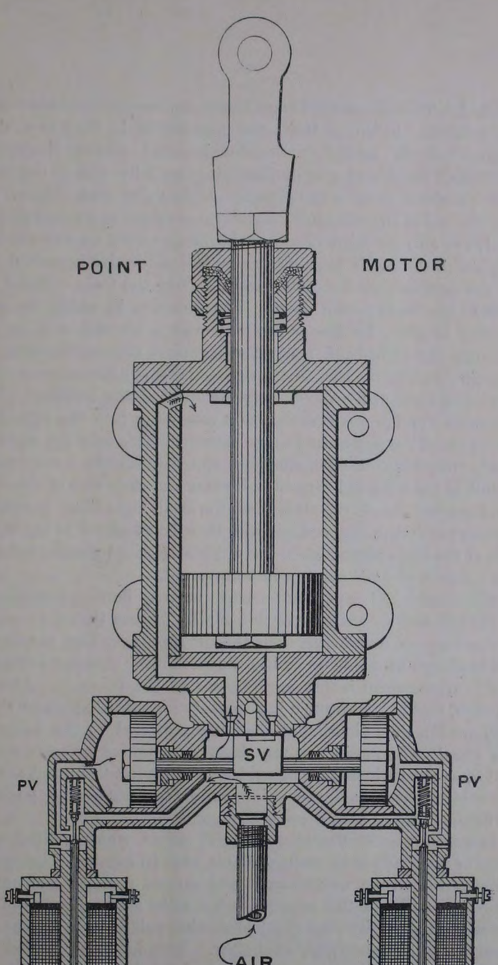


Fig. 10.

method. This slide-valve is mounted in a chamber constantly under air pressure, in much the same manner as is that of a steam engine. It is moved by a double-ended piston working in two small single-acting cylinders lying opposite one to the other, and provided each with a separate pin-valve and magnet. In practice one of these magnets is always energized so that air pressure is always on one small piston or the other—here on the left-hand one—with the result that in this case the slide-valve is pushed over to the left, and air has entered the top of the main cylinder and pushed the main piston down. The direction in which the air is flowing is given by the arrows. Should a current now be sent through the right-hand magnet, this would actuate the pin-valve and admit air to the back of the right-hand small piston, but without any effect on the slide-valve, as the air behind the left-hand piston exerts an equal pressure to that now streaming into the right-hand cylinder. Thus any stray foreign current which may get on to the conducting wires has no effect on the points. If, however, the circuit of the left-hand magnet is broken, and then that of the right-hand magnet closed, the air behind the small right-hand piston will reverse the slide-valve, and air will then be admitted to the underside of the main piston, while the upper side will be connected with the exhaust, and the points will be reversed.

Whether there is a constant electric current flowing through one or the other of the magnets or not, it will be seen that the motor is in constant communication with the air supply, so that the switch-rail is always kept well up against the stock-rail. Another advantage of this arrangement is that, in the event of the points being trailed through, that is, run through in a contrary direction to that for which they are set, the rail-switches are forcibly opened by the flanges of the wheels without in any way causing an undue pressure in the motor, as the air is simply pressed back into the air main, and as soon the vehicle has passed, the points return to their normal position, no damage having been done to any parts.

In the German system of working all points, whether fitted with locks or not, have to be made trailable, that is, capable of being run through the wrong way without any serious damage, and at the same time notice of this occurrence has to be automatically sent to the cabin, and all signals dependent on that pair of points have to be placed, also automatically, at danger. This has been carried out in the electro-pneumatic apparatus specially designed to suit the German market.

In *Plate* I. is seen an actual application of a motor to a pair of trailing points, that is, points through which a train runs in the same direction as the switch-rails are pointing. The motor with its two magnets is to be seen in the foreground, and the indication box containing the contacts at the extreme right, both being on a wooden foundation firmly bolted to the sleepers. It will be noticed that the motor is directly connected to the switch-rail on the far side, while the indication box is connected to the near switch; by this means any breakage of the stretcher-bar linking the two switches together is immediately detected. As you see, the indication box is connected through a sway-beam with unequal arms to the switch-rail, so that a very small obstruction at the points will cause a large variation in the stroke of the indicating apparatus, and so cannot fail to prevent its sending a releasing current to the lever.

Facing points, that is, points which face or point towards an approaching train, must in this country be fitted first with a bolt or plunger actually locking the points in both their extreme positions, viz., when set for the main or branch line, and secondly, with a lock or locking-bar consisting of a long angle or tee-bar usually placed inside the rails just in front of the points, and in such a position that it lies normally well below the top of the rail. This bar has to be lifted up before the points can be moved, and if there is a vehicle passing over it, this cannot be done, as the flanges of the wheels prevent the bar from rising, and so the points cannot be reversed so long as any vehicle is there. This bar is usually worked, together with the plunger, from a separate lever in ordinary manual signalling apparatus, but in the electro-pneumatic system the point lever serves to actuate these, as well as the points as shown in *Plate* II., where P is the plunger, and LB the lock-bar. The motor here is 5 inches in diameter, and has a stroke of 8 inches. The auxiliary reservoir and the point motor are as already described, except that here the valves are usually placed at the side of the motor, instead of at the end. The piston works a slide, the stroke of which is continuous in practice, but it may, for purposes of explanation, be considered as being divided into three portions. In the first portion the slide lifts up the lock-bar LB, and withdraws the plunger P, and so unlocks the points, and also breaks the indication contacts IB. A stud on the slide at the same time slides along the face of the escape-crank, or, as our American cousins happily call it "alligator jaw." In the second portion of the stroke the pin engages this jaw, and quickly reverses the points by means of the connections. In the last portion of the stroke this pin slides along the other face of the jaw, thus ceasing to have any effect on the points; but the motion of the slide lowers the lock-bar LB into its normal position, and at the same time re-locks the points, and makes a suitable contact in IB, thus sending a current to the lever in the locking-frame, and unlocking it, so that it may complete its stroke.

In practice, and with the air inlets reduced so as to prevent a too violent working of the points, the time required for reversing a pair of points and bringing the lever home may be taken as under two seconds. I would call your attention to the part of the piping between the auxiliary reservoir motor, and marked HC. This is formed by a piece of hose similar to that used for the air brake between the carriages of a train. As the motor is rigidly connected to the road through its foundation and the iron tie-bar T, which passes under the chairs, it is impossible to keep it free from vibration and movement due to passing trains; and so if the air piping be rigid, the joints would soon leak, and this piece of hose is therefore employed. Its use has a further advantage of allowing a certain amount of slewing to be done to the road without the necessity of disconnecting the motor from the cabin, thus avoiding during alterations to the road all hand signalling, with attendant risk of misunderstanding and accident.

We will now turn to the locking-frame itself, of which I propose to show actual photos, as the diagrams in connection with the signal and point circuits have already given you the essential parts.

Before showing you an electro-pneumatic frame, a photo of the interior of one of the manual cabins at Liverpool Street station on the Great Eastern Railway, and showing part of the frame, will be thrown upon the screen, so that you may see the difference between the manual and the electro-pneumatic frames. Here the levers are some 6 feet long, and spaced about 5 inches apart, whereas in the next view the levers are but $6\frac{3}{8}$ inches long, and spaced only $2\frac{1}{2}$ inches apart. In the manual frame the signalman has often to throw the whole weight of his body on the lever in order to work it, but in the electro-pneumatic system the levers are worked with the fingers only.*

The frame here shown (*Plate* III.) was recently exhibited at Paris, and is no model, but a full-sized 11-lever frame. Behind the levers are

* This has not been reproduced.—[Ed., *R.E.P.P.*].

to be seen the name plates (only two levers were fitted at Paris), and behind these is the diagram of the points and signals worked. The whole is encased in wood, which, in the second photo, is removed, so as to allow of the various parts being seen. The second view shows the frame as seen from behind. To the left are the levers, which, on being moved, impart a rotary motion to the horizontal shafts running from the front to the back of the frame. Close behind the levers are seen the indication locks actuated by the indication magnets placed underneath, and not visible in the photo; then comes a row of circuit-changer stands, those on the point levers alone being fully fitted up. Further along are the ebonite rollers on which the various contacts for working the motors and selecting the signals are to be seen. At the back of the frame and standing vertically is the mechanical locking. It is true that by means of electrical selection it could be made impossible to pull off conflicting signals at the same time, although they be worked by different levers, for if the lever were reversed, the signal would not be operated, owing to the current being interrupted through some points lying the wrong way; in practice, however, this was found not sufficient, as a signalman would be at a loss to know whether the failure of the signal to respond to his lever were caused by a defect in the apparatus or by some wrong combination of levers, and therefore mechanical locking is employed, actually preventing conflicting levers being over at the same time. As signal levers control very often more than one signal, there is a great deal of special or conditional locking, that is, locking coming into force only under certain positions of the points, and the style of locking adopted has been designed to meet this.

In the German system of signalling a constant visible indication of the state of the points and signals is required, together with special apparatus, not only to advise the signalman when the points are accidentally trailed through, but also under the same circumstances to automatically throw all signals which lead over such points to danger. This, with other special arrangements, has led to an entirely new form of frame being designed, but the principles of the system remain the same.

Plate IV. shows a locking-frame of 47 levers erected on the Great Eastern Railway, and which has now been in use over two years. It was made in America, and is of the same form as those in use there. The chief difference from the English frame, as already shown, lies in the form of the handles or levers, which here move sideways across the body of the signalman. Those on the extreme right of the photo are signal levers, and stand normally upright, moving to left or right as the case may be, while point levers are to be seen more in the centre of the frame standing normally to the left. As the sideways motion of the lever takes up a good deal of room, the handles stand alternately up and down. In Europe we have preferred to build the levers more in accordance with what the signalman is already accustomed to. The locking and all moving parts lie here in a horizontal plane, entailing a wide frame, which in this country, owing to differences in the functions of our signalmen, as compared with the American, is considered disadvantageous. The principles underlying the two types of frames remain practically the same.

The next view shows the great frame at the new Southern Station at Boston, U.S.A.* This contains 143 levers, of which 130 are in actual work, operating 171 points, 62 movable frogs or crossings (it is the custom across the Atlantic to move the crossings at the same time as the points, so as to insure no gaps in the continuity of the rails, and so lessen the shocks and chances of derailment at points), and 148 signals. It has been estimated that to fit Boston with a manual system would have necessitated a frame containing about 360 levers, and some five times as long as the electro-pneumatic frame, which, with the larger cabin necessary, together with the space required for the leading out wires and rods, would have reduced the capacity of the present siding room by 67 long American cars. In this frame is to be seen the track-model with which American electro-pneumatic frames are always fitted. This is a plan of the yard (where each road is represented by a brass bar), placed vertically behind the levers. The points are made movable, and so connected to the levers in the frame that they follow the movement of these, so that by glancing at the model the exact position of all points is clearly shown. The signals are painted on the foundation board, but the arms are not movable.

A diagram of the roads and signals operated from this frame is next shown (*Plate* V.), and it forms a splendid example of an up-to-date American station. To the left are to be seen the 28 tracks running into the terminus, any one of which can be used as an arrival or departure road, access being obtained to and from all roads by means of the large scissors crossing shown in the centre of the diagram.

* This has not been reproduced.—[Ed., *R.E.P.P.*].

The main signals are chiefly carried on signal bridges, while the small signals are for shunting only. At the top of the diagram are to be seen the up and down suburban roads in duplicate, which are brought underneath the main station and form a loop, so that the trains run in and out continuously without any need for shunting, thus effecting a great saving in time. These roads are signalled from Cabin 2.

A full description of this installation has been issued by the American firm who put it up, from which the above views and notes have been taken.

A diagram of the air connections requisite for an electro-pneumatic plant is shown in *Plate* VI. The compressor shown is of the horizontal type and steam driven, but it can be of any good type, and may be driven electrically, or by gas, oil, or even water. The pressure of the air chosen in the electro-pneumatic system is about 70 to 80 lbs. per square inch, as thereby the size of the motors may be kept within reasonable limits, and, further, the air may be used for working pneumatic tools and hoists, for cleaning carriages and carpets, hoisting sand on to the locomotives, and the thousand and one uses to which this useful form of power is now put. As power signalling is naturally mostly used at large stations and centres where the amount of traffic warrants a departure from the simpler manual system, it has been found that the secondary uses of compressed air as enumerated above make the quantity required for pneumatic signalling shrink into insignificance. The pressure chosen is far from excessive, and there is no difficulty whatever in keeping the joints tight.

After leaving the pump, the air deposits some of its moisture in a drip tank, and thence it passes through a condenser consisting of a row of small pipes placed in the open air. Thus cooled and dried, it enters the main which runs through the whole length of the installation, and in automatic signalling this length may extend to ten miles. From this, branch pipes convey it to the small auxiliary reservoirs near the motors, and should any further condensation take place, the water and sediment from the pipes is collected in these and periodically blown off. If proper precautions are taken in winter, it has been found that there is no fear of the motors becoming frozen up at the exhaust ports, for, as may be expected, it is here where the air expands that the greatest danger lies of frost affecting the working, the moisture coming from the atmosphere, and not from the compressed air. The amount of air used is not large, from 10 to 15 cubic feet of free air (that is, at atmospheric pressure) having been found sufficient at Bishopsgate, with its 43 points and 25 signals, and practically constant shunting.

As regards the source of the electrical energy, this is usually a set of accumulators, but, where there is any difficulty in re-charging these, primary batteries have been used. The pressure required is 14 volts, but the amount is very small, a large station like Boston consuming energy at the rate of less than 60 watts.

The current is conveyed to the motors from the locking-frame by small insulated copper wires, usually about $\frac{1}{16}$ inch diameter, and made up into various sized cables. From each point lever four wires lead out, no matter how many points may be worked off the lever, and from the signal lever there are as many wires as there are signals operated by the lever, plus one. One return or earth wire, usually uninsulated, runs through the whole installation, the air pipes having been found unsatisfactory as a return. These few cables take up but a very small fraction of the room required for the moving wires and rods of the manual system, and they are generally run in underground conduits, so as to be out of harm's way in case of vehicles becoming derailed.

To show the room required by manual rods and wires, this next slide is from a photo of an actual "lead out."* The whole of these moving parts, with their necessary guides and foundations, are replaced in the electro-pneumatic system by a few small cables.

The second slide* also shows an actual run of rods, and you will see what dangerous obstacles such apparatus forms to shunters and others working at a station.

Both compressors and batteries are supplied in duplicate, so that, in event of any necessary repairs, these can be carried out without stopping the signalling.

This view* shows the cabin at Bishopsgate on the Great Eastern Railway, together with the power house, the condenser being visible at the end of it. You will see that the cabin oversails in its upper storey, as, owing to the small room available, it could not be built the full width at the ground level. The ground floor is used as a workshop, there being but a few small cables coming down from the frame. With a manual frame the space would be occupied with rods and wires.

A diagram of the yard (*Plate* VII.) at this same place is here given, from which it will be seen that the new electro-pneumatic cabin has

* Not reproduced.—[Ed., *R.E.P.P.*].

replaced two old manual cabins. This is an exceedingly busy spot, as all goods trains running into and out of Bishopsgate Goods Depôt have to pass this point, and there is a continuous shunting of wagons into and out of the sidings. Since the opening of this cabin over two years ago the traffic has increased by 15 per cent. Signal 45 is an example of a slotted signal, that is, a signal which is under the joint control of two or more (in this case three) men in different cabins. All the men have to pull over levers before the signal comes off, but any one, on replacing his lever, puts the signal to danger. In the manual system this slotting is a fruitful source of dispute between the various signalmen, owing to the constant necessity of keeping the wires properly adjusted, and on the last man who pulls his lever always falls the full strain of moving the heavy counterbalance weights at the signals. With the electro-pneumatic system slotting is rendered quite easy, and not at the mercy of our variable climate, for all that is required is that the electric controlling circuit of the signal should be run through each lever commanding the signals, or through some light apparatus at the post operated by the levers of the distant men.

Automatic Signalling.

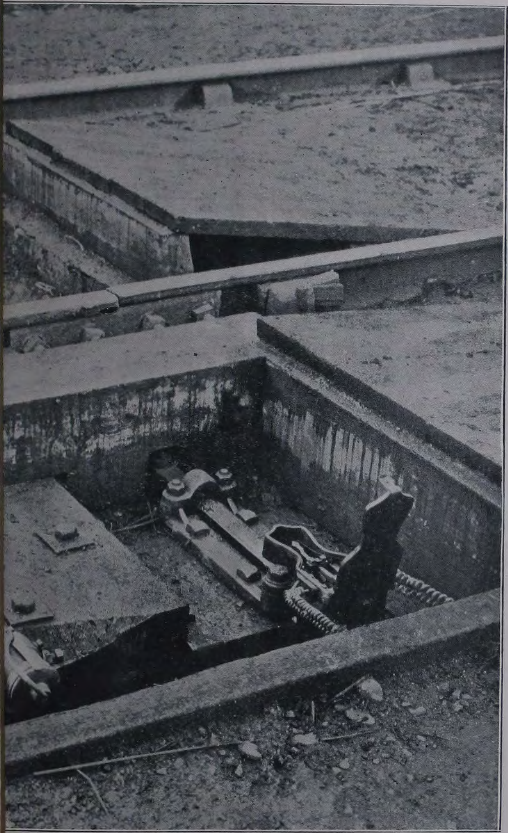
In the United States, where labour is dear, and there are long stretches of line running through sparsely inhabited districts, the question of automatic signalling came up for solution at an early date, and now the system evolved has been found so successful that it has been extended to many busy lines, among which may be cited the 90 miles of four-track road between Jersey City and Philadelphia on the well-known Pennsylvania railroad. Here, as elsewhere, the usual semaphore signal to which the drivers are accustomed has been retained, the necessary motive power being compressed air supplied from a main running the whole distance, and fed at various points.

Plate VIII. shows a simple application of the electro-pneumatic automatic signal system. The track is divided into sections insulated one from the other, and the rails form part of a circuit joining a copper-zinc cell at one end, with a sensitive relay at the other. A current therefore constantly circulates through the relay, and keeps it energized, with the result that the local circuit of the "home" signal is closed, and as this signal is fitted with an electro-pneumatic motor such as has already been described, it is held off by the air so long as the battery current circulates. Under each home signal is the distant signal of the home signal in advance, and this is held off so long as its own home signal and that on the same post are both off. This is the case at the right of the diagram, as the section in advance is clear. At the left, however, the distant is shown "on," its own home signal being "on." In the middle of the figure both signals are "on," and this is due to the presence of a train in the section, the current being short-circuited by the wheels and axles, thus causing the relay to become de-energized. The local circuit is thereby broken and the home signal goes to danger, and remains there so long as a vehicle remains in the section.

Surprise has been sometimes expressed that automatic signalling with track circuits has not been adopted, except in a few isolated cases, in this country, but the use of Mansell wheels, where the tyre is insulated from the axles by wood, on our passenger stock militates against the adoption of any such form of automatic working, as vehicles might be left on the road without an engine, in the case of a train breaking in two, for instance, and they would not automatically protect themselves, and disaster might very easily be the result. In America all tyres are metallically connected to the axles, and so no vehicle can be left without its presence being signalled. Again, in this country signalmen are required to examine a train as it passes, to see if all is in order or not, and therefore the railway authorities on this side of the Atlantic hesitate to do away with the human element. Seeing, however, that many accidents can be traced to this human element, which is not above losing its head occasionally, and that automatic signalling in the States has been brought to a high pitch of perfection, so that derangements and failures are of rare occurrence, we may, I think, look for its adoption in some form or other on this side too.

And now, gentlemen, I have nothing more to do but to bring this attempt to initiate you into the mysteries of electro-pneumatic signalling to a close, thanking you for your kind attention, and trusting that the subject has proved of interest to you. I would add that should any of you now, or at some future time, feel drawn to a further study of the fascinating art of railway signalling, I shall be very pleased to aid him as far as lies in my power.

IC SIGNALLING.



The circumstances, however, were not very suitable for observation, as the balloon had to be sent up in the valley, and by the time it had reached the limit of its ascent, the observer had practically no command over the ridge of hills he wanted to search. For it must be remembered that the general level of the country was about 3,000 feet above sea level, and the balloon had only a capacity of 10,000 cubic feet. We should have done better, I think, with balloons of 15,000 cubic feet capacity.

Telephones seem most desirable between the observer and the ground. I believe at home they have not been found reliable except in very quiet weather. The telephones used in Natal were very handy, being held to the ear by an aluminium clip, and the transmitter hung round the neck, thus leaving both hands free. In Ladysmith a megaphone was used with success.

The result of observations should be rapidly communicated to the general commanding, and, therefore, I think it is very desirable that he should be in telegraphic communication when a balloon is used on the battlefield.

After the relief of Ladysmith balloons were never used; the section under Captain Phillips was broken up, and, before we marched to turn the Biggarsberg, all balloon stores were handed in. The section under Major Heath was then organized into a field troop, a certain number mounted and the rest in mule waggons, and was attached to the 3rd Mounted Brigade, and was present at all operations from that date to the last march through Lydenburg and Pilgrims Rest. Their services were invaluable; they were always with the advanced cavalry, making drifts, repairing roads, and making the advanced arrangements for water supply. Their practical value, I may say the necessity for them, was so apparent, that on the other side field troops were gradually formed for all bodies of cavalry.

Telegraphs.

As in the case of balloons, the telegraph section was shut up in Ladysmith. However, a section was got together at Cape Town, and arrived at Frere in January. It was well equipped, but short in *personnel*, which rendered the work very heavy, when we left the railway at Frere for the operations culminating in Spion Kop and Val Krantz. Yet the work was carried out most admirably, and I heard only the highest praise from the headquarter staff.

During the siege of Ladysmith, I understand, the telegraphic arrangements were excellent and invaluable in the defence.

After the relief, telegraphs were, of course, in a better position, and able to meet the requirements of more extended operations, such as the outflanking of the Biggarsberg, *viâ* Helpmakaar to Dundee.

In the turning movement of Laing's Nek, *viâ* Botha's Pass and Allemand's Nek, a line was laid and maintained without interruption, and most of it recovered under escort, until a superior force of the enemy appeared, when it was deemed advisable to retire safely with the waggons and abandon the rest.

In the march from Paarde Kop on August 7th, *viâ* Amersfort to Bergendal, communication was kept up for the first three days' march, about 40 miles; it was then cut by the enemy. As a matter of fact, we considered ourselves lucky to have had the use of it so long.

From August 11th to August 15th we were accordingly without communication till we reached Twyfelaar, and could connect up with the Delagoa Bay wires to Pretoria.

Lastly, commencing about August 29th, with the remainder of our stores, a line was laid from Machadodorp to Lydenburg, and to within a few miles of Spitz Kop—about 50 miles—the fortified posts at Helvetia, Schuman's Nek, Witklip, and Lydenburg being put in telegraphic communication.

Every possible effort was made throughout to meet the requirements of the army with the means available, and I can safely say that the good work done by the telegraphs was fully recognized.

I consider, however, that telegraphic and telephonic communications should be still further developed, and that *personnel* and stores should be increased.

Signalling by Electric Light.

I will now, in a few words, tell you what was done in this direction.

Before my arrival at Maritzburg, and I may say before the naval light was installed, Lieut.-Colonel Rawson had fitted up a dynamo and lamp on an ox-waggon, a small metal shutter being fitted up inside the lamp and just in front of the carbons, worked by a lever or key from the outside, and this was found much the best arrangement.

The dynamo was driven by a direct acting engine on the ox-waggon, the steam for which was supplied from a portable boiler, with bullet-proof protection. These, after a successful trial, were loaded up on one railway truck, and despatched to Estcourt about 31st November, after the Boers had cleared from that district. The detachment to work it consisted of four civilians and an infantry corporal as signaller. If required to march with a column, the engine would have been drawn by oxen, and also the waggon containing dynamo and lamp.

On the light being required to be run, trenches would be dug for the wheels, to allow of the body of the waggon to be bedded down on sand bags. This was tried, and found quite satisfactory. As a matter of fact, however, the apparatus never left the railway, and was always worked from the truck.

The method of signalling was to direct the light at night on the lower edge of a suitable cloud, which was thus illuminated when the shutter was raised, ordinary Morse signals being used, but, of course, worked very slowly.

Messages were sent regularly every night to Ladysmith, a distance of 30 miles, and at first most of them were received, but latterly the Boers succeeded very often in confusing the signals by turning on their own search lights.

Under favourable conditions it is claimed that messages could be thus sent about 60 miles.

I regret that this light was only used for signalling, and not allowed to leave the railway. At any rate, the following are points in which it might be usefully employed :—

(*a*). Searching an enemy's position at night, thus disclosing any work he may be doing in the way of repairs or new works.

(*b*). As a sentry beam on an exposed flank.

(*c*). Many men, after an engagement lasting up till dark, lose their way and fall into the enemy's hands. If a beam were directed up into the sky it would guide many to camp.

After the relief of Ladysmith, when railway repairs were of supreme importance, this light was invaluable as enabling work at the bridges to go on all night.

TRACTION ENGINES.

These had no practical trial in Natal, for the short time they were at Frere they were usefully employed in hauling supplies about the different scattered camps.

Unfortunately, when we marched to Spearmans, the weather was wet, and so they could not go across the veldt—there was only one road, and that was occupied by troops and baggage ; still, very soon afterwards, they might have been used with advantage to haul supplies of food to the depôt at Springfield.

But I will show you how, when things are practically on trial, a small incident may determine their fate. About eight miles out, on our first day's march, a very bad drift was met, causing serious delay, and at one time a complete stoppage of all wheeled transport ; after careful consideration, it was decided that traction engines, if they could be got across, would prove most useful.

By hooking the steel wire rope into the trek chain, the engine would bodily wind up out of the drift both the ox-waggons and oxen. Accordingly a telegram was at once sent to Frere to send two traction engines out at once. Owing to a delay in transmission, this telegram did not arrive till dark. Through excess of zeal the engines were sent off in the dark on an unknown road ; small wonder that they soon got off the track and at once sank up to their axles. Unfortunately, Sir Charles Warren's division was coming close behind, and with it the headquarter staff, and they saw the block caused by this little eccentricity on the part of the traction engines. I believe the surrounding atmosphere was a little warm, not entirely due to the boilers. At any rate, they were ordered back to Frere, and an order issued shortly after that none were to leave Frere, and they soon went round to the Cape.

So you see, gentlemen, my experience of them on service is small. In the dry season I think they might have been most useful, but without further experience I cannot say whether, in a country like South Africa, the supply of coal might not prove a difficulty.

Pontoon Bridging.

Time at my disposal will not permit me to go into any details of pontoon bridging, and so I shall merely enumerate the different bridges that were thrown across the Tugela.

I think we have good reason to congratulate ourselves on the good work of the pontoon troop; their high training in peace time enabled them under trying circumstances, and often under heavy fire, to carry out work as expeditiously and steadily as if they were bridging the Thames or Medway.

As soon as A Troop arrived in Natal it was very evident that trestles would be necessary as well as pontoons. Accordingly 12 Weldon trestles were ordered from a firm at Maritzburg, and were promptly supplied. I may here say they proved most useful, in fact we could not have done without them. The opinion of all of us who saw the work they did is that it is a most valuable trestle. The chief thing to insist on for efficient working is that the tackles for raising the transoms are just slack enough not to take any weight when each transom is in position.

Those of you who have not seen the Weldon trestle at work have no idea how rapidly a transom is readjusted and the bridge levelled if one leg of a trestle sinks in the mud from any extra heavy load.

While on this subject, I may say we had specially light Weldon trestles made after Ladysmith, and issued to each field company in place of their two pontoons, sufficient for 75 feet of bridge, to carry infantry.

The first bridge thrown across the Tugela was on the morning of January 17th, at Trichard's Drift; the banks were high, and approaches were made by the 17th and 37th Companies. This was used by infantry field guns and light wheeled traffic.

Another bridge was made up stream for ox-waggons and heavy guns (*Plate* I.). For this, as you see, an island was taken advantage of, and the bridge consisted of Weldon trestles from the near bank to the island, and pontoons across from thence to the far bank. Here the stream was very rapid, and great difficulty was experienced in getting the pontoons into position.

On the near side a donga was utilized to facilitate the approach, but on the far side the bank was about 25 feet high, and a road had to be cut about 150 yards diagonally up the bank, with a nasty turn off the bridge. Infantry tackled this, and I confess when I saw the uncompromising look of that bank, and the work it meant, I thought it would break their hearts; but it was an Irish regiment, and they really seemed to like it. Rushes, reeds, and grass we put on the top to consolidate it, and also on the bridge to deaden the noise, and so not to frighten the oxen. That bridge carried all the heavy traffic, baggage, supplies, and ammunition for 10 days for a force of about 25,000 men, yet nothing went wrong, except that on our return we had to replace many worn-through chesses.

If mules give trouble in crossing a pontoon bridge, take off their blinkers; they will generally go quieter, or, at any rate, will never get their hind legs over the edge, which is generally how accidents happen; and never let them be checked on a bridge.

On recrossing after Spion Kop, on January 26th, an additional light bridge for the infantry was thrown over, about 600 yards above the ox bridge, selected with a view to being screened from possible fire—commenced at 5 a.m. and ready at 6 a.m., the rafts being made and rowed up from the island.

During the above 10 days the bridge first erected below the island was dismantled and taken to Potgeiter's Drift, where it was thrown across.

On the evening of February 4th a bridge of trestles and pontoons was thrown across.

On the morning of February 5th a pontoon bridge was thrown over at Munger's Farm, the bridge and approaches being completed in 1½ hours under a heavy fire from a Maxim and a high-velocity gun, a fine performance. The 17th and 37th Companies made the approaches; eight casualties in the three units.

At 10 a.m., on February 6th, No. 2 bridge was dismantled and re-erected under Val Krantz under shell fire; some of the gear was damaged, but no casualties.

On the night of February 7th these two last bridges were removed, and at 4.30 a.m. there was a general retirement.

Finally, at Colenso, on February 21st, a pontoon bridge was thrown across the Tugela opposite the north end of Langwhani; this was removed on February 25th, and thrown over about two miles further down stream, below the falls.

The next picture (not reproduced) is that of the Boer bridge just above the falls, rather ingeniously made by pairs of rails fish-plated together, and supported by cut pieces of sleepers built on the rocks, and the roadway made of sleepers.

After Ladysmith, pontoons were no longer required, and were stored; the A Troop then became Corps Engineers, and were most usefully employed, chiefly on railway repairs and defence of railway. Their training made them specially handy at railway work.

FIELD COMPANIES.

We now come to the work of the field companies, which may be subdivided into the following main headings:—Water supply; roads and communications; field entrenchments; railway repairs.

The water supply of a large army, where, as in Natal, water is often scarce, is a matter of anxiety for the R.E. officer, and requires careful attention, not only in developing the supply to the greatest extent possible, but also in getting the sources protected from pollution by efficient guards of infantry and mounted troops.

Distinguishing flags should be placed to point out the different watering places for men, animals, bathing, and washing.

When we arrived at Frere at the end of November, we had with us one field company, to provide water for about 25,000 men, 5,000 horses, 3,000 mules, 7,000 oxen; rather a large number to provide for.

At Frere the main water supply was from a railway dam, which subsequently was exhausted, and from the river Blawkrantz; the latter was of a light yellow colour, with sand held intimately in suspension.

Many systems of filtering were tried, including canvas tanks half sunk in the ground, the earth removed being piled up against the unsupported sides, into which the water was pumped, allowed to settle a little, and then alum added to precipitate the sand; but the filtering was only partial, nothing would really clear the sand.

For this class of water a good filter appeared to be barrack sheets, single or even double, tacked on to a wooden framework, supported on pickets, the filtered water being collected in channels of galvanized sheeting, and run into biscuit tins.

When water is scarce in a standing camp, ask that regiments may at once report any springs that are found; outposts and men wandering about and Kaffir boys often come across them.

I think, as a general rule, in dealing with small springs it is best only to arrange for collecting the water. Experience shows that if you try to open up and develop them, they often disappear altogether, but each case must be dealt with on its merits.

When you arrive at the end of a march I will tell you what happens on service—the men are dismissed, and immediately go to the nearest water and wash, and at once foul the water, for they are very fond of soap; and the animals other than horses are outspanned and wander off to the nearest water and foul it. In spite of repeated representations, it took a long time to get a proper system adopted, and from my experience I should advise any officer responsible for water supply to press for the following:—

That on the march an R.E. officer should accompany the staff officer selecting the camp, who usually proceeds with the advanced cavalry, and that a certain number of mounted police, 6 to 12, should be detailed for water guard, not forgetting an R.E. orderly to carry the distinguishing flags. As soon as the water supply has been selected, which nearly always governs the camping ground, the flags are sited to mark the different watering places, and the mounted men, being given their orders, are distributed as guards; some of these will be replaced by infantry on their arrival, but a certain number of mounted men will always be required to deal with mules and oxen, which are under little or no control.

Now, as regards pumps, I consider a Merrywether Little Steam Valiant very essential; it is most portable, requires very little coal, and fills a 100-gallon water cart in two minutes, which is an important factor when there is only one drinking-water supply.

The semi-rotary pumps, which were the only other ones we used, were very satisfactory. They are issued with an iron stand, but a certain number were locally bolted to wooden pickets, a decided advantage, being more stable where the ground would allow of the pickets being driven in.

Their defect seems to be in the valve, which, owing to the sand, often got out of order, and could not be repaired locally; this defect of not being capable of local repair might, however, be got over in construction, I think.

It is a question whether a lighter form of lift and force pump might not advantageously be introduced.

Each field company with a division at first carried six semi-rotary pumps; but after Ladysmith they only carried four, and each infantry brigade carried two, which was found to be an improvement.

When a force is camped on a railway, and water is scarce, preparations must be made for daily water trains from some station in rear. After the retirement from Colenso, December 16th to January 10th, the force at Chievely of 12,000 men was entirely supplied with drinking water by water tanks brought up from Estcourt and Frere. The necessity had been foreseen, and water trains marshalled.

Scarcity of water is a nightmare to the R.E. officer responsible, and I am thankful to say only one case occurred, and that was the night before we gained the Biggarsberg heights at Helpmakaar. Late in the afternoon the force arrived at Vermaaks Farm, to find that there was only one dam, supplied by a small trickling stream diverted out of a sandy donga, and that the advanced cavalry had ridden their horses into the dam and fouled it; then came the mules, and, finally, the oxen, and the greater part of them would not touch it, as it was by then nearly liquid mud. I may say it was a new division on the march that had no experience of water difficulties, so no precaution had been taken to guard the supply in the manner previously alluded to.

Well, the field company set to work to dig holes in the sandy bed of the donga, and dam up any trickling streams that could be found. Of course, no water carts could be filled, and the troops had to be marched down to fill their water bottles and kettles, and they were at it all night, so small and slow was the supply—it sufficed, and that is all.

I mention this to emphasize the necessity of a responsible officer accompanying the advanced cavalry, with an adequate water guard.

Roads and Communications.

On the march the field company was generally fully employed improving roads and making and improving drifts.

After Ladysmith each company had 50 to 100 Kaffirs told off to them, under one or two European superintendents; they were a most useful body, as the Kaffir boy is very handy with the pick and shovel.

The best and usual disposition of the company on the march was :—

Two sections with the advanced guard, taking two pumps with them.

The headquarter and one sub-section with the main body.

The remaining sub-section with the baggage.

But this, of course, would vary according to the information that could be gathered as to the character of the road; and on this point it is essential that we should have early information of the route to be taken, in order that it may be examined as far as possible beforehand, and the local guides questioned as to probable difficulties, so that preparations may be made to meet them.

As a rule, this can at any rate be found out before dusk the night before; then the officer who has to carry out the work should endeavour to ride out, at least, as far as the outposts, and have everything cut and dried for work at daybreak.

When difficult places are met with on the march, accustom yourself to decide rapidly the best way to improve the road or drift, or the best place to make new drifts across dongas or streams. It is astonishing how quickly you can train the eye to this sort of work, and it is essential where time is an important factor.

The first day's march from Frere, on January 10th, which led to the operations of Spion Kop and Val Krantz, gave us a very heavy job, and it certainly stands out as one of our stiffest problems.

Two infantry divisions and one mounted brigade were on the road with their mass of guns, waggons, baggage, supplies, etc., and, unfortunately, we had been given no opportunity of examining the road, consequently there was a terrible block of wheeled transport for about 36 hours. Eight miles from Frere we came to a spruit with good approach and rocky bottom, but a very steep and clayey out-take. The company did not arrive till a good deal of the lighter wheeled transport had crossed, every wheel and team of which carried water up the slope, which rapidly became a quagmire; then came the heavily-laden ox-waggons, which promptly stuck.

It was the only drift, and it was impossible then to put it in order without stopping the traffic for many hours; whereas a couple of hours' work before anything crossed would have enabled us to cover it with stones, and to put bundles of grass and reeds to keep the water off it, which was quite the best way of dealing with such places, as we subsequently proved.

It was imperative that the big guns, waggons, etc., should continue to cross, however slowly, and as many as 48 oxen were sometimes used for one waggon, and large infantry parties were also at work with drag ropes. It was, therefore, decided to make two drifts lower down—both difficult.

The first, here the spruit narrowed considerably, with a slab of rock in the centre, on which a stone transom was bedded, and the roadway completed with superstructure of the two pontoons of the company, heavy earth cutting on the out-take done by infantry working parties; this was completed in about two hours, but was only available for mule transport.

As regards the second drift the approaches were easy. In the centre a broad, flat bed of rock, with stream running in a narrow, but deepish, gully on the near side, and a muddy hole at the edge of the far bank, which was only discovered on the first ox-waggon crossing. The gully was filled in with stones from a neighbouring kraal, carried by infantry and in waggons. At 6 p.m. the first ox-waggon was got over, but it was a hard pull through the mud-hole; with timber this might be improved, so some logs of firewood were commandeered from a supply waggon which was waiting to cross, and by that means we managed to cross 10 more ox-waggons before darkness set in. Next morning at daybreak we started to improve this, and by 9 a.m. it was in grand working order, and we were passing over about three waggons for one at the main drift.

Meanwhile, a party of R.E. were cutting timber at Pretorius Farm, two miles off, and next day at No. 1 drift a trestle bridge for ox-waggons was constructed. During four days these drifts were satisfactorily used, and 14 days supply for the whole force passed over them.

Speaking of bridges reminds me that you would probably like to hear of what I consider one of the smartest bits of R.E, work in Natal.

Learning it was probable that an infantry bridge would be required across the Little Tugela, green, and consequently heavy, timber of all shapes was cut at Pretorius Farm at daylight on Sunday, January 14th, by the 17th Company. At 2 p.m. came the order that the bridge would be required ; the timber was loaded up, and drawn by two traction engines, used against the orders of the Chief of Staff, to get covering authority for which I rode 35 miles, as the bridge could not have been made without them, and the half-company marched eight miles to the river ; the bridge was supposed not to be required till about 11 a.m. next morning, but at 10 p.m., soon after my return from seeing the Chief of Staff, I got orders to have it ready by 8 a.m., so turned out with my assistant to find the half-company at work eight miles off, as it was necessary to tell them the change of hour. A pitch dark night, neither of us knew the way, only the general direction, but we made for the river and worked down it. I found the work progressing well, and it was interesting timing each trestle to see if we could do it in the time. The river was 130 feet wide, five feet deep in the centre, and current about three miles an hour. Eleven trestles were erected, worked from both ends ; roadway 5 feet 6 inches, roughly planked and hand rails.

At 8 precisely it was ready, and in addition a pontoon raft was made for ammunition carts, etc. ; it was a fine performance, as the timber was of all awkward shapes, and very heavy. Everyone seemed much pleased with it, especially General Hildyard. I am sorry I have no picture of it, but I lost my only photograph.

After our experience at Pretorius Farm Drift, it was seen that for boggy places railway sleepers would be most useful, and about 60 were ordered up from Frere ; it was lucky, for without them the night march to Trichard's Drift would have been delayed and its success imperilled. You see it is a terrible country to work in ; no timber, no brushwood.

In the march from Ermelo to Bergendal we had great difficulties to contend with in the way of boggy drifts ; luckily, now and then at the farms we found willows; these we cut and formed into fascines, which we carried on extra waggons, and they proved most useful.

The following are a few hints which may be useful:—

When a road or the approaches to a drift are poached, it is no use putting big stones into the ruts, they only get squeezed in all directions, and eventually a wheel gets blocked against them; if you use stones at all, you must pack it well all over. Roots of grass and bundles of rushes are the best, of course supposing no brushwood is available.

With sandy drifts it is astonishing how soon you will get a firm surface if you keep cutting and laying on coarse grass, laying the bundles across the road, not along it.

In making a drift, arrange the approaches, if possible, so as to get a straight pull through.

Similarly, in making a new road up a hill for a heavy gun, never mind the gradient, make it straight—that's all the oxen want; if necessary you can hook on 64 of them.

Field Entrenchments.

During the whole campaign the field companies did very little in the way of entrenching, except on the defensive posts on the rail between Volksrust and Greylingstadt, of which I will speak later. I do not, of course, refer to the 23rd Company in Ladysmith, who did plenty of good defence work.

On the night operations at Spion Kop, on January 23rd, Nos. 1 and 3 Sections of the 17th Company accompanied the attacking force, leaving the rendezvous at 10.30 p.m., and marched in the centre between the two battalions; each sapper, in addition to his arms, carried a pick and shovel, but owing to the steepness of the last ascent each man was told to drop a tool at that point. As each successive plateau was gained by the leading battalion, the R.E. were moved up ready to entrench if required; the summit was reached at 4.30 a.m., when a Boer picket was surprised, and the R.E. joined in the charge.

The sections being collected rapidly, pack mules were unloaded and tools issued to the infantry, and shelter trenches marked out. The ground was very rocky, so no depth could be got, and darkness, followed by a dense mist, probably prevented a good field of fire being obtained.

About 6 a.m. the mist lifted; no Boers could be seen, but desultory fire commenced. At 6 a.m. one sub-section went back to make a road in rear, and the remainder proceeded to make a trench on the right front, but after half-an-hour's work the fire was so hot the men had to lie down at intervals.

