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GIRDER BRIDGES.

FURTHER NOTES ON THE DISTRIBUTION OF HEAVY LOADS.

By Lieut. W. N. Thomas, R.E.

A few notes on this subject were given in the March issue of this *Journal*, but they dealt only with the case of a 6-in. gun passing over a bridge 10 ft. wide between the ribbands, and 10 ft. from centre to centre of the outside girders.

The present paper which deals with a different load, viz. a loaded 3-ton A.S.C. lorry, is intended to supplement the paper previously submitted, as one or two points of interest can be shown more clearly under the conditions here assumed. For instance, the width from outside to outside of the lorry wheel tyres is 6 ft. 5 in., so that the eccentricity of loading may vary from 0 to $21\frac{1}{2}$ in. on each side of the centre line of the bridge, whereas the width from outside to outside of the gun wheels is 9 ft. which allows a variation in eccentricity from 0 to 6 in. only.

The variations in the reactions on the different girders and in the bending moments on the decking, due to variations in eccentricity may accordingly be studied here in more detail and curves are given below to illustrate these.

The same notation has been adopted as in the previous paper, and as the calculations are very similar, they are not reproduced here. The load on the front axle of a loaded 3-ton lorry is 2·5 tons and that on the rear axle 5·5 tons, the length of wheel base being 14 ft. 5 in.

If a live load factor of $1\frac{1}{2}$ be adopted the equivalent dead load is 3·75 tons on the front axle and 8·25 tons on the rear axle. *Fig.* 1 shows other data for the rear axle load.

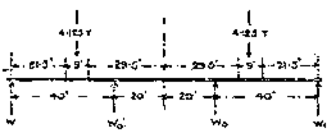


Fig 1. Equivalent Dead Load on Rear Axle.

If it is desired to adopt a live load factor of 2—and this is probably more satisfactory—the results can easily be deduced from those shown on the diagrams by multiplying by the factor $\frac{4}{3}$.

Reactions on Main Girders.—The full lines in *Fig.* 2 show the manner in which the rear axle loads are distributed upon the four girders of a 4-girder bridge, for different values of c.

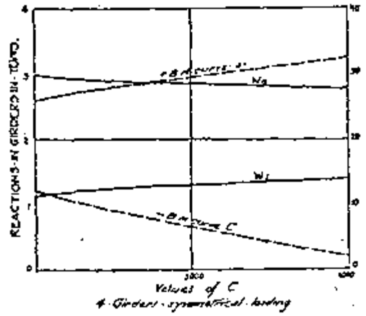


Fig. 2.

The girders are assumed to be equally spaced, and 10 ft. from centre to centre of the outer, and the load to be symmetrically placed about the central axis of the bridge as in *Fig.* 1.

The curve marked W_0 thus gives the reaction in each of the two inner girders, and that marked W_1 that on each of the two outer girders.

The full lines in *Figs.* 3 and 4, similarly give the same information when the eccentricity of the load is $10\frac{1}{2}$ in. and $21\frac{1}{2}$ in. respectively—in the latter case the wheel being against the right-hand ribband.

Thus W_0 is the reaction on the inner right-hand girder.
W_0^1 ,, ,, left ,, ,,
W_1 ,, outer right ,, ,,
W_1^1 ,, ,, left ,, ,,

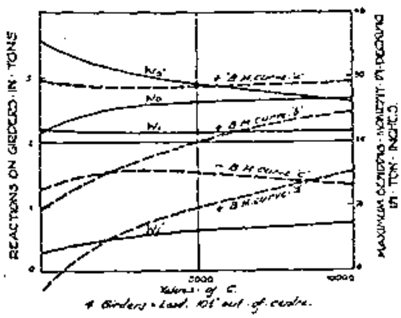


Fig. 3.

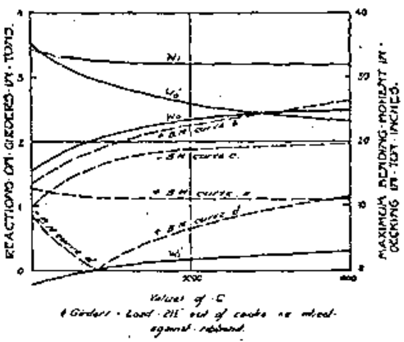


Fig. 4.

Fig. 5 is compiled from *Figs.* 2, 3, and 4, and from similar curves for other values of the eccentricity.

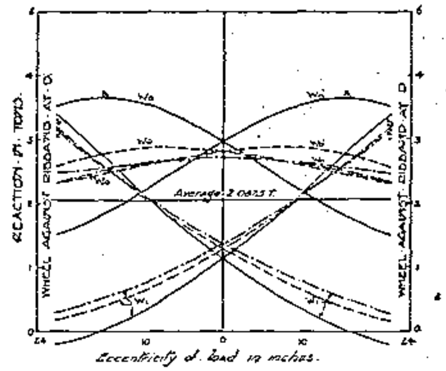


Fig. 5.

The full lines show how, when $c=0$, the reactions vary as the eccentricity of the load gradually changes from $21\frac{1}{2}$ in. to the left of the axis, through the symmetrical position, to an eccentricity of $21\frac{1}{2}$ in. to the right of the axis.

The dotted lines, and the "dot-and-dash" lines show the corresponding variations when $c=5{,}000$ and when $c=10{,}000$ respectively.

Similar curves may be drawn for other values of c, and these curves enable the maxima curves in *Fig.* 6 to be deduced.

Thus the maximum value of any full-line curve in *Fig.* 5 (*i.e.* $c=0$) is seen to be about 3·65 tons, *i.e.* at the point a, and this value is plotted for $c=0$ in *Fig.* 6 to give the point a there shown.

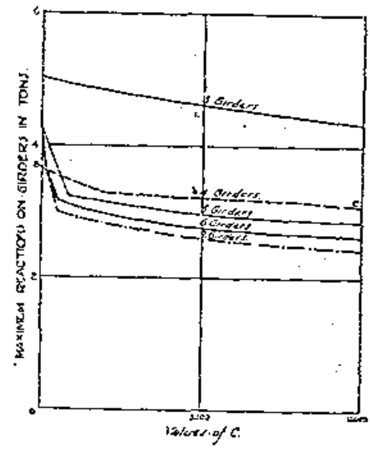


Fig. 6.

Similarly when $c=5{,}000$, the max. value is at b (*Fig.* 5), and when $c=10{,}000$, the max. value is at c (*Fig.* 5)—in each case when the wheel is against the ribband, and these values are transferred and plotted as shown in *Fig.* 6.

Evidently then, if a sufficient number of such points are located, a curve such as that given in *Fig.* 6 may be drawn to show the maximum pressure that can occur on any of the girders of the bridge.

Fig. 6 has been constructed in this way to show the maxima curves for 3, 4, 5, 6 and 7 girder bridges respectively.

Fig. 7 is of interest as showing the factor by which the average reaction (*i.e.* $\frac{8 \cdot 25}{N}$ tons, where N is the number of girders) must be multiplied in order to determine the maximum reaction for any particular value of c.

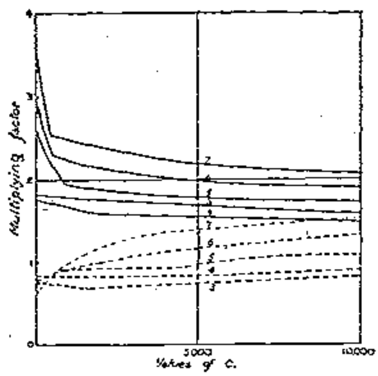


Fig 7.

Thus with four girders, the average reaction is $\frac{8 \cdot 25}{4} = 2 \cdot 0625$ tons, while the maximum value when $c=5{,}000$ is about 3·20 tons, so that the multiplying factor for this particular case is about 1·55.

The unevenness of the distribution is seen from these diagrams to be more than is perhaps usually recognized.

Bending Moments in Decking.—The dotted lines in *Fig.* 2 show for a 4-girder bridge, the bending moments in the decking for various values of c when the load is symmetrically placed about the axis of the bridge as in *Fig.* 1. Those in *Fig.* 3 show the bending moments when the load is $10\frac{1}{2}$ in. out of centre towards the right, and those in *Fig.* 4 the bending moments when the load is $21\frac{1}{2}$ in. out of centre towards the right, and consequently when the right-hand wheel is against the ribband.

The curves a refer to the max. B.M. under the right-hand wheel.
,, b ,, ,, ,, left ,, ,,
,, c ,, ,, over the inner right-hand girder.
,, d ,, ,, ,, left ,, ,,

Fig. 8 is compiled from these and from similar curves for other values of the eccentricity of the load.

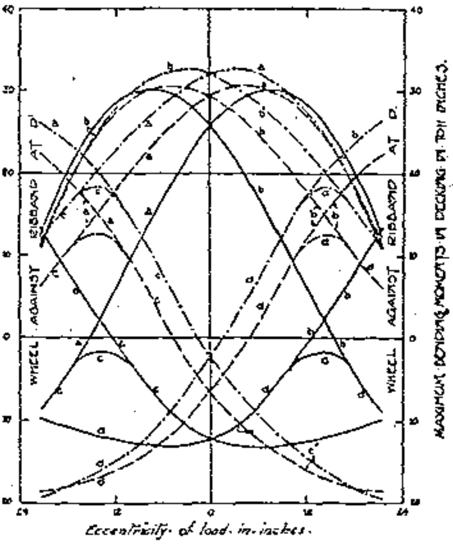


Fig. 8

The full-line curves show how for a 4-girder bridge the above curves a, b, c, d, vary as the eccentricity changes from $21\frac{1}{2}$ in. to the left to $21\frac{1}{2}$ in. to the right of the axis, when $c=0$.

The dotted lines give similar information when $c=5{,}000$, and the "dot-and-dash" lines when $c=10{,}000$.

From these and similar curves, the maximum values of the B.M.'s for any eccentricity and for various values of c, can be deduced, and plotted as in *Fig.* 9 where the curves for 3, 4, 5, 6, and 7 girders respectively are shown.