At 7 a.m. shell fire became so heavy that all work had to be suspended, and the Infantry and R.E. held the trenches. The trenches could not accommodate anything like the number of troops on the hill, but gave fair protection to those in them.

At 8.15 a.m. the other half-company marched up to make a zig-zag road up the reverse slope for the mule battery, and to dam up three small springs.

About 9 a.m. an order was received in camp to send up all available tools and sandbags to the top; most of the batmen and Kaffir drivers were turned out and carried them a certain way up, whence they could be carried up by the Infantry, indeed some of the batmen and Kaffirs went right up with them.

About 10 a.m. an order came to make a small dam in the spruit near the foot of the hill for water carts to fill from and take up to the mules with water mussocks, and to make a drift for ambulance waggons and guns; the few remaining batmen and Kaffir boys, 10 all told, under an Engineer clerk, turned out and did this; so you see on that day every single man was employed.

About 9 p.m. on that day, 24th January, the 37th Company arrived from Spearmans to make a road for the 12-pr. naval guns, but, as you know, that night came the retirement.

At the second Colenso, February 24th, a very hot pom-pom and rifle fire was directed on the railway bridge over a spruit running into the Tugela. The Infantry had to cross this in advancing to the attack of Hart's Hill, and were having many casualties, so two sections of R.E. were told off to revet the exposed side with sandbags; these were filled below and passed up to the three men on the bridge, who were laying them gradually across; there were luckily no casualties, but Co.-Sergt.-Major Smith, who was working all the time under a heavy fire at the head of the revetment as it was pushed out, had a bullet through his helmet; his coolness throughout was much to be admired.

After Ladysmith, 300 picks and 300 shovels, about 24 crowbars, and a good supply of sandbags were issued to each Infantry Brigade and carried by them. This was found a great improvement, indeed a necessity, to ensure tools being available immediately they were required to entrench a position.

There was nothing new or wonderful in the Boer trenches; they were roughly made, narrow and deep, giving perfect cover from shrapnel fire; but then you must remember they had unlimited Kaffir labour at their command, and as a rule the positions were prepared a long time beforehand. Their trenches were certainly well placed, and they freely used dummy trenches in conspicuous positions. Similarly, later on, at some of our posts we put up lengths of iron water pipes to represent big guns.

The 3-foot square trench, under ordinary circumstances, appears to be the best, for a man can sit down secure from shrapnel fire; but it can even be narrower if the sides near the bottom are scooped out front and rear, each man sitting facing the rear.

Conceal your trenches with grass and bushes.

If possible, never put any works on the sky line; the main line of defence should be on the front slope slightly below the crest, giving a good field of fire.

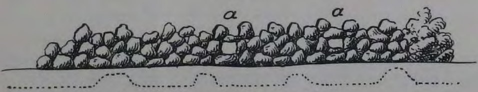
Any réduit should be retired well in rear of the crest, so as to sweep it, and prevent any chance of being rushed.

Experience shows that the height for a man to fire over with best effect is 4 feet 3 inches, not 4 feet 6 inches.

On rocky kopjes flanking posts, with from two to four reliable and good shots concealed amongst natural boulders, are most valuable adjuncts to the main defence.

Keep stone sangars as low as possible, making a shallow trench in rear, not bothering about big boulders where they occur; but whatever you do don't finish the wall off neatly, leave a big stone to protect each man's head, and he lays his rifle along the right-hand edge of it. This is as good as a loophole. The figures (1 and 2) will show you what I mean.

Fig. 1.



Dotted line represents trench.

Fig. 2.

Plate II. shows you a useful type of defensible quarters inside a redoubt. Fir scantling, 3″ × 3″, spiked to hard wood pickets driven into the ground, dry stone walling and corrugated iron, double thickness of iron at loopholes, supported on cross battens to carry wall, roof frames spiked together placed at 6-foot intervals, width about 15 feet, and length according to requirements.

At Standerton it was decided to guard the railway stations and the principal bridges between Volksrust and Greylingstadt by means of small defensive posts, but with deep trenches in all cases for the garrison to get into if exposed to shell fire.

Plates III. and IV. show types of the defence of the station buildings for a whole company or half, according to the size of the station.

At the bridges we built block-houses of loop-holed armour-plates, of which we had a good supply, built into the embankment, as shown in *Figs.* 3 and 4. The armour-plates were 6′ × 3′, two used at each end and six along the sides, the pair to hold 25 men; wire entanglements freely used, and where procurable railway lamps were used for sentry beams; plenty of tin cans were always attached to the wire entanglements to make a noise at night if the wire was interfered with.

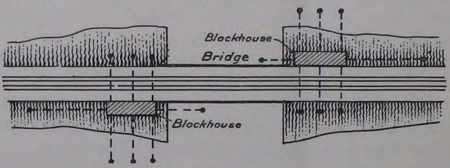


Fig. 3.

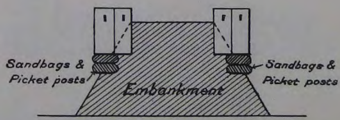


Fig. 4.

Fig. 5 shows how the stone parapet of a pier was utilized. The stone filling at AA was removed, and the parapet wall loopholed. B was a good position for a sentry.

When the enemy is in the neighbourhood of a railway, it is best for trains not to run at night, and before running is commenced for the day the line should be trollied over, and a report sent to the railway staff officers that the line is intact. For the purpose of trollying, the line should be divided up into sections.

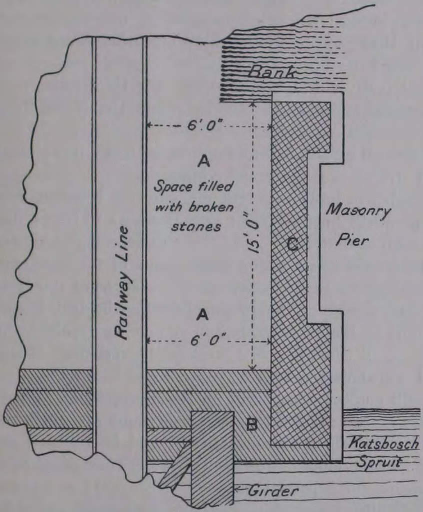


Fig. 5.

Railway Repairs.

We now come to my last subject, railway repairs.

The broken bridge at Frere was repaired by the Natal Government Railway early in December, and they started the big bridge at Colenso a day or two before we relieved Ladysmith.

After we had been about a week at Ladysmith, it was clear that the Natal Government Railway method of restoring railway communication was too deliberate; they preferred to work steadily on at one repair after another.

Accordingly, on March 11th, authority was obtained to start the 17th and 37th Companies on two bridges near Elandslaagte and the Sunday River bridge.

The former were respectively of five skew spans of 15 feet and three skew spans of 30 feet—in each case good deviations of about 500 yards were made; very little earth cutting was required, and the spruits were crossed where only two very low trestles were necessary, and these were completed before the Natal Government Railway caught us up.

At Sunday River bridge the footings for the trestles and part of the approaches were made by the R.E., and the Natal Government Railway erected the trestles.

After that all repairs had to stop till we had turned the Biggarsberg and arrived at Dundee and Newcastle.

The number of broken bridges and culverts between Waschbank and Glencoe will surprise you; there were 31 in four miles—spans ranging from 6 to 30 feet; and between Glencoe and Newcastle 10, mostly bridges of one, two, or three spans of 30 feet, except that over the Ingagane River, which was three spans of 100 feet.

I will now show you the principal broken bridges from Frere to Standerton in the Transvaal, and a few as repaired, but these repairs were all the work of the Natal Government Railway; our repairs I will show you later.*

Now will you come back with me to Newcastle on May 19th, two days after we had arrived there. On account of supplies it was of vital importance that communication should be restored as early as possible, and therefore it was felt that a big effort must be made and arrangements for repairs thoroughly organized; so having started the 17th Company to repair back from Newcastle, and the Pontoon Troop to proceed by rail from Ladysmith to Waschbank, I started to ride back the 48 miles, being armed with authority to stop the 5th Division that was marching up through Glencoe, near which place I met Lieut.-Colonel Sim, the C.R.E., who undertook, with large infantry working parties, to repair the bridges north of Glencoe. He had to lay out all the work himself, as the 37th Company were back at Waschbank.

The G.O.C. 5th Division agreed to send 30 ox-waggons back at once to Waschbank for the use of the Natal Government Railway.

* Colonel Wood showed several photographs at this point, three of which are reproduced in *Plates* V., VI., and VII., showing the repaired bridges at Umhazane and Zandspruit, and the temporary bridge at Colenso.

Arrived at Waschbank at 9 p.m., having started at daylight, saw the engineer-in-chief, Natal Government Railway, and discussed the situation. The railway officials had their hands full with the Waschbank bridge, two spans of 100 feet, where work was going on all night by electric light, but he agreed to send a party by road with all necessary stores in the ox-waggons to start the Ingagane bridge, three spans of 100 feet, 30 miles off. I may say it was a treat later on to see that party at work; they were as keen as mustard to finish before the line was repaired in their rear; and they did, too.

The 37th Company, Pontoon Troop, and very large Infantry parties repaired all the other 30 bridges and culverts to Glencoe, and great credit is due to Major Elliott, the A.D.R., for his energy and resource.

Waschbank bridge was commenced on 17th May, and the first train ran into Newcastle on the 28th, which I think may be considered a fine performance.

As regards the spending of our late Sovereign's birthday, the following order was issued:—

"The General commanding feels that the Queen's birthday cannot be better spent by the troops than by making it a record-breaking day of railway repairs."

Of course many of the smaller culverts, it being the dry season, were bodily filled in with rubble and earth, which I fear at first much shocked the Natal Government Railway officials.

The ruling gradient for deviations was $\frac{1}{30}$—the ruling radius for curves 300 feet, and four $12'' \times 12''$ baulks would suffice for a 15-foot span.

I will now show you (*Plates* VIII. to XI.) how the R.E. repaired these bridges and culverts. As you see, there is every variety, and the diagrams pretty well speak for themselves.

Clearing Laing's Nek tunnel was a big job; both ends were blown in, and also about 150 feet of lining at either end, consisting of big stone blocks; the Pontoon Troop cleared one end and the 17th Company, R.E., the other.

It was done in a week, and a special complimentary order was issued by the General commanding. Luckily the estimate of the time it would take worked out to the very day.

At Standerton an intricate but excellent deviation was made by the 17th Company, R.E., Pontoon Troop, and large Infantry working parties—about a mile long, with some very heavy cutting in clay, 15 feet deep, completed in 10 days, the Natal Government Railway making the low trestle bridge.

That completed the work of the R.E. in Natal.

Before concluding, I should like to mention one or two points which may be useful to some of you on service.

Remember that energy and cheerfulness have an enhanced value on service, and to that end look after the inner man; there are very few of us that can lay claim to either on an empty stomach. Young fellows are so apt, I speak from experience, to start out on their work without taking anything in their haversack, expecting to get back to a good meal, but, to their disgust, they are sent to other work. I can strongly recommend a small spirit lamp and pannikin, strapped on the saddle, with soup squares, cocoa, or coffee in the haversack; it will often do you far more good than sandwiches. Spirit goes a long way, I mean methylated spirit, and more often than not you can make a fire. Acid drops to relieve thirst are A1; I never was without them.

Try and foresee the wants of an army, and so be prepared with the necessary stores.

Be always ready to accept responsibility, a good reason for your action will always cover you.

Endeavour not to make difficulties in carrying out proposals, but rather smooth them over.

Remember that in many little ways the R.E. can add to the comfort of an army, apart from their legitimate work, so never hesitate to give the help required if reasonable.

Look well after the comfort of your men, and don't be afraid to praise them for good work done; if you keep them cheerful you will get twice the work out of them.

In giving the time by which any work will be completed, always add a little on, as a factor of safety.

Well, gentlemen, I have given you a general account of the R.E. work in Natal, and in thanking you for your most kind attention, I must apologize for its length; my only excuse is that it is a big subject, very interesting to me, and I was led away by it.

APPENDIX.

Notes on Railway Repairs.

2 baulks 12″ × 12″ under each rail will bridge a 15-foot span.

For trestles up to about 15 feet in height 9″ × 9″ will suit, above that 12″ × 12″.

Crib piers of sleepers might be used up to about 15 feet high, but not advisable.

Sharpest curve, 300 feet radius.

Steepest gradient, $\frac{1}{30}$; in special case $\frac{1}{20}$ might be used to get over special difficulty.

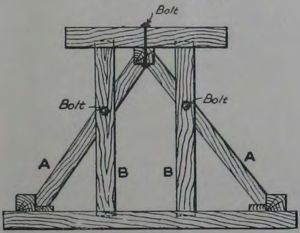
Cant for 300 feet curve, $4\frac{1}{2}''$ for speeds up to 22 miles an hour.

Dubbs' engine weighs 46 tons, giving a load on each pair of driving wheels of $8\frac{4}{11}$ tons; there are four pairs of drivers.

To cut steel rail, use cold set all round, put a little pressure with Jim Crow, and give end of rail a sharp tap.

Fig. 6 is a very economical trestle for jacking up a broken girder.

Longitudinal Section. *Cross Section.*



All 12″ × 12″ *Timber.*

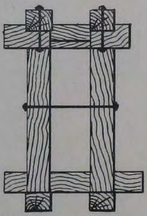


Fig. 6.

It will be seen by inserting the struts AA between the trestles the height of the pillars BB is halved.

N.B.—This form of trestle should have been used at Zand Spruit, and if placed under the broken member was all that need have been done.

At point A the top boom and tie rods were completely cut through by four shots from a 4·7″ gun.

Double trestles B and C were erected and wedged up from below, and strut D wedged in (*Fig.* 7).

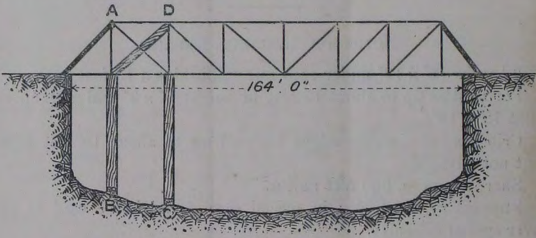


Fig. 7.

The other boom being undamaged, pillars wedged up at B and C would have done as a temporary measure, and no strut D was required.

Strut D was wedged as shown in *Fig.* 8. Wedging up of trestles from below done as shown in *Fig.* 9.

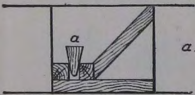


Fig. 8.

Fig. 9.

Type of Bridge Trestle.

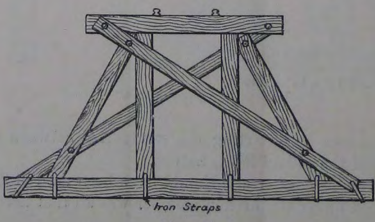


Fig. 10.

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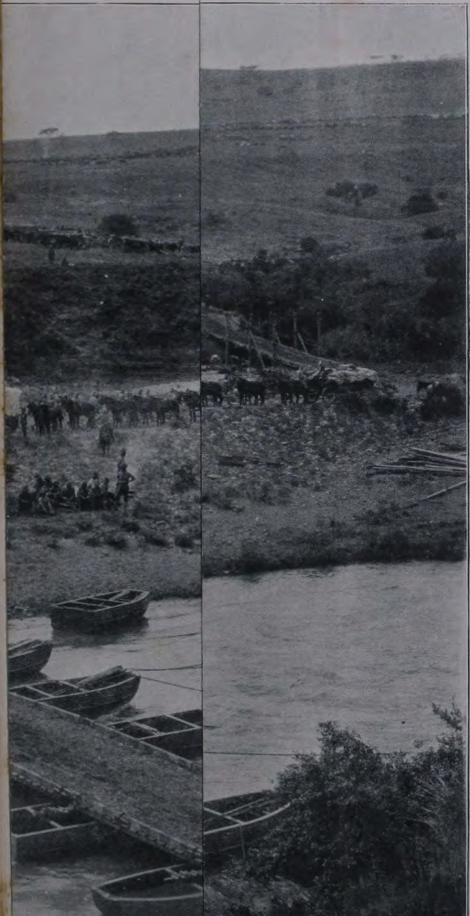


PAPER IV.

RECENT DEVELOPMENTS IN LOCOMOTIVE PRACTICE.

By C. J. Bowen Cooke, Esq.,

Assistant Running Superintendent, Loco. Department, L. & N.W. Railway.

Although in the course of the two papers that I hope to have the honour of reading on the subject of Modern Locomotive Practice I must of necessity confine myself chiefly to the details of the construction of the locomotive engine of to-day, as laid down in the synopsis that has been given to me as a framework on which to build, still I shall venture to introduce two additional phases of the subject, which I cannot but hope may prove of interest. One of these, a short historical sketch of the earlier development of the locomotive, I shall use as a preface to my first paper; the other, as a wind-up to the second, will be a brief discourse upon the management of locomotives after they are turned out of the shops and put to work on the line, as, perhaps, some of my hearers may eventually have more to do with the use and practical management of locomotives than with their actual construction.

Early History.

Time will not admit of my going into any lengthy details, however interesting they may be, of the early history of the locomotive, and I can only draw your attention to a few of the principal examples of the earliest types.

The first steam land carriage (*Fig.* 1) or self-moving locomotive of which there is any authentic record was made by a Frenchman named Nicholas Joseph Cugnot, in the year **1771**.

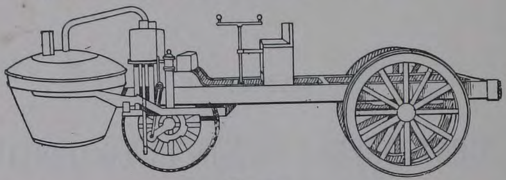


Fig. 1.

The boiler was a sort of kettle-shaped vessel made of copper, through which the cylinder passed, and the piston acted on a ratchet wheel on the driving axle, each stroke giving $\frac{1}{4}$ revolution to the driving wheel. The maximum speed attained is said to have been $2\frac{1}{2}$ miles per hour. The French government took some interest in this notion of a steam land carriage, thinking it might prove useful for military purposes, and voted a sum of money towards its construction; but on one of its trials the machine overturned in the streets of Paris, after which it was locked up in the arsenal, thus bringing its brief career to an abrupt termination.

James Watt, thirteen years later, brought out an idea for a locomotive. Like Cugnot's, it ran on three wheels and had a single vertical cylinder; the piston was connected to a beam pivoted at the opposite end, and attached by a connecting rod to the driving-wheel.

Fig. 2 shows Trevithick's engine built in the year **1803**; *this was the first locomotive ever made use of for a practical purpose*, and we may be proud of the fact that it was produced by an Englishman.

William Hedley constructed an engine which worked at the Wylam Colliery in **1811**. This is the celebrated "Puffing Billy," now in the South Kensington Museum.

George Stephenson's first attempt at a locomotive was made in the year **1815**. He still employed vertical cylinders; but the connecting rods were coupled direct on to the cranks, fixed on the wheels, and at right angles to each other, a system that has been invariably adopted since this engine was built at the beginning of the last century, the reason being that with cranks at right angles the engine is never on a dead centre. The wheels were coupled by an endless chain, and here we have history repeating itself, as this is the present system of coupling the driving gear to the wheels of the modern motor car.

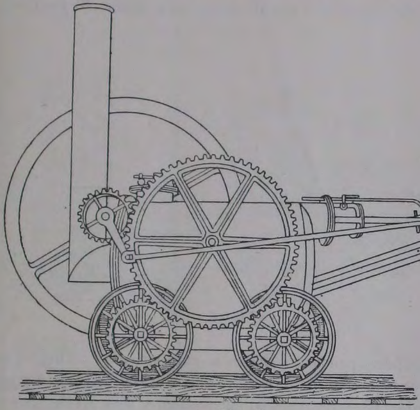


Fig. 2.

A steam coach (*Fig.* 3), built by Mr. David Gordon about this date, shows the ideas people had in those days. It was fitted with propellers, supposed to act in the same way as a horse's hind legs, being alternately pushed into the ground and drawn back again.

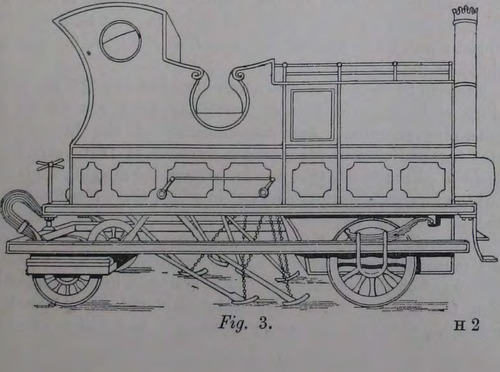


Fig. 3.

In **1825** the Stockton and Darlington Railway was opened, and *Fig.* 4 is a small sketch of the engine that drew the first train on the first public railway in the world, opened for traffic 76 years ago.

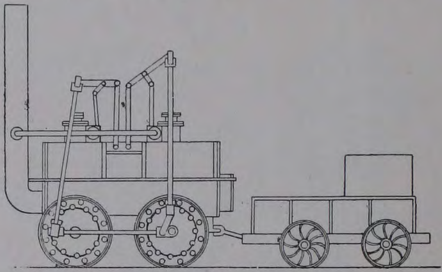


Fig. 4.

We may here pause to draw a comparison. This, the first passenger engine that ever ran in the world's history, weighed in working order $6\frac{1}{2}$ tons, the boiler pressure was 25 lbs. per square inch, the cost £600, and the speed of the train 15 miles per hour. Some of our modern engines weigh upwards of 80 tons, have a boiler pressure of 200 lbs. per square inch, cost over £3,000, and run at any speed up to 70 miles an hour.

The Royal George, built by Hackworth in **1827**, had the exhaust steam turned into the chimney, another important feature in the development of the locomotive. Here for the first time we have the "blast pipe," which has been described as the "life breath" of the high-pressure engine.

Even up to the date of the Rainhill contest in **1829** the practicability of locomotives as a commercial success was by no means generally recognized, and the directors of the Liverpool and Manchester Railway, which was completed in that year, had not decided on the power that was to be used for drawing their trains; but the famous historical contest, in which the "Novelty" (a tank engine carrying its own supply of fuel and feed water), the "Sanspareil," and the "Rocket" took part, settled once and for all the much debated question, by the victory won by Stephenson's "Rocket" on that notable day. The cylinders in an inclined direction, the firebox, the tubular boiler, and indeed all the leading principles of the modern locomotive engine and boiler, show them selves for the first time in the "Rocket," although still in a very crude form as regards detail of design (*Fig.* 5).

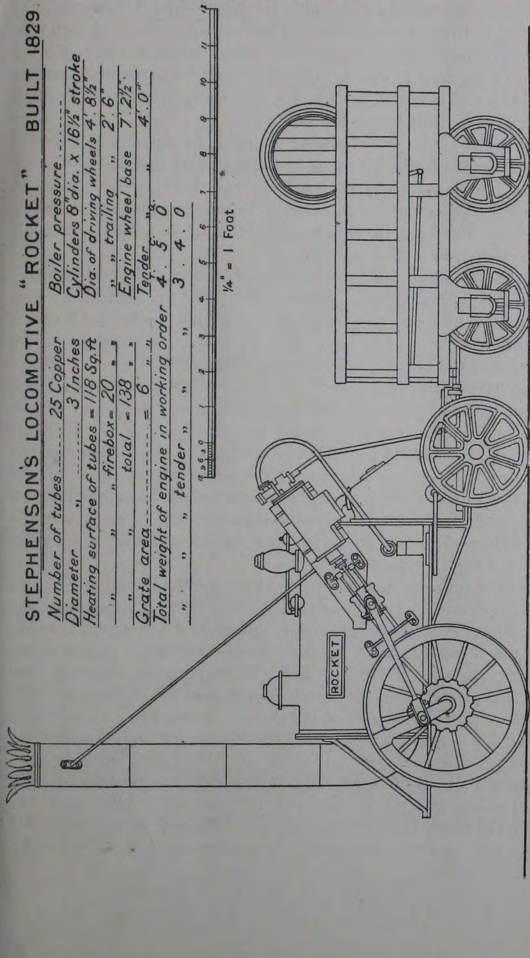


Fig. 5.

After the Liverpool and Manchester Railway was opened, locomotives and locomotive builders sprang up all over the country. An interesting engine was built in **1833** by "Carmichael," of Dundee, which had outside vertical cylinders connected on each side by cross-heads and side links to bell crank levers, transmitting the power to the driving wheels. This engine shows us the first example of the idea of a bogie, the trailing end being carried on a small truck with separate wheel base of its own.

Fig. 6 shows the class of engine on the Liverpool and Manchester Railway in 1834, which ran on four wheels and had 11″ × 16″ horizontal cylinders, and may be taken as the standard type of passenger engine working on the English railways for the succeeding ten years; in several respects an approach may be noticed towards a more modern form of design.

In **1847** began the great battle of the gauges, and Brunel's famous single wheel broad gauge engine (*Fig.* 7), built about that date, inaugurated a type of engine used by the Great Western Railway Company for many years, in fact until the date of the abolition of the broad gauge on May 20th, 1892.

The "Cornwall" (*Figs.* 8 and 8A), a single engine with 8-foot 6-inch driving wheels, built by Mr. F. Trevithick, was, indeed, and still is, a famous engine, running to-day on the L. & N.W. Railway, although built so long ago as 1847. Originally constructed with the boiler underneath the axle, to get the centre of gravity as low as possible, with a view to ensuring greater safety when running at a high speed; it was afterwards rebuilt and is still at work, and this time-honoured veteran at the ripe age, for a locomotive, of 55 years is still doing serviceable work.

A very powerful engine (*Fig.* 9), built by McConnell, and known as the "Bloomer" class, was put on the L. & N.W. Railway about the same time. It had larger fire-box, cylinders, and heating surface than any other contemporary engine. It ran for many years on the southern division of the L. & N.W. Railway, indeed up to the time that Mr. Webb built his 6-foot 6-inch coupled engines in 1873, which are running express trains to-day. These latter engines have really done splendid work on the line. As an example, the "Charles Dickens" (*Fig.* 10) has for 19 years worked from Manchester to London and back every day, except when stopped for repairs, and up to the end of December, 1900, had run 1,877,176 miles, thus holding the world's record in the number of miles run by any one engine. In the famous race from London

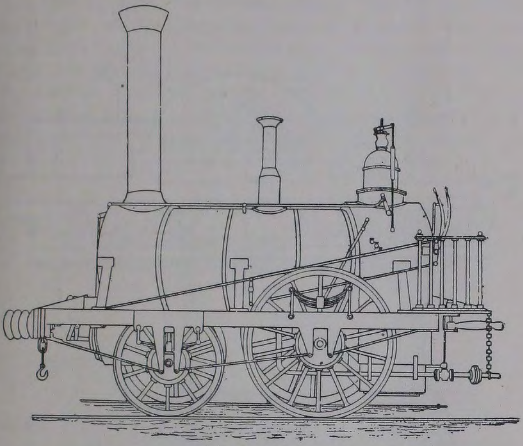


Fig. 6.

Fig. 7.

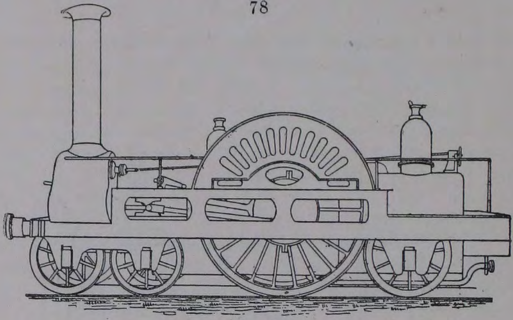


Fig. 8.

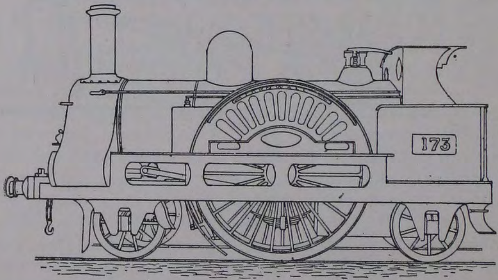


Fig. 8A.

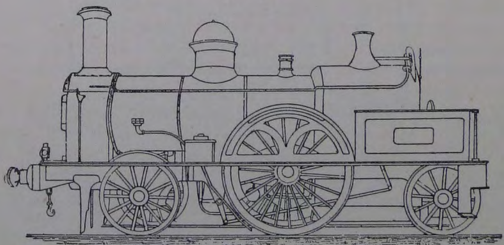


Fig. 9.

to Scotland in 1895, the Scotch express, worked by engine "Hardwicke" of the same class, ran from Crewe to Carlisle, a distance of 141 miles, at the rate of 67·2 miles per hour. When we take into consideration that this distance traverses over some of the heaviest gradients on any main line in the country, and that the notable bank at Shap Fell being on a gradient of 1 in 70 has to be ascended, the performance was indeed a remarkable one, and has never been beaten in this or any other country.

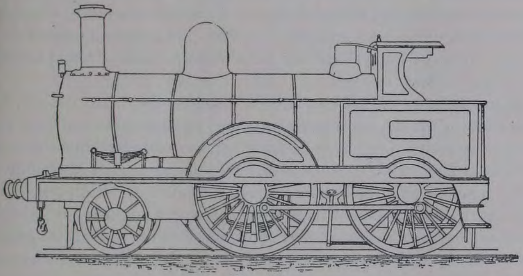


Fig. 10.

(1). The Conditions Governing the General Design.

Having led up, though very intermittently, to a more modern type of locomotive, we may now proceed to consider some of the conditions governing the general design of the locomotive of to-day.

During the latter part of the period we have briefly reviewed trains and engines were very much lighter than they are now, and the road upon which they had to run was of a totally different character to the modern permanent way. Fifty years ago rails weighed 75 lbs. to the yard; this has gradually increased, and now rails weigh about 100 lbs. to the yard.

Locomotives and trains have developed in weight, and it has now become necessary to increase the weight on the driving wheels to secure the necessary adhesion to the rails. This has frequently caused dissension between locomotive and civil engineers. While the former has been obliged to increase the size and weight of his engine to enable him to haul the increased weight of train authorized by his directors, the permanent way department has not always been able to keep pace with this increase, and the civil engineers have been continually crying out about the tremendously increased weight on the rails.

Plate I. shows at a glance the gradual increase in the length and weight of trains on the L. & N.W. Railway since the year 1864.

(*a*). *Load on Driving Wheels.*—It is of course evident that the greater the adhesive weight the less chance of slipping, but it is now generally accepted that the maximum weight on a single pair of wheels should not exceed 20 tons. In single engines this weight can only be utilized on one pair of wheels; it therefore follows that we soon reach a limit to the weight of train capable of being hauled by single driving engines.

The maximum of 20 tons is not often reached, because of the great strain on the permanent way, and on the older railways the bridges were not originally constructed to bear anything like this weight. The weight can, of course, be more equally distributed when coupled engines are employed, and it is now the general practice to couple four wheels with passenger engines, six wheels with express goods engines, and eight wheels with engines required to run heavy loads at slow speeds. *Plate* II. shows the weight carried on the different wheels with the principal types of standard engines on the L. & N.W. Railway.

(*b*). *Resistance to Traction.*—The resistance due to traction may be divided into three parts:—

Firstly.—Resistance dependent on velocity. Due to the friction of the moving parts of the engine and vehicles, and to the displacement of the air at the given speed.

Secondly.—Resistance due to gravity. In ascending an incline the train is of course raised vertically a distance, depending upon the length and inclination of the grade.

Thirdly.—Effect of wind and curves. High winds cause a very great increase in the resistance, this being particularly the case when the direction of the wind is at right angles to the rails, causing it to act upon the whole length of the train surface, thus producing excessive friction on the flanges of the wheels. The practical engine driver, who knows little of the theory of train resistance, knows only too well the difficulties he experiences in keeping time when there is a strong side wind, and when there is a gale blowing from the east or west the number of assistant engines worked on trains out of Euston in the course of one day is a serious item of expense. A head wind meeting the train fair and square does little harm, as the actual surface presented to the wind is only equal to the cross-section of the train. Curves also considerably increase the resistance, particularly with engines that have a long rigid wheel base. This resistance is considerably reduced by the provision of bogies, or radial axle-boxes, which will be alluded to later on.

Many elaborately theoretical calculations have been made, from which various formulæ have been deduced, to show the power required to be exerted by a locomotive to perform certain work under certain given conditions. I do not propose, however, to go into any of these theories or calculations, but I will show you in a very simple form the actual hauling power required, and the actual performance of certain standard passenger and goods engines working typical passenger and goods trains on the main line of the L. & N.W. Railway.

Mr. Webb has, at Crewe, a machine known as a "Dynamometer" car (*Plate* III.). This car is about 19 feet long and 8 feet wide, and is carried upon three pairs of wheels. It is used to register the tractive pull of the engine, to indicate the speed at which the train is running, and to locate any place or point on the road passed over. A roll of paper, K, about 1 foot wide, is fed across a table at a certain rate, say 3 inches per mile, by gear connected to the middle axle, and on this paper four pencils record lines; two of them (one fixed to record datum-line, and one free to travel with the draw-bar) are used to register the tractive pull of the engine. Both these pencils are in a line at point C when there is no pull on the bar.

When the draw-bar is in tension the cross-head H′ moves inwards and compresses the springs DD′, and when the buffers are in compression the cross-head H moves inwards and also compresses the springs, the pencil C connected to the draw-bar recording a line to the right or left of the datum-line accordingly.

The third, or speed pencil, is controlled by an electric magnet which is connected to a clock, and every half minute, as the paper passes over the table, the magnet causes the pencil to make a notch in the line, and by scaling the distance between these notches the speed can be ascertained.

The fourth, or locating pencil, is also controlled by an electric magnet which is connected to electric pushes fixed round the car, and by means of these pushes a notch can be made in the line at any desired spot, the name of station, mile post, etc., being written opposite to it.

The scale is constructed as follows :—

The paper is fed, as stated, at 3 inches per mile, therefore when the train is running at 60 miles per hour, or a mile in one minute, one half-minute interval would measure exactly one and a-half inches between the notches ; the one and a-half inches are, therefore, divided into 60 equal parts representing miles, and form a scale by which the speed can be read off.

The speed and locating pencils are not shown on the diagram, and I only propose to deal with the question of the pull on the draw-bar, which gives the actual practical train resistance and hauling power required, and the diagram shows in simple form how the draw-bar of the train is coupled up to the dynamometer car by means of this arrangement of levers.

I will now put before you several instances of the train resistance, etc., recorded in various trips with this car.

The records shown in *Plate* IV. were made on July 16th, 1893, with a special coal train from Rugby to Willesden, a distance of 77 miles.

AB is the datum-line described by the fixed pencil. The zigzag line is the diagram drawn by the pencil free to travel with the draw-bar.

The height of the diagram above the datum-line represents the actual pull on the draw-bar. Where the pencil travels below the datum-line, the draw-bar is in compression due to the brake being on the front part of the train.

The engine working the train was an 8-wheel non-compound coal engine, with 2,000 gallons tender. The train consisted of 57 loaded coal-wagons, 3 brake-vans, and dynamometer car. The total weight of the train, including engine and tender, was 852 tons 13 cwts. 1 qr. ; excluding engine and tender, 777 tons 12 cwts. 1 qr. ; and its total length was $1{,}263\frac{1}{2}$ feet. The steepest rising gradient on this section of the line is 1 in 326.

The highest speed recorded on the journey was 25 miles per hour.

As an example of the hauling power exerted, notice at X the steady pull on an up gradient of 1 in 330 at 12 miles an hour.

At this point the I.H.P. was 411, and the pull on the draw-bar $4\frac{7}{16}$ tons.

The highest I.H.P. developed was 557 on up gradient of 1 in 326 at 13 miles per hour, with a pull on draw-bar of 5 tons.

The pull on draw-bar at starting was $11\frac{1}{4}$ tons.

The ruling gradient on the southern section of the L. & N.W. main line is 1 in 330. It, therefore, follows that to haul a coal train weighing 777 tons at 12 miles an hour up this gradient the engine must be capable of exerting a direct and continuous pull equal to $4\frac{7}{16}$ tons.

The next diagram (*Plate* V.) was taken on November 29th, 1896, with a trip from Crewe to Carlisle, a distance of $141\frac{1}{4}$ miles, with a train consisting of 25 passenger vehicles worked by an 8-wheel compound coal engine, with 2,000 gallons tender, and the following particulars should be noted :—

The total weight of the train, including engine and tender, was 354 tons 9 cwts. 2 qrs.; excluding engine and tender, 278 tons 12 cwts. 2 qrs.

The total length of the train was 962 feet 6 inches.

Steepest rising gradient, 1 in 75.

Highest speed on journey, 48 miles per hour.

Speed up gradient of 1 in 75, 19 miles per hour.

I.H.P. on up gradient of 1 in 75, 704.

Pull on draw-bar on up gradient of 1 in 75, $5\frac{1}{8}$ tons.

The highest I.H P. developed was 781 on up gradient of 1 in 120, at 27 miles per hour.

The pull on draw-bar at starting from Crewe was 8 tons, and on starting from Carnforth was $11\frac{1}{2}$ tons.

The highest pull on the draw-bar whilst running was $5\frac{1}{8}$ tons, going up Shap Bank on rising gradient of 1 in 75, at 19 miles per hour.

Plate VI. shows a trial run with a heavy goods train, also worked by an 8-wheel compound coal engine of the same class, with 2,000 gallons tender, over a very heavy piece of road between Edgeley and Heaton Lodge, a distance of $29\frac{1}{2}$ miles, on December 1st, 1896, giving a good example of the working of a heavy goods train over a hilly road. The train consisted of 47 wagons.

Total weight, including engine and tender, 445 tons 14 cwts. 3 qrs.; excluding engine and tender, 369 tons 17 cwts. 3 qrs.

Total length of train, 991 feet.

Total number of axles in train, 103.

Steepest rising gradient, 1 in 66.

Highest speed on journey, 27 miles per hour.

Speed up gradient of 1 in 125, 21 miles per hour.

I.H.P. up gradient of 1 in 125, 745·5.

Pull on draw-bar up gradient of 1 in 125, $5\frac{1}{16}$th tons.

The highest I.H.P. developed was 767·8, on up gradient of 1 in 120, at 23 miles per hour.

The pull on draw-bar at starting was $9\frac{3}{8}$ tons.

The pull on draw-bar in starting on up gradient of 1 in 66 was $11\frac{1}{2}$ tons.

The highest pull on draw-bar whilst running was $7\frac{3}{4}$ tons.

The last of these examples (*Plates* VII. and VII.A) is of a famous run from Euston to Crewe and back, in the summer of 1899, with a train weighing, including engine and tender, 420 tons, conveying the members of the Institution of Civil Engineers. This is a very good example of the actual power exerted by an express passenger engine when running a heavy train an average speed of 50 miles per hour, which may be accepted as a fair standard of ordinary express passenger train speed in this country. The performance of the engine, however, was unique, because, although the speed was not out of the way, the weight of the train was altogether exceptional.

Euston to Crewe, June 8th, 1899 :—

Length of trip, 159 miles.

7-foot 4-inch wheels, coupled compound express passenger engine, "Iron Duke," 2,000 gallons tender, dynamometer car, and 13 saloon carriages.

Total weight of train, including engine and tender, 420 tons 5 cwts.

Total weight of train, excluding engine and tender, 339 tons 5 cwts.

Total length of train, 716 feet 2 inches.

Steepest gradient, 1 in 70.

Highest speed on journey, 65 miles per hour.

Speed up gradient of 1 in 330, 47 miles per hour.

Pull on draw-bar of 1 in 330, $2\frac{1}{2}$ tons.

The pull on draw-bar at starting was $4\frac{3}{4}$ tons.

The highest pull on draw-bar whilst running was $5\frac{1}{4}$ tons, going up Camden Bank, on gradient of 1 in 70, at a speed of 16 miles per hour.

The mean pull on draw-bar throughout the journey was 1·485 tons.

The trip of 159 miles was run in 3 hours 15 minutes without a stop.

Crewe to Euston, June 8th, 1899 :—

Length of trip, 159 miles.

The same engine worked the train, and the weights and lengths were similar to those on the down journey.

Steepest gradient, 1 in 177.

Highest speed on journey, 65 miles per hour.

Speed up gradient of 1 in 330, 48 miles per hour.

Pull on draw-bar of 1 in 330, $2\frac{3}{16}$th tons.

The pull on the draw-bar at starting was 7 tons.

The highest pull on draw-bar whilst running was $3\frac{1}{8}$ tons on up gradient of 1 in 177, at a speed of 37 miles per hour.

The train ran from Crewe to Willesden, 154 miles, without a stop.

In the two trips, up and down, the engine covered a distance of 318 miles.

The mean pull on draw-bar throughout the journey was 1·56 tons.

This trip, therefore, practically demonstrates that a heavy express passenger train running at 50 miles an hour develops a mean train resistance of 1·56 tons. Now, the well-known formula by D. K. Clarke for train resistance is

$$R = 8 + \frac{v^2}{171}$$

per ton for total resistance, including engine and tender.

Applying this to the L. & N.W. train, whose run we have been dealing with, we have

$$R = 8 + \frac{50^2}{171} = 22{\cdot}6 \text{ lbs. per ton.}$$

The whole train, including engine and tender, weighed $420\frac{1}{4}$ tons, which multiplied by 22·6 gives as a mean resistance 9,500 lbs., or 4 tons 4 cwts. 3 qrs. 8 lbs. It therefore appears that the formula gives far too high a result.

Commenting on this, the *Engineer* of the 14th July, 1899, remarks as follows:—

"Even if we omitted the constant 8, the result would be far too high. We believe that the resistance of the train was about $1\frac{3}{4}$ tons, or 4,000 lbs., and taking weight of train at 340 tons, we have resistance thus of 11·76 lbs. per ton, and taking resistance of engine and tender, including friction of machinery, at 20 lbs. per ton, we have 1,620 lbs. more, making 5,620 lbs."

Taking average velocity of 50 miles per hour, or 4,000 feet per minute, the locomotive exerted 750 H.P.

Weight per H.P. of the locomotive was 160 lbs.

H.P. found thus :—

$$\frac{4{,}400^{*} \times 6{,}520^{\dagger}}{33{,}000} = 750 \text{ H.P}$$

(2). The Framing.

The style of frame usually employed in this country consists of two single rolled plates of iron or steel about 1 inch in thickness. Each plate is exactly the same in every respect, and extends along the whole length of the engine at each side. They must be perfectly level and straight throughout, and these plates, together with the cylinders, cross-stays, buffer-plates, etc., which are bolted to them, form the foundation upon which the engine is erected.

Engines in this country are generally built on the single frame system, that is to say, one single frame down each side of the engine, as shown in *Fig.* 11, which is the frame of Mr. Webb's 4-cylinder compound. The elevation of the frame-plate is shown, looking at it from the inside. Although a single-framed engine, the framework is strengthened by a mid-feather, with a central axle-box to give increased bearing to the driving axle.

The frames are stayed together by means of—

(1). The buffer-plate.

(2). The spectacle or motion-plate.

(3). The transverse stay immediately in front of the fire-box.

(4). The trailing horn-blocks, which are connected to each other by a trough in which the axle works, extending between the frames.

(5). The frames are further made rigid by the cast-iron foot-plate bolted between them at the trailing end.

To illustrate at a glance how an engine is erected upon the groundwork formed by the two frame-plates, photographs were shown taken at various stages of its construction, beginning with the two bare frame-plates laid on trestles in the erecting shop at Crewe ready for the fitters to commence work.

The Midland and Great Western Railways have engines built with double frames. A diagram of double frames for Great Western single engines is shown in *Fig.* 12. IF is the inside and OF the outside frame; both of them extend along the whole length of the

* Feet passed over per min. lbs.

† 4,000 lbs. resistance for train at 11·76 lbs. per ton, and 1,620 lbs. for engine and tender at 20 lbs. per ton.

engine at either side, and are stayed at intervals by the transverse stay-plate TSP. The driving wheels have each two axle-boxes, each

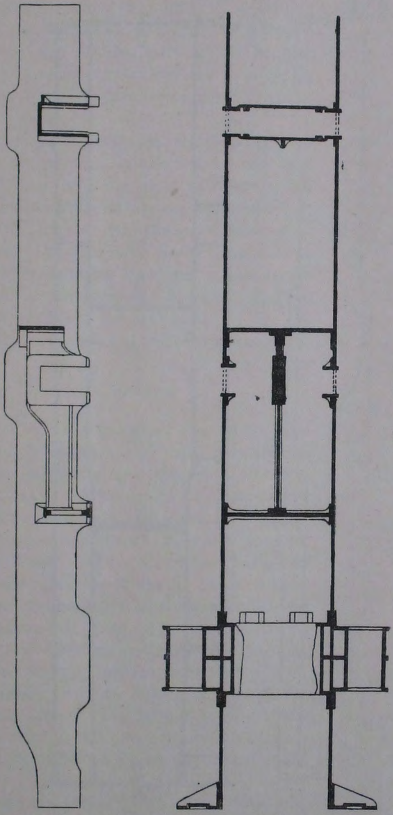


Fig. 11.

working in the horn-plates in their respective frames; the wheels are between the two frames. There are altogether six journals or bearing surfaces upon the driving axle without counting the eccentrics, so, as may be imagined, it is a costly piece of work. The

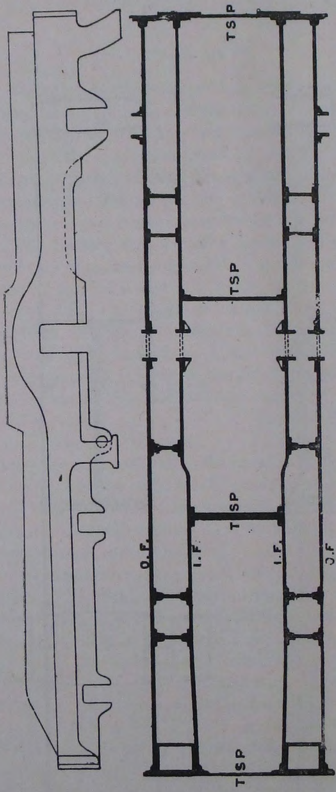


Fig. 12.

trailing wheels have axle-boxes on the outside frames only; the front end is carried on a bogie.

In America the frames are made of wrought-iron bars from 3 to 4 inches square; it is usual to make them in two parts, bolted together (*Fig.* 13). The leading part consists of flat bars, to which the cylinders are bolted; the trailing part is formed with guides or jaws for the axle-boxes to work in, and is made up of bars or braces forged together.

It is thought by some people that the wear and tear of the road is affected by the class of frame used, and the users of plate-frames and bar-frames respectively contend that their practice is the best for the permanent way. For my own part, I have never been able to find any data showing that one is superior to the other in this respect, but the English system is certainly, to my mind, by far the simplest, most economical, and workmanlike.

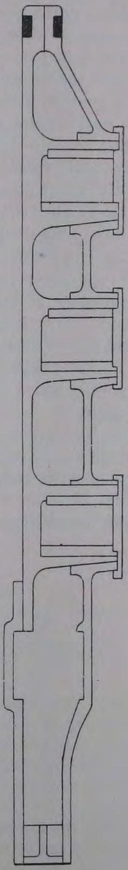


Fig. 13.

(3). Boilers.

I do not know whether it has struck any of you that in the matter of boiler construction locomotive engineers are hampered in ways which do not affect the designers of stationary engines, who, as a rule, can make their boilers of any size or dimensions they like, and fix them in any convenient spot, without having to consider the question of space. Now, with a locomotive no part may be more than 13 feet 6 inches above rail level. The width must not exceed 8 feet 6 inches or thereabouts, and the length must be in proportion to the wheel base of the engine, so as to enable it to traverse curves with safety. The weight must be correctly distributed, and, as already mentioned, must not exceed 20 tons on any one pair of wheels.

There are many other such restrictions, and when it is remembered that all the complicated details of a modern high-pressure or compound engine, capable of exerting something like 1,000 horse-power, together with a powerful boiler for maintaining steam at an uniform pressure, and driving that machinery, have to be compressed into such a limited space, and that they have to be specially constructed to stand the wear and tear of travelling over a metal road at upwards of 60 miles an hour, it will be recognized that the design, material, and workmanship of a locomotive engine must all be of the most perfect possible of their kind.

Generally speaking, the boiler of a locomotive may be said to consist of four principal parts :

(1). The barrel, that is, the cylindrical part extending from the fire-box to the smoke-box.

(2). The fire-box shell, or casing adjoining the barrel at one end, and rectangular in shape except at the top, where it is usually a continuation of the upper half of the barrel. The bottom part extends below the barrel, and is joined to the lower half of the barrel by the shoulder-plate.

(3). The fire-box, a square chamber inside the fire-box shell, with four walls and a roof, having an open space at the bottom for the fire-grate.

(4). The tubes, a number of small cylindrical flues extending through the barrel, for conveying the gases generated by the fire to the smoke-box and chimney.

Fig. 14 is an outline section through a locomotive boiler, and shows the position of the fire-box and tubes.

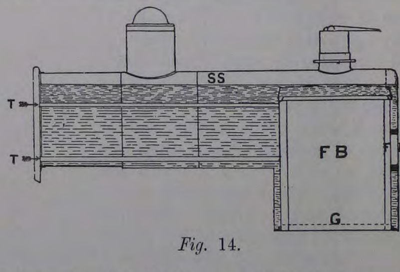


Fig. 14.

FB is the fire-box, TT the tubes, of which only two are shown, so that they can be more clearly defined. The space between them is in reality filled with tubes, the number being usually about 200.

The grate is at G, the fire-door at FD. The shaded part shows the water space, the steam space being above the water at SS.

The inside surface of the tubes and the fire-box plates comes directly into contact with the flames of the fire, and is called the heating surface. It is absolutely necessary that these tubes and the plates should (as shown in the diagram) be always surrounded by water when there is a fire in the fire-box. The space between the outside of the tubes is called the water space.

(*a*). *Material.*—The outer plates, viz., those forming the barrel and fire-box shell, are now almost universally made of mild steel. Mr. Webb was one of the first engineers in this country to successfully introduce Bessemer steel for boiler-plates, and as long ago as 1886 he had made 2,752 locomotive boilers of this material. At that date most engineers continued to make their boilers of Yorkshire iron, and some companies still retain this, to my mind, now somewhat antiquated custom.

The tubes are usually made of brass, although copper, steel, and iron all have their advocates, as being suitable for the purpose. Of course, the two latter have the recommendation of being much cheaper than brass or copper, and having the same co-efficient of expansion, and on some railways they have been successfully used. However, it is generally conceded by the majority of locomotive engineers that in the long run brass or copper tubes prove the most economical and satisfactory.

The usual thickness of the boiler-plates and tubes is as follows, varying slightly under certain conditions :—

Steel plates, barrel, and fire-box shell, $\frac{9}{16}$ inch.

Yorkshire iron, barrel, and fire-box shell, $\frac{9}{16}$ inch.

Steel plates, barrel, and fire-box shell, $\frac{13}{32}$ inch when pressure is less than 140 lbs. per square inch.

The external diameter of the tubes varies from $1\frac{1}{2}$ inches to $1\frac{7}{8}$ inches.

(*b*). *Size.*—With regard to the question of the size of locomotive boilers, this naturally depends very much on the work the engine has to perform. The great point to be aimed at is to provide sufficient heating surface to enable steam to be generated with sufficient rapidity to keep the boiler well up to its work, that is to say, not to let it "run out of breath," which is what happens when the cylinders are using the steam quicker than the boiler can supply it. Latterly, in many cases, the weight of trains has increased out of all proportion to the work the engines were originally built to perform.

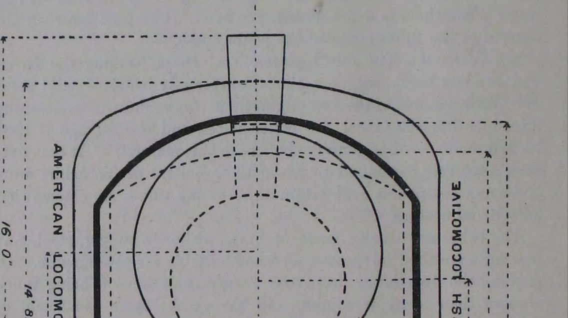

AMERICAN LOCOMOTIVE
16' 0"
14' 8½"
9' 8"
AMERICAN LOCOMOTIVE 10' 3"
ENGLISH „ 8' 4"
ENGLISH LOCOMOTIVE
8' 11"
12' 6"
13' 5½"
English Platform
AMERICAN LOCOMOTIVE
ENGLISH „
„ LOADING GAUGE

Fig. 15.

In trying to keep time with such trains, drivers are apt to "thrash" their engines, that is to say, they work the engine nearly in full gear instead of "cutting off" at 20 or 30 per cent. of the stroke, as originally intended, thus using a great deal more steam than the boiler can generate.

In order to gain the absolutely necessary increased power under modern conditions, engineers have been expanding the cylinder diameters, increasing the boiler pressure, and enlarging the boilers to attain increased heating surface, grate area, and steam space. The ordinary simple engine of to-day has cylinders varying from 18 to 20 inches in diameter, and probably a boiler pressure of 200 lbs. to the square inch. But the English engineer, whilst he can enlarge his cylinders and increase his boiler pressure, cannot follow the lead of his American cousin in the matter of boiler construction, because, whereas the loading gauge in this country is restricted to the dimensions I have already given, in America these restrictions practically do not exist. So long as the construction of an engine admits of safe running it practically does not matter how far it bulges out in any direction.

The diagram (*Fig.* 15) shows this very plainly. The black lines represent the external diameter in width and height of the modern American engine, while the dotted lines show the external dimensions of the latest Lancashire and Yorkshire passenger engine, which has attained the extreme limit possible with the English loading gauge, which gauge is shown by the thick black line. This, without comment, will give you some idea of the different conditions under which English and American engineers have to work to attain the same standard of boiler efficiency.

The following table gives the standard proportion of the heating surface of locomotive boilers on the principal English railways. The smallest boiler of any modern-built engine is that of the Midland Railway single-wheeled engine, while the largest is that of the Lancashire and Yorkshire Railway.

Again, to emphasize the points of comparison between English and American practice, I show the same figures with regard to some typical American engines.

English.

Railway.	Diameter of Cylinders.	Fire Grate Area.	Heating Surface. Fire-box.	Heating Surface. Tubes.	Heating Surface. Total.
	Inches.	Sq. ft.	Sq. ft.	Sq. ft.	Sq. ft.
L. & S.W., 6′ 7″, Coupled...	18 × 26	24	148	Fire Tubes 1187 Water Tubes 165 1352	1500
Midland, 7′ 9″, Single ...	$19\frac{1}{2}$ × 26	24·5	147	1070	1217
Metropolitan, 5′ 6″, Leading Tank.	17 × 26	16·7	95·6	1050	1145
L.B. & S.C., 6′ 9″, 4-Wheel, Coupled.	18 × 26	—	110·35	1349·94	1460·39
Great Central, 5′ 1″, Goods, Coupled.	18 × 26	18·85	99	1179	1278
Great Central, 7′, Passenger	$18\frac{1}{2}$ × 26	20	109	1209	1318
Great Western, 6′ 8″, Coupled.	18 × 26	23·15	124·41	1395·62	1520·03
L. & Y., 7′ 3″, Coupled ...	19 × 26	26·05	175·8	1877	2052·8
Midland, 5′, American Goods, 6-Wheel, Coupled.	18 × 24	16·5	120	1241·3	1361·3
G.N., re-built, 8′, Single ...	18 × 28	23·3	114	1096	1210
L. & N.W., Jubilee Type ...	2 H.P. 15 × 24 2 L.P. $19\frac{1}{2}$ × 24	20·5	159·1	1241·3	1400·4
North Eastern, Compound...	1 H.P. 19 × 24 2 L.P. 20 × 24	23·0	—	—	1328

American.

	Diameter of Wheels.	Diameter of Cylinders.	Stroke Cylinder.	Heating Surface.	Grate Area.	Steam Pressure.
		Inches.	Inches.	Sq. ft.	Sq. ft.	Lbs.
Class P, 1896, 4-Wheel, Coupled.	6′ 8″	$18\frac{1}{2}$	26	1900	33	185
Class P, Chicago & N.W. Railway.	6′ 8″	$19\frac{1}{2}$	26	2507	—	—
Mogul Type, 6-Wheel, Coupled.	6′ 8″	20	28	2917	34	210
Atlantic Type	7′ 0″	$20\frac{1}{2}$	26	2320	69	185

Mr. Aspinall's boiler has such proportions that the extreme width and height limit possible on an English railway is reached. It has a heating surface of 2,052 square feet, with a grate area of 26·05 square feet. The fire-box is of the "Belpaire" type, about which I shall speak presently.

The outside diameter of the barrel of the boiler is 4 feet 10 inches, and the length 17 feet $1\frac{3}{8}$ inches; the centre of the boiler is 8 feet 11 inches above rail level. It contains 239 steel tubes 15 feet long by 2 inches outside diameter, and the working pressure is 175 lbs. per square inch.

(*c*). *Working Pressure.*—Mr. Aspinall by no means reaches the approved limit of steam pressure according to modern ideas.

Ten years ago 175 lbs. was considered a very high pressure to carry, but now 200 lbs. per square inch is not infrequently used in this country, while in America the "Mogul" type of boilers carry a pressure of 210 lbs. per square inch, and the new engines on the Chemin-de-fer du Nord in France have a pressure of 212 lbs. per square inch. It may now be generally accepted that the working pressure on English railways varies from 160 lbs. to 200 lbs. per square inch.

When boilers of different classes of engines performing work of unequal importance are interchangeable, it is sometimes the practice, as the boiler gets older, to reduce the pressure it carries, and put it on the locomotive performing the less important class of work.

It is difficult to give any correct data with regard to the life of a boiler, this depending so much on the conditions under which it works. It is never correct to give it in years, but it should always be in miles. For instance, on the L. & N.W. Railway all important express engines run on an average at least 300 miles a day, whereas on many other lines about 150 miles is considered a good day's work. It is therefore manifest that, given the same conditions, a North Western boiler would only last half the time. I have known cases of Crewe-built boilers running from 500,000 to 700,000 miles before being condemned.

(4). Fire-Box.—Relative Merits of Copper and Steel.

(*a*). The fire-box plates are almost invariably made of copper on account of its high conductivity for heat, and its ability to stand alternate expansion and contraction from heat and cold without cracking and molecular change.

Since Bessemer steel has attained its present state of perfection, making it available for boiler-plates, some enterprising engineers have tried to use it also for fire-box plates in locomotives. A measure of success has attended these experiments, but the general result has been to demonstrate that the very best copper that can be procured is far superior to any other metal for the purpose.

The temperature in a locomotive fire-box varies to a great extent, the variations at times being very sudden, and covering a great range. At one moment an engine is dragging a heavy train at high speed, with a fire urged by a fierce blast, and fed by a strong draught from below. Under such conditions the furnace is developing the maximum heat it is possible of producing. The next moment steam is shut off and the blast ceases, the damper is shut and there is no draught from below, all possible means being used to check the heat, and prevent the generation of steam not then required for working the engine. Steel fire-box plates will not stand such sudden strains, and although they are cheaper than copper in the first instance, the enduring powers of the latter under the conditions described, and its superiority as a conductor of heat, have proved it again and again to be the most economical in the long run.

With a boiler constructed in the ordinary way the top of the fire-box shell is cylindrical, whereas the top of the fire-box itself is flat, and it is most important that the roof of the fire-box should be efficiently stayed. There is great pressure on this plate. For instance, with a L. & N.W. 7-foot compound engine pressed at

200 lbs. per square inch, the total pressure on the top of the fire-box amounts to no less than 257 tons.

The usual way of staying the top of a fire-box is by strong wrought-iron girders placed longitudinally across the top of the box, to which they are attached by $\frac{7}{8}$-inch bolts screwed in steam tight through the top of the fire-box plate. These girders are slung to angle irons attached to the inside of the fire-box shell, thus making the whole thoroughly rigid when subjected to downward pressure. The view (*Figs.* 16 and 17) shows how this is done. The sides of the fire-box are secured to the sides of the fire-box shell by copper stays. The stays have threads on them; one end is screwed into the fire-box plate, and the other into the shell. After they are screwed into position the ends project beyond the outside of each plate, and these ends are riveted over.

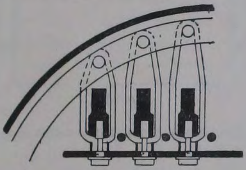


Fig. 16.

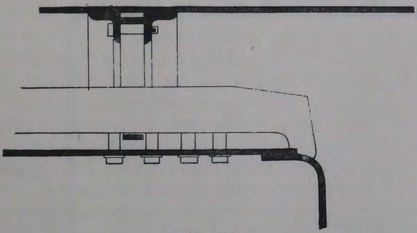


Fig. 17.

(*b*). The latest type of boiler and fire-box, known as the "Belpaire," embodies several improvements. It admits of a larger steam space above the top of the fire-box, does away with the space taken by the cumbersome roof bars, and with the many crevices and projections in which dirt is apt to accumulate.

With the "Belpaire" boiler the top of the fire-box shell is flat, and the top of the fire-box is stayed direct to the fire-box shell, as shown in *Figs.* 18 and 19; the flat sides of the fire-box shell above

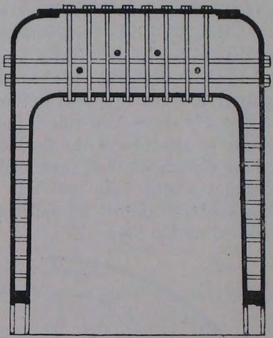


Fig. 18.

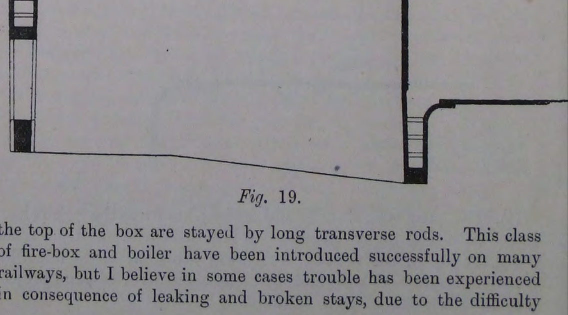


Fig. 19.

the top of the box are stayed by long transverse rods. This class of fire-box and boiler have been introduced successfully on many railways, but I believe in some cases trouble has been experienced in consequence of leaking and broken stays, due to the difficulty in efficiently staying such a large area of flat plates subjected to high pressures and heavy strains.

Without resorting to the "Belpaire" fire-box, Mr. Drummond, the Locomotive Superintendent of the South Western Railway, obtains the same freedom of circulation above the fire-box roof by the arrangement of roof-stays, shown on the sketch (*Plate* VIII.). In this system the roof-stay bolts are fixed to the hangers, which are attached by bolts to a row of double angle iron, riveted inside the fire-box shell. While these bolts efficiently bear the weight of the whole downward pressure on the top of the box, they are free to work upwards in the bolt holes, and a lateral movement is also given, thus freely allowing for any difference in expansion and contraction between the copper fire-box plates and steel boiler-plates.

(*c*). *Drummond Cross Tubes.*—It is a generally accepted fact that by far the most effective portion of the heating service of a locomotive lies in the fire-box; in fact, the surfaces of the tubes nearest the smoke-box are very little good indeed as regards their heating surface capabilities. Indeed, Mr. Drummond goes so far as to assert that their utility in this respect is of little value except for the first foot from the fire-box tube-plate.

Here again we see the difficulties of constructing a large boiler for an English locomotive. It is useless to lengthen the barrel, because long fire tubes do not cause additional effective heating surface, and the length of the fire-box is practically determined by the strength of the fireman's arms. It is not a bit of good having a fire-box so long that the fireman cannot throw the coal right into the front far corners. With a view of increasing the fire-box heating surface, Mr. Drummond has introduced into the fire-box a number of almost horizontal water tubes, which are arranged transversely in the top of the fire-box (*Plate* IX.). The total heating surface of the boiler is 1,500 square feet, of which the fire-box furnishes 313 square feet, which is more than twice the usual heating surface for which the fire-box is responsible.

These water tubes are made of steel, solid drawn, $2\frac{1}{2}$-inch bore by $\frac{1}{8}$ inch thick. There are altogether 61 of them, and they give a total heating surface of 165 square feet. The manner in which they are fixed in the fire-box is clearly shown in the plate. The slope is given to promote circulation, and it is equal to the diameter of the tubes. Each tube has a stay passing through the centre of it in the manner shown. This outer cover can be taken off for the purpose of inspection.

It is found in actual practice that very little scale or dirt collects in these cross tubes, and Mr. Drummond is satisfied that they add very greatly to the boiler efficiency of the South Western engines.

(5). Grates.

The area of the grate surface in its relation to the heating surface of the boiler is a very important factor in the construction of the locomotive, but it is a subject upon which there is considerable diversity of opinion and practice.

Again referring to the table with reference to the heating surface, you will see how very different is the practice with regard to the fire-grate area on the different railways, varying from 20 to 26 square feet, with the same size of cylinder, and practically the same heating surface.

You will notice that the Midland American goods engines have a very small grate area, viz., only 16·5 square feet, and I believe that these engines have been found to be very expensive in the consumption of coal. A fairly large grate area and a well-managed fire conduce in a great measure to economical working. With a small grate area the fire must be continually urged and replenished in order to maintain steam. You will also notice the extent to which it has been possible to increase the grate area on the American locomotive.

The American engine with the largest grate area is the "Atlantic" type, running on the much advertised "fastest express trains in the world," on the Philadelphia and Reading Railway, from Camden to Atlantic City. These trains are timed to run 55½ miles in 50 minutes, being a booked speed from the start to stop of 66·6 miles per hour, and according to the official records time is not only being kept, but actually made up with very respectable loads.

(*a*). *For burning Ordinary Fuel.—Fig.* 20 shows the arrangement of the bars in an ordinary coal burning fire-box. The fire-bars FB rest upon the carriers CC; two of these carriers are made of cast iron and extend from side to side of the fire-box, one at the front underneath the tube-plate, and the other at the back under the fire-hole.

The central carrier is made of wrought iron, and extends across the centre of the box.

The front and back carriers are held in position by the bolts B which pass through the foundation ring, and are riveted over at R. These bolts project some 4 inches into the fire-box, and upon them are fixed washers W to keep the carriers away from the side of the box.

The carriers are screwed up by the nuts N against the washers, and are thus kept firmly in position.

The central carrier is supported by brackets which are riveted to the fire-box plate through the foundation ring.

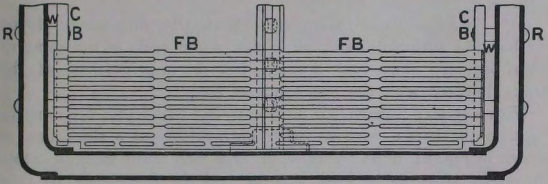


Fig. 20.

To prevent the gases from being drawn away by the blast before they are properly consumed, a brick arch is fixed in the position shown in *Fig.* 21 ; this deflects the gases as they arise from the furnace, and throws them back where the blast is greatest, thus causing their full combustion.

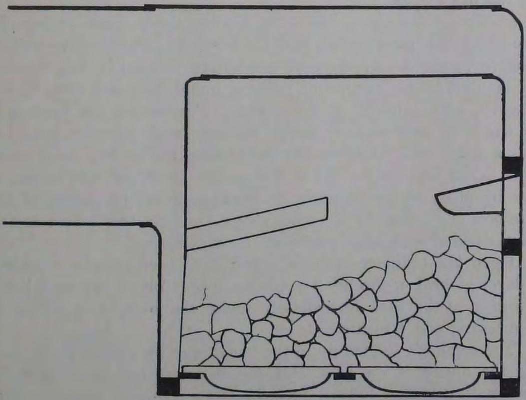


Fig. 21.

The baffle-plate over the fire-hole door acts in a similar way and throws down the air admitted to the fire-box when the door is opened; this helps combustion and prevents cold air from getting to the tube-plate and tubes. There is no baffle-plate fixed in the L. & N.W. fire-boxes; by an arrangement of Mr. Webb's the fire-hole door is made to open inwards, and thus serve the double purpose of baffle-plate and door.

(*b*). *For burning Anthracite Coal.*—Practically the grate employed for burning anthracite coal, or Welsh steam coal, is the same as when ordinary sharp coal is used, but the manipulation of the fire is different with the two kinds of coal.

With ordinary "sharp" or quick-burning coal a thin fire must be kept on the bars; whereas with anthracite coal a thick fire, as shown in *Fig.* 21, must be made up and well burnt through before the engine attempts to work a train, and the fire should be kept at this consistency while running, to ensure the most economical results.

It is very important in constructing the fire-grate of a locomotive that the bars should be easily taken out, as they are apt to fuse from excessive heat when burning coal that forms clinker. It is also necessary to pull out several bars to drop the fire at the end of the day's work.

(*c*). *For burning Liquid Fuel.*—Mr. Holden, the Locomotive Superintendent of the Great Eastern Railway, has introduced a very important feature in the development of locomotive practice in this country by inaugurating a system of burning liquid fuel, and *Plate* X. is a drawing giving details of the system. Practically, the fire-box is of the same construction as an ordinary coal burning box, but has a brick wall next to the tube-plate under the brick arch. The liquid fuel, carried in a 500 gallon tank on the tender, is led by pipes to two injectors or burners placed in orifices in the fire-box plates exactly 12 inches above the bars, this height having been decided upon after a number of experiments.

Upon the ordinary fire-bars which have been already described a layer of broken fire brick is spread, the depth of the layer being 9 inches at the back immediately under the burners, 4 inches in the centre, and 6 inches in front.

The engine is lighted up in the usual way by a small fire of coal on the centre of the bars, and the injectors are not used as a rule until it is time to start with the train. During the whole time while running, the injector steam cocks are kept open, and the admission of oil is regulated by the oil cocks according to the working of the engine.

When standing, only a small jet of oil can be used, because in order to consume any quantity the action of the blast is necessary.

When working heavily, the oil is admitted in larger quantities; when notched up, the admission is reduced.

When running, no coal is used unless it is found the engine is not steaming well, in which case a thin fire is kept over the bricks.

A small fire is also put on preparatory to coming to a stand for any length of time, because if the burners are shut off, the bricks soon cool down and become black, and when the spray of liquid fuel is put on again it fails to ignite.

The supply of air to the injector is from the front of the engine through a bell-shaped orifice at the bottom of the smoke-box, whence it passes through a number of small pipes running round the smoke-box, and eventually through a larger pipe to the injector.

This raises the temperature of the air, which at the time of entering the injector is about 400 degrees Fah., the oil 200, and the steam 250.

The injectors or sprays are said to use about 2 or 3 per cent. of the steam generated, according to the class of oil they are using.

Mr. Holden is an engineer who keeps well ahead of the work expected of the engines running on the Great Eastern Railway; his latest liquid fuel burning engines have 7-foot coupled wheels, and 19″ × 26″ cylinders. The "Claud Hamilton," an engine of this class, represents a very fine specimen of English design and high-class workmanship. It was exhibited at the Paris Exhibition, where it was greatly admired.

(6). The Value of Steam Domes for Obtaining a Supply of Dry Steam for the Cylinders.

The use of the dome is to afford additional steam space. The diagramatic illustration of the boiler (*Fig.* 14) shows how very small is the actual space available for steam alone. The dome is therefore provided to enable the steam for the regulator to be taken from as high a point as possible above the level of the water.

On the drawing (*Fig.* 22) the position of the regulator and the steam-pipe conveying the steam from the dome to the cylinders is shown.

The object of taking steam from as high a point as possible is to avoid priming, a term used to describe the state of affairs when water enters the steam chest and cylinders.

It is absolutely necessary that the steam should be conveyed to the cylinders as dry as possible. Water in the cylinder is a source of danger, and an engine priming badly has been known to actually blow the cylinder cover off; besides which, water mixed with steam detracts from the elastic properties of the latter, and causes it to be more sluggish in its entrance to and exit from the cylinders.

For many years the Great Northern Railway engines were not fitted with steam domes, and to check the passage of water, the steam was taken from a long perforated pipe fixed inside the barrel of the boiler, as near the top as possible. Mr. Ivatt, however, the present Locomotive Superintendent of the Great Northern Railway, is now fitting domes to all the new engines, and to the old ones when they go into the works to be re-boilered.

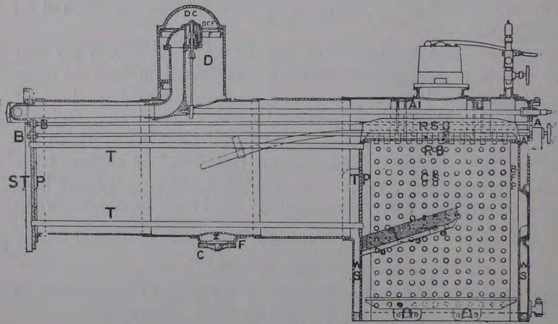


Fig. 22.

(7). Cylinders.

When the cylinders are placed side by side between the main frames, the engine is known as an "inside cylinder engine." This position necessitates the employment of cranks upon the driving axles, to communicate the force of the steam pressure to the driving wheels.

Fig. 23 illustrates the details of a pair of inside cylinders cast in one piece and bolted to the main frames at the points B. The main casting forms part of the back cover, to which the small cover BC is permanently attached. The front cover FC must be of a larger diameter, to enable the piston to be taken out for the purposes of examination, etc. In this case the valves are placed above the cylinders, a system which admits of the employment of much larger cylinders than when the valve chest is between them.

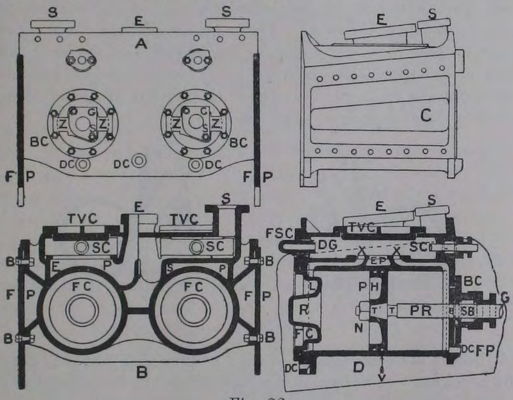


Fig. 23.

Fig. 24 shows the position of the valves when they are placed in the latter position, and in this case the two cylinders are cast separately, and afterwards bolted together. At one time they were always cast separately in this way, but owing to the joint between them being a source of trouble, it is now customary to cast the cylinders in one piece.

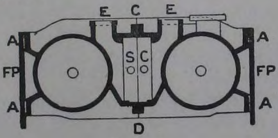


Fig. 24.

An "outside cylinder engine" has the cylinders outside the main frames on either side of the engine, and the pistons and connecting rods work on crank-pins fixed to the driving wheels. With this arrangement the axle between the driving wheels is straight, no cranks being needed.

Fig. 25 is a cross-section of the 18-inch outside cylinders of a Great Northern Railway express passenger engine built by the late Mr. Stirling. It will be seen that they are outside the frames FP at either side of the engine, each cylinder having a separate steam chest on the inner side of the frame. The frames in this case are of different design to those of an engine having inside cylinders, so as to allow space for this special form of casting. Whether the cylinders are inside or outside, they are always kept in position by being securely bolted to the main frames, as shown at A.

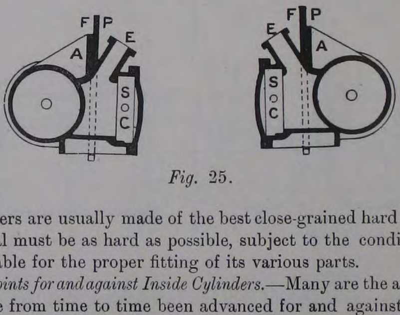


Fig. 25.

Cylinders are usually made of the best close-grained hard cast iron. The metal must be as hard as possible, subject to the condition that it is suitable for the proper fitting of its various parts.

(*a*). *Points for and against Inside Cylinders.*—Many are the arguments that have from time to time been advanced for and against the employment of inside or outside cylinders. The question is not one that concerns the cylinders alone, but it affects the whole of the general design of the engine, and each system has its own particular merit according to circumstances.

Mr. Webb disposes of the question in a very broad-minded way in his latest 4-cylinder compound engine by using both systems simultaneously. The two L.P. cylinders are between the frames, the two H.P. cylinders outside, and the arrangement has been found to give every satisfaction.

To my mind, a strong argument against outside cylinders with simple engines is the unequal distribution of the strain on the frames in consequence of the cylinders being bolted and fixed to them on one side only. Outside cylinder engines now carry a much higher boiler pressure than in the days of Stirling and Ramsbottom, their chief upholders. This increased pressure on the piston surface puts more strain on the joint between the cylinders and the frames, and trouble is often caused by the cylinders working loose in the bolt-holes in consequence.

Another argument ágainst outside cylinders is the cooling effect due to their exposed position, which is said to cause an excess of 16 per cent. in the condensation as compared with inside cylinders. In their favour it may be said that they are simpler and less costly in design, admitting without difficulty the use of a cylinder of large diameter; the working parts, glands, piston-rods, slide-bars, etc., are more easily accessible to the driver, and, above all, with this class of engine there is no crank axle, which is one of the most expensive parts of a locomotive, and which is occasionally liable to fracture.

The rigidity and strength given to the leading end of the engine by the solid casting of the two cylinders bolted between the frames is a point in favour of inside cylinders, and there are other advantages which have been pointed out by the comparison I have already drawn. There is, however, a difficulty in designing inside cylinders of modern dimensions with the steam chest between them, due to the fact that the area in which they must be fixed is limited to the distance of 4 feet 2 inches between the main frames, and it requires a great deal of scheming to arrange cylinders of any diameter above 18 inches with sufficiently large steam passages, and the proper thickness of metal, in this confined space.

Mr. Webb was one of the first locomotive engineers to cast the two cylinders and steam chest in one piece, and he got over this space difficulty with his 6-foot 6-inch coupled engine by placing the valves at an angle, as shown by the diagram (*Fig.* 26). This arrangement has been most successful from every point of view.

It is better, when possible, to put the steam chest in this position or directly between the cylinders, as they can be cast lighter than when there are separate steam chests above or below them, as shown in the upper one of the two diagrams.

I may here mention a few well-known types of inside and outside cylinder engines.

Coupled Engines.—The outside cylinder 7-foot coupled engine designed in the year 1881 for the South Western Railway by Mr. Adams, the then Locomotive Superintendent, was a very good specimen of a powerful engine at that time. Mr. Drummond, the present Locomotive Superintendent, builds engines with inside cylinders, and his latest coupled engine with water tubes in the fire-box is of this type.

Single Engines.—The late Mr. Stirling's outside cylinder single-wheel engine with 8-foot driving wheels is famous for the good service it has done in past years on the Great Northern Railway; and the inside cylinder engine built by Mr. S. W. Johnson for the Midland Railway in 1889 is still doing good work.

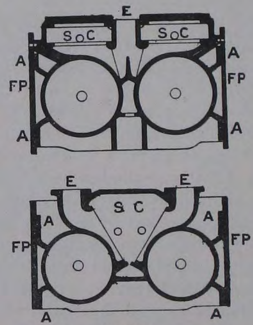


Fig. 26.

(*b*). *The Disadvantages or otherwise of Inclined Cylinders.* — With regard to the question of inclining the cylinders, or placing them horizontally. This, in a very great measure, depends upon the diameter of the wheels they have to drive, and I really do not think the inclination or otherwise of the cylinders effects any actual advantage or disadvantage as regards the working capacity of the engine. The North Western compound coal engine has the cylinders inclined to an angle of 1 in $8\frac{1}{2}$, in order to give the inside L.P. slide-bars the necessary clearance above the axle of the leading wheels. This could not be obtained if the cylinder was fixed horizontally.

I have pointed out that, with the ordinary modern simple engine, the diameter of the cylinders is from 18 inches to 20 inches, and I have also pointed out the necessity of increased boiler capacity to supply cylinders of this area. This leads us to the consideration of a very important question in connection with modern locomotive development.

(*c*). *The Advantages or otherwise of Compounding.*—This is a question that has seriously exercised the minds of locomotive engineers ever since Mr. Webb first placed his engine "Experiment," No. 66, on the L. & N.W. Railway in the year 1882. Prior to that date various experiments had been made on the subject of compounding, but the matter was then for the first time seriously taken in hand, and a compound engine built and put into main line traffic on one of the leading railways in the world. While Mr. Webb has perfected and developed the system in this country, he has had few followers among contemporary engineers. On the Continent, and in other parts of the world, locomotive engineers have, however, realized the advantages to be gained by adopting his principle.

The difficulty in this country of building boilers capable of generating and maintaining sufficient steam for cylinders 18 inches to 20 inches in diameter, when working heavy loads at high speeds, is admitted by every locomotive engineer. Now with the L. & N.W. compound engines the boilers supply steam to one pair of cylinders 15 inches in diameter, the steam being exhausted into the L.P. cylinder or cylinders.

It may be argued that this is not a fair comparison, as the boiler has to supply steam not only to the high but also to the L.P. cylinders. This is no doubt partially true, but only to the extent of the difference in the cut-off between the H.P. cylinder of a compound engine and the cylinder of a simple engine, which latter, as it only uses the steam once, and in a larger cylinder has an earlier cut-off in ordinary working than in the case with a smaller H.P. cylinder with a compound engine; and it must be remembered that this H.P. cylinder is the only one receiving its direct supply of steam from the boiler.

If we can show that a compound engine, the boiler of which only has to feed a pair of 15-inch cylinders, can successfully work the heaviest and fastest trains running in the country, it ought, I think, to be a very strong argument in favour of the application of the compound principle to locomotive engines. This conclusion also seems to point to the fact that any further development required to meet the ever-increasing demands for additional power will have to be on the same lines.

At the Paris Exhibition, the world's hub for the time being, where were collected specimens of every up-to-date improvement in applied science, there were altogether 48 typical passenger and goods engines exhibited. Of these 48 only 14 were not compound engines.

Of the simple engines three were strictly British exhibits—one being a Baldwin goods engine for the Great Northern Railway Company; two were designed by Mr. McIntosh for the Belgian State Railways, and one was built by Messrs. Neilson, of Glasgow, for the Niederlandische Railway. Seven of the 14 were therefore of distinctly British origin.

Plate XI. is an illustration of the latest type of L. & N.W. Railway 4-cylinder compound engine, and this is the engine which was exhibited at the Paris Exhibition. The two H.P. cylinders are 15 inches in diameter by 24 inches stroke, and the steam is exhausted into two inside L.P. cylinders $20\frac{1}{2}'' \times 24''$ stroke.

Among the advantages that may be mentioned in connection with the compounding of locomotives are :—

(1). Increased cylinder power in proportion to the capacity of the boiler.

(2). Economy in consumption of fuel.

(3). The whole of the available power of the expanding steam is used from its entrance to the H.P. cylinder at full pressure to its exit from the L.P. cylinder after being twice expanded.

(4). There is less loss due to condensation. In a simple engine there is a great range in temperament in the walls of the cylinder, because at every half-stroke of the piston steam is admitted at full pressure, and expanded down to atmospheric pressure. Now with the compound engine there is always steam pressure on both sides of the piston in the H.P. cylinder, thus keeping the walls of the cylinder at an even temperature, and the expansion in the L.P. cylinder is more gradual, and there is less variation in temperature.

(5). A more even distribution of the strains on the working parts, and larger bearings for the axles.

There are at present 40 4-cylinder compound engines at work on the L. & N.W. Railway, every one of which is double manned, is in steam 6 days of every week, and has a minimum of 316 miles cut out for its daily work. It may therefore be taken that while bearing the strain of running this enormous mileage day by day, a mileage which, to the best of my knowledge, is in excess of that expected from any other engine in existence, these compound engines are daily without assistance drawing loads of 300 tons, and running at an average speed of 52 miles an hour. The first one, "Diamond Jubilee," was turned out on 20th June, 1897, and the actual mileage run by this engine from when it was first put into traffic until the 31st December, 1900, was 221,510.