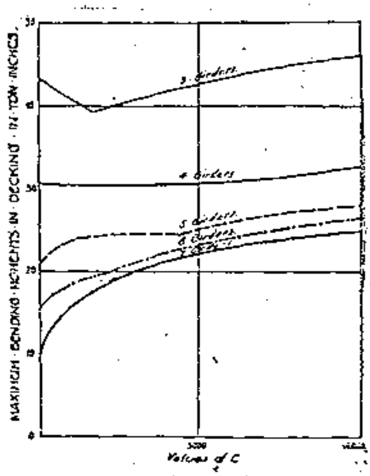


Fig. 9.

The dotted lines in *Fig.* 7 show the factors that must be employed to obtain in any case the max. B.M. from the value obtained by calculation on the assumption that the strip of decking carrying the load, is a simply supported beam with a span equal to the distance from centre to centre of the main girders.

Example.—A bridge of 12-ft. span, and of the type under consideration is to be constructed, using 9-in.×4-in.×21-lb. R.S.J.'s and 10-in.×5-in. timbers for the decking.

The max. B.M.'s, both in the girders and in the decking, will occur when the rear axle load is in the centre of the span, so that the front axle load need not be taken into consideration.

$$I \text{ for the decking} = 104{\cdot}16.$$

$$I_1 \quad ,, \quad \text{girders} = 81{\cdot}1.$$

$$c = \tfrac{1}{48} \cdot \frac{L^3EI}{E_1I_1}$$

$$= 3{,}550 \text{ nearly.}$$

With 4 main girders the maximum load on a girder (*Fig.* 6) is about 3·20 tons, which produces a stress of about 6·4 tons per sq. in. independent of the stress produced by the dead load of the superstructure. The B.M. in the decking (*Fig.* 9) is about 30·4 ton-inches, which gives a stress in the timber of about 1,630 lbs. per sq. in.—an excessive amount.

With 5 main girders, the max. load is about 3 tons on a girder, and the stress in the steel about 6 tons per sq. in.

The max. B.M. in the decking is about 24·4 ton-inches, and the corresponding stress in the timber about 1,310 lbs. per sq. in.

At least 5 girders are required therefore, although, as the girder reactions are taken as "point" loads, the above stresses on the timber may be rather higher than would actually be the case.

Effect of Several Axle Loads.—The type of bridge under consideration is not economical for large spans and is not likely to be adopted for such, so that in all general cases, *i.e.* for spans up to about 30 ft., it is sufficient to consider only the case when the heavy axle load is in the centre of the span, as in the diagrams given above.

The accurate determination of the maximum B.M.'s on the main girders and in the decking, in the case of larger spans carrying a train of lorries, becomes very complex, and a rigid solution is not attempted here.

A few general notes however are appended.

1. The fore wheels of the lorry have only single tyres, while the rear wheels are fitted with twin tyres. The loads on the former are therefore more concentrated than those on the latter, and consequently the curves given in the preceding notes altered in proportion

to the total axle load, are not strictly applicable to the fore wheel loads, though the discrepancies should not be very great.

2. The value of c $\left(\text{where } c=\frac{KL^3EI}{E_1I_1}\right)$ varies according to the position of the load upon the span: as already explained c diminishes and approaches the value $c=0$ as the abutments are approached. The distribution varies as c varies (*vide Fig.* 2—6) so that every wheel load on one side of the axis is transferred in a different proportion on to the supporting girders.

3. The deflections of the main girders under each load are increased by the effect of the other wheel loads; the differences in deflection are increased and the distortion of the decking under the load is increased. This is equivalent to an increase in the value of c, say from c_1 to c_2, and hence there occurs a further alteration in the distribution of the loads on the main girders. The tendency is then for the maximum reaction on a main girder to be diminished and for the B.M. in the decking to be increased; this diminution in the reactions is accompanied by a slight diminution in the deflections due to these reactions, so that part of the increase in c just mentioned is neutralized, and the final value of c is between c_1 and c_2.

It would be on the safe side then to calculate the maximum B.M.'s in the main girders from the reactions which correspond to the values of $c=c_1$; and to calculate the B.M.'s in the decking from the values of the centre reactions which occur when $c=c_2$.

TABLE I.

Span in Feet.	A	B
28 8	1	—
30	1·05	27·12
35	1·23	7·30
40	1·37	5·57
45	1·46	4·99
50	1·54	4·69

In the table above, the beam is subjected to 3 axle loads—a rear axle load in the centre of the span, and a fore axle load 14 ft. 5 in. on each side—distributed in the same proportion on the main girders.

A is then the ratio $c_2 : c_1$ under the central load.
B ,, $c_2 : c_1$,, outer loads.

I am indebted to Lance-Corpl. F. Tomkinson, R.E., for his help in preparing the diagrams.

CONCEALMENT IN FIELD WORKS.

By C. DE L.G.

IN *Military Engineering*, Part I., Section I. (which is really the most important section of the whole book, and it should be impressed upon all young R.E. officers that, as stated in that section, it is principles of Field Works Construction which should guide him and that it is impossible to lay down hard and fast rules as to exact dimensions, shape, etc., of works in the Field as these entirely depend upon the armament of the forces engaged at the time, tactical considerations, material, labour and time available, the action of the enemy, the lie and nature of the ground and a hundred other factors), it is stated :: " It is essential that in construction of works of defence the greatest precautions should be taken to ensure their concealment." As in defence concealment is essential, so it is equally in all works in the Field, especially now with the increase of air reconnaissance and aerial photography, in which the smallest detail of work can be picked out, unless very carefully concealed. And this great necessity for concealment is one of the foremost principles which must guide us in the construction of works in the Field.

But often one sees not the slightest attempt to adhere to this principle. Almost anywhere in France may be discovered important works—M.G. emplacements, headquarters, etc., made into the most appalling "cockshies." The only excuse that seems at all acceptable in many cases is that it is so obvious that the enemy would be sure to assume that it was a dummy and therefore pay no attention to it.

Now consider the purposes of paying this great attention to concealment of all works, or "camouflage" as it is better known now, and this name seems to frighten many people into thinking that it is something new and mysterious, whereas concealment of works in War is known to have been practised as far back as history carries us. The object of concealment is to prevent the enemy from knowing our dispositions either in defence or preparatory to attack. For instance, supposing when the enemy is attacking, a machine-gun, which has been kept in a carefully concealed emplacement which the enemy has not spotted and therefore has not bombarded, or registered on or neutralized by his fire, suddenly opens fire, it will cause great disorganization and loss to the attacking forces. While *vice versa*, from an obvious M.G. emplacement, even if it has 4 ft. of concrete cover, a machine gun will not have nearly so great an effect, partly because it will be so very unhealthy from enemy projectiles (splinters and bullets may always get through the loopholes even if a direct hit at the base of the emplacement does not destroy it) and partly because the enemy, knowing its presence will try to avoid it frontally, by means of utilizing the lie of the land, and will work round to its rear. Its importance in connection with work preparatory to attack is obvious, if any sort of surprise attack is to be effected, and the value of surprise attack has been clearly shown innumerable times during the last twelve months. Another object of concealment besides that of causing surprise is to attain security—also by hiding the dispositions of your garrison from the enemy. Thorough concealment is more protection than a great deal of cover over an obvious shelter which the enemy will keep under fire to catch the inmates emerging, For this reason too much care cannot be paid to the disposal of spoil from dugouts. In nine cases out of ten the position of dugouts can be picked out on aeroplane photographs by the mass of spoil on the parapet and parados all round the entrances to them; it is very easy to dispose of spoil without showing the position of a dugout in the very least with a little careful thinking out and organization.

The means of attaining concealment are study of surroundings, common sense and making careful plans before you start work, and discipline. The latter point is where so many fail. If care is not taken and strict discipline maintained the men employed on the work will become careless, leave their tools lying about on the site of work, walk about there showing themselves to the enemy, make innumerable tracks up to the work, all of which the enemy will spot and make him suspect that there is something there worth keeping an eye on.

In assimilating surroundings, it is obvious that natural "camouflage" is the most effective—making use of hedges, trees, houses (for concrete M.G.E.), haystacks and turnip heaps (also for M.G.E.'s), etc., all of which offer great possibilities with a little ingenuity. The difficulty comes when the work has got to be done in the open; and to assist, the camouflage service has been formed, to give advice and supply material. But this does not mean that absolute dependence should be placed on such a device. An excellent pamphlet on camouflage has been issued by G.H.Q. in France and should be studied by all R.E. officers.

It is not intended to go into details. What is wanted is some material the same colour as the surrounding ground to cover the work with—always bearing in mind that foliage changes colour with the seasons. Remember, too, that nothing is of regular shape in nature, so avoid regularity of outline, and, above all, avoid shadows. Tracks must be very carefully watched; every track, however little worn, if the grass is at all bent, shows up in an aeroplane photograph. If it is impossible to avoid making them or to conceal them, continue them on beyond the work. It is absolutely necessary, of course, in the case of using artificial camouflage to erect it before you start work of any sort. Owing to the deep shadow caused in them, open trenches are practically impossible to hide from the air. They can of course easily be hidden from ground observation by planting sods, etc., on the parapet. Saps can be hidden from air easily enough by stretching "scrim" (close netting) coloured the same as the surrounding country over them. To avoid giving away position of headquarters, cable trenches can very easily be concealed for some distance on each side of the headquarters by placing "scrim" over the plain earth of the filled-in trench, and making a dummy one leading off somewhere else. In a trench system, however, the great thing is to conceal the position from which big fire effect will be brought, *i.e.*, M.G.'s, L.G.'s and the positions of the shelters of your garrison; and thus keep the enemy in the dark as to your dispositions.

The broad outlines of how to tackle the application of this principle of concealment have been touched upon; the thing to aim at is "to conceal the fact that you are concealing anything" and spare no pains in effecting this by careful thinking out and using common sense. It is surely the most important principle of any in the construction of works in the Field and should be very carefully studied by all R.E. officers, who are experts in all constructions of any description and as such must be ready to give advice at any time upon anything connected with the design and execution of such works.

DEMOLITIONS IN THE FIELD.

By C. de L.G.