The L. & N.W. 8-wheel 3-cylinder compound engine of the "Greater Britain" class has two outside H.P. cylinders 15 inches in diameter, which exhaust into one L.P. cylinder 30 inches in diameter. This was the type immediately preceding the 4-cylinder compound engines now running on the same railway. From October 30th, 1891, when it was first put to work, until 31st December, 1900, "Greater Britain" ran 445,928 miles.

The "Jeanie Deans," a 6-wheel 3-cylinder compound engine, for many years worked the 2 p.m. corridor express from London to Crewe, returning with the up corridor train from Crewe, two of the heaviest trains in Great Britain. The actual mileage run by this engine from the time it was first put to work on 23rd December, 1890, until the 31st December, 1900, was 663,717, roughly speaking, 66,000 miles per annum. I may here give you a few interesting particulars of the mileage and consumption of the compound engines on the L. & N.W. Railway.

Statement showing the Miles run, quantity of Coal consumed, and consumption per Engine Mile by all of the Compound Engines since the date of first turning out to 31st December, 1900.

Number of Engines.	Class.	Total Miles Run.	Coal Consumed.	
			Cwts.	Lbs. Per Mile.
29	7′ Compound, 4-Cylinder.	2,897,916	1,077,217	42·8
10	7′ Compound, 8-Wheel.	3,434,689	1,184,897	39·8
10	7′ Compound, 6-Wheel.	6,180,648	2,084,456	38·0
10	6′ Compound, 8-Wheel.	1,243,518	498,319	46·1
40	6′ Compound, 6-Wheel.	21,277,250	7,444,175	40·4
30	6′ 6″ Compound, 6-Wheel.	16,798,587	5,041,740	34·8
110	4′ 3″ Compound, Coal.	8,259,379	4,048,591	56·1
	Grand Total and Average...	60,091,987	21,379,398	39·8

The figures for the consumption in the right-hand column include 1·2 for lighting up, standing waiting for trains, delays on the road, experimental runs, and all other purposes.

The 8-wheel 6-foot compound engines have been working on the heavy road to Carlisle, hence you will notice that their consumption is heavier than some of the others.

The 4-foot 3-inch compound coal engines are working the heavy coal, etc., trains to which I have already alluded.

(8). The Leading Varieties of Valve Gear.

The scientific and mathematical treatment of this important part of the machinery of a locomotive would form an inexhaustible topic, upon which I do not propose to enter at all, but the essentials of a good valve gear may be here stated.

It is necessary that when employed to work expansively it should admit steam freely to the cylinder during the period of the stroke when the admission is required, the ports being properly uncovered during the whole time of admission, to allow the free passage of the steam to the cylinders, and so prevent wire drawing or gradual reduction of pressure.

The cut-off should take place as quickly as possible, and the expansion should be as long as is consistent with satisfactory working. The release of steam from one side of the piston and the compression of the remainder in the cylinder on the other side should take place at such a point in the stroke as to avoid unnecessary back pressure, and yet provide sufficient resistance to balance the pressure of steam equally at both sides of the piston at the end of the stroke. By this means the momentum of the crank is allowed to overbalance the dead point at the end of the stroke.

The pre-admission should be just sufficient to allow the steam to gain its full pressure on the piston at the commencement of the stroke.

In 1843 the now famous link motion, illustrated in *Fig.* 27, was invented by a man named Howe, and applied by Messrs. Stephenson to the engines they were building. This valve gear solved the problem of working the steam expansively. In all other previous gears the engine could only be worked over at full throw, either travelling forwards or backwards. This, of course, meant that the engine was working at a great disadvantage, and under conditions that precluded the possibility of running at anything like a high speed. The simplicity of its construction and the favourable results that were obtained from Howe's gear at once brought about its almost universal adoption.

Many link and radial motions have since been produced, but Howe's is still the valve gear most extensively used in this country, although it has undergone considerable and continuous improvements in details of construction. The chief feature of this motion is the curved link, having as a radius the length of each eccentric rod.

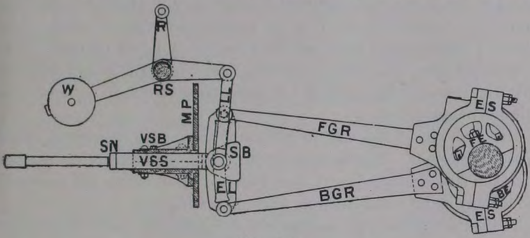


Fig. 27.

The gear is operated by a lever from the foot-plate. When in the forward position the top eccentric rod is brought in direct line with the valve spindle. When in back gear the bottom eccentric is brought in direct line with the valve spindle. When in mid-gear each eccentric revolves without operating the valve spindle. When it is desired to work the steam expansively, the curved link is gradually moved from the full gear position towards mid-gear, the period of cut-off depending on its proximity to the central position.

In 1865 Mr. Allen, Locomotive Superintendent of the Scotch Central Railway at Perth, invented the straight link motion, and *Fig.* 28 shows Allen's motion as applied to the express passenger and other locomotives on the London and N.W. Railway.

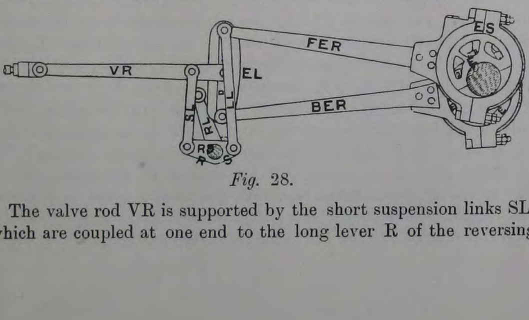


Fig. 28.

The valve rod VR is supported by the short suspension links SL, which are coupled at one end to the long lever R of the reversing shaft. The short lever S is coupled to the long suspension or lifting links. These latter are attached at the other end to the forward eccentric rod FER, and to the top of the expansion link EL, the back gear eccentric rod BER being attached to the other end of the expansion link. EE are the eccentrics of cast iron, the eccentric rods being of Bessemer steel, fastened by screws and riveted to the cast-iron eccentric straps ES. D is the motion block or die block, which slides in the straight link, and is fixed to the end of the VR by means of a pin. RL is the reversing shaft arm (or lever), which is operated from the foot-plate by the reversing screw, or by any other suitable arrangement.

Mr. Webb has fitted the "Joy" valve gear to a number of North Western engines. The arrangement of this gear entirely dispenses with the four eccentrics and rods of the link motion, the necessary movement being obtained from the connecting rod.

The construction of locomotives to meet the demands of increased speed and power has necessitated the employment of larger cylinders, which, owing to the impossibility of altering the distance between the main frames, prevents the valve chest being placed between the cylinders. Now the "Joy" motion allows the valve chest to be placed either above or below them, and also admits of larger bearing surfaces being used for the driving axles.

Among the advantages claimed for this motion are :—

The number of working parts reduced.

The weight of the gearing reduced, and the fact that all the strains are central.

Its operation is said to be more correct and reliable, and gives the nearest approach to a theoretically correct distribution of steam in the cylinder.

Mr. Webb saw the benefits likely to be derived from this motion, and he was one of the first to practically apply it to locomotive engines. He first fitted it to a number of 6-wheel coupled goods engines with 18-inch cylinders with the most satisfactory results, and subsequently to the compound engines built at Crewe. *Fig.* 29 shows the "Joy" valve gear as applied to the low-pressure valve of a 3-cylinder compound engine. Q is the quadrant shaft of cast steel, carried by brackets fixed to the frames; the quadrant guides or facings FF are bolted to the shaft; working in the grooves of the quadrant guides are brass slide blocks SB, carried by the valve lever VL. At the point P the top joint of VL is attached to the connecting link CL at the point A. The connecting link is coupled to the connecting rod of the engine CR at C, and at the other end to the anchor link AL, which is attached at the other end of the bracket B. This attachment is the only fixed point about the motion; the bracket is bolted to the guide plate of the leading radial axle-box. It is interesting to notice that while the point C of the connecting rod (to which the connecting link is attached) describes an oval, the point A of the latter describes a flattened ellipse, thereby imparting an equal motion to the point X. The motion is reversed by the lever R, which is fixed to one end of the quadrant shaft Q. The direction of the engine and the travel of the valve is regulated by the position in which the quadrant shaft is placed.

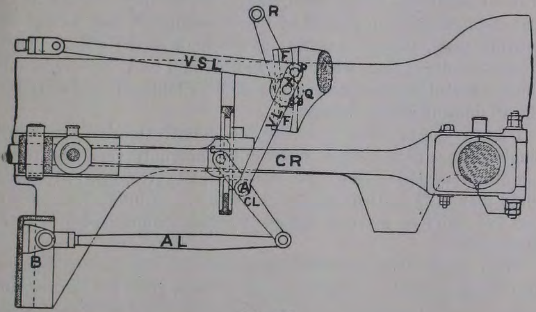


Fig. 29.

Several Locomotive Superintendents are using this valve gear with very good results.

With Mr. Webb's more recent type of 4-cylinder compound engines the valve gear used is "Joy's," which is applied to the low-pressure cylinders in the usual way. The low-pressure valve spindles are prolonged through the front of the valve chests, and each spindle is coupled up to a lever of the first order, which is carried on a pivot securely fixed to the frame, the other end of the lever being connected to the high-pressure valve spindle. Thus the high-pressure valves are worked from the low-pressure motion, through the intervention of the lever, which is so proportioned as to give the required travel to the high-pressure valve.

The lecturer here showed a very beautiful little model illustrating this arrangement, which had been kindly lent by Mr. Webb for the purpose of the lecture. The model clearly shows how the steam is exhaust from the high to the low-pressure cylinders, and also illustrates the piston valve, etc.

(9). The Use of Single or Coupled Driving Wheels.

The question of the relative uses of single and coupled driving wheels has already been alluded to, but I may here again briefly refer to it. It is generally admitted that single engines run with greater ease and freedom than when the wheels are coupled, and that all conditions being equal, they are probably superior in the matter of economy in respect of fuel consumption, also, having less wearing parts, they do not cost so much in shed repairs. There is also no doubt that when the weather and loads are favourable, single-wheeled engines possess greater possibilities in the matter of the attainment of high speeds.

I have known cases in which Mr. Ramsbottom's 7-foot 6-inch single engines have worked successfully, not only very fast trains, but also very heavy ones; but it is now, however, generally recognized that with modern express trains it is absolutely necessary to use two pairs of driving wheels if reliable timekeeping is to be maintained.

With single-wheel engines a good run one day may be followed by a fiasco the next. A slippery rail causes a great loss of time, and indeed single engines are not only often brought to a dead stand by slipping when working heavy trains up an incline, but when working trains of a very moderate weight.

The late Mr. Stirling made himself, and the Great Northern Railway, famous with the 8-foot single engines with outside cylinders $18'' \times 28''$ stroke, which made such splendid runs on the east coast route to Scotland; but Mr. Ivatt, his successor, realizes that single engines are not reliable for very heavy trains, and he is therefore building for the Great Northern Railway powerful engines with 6-foot 6-inch coupled driving wheels; this is a ten-wheeled engine with a large boiler and heating surface. It has cylinders $19'' \times 24''$, and is successfully working very heavy trains at high speeds.

For modern locomotive practice coupled engines with wheels from 6 feet 6 inches to 7 feet in diameter are the generally accepted type for working heavy express passenger trains. Mr. Webb's latest express passenger compound engines have coupled wheels of the latter diameter.

The finest modern-built single-wheel engine is Mr. Johnson's, with 7-foot 9-inch driving wheels, a splendid specimen of which, "The Princess of Wales," was exhibited at the Paris Exhibition.

It has $19\frac{1}{2}'' \times 26''$ cylinders, 7-foot $9\frac{1}{2}$-inch driving wheels, and carries a pressure of 180 lbs. to the square inch. These engines are working trains of 150 to 200 tons at 52 miles an hour.

(10). Regulators.

Regulators are usually made of cast iron or brass, and are placed either in the dome or in the smoke-box adjoining the tube-plate. An early type of regulator, and one still commonly used, is shown in *Fig.* 30. It is an ordinary flat side valve working on a face with ports. The first movement of the regulator opens the small port, and the further opening of the regulator opens the large port, giving the full supply of steam to the cylinders.

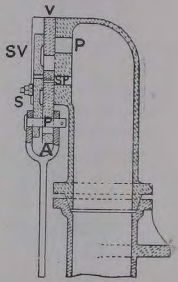


Fig. 30.

The "Ramsbottom" regulator, a modification of which is still in use on the L. & N.W. Railway, is shown in *Fig.* 31.

It consists of a double-seated valve V, fixed vertically in the dome on the end of the steam pipe SP. Attached to this valve is a rod R, which extends downwards and is connected to a small eccentric fixed on the end of a long rod, which extends horizontally through the barrel of the boiler, above the fire-box, and through the stuffing-box on the back plate of the fire-box shell to the regulator handle on the foot-plate.

At the end of this rod, working in a quadrant Q affixed to the boiler-plate, is a handle H, by means of which the driver moves the rod, thus causing the eccentric to revolve in the segment of a circle, and transmit the movement to the regulator valve, opening and shutting it to the extent to which the handle is moved.

When the boiler has no dome, another form of regulator is frequently used. It is placed in the smoke-box, and has two slide valves working horizontally, which are actuated by a rod passing from the regulator handle through the stuffing-box on the fire-box casing.

The majority of regulators are so constructed that the first movement of the handle opens a small port, the object being to prevent steam entering the cylinders too suddenly ; when the piston heat is subjected to a sudden steam pressure, a great strain is placed on the engine, to avoid which steam should be applied very gently in starting an engine.

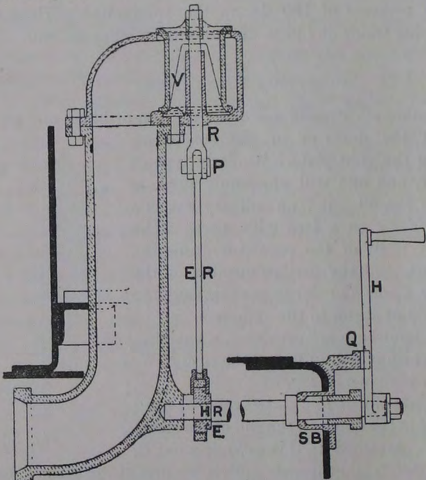


Fig. 31.

Mr. Webb has designed a regulator, which is placed in the smokebox. It takes the steam from the dome, but as the valve controlling the admission of the steam to the cylinders is so much closer to its work, there is less tendency to wire drawing, and a leak in the boiler steam pipe is no detriment.

(11). Blast Pipes.

The diameter of the orifice of the blast pipe is an important matter ; the smaller it is the sharper the blast, and the more powerful its action upon the fire. A strong blast causes an engine to steam well, but when the fire is too fiercely urged, a greater quantity of fuel is burned, besides which the contracted orifice for the outlet of the exhaust steam causes a back pressure in the cylinders, and prevents the engine from working freely. The point to be aimed at is to get the blast pipe as large as possible, consistent with the boiler making steam satisfactorily. There have been many experiments made from time to time in the construction of blast pipes, to determine their effect upon the working of an engine and the consumption of coal. It has been found that the influence exercised by the blast pipe upon the coal bill of a large railway company is very great, a variation of no more than an eighth of an inch in the size of the orifice producing most important results. An engine that has the heating surface and grate area properly proportioned to the size of the boiler and cylinders should, under ordinary circumstances, be capable of making steam with a blast pipe orifice not less than 5 inches in diameter.

The top of the blast pipe is usually about level with, or slightly above, the top row of tubes. It has often been thought that the vacuum in the smoke-box, caused by the blast, has a much stronger effect upon the upper than upon the lower rows of tubes, and therefore that the heating surface proper of the tubes is unequally distributed, the upper rows doing the greater part of the work. But whether from this cause or not, the upper rows do certainly wear away more quickly than the lower tubes, and more frequently fail from this cause.

To obviate this, and distribute the work evenly over the whole of the tube surface, the blast pipe is sometimes made shorter, and the barrel of the chimney extended downwards into the smoke-box, with a bell mouth above the top of the blast pipe. This arrangement has been applied to many L. & N.W. Railway engines with good results.

Mr. Adams, lately of the South Western Railway, brought out a blast pipe, for which he claimed that it acts equally upon all the tubes in the boiler. A transverse section of the smoke of a South Western Railway locomotive, fitted with the Adams vortex blast pipe, is shown (*Fig.* 32). It will be seen that the area at the orifice where the steam is discharged is between the two pipes BP and AP. The central pipe extends downwards, and diverges into a large bell mouth in front of the lower rows of tubes, through which the air is directly drawn. Thus the blast is made to act upon the lower rows of tubes. By this arrangement Mr. Adams claimed a great saving in the fuel consumed by the South Western engines.

Certain experiments to determine the amount of vacuum produced in the smoke-box prove that it averages 2·8 inches of water at the centre of the tube-plate to 15 inches at the base of the chimney.

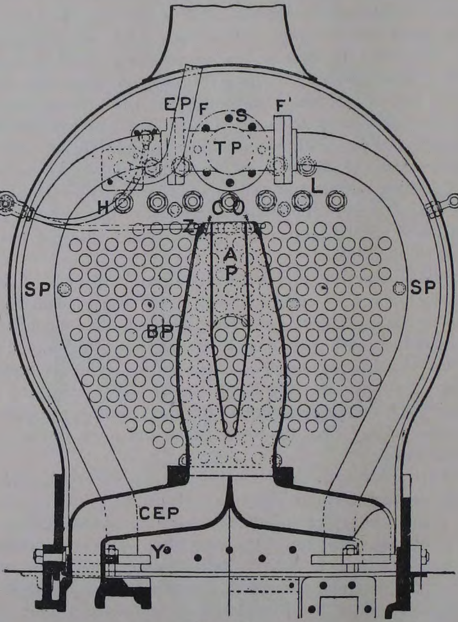


Fig. 32.

Closing the damper has the effect of raising the vacuum, and the greater the blast the greater the vacuum. What is needed is to regulate the damper in such a way that air is admitted below the bars in due proportion to the vacuum in the smoke-box.

Many experiments have been made with a view of improving the form of the blast-pipe. On the Continent, and on some English railways, adjustable blast-pipes are used, but most English engineers, having arrived at a suitable size of blast-pipe for the working of the particular design of engine to which it is fitted, think it better to adopt the standard, because drivers, to save themselves trouble, are apt to run with a smaller size pipe than necessary, thus causing a great waste of fuel.

An ordinary form of blast-pipe, as used by Mr. Drummond on the South Western Railway, is shown on *Fig.* 33.

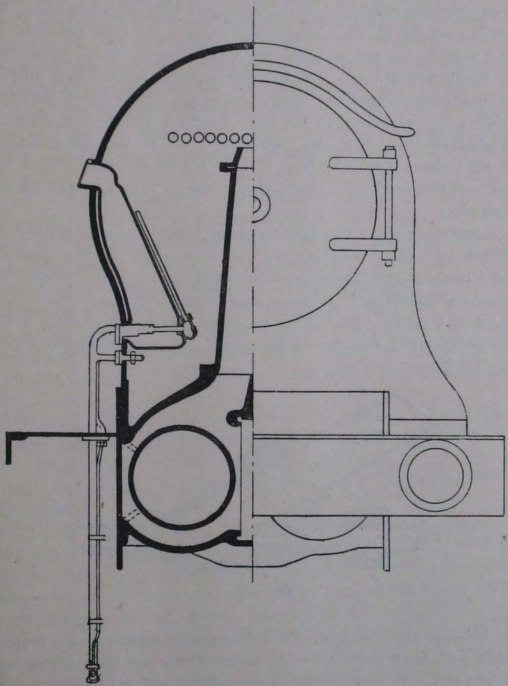


Fig. 33.

(12). Sanding and Steam Blast Arrangements.

The adhesion per ton of load on the driving wheels varies from 200 lbs. when the rails are slippery to 600 lbs. when they are dry. Every engine carries a supply of dry sand, stored in boxes, fitted with outlet valves worked from the foot-plate. When the rails are slippery the sand is allowed to run on them, and thus promote adhesion.

The sanding of rails is a most important function, indeed upon this the successful working of a single engine entirely depends if the rails happen to be in a slippery condition. I may go as far as to say that, had it not been for the great improvements in sanding gear lately brought out, single-wheel engines for working modern passenger trains would have been obsolete. The old-fashioned way of delivering sand on to the rails, perhaps two feet in front of the point of contact of the rail and tread of the wheel, means that the engine may slip very badly before the wheels get the benefit of the sand, if, indeed, they manage to get to the sanded rail at all.

By means of the steam blast sanding apparatus a combined jet of steam and sand is projected on to the rail at the point of contact between the wheels and the rails, and *Fig.* 34 shows Mr. Drummond's application of Gresham's patent sanding gear. You will notice that the sand-boxes are placed in the smoke-box, which is an excellent arrangement, and keeps the sand always dry and ready for use.

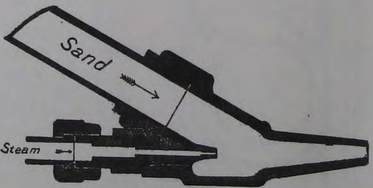


Fig. 34.

It is important that sand-boxes should be placed in such a position that they cannot get water in them. Failures have often been brought about by water congealing the sand, and preventing it from flowing freely.

(13). The Relative Merits of Steam and other Brake Gear.

There are three standard forms of brake fitted to locomotives in this country, viz., the steam brake, the vacuum brake, and the Westinghouse brake. According to the Board of Trade regulations, it is necessary that the brake on the engine should act automatically with the continuous brake on the train, and many of the railway companies using the vacuum or Westinghouse brake have that brake applicable to the wheels of the engine, so that the brake is uniformly applied on all the wheels either of the engine, tender, or train. This practice, no doubt, may have its merits, and those locomotive engineers, whose engines are fitted with the vacuum brake, inform me that it works well on the engine, and gives little trouble.

In cases where the Westinghouse brake is used I believe it is the universal practice to utilize the same brake on the engine as on the train. Of the two brakes, the one most favoured in this country is the automatic vacuum.

As you all know, the difference in principle between the two brakes is that the Westinghouse brake is worked by a pressure of from 75 to 80 lbs. per square inch, acting on a piston connected to the brake gear. With the vacuum brake the air is exhausted from the train-pipe reservoir and cylinder above and below the piston to the extent of 20 inches of vacuum, and the admission of air to the train pipe and lower part of the cylinder automatically cuts off the lower part of the cylinder from the reservoir and upper part of the cylinder upon which the piston is forced up by atmospheric pressure, and actuates the brake blocks.

On several of the leading railways the engines were fitted with steam brakes long before the introduction of continuous brakes. This was the case with the L. & N.W. Railway, Mr. Webb having fitted many of his engines with steam brakes several years before the introduction of the vacuum brake.

In order to comply with the requirements of the Board of Trade, the steam brake had to be made to work automatically with the vacuum brake. This is brought about by means of an ingenious arrangement, in which the valve actuating the steam brake is opened by a small piston, operated by steam from the boiler. This valve is closed by a piston of larger diameter, operated by atmospheric pressure due to the exhaustion of air from the train pipe. The atmospheric pressure acting on the larger valve diameter overcomes the pressure from the boiler, but when the brake is applied the steam pushes out the small piston, and the brake valve is opened until the vacuum is again re-created. The steam brake is undoubtedly the most powerful, and on the whole it is perhaps the best brake that can be fitted to an engine.

The drawing (*Fig.* 35) illustrates Mr. Webb's steam brake, and its action can easily be seen. Steam is admitted to the cylinder below the piston, which it forces upwards, drawing up the arm of the lever which acts on the pull rod of the engine brake, and on the pull rod of the tender brake in the opposite direction, each set of blocks, so to speak, forming the fulcrum of the lever actuated by the pressure of steam.

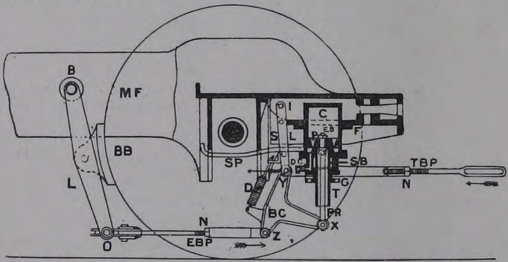


Fig. 35.

(14). Radial Bogies and Flangeless Coupled Wheels.

The radial bogie, or radial axle-box, has a very staunch advocate in Mr. Webb, who has always preferred its use for easing the rigid wheel base of his locomotives, instead of the more generally adopted form of bogie, and the Webb radial axle-box, illustrated in *Fig.* 36, has been successfully used on the L. & N.W. Railway. It possesses the great merit of economy and reduction of working parts, inasmuch as one pair of wheels is used instead of two.

Stretching between the main frames FF, and bolted to them in the manner shown, are the curved guides GG. These guides are rigid with the framework of the engine, and so is the spring frame SF, which is fixed to the centre of the guides. The radial axle-box AA is made of cast iron, and extends across, between, and through the frames, being curved to slide transversely in the guides. Bearings of the ordinary description are fitted at either end of the radial axle-box.

Attached to the axle-box in the manner shown is the rod R, which passes through the spring frame, and is connected to the horizontal spiral springs HS, which are coiled right and left round the rod. When the engine enters a curve the springs are compressed towards one side, and take away any shock which may be transmitted through the wheels from the rails, allowing the box to slide laterally in the guides. When the engine gets on the straight road again, the springs resume their normal position, and keep the wheels central.

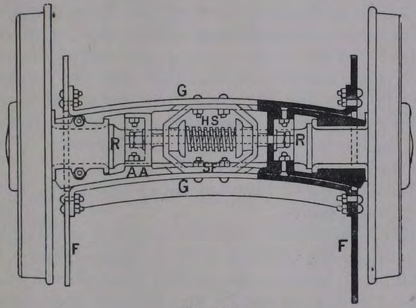


Fig. 36.

With the latest type of 4-cylinder compound engine one pair of wheels is not considered sufficient to carry the leading end, which is therefore mounted on a double radial truck. This truck has four wheels, but instead of being pivoted (as with the ordinary bogie), it is fitted with Mr. Webb's radial axle-box, with central side controlling spring, as shown in the illustration (*Plate* XII.).

Mr. T. W. Worsdell also designed a radial axle-box, which was used on the G.E. and N.E. Railways. This box had stays fitted to the guides, carrying an elliptical check spring of four plates, which acts in the same way as the spiral spring on Mr. Webb's box.

Radial axle-boxes are used on the L. & N.W., the G.E., the N.E., and the L. & S.W. Railways.

With engines that have six or eight wheels coupled, the rigidity of the wheel base can be minimized, and the engine given greater freedom for travelling over curves, by having one pair of intermediate wheels without a flange. This is the case with the L. & N.W. 8-wheel compound coal engines, the pair of wheels immediately in front of the fire-box being so constructed.

(15). Leading and Trailing "Ponies" and the Adams "Bogie."

The "Bissel" or "pony truck" is much used in America for single axles. It consists of two ordinary axle-boxes sliding in guides attached to a short triangular frame, with its apex towards the centre of the engine, and secured by a pin on the centre line at a fixed point. A number of engines have been specially constructed by Mr. Webb for travelling round the sharp curves which abound on the brewery lines in and about Burton-on-Trent. These engines have the trailing end carried on a "pony," sketches of which are shown (*Figs.* 37 and 38).

The G.E. Railway had some engines of the American "Mogul" type fitted with "ponies."

The "Pony" or "Bissel" truck cannot, however, be said to have obtained any place in general English locomotive practice, and the ordinary form of bogie is most generally adopted to obviate a long wheel base. With goods engines that have six wheels coupled, the lateral play in the axle-box and horn-plates and the elasticity of the frames enable the engines to take ordinary curves with safety, but with passenger engines that have to travel at high speeds it is the general practice to have only two pairs of wheels rigid with the main frames, the leading end being carried on a bogie. Tank engines for local passenger services are usually fitted with bogies, sometimes at the leading and sometimes at the trailing end.

An example of the "Adams" bogie, which is a favourite type on English railways, is shown in *Fig.* 39. The bogie frames BF are made of steel, and are fitted with horn-plates in a similar manner to the main frames.

It must be clearly understood that the bogie is an entirely separate carriage, with its own independent wheel base, wheels, axles, axle-boxes, horn-plates, and all other fittings appertaining to a vehicle constructed to run on a line of rails. The only point at which the bogie comes in direct contact with the main construction

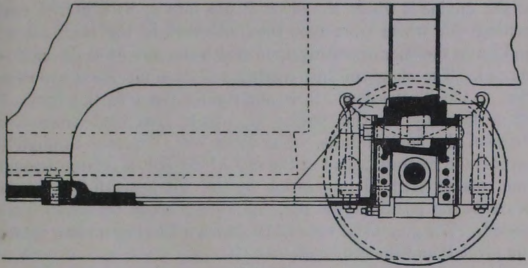


Fig. 37.

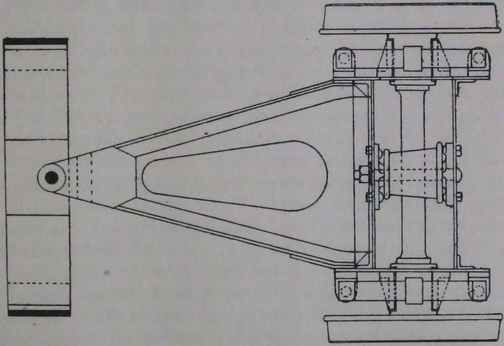


Fig. 38.

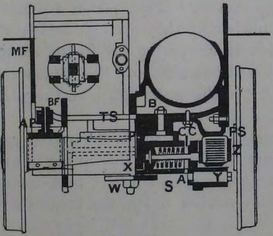


Fig. 39.

of the engine is where the pivot P fits into a hole in the centre casting CC, which rests upon the framework of the bogie carriage, and forms the floor or seating upon which the weight of the engine is carried. The shape of this casting will be understood upon referring to the illustration. It is not rigidly fixed to the bogie, but slides laterally in the guides G, which are fixed transversely between the bogie frames. The large bolt X passes through the pivot P and casting C, and at the end of the bolt is a large wrought-iron washer W, held in position by the nut beneath it; this bolt prevents the possibility of the engine and bogie becoming disconnected. The gun-metal ring GMR forms a bearing surface between the pivot P and the centre casting CC.

The bogie has two separate movements, viz., a circular motion round the pivot P and a lateral traverse between the guides G. The space I, which is $\frac{3}{4}$ inch, represents the distance allowed on either side between the centre casting and the bogie frame for the lateral traverse of the bogie in the guides G. The lateral or transverse movement is controlled by spiral springs at either side of the casting; one of these springs is shown in section at S at one side of the bogie. When the engine enters a curve the spring on the inner side is compressed, and when it passes from a curve on to a straight road the spring resumes its normal position, and the two springs keep the vehicle central. The weight is transmitted to the axle-boxes through the inverted plate spring PS, which is attached by the pin Y to the bogie frame at A. The ends of the springs rest in the stirrup-links LL, which are attached to the spring cradle Z, which transmits the weight to the top of the axle-boxes through the pillars AP, which can be screwed up and down to adjust the weight; the spring cradles Z are at either side of the bogie frames on the outside. Each cradle consists of two wrought-iron plates, between which the spring is fixed. These plates are brought together and welded at the ends, where they are attached to the adjusting pillars AP. The position of the spring PS in the cradle will be best seen in the cross-section at one side, and the attachment of the cradle to the axle-box at AP in the same figure on the other side, and at AP in the longitudinal section.

An advantage claimed for the Webb radial axle-box is that the natural tendency of the box and the spring is to resume its normal position. With a bogie, if one of the side springs is stronger than the other, it has a tendency to run the bogie sideways.

(16). SPRINGS, SPRING HANGERS, AND EQUALIZING LEVERS.

Of the springs generally used to act as a cushion between the dead weight of the engine and the journal of the axle-box upon which it runs there are three kinds, viz. :--

(1). Laminated steel plate springs.
(2). Spiral springs.
(3). Volute springs.

The most usual form of spring is composed of a number of curved steel plates fitting closely to each other, but not fastened together in any way except by the buckle in the centre; in fact, the ordinary locomotive spring is precisely the same as an ordinary carriage spring, except that it is much stronger.

The sketch (*Fig.* 40) shows a very simple form of spring attachment. The spring itself is composed of 19 steel plates, kept in position by the buckle; immediately under this buckle is the spring pillar, which works direct on the top of the axle-box through a guide bracket riveted to the frame. This pillar transmits the weight from the axle-box to the spring. The spring links or hooks are secured to the frame as shown, and the two ends of the spring fit into the hooks. In this form of attachment the spring and axle-box are self-contained, and are in no way connected with the weight upon any of the other axles.

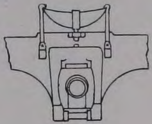


Fig. 40.

The springs must be adjusted with care, otherwise it may happen that some of the journals are carrying a great deal more weight than they should, while others are not carrying proper weight. It is sometimes the practice to use what is called equalizing levers. A North Western compound coal engine gives a very good example of a succession of equalizing levers automatically adjusting the weight between all the wheels on each side of the engine, and the diagram (*Fig.* 41) clearly shows the arrangement.

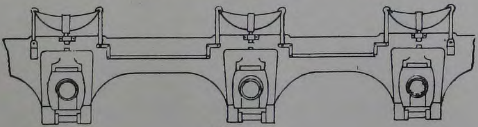


Fig. 41.

Fig. 42 shows the equalizing lever used between the two coupled wheels of a South Western express engine. In this case the springs are below the axle; the manner in which the carrying pin is coupled up to the top of the spring buckle, and in which the self-adjusting lever is coupled up to the ends of the springs, is clearly shown. With these equalizing levers it is necessary that the leverage should be exactly the same at each end, otherwise the weight is not equally distributed. Springs must, of course, be of the very best steel, carefully tempered.

Fig. 43 shows the spiral springs carrying the weight of the trailing

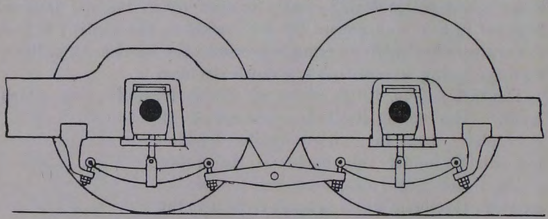


Fig. 42.

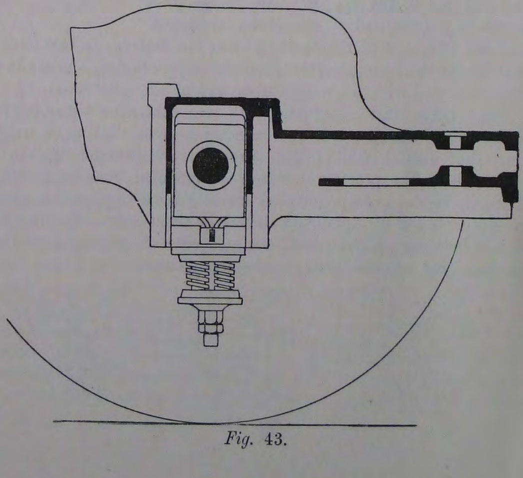


Fig. 43.

end of a L. & N.W. Railway 7-foot compound engine. There are four double springs, making a nest of eight springs connected by the hanger, or link, to the bottom of the axle-box. The weight is carried on the plate at the bottom of the spiral springs, and above the axle-box is the clearance for it to work up and down in the horn blocks.

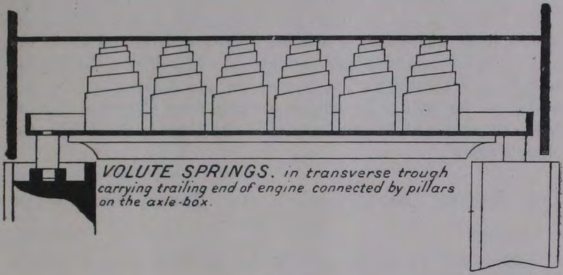


Fig. 44.

Fig. 44 shows the arrangement of Volute springs carrying the trailing end of a goods engine ; the springs are placed in a transverse trough resting on the top of the trailing axle-box, and the engine is lowered on to them, the underpart of the foot-plate casting resting on the top of the springs.

(17). Increased Boiler Capacity due to Steam Train Heating.

I have already enlarged at some length upon the necessity of increased boiler capacity to meet the ever-increasing weight of modern trains.

This is the chief cause of the necessity for making larger boilers, and with steam-heated trains the steam used for this purpose does not in ordinary practice appreciably affect the working of the engine. An additional coach put on to a train of 15 vehicles puts a far greater tax on the boiler than the small amount of steam required for heating the train.

With L. & N.W. Railway steam-heated trains it is not necessary to keep the steam on continuously. Each compartment is provided with a "heater" containing acetate of soda. The driver every now and then turns steam on from the engine, and the latent heat in the soda keeps the compartment warm.

The Midland trains are fitted with steam pipes running the whole length of the train on either side. The steam from the boiler passes down one side, and is led back by the other into the tank. The South Western also use a steam pipe, but the steam is taken from the exhaust, so there is no direct drain upon the boiler.

Far greater is the tax upon the boiler with a train fitted with electric light, where each vehicle has a dynamo driven off one of the axles. In this case additional power required for driving the dynamo is indirectly thrown on the locomotive, and practically acts as a brake on the train. An engine working from Crewe to London burns an additional 14 cwt. of coal if the train is fitted with the electric light.

(18). Tenders, Loads to be Carried, Tanks, and Pick-up Troughs.

Tenders in this country usually run on three pairs of wheels, from 3 feet 6 inches to 4 feet in diameter.

The framework of the tender consists of plates kept in position by cross-stays and the foot-plate at the leading end, which adjoins the foot-plate of the engine. The frames are fitted with horn-blocks, and the weight is carried by springs fixed in the same manner as shown in the illustration (*Fig.* 40) I have given of a North Western coal engine. Lately, in consequence of the increased weight of trains, and the long runs made without stopping, many companies have had to increase the size of their tenders, and tenders mounted on two bogies, with tanks carrying 4,000 gallons of water, have been introduced.

A good example of a tender running on two 4-wheel bogies is the one attached to Mr. McIntosh's express passenger engine running on the Caledonian Railway, and bogie tenders are now in use on various other lines.

Mr. Webb has remarked that he thinks the tendency of some engineers is to build their tenders as if they were very important pieces of machinery, spending a lot of money on them. He himself has always looked on them as water-carts, which should be built and hauled about as economically as possible.

The usual weight of a main-line tender in working order, with its maximum equipment of coal and water, is from 30 to 35 tons.

Mr. Ramsbottom's water pick-up apparatus introduced some 40 years ago renders North Western engines entirely independent of "water-stopping places," and enables this company to run with lighter tenders than other companies not using this system, as there is an appreciable diminution of the weight to be hauled.

The following table shows the different weights in working order of standard tenders on various railways, and it will be noticed that the North Western tenders are much the lightest :—

Railway.	Tank Capacity.	Amount of Coal carried for Weight given in Col. 3.	Weight in Working Order.
	Gallons.	T. C. Q.	T. C. Q.
London, Brighton & South Coast ...	2,250	2 0 0	27 7 0
Midland	3,250	3 10 0	36 1 1
Caledonian	2,850	—	33 9 0
Great Northern	2,800	—	34 18 3
Great Eastern...	2,640	3 0 0	30 12 0
Manchester, Sheffield & Lincoln ...	3,080	4 0 0	35 0 0
North Eastern...	3,940	4 0 0	40 1 0
London, Chatham & Dover	2,600	4 15 0	34 3 0
London & South Western	3,000	—	32 0 0
Great Western	3,000	2 10 0	32 0 0
London & North Western	1,800	4 0 0	25 0 0

An example of the "Ramsbottom" pick-up arrangement is shown in *Fig.* 45. The scoop is lowered by the engineman into the trough, and the speed of the train forces the water into the pipe P, from which it passes into the tank. When the tank is full, the scoop is placed in the "out-of-gear" position, where it is clear of the troughs.

Several other railway companies' engineers are now adopting the water pick-up arrangement. Mr. Ivatt, of the Great Northern, and Mr. Aspinall, of the L. & Y. Railway, are among those who have done so, and on their tenders the scoop is actuated by atmospheric pressure in connection with the vacuum brake.

The L. & N.W. troughs are usually about 500 yards long; they are 17 inches wide, and 6 inches deep. They are laid in the centre of the rails in the four-foot way; the depth of the water is about

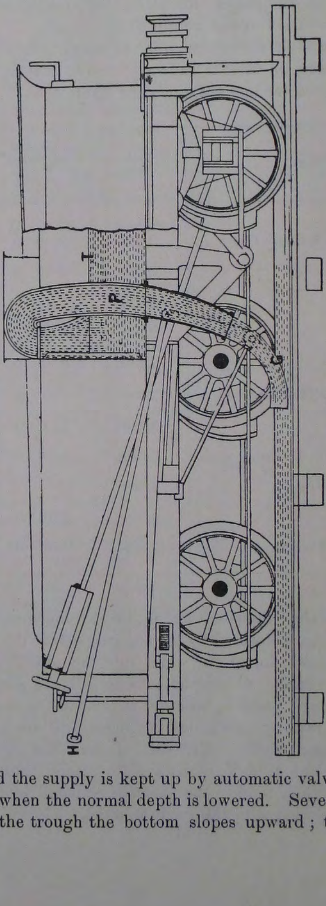


Fig. 45.

4 inches, and the supply is kept up by automatic valves, which refill the troughs when the normal depth is lowered. Seventy yards from each end of the trough the bottom slopes upward; the gradient of

the line 1 in 200 follows this slope, so that practically the bottom plate of the trough is at all times (whether in or out of water) in the same position with regard to the rail level.

(19). THE RELATIVE MERITS OF THE VARIOUS KINDS OF FUEL.

Wherever coal at a reasonable cost is obtainable, it is invariably the fuel of the locomotive, and the best kind for engines in this country is the anthracite, or blind coal, found in South Wales. It is expensive, but it contains at least 10 per cent. more carbon than any other kind of coal. It is the best for making steam, and perhaps not more expensive than cheaper coals in the long run when properly handled.

Coke has practically gone out of use altogether; in fact, a coke fire would not stand the fierce draught imposed on the modern locomotive.