The great majority of demolitions carried out on Active Service are done so during retirements, and to effect real delay to the enemy complete destruction only is of use. In order to obtain this completeness, the principles given in the Military Engineering text books are guides to us. Remember that explosives deteriorate, and that they are not quite so effective as supplied now as they were, and allow plenty in excess; let your 50 per cent. be well on the large side!

But besides the calculation of the size of the charge, the method of placing and fixing the tamping, etc., there are two other considerations which must be dealt with in demolitions carried out during a retirement. Firstly, time to prepare and fix the charge; the retirement may be going so quickly that this cannot be done, or only hurriedly done so that bridges—or whatever it may be—are left intact for the enemy to come on unhindered; in other words, the R.E. have not done their job. Secondly, certainty that all our forces are clear before the demolition is effected, so that some are not cut off or injured, as cases have sometimes occurred.

With regard to the preparation of charges, it is suggested that all important constructions—such as main bridges, railway depôts, mines at important cross-roads—should be prepared for demolition for a considerable distance back in the War zone during periods of stationary warfare. This work should be considered just as much a necessary defence measure as the construction of defensive lines in depth. If it is not considered necessary or advisable to actually place the charges, the scheme for demolition should be made out, showing the size of charges, their placing, arrangement of leads, etc., so that actual work can be done in the minimum time. The possibility of the enemy overrunning our advanced positions quickly makes it advisable that the charges at points near the firing line shouldbe actually placed, protected from weather and ready to be detonated and blown at very short notice. In all cases the responsibility for the actual blowing should be detailed to a certain individual.

Having got the charge ready and the party detailed to carry out the demolition prepared to do so at any moment, the difficulty of knowing when to do it arises. Unless the position and activities of all troops operating in the neighbourhood are known it is extremely difficult to ascertain if all our troops are clear. The responsibility for the ordering of the actual demolition is therefore delegated by the General Staff to the commander of the lower formation who will have troops last to get clear. This is fairly simple in the case of an orderly rearguard action, but if the retirement is at all hurried and there may be other troops mixed up and not actually under the orders of the commander concerned, the communications may not be of the best, then it is impossible for him to know the exact position of all troops. In that case the R.E. officer who is responsible for the demolition may be badly let down by the order being given too late; the writer knows of a case like this occurring recently, with the result that the officer lost his life and the charge was not blown, because the enemy were on top of the party before the demolition could be carried out. The only way to overcome the difficulty is for the officer of the demolition party to ascertain from the commander who has been detailed to give the order for the demolition to take place, all details of all troops known to be operating in the neighbourhood, and their probable action—" probable " because nothing definite can be foretold when troops are in contact with the enemy. Knowing this, and keeping in close liaison with the nearest headquarters as long as possible, with his charge ready to be blown any minute, the R.E. officer must then use his own judgment and initiative in deciding when to blow—it will often be just as the enemy is appearing on the scene—and get away and report the result as quickly as he can.

As so many failures to carry out demolitions have arisen from both these causes recently, it is thought that this short note may be of value; the gist of it is that organization plays a great part—as in all R.E. work—in the execution of successful demolition.

NOTES ON THE AIRLIFT PUMP.

By Bt. Major H. S. Briggs, R.E.

(I.). General Description.

The airlift is a device for raising water from a depth by means of compressed air. The method of operation is such that a column of water unmixed with air is opposed to a column of air and water mixed. A mixture of air and water has a lower specific gravity than that of plain water, depending on the relative volumes of air and water in the mixture. When the difference between the weights of the two columns is in favour of that of plain water, the column of mixture is set in motion, and under favourable circumstances the air and water are discharged above ground level. When the columns balance one another, no motion ensues.

Fig. 1 shows an airlift installation in diagram form. This system is known as the "Central Air Pipe System." Other systems are in use, which differ only in the arrangement of piping, but which in principle are identical.

It is evident from the diagram that the pressure of the air admitted to the water must at least be equal to the head of unmixed water above the point of entry of the air; in other words, the air pressure depends on the degree of submergence of the air pipe, and *not*, as is commonly supposed, on the height to which the water is lifted, although a certain degree of submergence is necessary to set the column in motion.

In practice the working air pressure will slightly exceed that equivalent to the external column of unmixed water, by an amount corresponding to the frictional resistance encountered during the passage of the air through the air pipe.

The "starting pressure" is almost always greater than the "working pressure" for two reasons:—First, because the standing water level is usually lowered when pumping is in progress, and secondly, on account of the extra energy required to set the column in motion.

The latter amount is approximately the equivalent of the velocity head of the moving column of water, and therefore equal to $\frac{V^2}{2g}$ ft.

of water, where V is the velocity in ft. per second of the *water*. In most cases this amount is small and can be neglected, *e.g.*, for a flow of about 100 gals./min., in a 4-in. pipe the velocity is about 3 f.s. and the velocity head is about $\frac{9}{2\times 32.2}=0.14$ ft. of water or 0.06 lbs./sq. in.

In some cases (owing to low Submergence Ratio) difficulty has been found in overcoming the initial inertia of the system, and air connections* have been arranged so that air pressure could alternately be put on to the surface of the free water column and the bottom of the air and water mixture column, thus getting up a kind of "bounce" in the system. This method should not be necessary if the system is properly designed, and no difficulty should be found in getting the lift to start. The air should be admitted slowly until the first head is blown off, and the lift is in operation.

(II.). The Advantages of the Airlift.

The advantages of the airlift over other forms of pumps for raising water from a depth may be summarized as follows :—

(*a*). All the moving parts and machinery are on the surface of the ground and are open to inspection and proper maintenance. The expense of a breakdown is one of the most serious objections to the ordinary pattern deep-well pump, when several hundred feet of rods have to be lifted from a well.

(*b*). More water can be lifted from a borehole by an airlift than by a deep-well pump, provided the water is there.

(*c*). The pumping station can be located in any desired position, regardless of the position of the well. It follows from this that existing sources of power situated some distance from the well can often be utilized for driving the compressor.

* This necessitates sealing the top of the well between the casing and the rising main so that a pressure can be exerted in the space above the free surface of the water. Some authorities maintain that this should always be done, it being claimed that a few pounds pressure on the surface of the water while the lift is in operation tends to prevent surging of the two columns and to produce a more even flow. It is doubtful, however, if any appreciable increase of efficiency results.

In a well liable to become sand choked, and where the water is drawn in through perforated casing, it is of great advantage if the well is capped and air connections arranged as just described. If a pressure is built up periodically in the space above the rising main the water will be forced back into the feeding strata or fissures, and the sand washed away from around the casing.

(*d*). The airlift is the only pumping system which permits of a standby plant being provided for working a borehole.
(*e*). Several wells can be driven from one plant.
(*f*). The water is often sensibly purified by the aeration to which it is subjected.
(*g*). The yield of the well is often increased.
(*h*). Sandy or gritty water can be pumped without detriment to the plant. This is one of the most fruitful causes of breakdown of deep-well pumps.
(*j*). It is not affected by frost.

The disadvantages of the system are :—

(*a*). Low thermal efficiency.
(*b*). The well should be roughly twice as deep as the working lift for moderate lifts and about one and a-half times as deep for high lifts.

(III.). Theory of the Airlift.

It has already been stated that the operating factor is the difference of pressure—or weight—of two columns, one of unmixed water, the other of air and water mixed. This pressure difference is the driving force which produces the discharge of the air and water mixture. A greater difference of pressure results in an increased delivery of water ; at least, up to a point at which frictional and other losses counterbalance an increased pressure difference. If the difference of pressure is not sufficient, no water is lifted. This fundamental axiom is frequently lost sight of, or obscurely expressed, by writers on the subject.

The action of the airlift is often ascribed to " piston-like volumes of air which, expanding, induce the flow of water " or to the " buoyancy of the air bubbles " and similar vague expressions.

It is unfortunately the case that the airlift is an apparatus in which the effects of " losses " of one sort or another are very much more pronounced than in perhaps any other hydraulic machine. The laws governing the flow of water in a pipe have been investigated with tolerably accurate results, and the same is true, though to a lesser degree, of air. The motion of a mixture of air and water in a pipe has not, however, been fully investigated, though the friction co-efficient is said to be about six times that of water alone at the same velocity (*Gibson*).

When this motion is complicated by the fact that the pressure of the air is continually decreasing and consequently, the volume of each air bubble is increasing, with a resultant tendency for the air bubbles to coalesce, the problem becomes one of considerable difficulty.

Although a large amount of experimental work has been carried out on the subject, chiefly by manufacturers concerned in the sale of airlift pumps, there do not appear to exist any records of experiments on a really extensive scale, conducted under scientific conditions of accuracy, and under commercial conditions of application. This is unfortunate when the many advantages possessed by the airlift pump over other types of pumps are considered.

The driving force of the airlift has been defined as the pressure difference of a column of unmixed water and a column of air and water mixed.

This pressure difference will, broadly speaking, increase as the ratio* of the working submergence to working lift increases, and also, as the ratio of the volume of air to water in the mixture is increased.

The driving force varies, then, with each of two independent factors, but the utilization of the driving force to obtain delivery of the maximum amount of water for the minimum expenditure of energy, depends on the proper adjustment of the two factors referred to, viz. :—

(*a*). Submergence ratio.
(*b*). Air volume per unit volume of water delivered.

To take an extreme case, the air volume might be so increased as to fill the whole of the rising main, in which case for a given submergence ratio the driving force would be a maximum but the amount of water raised would be *nil*.

The factors governing the proportions of air to water employed, the proper adjustment of the submergence ratio, and the determination of the proportions of the rising main will be briefly discussed, but the discussion will be prefaced by a consideration of the losses involved in the system.

The magnitude and diversity of the losses involved preclude any attempt at a strict mathematical investigation into the operation of the airlift. This fact will be realized when the following sources of loss of energy are considered.

The overall losses in the system may be divided into two classes :—

(1). Loss in energy from compressor to footpiece.
(2). Losses in rising main.

The losses in Class (1) include those due to bad mechanical efficiency of the compressor plant, air friction losses in air mains and footpiece, and loss of heat of compression, but are in general small compared with the losses in the rising main.

* Submergence ratio.

The losses in the rising main, however, are considerable, and must be considered as mutually affecting one another, although for present purposes they may be classified as follows :—

(i.). Losses during entry of the water into the rising main before admixture of air.
(ii.). "Friction" losses due to the roughness of the interior of the rising main and obstruction of bends, etc.
(iii.). "Turbulence" and eddy losses in the air and water mixture.
(iv.). "Slippage" of air bubbles through the surrounding mixture.
(v.). Losses due to surging of the air and water mixture, or "Surgence."

The determination of the mutual effect of all the above sources of loss (together with other minor losses) calls for a very large number of experiments.

The records at present available on this subject are far from complete, but the results attained are such as to encourage continued research, in view of the numerous advantages of the airlift over other pumping systems.

Considering the losses in the order enumerated above, the lines on which modern airlift pumps seek to overcome them are stated in general terms as follows :—

Losses in Air Energy.—The air pipe should not be too small, but when the central air-pipe system is employed, should not be so large as to reduce too much the mean hydraulic depth of the rising main.

The means of admission of air to the water should obstruct the air as little as possible, but must be such as to divide the air into fine streams.

Loss due to Entry of Water.—A bellmouth is often fitted at the bottom of the rising main to reduce entry losses. The length of rising main below the point of entry of the air should be as short as possible, but must be long enough to ensure that the air does not blow out outside it.

Loss due to Friction of the Air and Water Mixture.—The interior of the rising main should be as smooth as possible, and sharp bends should be avoided.

The mean hydraulic depth should be as large as possible, consistent with the limitations imposed by considerations of "slippage" and "surgence" losses. When the central air-pipe system is employed, the air pipe should be as small as possible, provided that the loss through air friction is not excessive.

Turbulence, Slippage, and Surgence.—These three effects together probably account for the major portion of the losses associated with the airlift system.

A cluster of bubbles admitted at the lower end of the rising main will at once begin to rise, and rising will expand in volume all the way up. Opinion differs as to whether such expansion is isothermal or occurs at an equal rate from maximum pressure to atmospheric pressure at the discharge. The probability is that the expansion is irregular but is approximately isothermal.

If the motion were non-turbulent, and non-surging and if slippage did not occur, the bubbles would, if the proportions of air and water permitted, arrive at the discharge as separate volumes of air. In practice, no such action occurs; the discharge is frequently irregular, and consists of alternate volumes of air and water. According as perfection of design is reached, the discharge will be continuous and consist of a homogeneous mixture of air and water, and the residual kinetic energy of the mixture at the discharge will be a minimum.

Of the three sources of loss now under consideration that of slippage is probably the most important. It can be shown* that the slippage of an air bubble is in direct proportion to the square root of its volume. It is also evident that the effects of slippage will be the less, the greater the mean velocity of the air and water mixture.

The acceleration of the mixture is liable to be uneven from the varying frictional resistances encountered, and there is a tendency for portions of the column to break away from those below. A coalescence and expansion of air bubbles to fill the spaces between the broken portions then takes place, with a consequent falling back of the superincumbent column to correct such expansion. A surging effect is thus produced which in some cases is the cause of a great loss of energy.

The losses just enumerated may be reduced if the following conditions are observed:—

(*a*). A correct submergence ratio.
(*b*). Correct proportions of air and water.
(*c*). Correct velocity of the mixture in the rising main.

The above three considerations are dealt with in subsequent sections.

(*d*). The rising main should contain as few obstructions as possible and any necessary bends at the well head should be easy.
(*e*). The air should be introduced into the water in fine streams.

The last condition is now generally admitted to be a *sine quâ non* in efficient design.

* See "Pumping by Compressed Air," *Ivens*, p. 97 *et seq.*

Considerations Affecting the Determination of the Correct Submergence Ratio and Proportion by Volume of Air to Water.—It is necessary to consider the above two factors together since they mutually affect the efficiency of the airlift.

Inspection of the isothermal and adiabatic compression curves will show that the energy contained in unit volume of air increases more rapidly as the final pressure is raised.

Assuming the lift to be constant, and with a given ratio of free air to water volume and a given amount of work to be done (*i.e.*, a given quantity of water to be raised) it is evident that the slippage losses are reduced as the submergence is increased. In other words the efficiency in the lower portion of the rising main, at any rate so far as losses due to slippage in that portion of the rising main are concerned, increases as the submergence ratio is increased.

On the other hand, an increased submergence ratio involves a greater length of rising main. An increased length of rising main means greater losses due to surgence, turbulence, and friction, and more important still, the rapidly expanding air in the upper portion of the rising main involves increased slippage losses.

So far as the submergence ratio is concerned, then, the efficiency will increase as the submergence ratio is increased up to a point of maximum efficiency. In the same way, for a given submergence ratio, there will be an economical proportion of air to water by volume.

The economical proportions in each case can only be gauged by the results of tests.

Fig. 4 shows the most efficient submergence ratios, as found by experiment, for various lifts (*Ivens*).

As regards the proportion of air to water the following empirical formula is good practice (*Rix & Abrams*).

$$V_a = \frac{h}{C \log \frac{H+34}{34}}.$$

Where V_a=Cubic ft. of free air per minute (piston displacement) per gallon of water.

h=Lift in ft.

C=Constant.

H=Submergence in ft.

Values of C are as follows:—

Lift.	*C.*
10 to 60 ft.	245
61 to 200 ft.	233
201 to 500 ft.	216
501 to 650 ft.	185
651 to 750 ft.	156

The economical proportions for any particular well should be invariably adjusted by experiment, and this from the nature of the plant involved is a matter of small difficulty.

The preceding remarks have been concerned mainly with the conditions necessary for economical working. Cases arise, however, when efficiency is of secondary importance, and it is desired to lift the maximum quantity of water possible from the well.

In such cases it will be found that the delivery will increase, beyond the delivery corresponding with maximum efficiency, up to a certain point, both as the submergence ratio, and the quantity of air admitted, are increased.

Considerations Influencing the Determination of the Correct Cross Sectional Area of the Rising Main.—From the preceding discussion it is apparent that the cross sectional area of the rising main at any point, which governs the velocity of the mixture at that point must be such as to satisfy so far as is possible each of the following conflicting demands :—

(*a*). To reduce losses due to turbulence, the area should be such that the velocity is constant throughout the rising main.

(*b*). To reduce the effects of slippage, the velocity should be high, and should increase as the air in the mixture expands.

(*c*). To reduce surgence losses, the velocity should be low, and uniform.

(*d*). To reduce friction losses, the velocity should be low.

It has already been stated that slippage losses are the most important, and for this reason it would appear reasonable to allow the consideration indicated in (*b*) above to outweigh the others.

The determination of the limits within which, in actual figures, the velocity should lie, must necessarily depend on the results of practical experiment.

Authorities agree that the velocity of the air and water mixture should neither be less than 6 f.s. nor more than 25 f.s.

In a rising main of uniform cross section, owing to the expansion of the air in the mixture, the velocity will increase from bottom to top, and one of the requirements dictated by the effects of slippage will be satisfied.

In a long rising main, however, the velocity near the top may be excessive, or it may be found that an unduly long portion of the rising main may have to carry the mixture at a velocity approaching the maximum stated.

In such cases recent practice has been to make the rising main in two or more portions increasing in cross sectional area from the bottom upwards.

The determination of the arrangements of pipes required may be made by plotting the velocities of the mixture at points down the rising main, assuming of course an initial velocity at entry. From the velocity curve, a curve of pipe diameters may be drawn, which will represent the theoretical form of the rising main. The sizes and lengths of straight pipes can then be selected to suit as far as possible the curve thus obtained.

This method of varying the size of the rising main will not usually be required, since it will be found that with moderate lifts, deliveries, and compression ratios, that a rising main of uniform cross section will be suitable.

(IV.). The Airlift in Practice.

(*a*). *Arrangement of Piping.*—The usual methods of arranging the air pipe and rising main are as follows (see *Fig.* 3) :—

(i.). Air pipe suspended centrally within rising main.
(ii.). Air pipe outside and separate from rising main.
(iii.). Rising main suspended within air pipe.

The first method is the handiest for practical purposes, since the air pipe can readily be withdrawn or altered.

The second method possesses the advantage of leaving an uninterrupted passage for the mixture and reducing friction losses.

The third method requires other things being equal, a larger bore-hole than either of the first two methods.

(*b*). *Method of Admitting the Air to the Water.*—There are innumerable patterns of patent air pipes footpieces on the market, most of which merely serve as an obstruction to the water flow without materially increasing the efficiency.

With the central air-pipe system, the type of footpiece shown in *Fig.* 7 is recommended. It will be noted that a length of plain pipe is attached below the point of admission of the air. If this pipe is omitted, it is found that the air is apt to blow straight through the open end instead of passing through the holes in fine streams.

The length of plain pipe, while permitting scale and dirt to escape from the air pipe through the open end, secures a resisting head of water and the air taking the line of least resistance passes through the small holes.

The end of the air pipe should not be plugged as is sometimes done, since the scale and dirt from the inside of the air pipe will eventually block up the small holes.

The point of entry of the air to the water should be several feet above the bottom of the rising main to avoid any danger of the air blowing up between the rising main and the casing, or, where the casing is used as a rising main, between the casing and the side of the hole.

The total area of the small holes should be at least one and a-half times that of the interior of the air pipe.

A further development of the principle of splitting up the air into fine streams would be to drill a number of relatively large holes, say $\frac{3}{8}$-in. diameter, in the air pipe and cover these with fine wire gauze. This method has not, so far as is known, yet been tried, but should give good results.

The arrangement of making the air pipe separate from the rising main, with a footpiece as shown in *Fig.* 6 is probably the most efficient yet devised.

(*c*). *Arrangements at the Head of the Discharge Pipe.*—There are several methods of dealing with the discharge, three of which are shown in *Figs.* 8 to 10.

In any case, the discharge pipe conveying the air and water mixture should be as short as possible in order to reduce friction.

A long discharge pipe carrying a mixture of air and water very greatly reduces the flow of water.

Circumstances, may however, render it necessary to put in a long discharge pipe even at the expense of a considerable loss in efficiency. In one case a 4-in. pipe was used to convey the air and water mixture over half a mile but the flow which was about 8,000 gals. at the bore-hole was reduced to 3,000 gals. per hour at the end of the discharge pipe.