With regard to liquid fuel, this has already been touched upon, but I may further remark that the liquid fuel that gives most satisfactory results is called "Astatki," which is a petroleum refuse obtained from Russia. Its S. gravity is ·8, and the flash point is 240°. The cost, however, of this oil in England is prohibitive, the price being 45s. per ton. The next best fuel is Borneo oil, a natural mineral petroleum with a flash point of 300°. This costs 40s. per ton in bulk in England.

The usual fuel used is gas tar oil, whose S. gravity is 1·1, and the flash point 300°. This oil is obtained from various gasworks in different parts of the country, the cost ranging from 20s. to 25s. per ton. It is roughly estimated that the total inclusive cost of this fuel, including labour, etc., by the time it gets into the tender tank, is 30s. per ton. It is also estimated on some railways that the cost of coal when put on the tender is 20s. per ton.

It is stated that 1 ton of oil in actual practice is equivalent to about 2 tons of coal, therefore 1 ton of liquid fuel at 30s. is equal to 2 tons of coal costing 40s.

In some parts of Europe, particularly in Russia, different kinds of fuel are employed on the same line of railway. For instance, wood may be the best and cheapest fuel on one locality traversed, coal on another, and liquid fuel on another; and a passenger without changing his seat on a long journey may be hauled by engines using three different systems.

Shed Repairs.—There is, perhaps, a general impression among the uninitiated that a new or recently repaired locomotive, when turned out of the works, will run almost without attention until it is time for the engine to be again sent to the works for repairs.

This is quite erroneous. An express passenger engine ultimately intended to work trains running 150 miles or over without stopping, must first run several trips on local trains to enable the lubricator trimmings to be properly adjusted, and the wearing surfaces of the axles, valves, eccentrics, crank, coupling rod pins, and brasses to acquire that glassy smoothness which is only obtained by work, but which it is necessary to obtain before the engine can be said to be in perfect working order, and fit to run 200 miles without stopping, as is now frequently done, without a warm bearing or pin.

It is true that for the first few months after coming from the works an engine will require very little attention in the matter of repairs, provided the boiler is regularly washed, and no dirt allowed to accumulate in the water spaces.

But after two or three months hard running an engine begins to show signs of decreased efficiency, and it is necessary to overhaul the valves (especially in the case of piston valves), the pistons, and the slide blocks. It will often be found that piston and piston valve rings have lost their spring, thus allowing the steam to blow through, and with ordinary slide valves the faces may be wearing unevenly, in which case they must be taken out and faced up on the planing machine.

It will also be found that the pistons will require their rings changing, and that the slide blocks will require a liner inserting between the crosshead and blocks to take up the knock, or the blocks re-metalled. After three or four months' work, according to the quality of the water of the locality in which the running shed is situated, the boiler will begin to give trouble on account of leaking tubes, caused by the accumulation of scale in the barrel, preventing the proper circulation of water round the tubes, the ends of which become burnt off.

A number of tubes, sometimes as many as 30 or 40, will now require taking out to remove this scale, and at the same time the safety valve has to be taken off to clean the scale from the top of the fire-box. The rapidity with which scale will accumulate on the top of the fire-box is astonishing, and in some localities, if an engine were allowed to go six months without the top being cleaned, it would probably be found that the whole space between the top of the fire-box and the roofing stays was a mass of solid scale.

All accumulation of scale detracts from the steaming capabilities of the boiler, and it is also most important that the water spaces round the fire-box, as well as the top, should be kept perfectly free from dirt. Fast dirt in the water spaces causes damage to the fire-box through overheating of the copper plates and stay-bolts, causing the former to bulge and crack, and the heads of the latter to be burnt off. Occasionally it is found necessary to remove stays for the purpose of removing dirt, although a good deal can be got down by hammering the stays after the steam and water have been blown out of the boiler, and the latter thoroughly dried.

The sketch (*Fig.* 46) shows what may happen if dirt in the water spaces is neglected. First, a cone of scale forms round the stay, then the copper plate wastes on the furnace side, because the water is not touching it on the other side. As the dirt accumulates the plates crack and bulge, and further neglect will result in the breakage of the stays; then the whole structure becomes dangerous. We had a very forcible object-lesson on the necessity of attention to fire-box plates and stays in the Government Inspector's report lately issued upon the recent boiler explosion on the Great Eastern Railway. It is a very interesting document, and I recommend its perusal to all those interested in the subject of locomotive maintenance.

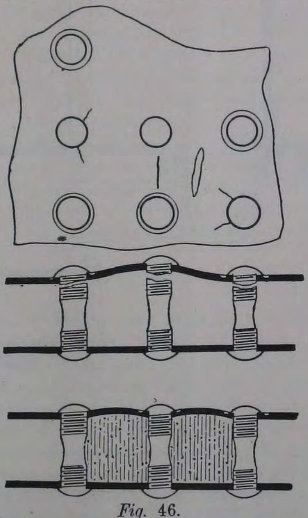


Fig. 46.

The shed boilersmith will, when a boiler-plate begins to crack in the stay-hole, drill and tap the plate through the crack, and after removing the stay insert a specially made rivet, which he draws into position through one of the wash-out plug holes at the bottom of the fire-box by means of a piece of string. The rivet is then screwed off and the head riveted over, thus filling up the crack.

At sheds where the water is bad it is necessary to remove tubes for the purpose of cleaning the boiler about every four months, and the fusible plugs are changed every three months.

If an engine steams badly owing to leaking tubes, stays, or other defects, some drivers are in the habit of contracting the orifice of the blast-pipe, and sharpen the draught of the fire by using an instrument called a "jemmy." "Jemmies" are of various shapes, and the one which finds favour with drivers at the present time is shown in *Fig.* 47. The sharpened end is hooked over the top of the blast-pipe, and a wagon coupling hung on the bottom hook to prevent it being blown out by the exhaust.

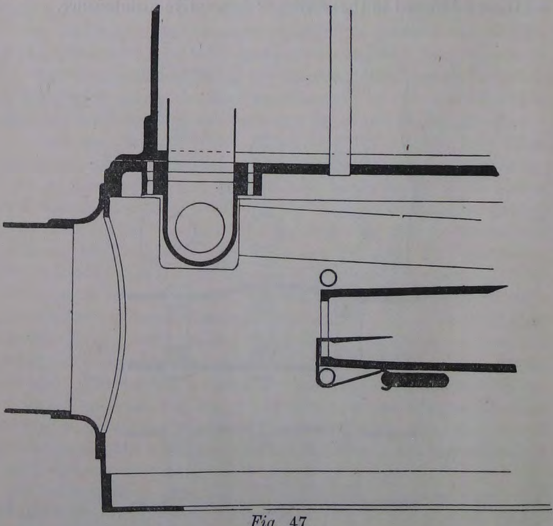


Fig. 47.

"Jemmies" are wrong, and should be suppressed when discovered. They cause back pressure in the cylinders, and the sharper blast is very detrimental to the boiler tubes.

A good driver should take steps to ascertain the cause of his engine steaming badly, and not resort to illicit means to get steam; but I fear that to a lazy fireman a "jemmy" is a friend, even when his engine is all right.

As regards the mileage an engine is capable of running between general works repairs, should no special defect occur, such as a cracked tube-plate or flawed axle, eighty thousand or even a hundred thousand miles is sometimes the figure attained, and some excellent mileage has been got out of the compound passenger engines stationed at Rugby.

As a general rule, however, it is found advisable to send an engine to the works when it has run seventy thousand to eighty thousand miles, because, although the engine may not be necessarily "run down," the wheel tyres will have worn hollow, and the flanges deep. This is a matter that requires careful watching; an engine working well, and giving little trouble, is liable to have this point overlooked. *Fig.* 48 shows the proper section of a tyre, and a tyre allowed to become so badly worn that the flanges do not clear the locking bars of the points. By the time the tyres are so worn as to require re-turning, the axle-boxes will require lining up where they fit in the horn-blocks. Their bearings will want re-fitting on the journals, and the tubes will require taking out.

The engine may then be said to require light general repairs, but when it is desirable to keep the engine out of the shops some time longer these repairs can be, and are, frequently done at the larger running sheds, where there is a wheel lathe, facilities for removing the wheels, and other machinery necessary for the execution of such work.

An engine requiring heavy boiler repairs should always be sent to the works.

I may now say a few words regarding the ordinary repairs done to engines between their trips. When a driver has hooked off his train, after completing his day's run, he brings his engine into the locomotive yard, and places it over a pit between the rails. Before leaving it is his duty to thoroughly examine every part of it, and assure himself that there is no undue play in any of the working parts, no nuts or pins missing, and that all the axles and other moving parts of the machinery have run perfectly cold.

He then proceeds to the shed and inserts details of the repairs required in a book provided for the purpose, leaving his engine to have the fire dropped, and be coaled for the next trip.

The fire is dropped by inserting a long hook through the fire-hole door, and lifting one end of the fire-bars out of the rack, the fire then dropping into the ash-pan, whence it is raked out into the pit with a long rake.

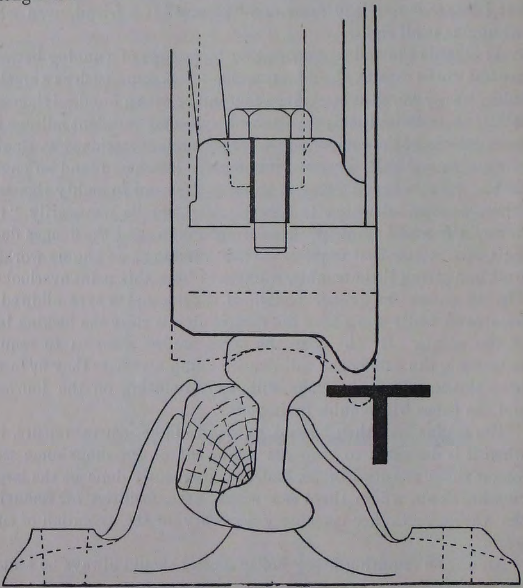


Fig. 48.

In warm weather, and especially when a very hot day succeeds a spell of cooler weather, an epidemic of hot axles usually breaks out, owing to the greater fluidity of the lubricant at the increased temperature, which causes it to run away through the syphons too quickly, and empty the oil boxes.

If an axle has been very hot, the wheels have to be taken out for the brasses to be refitted. In bad cases the white metal in the axle-box bearing will have been melted, and the journal of the axle cut. In bad cases of overheating, journals have been known to twist completely in two.

In order to remove the wheels the engine is brought into the shed, and run over a drop table, the construction of which may be seen in the diagram (*Fig.* 49).

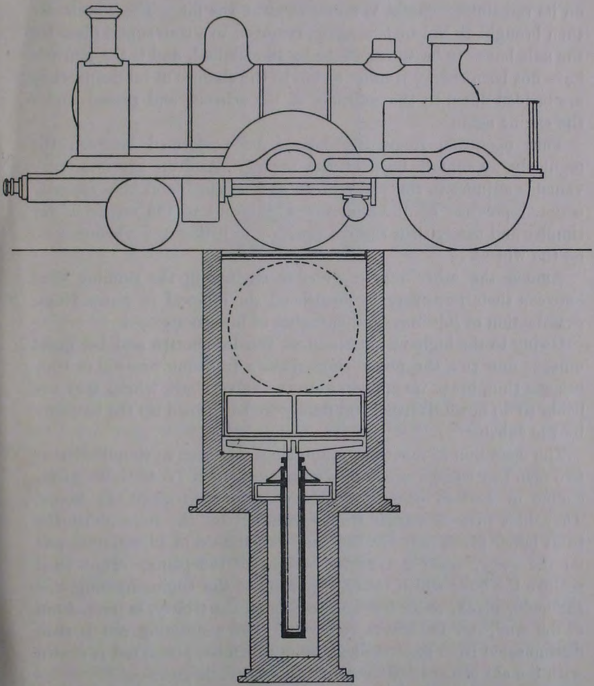


Fig. 49.

The engine is placed, with the pair of wheels which it is desired to remove, upon this table, which at the time is set and locked in its highest position. The horn-plate keeps, which secure the axle-boxes in the horn-plates, and all attachments having been removed, the bolts securing the table are shot back, and the table lowered by the hydraulic cylinder, taking the wheels and axle-boxes with it.

On the table reaching the bottom of the pit another set of rails come automatically in position underneath the engine, which, resting on its remaining wheels, is taken clear of the pit. The wheels are then brought to the surface again, removed to a convenient place for the axle-boxes to be taken off to be re-metalled, and if the journals have not been cut by friction owing to the absence of lubricant, they are bedded down to the journals of the wheels, and placed under the engine again.

This operation frequently has to be performed between the regularly appointed trips of the engine. A drop lift is a very valuable adjunct to the plant of an engine shed, and this recently adopted practice of dropping the wheels out of the engine is far simpler and better than the old practice of lifting the whole engine off the wheels.

Among the other repairs done to engines in the running shed between their trips may be mentioned the renewal of piston rings, examination of injectors, and changing of broken springs.

Owing to the high piston speed of the locomotive and the great mileage now run, the piston rings require frequent renewal or they become thin, break up and get into the valve chest, where they are liable to do much damage, and finally to be thrown up the chimney by the exhaust.

The operation of renewing piston rings has been so simplified that two men can change a set of piston rings of a L. & N.W. goods engine or 4-wheel coupled passenger engine in about 1½ hours. They first place a special trolley running on the rails under the front buffer plank (see *Fig.* 50), and with the aid of adjusting screws on the same, make it take the weight of the plank. They then remove the bolts which fasten the plank to the engine framing, and the buffer plank, being free and resting on the trolley, is pushed out of the way, and the covers removed. The connecting rod is then disconnected from the cross-head from which the piston rod is drawn with the aid of a specially constructed hydraulic jack.

The piston heads and rods can then be removed, the old rings removed, new ones substituted, and the engine coupled up again.

Broken springs are also a prevalent locomotive malady. It is important that all the springs of an engine should be of approximately equal strength, in order that the weight on the different axles may be properly distributed. The weights on the axles of engines not fitted with compensating arrangements can be altered by means of adjusting screws, which increase or decrease the camber of the springs. When an engine is fitted with a new spring it is run upon the tables of a special weighing machine, which registers the weight on each wheel, and the weights are adjusted while the engine stands on the table.

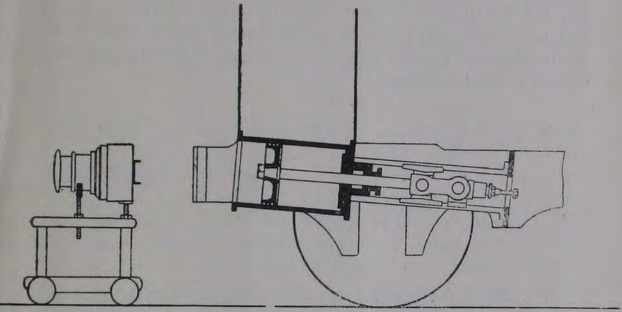


Fig. 50.

Amongst other shed work may be mentioned the making of cylinder and valve cover joints, safety valves, and dome cover joints.

Cylinder cover joints often develop a blow owing to the carelessness of the drivers in allowing water to accumulate in the cylinders when the engine is standing. In the case of the back covers blowing, the re-making of the joint is a job of considerable magnitude, involving the taking down of the slide bars, cross-head, piston, etc.

Grinding in equilibrium regulator valves, injector steam valves, closing of eccentric straps, big end connecting rod brasses, and making whistle stand joints, a job which necessitates removal of cab, etc., steam-pipe joints in boilers and smoke-boxes, and other jobs too numerous to mention, form other items of shed repairs.

Besides being examined by the driver after his daily trip, all engines are periodically examined in the shed by an examiner, who looks out for such special defects as cracks in axles, coupling rods, and motion links, defective springs, etc., which a driver would probably not notice. Cracks in the eccentric rods and smaller parts of an engine can usually be put right if discovered before they have become far developed by heating the rod at the crack, and inserting a wedge, but if this is not done at once the crack is liable to extend ; in the same way a crack may develop in a sheet of glass or lamp globe.

Coupling rods frequently develop flaws on their under side, usually about their middle, owing to the whip of the rod when the engine is running at high speed. Flaws sometimes develop in forged steel crank axles, the cracks appearing usually at the points shown in the sketch (*Fig.* 51), and they are liable to extend until they become a source of danger.

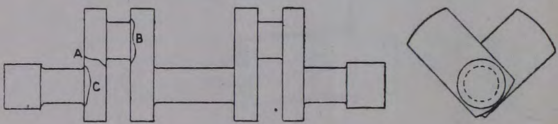


Fig. 51.

Mr. Ivatt, in 1891, read a very interesting paper on this question, in which he proved that this development may not be brought about by actual strain in ordinary working, but by vibration. If the crack could be seen directly it commenced, and cut right out, the axle, although weakened in sectional area, would last much longer than if the crack had been allowed to go on. Believing that the vibration alone would cause a crack in a steel axle to extend as rapidly as it would under ordinary working, he had an axle of the kind shown in *Fig.* 51 slung up, and subjected to blows at the end from a weight swinging to and fro on a pendulum at the rate of 3·6 blows per minute.

These blows were continuous, and were worked off a cam attached to a stationary engine.

The original crack, in consequence of the discovery of which the axle was taken out of the engine, was at the point A. The crack at B began to show about three or four months after the experiment commenced, and after the axle had received some 645,000 blows. The crack at C was discovered later some two months before the axle finally dropped off at the crack B, so that although there had been a bad flaw at A, the axle did not finally break, but developed flaws at B and C when doing no work at all, but when subjected to the vibration described.

When a crack in the web is discovered, and has not gone too far, the axle may be made fit to work by shrinking on iron hoops, as shown in *Fig.* 52.

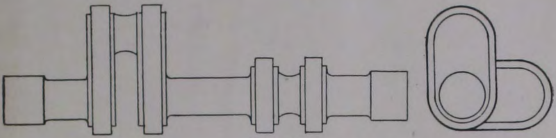


Fig. 52.

On the L. & N.W. Railway built-up cranks are largely in use. These are cheaper to manufacture than forged cranks, and are not so liable to develop flaws.

I might say much on the work of the engine driver, his duties and responsibilities, but I have already tried your patience too far. These responsibilities have vastly augmented since the time when the early trains on the Liverpool and Manchester Railway weighed about 75 tons, and jogged along at the comfortable speed of 15 miles an hour. How different are the conditions existing to-day, when, with all the complex machinery of the modern locomotive to look after, he has to work trains weighing three to four hundred tons mile after mile at 60 miles an hour, and has in all weathers, by day or by night, to pick out his own particular signals from the gigantic array that face him as he approaches the many complicated junctions and busy depôts which abound on our English railways.

PAPER V.

DESTRUCTORS AND STEAM PRODUCTION.

By William H. Maxwell, Esq., Assoc. M. Inst. C.E.

When I had the honour of being invited to deliver a lecture to you on the subject of "Destructors and Steam Production for Electric Lighting and Other Purposes," I felt, after some little consideration, that in order to bring the subject within the time allotted me it would be more useful to deal with the question in a general way than to attempt to enter into the full details of any special branch, and I trust I shall be able to bring together some of the principal features of the subject in such a manner as may be of service to you.

In all large centres of population there appears to be at least two questions of yearly increasing magnitude; one is the removal and sanitary disposal of the town's refuse, and the other the growing need for motive power for the economical performance of various municipal services, such as lighting, traction, pumping, and other work. To put it shortly, the question of "Destructors and Steam Production" is the utilization of the former for the economical production of the latter. This may be termed the commercial aspect of the subject, which, from its important bearing upon public funds, has of recent years called for the most careful consideration of those responsible for its satisfactory solution.

At the present day the importance of the elements of sanitary science are sufficiently well recognized to render it unnecessary to dwell upon the need for the removal and efficient disposal of all refuse matter created by a population, affecting most vitally as it does the health and well-being of the public.

Various means for the disposal of a town's refuse are adopted in different districts, according as best suits local circumstances. These methods it is found necessary to modify from time to time as the town developes and the population increases. The old methods, such, for example, as the tipping of refuse upon hollows or waste land, become exhausted ; the cartage or barging of the material to sites at considerable distances from the town boundaries becomes increasingly expensive, besides being at best an insanitary mode of disposal.

In dealing with this material on the destructor system, its mere disposal, however, is not by any means the only consideration. For a number of years past scientific experts, municipal engineers, and public authorities have been directing their attention to the utilization of refuse as fuel for steam production, and such progress in this direction has been made of late that in many towns its calorific value is now being utilized daily in operating machinery of various kinds and powers. There is, however, a proper degree of caution to be observed in the application of refuse fuel to steam raising purposes, and this is only obtained by actual experience in its use.

At the time when the value of town refuse as a low class fuel was first recognized, the idea was disseminated that the refuse of a given population was of itself sufficient to develop the necessary steam power for supplying that population with the electric light. The economic importance of a combined destructor and electric undertaking of this character naturally presented a somewhat fascinating stimulus to public authorities, and possibly has had much to do with the recent development, both of the adoption of the principle of dealing with refuse by fire, and also of lighting towns by electricity. However true this aspect of the question may be as the statement of a theoretical scientific fact, experience, so far, has not shown it to be a basis upon which engineers may with safety venture to calculate, although, as I will endeavour to show a little later, under certain conditions of equalized load a well-designed destructor station can be made to perform an important commercial service to an electric or other power-using undertaking.

The primary function of the destructor, however, is, of course, the sanitary disposal of the refuse, whilst every advantage should be taken of the heat generated, in order to form a set-off against the cost of the refuse disposal account.

In the case of the town which I have the honour to serve as Borough Engineer over 9,000 tons of refuse were collected last year, and I have recently had occasion to consider the question of the treatment of this by a destructor plant, and the utilization of the calorific value of the same. I found that the annual cost of running a station suitable for dealing with this quantity of material would be about £1,190, inclusive of interest and repayment of capital, working expenses, and removal of clinkers.

The remaining question was to what extent can these heavy annual charges be reduced, or wiped out altogether, by using fully the thermal energy generated in the process of burning the refuse. From actual experience it has been ascertained that the calorific value of unscreened house refuse varies from 1 to 2 lbs. of water evaporated per pound of refuse burned, the exact proportion depending on the quality and condition of the material to be dealt with. Taking the evaporative power of coal at 10 lbs. of water per pound of coal, this gives for domestic house refuse a value of from $\frac{1}{10}$th to $\frac{1}{5}$th that of coal. Now, if we put this at the lower value of $\frac{1}{10}$th, a year's refuse of 9,000 tons, if so burnt as to fully utilize the heat generated, would represent 900 tons of coal, which, at 25s. per ton, equals £1,125, which is a very fair set-off against the working expenses (£1,190) of the station.

Or, we may put this in another form. Calculating on the same basis of 1 lb. of water evaporated per pound of refuse, the destructor would be capable of generating 2,302 lbs. of steam per hour, which, on the basis of 20 lbs. of steam per I.H.P. per hour, is equal to 115 I.H.P. continuously throughout the year, day and night. About 14 per cent. of this power would be consumed in driving the forced draught to the furnaces, thus leaving about 100 H.P. available for external work. It will thus be apparent that the turning of the heat energy to some useful work is an important factor in the design of a destructor plant and the economical working of such a station.

It will be well now to turn our attention for a moment to consider the nature and approximate constituents of the refuse material we are discussing, as its value for fuel purposes naturally varies according to its composition. This is dependent very largely upon the locality, whether situated in a coal-producing area or not, also upon the habits and industries of the population. Varying proportions of cinders and unburned fuel are also to be observed in the refuse from different parts of the same town, and it is sometimes noticeable that those householders who burn their own coal are generally less wasteful than a higher class population, who are at the mercy of servants. The degree of moisture in the refuse is affected largely by the system of collection and the mode of storage on the householders' premises awaiting collection. In the summer the heat value of the refuse is less, owing to the smaller proportion of cinders and ashes and the increased percentage of vegetable matter and garden refuse which wrongfully finds its way into the dustbin.

One hundred tons of London ashbin refuse have been found to contain approximately the following proportions:—

Constituents of Refuse.	Tons per hundred.
Cinders and ashes	63·6
Fine dust	19·6
Rags, waste paper, straw, cardboard, etc.	7·9
Vegetable and animal refuse	4·7
Crockery, broken glass, bottles, etc.	1·9
Hardware, tins, old iron, etc.	1·0
Coal and coke	·8
Bones	·5
Total	100·0

A cubic yard of house refuse weighs from 12 to 15 cwts., and upon this is based the amount of storage room required on the "tipping platform" of the destructor. London yields about 4 to 5 cwts. of refuse per head per annum, or about $1\frac{1}{4}$ million tons yearly; the quantity in the north of England averages about 8 cwts. per person per annum.

The modern refuse destructor and its various accessories is by no means the product of one inventive mind, but is the outcome of many years experience and failures in the burning of refuse. Furnaces of a sort were in use in London and the north of England over 40 years ago, and it was somewhere about the year 1876 when the well-known "Fryer" destructor was erected at Manchester. This furnace contained features which have been copied, modified, and improved upon by many later patentees and manufacturers.

Time will not permit, however, of our tracing the history of the evolution of the modern destructor in detail, and we will now pass on to consider briefly the principal types of furnaces of the present day. I will refer to Fryer's improved type, Warner's "Perfectus," Horsfall's, Beaman & Deas', Meldrum's "Simplex," and Baker's destructor.

Fryer's Improved Type (*Plate* I.).

A destructor built upon this system consists of a block of cells or furnaces, usually arranged "back to back" in pairs. The top of the cells is formed level, as will be seen from the diagram, so as to provide accommodation in the shape of a "tipping platform" for the storage of refuse and for the feeding of the cells. Each furnace, or cell, measures internally about $9' \times 5'$ in width, and is covered by a fire-brick arch 3 feet 6 inches above the grates. The furnace floor slopes, it will be observed, at an inclination of about 1 in 3, the rearmost portion of which next the fire-bridge for a width of 4 feet forms a fire-brick hearth or dead plate, the remaining portion consisting of fire-bars with an area of 25 square feet, the fire-brick or drying-hearth being about 20 square feet in area. A large main flue, which acts also as a dust-catcher, is placed under the drying-hearths.

This furnace has the outlets for the products of combustion at the back of the cells near the refuse feed-opening, an arrangement which is undesirable, inasmuch as whilst a charge is burning on the firegrate, the next charge remains on the dead hearth near the outlet flue. Here it undergoes a partial decomposition, and gives off offensive vapours, which may pass away direct to the main flue and to the chimney without being first exposed to a sufficiently high temperature to render them innocuous, thus giving rise to nuisance. With the view of meeting these difficulties, a secondary furnace, known as a "cremator," was formerly introduced into the main flue, and in which coke breeze was burned, in order to thus obtain a higher temperature to cremate the fumes given off by the cell itself. This arrangement in many cases proved very costly, and so led to its disuse.

A Fryer furnace ordinarily deals with from 4 to 6 tons of refuse per cell per 24 hours, and is known as a low temperature destructor.

Warner's Destructor (*Plate* II.).

Though similar to Fryer's furnace in general arrangement, Warner's "Perfectus" destructor possesses points of detail differing from that type. For example, it provides special charging hoppers, dampers in the flue, dust catching arrangements, rocking fire-bars, and a modified position of the outlets for the escape of the products of combustion.

The grate area is 25 square feet, with an inclined fire-brick drying hearth in the rear. The patent rocking bars are actuated by a lever for the removal of the clinker. The cast-iron furnace doors are of the sliding type, and have hollow backs to allow of the attachment of baffled plates.

The outlet openings for the gases are fitted with flap dampers, operated by horizontal spindles, having levers at the front of the furnace, and by means of which each cell can be operated independently of the others.

This furnace is not of the high temperature type, and forced draught is not ordinarily applied. The patentees, however, have an improved arrangement for increasing the steam-raising capabilities of the destructor by the placing of a tubular boiler close up to the cells and introducing forced draught.

At Royton the Warner destructor consumes about 5 tons of refuse per cell per 24 hours, whilst the maximum usually dealt with by this type reaches about 8 tons.

The Horsfall Destructor (*Plate* III.).

The first complete plant erected on the Horsfall system was that installed at Oldham, where, at the present time, something like 330 I.H.P. per hour is being utilized from the destructor plant for various municipal uses. A model of the Horsfall destructor is on the table for your inspection.

The Horsfall furnace is a high temperature destructor which has been on the market for many years past, and has been subjected to various improvements from time to time.

As will be seen, it retains the back-to-back sloping grate arrangement possessed by the types already described, with the important alteration of the position of the outlet flue and the introduction of forced draught. There are at present some 350 cells of this type of furnace in operation in this country and abroad. This system may be seen in use at Bradford, Leeds, Edinburgh, St. Luke's, Fulham, Hamburg, Brussels, and many other places.

The special features of this destructor are the patent front exhaust flues situated in the furnace crown over the clinkering door and at the opposite end from the charging hole, thus ensuring better cremation of the foul gases. Cast-iron side boxes, having renewable plates next the furnace, are provided to protect the brickwork from the erosive action of clinker, and heat the blast before it enters the fire. Over the main flue is a desiccating hearth of large dimensions, and improved sectional grate bars of cast iron run the full length of the grate, with no joints to catch firing tools. The furnace mouths have lift-up clinkering doors with balance weights, which provide an opening the full width of the furnace. The destructors are fed at one end and clinkered at the other, thus reducing the possibility of unburnt refuse going away with the clinkers.

One of the best examples of the Horsfall standard back-to-back type of furnace is the twelve-cell destructor at Hammerton Street, Bradford, of which six cells started working in September, 1897, and the other six in January, 1898.

During a fortnight's test at this destructor, completed on July 7th, 1900, the following average working results were obtained :—

Total refuse burned per cell per 24 hours ...	9.3 tons.
,, ,, ,, ,, sq. ft. of grate area...	34 lbs.
Cost of labour per ton burned	9d.
Total weight of water evaporated per hour...	7,744 lbs.
,, I.H.P. per hour (at 20 lbs. of steam per I.H.P.)	387·2
Total I.H.P. per cell continuously	32·2
I.H.P. hours per ton burned	83·2
Water evaporated per lb. of refuse burned...	·743
Percentage of residuals	29·36
Steam pressure maintained	60 lbs.
Temperature of gases in main flue	1,800° Fah.
Average in pressure (water gauge)	$\frac{7}{8}$ in.

The Norwich Corporation have put down a two-cell plant at the New Mills sewage pumping station, specially for the purpose of raising steam, tenders having been invited upon the basis of specifying the quantity of steam to be raised instead of specifying the number of cells required. This destructor is of the single row type, but is fed from the top. The boiler is of the Babcock and Wilcox type of 735 square feet of heating, and is placed as close as possible to the pair of cells, and communicates directly with the chimney. The steam is supplied for driving air compressors for Shone's patent sewage lifting machinery. The working pressure is 120 lbs. per square inch. The furnaces burn 15 tons of refuse per cell per 24 hours, and evaporate over 2,400 lbs. of water per hour from cold river feed to the pressure above named.

A combined Horsfall destructor and electric station has recently been put down at Fulham, and was formally opened in February of this year.

Beaman and Deas' Destructor (*Plates* IV. & V.).

Another modern high temperature furnace is the Beaman & Deas' type, the patents for which, however, have now been taken over by Messrs. Meldrum Bros., of Manchester. The illustration is a plan and cross section of this destructor as installed at Leyton. It may also be seen in operation at Canterbury, Wimbledon, Rotherhithe, Colne, Llandudno, and other places. The special features of this type are the flat grate area of 25 square feet, fed from a hearth inclined at an angle of about 52 degrees, a high temperature combustion chamber, placed between the cell proper and main flue, and the use of a secondary air supply introduced through small ducts and discharged to meet the fumes, etc., as they pass over the fire-bridge; a powerful air blast also delivers into a sealed ashpit. A Babcock & Wilcox boiler is shown in close connection with the main flue for the utilization of the heat generated. The cells, it will be noted, are worked in pairs; when one cell is being re-charged with fresh refuse and its temperature is low, the adjoining cell is at full red heat, and so the temperature of the combustion chamber is more uniformly maintained, and the escape of noxious vapours minimized during the re-charging process.

This destructor will consume about 20 tons of house refuse per cell per 24 hours, or about 75 lbs. of refuse per square foot of grate area per hour, each cell being of 25 square feet area. At Llandudno the amount burned is 71·7 lbs. per square foot per hour. At Leyton a battery of 8 cells deals with the house refuse and filter press sewage sludge from a population of over 100,000 persons. This material is burned in nearly equal proportions at the rate of about 17 tons per cell per 24 hours, and steam power is developed thereby equal to from 35 to 40 I.H.P. per cell per hour at an average steam pressure in boilers of 105 lbs. The cost in labour of burning the mixture is 1s. 7d. per ton. The block plan of this plant now exhibited shows the general arrangement of the destructor.

At Canterbury is installed a combined destructor and electric undertaking on this principle, and in a test conducted by the City Surveyor the evaporation from the destructor was at the rate of 4,717 lbs. of water per hour, *i.e.*, taking 20 lbs. of steam per I.H.P. per hour, the plant is capable of yielding 235 I.H.P. per hour under the conditions of the test, and, with the exception of the steam used in pumping and heating the feed water and working the forced draught and lift, this power is available for external work in the electric undertaking.

MELDRUM'S DESTRUCTOR (*Plate* VI.).

The Meldrum "Simplex" destructor is a modern high temperature furnace, which has proved capable of giving good steam-raising results, and is in operation at Rochdale, Darwen, Hereford, Nelson, and many other towns. The general design of the destructor differs widely from any of the foregoing, and is practically one long cell, fed and clinkered at four or five different furnace mouths, according to the number of grates installed, and, by this means, an approximately uniform temperature is maintained throughout. The grate areas are arranged side by side, and are separated only by dead plates. The ashpit, however, is divided into sections corresponding to the grate areas in order to localize the forced draught. Each section is closed air-tight by a cast-iron plate, and there is an air-tight door for the removal of fine ash.

The destructor is fitted with the Meldrum steam jet blowers, and in which only about 14 to 15 per cent. of the total steam generated is used. It will be instructive to note that at Shoreditch the electrically driven air fans also absorb 14 per cent. of the current produced.

The diagrams show this destructor as constructed at Darwen, where it is run in conjunction with an electric lighting and power station. The heated gases, after passing over the fire-bridge common to all the grates, enter a combustion and settling chamber, the temperature of which is about 1,800° to 2,000° Fah. The heat in the flue gases, after leaving the boiler, is again made use of in heating the air supplied to the furnaces. This is done by means of an air-heater, or continuous regenerator, placed just beyond the boiler, before the gases escape away into the main flue leading to the chimney shaft. The air, thus heated, is delivered to the furnaces through Meldrum "blowers" at a temperature of about 300° Fah.

A destructor of the Meldrum regenerative type has recently been put down at Nelson, and yields excellent steam-raising results. The grate area is 100 square feet, and is fed through four firing doors. About 7,500 tons of refuse have to be dealt with annually. At a test of one month's duration the average water evaporated per hour was 4,490 lbs., equivalent to about 225 I.H.P. per hour, of which, in this case also, about 15 per cent. was used in the forced draught. The water evaporated per lb. of refuse burned was 1·546 lbs., and the average steam pressure 120 lbs. The calorific value of Nelson refuse is proved to be from $\frac{1}{7}$th to $\frac{1}{5}$th that of coal, and for steam-raising purposes is worth about 2s. 6d. per ton in that town. The cost of burning the refuse, and including capital charges, amounts to 2s. 5d. per ton.

There are many other plants on this system giving very satisfac-factory steam-raising results in different parts of the country, but time will not permit of detailed reference thereto.

Baker's Destructor (*Plate* VII.).

Baker's destructor is of recent design, the general features of which are shown in the diagram which illustrates the latest model of this type. It will be seen that the drying hearth is built over the furnace proper, and the moisture and gases from the drying refuse are withdrawn from this chamber by the forced-draught fan and driven with the air supply into the ashpit and through the fire-grate. The standard size of grate area adopted is 42 square feet.

A Baker's destructor has been constructed at Phœnix Wharf, Lambeth, and an improved design is being installed at Buenos Ayres.

There are several other types of refuse furnaces in the market, but the foregoing makes are sufficient to explain the general principles common to all, and to illustrate the best working results obtainable in the burning of refuse and the utilization of the heat generated.

General Remarks on the Design of Destructor Plants.

Having briefly noticed the principal destructors in use I will now make a few general observations as to their construction and working. It would be unwise to lay down a hard and fast rule as to any particular type of plant or system of refuse destruction as being absolutely the best and suitable to all conditions and localities, but the following points may be taken as generally applicable :—

1. A destructor must be simple in construction and without mechanical complications upon which stokers may lay the blame of bad results. It must be easily worked without stoppages.

2. Must be strong, able to withstand variations of temperature, and not be too liable to get out of order or difficult to repair. It should also be capable of being easily understood by firemen and stokers of average intelligence, so that the continuous working of the plant may not be disorganized by change of workmen.

3. The temperature maintained in the cells should be sufficient to reduce the refuse to an entirely innocuous clinker, and all fumes or gases should pass through an adjoining red-hot cell or chamber, whose temperature is maintained by the ordinary working of the destructor itself to a degree sufficient to exclude the possibility of escape of any unconsumed gases, vapours, or particles. From 1,500 to 2,000° is a suitable temperature.

4. The furnaces should be so designed as to admit of their clinkering and re-charging being quickly and economically performed, with the minimum of labour and discomfort to the stokers, the furnace doors also being open for the minimum length of time.

5. Forced draught must be provided to assist the chimney draught either by means of fans or steam jet giving a pressure in the ashpit of from 1 inch to 2 inches by water-gauge.

6. Boilers for steam raising should not be placed immediately over the furnace, so as to present a cooling surface to the cell and so reduce its temperature, as nuisances may result from the incomplete combustion of the refuse fumes.

7. Ample boiler capacity or hot water storage feed tanks should be included in the design where steam power is desired, and as much of the heat as possible should be extracted from the fumes or gases before allowing them to escape into the chimney shaft.

Accessory Plant.

We shall not be able to fully consider the details of the various accessory and labour saving plant which is now usually installed at modern destructor stations. These include overhead railways for removal of clinker, clinker utilization plant, hydraulic presses for flag making, patent centrifugal dust-catchers, solder extraction furnaces, hydraulic or electric lifts, charging tank apparatus, travelling cranes, boilers, economizers, superheaters, and various other plant, all of which find their places in the up-to-date station.

In the following table I will give you the particulars of the steam power which was being derived from the destructors at the towns named during the periods of the various tests from which the data are taken :—

Town.	Make of Furnace.	Water Evaporated per hour.	Approximate I.H.P. Developed per hour at 20 lbs. Steam.	Water Evaporated per 1 lb. of Refuse (Actual).	Average Steam Pressure.
		lbs.		lbs.	lbs.
Canterbury ...	Beaman & Deas ...	4,717	235	1·40	132
Bradford ...	Horsfall	7,744	387	·743	60
Darwen	Meldrum	6,129	306	1·39	195
Hereford ...	Meldrum	2,980	149	1·51	70·92
Rochdale ...	Meldrum	7,290	364	1·47	113
Shoreditch ...	Manlove	14,445	722	·96	—
St. Helens ...	Beaman & Deas ...	6,575	328	1·27	132
Nelson	Meldrum	4,490	224	1·54	120

In working a station in conjunction with an electric lighting plant it is found almost impossible to fully utilize the entire thermal energy given out by a destructor without some means for the storage of energy. This arises from the fact that a destructor usually works continuously at a uniform rate, whilst the demand for electric energy is very irregular, the period during which the demand for current exceeds the mean not exceeding about 6 hours out of the 24, whilst for a portion of the time the demand may not exceed $\frac{1}{20}$th of the maximum demand. This difficulty is greatly reduced in districts where a day load exists, as in the running of motors, tramways, lifts, etc., whereby the load on the generating plant is more nearly equalized throughout the 24 hours, and, as the employment of electric energy for these services is rapidly becoming general, little difficulty need be anticipated in the successful running of combined destructor and electric plants where these conditions prevail.

Residue from Destructors.

On the table are samples of furnace clinker, concrete paving slabs, and bricks, kindly forwarded me by the superintendent of the Bradford destructors.

The residuum clinker from destructors amounts to from 25 to 30 per cent. of the bulk dealt with, and its economical disposal or utilization is a matter of considerable importance. At Bradford this material is converted by hydraulic pressure into paving slabs, with an admixture of granite chippings and cement, and is sold at 3s. 2d. per square yard. Concrete bricks are also similarly made, and, when consisting of 10 per cent. mixture of hydraulic lime and clinker, and properly seasoned, are said to be nearly 50 per cent. stronger than the ordinary building brick used in Bradford, and can be made at a cost of 14s. per 1,000. A small machine turning out 8,000 bricks per day will utilize about 20 tons of clinkers.

PAPER VI.

"FIREPROOF" CONSTRUCTION.

BY EDWIN O. SACHS, ESQ.,
Chairman, British Fire Prevention Committee.

THE subject for the meeting this evening is "Fireproof Construction," and I assume that my treatment of the subject is to have special bearing on the requirements of the army, and the Royal Engineers in particular.

The subject is, of course, a very wide one, but I am not quite sure if the title given me for the paper I am presenting is exactly a happy one, seeing that the word "Fireproof," as commonly used, is, unfortunately, to a great extent a misnomer, for, in the few instances where it can be used with veracity, it generally refers to work which is outside the practical politics of ordinary construction, that is to say, it relates to a class of structure that may be termed absolutely exceptional. What is really required for practical purposes is "fire-resisting" or "fire-retarding" construction, in which case the resistance offered is intended to meet the effects of a severe outbreak of fire for a certain time, during which period it is anticipated that the local fire-combating forces will have obtained a mastery of the conflagration.

And here I should take the opportunity of reminding you that the question of "fire-retarding" or "fire-resisting" construction, or, in fact, any form of construction utilized with a view of minimizing the risk and effect of fire, only forms one of many that have to be dealt with, when treating with so vast a subject as fire-protection generally, which comprises the two distinct chapters of fire prevention and fire-combating. For "fire-resisting" construction is only one section of that large chapter entitled "Fire Prevention," inasmuch as the question of fire prevention alone comprises not only all matter relating to construction and equipment, but the many matters relating to the safeguards obtained by the careful regulation of work from day to day, by inspection, supervision, and watching. Fire-resisting construction is no doubt a great preventative against the outbreak and extent of fire, but the effect of the best of construction is materially marred, if the preventive measures adopted do not also comprise the commonsense safeguards which are, unfortunately, so often neglected, namely, the careful attention of a building, its order, cleanliness, and the like. To exaggerate, it is almost useless to build a fine joiner's workshop unless attention has been paid to the question of removing the shavings, to the use of glue-pots, gas-burners, oil and varnish storage and other matters relating to the general conduct of the business in that shop. It is too much to ask ordinary, practical, everyday, fire-resisting construction to take upon it the whole brunt of preventing an outbreak of fire, or limiting its spread. Construction does, of course, often prevent an outbreak from many sources, but it is mainly intended to limit the extent of the outbreak, in other words, to be a preventative in extent rather than a preventative in cause.

I suppose that, for the purposes of this meeting, questions of principle are not so much what you wish me to deal with as some of the questions of practice, and yet it is useless to be actively associated with the practice of "fireproof construction" unless the purpose of this construction, the requirements of the case, and the limitations of purse and purpose are quite clearly comprehended. Perhaps, in mentioning the word limitation, I might go so far as to say that assuming Woolwich Arsenal had the best and most elaborately-equipped fire-brigades, an excellent system of water-supply, a full service of fire-alarms, and everything else that goes towards rapid combating of a fire, then if these assumptions were true, the degree of fire-resisting construction to be practised at the Arsenal need not be of so high a standard as if the Arsenal had to rely, as it does to a great extent, on outside help, which can only arrive after considerable time. In other words, the capital expenditure on the new buildings of the Woolwich Arsenal, which are intended to be fire-resisting, could be materially less if there were absolute reliance on immediate and effective fire-combating. Or, to put it still more pointedly, namely, that under the present circumstances it would be well if every building were constructed fire-resisting as far as possible, seeing that there must be delay in the arrival and application of the fire-combating forces, whilst if the fire-combating forces were of a very high standard and in closest proximity to the possible scene of a fire, a mere slow combustion, or a mere fire-retarding building of low standard and but small resistance, would suffice.

If, on the other hand, to take an instance, a private arsenal, such as Messrs. Krupp's, the great gunmaker, does not really require the question of fire-resisting construction to be seriously dealt with, it is because Messrs. Krupp have probably the most brilliantly-organized fire-alarm, fire-brigade, and general watch-service that is to be found in the world, including those of any of the American institutions.

Now, as it happens that nearly all our great military arsenals—and our naval arsenals too—are not necessarily equipped with the most modern fire-combative means, not to say lack supervision and inspection from the fire point of view, you may take it as a general rule that for army purposes the best of fire-resisting construction should be universally adopted, both in Great Britain and in our dependencies.

But there is another reason, quite irrespective of the only partial protection afforded by supervision and fire-combative forces, that necessitates considerable attention being given to fire-resisting construction for army purposes, and that is, that in very many cases the buildings of the army are in localities where they may be exposed to an enemy's attack, and even to a siege, and where the question of fire-combating, *i.e.*, fire-brigade work, when it actually occurs during war-time, would be an exceedingly difficult one, for, although I believe we have, to a greater or less extent, according to districts, some service of fire-pickets in time of peace which is also utilized in time of war, there has never been in this country a really comprehensive scheme to consider what should be done in respect to fire-protection, when some day our big fortified places, such as Dover, Portsmouth, or Plymouth, are under the fire of an enemy's guns, a fire which, if I am rightly informed, nowadays means the carrying of high explosives liable to set buildings alight in a very rapid manner. We, of course, know of the navy how in the Chinese-Japanese War and in the American-Spanish War this question of fire on board ship played a very important *rôle* with the modern explosive, and how our Admiralty have been giving considerable thought to the question of reducing the amount of inflammable material on board ship, and have installed systems of water-mains, etc., on board ship in a far more elaborate manner than was ever anticipated before these wars taught us the lessons in question. There appear to have been numerous small fires at Ladysmith and at Mafeking; but the really high modern explosive does not seem to have been used to any considerable extent by the Boers when firing at these places, so that recent military experience on the fire question appears to be small indeed. But let us just think what an attack on Dover would mean, a town not particularly well built, having at its most conspicuous positions barracks, stores, and the like, and let us imagine the effect of high explosives in a town of this kind under siege, and of what enormous importance it is in such cases that the effect of a fire in a storehouse, at the barracks, or in the workshops should be limited by the best construction, and that the extinguishing of the fire in individual risks should be facilitated by the fact that the structional parts are of the best construction. I think you will agree that if we take War Office buildings of this description, as erected during the last twenty years, you will only find material improvement from the fire point of view during the last few years, but the very tangible lessons we have already had in times of peace, such as the big barrack-fires of recent years, should bear fruit.

The subject is one that has to a great extent been neglected, in fact, has only in recent years had any really serious attention, and I only trust that the coming generation of army men will remember that, with the ever-increasing effect of explosives, the question of limiting the risk in military buildings is a question of growing importance.

And now, gentlemen, in which direction, you will ask me, should you look for improvement in the construction of a military building?

First and foremost, do *not* look for it solely in the actual building materials, but look for it in your plans. It is the separation and grouping of the buildings, it is the division of the buildings into individual risks, that will give you safety from the spread of fire. The careful grouping of the buildings so that fire does not spread all too easily, the careful separation of the buildings where they adjoin one another, and the separation of individual large buildings into vertical risks of smaller extent are the first points to observe in military construction. Everything else comes afterwards.

It is useless to think that because you have Mr. Jones' or Mr. Smith's patent floor, or Mr. A.'s or Mr. B.'s patent partition, you are going to really solve the question of the reduction of risk in the large areas you often have to deal with. The sooner the grouping and the separation of buildings are appreciated as important factors in military fire protection, the better for their safety.

Look upon the question of separation of your storehouses in the same way as the most go-ahead of warehouse-builders look at them in a city like Hamburg or Bremen. Look upon them as far as the separation of individual risks are concerned in the same light as the large mill-builders of the United States. Do not think of them merely in the light of ordinary, everyday structures. There is art in grouping with a view of fire resistance. There is art in separation with a view of fire resistance. You have to consider questions of wind-proximity, of other risks, and even facilities of water-supply when you are grouping your buildings, and when you are separating them try and bring every individual risk to as small a superficial area as you possibly can.

In the County of London the ordinary cubical contents of a building is now limited since 1894 to 250,000 cubic feet, and only by obtaining special permission from the L.C.C. can one make these cubical contents 450,000 cubic feet. This limitation is correct, and it is one of those points which military builders should observe, although not restricted by any local Act.

Given good grouping and good separation, think next of the actual plan of the individual risk you have in mind. Do not arrange your building or individual risk in such a manner that the floors are connected by open lift-shafts, by some internal staircase, or by some other arrangement which brings about the immediate destruction of a building, should a fire occur at one point. Good construction retards a fire, good construction may even withstand very hot fires, if its area is limited, but, given a bad plan with open lift-shafts, with internal staircases, with trap doors and the like, the chances are ten to one the building will go down, no matter what the construction may be.

Given your good grouping, your good separation, and the last-named good plan, you must then, and only then, turn to the question of construction, and here in the first place comes the question of the floor and the support of the floor.

It is useless to provide some excellent system of flooring supported upon exposed iron girders, may be supported by cast-iron columns. The support of the floor, both vertical and horizontal, must be protected in every possible way, for these are the tenderest spots in the construction should a fire break out. How often I have seen the best of floors with the best partitions standing on some light metal support, and I have only known too well that the mere catching alight of an ordinary room full of furniture would probably give sufficient heat to slightly deflect the vertical support and bring down the whole building. I have seen buildings erected by the most scientific of engineers, who, thinking, no doubt, that the engineering side of their work should be conspicuous, have had their light lattice-work supports beautifully painted blue, with little dark spots on the rivets, and this beautiful piece of construction has supported the most expensive of floors. Hence, to summarize, as far as actual construction goes, after the grouping, separation, and planning have been decided on, remember that it is the main vertical support and the main horizontal support that have to be protected, and that these must be given precedence even to any question of actual flooring. It is illogical to make a floor better than its supports.

After the floor comes the partition, and this is mainly a question of splitting up large definite risks into a number of minor indefinite risks.

The individual room and the individual workshop have often to be separated by partitions, and naturally it is of importance that these light partitions should do their duty. It is, however, useless to expect the same amount of resistance from a light partition as is required from a floor. The ratio of the resistance of a floor as compared to that of a light partition should be as 2 to 1. Where a floor in a fire-resisting building, with its supports, is designed to withstand a strong fire for two hours, it would suffice if a minor separation by a light partition would stand an hour.

After the floors and partitions come all those minor points, highly important in themselves, but minor as compared with the great questions of walls and partitions. There are the openings in walls, floors, and partitions to be protected; in other words, the doors, trap-doors, windows, and skylights have to be considered. I need hardly say that the double door in the party-wall plays a most important part among the accessories of fire-resisting construction, and, in specifying them, it should always be remembered that these doors should be easy to close, as otherwise they will always be open and never closed when wanted.

What applies to the heavy iron door and double iron work in the party-walls applies, in a minor degree, to the various hard wood doors and armoured doors in partitions and the like ; and I cannot but too strongly impress upon you the value, even in the most ordinary construction, of a well-made hard wood door, well fitted, and well hung.

As far as windows are concerned, we have to consider not only the possibility of the spread of fire through a window on a lower floor out and up into a window of the floor above, but we have also to think of the spread of fire from one building to an adjoining building, and we must remember that a fire will, more particularly when occurring in a certain class of inflammable goods and facilitated by a strong wind, easily drive 30 or 40 feet of actual flame, quite irrespective of any question of sparks or heat.

The various forms of fire-resisting glazing, and also of the protection of windows by shutters and by fire-blinds, hence deserve your attention.

Lastly, in connection with this we must remember that the trap-door should be treated just like a party-wall door, and the skylight just like the window in a dangerous position.

Those three chapters—floors, partitions, and accessories—cover the principal points to be raised in ordinary practical construction. I will not touch upon but merely indicate that construction-designers should think of the equipment of a building with the view of fire-combating by the installation of sprinklers, hydrants, etc. ; but these matters do not really belong to construction proper, and it is construction proper to which we wish to give attention to-night.

And now for some examples of what different forms of construction and different materials will do when attacked by fire, as it may be of interest to you to know what the results of the most recent investigations in this direction have shown us.

In selecting the examples I, of course, can only here refer to the results of actual independent tests duly executed under proper supervision, and not to the many haphazard commercial tests which take place for purposes of demonstration and advertisement, mostly under somewhat peculiar circumstances.

The investigations which serve as a basis for the examples I am giving you are those of the British Fire Prevention Committee, a society of engineers, architects, and others interested in fire-protection, who have a testing station in Bayswater, where tests and investigations are not only carried out with materials and systems put before the committee by inventors and merchants, but also with the more common forms of construction practised in the Metropolis, which are not subject to any municipal license or specific right.

As to the actual way in which the tests are carried out, I believe this is known to you, and I need not dilate on the actual practical detail of a test beyond stating the fact that every effort is made to obtain the actual conditions of a fire, and if anything, rather severer conditions, and that all records and the like are taken in a most comprehensive manner.

I have the pleasure this evening of having the kind co-operation of the Master of the Worshipful Company of Tylers and Bricklayers, Mr. Ellis Marsland, who is the chairman of the testing station sub-committee, and who has generously lent me a number of slides which have been prepared from photographs taken from actual tests, and it is these photographs which I will now have the honour of presenting to you.*

I should, of course, have liked to give you examples of all the more important systems of construction and materials that one comes across in actual practice, whether they be used for floors, partitions, ceilings, or accessories, but the time-limit prevents my attempting this to-night. I am, hence, going to limit myself strictly to two departments of construction, namely, floor-construction and door-construction; but these two departments will give you an idea of not only what has been done, but of what an enormous scope there is in this field of investigation and the collection of reliable data.

Starting with experimental tests with floors, the first to which I shall direct your notice is an ordinary floor with deal joists and floor, the soffit of which was protected by plaster, termed asbestic plaster (*Fig.* 1, *Plate* I.). This was applied on ordinary wood lathing, and the thickness of the plaster after completion was about $1\frac{1}{8}$ inches. On drying, this reduced itself to about $\frac{7}{8}$ of an inch, and during the process of drying, cracks developed over the surface. Before the test these were stopped, and the appearance of the soffit, as you now see it, is due to this cause.

* An elaborate series of lantern slides were shown. The illustrations presented here (reproduced from these slides) are from the *Journal of the Society of Architects.*

The testee decided to have a 45 minutes' test, 15 minutes at a temperature not exceeding 500°, then a gradually increasing temperature for the remaining 30 minutes up to 1,500°. The summary of effect is as follows:—No perceptible difference in the ceiling was observed during the progress of the test. The application of water caused no injury to the ceiling. No portion of the ceiling fell, either during or after the test. When examined after the test, cracks had developed over the surface and some of the wood laths were charred, but none had ignited. This test may be considered satisfactory, as the object was attained, viz., to render the floor fire resisting for 45 minutes, which would, under ordinary circumstances, have allowed the occupants in the rooms over to have escaped.

The next floor was of ordinary joists and boarding, but the protecting material to the soffit was slag wool $1\frac{3}{4}$ inches thick (*Fig.* 2, *Plate* I.). This was secured with screws to the soffit of the joists, and a $\frac{7}{8}$-inch matchboarded ceiling was placed under the slag wool. The testee decided to have a test of one hour's duration, with a gradually increasing temperature to 1,800°.

The summary of effect was as follows:—At the conclusion of the test the flooring on top was, so far as could be seen, uninjured, and when the joists were examined, they were sound. The boarded ceiling had, of course, disappeared, but the slag wool remained in position, and had protected the floor. A good deal of heat was retained in the floor, and at one point, where water had not been applied, a small hole was burnt in the flooring some three hours after the test was concluded. This test may also be considered satisfactory, as it retarded the spread of the fire for at least an hour.

We now come to a floor of simple baulks of timber laid side by side, any spaces between being filled with fire-clay grout, the soffit not being protected in any way; the depth of the baulks was 9 inches (*Fig.* 3, *Plate* I.). This was the committee's own test, and it was decided to have an 80 minutes' test with a gradual temperature up to 2,000° F.

The result was that the under surface of the wood beams was charred to an average depth of about 2 inches, but beyond this no damage was done. The test clearly demonstrates what fire resistance there is in such a floor, but it must be carefully borne in mind that no space must be left between the timbers that is unfilled by the grouting, otherwise the fire draws up through and spreads to the next floor.

Another floor shown in *Fig.* 4, *Plate* I., comprises 7 by 2 joists, $\frac{7}{8}$-inch flooring, coke breeze and Portland cement concrete, 5 to 1, filled in between the joists to a depth of 5 inches, and kept in position by 1 by $\frac{3}{4}$-inch fillets nailed to the sides of joists 2 inches from the bottom; a ceiling was nailed on to the soffit formed of $\frac{5}{8}$-inch matchboarding. The time decided for the test was 75 minutes, commencing with a temperature of 500°, and increasing to not more than 2,300°. The floor also was to be loaded with 100 lbs. per square foot distributed. The result of the test was that the floor collapsed in 82 minutes.

The summary of effect is as follows:—In 15 minutes all the boarding to the soffit was consumed; in 54 minutes flame came through the floor between the last joist and the wall.

I should like to point out here what an important part the 1 by $\frac{3}{4}$ fillets played in the construction of the floor in preventing the fire getting through, and it was in consequence of the fillets being omitted on the outer side of the two end joists that the flame came through there, and these two joists were the most damaged.

The concrete between the two east joists fell out in 74 minutes; meanwhile the fire had been gradually eating its way up the other joists some 2 to $2\frac{1}{2}$ inches; they being thus reduced from 7 inches to 5 inches or $4\frac{1}{2}$ inches, could no longer sustain the weight of 100 lbs. per square foot, and the floor and load collapsed in 82 minutes. The floor boards are not burnt, but only blackened by the smoke.

A test of a somewhat similar character to the one just mentioned was instituted to discover the fire-resisting qualities of different descriptions of concrete.

The floor (*Fig.* 5, *Plate* I.) was constructed of 3 by 9 deal joists spaced $16\frac{1}{2}$ inches centre to centre, which gave seven bays. Two of these bays were filled in to the full depth of the joists with coke breeze and cement concrete, 6 to 1. The next two bays were filled in with pit ballast and cement concrete, 6 to 1, and the remaining three bays were filled in with concrete composed of pit ballast three parts, coke breeze three parts, and cement one part. The concrete was supported between the joists by $1\frac{1}{2}$-inch by $\frac{7}{8}$-inch fillets. The soffit of the ceiling was plastered, render, float and set, and $\frac{7}{8}$-inch flooring was nailed on top of the joists to complete the floor.

It was decided to test this floor for $1\frac{1}{2}$ hours to a gradually increased temperature up to 2,500° F., and then to apply a stream of water for 4 minutes.

The summary of the test was that after a few minutes the plaster of the ceiling began to fall, whereupon the lower edges of the joists became ignited and gradually burned upwards.

At the end of the period the whole soffit of the floor was seen to be fully incandescent, particularly that in the coke breeze and cement bays. On the application of water the soffit of the ballast and cement concrete and the ballast, breeze, and cement concrete immediately disintegrated, and about 3 inches in depth of it fell. The coke breeze and cement alone were not affected. The floor remained in position at the conclusion of the test, but appeared seriously weakened and deflected.

It is to be regretted that it did not remain in position sufficiently long to be photographed, but after a test of this description, a good deal of latent heat remains in the materials, and the joists being of combustible material continued to smoulder, and the result was the collapse of the floor 5 hours after the test. On examining the remains the joists were found to be burnt through from 2 to 6 inches deep, and tapering to a further depth at the ends. The boarding was found to be slightly charred on the underside and at the joists, but otherwise was sound.

It could not be said the fire had passed through the floor, although smoke came through, and I think the floor may be considered a fire-stop, although the weight of the concrete caused the collapse of the floor, and might constitute a source of danger on that account.

The behaviour of the ballast concrete shows it an undesirable material for fire resistance, while coke breeze has many advantages.

The experience gained by the last two tests paved the way to the next; both the previous tests had shown that if the soffit of the joists had had further protection, the fire resistance of the floor would have been greater; consequently a test was arranged as shown, with an expanded metal ceiling suspended 2 inches below the bottom of the 7 by 2 wooden joists (*Fig.* 6, *Plate* I.), which formed a centering for the concrete as well as a key for the plaster. The construction will need no further description beyond that the concrete below the joists was of dry ashes and Portland cement, and that between the joists was composed of coke breeze three parts, dry ashes two parts, and Portland cement one part.

The test was arranged for 2 hours, which is the longest time yet given for a floor formed partly of combustible material. The temperature was not to exceed 2,300° F., and to be followed by a stream of water for 2 minutes. The floor also was to be loaded with 100 lbs. per foot, distributed.

The summary of effect is very short. In 28 minutes plaster began to fall in patches from the ceiling, and continued to fall at intervals till the end of the test, when water was applied and further plaster was washed away. No other effect of the fire was noticeable, and at the conclusion of the test the floor was intact and carried its load. This floor did not subsequently collapse, although it smouldered all night. It was found that all the joists had been more or less damaged by the fire smouldering all night; portions of them were quite consumed, leaving the matrix only in the concrete. The least damaged of the nine joists forming the floor was the centre one, which was intact but for a piece about 12 inches long and 5 inches deep, which was consumed about 15 inches distant from the south end.

The next test, which was submitted by a manufacturer, deals with a floor supported by 9 by 3 wooden joists with a terra-cotta wired lath suspended ceiling, and an air space between the ceiling and the concrete filling between the joists (*Fig.* 7, *Plate* I.). The lathing was spread over the top of the joists and depressed in the centre to the shape of an inverted arch; upon this the concrete was placed to a depth of 7 inches in the centre, which, when levelled, brought it 2 inches thick over the top of the joists. The concrete was of Portland cement and washed sand, in the proportion of one yard of sand to two bags of cement. The suspended ceiling was formed of terra-cotta wired lathing secured to iron rods fixed to the soffit of joists with iron hooks. Ordinary three-coat work was applied to the lathing, but a proportion of plaster of Paris was incorporated with the material. The thickness of the plastering was $1\frac{1}{8}$ inches.

The test was arranged for $1\frac{1}{4}$ hours, the temperature was not to exceed 2,000° F., and the floor was to be loaded with 56 lbs. per foot, distributed.

The summary of the effect was that a considerable portion of the plaster ceiling fell during the test, some of the lathing being bare before the test closed. The floor cracked at each side to the extent of $\frac{1}{2}$ inch, and dropped $\frac{1}{4}$ inch. When water was applied, smoke, steam, and sparks came through the cracks in the top of the floor. One of the joists carrying the ceiling was entirely destroyed, two partially so, and one, though discoloured, was practically sound.

This floor did not collapse, but its supports were practically destroyed; it trusted for its fire-resistance to the suspended ceiling on the terra cotta wired lathing and air space, but after the ceiling was pierced, the heat had full play around three sides of the deal joists, and so brought about its ruin. A floor of similar construction, but with iron supports, will be mentioned later.

We now come to floors having pretensions to be fireproof, *i.e.*, the constructional parts of the floor are of non-combustible material, and the committee started with a simple iron and concrete floor, the soffits of the iron joists forming the floor being exposed. The floor (*Fig.* 8, *Plate* I.) is constructed of 5 by $4\frac{1}{2}$ steel joists placed 2 feet 6 inches apart, and filled in with coke breeze and Portland cement concrete, 5 to 1. It was loaded with 168 lbs. per foot, distributed. It was proposed to test this floor for $2\frac{1}{2}$ hours up to a temperature of 2,300° F., but after 1 hour and 25 minutes, and at a temperature of 1,650°, the bulk of the concrete in the two outer bays collapsed, owing to the deflection of the steel joists. The floor began to deflect after 20 minutes at a temperature of 1,200°, and a maximum deflection of $10\frac{1}{2}$ inches was recorded in one of the joists. The coke breeze concrete was but little deteriorated.

The disadvantage of filling in concrete between joists is in setting up and striking the centering, and the attendant obstruction to the progress of the works by the supports.

The committee instituted the following test, in which corrugated iron filled in between the iron joists was the centering employed, and the coke breeze and cement concrete, 5 to 1, filled in on top (*Fig.* 9, *Plate* I.).

The soffit of the joists and corrugated iron centering was protected by 2 by 3 deal ceiling joists suspended from the joists, and wire netting, $\frac{1}{2}$-inch mesh, was used as lathing, and a plaster ceiling, 3-coat work, applied; inch floor boards were nailed into the breeze concrete on top, the floor and ceiling having a total thickness of about 12 inches. The floor was loaded with 168 lbs. per square foot, distributed. The test was to last $1\frac{1}{4}$ hours, the temperature 2,000° F. In half an hour the ceiling began to fall, and in 1 hour the ceiling and ceiling joists had all fallen. At the conclusion of the test the soffit of the iron joists and corrugated iron centering were observed to be red hot, and the joists had deflected about $2\frac{3}{4}$ inches, but on cooling, returned to within 1 inch of level. The fire did not pass through the floor, but perhaps the test was hardly sufficiently long to enable a comparison with the former floor to be made; but certainly the deflection of the joists was not so great, and the floor would have been serviceable without re-construction, which the former floor would have not.

The next floor is one in which expanded metal forms a centering as well as lathing. The construction of the floor (*Fig.* 10, *Plate* I.) is by iron joists 4 feet $9\frac{1}{2}$ inches apart, on the top of which the expanded metal is stretched, and 3 inches of furnace ash and Portland cement concrete laid and finished on top with $\frac{1}{2}$ inch of cement and sand. The joists are protected with a suspended ceiling, as shown, of expanded metal, and ordinary plastering applied. The space between the floor and ceiling was ventilated by means of holes in the walls of the chamber. The floor was loaded 140 lbs. per foot, distributed. The test was to last $1\frac{1}{4}$ hours and the maximum temperature was to be 2,000° F. The result was that during this period the fire did not pass through the floor. The plaster ceiling remained intact until the application of water, when some of it was washed away. There was a slight deflection of the floor and ceiling.

We now come to the floor to which I before alluded, and it is on the same principle, but steel joists are substituted for the wooden ones (*Fig.* 11, *Plate* I.).

Terra-cotta wire lathing is used both for the centering and ceiling. The figure will explain the construction in detail. The test was to be of $1\frac{1}{4}$ hours' duration, and the temperature was not to exceed 2,000°, and the load $1\frac{1}{2}$ cwt. per square foot, distributed. The result was the fire did not pass through the floor, but, on water being applied, some of the plastering was washed from the lathing. So little was the floor damaged that the testee decided to re-plaster the ceiling, and the test was renewed at a subsequent date, when practically the same results were observed.

The last floor test to which I invite your attention is one of $2\frac{1}{2}$ hours. The floor was constructed of iron and concrete, in which all the ironwork was embedded (*Fig.* 12, *Plate* I.). The steel joists are spaced 6 feet apart, over which are placed stirrups to receive the bridging bars, spaced 20 inches apart. A slab of concrete is suspended to the soffit of girder, and a wood centering is necessary for filling in the concrete, which is composed of clinkers, broken small, sand, and Portland cement in the proportion of four parts clinkers, two parts sand, and one part Portland cement. The concrete was 4 inches thick; a further depth of coke breeze and Portland cement concrete, 2 inches thick, was filled in on top of this between the floor strips; the soffit of the floor and the sides and soffits of the steel joists were rendered in plaster, three coats.

The summary of this test is thus recorded:—The plaster on the underside of the ceiling and around the beams cracked slightly before the application of water. On the application of water some of the plaster fell off the soffit of the ceiling and beams. The concrete forming the floor was not damaged. That enclosing the beams was slightly damaged and cracked. The fire did not pass through the floor. The wood strips bedded in upper surface of the concrete were uninjured.

I now come to a very interesting series of tests with doors of various constructions and various materials.

For the purposes of comparison it became necessary to first of all ascertain the resistance of any ordinary deal door, and then of a solid 2-inch door of the same material. These tests are made more interesting, as the committee were enabled to take photographic records of the outside of the several doors during the progress of the tests. You will find on *Plate* II. a photographic diagram showing the condition of the various doors at intervals, in most cases of five minutes, taken during the tests.

The first of the tests is that of an ordinary 1-inch ledged door and a 2-inch four-panel moulded both sides door, with panels $\frac{5}{8}$ inch in thickness (*Fig.* 20, *Plate* III.). They were fitted into the recessed wall, built about 14 inches back across the hut, one side of the door being in the chamber, and the other side exposed to the external air. This arrangement was identical for all the tests, so that a separate description of the size and position of each door will be unnecessary. *Fig.* 21, *Plate* II., shows the condition of the doors after the gas had been lighted 19 minutes, and *Fig.* 22, *Plate* II., at 25 minutes, when the doors were practically destroyed.

Following upon this are two 2-inch bead butt both sides doors, with 2-inch solid panels. One was of deal and the other pitch pine. *Fig.* 23, *Plate* III., shows a view of the doors, and the doors of this set which are to follow are identical in construction. In 17 minutes flame appeared over the top of the deal door, and in 20 minutes over the top of the pitch pine door. *Fig.* 24, *Plate* II., shows the condition of the door after 30 minutes, and *Fig.* 25, *Plate* II., after 55 minutes, when the doors were mostly consumed.

We now come to the hard wood doors which are to be the fire-stop, one of American oak and one of Moulmein teak. After 30 minutes' test the condition on the outside was thus (*Fig.* 26, *Plate* II.):— The fire came over the top of the teak door in 7 minutes, but it did not appear over the top of the oak one for 35 minutes; in 55 minutes the doors were practically destroyed (*Fig.* 27, *Plate* II.). It should be pointed out that it is very desirable that the doors should fit as closely as practicable; the reason for the flame coming over the top of the teak door so soon was in consequence of its not fitting closely to the frame. Another teak door of similar construction, but somewhat thinner, and with the panels in two thicknesses, will appear later on, when the first appearance of flame was after 18 minutes.

The next two doors are of Austrian oak and American walnut; the flame did not come over the top of the oak door till 33 minutes after the fire was started, but in the walnut door flame appeared at intervals after 15 minutes. *Fig.* 28, *Plate* II., shows the condition of the doors after 30 minutes, and *Fig.* 29, *Plate* II., after 50 minutes, when, as you see, the oak door had had the worst of it.

The last doors tested in this series were of Honduras mahogany and poplar. The fire came over the top of the poplar door in 3 minutes, and over the top of the mahogany one in 10 minutes. The condition of the doors after 30 minutes was thus (*Fig.* 30, *Plate* II.):— The poplar door, as will be seen, has all the upper part consumed. It had all disappeared in 40 minutes, and a temporary door had to be fixed in its place to continue the test of the mahogany door, which collapsed at 50 minutes (*Fig.* 31, *Plate* II.).

It will be observed that these two doors did not stand so well as the deal and pitch pine ones, although, in justice to the poplar door, it had somewhat warped away from the frame at the top, and greatly facilitated the flame coming over, and its consequent rapid consumption.

The committee's experience with this series of doors led them to experiment with doors made of material in three thicknesses, and two doors were made, one of deal and the other of pine. The material was in three thicknesses, the two outer faces being vertical, and the inner one horizontal (*Fig.* 32, *Plate* III.). The boards were in about 6-inch widths, and securely nailed together with 3-inch clasp nails, and clinched on the outside; the total thickness was $2\frac{5}{8}$ inches. Each door was hung with one pair of strap hinges, 2 feet 6 inches long, into brick rebates, and before the doors were put in position the rebates were screeded, so that the doors should fit as close to the rebates as possible. These doors stood a longer test than the former series, as will be seen by their condition after 55 minutes (*Fig.* 33, *Plate* II.). Flame was not seen through the pine door till 60 minutes, although in the deal door flame came through in 39 minutes. The destruction of the doors was very rapid after the fire came through, and at 65 minutes the test was concluded (*Fig.* 34, *Plate* II.). The iron was the ruin of the doors, as on the nails and bolts becoming red hot, they charred the timber around them and allowed the fire to come through.

This led the committee to test three doors of similar construction to the last, *i.e.*, in three thicknesses, but the thicknesses were secured together by $\frac{3}{8}$-inch double wedge-shaped pins, driven in from both sides, instead of clasp nails (*Fig.* 35, *Plate* III.). These doors had frames, and the frames were rebated. The three doors were respectively of deal, teak, and oak. The test with these doors gave the best results of any of the previously tested fire-resisting doors.

The deal door of this construction was tested against a 4-panelled teak door (*Fig.* 36, *Plate* II.), with the result that at the end of 60 minutes the teak door was almost consumed, but the deal door was practically intact as a fire-stop (*Fig.* 36A, *Plate* II.). The oak and teak door of the same construction as the deal door presented this appearance at 60 minutes (*Fig.* 37, *Plate* II.), and at 75 minutes were still in position, the teak one being the better of the two (*Fig.* 37A).

This ends the series of tests with fire-resisting doors, and we come now to a comparative test with an iron door, meeting the requirements of the Building Act under Section 77, and a door constructed of wood, and encased with tinned steel sheets, lock-jointed and screw-nailed (*Figs.* 38 and 39, *Plate* III.). The test was to be one hour, and the summary of effects is as follows:—

The wood door covered with tinned steel plates remained in position, but was much buckled and bulged, and the upper part gradually inclined inwards to a considerable extent, permitting the passage of flame. The first spurt of flame over the top of door was seen after 5 minutes. The iron-framed and panelled door remained in position, but became red-hot, buckled and warped considerably, together with its rebated frame. The upper corner on the lock side gradually inclined inwards to a considerable extent, permitting the passage of flame. The first spurt of flame between door and flame was seen after 20 minutes. Notwithstanding that the iron door buckled, I am of opinion it is the best fireproof door at present in use, but to be effective it requires three hinges and three bolts, and the tendency to buckle is thus hindered.

Fig. 40A, *Plate* II., shows the result of a test with an iron door with styles and rails on both sides, and one with styles and rails on one side only. The test demonstrated the advantage of the door being secured at six points.

With the presentation of these few examples of fire-resisting construction I will now terminate my paper.

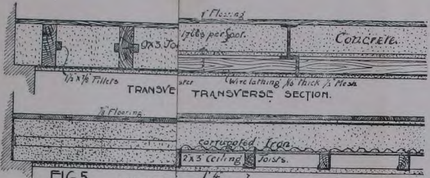
Whilst in conclusion, wishing to impress upon you the great importance of the whole question of fire-proof construction and fire-protection in the buildings of our army, not only in time of peace but particularly in time of war, I again repeat that the points of the greatest urgency for you are those of the grouping of buildings, those of the separation of buildings, and those of the planning of buildings, which points take precedence to any question of construction. After that comes the question of the support of floors, then the actual floors, and then the partitions, whilst, lastly, come all the contrivances of the closing of openings and the like.

But the essence of "fireproof construction," as you have called it, or "fire-resisting construction," as I generally call what is practical in this direction, is, as far as you are concerned in army buildings, the application of the principle of separation and the diminution of the extent of the individual risk.

IREPROOF"

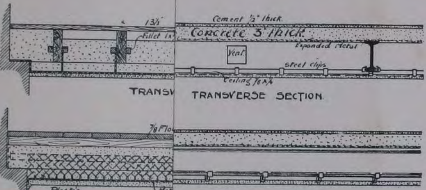
PLATE I.

REFERRED TO BY THE
ITISH FIRE PREV



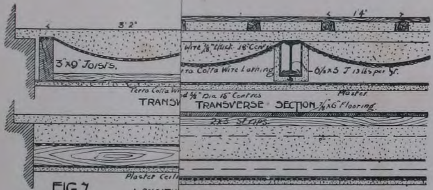
TRANSVE TRANSVERSE SECTION.

FIG.5. LONGITUDI LONGITUDINAL SECTION.



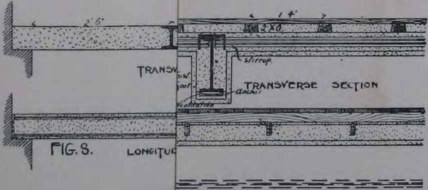
TRANSV TRANSVERSE SECTION.

FIG.6. LONGITUD LONGITUDINAL SECTION.



TRANSV TRANSVERSE SECTION

FIG.7. LONGITU LONGITUDINAL SECTION.



TRANSV TRANSVERSE SECTION

FIG.8. LONGITUD

LONGITUDINAL SECTION.

PAPER VII.

NOTES ON CORDAGE, ROPE, CHAIN, BLOCKS, AND TACKLES.

BY MAJOR W. BAKER BROWN, R.E.

THE following notes are a revision of an article on Blocks and Tackles which appeared in the *R.E. Journal* for May, 1900, with some new matter added.

I have been permitted to use and print the official specifications of the articles referred to. I have expressed opinions in these notes which are at variance in some respects with official practice, and any who read this article will thus have an opportunity of comparing such opinions with the facts on which they are based.

The tables of breaking-strains, as given in these specifications, differ very largely from any figures usually given in military or other textbooks, and the information in these latter as to the relative strength of different materials or different methods of lay is very vague and often inaccurate. For instance, Major Scott-Moncrieff's *Field-Service Pocket-Book*, following apparently the official textbook of *Instruction in Military Engineering*, says the strength of coir rope is equal to that of hemp rope, whereas it has in reality only $\frac{1}{4}$ of the strength !

I have, therefore, in these notes endeavoured to bring the information on the subject up to date, with special reference to points on which the present knowledge seems vague or incomplete.

Some inconvenience having been found in using the term "rope" for all purposes, this name is now officially used for ropes made of iron or steel wire, the term "cordage" being used for ropes made of hemp or other fibre. "Rope" is, of course, still used colloquially for both classes, and the term "a rope" is used to signify a piece of cordage.

Cordage.

Cordage for military purposes was formerly supplied from the Royal Dockyards, but is now all obtained direct from contractors. The standard of strength and details of manufacture are, however, practically the same as those in force in the dockyards.

The strength of any cordage, and the use to which it can be put, depend on many details; these may be considered under the headings of "material," "lay," and "size."

The official nomenclature of cordage has recently been altered to give the information under all these heads, thus :—Cordage, Manilla, hawser, 3-strand, tarred, 3-inch.

Material.

The materials used are generally classified as hemp fibre, Manilla fibre, and coir fibre, but this classification is hardly sufficiently explicit, as, excluding several inferior qualities of hemp used for spun yarn, etc., there are three varieties of hemp fibre used for cordage, which differ considerably from one another in strength. They are known as Italian, Riga, and Petersburg hemp.

There are thus five different materials to consider. Further, Italian hemp or Manilla fibre is used either tarred or white, while Riga and Petersburg hemp are always tarred, and coir is always untarred, or natural colour.

Hemp fibre is obtained from the hemp plant. Italian hemp has a white, silky fibre; it is stronger than either Riga or Petersburg, and is used in the manufacture of all white hemp cordage, except spun yarn, and also for tarred bolt-rope cordage. Riga and Petersburg hemps have a green tinge, and are coarse grained. Riga is stronger than Petersburg, and is used for tarred hawser-laid ropes up to 6 inches, and for lashings. Petersburg hemp is used for tarred hawser-laid ropes over 6 inches. Spun yarn is made from Petersburg hemp, or from Italian or Riga of lower quality.

Coir fibre is obtained from the outer husk of the cocoanut. It is very light and elastic, and will float until it becomes saturated with water. When constantly wet it does not rot as hemp would.

Manilla fibre is obtained from the outer layers of the leafstalk of a species of plantain. It is more elastic than hemp fibre, and rope made from it is less likely to kink. It is much less affected by wet. It is sometimes erroneously called Manilla hemp.

The official standard for Manilla cordage has varied from time to time; a couple of years ago it was higher than any other class of equal size, but difficulty being found in obtaining supplies to this standard, the latter has been reduced, and is now about midway between the standards for tarred hemp and white hemp cordage.

The relative strengths of the different varieties of hemp will be seen from Table I., which gives the breaking-strain of a "yarn" of a certain size in each material.

A yarn is formed by twisting together several fibres of the material required. The size of the yarn used depends on the ultimate size of the rope, small ropes being formed of small yarns. Several yarns twisted together form a strand, three or four strands twisted together form a rope.

Lay.

By the term "lay" is meant the system on which the strands forming the rope are twisted together. Again omitting lashings, etc., the systems to consider are "hawser, 3-strand," "hawser, 4-strand," and "bolt" or "bolt-rope," which is always 3-strand. These terms really indicate the tightness with which the strands are laid up, and the three varieties can be measured in the finished rope by the angle between the direction of each strand and the direction of the centre line of the rope; these angles for the three kinds given above are 42°, 45½°, and 36½°.

Four-strand cordage is sometimes called "shroud-laid." There is also a system called "cable-laid," which consists of three 3-strand ropes laid up together, but this is only used in the military service for special small lines.

Size.

The size of a rope is denoted by its circumference in inches. The stock sizes used by Government vary from ½ inch to 12 inches; full details of the sizes are given in the vocabulary of stores, and in the accompanying specifications.

It will be seen from the above notes that to identify a piece of cordage we must specify the material, and whether tarred or white, the lay, the number of strands, and the size. Fortunately for the student, all the different combinations possible do not exist in practice. There are, however, nine varieties of cordage in the service, as given in the first column of Table II.

The figures in the third and fourth columns are for 3-inch cordage, which I have selected as being in general use in all branches of the service; they are taken from the Government specification, and give the breaking-strain and the weight per fathom of each class of rope. The figures in the third column will indicate the relative strengths of the different materials and methods of lay.

The strength of other sizes, from $1\frac{1}{2}$ up to 4 inches, can be obtained from the specifications or can be calculated from this table, on the basis that the strength varies with the square of the circumference of the rope. Larger sizes than 4-inch follow nearly the same rule, but are not quite so strong in proportion.

It is popularly supposed that the length of a coil of rope is always 113 fathoms; but this is not the case, as bolt and 3-strand Manilla are issued in 122-fathom coils, while the length of coils of lashings, spun yarn, etc., vary considerably according to the size of the cordage. Steel wire rope is issued in 100-fathom coils.

Strength of Cordage.

To the Engineer the main point of interest is in the strength of a rope. This will naturally vary with any variation of the details discussed above.

As regards materials, white Italian hemp is the strongest, then white and tarred Manilla, then tarred Riga hemp, then coir fibre.

As regards lay, bolt is the strongest, then hawser; 3-strand rope is stronger then 4-strand.

To test cordage on delivery from a contractor, a short piece off the end of each coil of rope is tested in a special machine until it breaks; the load with which it just breaks is called its "breaking-strain." A standard breaking-strain is laid down for each size and pattern of rope, which any supply must reach.

The "safe load" which can be put on a rope is necessarily very much less, and should never exceed $\frac{1}{3}$ of the standard breaking-strain, or a factor of safety of at least three should be used. In practical work, especially using worn ropes and with live loads, a larger factor is necessary.

It is a common practice in textbooks to give a rough rule for the strength of ropes based on the square of their circumference, such as $\frac{C^2}{10}$ or $\frac{C^2}{20}$ tons; but I would strongly urge any engineer or other person who wishes to make a scientific use of the means at his disposal not to be satisfied with such a formula, and I think all text-books, except actual pocket-books, might well give a little space to a table of the actual breaking-strains of the patterns of cordage in general use.

But though for any permanent or semi-permanent use or for work in a fortress, such as lifting heavy guns, reference to textbooks is easy, and in some cases compulsory, there may often be cases in the field where recourse must be had to a "rule of thumb," and therefore it is important to get clear ideas as to the value of the various formulæ in the textbooks.

Now I venture to lay down that a formula to be readily and easily applied, often by inexperienced men, should be simple, safe for the weakest class of rope likely to be met with, and without variable factors.

Referring to Table II. again, it will be at once seen that no practical formula can be constructed to include coir cordage with the others; this is, however, only used for special purposes, and should its strength be important, it may be taken as $\frac{1}{4}$ that of the weakest form of hemp.