A method which may be employed in certain circumstances and which will result in an increased efficiency is that shown in *Fig.* 9. Here the standpipe admits of the escape of the air, while sufficient head is given to allow of the air-free water flowing down the discharge main at the required velocity.

A further development of this principle is found in the so-called "Booster" pump, in which the standpipe in *Fig.* 9 takes the form of a receiver and the air valve is replaced by an air-escape valve which can be set to blow off at any desired pressure.

The pressure remaining in the air on its arrival at the top of the rising main is made use of to force the water along the discharge pipe.

A sketch of this apparatus is shown in *Fig.* 11.

Where, however, any considerable height or length of discharge is to be encountered after the water leaves the well head, some form of surface pump should be employed to boost the water on.

The airlift at best is of low efficiency, and it is desirable to keep the working lift, both static and frictional, as low as possible.

(*d*). *Data for Design.*—The following table gives the preceding information in a summarized form.

On this information a preliminary design may be based, due account being taken of the general principles already formulated.

Local conditions vary so much that the last degree of efficiency possible can only be obtained after successive tests on the plant installed.

No mention is made of conditions affecting compressor efficiency as these are either well known or can be found in any standard work on the subject.

(A). *Velocity of air in air pipe.*	Should not exceed 30 ft. per sec., but whenever possible should be kept below 20 ft. per sec.
(B). *Admission of air to water.*	Should be in fine streams, and can conveniently be through small holes not more than $\frac{1}{8}$-in. dia. The total area of the holes should be at least $1\frac{1}{2}$ times that of the main air passage.
(C). *Position of point of entry of air with reference to bottom of rising main.*	10 to 20 ft. above foot of rising main.
(D). *Ratio of volume of air to water raised.*	From formula $V_a = \dfrac{h}{C \log \dfrac{H+34}{34}}$. Where V_a = Cubic ft. of free air per minute (piston displacement) per gal. of water. h = Working lift in ft. C = Constant. H = Submergence in ft. Values of "C" for various lifts are :— 10 to 60 ft.—245. 61 to 200 ft.—233. 201 to 500 ft.—216. 501 to 650 ft.—185. 651 to 750 ft.—156.
(E). *Submergence ratio.*	See *Fig.* 4. (This gives "working" submergence ratio).

(F). *Velocity of mixture.* Not less than 6 f.s. nor more than 25 f.s. It may be necessary to enlarge the rising main from bottom upwards.

(G). *Fall of water level while pumping.* This can only be found by test. The difference between the starting and running pressures, after correction for air friction in air pipe and $\frac{V^2}{2g}$, gives the drop in water level.

Example.—An example will show the application of the foregoing data.

Well.—6-in. borehole in chalk—300 ft. deep cased 100 ft.

Water level stands 100 ft. from surface.

Plant Available.—Compressor giving 60 ft.^{3}/min. (piston displacement) of free air at 100 lbs./in.^{2}.

It is desired to work the compressor off the shafting of a factory situated $\frac{3}{4}$ mile from the well. Ample power is available.

Delivery from Borehole.—The factory works 10 hours a day and a maximum supply of 50,000 gallons per day is required.

A reservoir can be built near the borehole which will command a gravity supply over area to be supplied, and under these circumstances the delivery pipe from the well head would be 250 ft. long with a rise of 5 ft.

The following are the calculations required :—

Air Volume.—In order to operate the compressor at its rated speed, the economical delivery of water can be found from the formula

$$V_a = \frac{h}{C \log \frac{H+34}{34}}.$$

From examination of wells in the neighbourhood the fall in water level while pumping is assumed to be about 10 ft.

Assuming lift above ground to be (with friction over 250 ft. of horizontal pipe) about 10 ft., total h is 120 ft.

From *Fig.* 4 a 64 per cent. submergence should be adopted. The running submergence in feet will then be 213 ft.

$$\therefore V_a = \frac{120}{233 \log \frac{213+34}{34}}$$

$=0.597$ ft.^{3} free air per min. per gallon of water.

Then economical delivery of water is about $\frac{60}{0.597}$ or about 100 gals./min. This amount will be sufficient.

Air Pressures.—The maximum total air pressure will be air pressure equivalent to 223 ft. of water* + pressure due to air friction in air pipe in well + pressure due to air friction in air pipe between factory and well.

At a velocity of 20 f.s. and delivery of 60 ft.³/min. of free air compressed to about 100 lbs./in.² the smallest size pipe that should be used is a little over 1-in. dia.

Assume 1-in. air pipe in well and $1\frac{1}{2}$-in. air pipe between compressor and well.

Between compressor and well (distance 3960 ft.)†

$$P_1^2 - P_2^2 = (114.7)^2 - P_2^2 = 30.48 \times 39.6 \text{ (\textit{vide table, p.} 178)}$$

$$= 1208$$

$$\therefore P_2^2 = 13120 - 1208 = 11912$$

$\therefore P_2 = 109.1$ lbs./in.² abs. or 94.4 lbs./in.² gauge pressure.

Then the air friction between compressor and well will be

5.6 lbs./in.²

For the loss in 323 ft. of 1-in. piping—

$$P_1^2 - P_2^2 = (109.1)^2 - P_2^2 = 224 \times 3.23 \text{ (\textit{vide table, p.} 178)}$$

$$\therefore P_2^2 = 11912 - 723$$

$$= 11189$$

$\therefore P_2 = 105.7$ lbs./in.² abs. or 91.0 lbs./in.² gauge.

A submergence (starting) of 223 ft. is equivalent to a pressure of 96.5 lbs./in.² and a running submergence of 213 ft. is equivalent to 92.2 lbs./in.² With pipe sizes as stated this means running the compressor at pressures of respectively 5.5 lbs./in.² (approx.)‡ and 1.2 lbs./in.² (approx.) above the rated figure for starting purposes and while running.

As, however, it is assumed that the water level is at its highest point having regard to seasonal variations, the slight overburden on the compressor can be accepted.

* Starting submergence.
† See Section VI. *seq.*
‡ Plus pressure due to starting inertia which will be small.

The compressor may now be put down and the pipe line to the well laid.

Size of Rising Main.—Equivalent volume of 60 ft.³/min. free air at $(92.2+14.7)=106.9$ lbs./in.² abs. pressure,—

$$=\frac{14.7}{106.9}\times 60 \text{ ft.}^3/\text{min. or } \frac{14.7}{106.9}=0.137 \text{ ft.}^3/\text{sec.}$$

$$\text{Volume of water per sec.}=\frac{100}{60\times 6.25}$$

$$=0.267 \text{ ft.}^3/\text{sec.}$$

Then total volume of mixture

$$=0.137+0.267=0.404 \text{ ft.}^3/\text{sec. at bottom of rising main.}$$

Assuming an initial velocity of 9 f.s.

$$\text{Area required} \quad =\frac{0.404}{9} \text{ ft.}^2$$

$$=\frac{0.404\times 144}{9} \text{ in.}^2$$

$$=6.46 \text{ in.}^2$$

Assuming that the central air-pipe system is employed, the outside area of a 1-in. pipe is 1.33 in.²

Then inside area of rising main

$$=1.33+6.46=7.79 \text{ in.}^2$$

The diameter of pipe to give this is between 3 in. and 3¼ in.

Assume a rising main of 3-in. uniform inside diameter be employed, this has an area of 7.068 in.², and the velocity at the bottom is consequently increased to

$$\frac{0.404\times 144}{7.068-1.33}=\frac{0.404\times 144}{5.738}$$

$$=10.1 \text{ f.s.}$$

For the velocity at the top, the total volume is now

$$\frac{60}{60}+0.267=1.267 \text{ ft.}^3/\text{sec.}$$

$$\text{and velocity} \quad =\frac{1.267\times 144}{5.738}$$

$$=31.8 \text{ f.s.}$$

This velocity is rather on the high side, so it will be advisable to enlarge slightly the rising main towards the top.

Taking the next larger size of pipe, viz. $3\frac{1}{2}$ in., this would give a velocity of

$$\frac{1.267 \times 144}{9.621 - 1.33} = \frac{1.267 \times 144}{8.291}$$

$$= 22 \text{ f.s.}$$

This is within the limit, so a $3\frac{1}{2}$-in. rising main will be adopted for a certain proportion of the depth. The next point is to determine what proportion of the length should be $3\frac{1}{2}$ in. and what proportion should be 3 in.

Fig. 12 shows velocity curves drawn for 3-in. and $3\frac{1}{2}$-in. rising mains. The most favourable point to make the change appears to be 188 ft. from the bottom. The curve drawn in firm line is the resulting velocity curve.

The step down in velocity where the change in section occurs will be a source of loss, and to lessen this, the difference in pipe sizes should certainly not be more than $\frac{1}{2}$ in. Nothing would probably be gained by inserting a tapered junction piece.

The well can now be piped up, the bottom of the air pipe, etc., being arranged as in *Fig.* 7, and final adjustment of submergence made when the actual drop of water level has been ascertained.

Discharge from Well.—Some arrangement as in *Fig.* 9 can be adopted to lead the water to the reservoir.

For the height of the stand pipe,—

Assume a 4-in. surface line, with no elbows.

Friction head	=	3.61
$\frac{V^2}{2g}$	=	0.14
Static head	=	5.00
Total		8.75
Allow for air space at top	=	3.25
Height of stand pipe	=	12.00 ft.

In designing an airlift installation for a well, the qualities of which are unknown, the most difficult quantities to estimate are :—

(*a*). The economical capacity of the well.

(*b*). The drop in water level when pumping.

Both the above particulars can only be ascertained with certainty by test, but when there are other wells of the same nature in the locality a fairly near estimation can be made.

If the drop in water level is plotted together with the delivery of water, it will usually be found that the resulting curve is a straight line up to a certain point, which denotes the economical capacity of the well, and after this point the curve is irregular. It will usually be advisable to work the well at its economical capacity, but cases may occur of course in which it is desired to obtain the maximum quantity of water possible from the well.

The drop in water level should be determined for the delivery at which it is intended to pump the well before the final arrangement of piping is made, since this figure affects the submergence ratio. In some cases the drop of water level is so great as to render it impracticable to work in a single lift.

If conditions permit a "Compound Lift" may be employed.

A two-stage lift is shown diagrammatically in *Fig.* 2.

(V.). THE EFFICIENCY OF THE AIRLIFT.

Some of the effects resulting from variations in the various working constants of an airlift system are illustrated by the curves shown in *Fig.* 5.

The curves shown on this figure are derived from the means of a number of experiments carried out by Lieut. A. R. Evans, R.E.

The particulars of the plant, etc., were as follows :—

Well.—This was a 6-in. diameter borehole about 300 ft. deep in the chalk.

Working Lift.—About 60 ft., and did not appreciably vary throughout the tests.

Rising Main.—4-in. diameter with 10-ft. horizontal run after leaving well head.

Air Pipe.—Was central within rising main.

Three different sizes of air pipe were experimented with, viz. :— 2 in., 1½ in. and 1 in.

Air-Pipe Footpiece.—The air pipe had an open end in each case and no arrangement was adopted for splitting the air into fine streams.

Plant.—8-in.×8-in. horizontal Ingersoll Rand air compressor driven by a de Dion 4-cylinder petrol engine, close to well head.

Investigation of the curves brings out the following points :—

(A). *For a given submergence ratio the efficiency decreased as the size of the air pipe was increased.**

The net effects of increasing the size of the air pipe (a 4-in. rising

* The efficiency referred to here is the efficiency attained so far as the losses in the rising main are concerned.

main was used throughout), on the principles formulated in Section III., may be summarized as follows :—

(i.). The cross sectional area was decreased, thus increasing velocity and decreasing slippage losses. The relative areas, and the relative velocities of mixture per second for equal volumes with a 1-in. and 2-in. air pipe were as 1.36 to 1.00.

The above consideration would tend to increase the efficiency.

(ii.). A larger air pipe involved a reduced mean hydraulic depth, thus increasing frictional losses. The relative mean hydraulic depths using a 1-in. and 2-in. air pipe were as 1.63 to 1.00.

(iii.). A larger air pipe involved, since it was open ended, air bubbles of larger initial volume. This meant increased slippage losses, turbulence, and surgence. This was borne out by the fact that with the 2-in. air pipe the discharge was very irregular and consisted of alternate gushes of water and large gushes of air. If it be taken that the volume of the bubbles on admission varied with the area of the air pipe and the slippage with the square root of the volume of the bubbles, the slippage was about twice as much with the 2-in. air-pipe arrangement as with the 1-in.

The last two factors evidently outweighed the first, and there is no doubt that the greatest loss was due to the larger initial volume of the air bubbles. This emphasizes the great importance of dividing the air up into as fine streams as possible.

(B). *For a given submergence ratio the efficiency decreased as the volume of air per minute was increased.*

It will be well to consider first of all the following expression, which is based on the assumption that the work done on the air during isothermal compression from atmospheric pressure $=p_a$ to $p_1=$ absolute pressure at base of rising main, is available for raising water together with overcoming resistances due to the various sources of loss.

The efficiency

$$E=\frac{62.4\times V_w\times h_d}{p_a V_a \log_e \frac{p_1}{p_a}}$$

Where V_w = volume of water raised in cubic ft. per second.

V_a = volume of air used in cubic ft. per second at atmospheric pressure p_a.

p_1 = absolute pressure at point of entry of air.

h_d = working lift in ft.

Keeping all other factors constant the efficiency will decrease as V_a is increased.

It is evident that for maximum efficiency the least possible volume of air for unit volume of water raised should be employed.

This figure is governed by the impossibility of getting the lift to work below a certain proportion of air to water.

For the 1-in. air-pipe arrangement, which presented the best general efficiencies, the lowest volume of air at which the lift would work satisfactorily was about 40 ft.^{3}/min.

The following table shows a comparison between the figures obtained in the "Evans" experiments and those got from the formula given in Section (IV.) (*d*) :—

Lift in feet.	Submergence in feet.	Submergence Ratio.	Number of cubic feet free air per minute per gallon of water for maximum efficiency.	
			"Evans" Experiments.	From Formula on p. 168.
(1).	(2).	(3).	(4).	(5).
60	60	1.00	0.615	0.555
60	90	1.50	0.461	0.437
60	120	2.00	0.421	0.374

The curve plotted from the formula

$$V_a = \frac{h}{C \log \frac{H+34}{34}},$$

with air consumption and water delivery as co-ordinates, other factors being constant, should be a straight line.

The falling away of the curves in *Fig.* 5 from the corresponding straight line forms derived from the above formula, may be ascribed to increased slippage, etc., losses consequent on the use of an open-ended air pipe. Such losses will naturally increase with the amount of air in the rising main.

The falling away from the corresponding straight line becomes less as the size of the air pipe is diminished.

(C.). *Velocities of Mixture in Rising Main.*—The velocities for the 1-in. air-pipe arrangement were as follows :—

Submergence Ratio. Lift—60 ft.	At 40 ft.³ free air per minute.		At 100 ft.³ free air per minute.	
	Velocity at top of Rising Main, in feet per sec.	Velocity at bottom of Rising Main, in feet per sec.	Velocity at top of Rising Main, in feet per sec.	Velocity at bottom of Rising Main, in feet per sec.
2.00	11.8	5.1	26.3	9.7
1.50	11.5	5.3	25.7	10.2
1.00	11.0	5.5	25.0	11.4

The velocities at 40 ft.³/min. were on the low side and an increased efficiency would probably have been obtained had a smaller rising main been employed.

(D). *Variation of Efficiency with Lift.*—Owing to the fact that the water level was practically constant for all deliveries, no experiments could be made in this direction.

It is found that in general the efficiency decreases as the lift is increased.

It may be stated that modern airlift systems if properly designed, and if the well is worked at its economical capacity, should show efficiencies varying from about 50 per cent. for a 50-ft. lift to about 25 per cent. for a lift of 600 ft. For deliveries up to about 3,000 gallons an hour these figures compare favourably with the efficiencies obtainable with ordinary deep well pumps, while for higher deliveries the lower maintenance charges associated with an airlift system may often counterbalance the difference in operating efficiency.

(VI.). The Compressor and Air Mains.

It is not intended here to enter into a detailed description of the many types of compressors on the market.

Information on this subject can be found in several standard works. Compressors may be one or multi-stage, and it is generally considered economical to adopt single stage compression up to about 80 lbs./sq. in. and multi-stage after that point.

(A). *Air Compressor Installation and Operation.*—The following is a *précis* of an article on the subject by E. M. Ivens (*Power*, December 30th, 1913).

"Instances of unsatisfactory operation of air compressor plant and disastrous explosions in receivers and air lines usually result from improper installation or negligence on the part of the attendant.

Location.—A clean and cool place should be selected with room to walk round and inspect the plant.

Foundation.—Should be designed with a view to absorbing the shocks to which a compressor is subject.

Receiver.—The functions of a receiver are :—

(1). To act as a cushion.

(2). To serve as a storage of power.

(3). To cool the air and precipitate any oil or moisture carried in entrainment.

(4). To reduce friction losses by cooling the air before it reaches the pipe line.

The receiver should be located near the compressor and in a cool spot.

The receiver should be provided with pressure gauge, safety valve, and blow-off cock.

Air-Inlet Piping.—The piping or conduit should have double the cross sectional area of the compressor inlet opening, and be arranged so as to draw air as cool as possible, and free from dust or grit. The inlet piping should have as few bends as possible.

Discharge Piping.—The pipe connecting compressor and receiver should be at least of the diameter of the discharge opening of the cylinder, and should contain as few bends as possible.

No stop valve should be placed between compressor and receiver.

Lubrication.—The same attention should be paid to the lubrication of the wearing parts as in the case of any other machine.

The lubrication of the air cylinder requires a special oil, with an ignition point depending on the degree of compression attained.

A compressor working at 70 lbs./sq. in. will discharge air at a temperature of about 350° F. The ignition point of common lubricating oil is about 295° F. and of common cylinder oil about 400° F.

The necessity for an oil of high ignition point is thus apparent.

A scored piston or cylinder wall may allow air at discharge temperature to escape back to the suction side of the piston. On the compression stroke the temperature may be raised to an abnormal and dangerous degree.

All this shows the necessity of using a suitable compressor oil and of supplying air as clean and cool as possible to the compressor.

A fusible alarm plug can be obtained for insertion in any pipe line.

The amount of oil required for the cylinder may be gauged as follows :—

Cylinders	6 to 10-in. stroke	—1 drop in	1 minute.
,,	12 to 16-in. ,,	—3 ,,	2 minutes.
,,	18 to 24-in. ,,	—2 ,,	1 minute.
Larger cylinders		—3 to 5 in	1 ,,

Circulating Water.—The object of circulating water is to facilitate lubrication of the air cylinder.

Care should be taken when installing the compressor that the circulation is satisfactory.

It is of advantage if the water outlet is in plain view of the operator. The circulating water should be clean and its pressure should not exceed 50 to 60 lbs./sq. in.

Water jackets should be drained after shutting down, if there is danger of frost.

Inspection and Cleaning.—The compressor should be thoroughly inspected at stated intervals.

The points requiring special attention are the air valves, ports and passages. These should be slightly oily, and free from carbonaceous deposits.

The inside of the air cylinder may be cleaned effectively by filling the lubricator with a strong solution of soap and water, and feeding liberally throughout a day's run. At the end of the run, the lubricator should be filled with oil and the compressor operated for a while.

Paraffin should never be used for cleaning the cylinder, on account of its low flash point.

The following instructions might well be posted in every compressor room :—

Every Morning.

(1). Drain the receiver.
(2). Note the height of lubricating oil in the crank case (or in oil cups) and replenish if necessary.
(3). Adjust lubricator for proper amount of oil feed.
(4). Start circulating water.

Every Week.

(5). Remove crank-case oil and filter.
(6). Remove and examine suction and discharge valves. If worn or cut, they should be ground to a tight fit.
(7). Test safety-valve by raising air pressure to point of blow off.
(8). Take up lost motion in pins and bearings.