Even omitting this variety, there are still eight others to be included, with a margin of 50 per cent. between the two extremes, so that a rough rule, which is safe for the weaker cordage, will be much below the capabilities of the strongest.

Various formulæ are used in the artillery, engineering, and submarine mining manuals, and in various pocket-books. Nearly all are based on a formula for the breaking-strain of $\frac{C^2}{3}$ tons, where C is the circumference in inches. This formula is practically right for tarred, 3-strand, hawser, hemp cordage, and may, therefore, be safely adopted.

Taking $\frac{1}{3}$ of this as our maximum safe load, we get $\frac{C^2}{9}$ tons; but this would be unsafe for anything but quite new cordage, and we must use a larger factor of safety for general work.

On referring to the various manuals I find the Garrison Artillery use a factor of $2\frac{2}{3}$, or a formula for safe load of $\frac{C^2}{8}$ tons. *Instruction* *in Military Engineering*, Part III., takes the breaking-strain at $\frac{C^2}{3}$, but gives different tables of safe loads for "when not exposed to wet" and for "field service." The figures in these tables are apparently based on the formulæ $\frac{C^2}{8}$ and $\frac{C^2}{15}$ tons. The *Manual of Military Engineering* uses a factor of 5 and formula of $\frac{C^2}{15}$, and the *Submarine Mining Manual* a factor of $\frac{3}{20}$ and a formula of C^2 in *cwts.*

In Lord Wolseley's pocket-book the factor of safety is $\frac{3}{20}$, but the formula for the breaking-strain is given at $\cdot 28 \times C^2$. In Major Scott-Moncrieff's pocket-book the safe load is given at $\cdot 8 \times C^2$ in cwts. for Manilla, and $1 \cdot 25 \times C^2$ for hemp or coir rope.

Hurst and Molesworth's pocket-books give two different formulæ, but these are not suitable for military requirements.

Of the above it seems evident that the formula $\frac{C^2}{8}$ tons is unsafe for tarred hemp rope, or indeed for any rope whose breaking-strain equals $\frac{C^2}{3}$ tons, though it would be safe for the better classes of rope. As a general formula it should be rejected.

After a good deal of consideration and discussion the following rough rule has, on the recommendation of the R.E. Committee, been recently adopted officially for all R.E. textbooks.

"Safe load for ordinary work equals *C^2 in cwts.*, but under favourable conditions this may be increased up to a *maximum* of $2C^2$."

Such a formula can hardly be misapplied, and meets all practical requirements. If it is absolutely necessary to use a rope with a strain which is nearer its breaking weight, a reference should be made to the exact breaking-strain of rope of the particular class, and a suitable factor, not less than 3, should be selected according to circumstances.

All the formulæ discussed above are tabulated in Table III.

Manual of Military Engineering (provisional edition), 1901, still adheres to the old formula, and takes no notice of the above rule. A table of strains and weights is given, but it is simply a series of arithmetical calculations based on a rough rule, while the description of cordage in the heading of the table—"Italian hemp, hawser-laid (tarred)"—does not exist in the military service.

A table professing to give the safe working-strain of rope and rope slings was issued with Army Orders in 1890, and may be found in Appendix II., *Regulations for Army Ordnance Services*, 1900. It is practically identical with similar tables in garrison artillery drill. The table given makes no distinction between the various patterns of cordage; and though it is said to be based upon the average breaking-strain, an inspection of the table shows that the working-strains given therein are simply a series of calculations of the formula $\frac{C^2}{8}$ tons, which we have seen is unsafe for certain classes of cordage.

Testing Cordage.

This table also gives a column of test loads, which are in all cases 50 per cent. over the working-strains, and in the case of tarred hemp cordage are more than half the ultimate breaking-strain. Such a high test load seems likely to cripple the rope before it is actually used. *Instruction in Military Engineering*, Part III., also gives a table of test loads, which are considerably less than those in the *Regulations for Army Ordnance Services*, but which do not appear to follow any fixed rule.

Personally, I do not believe any good purpose is served by these tables; should any doubt exist as to the quality of any length of rope, a small portion should be actually broken, and the proper factor of safety applied to the remainder, or if it is desired to test the whole length, it should be made up into the tackle in which it is to be used, and the whole tried with a weight 10 per cent. in excess of the proposed working load.

Weight of Cordage.

The weight of the various patterns of cordage are given in Table II. They vary very considerably in the different patterns; the formulæ given in *Instruction in Military Engineering* are only approximate. As a general rule the weight of all hemp or Manilla cordage per fathom is between $\frac{C^2}{4}$ and $\frac{C^2}{5}$ lbs., and of coir is $\frac{C^2}{10}$.

Strength and Weight of Wire Rope.

It is usual to take the weight of wire rope as equal to C^2 in lbs. per fathom, and the breaking-strain as C^2 tons for iron, and $2C^2$ tons for steel wire. The actual weight and strength of 3-inch steel wire rope to Government specification is given at the end of Table II.

General Remarks on Cordage and Rope.

The particular class of rope to be used, when a choice is possible, depends of course on other details than only strength and weight, such as liability to damage by wet, pliability, and so on. Bolt-rope cordage was intended mainly for the edges of bolt-ropes of sails, and is little used for military purposes; it is, however, very pliable, and might have uses. Manilla is used largely by submarine miners, and also very largely in civil life for yachts.

For field service, white hemp cordage has been substituted for tarred hemp since the first issue of these notes, and I thus hope that the prejudice which formerly existed against white cordage will now die out; it mainly depended on its supposed inferiority in wet weather, but this is really more a matter of proper stowage and care than anything else, as the extensive use of white cordage on yachts clearly shows. No doubt for drill purposes, where the same piece of cordage is used over and over again, sometimes for years, tarred cordage would wear best; but these are hardly the conditions of field service, and, in any case, using white cordage we start with an increase of 30 to 50 per cent. of strength, and a saving of 20 per cent. of weight.

More extended use might be made of Manilla cordage, though I believe it is too elastic for use in lashings.

Table I.

Breaking Strains of "25-Thread" Yarns, showing the Relative Strength of various Qualities of Hemp.

Material.	Breaking Strain.
	lbs.
Italian, white	140
Italian, tarred	130
Riga, tarred	120
Petersburg, tarred	113

Table II.

Giving Breaking Strains and Weights of various Patterns of 3-Inch Cordage and Wire Rope taken from Government Specifications.

Nomenclature.	Material of which composed.	Breaking Strain.		Weight in lb. per fathom.
		tons.	cwts.	lbs.
Cordage.				
Hemp, bolt, 3-strand :				
Tarred	Italian hemp	3	10	1·97
White	ditto	4	8	1·65
Hemp, hawser, 3-strand :				
Tarred	Riga hemp	3	0	2·13
White	Italian hemp	4	4	1·78
Coir, hawser, 3-strand ...	Cocoanut fibre	0	14	·85
Manilla, hawser, 3-strand :				
Tarred	Manilla fibre	3	7	1·89
White	ditto	3	13½	1·65
Manilla, hawser, 4-strand :				
Tarred	ditto	3	0	2·04
White	ditto	3	6½	1·79
Rope.				
Steel wire	—	17	0	7·00

Table III.

Showing the Formulæ for Safe Load used in various Manuals and Handbooks, with Result calculated for 3-Inch Cordage.

Name of Book or Manual.	Formula used.	Result calculated for 3-Inch Cordage.	
		tons.	cwts.
Garrison Artillery Manual, Vol. II.	$\frac{C^2}{8}$ tons	1	2·5
Instruction in Military Engineering, Part III. :—			
When not exposed to wet...	—	1	2·5
Field Service	—	0	12
(Test load)	—	(1	6)
Manual of Military Engineering...	$\frac{C^2}{15}$ tons	0	12
Manual of Submarine Mining ...	C^2 cwts.	0	9
Lord Wolseley's Pocket-Book ...	$3 \times {\cdot}28 \times C^2$ cwts.	0	7·5
Major Scott-Moncrieff's Pocket-Book	$1{\cdot}25 \times C^2$ cwts.	0	11·25
Regulations for Army Ordnance Services, 1898 :—			
Safe load	—	1	2·5
(Test load)	—	(1	13·75)
Formula now adopted for all R.E. Services :—			
Ordinary	C^2 cwts.	0	9
Maximum	$2C^2$ cwts.	0	18
Actual value for tarred hemp, hawser-laid cordage, from Table II.	$\frac{1}{3}$ actual breaking-strain	1	0

Chains and Shackles.

Chain is identified by the diameter of the iron forming its link, and may be short-link, long-link, or studded. Long-link chain is weaker than either of the others, and is not now used for military purposes.

Short-link chain is called crane chain; studded chain is called cable chain. The details and sizes of the links are given in the specification, but, speaking generally, each link of short-link chain has a length equal to five times the diameter of the iron used for the links, and studded chain has a length of six times this diameter.

Any chain over five diameters in length and not studded is called long-link chain.

Both short-link and studded chain have a width of $3\frac{1}{2}$ times this diameter. Chain is issued in various lengths according to the work to be done, and is measured in fathoms. The smaller sizes of short-link chain are usually galvanized; studded chain is issued natural colour. Chains are usually connected by shackles, and when used as moorings swivels are also fitted.

The following table of the relative strengths of short-link and long-link chain, and of shackles and hooks, is taken from the *S.M. Manual*:—

$$\left.\begin{array}{lll} \text{Strength of} & \text{long-link chain} \quad \ldots & = \frac{5}{6} \\ \quad ,, & \text{studded} \quad ,, \quad \ldots & = \frac{3}{2} \\ \quad ,, & \text{shackles (service pattern)} & = \frac{3}{4} \\ \quad ,, & \text{hooks} \quad \ldots \quad \ldots & = \frac{1}{9} \end{array}\right\} \begin{array}{c} \text{The strength of short-} \\ \text{link chain made of iron of} \\ \text{the same material.} \end{array}$$

It will be seen that the shackles used for any chain must, for equal strength, be of larger diameter of metal than the chain, and thus will not fit easily in the end link; so it is generally necessary to fit each end of a chain with a special large link, called a "long link," into which the shackle can be fastened. To get equal strength the metal in the long link should be $\frac{1}{6}$ stronger than that used in the chain; this can be obtained by making the long link of metal $\frac{1}{8}$ thicker than that used in the chain. Thus $\frac{7}{16}$ chain should have long links of $\frac{1}{2}$-inch metal and $\frac{5}{8}$-inch shackles.

Strength of Chain.

All chain before issue is tested to a strain called the proof strain, which is given in the specification; but short pieces are tested with a load which may be taken as the equivalent of the breaking-strain of cordage. This strain is double the proof strain for short-link and $\frac{3}{2}$ proof strain for studded chain. On an emergency new chain may be used up to the proof strain, but for ordinary use half of this amount should not be exceeded.

The following rough rule for short-link chain, which follows very nearly the similar rule for cordage, is suggested, but it has not received any official approval.

If d = the diameter of the iron of the links measured in *sixteenths of an inch*, then the ordinary working load $= \frac{d^2}{2}$ in cwts., which may with new chain, and in an emergency, be increased up to d^2 in cwts.

Studded chain is tested to a proof strain 50 per cent. greater than short-link chain of the same size and material, and is slightly lighter.

A good rule for the weight of either class of chain is $\frac{d^2}{4}$ lbs. per fathom, which is very nearly accurate.

SHACKLES.

The shackles used in the military service are designed mainly for use by submarine miners. They are of two kinds, "snap" and "screw."

The snap shackle was designed by Lieut.-Colonel R. M. Ruck, R.E., and has an indiarubber washer which holds the pin locked. It is very easily and quickly closed, but cannot be undone with a strain on it.

To get good results it requires to be rather accurately fitted, which is difficult to obtain with large supplies; and this, combined with the perishing of the indiarubber, has prevented this pattern from fulfilling the hopes of its inventor, so that after several years trial it is gradually being superseded by the screw shackle.

Taking everything into consideration, the screw shackle is the best all-round pattern, and is that generally used with chain whenever it is desired to connect or disconnect a chain quickly. The special pattern for S.M. service has a fibre washer, which, expanding when wet, tends to lock the pin, and also has a few modifications of detail, to enable it to be quickly screwed up and unscrewed.

All screw shackles should be tightly screwed up with a marline spike, and if intended to remain out for any length of time should be wired, that is, the eye of the pin should be lashed to the bow with a few turns of wire.

A third pattern of shackle often met with has a plain pin, with a slot and split key. Such a form is used on permanent moorings, but if often closed and unclosed the key is apt to break.

BLOCKS AND TACKLES.

In nearly all our textbooks on the use of blocks and tackles too much dependence is placed on rules of thumb.

The rules in use, such as "the length of a block is equal to three times the diameter of the rope with which it is to be used," were devised for the old pattern wooden blocks, and were probably based on considerations of the strength of the wood frame, rope strapping, and similar details.

Now that blocks of iron are largely superseding those of wood, the proportion no longer holds; and while the usual pattern blocks are shorter than they would be under this rule, there is considerable advantage in some cases in using blocks with larger sheaves, and consequently longer shells.

Description of Blocks.

The main parts of a block are the sheave and pin, shell and strap. The *sheave* is now always made of iron, brass, or gunmetal; iron sheaves are used for ordinary iron blocks, and brass or gunmetal in blocks of a superior type. The width of the sheave determines the size of cordage or rope to be used with the block. The diameter of the sheave depends on other considerations, which are investigated below. The sheave revolves on the pin, which is fixed in the framework of the block; this framework was formerly in two parts—a shell whose principal use was to prevent the rope slipping off the block, and a strap holding the pin and carrying the hook or other attachment to connect the block to the weight. In iron blocks a shell is not always provided, but when provided, it and the shell are all in one piece.

One or more sheaves may be fitted in one frame, and the blocks are called "single," "double," "treble," etc.

Single blocks are sometimes made with a cut in one side of the shell, so that the fall can be slipped in or out without the trouble of unreaving. Such blocks are called "snatch" blocks. In order that the block may not be unduly large, the sheaves of such blocks are made smaller than the corresponding size of a single block.

Blocks are identified by their material, number of sheaves, and length of shell, thus:—"Blocks, malleable cast iron, double, 8-inch." The size of rope to be used was supposed to be indicated by the rough rule referred to above, but this is no longer applicable, and W.D. blocks are in future to be marked with the size of cordage or rope they will take, as well as the length of shell (see the typical drawings in the specification).

One of the important details is, however, omitted, that is, the diameter of the sheave. Neglect of this detail is very noticeable in the snatch block. Blocks should be identified thus :—"Blocks, malleable cast iron, double 3-inch cordage, 8-inch sheaves."

There are two fittings to blocks to consider. On the inner end, that is the end which is inside when the block is used in a tackle, there is a loop or eye called a "becket"; this can be fixed or swivelled—the former is simpler and better. This eye is used to secure the end of the fall, and in all military patterns is fitted with a thimble. Beckets are sometimes omitted in civil patterns, so in ordering blocks from civil firms this detail must be specified.

On the outer end the usual fittings are an eye or a hook—either may be swivelled or fixed. The eye may be fitted with a shackle or left plain. The shackle in military blocks is fitted with a split pin, but an ordinary service screw shackle may be used with advantage. In some civil patterns the bow of the shackle is placed in the eye and welded in so that it cannot be withdrawn. This form is convenient for standing rigging.

When a hook is used it is important that the point which takes the bearing of the weight shall be in line with the axis of the block; if not, the fall will not run true, and there is a waste of power. When a hook has been sprung at all, the block should not be used if it can be avoided.

Some blocks, especially those used in the S.M. service, are fitted with a swinging hook, that is, a hook fixed to an eye. In such cases the weight always hangs below the centre of the block, and this form has also advantages in enabling the hook to be hooked in or out without taking the weight of the block.

At present practically all military blocks used for field service are fitted with fixed swivelled hooks, but I do not think this is the best form of attachment.

A reference to the table above shows that a shackle is about seven times as strong as a hook, and practical trials show that a hook to be of equal strength with the other parts of a block will weigh about as much, and be nearly as large, as all the rest of the block.

The use of a shackle and eye will, therefore, save weight and space in carriage, and give some additional lift; the only disadvantage is that it takes somewhat longer to apply.

For deliberate lifts of heavy weights, and in all cases where hooks would be moused, the shackle has the advantage.

Where a large number of light or moderate loads have to be lifted quickly the hook has the advantage.

In the submarine mining service, where sometimes one or two lifts a minute have to be taken for an hour or two at a time, the hook (swinging) has decided advantages ; but all other blocks, save that nearest the weight, are usually fitted with shackles.

TACKLES.

Tackles are of two kinds, differential and ordinary.

Differential tackles are always issued complete ; they have a chain fall and upper and lower blocks, the upper block being a differential one.

Military patterns exist to lift up to 4 tons, and are fitted with hooks for attachment.

These are the only details which need be specified, except, of course, the test load, which for military patterns is $1\frac{1}{2}$ times the working load.

Ordinary tackles are composed of ordinary blocks such as we have considered above, and a fall of wire rope, chain, or cordage.

Wire rope being much smaller in diameter than cordage of equal strength, it is usually necessary to have specially designed blocks for wire rope tackles, though, of course, ordinary blocks designed for cordage can be used up to their limits of strength.

Chain falls require sheaves of about the same thickness as cordage of equal strength, and can be used with ordinary blocks.

Strength of Tackles.

Tackles are used, as every schoolboy knows, by attaching one block to a fixed point, and one to a moving object called the weight. The end of the fall may issue at either block, but if it issues at the block connected to the weight it must be led off parallel to the other returns to get the maximum advantage.

If this condition is fulfilled, and the blocks are assumed to run without friction, the proportion between the weight and the power required to move it will be equal to the number of returns of the rope at the moving block. Thus, if the moving block is single, with a becket, and has three parts of rope issuing from it, $W = 3P$, or $\frac{W}{P} = 3$. The fraction $\frac{W}{P}$ is called the "theoretical mechanical advantage."

We cannot, of course, neglect friction, and, therefore, this fraction has to be considerably modified in practice.

Friction in Blocks and Tackles.

What is usually called loss by friction may be considered under three heads :—

(i.). Friction of the parts of the rope against each other or against the shell of the blocks.

(ii.). Friction between the sheave and the pin.

(iii.). Power used up in bending the fall round the sheave and in straightening it again.

The first cause is preventable by keeping the falls parallel and the blocks from twisting, but this is difficult to do with newly rove tackles. The loss from this cause may vary from 0 to ∞, as it is quite possible, if the tackle is twisted sufficiently, to stop all movement.

The second cause is present in all blocks. The loss due to it may be reduced by increasing the diameter of the sheave and reducing the diameter of the pin, but there are, of course, practical limits to this. It may also be reduced by lubrication, and when this is perfect, or practically so, the loss is *nil.* Perfect lubrication requires ball bearings running in a bath of lubricant, and is, therefore, unpracticable in the field, but moderate lubrication is possible, though often neglected.

The third cause is present in all tackles, though it is seldom mentioned in the textbooks. It is greater with wire rope than with cordage, and greater with tarred cordage than with white.

Calculations for Friction.

The rough rule for friction which is taken in nearly all the books is as follows :—

Suppose $\frac{1}{n}$th of the power P exerted on one side of a sheave is used in overcoming friction, bending the fall, etc., then $\frac{n-1}{n}$ P is the strain on the second return of the fall, $\frac{n-2}{n}$ P is the strain on the third return, and so on.

Put into algebraical form it may be stated thus :—

If $\frac{1}{n}$th is lost in friction, S is the number of sheaves, and equals the number of returns at the moveable block, then—

$$\frac{W}{P} = \frac{nS - \frac{S(S+1)}{2}}{n}.$$

Instruction in Military Engineering, 1894, has a simpler form of this rule, which is probably sufficiently accurate for field purposes, as it is rather against the tackle. It, however, is based on a loss of only $\frac{1}{10}$ per sheave for friction, a rather low estimate.

This calculation is, however, not correct, as the loss is really a geometrical, not an arithmetical, progression, and the strains on the subsequent returns are $\frac{n-1}{n}$ P, $\left(\frac{n-1}{2}\right)^2$P, and so on, the formula being :—

$$\frac{W}{P} = \frac{nS}{n+S}.$$

This latter formula is quite as easily applied, and is more accurate than the former. The use of either formula depends on the value given to *n*; this is usually taken at 8, apparently quite arbitrarily.

I know of no recent experiments on this point with modern blocks, and in the absence of such experiments I make the following suggestions. It is probable that even with well-lubricated blocks, carefully stretched fall, and sufficient precautions against twisting the loss due to the causes enumerated above is *never less than* $\frac{1}{8}$, that is, to move a weight W by a rope passed over one fixed block a power $P > \frac{9}{8}W$ will be required.

With permanent tackles, such as on S.M. vessels, these conditions can be realized, but with ordinary gear, on field service, it is probable that the loss by friction is much greater, and will reach $\frac{1}{6}$, or even $\frac{1}{4}$.

Precautions to Reduce Friction.

In addition to efficient lubrication, very careful attention is required in preparing the fall. Every length of rope or cordage when new is more or less stiff, is difficult to bend, and when stretched is inclined to untwist. A tackle made up with an unstretched rope will, when first rove, twist up badly, and the fall will also twist on the sheaves.

Before using a piece of new cordage for a tackle it should be stretched for 24 hours, using a small tackle to give the strain, one end of the rope being fastened to a swivel or swivel block, so that the turns can unlay as they stretch.

Such stretching, while increasing its use as a fall, no doubt reduces the strength of the cordage considerably below the standard breaking strain of its class.

If a factor of safety of S is always used this loss of strength should be covered. The best piece of cordage obtainable should always be used for tackles.

Tackles should be kept made up, as they work better after being a little time in use; the fall has then been bent round the sheaves, and has become more flexible.

This point is consistently neglected in our field units, the blocks and fall being carried separately. Garrison artillery store their tackles ready for use, properly stretched and rove; and this is also the naval practice. In field companies the two blocks to form a tackle are kept in separate parts of the tool cart. I do not know if this has been found an inconvenience in practice, but it seems one of those cases where convenience of transport has been allowed to prevail to the detriment of working efficiency.

If any doubt exists as to the strength of a tackle, the whole should be tested, as far as possible, under the conditions in which it will be used, but with a load which is 10 per cent. over its maximum working load.

Permanent cranes, derricks, and tackles are tested in this way periodically under regulations, and always after any repair, alteration, or renewal of fall.

Leading Blocks.

When tackles are used to lift weights, it is customary to bring off the fall at the upper block and through a leading block to the crab, capstan, or hauling party.

Snatch blocks are commonly used as leading blocks, and here, I think, the practice is wrong, at any rate, for field service, where short falls and short lifts are the rule. If an ordinary single block is used as a leading block, the fall can easily be rove through it if required; or, better still, the leading block can be carried rove on to the fall.

The disadvantages of snatch blocks are the increased weight, smaller sheave, and also their weakness as compared with the ordinary pattern, any bad fit at the snatch causing an unequal strain on the other parts of the block.

If a leading block is kept rove it can be used on an emergency to reinforce the moving block, as in *Fig.* 2.

In lifting heavy weights some form of mechanical appliance, as a crab or capstan, should be used; a working party hauling by jerks gives practically a live load, and may increase the strain on the fall by 50 per cent.

Practical Applications.

In the S.M. service the lifting gear is kept permanently ready for use, either in mine store on pier head or on the S.M. vessels. In mine stores differential tackles are employed, on the pier head cranes with chain falls, on the vessels steel wire rope or chain falls, and ordinary blocks; cordage is seldom used, except for rigging or for auxiliary tackles. Power is applied by steam crabs or capstans. The wire rope falls are 2-inch steel wire rope, and are usually employed as a single whip to save time in lifting. Chain tackles are usually $\frac{5}{16}$-inch or $\frac{3}{8}$-inch crane chain, with single block (3 returns) at the weight, double block at the derrick end, and then through leading blocks to the crab. Sometimes the upper block is a single one, and the fall is lead through a sheave in the derrick end, through a leading block at the masthead, and through other blocks to the crab.

Leading blocks can be ordinary single blocks. The maximum working load is usually 30 cwt. Sheaves 8 inches in diameter have been found the best for all-round work, both with the rope and chain falls.

For field service the field companies and field park, according to the existing equipment tables, carry 2-inch and 3-inch white hemp cordage and suitable blocks. No tackles are carried rove, and the parts are not kept together. Railway companies carry a pair of 8-inch Bothway blocks and 4-inch cordage.

I suggest the following :—

In each cart of a field company *one light tackle*, composed of one single and one double block, a fall of 2-inch white hemp, hawser, 3-strand, cordage, and a leading block kept on the fall; all blocks will have *hooks*.

Such a tackle used, as in *Fig.* 1, would lift a maximum weight of $1\frac{3}{20}$ tons, taking P at $\frac{1}{3}$ the breaking strain of the rope, and friction at $\frac{1}{8}$. Used as in *Fig.* 2, a strain of $1\frac{15}{20}$ tons would be exerted.

The headquarter cart would carry, in addition, a heavy tackle of 2 double blocks, a fall of 3-inch white hemp, hawser, 3-strand, cordage, and a leading block kept on the fall; all blocks to have screw shackle attachment.

In addition, one or two snatch blocks for 3-inch cordage to be carried. These could be used with either 2-inch or 3-inch in an emergency.

The heavy tackle would lift $3\frac{15}{20}$ tons, as in *Fig.* 1, or pull $5\frac{2}{20}$ tons, as in *Fig.* 2.

The field park should carry a reserve of both classes, say two of each, and in addition a 5-ton differential tackle.

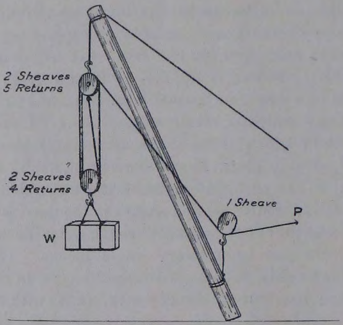


FIG. 1.—*Ordinary tackle and leading block.*

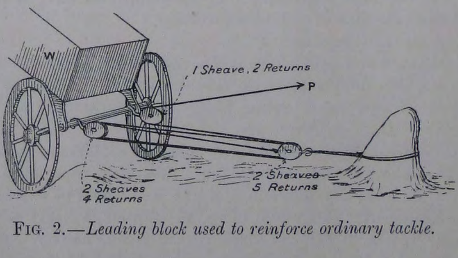


FIG. 2.—*Leading block used to reinforce ordinary tackle.*

The railway companies at railhead could have any of the above, but probably differential tackles would suit them best.

Railway repairing companies and other units on the lines of communications, who are not limited by the requirements of field transport, should have in their equipment heavier tackles, probably with wire rope falls. No tables exist for the equipment of such units, and it would be undesirable to seal patterns of such stores, but some should be obtained from the trade for peace practice. The stores for any large work, such as a girder bridge, should include proper lifting tackle, so such cases need not be provided for in the ordinary equipment of units.

Conclusion.

In concluding this article I would offer a few words of personal explanation.

I have usually found it assumed that the use of blocks and cordage is especially a subject to be dealt with by the officers of field units. Their use is taught the young officer in his course of field works, and chapters on the subject are included in *Instruction in Military Engineering*. He also has a similar course at the R.M.A., Woolwich.

Even with this amount of instruction it is found necessary to give all officers joining the S.M. service a further course, and the chapters on this subject in the *S.M. Manual* differ largely from those in *Instruction in Military Engineering* and other textbooks.

As regards experience in the use of ropes and tackles, the garrison artillery must take first place, though I think they are still inclined to cling to obsolete formulæ and rules of thumb rather than use actual figures.

Of the R.E. units the S.M. service is easily first. At any of the larger S.M. stations the number of lifts by crane or tackle during the year probably reach 10,000, which, I believe, is far in excess of any other branch of the Corps.

I have, therefore, felt justified in giving the S.M. experience in various cases, but in attempting to apply this experience to the requirements of field service I may have blundered. If I have, no doubt many candid friends will be found to tell me my faults.

After all, much of the value of an article of this description is not in the expression of the personal opinion of any individual, but in the fact that it gives cause for original thought among other members of the Corps, and possibly to discussion in the *R.E. Journal*, and thus tends to prevent too great reliance on stereotyped formulæ or text-book calculations.

CORDAGE.

ROPE.

Specification to Govern Manufacture and Inspection.

Approved, 8th June, 1900.

1. *General.*—The cordage supplied is to conform in all particulars with the sealed patterns and with this specification.

The length of the coils in which the cordage is to be supplied are given in the tables annexed, such lengths to be exclusive of the fag-ends and test pieces, and in all cases in one length, except for coil, of over 125 fathoms. The contractor will, therefore, only be paid for the length of serviceable cordage after inspection is completed.

2. *Material and Workmanship.*—The whole of the material is to be manufactured from the best material of its class, whether Italian, Riga, or Petersburg hemp or coir, and the cordage is to be free from defects and imperfections of every description.

The tarred cordage must be made from well-seasoned yarn, and must contain not more than $\frac{1}{6}$ of its weight of tar.

3. *Marking.*—Each contractor will be required to work a coloured thread into the cordage made by him, for purposes of identification; particulars as to colour will be furnished by the Chief Inspectors Royal Arsenal, Woolwich.

Each coil to have a label attached giving the following particulars:—

Name of contractor.
Date of manufacture.
Size of rope and thread. } To be in accordance with
Length of coil. } the annexed tables.

4. *Delivery.*—Each coil of the cordage will be delivered tied with cordage of sufficient strength to allow the coil to be slung by any of the ties, such ties to be included in the cost of the cordage.

5. *Testing.*—Samples of the thread used may be tested to destruction by the inspector at the contractor's works. Breaking strains to be not less than those shown on the table annexed.

Each coil will be tested in a testing machine by submitting a piece cut therefrom to the strain laid down in the table annexed for the particular size of cordage.

The acting length of the test piece will be one fathom from stop to stop of the machine.

6. *Weight.*—The weights shown in the annexed table are approximate only; supplies must not differ from these by more than 10 per cent.

7. *Samples.*—Patterns showing the make of cordage required may be seen on application to the Chief Inspector, Royal Arsenal, Woolwich, and the supply must in no particular be inferior thereto. Samples will be supplied when required to guide manufacture. Each will have a sealed label setting forth the nature of the cordage, and must be returned with the supply.

8. *Claim.*—No claim based on insufficiency of detail in this specification will be allowed, as the contractor may obtain a full explanation of the work, etc., as required, on application to the Chief Inspector, Royal Arsenal, Woolwich.

9. *Inspection.*—The cordage may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

Cordage—Various.

Size of Rope in Inches.	No. of Threads in Rope.	Tarred.							White.						
		Approximate Weight of Coil.				Breaking Strain.		Approximate Weight of Coil.				Breaking-Strain.	
		Of Fathoms.	cwts.	qrs.	lbs.	tons.	cwts	Of Fathoms.	cwts.	qrs.	lbs.	tons.	cwts.
Common Lashing.													
2½	42	125	1	2	10	1	18	—	—			—	
3	60	125	2	1	1	2	15	—	—			—	
3½	81	125	3	0	5	3	0	—	—			—	
4	108	125	4	0	7	4	0	—	—			—	
Lasso.													
2	36	—	—			—		102	0	2	24	1	10
Signal Halyard.													
1¼	27*	—	—			—		122	0	1	7	1	3

Coir, Hawser, 3-Strand.

Size of Rope in Inches.	Number of Threads in Rope.	Approximate Weight of Coil.				Breaking Strain.	
		Of Fathoms.	cwts.	qrs.	lbs.	tons.	cwts.
2½	3-strand	113	0	2	11	0	9½
3	3-strand	113	0	3	12	0	14
3½	3-strand	113	1	0	19	0	18½
4	3-strand	113	1	2	2	1	5½
5	3-strand	113	2	1	14	2	0
6	3-strand	113	3	1	21	2	17
7	3-strand	113	4	2	1	3	16
8	3-strand	113	6	0	11	4	17
9	3-strand	113	7	2	24	6	8

* 21 right way spun, 6 reverse way spun.

Cordage, Hemp, Hawser, 3-Strand.

Size in Inches.	Number of Threads in Rope	Tarred. Approximate Weight of Coil of 113 Fathoms.			Tarred. Breaking Strain.		White. Approximate Weight of Coil of 113 Fathoms.			White. Breaking Strain.		
		cwts.	qrs	lbs.	tons.	cwts.	cwts.	qrs.	lbs.	tons.	cwts.	
½	6	—	—	12½	—	3	—	—	10½	—	4¼	
¾	12	—	—	25	—	6	—	—	21	—	9	
1	15	—	1	3½	—	8	—	—	26½	—	12	
1¼	21	—	1	14	—	10	—	1	7	—	15	
1½	33	—	2	11	—	15	—	2	0	1	1	
1¾	42	—	3	1	1	0	—	2	15	1	8	40-thread yarn. Riga hemp for tarred. Italian hemp for white.
2	54	—	3	25	1	7	—	3	7	1	17	
2¼	66	1	0	21	1	14	—	3	27	2	7	
2½	84	1	2	1	2	0	1	1	1	2	18	
2¾	102	1	3	9	2	10	1	2	3	3	10	
3	120	2	0	17	3	0	1	3	5	4	4	
3¼	105	2	2	1	3	10	2	0	10	4	14	
3½	123	2	3	21	3	18	2	1	22	5	12	
4	159	3	3	5	5	0	3	0	18	7	5	30-thread yarn. Riga hemp for tarred. Italian hemp for white.
4½	201	4	3	5	6	9	4	0	0	9	5	
5	249	5	3	21	7	18	4	3	22	11	10	
6	360	8	2	9	11	10	7	0	17	16	10	
6½	351	10	0	4	12	16	8	1	13	17	5	
7	408	11	2	18	14	16	9	2	25	20	0	
7½	468	13	1	14	17	0	11	0	17	23	0	25-thread yarn. Petersburg for tarred. Italian for white.
8	534	15	1	1	19	8	12	2	25	26	0	
9	675	19	1	5	24	0	16	0	9	33	0	
12	1200	34	1	5	43	10	28	2	9	58	10	
16	—	—	—	—	—	—	—	—	—	110	0	

Cordage, Hemp, Bolt, 3-Strand.

Size in Inches.	Number of Threads in Rope.	Tarred.					White.					
		Approximate Weight of Coil of 122 Fathoms.			Breaking Strain.		Approximate Weight of Coil of 122 Fathoms.			Breaking Strain.		
		cwts.	qrs.	lbs.	tons.	cwts.	cwts.	qrs.	lbs.	tons.	cwts.	
½	6	—	—	12½	—	3¾	—	—	10½	—	4	40-thread yarn. Italian hemp.
¾	12	—	—	25	—	7½	—	—	21	—	8	
1	15	—	1	3½	—	9½	—	—	26½	—	12	
1¼	21	—	1	14	—	12½	—	1	7	—	15	
1½	33	—	2	11	—	19	—	2	0	1	2	
1¾	42	—	3	1	1	3	—	2	15	1	10	
2	54	—	3	25	1	10	—	3	7	1	17	
2¼	66	1	0	21	1	18	—	3	27	2	7	
2½	84	1	2	1	2	10	1	1	1	2	18	
2¾	102	1	3	9	3	0	1	2	3	3	14	
3	120	2	0	17	3	10	1	3	5	4	8	
3¼	105	2	2	1	4	0	2	0	10	4	16	30-thread yarn. Italian hemp.
3½	123	2	3	21	4	12	2	1	22	5	11	
4	159	3	3	5	6	0	3	0	18	7	5	
4½	201	4	3	5	7	12	4	0	0	9	3	
5	249	5	3	21	9	10	4	3	22	11	7	
7	489	11	2	17	18	10	9	2	24	21	15	
8	639	15	0	25	24	0	12	2	21	28	9	

Breaking Strains of Yarn.—A Yarn is 170 Fathoms

Standard Weight and Breaking Strain.	Size and Description of Thread.									
	20	25	25	25	30	30	40	40	50	80
	Petersburg.	Italian.	Riga.	Petersburg.	Italian.	Riga.	Italian.	Riga.	Italian.	Italian.
White.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Weight	$3\frac{1}{2}$	$2\frac{4}{5}$	—	—	$2\frac{1}{3}$	—	$1\frac{3}{4}$	—	$1\frac{2}{5}$	$\frac{7}{8}$
Breaking strain	140	140	Not in Service.		120	Not in Service.	85	Not in Service.	60	35
Tarred.										
Weight	$4\frac{1}{5}$	$3\frac{9}{25}$	$3\frac{9}{25}$	$3\frac{9}{25}$	$2\frac{4}{5}$	$2\frac{4}{5}$	$2\frac{1}{10}$	$2\frac{1}{10}$	Not in Service.	
Breaking strain	135	130	120	112	110	100	80	75		

Table of Cordage.

Description of Yarn and Cordage.	Description of Hemp.	Size of Yarn.	Size of Cordage.	Forming Distance.	Hardening Distance.	Length when Hard.	Laying Distance.	Length when Made.	Angle at which: Formed.	Angle at which: Hardened.	Angle at which: Laid.	Proportion of Twist by Laying Machines. No. of Turns. Fore.	Proportion of Twist by Laying Machines. No. of Turns. After.
Cordage, Tarred.				fms.	fms.	fms.	fms.	fms.					
Boltrope	Italian ...	40 30	3 inches and under ... 3½ ,, ,, upwards	152	8	144	22	122	27	32	36½	7½	10
Hawserlaid (3 strands)	Riga ... ... Riga ... ... Petersburg ...	40 30 25	3 ,, ,, under ... 3½ ,, to 6 inches... 6½ ,, and upwards	152	10	142	29	113	27	37	42	7	10
Common lashing ...	Petersburg Italian toppings Riga bands Petersburg bands Selected yarn	20	2½ ,, to 4 inches	Length to warp 170	25½	144½	19½	125	—	31¾	34¾	7½	10
Cordage, White.													
Boltrope	Italian ...	40 30	3 inches and under ... 3½ ,, ,, above ...	152	8	144	22	122	27	32	36½	7	10
Coir-hawserlaid	Coir yarn	—	2½ ,, to 9 inches...	142	3	139	26	113	27	37	42	7	10
Hawserlaid	Italian ...	40 30 25	3 ,, and under ... 3½ ,, to 6 inches... 6½ ,, and upwards	152	10	142	29	113	27	37	42	7	10
Lasso rope, cable laid ..	Italian	30	2 ,, strands ...	152	10	142	24	118	27	37	39	7¼	10
			closing ...	—	3	115	13	102	—	40¼	31	7	10
Signal halyards	Italian	50	1¼ ,, ...	139	—	133	—	122	27	34	36	—	—

CORDAGE, MANILLA.

SPECIFICATION TO GOVERN MANUFACTURE AND INSPECTION.

Approved, 12th May, 1899.

1. *Material and Workmanship.*—The whole of the material is to be manufactured from the best Manilla fibre.

Samples showing the make of the cordage required may be seen on application to the Chief Inspector, Woolwich, and the supply must in no particular be inferior thereto. The whole of the cordage is to be free from defects and imperfections of every description.

The tarred cordage must contain not more than one-seventh of its weight of tar. The hearts for four-stranded rope of 3-inch and under should be of spun yarn, and those above soft laid.

2. *Length and Weight of Coils.*—The length of the coils in which the cordage is to be supplied is given in the tables annexed; such lengths are to be exclusive of the fag-ends, and in all cases in one length.

The amount expended in testing will be supplied free of charge; the contractor will therefore only be paid for the length of serviceable cordage after inspection is completed.

The weight of coils shown in the appendix is approximate, but supplies must not differ by more than 10 per cent.

3. *Identification.*—Each contractor will be required to work a coloured thread into the cordage made by him, for the purposes of identification; particulars as to colour will be furnished by the Chief Inspector, Woolwich.

4. *Tests.*—Samples of the thread used will be tested to destruction by the inspector at the contractor's works. Each coil will be tested in a testing machine by submitting a piece cut therefrom to the strain laid down in the Appendix for the particular size of cordage. The acting length of the test piece will be one fathom from stop to stop of the machine.

5. *Marking.*—Each coil to have a label attached giving the following particulars :—

Name of Contractor.
Date of manufacture.
Size of rope and thread. } To be in accordance with the
Length of coil. } Appendix.

6. *Delivery.*—Each coil of cordage will be delivered tied with cordage of sufficient strength to allow the coil to be slung by any of the ties, such ties to be included in the cost of the cordage.

7. *Claim.*—No claim based on insufficiency of detail in this specification will be allowed, as the contractor may obtain a full explanation of the work, etc., as required, on application to the Chief Inspector, Woolwich.

8. *Inspection.*—The cordage may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

APPENDIX.

Manilla, Hawser, 3-Strand.

To be in Coils of 122 *Fathoms each.*

Size of Yarn.	Size of Rope in Inches.	Threads in Rope.	Approximate Weight of White.			Breaking Strain.		Approximate Weight of Tarred.			Breaking Strain.	
			cwts.	qrs.	lbs.	tons.	cwts.	cwts.	qrs.	lbs.	tons.	cwts.
40-thread	1	15	—	—	27	—	10½	—	1	3	—	9
	1½	33	—	2	0	—	18½	—	2	8	—	17
	2	54	—	3	7	1	12	—	3	20	1	9
	2½	84	1	1	1	2	8	1	1	21	2	6½
	3	120	1	3	5	3	13½	2	0	6	3	7
30-thread	3½	123	2	1	22	4	18½	2	3	6	4	9½
	4	159	3	0	18	6	7	3	2	12	5	16
	4½	201	4	0	0	7	14½	4	2	8	7	8
	5	249	4	3	22	10	2½	5	2	18	9	4
	5½	303	6	0	2	12	4	6	3	14	11	0
	6	360	7	0	17	14	8	8	0	19	13	4

Manilla, Hawser, 4-Strand.

To be in Coils of 113 *Fathoms each.*

Size of Yarn.	Size of Rope In Inches.	Threads in Strand.	Threads in Heart.	Total Threads in Rope.	Approximate Weight of White.			Breaking Strain.		Approximate Weight of Tarred.			Breaking Strain.	
					cwts.	qrs.	lbs.	tons.	cwts.	cwts.	qrs.	lbs.	tons.	cwts.
40-thread	1	3	2	14	—	—	24	—	8	—	—	27½	—	7
	1½	7	4	32	—	1	25	—	17	—	2	4½	—	14½
	2	12	5	53	—	3	4	1	9	—	3	16½	1	6½
	2½	20	7	87	1	1	4	2	3	1	1	24½	1	19
	3	28	10	122	1	3	6	3	6½	2	0	7	3	0
30-thread	3½	29	9	125	2	1	25	4	9	2	3	8	4	0
	4	37	12	160	3	0	17	5	14½	3	2	11½	5	3
	4½	47	15	203	4	0	0	6	19	4	2	8	6	5½
	5	58	21	253	4	3	25	9	2	5	2	20½	7	18½
	5½	71	24	308	6	0	7	11	0	6	3	20	9	18½
	6	84	30	366	7	0	21	12	19	8	0	24	11	13½

		Sample No.
CORDAGE	3-INCH, BOLT, WHITE, FOR TRACES	498
	$1\frac{3}{4}$,, ,, ,, ,, ,,	519

Approved, 29*th January*, 1898.

1. The cordage supplied must conform in all particulars to the respective sealed samples deposited at the Royal Dockyard, Woolwich.

2. It must be 3-strand, best white Italian hemp, well dressed, and equal in quality to that in the respective sealed samples. It is to be made from 40-thread yarn, evenly spun.

3. A yellow thread must be worked into one of the strands of the cordage, and each contractor will also be required, for purposes of identification, to work a thread or threads of other colours into a second strand; particulars as to colours will be furnished by the Chief Inspector of General Stores, Royal Dockyard, Woolwich.

4. The cordage is to be supplied in coils of 122 fathoms, exclusive of the fag-ends and test pieces, and in all cases in one length. The contractor will therefore only be paid for the length of serviceable cordage after inspection is completed. Each coil of 122 fathoms must not be less than 1 cwt. 3 qrs. 5 lbs. in weight for the 3-inch, and 2 qrs. 12 lbs. for the $1\frac{3}{4}$-inch.

5. Two and a-half fathoms will be cut from each coil for testing purposes. The acting length of the test piece will be one fathom from stop to stop of the machine. The breaking strain must not be less than 4 tons 8 cwts. for the 3-inch, and 1 ton 10 cwts. for the $1\frac{3}{4}$-inch.

6. The whole of the cordage must be free from defects and imperfections of every description, and must be delivered perfectly dry.

7. Each coil must be delivered tied with cordage of sufficient strength to allow the coil to be slung by any of the ties, such ties to be included in the cost of the cordage.

8. Each coil to have a label attached, giving the following particulars :—

Name of contractor.
Date of manufacture.
Size of rope and thread.
Length of coil.

9. If one-fourth of any delivery be found to be inferior to the respective sealed samples, or contrary to the terms of this specification, the whole delivery may be rejected.

10. Should the samples lent or exhibited to the contractor differ from the respective sealed samples or specification, the differences will be detailed on the label attached thereto ; but the sealed samples, as described by this specification, must be strictly adhered to in the supply.

CORDAGE, ITALIAN HEMP, TANNED, 1-INCH.

Specification to Govern Manufacture and Inspection.

Approved, 27th January, 1896.

1. The cordage to be of the best material and workmanship throughout, and to conform in all particulars to the pattern deposited in the Pattern Room, Carriage Inspection Division, Royal Arsenal, Woolwich.

2. The cordage to be made from the best Italian hand-dressed hemp; to be of three strands, each containing three yarns properly tanned, and laid up "soft" to agree with the pattern.

3. *Length and Weight.*—Each coil to be 128 fathoms in length (exclusive of the piece for testing), and not to exceed 28 lbs. in weight.

4. *Tests.*—The cord to bear a strain of 1,300 lbs. The test piece to be not less than 9 feet long, and to be cut from any part at the option of the inspector.

5. The amount expended in testing to be supplied free of charge; the contractor will therefore be paid only for the length of serviceable cordage after inspection is completed.

6. *Samples.*—Samples showing the make of cordage required may be seen on application to the inspector, and the supply must in no particular be inferior thereto.

7. *General Conditions.*—Each coil to have a label attached giving the following particulars:—

Name of contractor.
Date of manufacture.

8. Each coil to be delivered tied with cordage of sufficient strength to allow it to be slung by any of the ties; such ties to be included in the cost of the cordage.

9. No claim based on insufficiency of detail in this specification will be allowed, as the Contractor may obtain a full explanation of the work, etc., as required, on application to the inspector.

10. The cordage may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

CORDAGE (VARIOUS).

SPECIFICATION TO GOVERN MANUFACTURE AND INSPECTION.

Approved, 26th March, 1900.

1. *General.*—The cordage supplied is to conform in all particulars with the sealed patterns and with this specification.

The length and weight of the coils or skeins in which the cordage is to be supplied is given in the Appendix. The weights of each skein or coil are shown approximately, and are subject to an allowance of 5 per cent. above or below the weights laid down, the high limit being the maximum for which the contractor will be paid.

2. *Material and Workmanship.*—The whole of the material is to be manufactured from the best material of its class, whether Italian, Riga, or Petersburg hemp, and the cordage is to be free from defects and imperfections of every description.

The tarred cordage must be made from well-seasoned yarn, and contain not more than one-sixth of its weight of tar.

3. *Marking.*—Each coil to have a label attached giving the following particulars :—

Name of contractor.
Date of manufacture.
Nature of cordage and size of thread. } To be in accordance with
Length of coil. } the annexed tables.

4. *Delivery.*—Each coil of the cordage and deep-sea line will be delivered tied with cordage of sufficient strength to allow the coil to be slung by any of the ties, such ties to be included in the cost of the cordage. Hambro' lines will be delivered in skeins, and box lines in coils.

5. *Samples.*—Patterns showing the make of cordage required may be seen on application to the Chief Inspector, Royal Arsenal, Woolwich, and the supply must in no particular be inferior thereto. Samples will be supplied when required to guide manufacture. Each will have a sealed label setting forth the nature of the cordage, *which must not be removed*, and must be returned with the supply.

6. *Claim.*—No claim based on insufficiency of detail in this specification will be allowed, as the contractor may obtain a full explanation of the work, etc., as required, on application to the Chief Inspector, Woolwich.

7. *Inspection.*—The cordage may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

Cordage—Various.

Size of Cordage in Inches.	Number of Threads in Rope.	Approximate Weight of Coil. Of Fathoms.	cwts.	qrs.	lbs.
Cordage, White, Packing.—Russian Hemp.					
$1\frac{1}{2}$	9	280*	1	0	0
$1\frac{3}{4}$	12	200*	1	0	0
2	15	155*	1	0	0
Cordage, White, Spun Yarn.—Flax.					
5-thread—10 yards to 1 lb.		280*	0	2	0
Line, Hambro'.—Russian Hemp.					
3-strand, 12-thread.	Russian Hemp	20	0	0	3
Line, White, Deep Sea.—Cable Laid.					
3-strand, 18-thread		42	0	0	$9\frac{1}{2}$
Line, Box.—Hemp.					
Large. 3-strand, 6-thread		196*	0	1	0
Small. 3-thread		280*	0	1	0

* In lengths as long as possible, but not less than 30 fathoms.

Table of Cordage.

Description of Yarn and Cordage.	Description of Hemp.	Size of Yarn.	Size of Cordage.	Forming Distance.	Hardening Distance.	Length when Hard.	Laying Distance.	Length when Made.	Angle at which Hardened.	Angle at which Laid.
Cordage, Tarred.				fms.	fms.	fms.	fms.	fms.	deg.	deg.
Seizing or Nettlestuff*	Riga	40	3 yarn (reverse spun)	85	3	82	7	75	27	22
Yarn, spun*...	Petersburg ... ... Italian toppings ... Riga bands ... ... Petersburg bands ... Selected yarn ...	20	1, 2, 3, 4, 6, 10 thread	—	—	—	—	—	28	—
Cordage, White.										
Yarn, spun*...	Petersburg ... ... Riga bands ... ... Petersburg bands ... Italian toppings ...	20	2, 3, 4, 5, 6, 10 thread	—	—	—	—	—	28	—
		No. of threads								
Lines, White ...	Italian	21 15 15 12 9 9 6	Skein of 4 lbs. ... ,, 3 ,, ... ,, $2\frac{1}{2}$,, ... ,, 2 ,, ... ,, $1\frac{1}{2}$,, ... ,, 1 ,, ... ,, $\frac{3}{4}$,, ...	28	—	$23\frac{1}{2}$	—	20	34	$40\frac{1}{2}$

* To be supplied in coils of 56 lbs. weight.

TWINE.

Approved 5*th June*, 1900.

			Pattern No.	Approved.
TWINE	*Baling*, 3-thread, blue strand ...		3115	1. 11. 66 57 / 24 / 4378
	Choking ...	5-thread	3123	28. 8. 62 57 / Woolwich / 4197
		3-thread	3127	13. 10. 84 57 / 24 / 9938 (3127, 3108, 3109)
	Packing ...	Large	3108	
		Middling	3109	
		Small	3103	22. 4. 72 ... / 6756
	Sail-sewing, plain		3122	13. 10. 84 ... / 9938
	Roping		3112	29. 5. 88 57 / 2 / 4224
	Quilting		3125	24. 4. 58
	Whipping ...	Fine	3110	29. 5. 88 57 / 2 / 4224 (3110, 3111)
		Coarse	3111	

1. The twine supplied must conform in all particulars (as regards make) to the respective sealed patterns deposited at the Royal Dockyard, Woolwich. This yarn may, however, be spun by hand or machine.

2. The baling, packing, and quilting twines to be made from good long Russian hemp. The choking twine to be made from good Italian hemp. The sail, roping, and whipping twines to be made from flax. All to be clean, well dressed, well made, and to be delivered perfectly dry. The twine made up in balls must be perfectly dry before being balled.

3. The blue strand in the baling twine is to be similar in colour to that in the sealed pattern, and the dye is to be sound. The twine is to be from 180 to 190 yards in length per lb., and to be delivered in ½-lb. balls, or 20 balls to every 10 lbs.

4. The choking twine, 5-thread, to be from 310 to 330 yards in length per lb.; the 3-thread from 1,240 to 1,300 yards per lb. Both to be delivered in ½-lb. balls, or 20 balls to every 10 lbs.

5. The large packing twine to be 4-thread; to be from 55 to 60 yards in length per lb.; and to be delivered in 1-lb. balls, or 10 balls to every 10 lbs.

6. The middling packing twine to be 3-thread; to be from 130 to 140 yards in length per lb.; and to be delivered in ½-lb. balls, or 20 balls to every 10 lbs.

7. The small packing twine is to be 2-thread; to be from 320 to 330 yards in length per lb.; and to be delivered in ½-lb. balls, or 20 balls to every 10 lbs.

8. The quilting twine to be 3-thread. It is to be delivered in ½-lb. balls, or 20 balls to every 10 lbs.

9. All the twine supplied in balls must be tied securely together in bundles of 10 lbs. each, before being papered.

10. The sail twine to be 3-thread. It is to be delivered in ½-lb. hanks, and in paper parcels containing 10 lbs. each.

11. The roping twine to be 3-thread. It is to be delivered in ½-lb. hanks, and in paper parcels containing 10 lbs. each.

12. The whipping twine, fine and coarse, to be 2-thread. It is to be delivered in ½-lb. hanks, and in paper parcels containing 10 lbs. each.

13. All weights must be exclusive of the paper.

14. All packages are to be so marked that the goods contained in them may be easily identified with the invoice.

15. If one-fourth of any delivery be found to be inferior to the respective sealed patterns, or contrary to terms of this specification, the whole delivery may be rejected.

16. Should the samples lent or exhibited to the contractor differ from the respective sealed patterns or specification, the differences

will be detailed on the labels attached thereto; but the sealed patterns, as described by this specification, must be strictly adhered to in the supply.

ROPE, STEEL, WIRE, MARK I. (GALVANIZED).

SPECIFICATION TO GOVERN MANUFACTURE AND INSPECTION.

Approved, 2nd June, 1899.

1. *General.*—The rope supplied is to conform in all particulars with the sealed patterns and with this specification.

2. *Material.*—The rope is to be made of wire drawn from the best homogeneous steel, and galvanized or electro-plated, at the option of the contractor, with zinc containing not more than 2 per cent. impurities, and is to conform in every respect to this specification.

3. *Manufacture.*—The rope is to be laid up evenly and uniformly throughout as regards size and angle; and the wires in the strands and the strands in the ropes are to be laid up in opposite directions. The rope is to contain a proper-sized hempen rope heart or core, and each strand is also to contain a proper-sized jute rope heart or core. The cores are to be saturated with an anti-corrosive composition consisting of pine oil and tallow.

4. *Galvanizing.*—The galvanizing is to be of the best quality, and each wire must be completely coated. This will be tested by immersing a sample of the galvanized wire in a saturated solution of sulphate of copper at 60 degrees Fahrenheit for a period of one minute; it will then be washed in clean water and wiped with a clean rag. The galvanizing must admit of this process being performed three times for ordinary ropes and four times for submarine mining rope with each sample, without any sign of a deposit of metallic copper on the wire.

5. *Weight.*—The weight per fathom is to be as laid down in the Appendix at the end of this specification; a latitude not exceeding 5 per cent. over or under the prescribed weights will be allowed.

6. *Wire Tests.*—Each wire of a number to be selected by the inspector will be subjected to a torsion test, as laid down in the Appendix; the length in which the specified number of turns is to be taken will be 8 inches.

7. *Tensile Tests.*—The rope is to be tested as to tensile strength by means of the hydraulic testing machine in use for that purpose at the Royal Arsenal, Woolwich; the method of securing the rope for

testing to be by grooved wedges or holders, or by splicing each end of the rope round a thimble of suitable size, at the option of the inspector. The length tested in the clear between the points of securing to be 1 fathom, and the strain to be gradually applied till the breaking of the rope.

The elongation is to be first measured when $\frac{1}{6}$, and again measured when $\frac{4}{5}$, of the standard strain has been applied. The standard breaking strain for different sizes of rope is laid down in the Appendix.

8. *Samples for Tests.*—Samples from each delivery of rope will be tested to destruction, and should any break at a strain less than the standard, or fail to pass the torsion or galvanizing tests, the lot from which the sample is taken will be rejected.

The amount of rope used for testing will be supplied free of charge, and will be deducted from the total amount of rope accepted for payment. The inspector may, if he consider it necessary, test each coil delivered.

9. *Delivery and Marking.*—The wire rope is to be delivered in coils of the length stated in the Appendix, each coil having at least four good wire binders. A brass label is to be attached to the inner end of each coil, bearing the maker's name, year of supply, and length in fathoms, thus :—

Name of maker,
Length of coil,
Size of rope, and
Year of supply,

stamped on it.

10. *Claim.*—No claim based on insufficiency of detail in this specification will be allowed, as the contractor may obtain a full explanation of the work, etc., as required, on application to the Chief Inspector, Woolwich.

11. *Inspection.*—The rope may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

APPENDIX.

Size of Rope.	Strands in Rope.	Wires in Strand.	Weight per Fathom.	Torsion Test for a Wire of the Rope.	Standard for Breaking or Receiving Strain to be not less than	Elongation.	No. of Fathoms in Coil.
Inches.			lbs.	No. of turns.	tons.	Per cent.	
6	6	30	31	15	84	7	100
$5\frac{1}{2}$	6	24	28	15	71	7	100
5	6	24	23	17	59	7	100
$4\frac{1}{2}$	6	12	15	15	39	5	100
4	6	12	12	17	31	5	100
$3\frac{1}{2}$	6	12	9	18	24	5	100
3	6	12	7	22	17	5	100
$2\frac{3}{4}$	6	12	$5\frac{1}{2}$	25	$14\frac{1}{2}$	5	100
$2\frac{1}{2}$	6	12	$4\frac{1}{2}$	26	12	5	100
$2\frac{1}{4}$	6	12	$3\frac{3}{4}$	28	9	5	100
2	6	12	$2\frac{3}{4}$	33	7	5	100
$1\frac{3}{4}$	6	12	2	36	$5\frac{1}{2}$	5	100
$1\frac{1}{2}$	6	12	$1\frac{3}{4}$	41	4	5	100
$1\frac{1}{4}$	6	12	$1\frac{1}{4}$	47	$2\frac{7}{8}$	5	100
1	6	12	$\frac{3}{4}$	60	$1\frac{3}{4}$	5	100
			ozs.				
$\frac{3}{4}$	6	6	$7\frac{1}{4}$	75	$1\frac{1}{2}$	5	100
					cwts.		
$\frac{1}{2}$	6	6	3	80	10	5	100
$\frac{7}{16}$	6	6	$2\frac{3}{4}$	90	8	5	100
$\frac{3}{8}$	6	6	$2\frac{1}{4}$	100	6	5	200

ROPE, GALVANIZED STEEL WIRE, | L | FLEXIBLE 1¾ INCHES, MARK II.

SPECIFICATION TO GOVERN MANUFACTURE AND INSPECTION.

Approved, 29th August, 1899.

1. *General.*—The rope supplied is to conform in all particulars with the sealed pattern and with this specification.

2. *Material.*—The rope is to be made of wire drawn from the best homogeneous steel, and galvanized, or electro-plated, at the option of the contractor, with zinc containing not more than 2 per cent. of impurities.

3. *Manufacture.*—The rope is to be laid up evenly and uniformly throughout as regards size and angle; and the wires in the strands and the strands in the ropes are to be laid up in opposite directions. The rope is to contain a proper-sized hempen rope heart or core.

4. *Galvanizing.*—The galvanizing is to be of the best quality, and each wire must be completely coated. This will be tested by immersing a sample of the galvanized wire in a saturated solution of sulphate of copper at 60 degrees Fahrenheit for a period of one minute; it will then be washed in clean water and wiped with a clean rag. The galvanizing must admit of this process being performed four times with each sample without any sign of a deposit of metallic copper on the wire.

5. *Weight.*—The weight per fathom is to be 2 lbs. 10½ ozs.; a latitude not exceeding 5 per cent. over or under the prescribed weight will be allowed.

6. *Wire Tests.*—Each wire of a number to be selected by the inspector will be subjected to a torsion test, as laid down in the Appendix; the length in which the specified number of turns is to be taken will be 8 inches.

7. *Tensile Tests.*—The rope is to be tested as to tensile strength by means of the hydraulic testing machine in use for that purpose at the Royal Arsenal, Woolwich; the method of securing the rope for testing to be by grooved wedges or holders, or by splicing each end of the rope round a thimble of suitable size, at the option of the inspector. The length tested in the clear between the points of securing to be one fathom, and the strain to be gradually applied till the breaking of the rope.

The elongation is to be first measured when $\frac{1}{6}$, and again measured when $\frac{4}{5}$, of the standard strain has been applied. The standard breaking strain is laid down in the Appendix.

8. *Samples for Test.*—Samples from each delivery of rope will be tested to destruction, and should any break at a strain less than the standard, or fail to pass the torsion or galvanizing tests, the lot from which the sample is taken will be rejected.

The amount of rope used for testing will be supplied free of charge, and will be deducted from the total amount of rope accepted for payment. The inspector may, if he consider it necessary, test each coil delivered.

9. *Delivery and Marking.*—The wire rope is to be delivered in coils of the length stated in the Appendix, each coil having at least four good wire binders. A brass label is to be attached to the inner end of each coil, bearing the maker's name, year of supply, and length in fathoms, thus :—

Name of maker,
Length of coil,
Size of rope, and
Year of supply,

stamped on it.

10. *Claim.*—No claim based on insufficiency of detail in this specification will be allowed, as the contractor may obtain a full explanation of the work, etc., as required, on application to the Chief Inspector, Woolwich.

11. *Inspection.*—The rope may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

APPENDIX.

Size of Rope.	Strands in Rope.	Wires in Strand.	Weight per Fathom.	Torsion Test for a Wire of the Rope.	Standard for Breaking or Receiving Strain to be not less than	Elongation.	No. of Fathoms in Coil.
Inches.			lbs. ozs.	No. of turns.	tons.	Per cent.	
$1\frac{3}{4}$	6	37	2 $10\frac{1}{2}$	100	10	5	100

ROPE, GALVANIZED, STEEL WIRE, $\frac{3}{4}$-INCH, SPECIAL MARK I. | L | (FOR RUNNING TARGETS, SHOEBURYNESS).

SPECIFICATION TO GOVERN MANUFACTURE AND INSPECTION.

Approved, 20*th December*, 1900.

1. *General.*—The rope is to conform in all particulars with the sealed pattern and with this Specification.

2. *Material.*—The rope is to be made of wire, drawn from the best homogeneous steel, and galvanized with zinc containing not more than 2 per cent. of impurities.

3. *Manufacture.*—The rope is to be laid up evenly and uniformly throughout as regards size and angle, and is to be composed of a strand of 7 wires, each ·072 inch in diameter (No. 15 S.W.G.). The strand is to laid up as follows :—

The centre wire to be straight, and the remaining six wires to be laid up helically with a left hand lay of 3·5 inches. Each wire is to be of uniform diameter and circular section, and to be free from cracks, splits, welds, or flaws.

4. *Galvanizing.*—The galvanizing is to be of the best quality, and each wire must be completely coated. This will be tested by immersing a sample of the galvanized wire in a saturated solution of sulphate of copper at 60 degrees Fahrenheit, for a period of one minute ; it will then be washed in clean water and wiped with a clean rag. The galvanizing must admit of this process being performed four times with each sample without any sign of a deposit of metallic copper on the wire.

5. *Weight.*—The weight should be about 28 lbs. per 100 yards ; a latitude not exceeding 5 per cent. over or under the prescribed weight will be allowed.

6. *Wire Tests.*—Each wire of a number to be selected by the inspector is to have a breaking strain of not less than 910 lbs., and to be capable of taking not less than 15 twists in 8 inches.

7. *Tensile Tests.*—The rope is to be tested as to tensile strength by means of the hydraulic testing machine in use for that purpose at the Royal Arsenal, Woolwich ; the method of securing the rope for testing to be by grooved wedges or holders, or by splicing each end of the rope round a thimble of suitable size, at the option of the Inspector. The length tested in the clear between the points of

securing to be one fathom, and the strain to be gradually applied till the breaking of the rope.

The breaking strain is to be at least 5,400 lbs.

8. *Samples for Tests.*—Samples from each delivery of rope will be tested to destruction, and should any break at a strain less than the standard, or fail to pass the torsion or galvanizing tests, the lot from which the sample is taken will be rejected.

The amount of rope used for testing will be supplied free of charge, and will be deducted from the total amount of rope accepted for payment. The Inspector may, if he consider it necessary, test each rope delivered.

9. *Delivery and Marking.*—The wire rope is to be delivered in continuous lengths of 4,000 yards, neatly coiled on suitable wood drums. The exposed portion of the wire to be covered with canvas. The drums to become the property of the War Department. A brass label is to be attached to each rope, bearing the maker's name, year of supply, and length in fathoms, thus:—

Name of maker,
Length of coil,
Size of rope, and
Year of supply,

stamped on it.

10. *Claim.*—No claim based on insufficiency of detail in this specification will be allowed, as the contractor may obtain a full explanation of the work, etc., as required, on application to the Chief Inspector, Woolwich.

11. *Inspection.*—The rope may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

CHAIN, IRON (Short Link or Crane. Stud Link or Cable).

Specification to Govern Manufacture and Inspection.

Approved, 9th March, 1898.

1. *General.*—The chain supplied is to conform in all particulars with this specification.

2. *Material and Workmanship.*—The iron from which the chain is to be made is to be of the best smithing quality; when nicked and broken it is to show a good fibre throughout, and must be capable of sustaining

a tensional strain of 23 tons per square inch, with a reduction of area of not less than 50 per cent. at the point of fracture, and an elongation of 17 per cent. in a length of 4 inches. It must also stand the forge tests in use at the Royal Arsenal, Woolwich, viz. :—Ram's horn, punching (diameter of punch = $1\frac{1}{4}$ diameter of iron), and bending cold through 180 degrees.

The workmanship throughout must be of the best quality. All welds are to be scarfed and dollied. In chains under $\frac{3}{8}$ inch the points of the links are to be crossed, welded, and dollied.

The difference between the link at the weld and the ordinary section of the iron from which the link was made in each description of chain must not exceed 1 per cent. in diameter.

3. *Samples for Test.*—For the purpose of testing the material before manufacture the contractor is to give notice to the inspector when the iron is ready at the works, in order that the inspector or his deputy may attend to see three samples for testing cut from each size ; each sample is not to be less than 12 inches long. The contractor is to cut and forward these samples at his own expense to the inspector.

No iron is to be used in the manufacture of chain until the contractor has received, in writing, from the inspector a notification that it has been approved.

4. *Cost of Samples.*—No charge for any samples of iron or of chain taken for testing will be allowed, and the contractor must supply for this purpose an additional 3 feet per 100 fathoms or less actually ordered, which will be deducted from the amount accepted for payment.

5. *Inspection of Chain during Manufacture.*—The inspector or his representative may attend to watch manufacture, and take such samples of chain as may be considered necessary from the men at the fires, for testing to destruction in the machine at the contractor's works.

Construction.

6. *Shackles, Swivels, etc.*—The chain is to be provided with such large links, joining shackles, and swivels as may be ordered, the dimensions of such fittings to be the same as in those supplied to the Admiralty for the respective sizes of chain. The stud-link chain to be provided with proper cast-iron studs to each link.

7. *Size of Links.*—For short-link chain the links must not exceed 5 diameters of iron in length and 3·6 diameters in width across the

centre, or be less than 4·8 in length and 3·4 in width. For stud-link chain the links must not exceed 6 diameters of iron in length and 3·6 diameters in width across the centre, or be less than 5·8 diameters in length and 3·4 diameters in width.

8. *Size and Weight of Chains.*—The size of a chain is measured by the diameter of the iron of its ordinary or common links, and each size of chain must agree with the particulars enumerated in the Appendix. A latitude not exceeding 5 per cent. over or under the prescribed weights will be allowed.

9. *Marking.*—The following is to be legibly stamped at each end of every length :—

Name of maker.
Year of manufacture.

10. (*a*). *Testing.*—For purposes of test portions of the chain will be cut from the lengths of chain delivered, as the inspector may direct. Each test piece so taken will not be less than 36 inches in length. These pieces will be subjected to the loads shown in the Appendix, which they must stand without breaking.

(*b*). The complete chain will be tested to the proof strain, and should any length fail to stand this strain or show any sign of defect during or after test, it will be rejected, and should the links, when nicked and broken, not show a good fibrous quality of iron equal in every way to the samples of bar iron sent to be tested (a portion of which may be kept for reference), the length to which the piece belongs will be rejected.

When each length of chain is under the proof load, each link will be tapped with a hammer and examined, to see that the weld is sound.

11. *Galvanizing.*—The chain is to be delivered self-coloured, except the lengths ordered "galvanized," which are to be galvanized with zinc, having not more than 2 per cent. of impurities ; the galvanizing is to be clean and free from defects, and capable of standing being dipped four times in a saturated solution of sulphate of copper at 60 degrees Fahrenheit for a period of one minute at each dip, it being wiped clean after each dip, and must not show any sign of deposition of copper when the test is completed.

12. *Claim.*—No claim based on insufficiency of detail in this specification will be allowed, as the contractor may obtain a full explanation of the work, etc., as required, on application to the Chief Inspector, Woolwich.

13. *Inspection.*—The chain may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

Appendix.

Diameter of Iron.	Short Link or Crane Chain.			Stud Link or Cable Chain.			Diameter of Iron.
	Weight per Fathom.	Proof Strain.	Load on Test Piece.	Weight per Fathom.	Proof Strain.	Load on Test Piece.	
Inches.	lbs.	tons.	tons.	lbs.	tons.	tons.	inches.
$\frac{1}{4}$	$4\frac{1}{2}$	$\frac{3}{4}$	$1\frac{1}{2}$	$3\frac{1}{2}$	$1\frac{1}{8}$	$1\frac{3}{4}$	$\frac{1}{4}$
$\frac{5}{16}$	$6\frac{1}{4}$	$1\frac{1}{8}$	$2\frac{3}{8}$	5	$1\frac{3}{4}$	$2\frac{5}{8}$	$\frac{5}{16}$
$\frac{3}{8}$	9	$1\frac{5}{8}$	$3\frac{1}{4}$	$7\frac{1}{2}$	$2\frac{3}{8}$	$3\frac{5}{8}$	$\frac{3}{8}$
$\frac{7}{16}$	12	$2\frac{1}{4}$	$4\frac{1}{2}$	$11\frac{1}{4}$	$3\frac{1}{2}$	$5\frac{1}{4}$	$\frac{7}{16}$
$\frac{1}{2}$	16	3	6	$15\frac{1}{2}$	$4\frac{1}{2}$	$6\frac{3}{4}$	$\frac{1}{2}$
$\frac{9}{16}$	20	$3\frac{3}{4}$	$7\frac{1}{2}$	19	$5\frac{1}{2}$	$8\frac{1}{4}$	$\frac{9}{16}$
$\frac{5}{8}$	25	$4\frac{5}{8}$	$9\frac{1}{4}$	23	7	$10\frac{1}{2}$	$\frac{5}{8}$
$\frac{11}{16}$	29	$5\frac{5}{8}$	$11\frac{1}{4}$	28	$8\frac{1}{2}$	$12\frac{3}{4}$	$\frac{11}{16}$
$\frac{3}{4}$	$35\frac{1}{2}$	$6\frac{3}{4}$	$13\frac{1}{2}$	34	$10\frac{1}{8}$	$15\frac{3}{16}$	$\frac{3}{4}$
$\frac{13}{16}$	41	$7\frac{9}{16}$	$15\frac{3}{4}$	39	$11\frac{7}{8}$	$17\frac{3}{4}$	$\frac{13}{16}$
$\frac{7}{8}$	49	$9\frac{1}{8}$	$18\frac{1}{4}$	45	$13\frac{3}{4}$	$20\frac{5}{8}$	$\frac{7}{8}$
$\frac{15}{16}$	54	$10\frac{1}{2}$	21	51	$15\frac{3}{4}$	$23\frac{5}{8}$	$\frac{15}{16}$
1″	62	12	24	58	18	27	1″
$1\frac{1}{8}$	75	$15\frac{1}{8}$	$30\frac{1}{2}$	72	$22\frac{3}{4}$	$34\frac{1}{8}$	$1\frac{1}{8}$
$1\frac{1}{4}$	95	$18\frac{3}{4}$	$37\frac{1}{2}$	90	$28\frac{1}{8}$	$42\frac{1}{4}$	$1\frac{1}{4}$
$1\frac{3}{8}$	112	$22\frac{5}{8}$	$45\frac{1}{4}$	108	34	51	$1\frac{3}{8}$
$1\frac{1}{2}$	135	27	54	130	$40\frac{1}{2}$	$60\frac{3}{4}$	$1\frac{1}{2}$

BLOCKS, MALLEABLE CAST IRON, GALVANIZED, SINGLE DOUBLE, TREBLE, AND SNATCH.

SPECIFICATION TO GOVERN MANUFACTURE AND INSPECTION.

Approved, 27th September, 1899.

1. The blocks must conform with this specification, and in form and dimensions (within reasonable manufacturing limits) with the patterns deposited in the Pattern Room, Royal Arsenal, Woolwich.

The size of rope to be used in the respective blocks, the test load of each block, and the test load of the beckets are to be as laid down in the Appendix.

All blocks are to be furnished with beckets and thimbles, except when otherwise ordered.

When blocks are ordered of which no pattern is held, the contractor is to submit a sample block for approval before the remainder of the order is executed.

2. *Material and Workmanship.*—The whole of the materials are to be of the best description, and the blocks in finish and workmanship equal to the patterns, and to the entire satisfaction of the inspector.

3. *Shells.*—The shells, sheaves, and snatches are to be made of the best malleable cast iron, free from flaws, blow-holes, or other defects, and properly annealed. Any portion cut therefrom is to have a tensile strength of 20 tons per square inch of original section, with an elongation of 3 per cent. in 2 inches, and to bend through an angle of 135 degrees without showing signs of fracture.

The shells after annealing are to be trimmed clean, the edges well rounded, the centre bored to fit the sheave pin, and the head bored and faced for the shank collar and nut of the hook, or loop.

4. *Furniture.*—Each block is to be furnished with either swivel or fixed hook, swivel or fixed loop, shackle or loose hook, as may be ordered.

Swivel Hook.—To be made of the best mild steel, neatly forged or stamped, turned and screwed at the shank, and secured in the shell by a wrought iron screwed collar riveted to prevent it unscrewing or screwing up; all sharp edges and corners are to be neatly rounded, and when finished and fitted the hook must swivel quite freely both with and without the load.

Fixed Hook.—To be made of the best mild steel, forged or stamped, and in shape similar to the swivel hook, but secured by screwing the collar until the hook is fixed, and riveting the end of the screw over.

Loop and Shackle or Loose Hook.—The loop is to be made of the best mild steel, forged or stamped, secured to the shell in a similar manner to the fixed or swivel hook, and of sufficient size to easily take the shackle or loose hook of necessary strength. The shackle is to have a steel bolt passing through the two ends, provided with a flat head, and secured in position with a steel split pin. The loose hook is to have an eye at the lower end passed through the loop and welded to the shank of the hook.

5. *Sheaves.*—The sheaves are to be cast hollow as shown, turned in the groove, faced on the bosses, bored to revolve truly and freely on the pins, and made interchangeable on blocks of the same size and description.

6. *Pins.*—The sheave pins are to be made of the best mild steel, forged, turned to Whitworth standard gauges, and made interchangeable in blocks of the same description and size. They are to have a solid head at one end, the other being bevelled off and the edges rounded, a hole being drilled through the bevelled end to take a steel split pin. For snatch blocks the pin is passed through from the side on which the snatch is fixed, prevented from turning by a feather, and fixed at the other side by a nut.

7. *Beckets.*—The beckets are to be cast solid on the shells, must stand the strain specified in the Appendix, and be of sufficient size to take the rope with the thimble in.

8. *Thimbles.*—The thimbles are to be made of wrought iron, forged and set to take a proper bearing on the inner surface of the beckets.

9. *Snatches.*—With snatch blocks the snatches are to be bored and fitted to work freely upon turned wrought-iron joint pins, and to take a proper bearing upon the projections on the shell when closed; the holes are to be bored out and counter-sunk to clear the sheave pins.

10. *Hooks for Snatches.*—The securing hooks for the snatches are to be of wrought iron, forged or stamped to work freely on the wrought-iron joint pins riveted into the snatches, and to fit the holes in the sheave pins properly, so that they will not work out in any position of the blocks.

11. *Galvanizing.*—After the blocks have been fitted up, the whole of the parts are to be well galvanized, the sheave pins and holes in the sheaves for the same wiped smooth, and the blocks put together and adjusted to work quite freely.

12. *Marking.*—The shell of each block is to have cast upon one side the size of the block and the size of the rope, and upon the reverse side the year of supply and the manufacturer's initials or recognized trade mark, thus :—

3″ rope	1899.
8 in.	A.B.
	LONDON.

The letters and figures to be raised above the surface and clearly defined.

13. *Tests.*—Each block is to be tested with the specified load ; for this purpose it is to be rove with a hemp or wire rope fall, and the load brought upon the hook by hauling the running end of the fall by a crab winch or hydraulic testing machine.

After the blocks have satisfactorily passed the foregoing test, the beckets are to be tested with the specified weights according to their size.

14. *Claim.*—No claim based on insufficiency of detail in this specification or the drawing will be allowed, as the contractor may obtain a full explanation of the work, etc., as required, on application to the Chief Inspector, Woolwich.

15. *Inspection.*—The blocks may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

Appendix.

Description of Block.	Size of Block.	Size of Rope.	Maximum Working Strain of Rope. $\frac{C^2}{8}$	Test Load of Block.	Test Load of Becket.
	inches.	inches.	cwts.	cwts.	cwts.
Single or snatch	4	$1\frac{1}{2}$		18	
Double	4	$1\frac{1}{2}$	$5\frac{5}{8}$	29	6·5
Treble....................	4	$1\frac{1}{2}$		37	
Single or snatch	5	2		30	
Double	5	2	10	45	10
Treble..	5	2		58	
Single or snatch	7	$2\frac{1}{2}$		51	
Double	7	$2\frac{1}{2}$	$15\frac{5}{8}$	76	17
Treble....................	7	$2\frac{1}{2}$		97	
Single or snatch	8	3		73	
Double	8	3	$22\frac{1}{2}$	107	25
Treble....................	8	3		136	
Single or snatch	10	$3\frac{1}{2}$		93	
Double	10	$3\frac{1}{2}$	$30\frac{5}{8}$	141	31
Treble.............	10	$3\frac{1}{2}$		180	
Single or snatch	12	4		121	
Double	12	4	40	184	40
Treble....................	12	4		238	
Single or snatch	14	5		193	
Double	14	5	$62\frac{1}{2}$	291	63
Treble................ ...	14	5		372	

TACKLES, DIFFERENTIAL | L | WESTON'S.

Specification to Govern Manufacture and Inspection.

Approved, 2nd March, 1900.

1. *General.*—The tackles are to conform in all particulars with this specification.

2. The proportions of the several sizes, the dimensions of the chains, etc., and the material of which the several parts are to be made are stated in the table given on page 233, and these must be strictly adhered to in the supplies.

3. *Material and Workmanship.*—The materials used in the manufacture of these tackles are to be of the best quality, and the best workmanship is to be employed.

Construction.

4. *Guides.*—Each tackle is to be fitted with chain guides, having wrought-iron arms and malleable cast-iron guides ; the arms are to be bored out, the guides turned to swivel therein to any angle, and so fitted that the chain will pass quite freely through them.

5. *Chains.*—Unless otherwise ordered, each tackle, up to and including the size to lift $1\frac{1}{2}$ tons is to be fitted with 40 feet of lifting chain, and the remaining sizes with 26 feet of lifting chain and 20 feet of hand chain. The lifting and hand chains are to be fully equal to the breaking strength given in the table, the links being blocked, and the chains finished bright.

6. *Frames and Pins.*—The frames for both the top and the bottom blocks are to be truly bored out for the sheave pin and hook, and the pins truly turned throughout and secured in the frames by the steel split pins.

7. *Hooks.*—The hooks are to be soundly forged, turned at the neck, screwed, and secured in the frames by a screwed wrought-iron collar, having the end of the hook riveted over with sufficient clearance under the collar to allow the hook to swivel quite freely. The hooks are to be of sufficient strength to withstand the test load without opening.

8. *Sheaves and Sprocket Wheels.*—The sheaves (except the one in bottom block) and sprocket wheels are to be cast with recesses made to the form of the chain, so that it will work therein without slip or

undue friction, and are to be truly bored out to fit the respective pins.

9. *Marking.*—The name of the manufacturer and the year of supply are to be cast upon the large side of the top sheave, thus :—

JONES & CO.,
1900,

and the working load upon the small side of the top sheave, thus :—

"To lift _____tons."

10. *Delivery.*—The tackles are to be delivered unpainted, but the chains and other bright parts are to be well oiled to prevent rusting.

11. *Tests.*—Each tackle on delivery will be taken to pieces and thoroughly examined, and afterwards tested with its specified test load, to see that it is in accordance with this specification and in perfect working order; should the tackle, or any part of it, be found in any way defective, the same must be remedied by the contractor to the entire satisfaction of the inspector. A portion of the chain from each delivery may be cut out and tested; should such portion fail to reach the specified breaking strength, the whole delivery may be rejected.

12. *Claim.*—No claim based on insufficiency of detail in this specification will be allowed, as the contractor may obtain a full explanation of the work, etc., as required, on application to the Chief Inspector, Woolwich.

13. *Inspection.*—The tackles may be inspected during manufacture by, and after delivery will be subject to testing by, and final approval of, the Chief Inspector, Royal Arsenal, Woolwich, or an officer deputed by him.

Table.

Size.		Chains.				Recesses in Sheaves of Top Block.		Gearing.		Sprocket Wheel.	Materials.							
		Lifting.		Hand.				No. of Teeth.			Frames.		Sheaves.			Gearing.		
To lift	Tested to	Size.	Breaking Strength.	Size.	Breaking Strength.	Large.	Small.	Wheel.	Pinion.	Diameter to Tread of Chain.	Top.	Bottom.	Top.	Bottom	Pins, Hooks, and Chains.	Wheel	Pinion.	Sprocket Wheels.
tns.	tns.	ins.	tns.	ins.	tns.	No.	No.	No.	No.	ins.								
$\frac{1}{4}$	$\frac{3}{8}$	$\frac{7}{32}$	$1\frac{1}{2}$	—	—	8	7	—	—	—	Malleable cast iron.	Malleable cast iron.	Cast iron	Cast iron	W'ght iron	—	—	—
$\frac{1}{2}$	$\frac{3}{4}$	$\frac{1}{4}$	2	—	—	12	11	—	—	—	Do.	Do.	Do.	Do.	Do.	—	—	—
$\frac{3}{4}$	$1\frac{1}{8}$	$\frac{9}{32}$	$2\frac{1}{2}$	—	—	13	12	—	—	—	Do.	Do.	Do.	Do.	Do.	—	—	—
1	$1\frac{1}{2}$	$\frac{5}{16}$	$3\frac{1}{4}$	—	—	15	14	—	—	—	Do.	Do.	Do.	Do.	Do.	—	—	—
$1\frac{1}{2}$	$2\frac{1}{4}$	$\frac{3}{8}$	$4\frac{1}{2}$	—	—	17	16	—	—	—	Do.	Do.	Do.	Do.	Do.	—	—	—
2	3	$\frac{7}{16}$	6	$\frac{1}{4}$	2	13	12	34	8	10	Wr'ght iron	Do.	Do.	Do.	Do.	Cast iron	W'ght iron	Malleable cast iron
3	$4\frac{1}{2}$	$\frac{9}{16}$	$8\frac{1}{4}$	$\frac{1}{4}$	2	6	5	51	8	12	Do.	Wr'ght iron	Do.	Do.	Do.	Do.	Do.	Do.
4	6	$\frac{5}{8}$	$10\frac{1}{4}$	$\frac{1}{4}$	2	6	5	56	8	15	Do.	Do.	Do.	Do.	Do.	Do.	Do.	Do.