Every Month.

(9). Renew crank-case oil and thoroughly cleanse the inside of crank case.

(10). Thoroughly inspect all parts, including air and water passages."

(B). *Air Friction and Air Mains.*—Most of the published tables giving air friction figures are incorrect, generally because the air is assumed to travel with uniform velocity through a pipe of uniform cross sectional area.

The following table gives figures for moderate air deliveries which may be taken as tolerably accurate ("Pumping by Compressed Air."—*Ivens*).

Equivalent volume in cubic feet of free air per minute passing through pipe.	Size of pipe in inches.							
	1	$1\frac{1}{4}$	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	$3\frac{1}{2}$	4
	$P^2_1 - P^2_2$ = difference in squares of initial and final absolute pressure, per 100 ft. of pipe.							
50	150	49.2	20	4.8	—	—	—	—
75	335	98.5	46.2	10.5	—	—	—	—
100	600	197	79	18.8	6.15	—	—	—
150	1350	443	178	42.2	13.8	5.5	—	—
200	2400	788	316	75.0	24.6	9.9	2.0	2.4
250	3750	1230	494	117	38.5	15.4	7.1	3.6
300	5400	1770	711	168	55.4	22.2	10.3	5.3
400	9600	3150	1263	300	98.3	39.5	18.2	9.4
500	15000	4920	1978	470	154	62	28.5	14.6

As an example, suppose the following to be the data given :—

Volume of free air—100 ft.^{3}/min.
Length of air main—2 miles.
Compressor working pressure—100 lbs./sq. in.
Terminal working pressure—90 lbs./sq. in.

It is required to find the size of the air main necessary.

$$P_1^2 - P_2^2 = (114.7)^2 - (104.7)^2$$
$$= 2196 \text{ for } (2 \times 5280) \text{ ft.}$$

Then $$P_1^2 - P_2^2 \text{ per 100 f.r.} = \frac{2196 \times 100}{2 \times 5280} = 20.8.$$

From the table it will be seen that a 2-in. pipe will be a suitable size.

Transmission of power by compressed air offers many advantages in certain cases, especially in borehole work, since a range of bore-holes can be worked from a centrally situated compressor station. In this system, either of two methods of operation may be adopted. In the first method each well is worked separately for a certain period each day, and the compressor furnishes only sufficient air to work one well. The wells may be connected to the compressor by independent air mains or may be teed off a common main with a valve at each well.

In the second method all the wells are worked simultaneously, and the compressor furnishes enough air for the purpose. In this case the delivery to each well is usually teed off a common main of suitable size to carry the requisite volume of air for the wells supplied.

The former method possesses the advantage that it is easily operated and does not require adjustment of pressure at each well to take care of variations of water level (and consequently variations of submergence and working pressure).

Where, however, several wells are worked in order to obtain the united delivery of water from them all, the second method must be employed. It is rarely possible to adjust the submergences so as to obtain an equal working pressure at each well, so some form of pressure regulating valve on each air delivery must be provided.

It is desirable to insert a second cock so that the well may be shut off without disturbing the setting of the regulating valve.

As regards laying air mains, it is most necessary that good joints should be made. Ordinary screw joint water pipe is quite suitable for moderate pressures.

The sealing compound should be applied to the male end of the joint, otherwise it is liable to be squeezed inside the pipe.

The pipe used should be clean and care taken that dirt is not introduced during laying. In pronounced dips in the line a blow-out cock should be inserted to release any water that may collect, but this is only necessary in long lines.

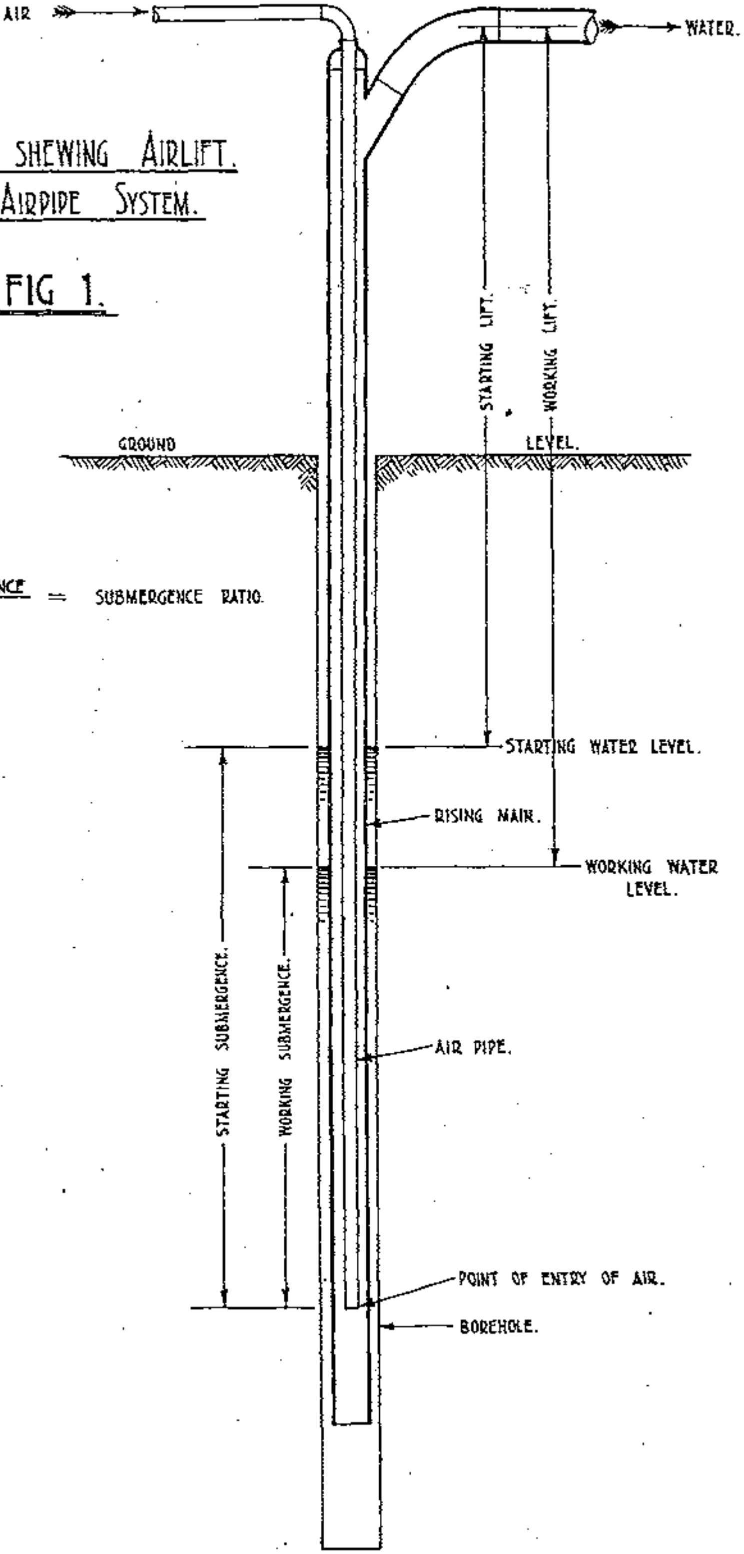
A similar cock should be provided at the end of the line.

When the line is complete, it should be filled with air rather above

AIRLIFT PUMPS

DIAGRAM SHEWING AIRLIFT.
CENTRAL AIRPIPE SYSTEM.

FIG 1.



$$\frac{\text{SUBMERGENCE}}{\text{LIFT.}} = \text{SUBMERGENCE RATIO.}$$

FIG. 2. — COMPOUND AIRLIFT. —

COCK "A" IS KEPT SHUT AND COCK "B" OPEN UNTIL WATER LEVEL IS SUFFICIENTLY LOWERED. "A" IS THEN OPENED AND "B" SHUT, AND THE AIRLIFT OPERATED BY MEANS OF THE INNER AIRPIPE.

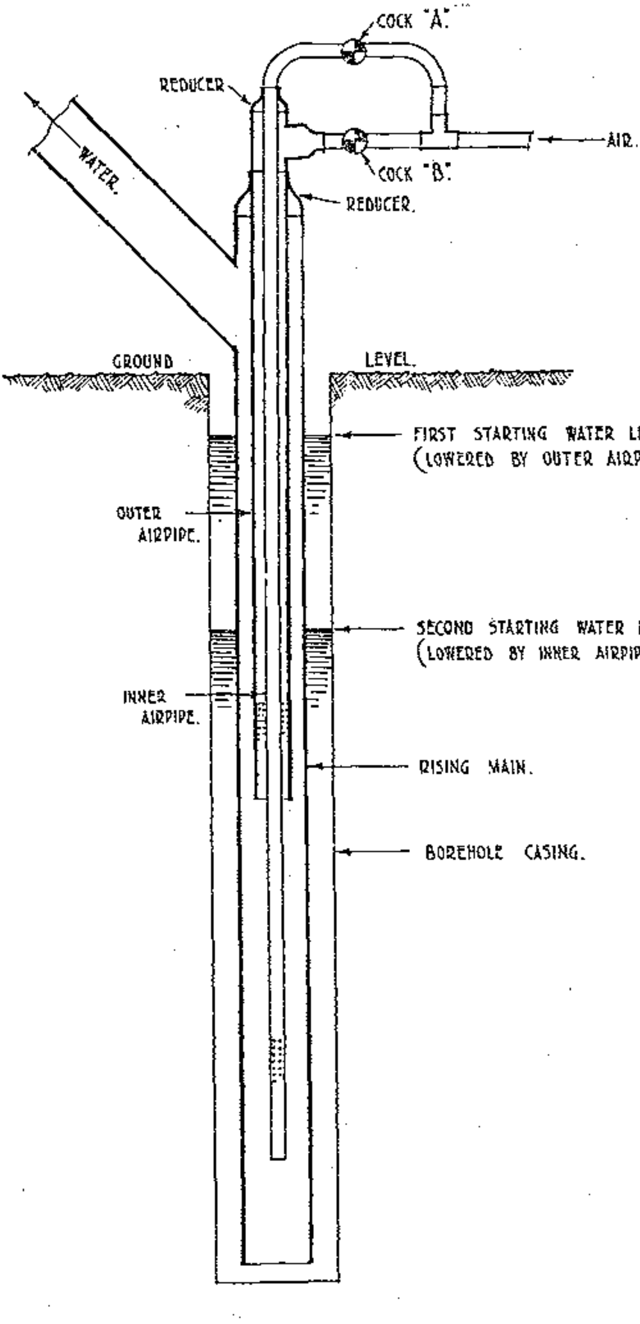


FIG. 3.

— METHODS OF PIPING WELLS. —

FROM DIAGRAMS CONTAINED IN INGERSOLL-RAND COY'S CATALOGUE Nº 76.

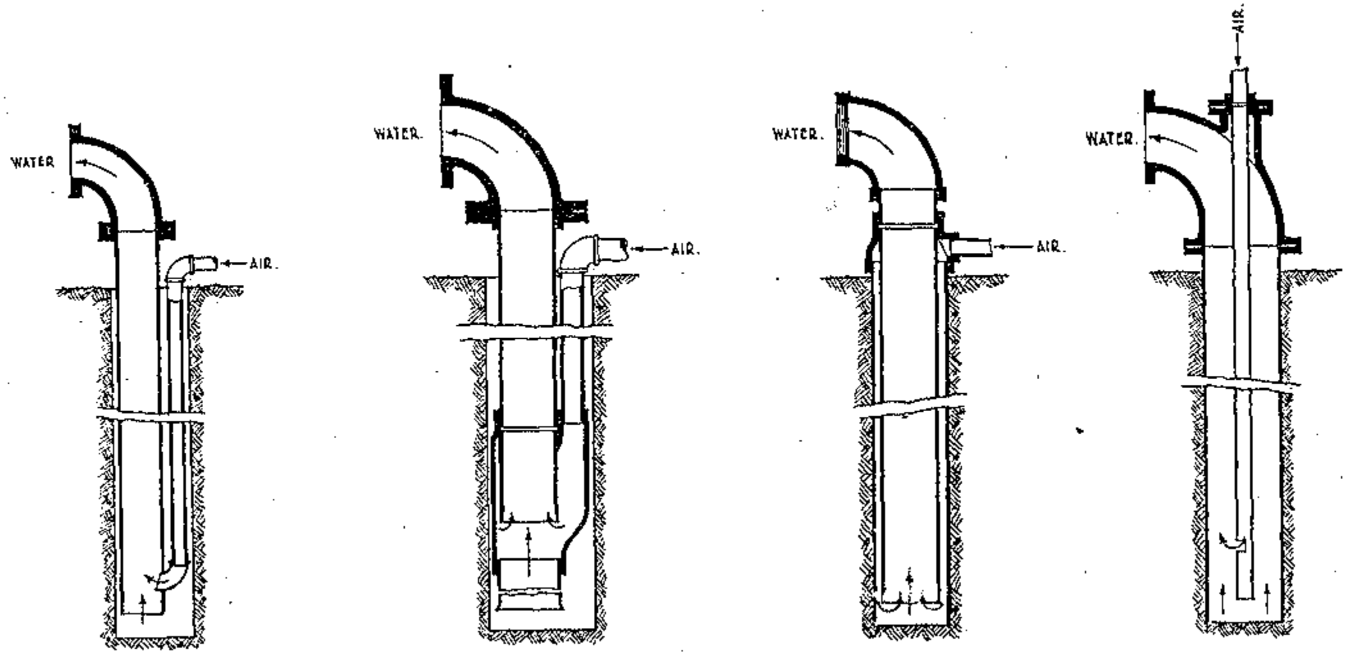
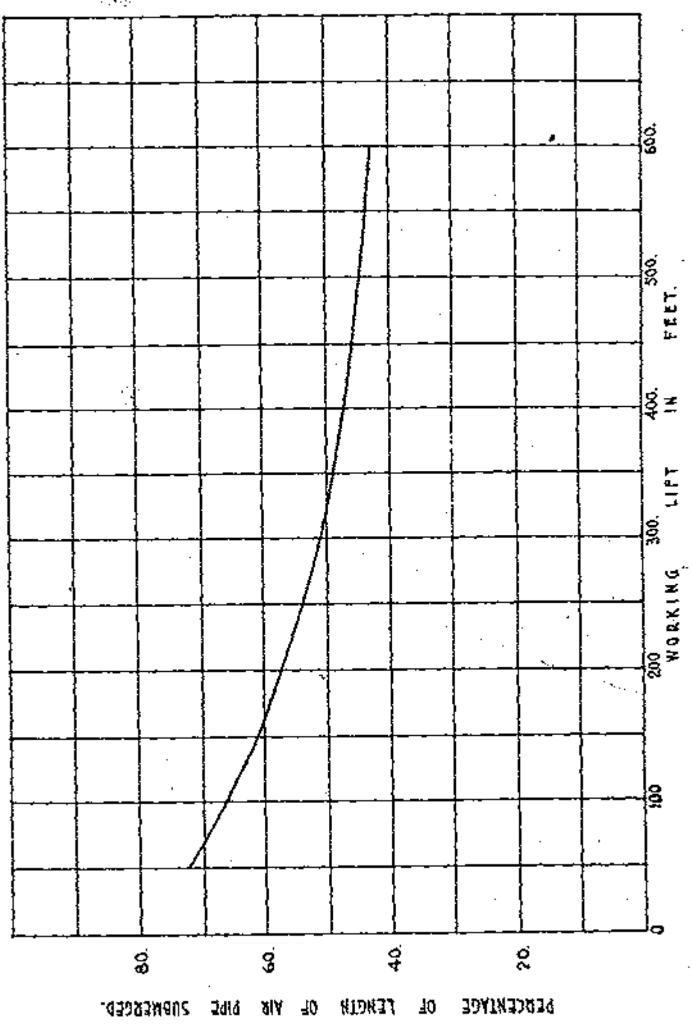


FIG. 4.

CURVE GIVING MOST EFFICIENT SUBMERGENCE FOR VARIOUS LIFTS.

(FROM "IVENS' PUMPING BY COMPRESSED AIR").



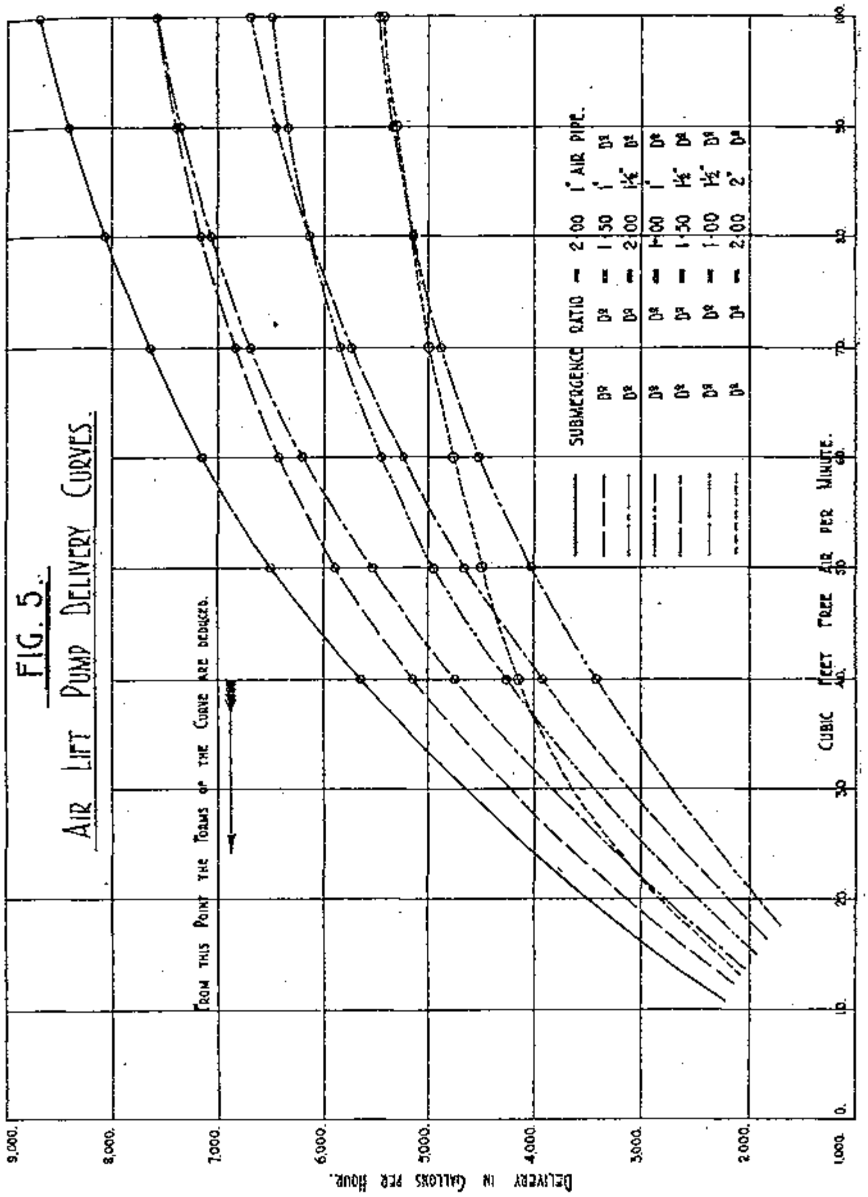
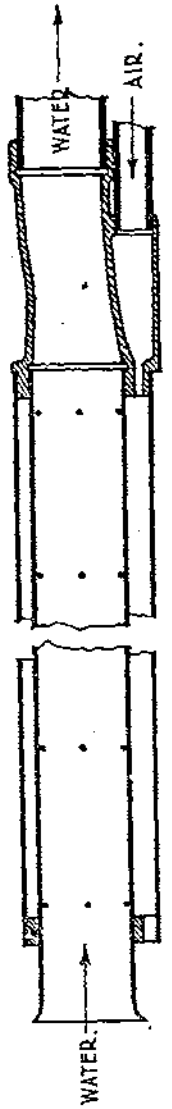


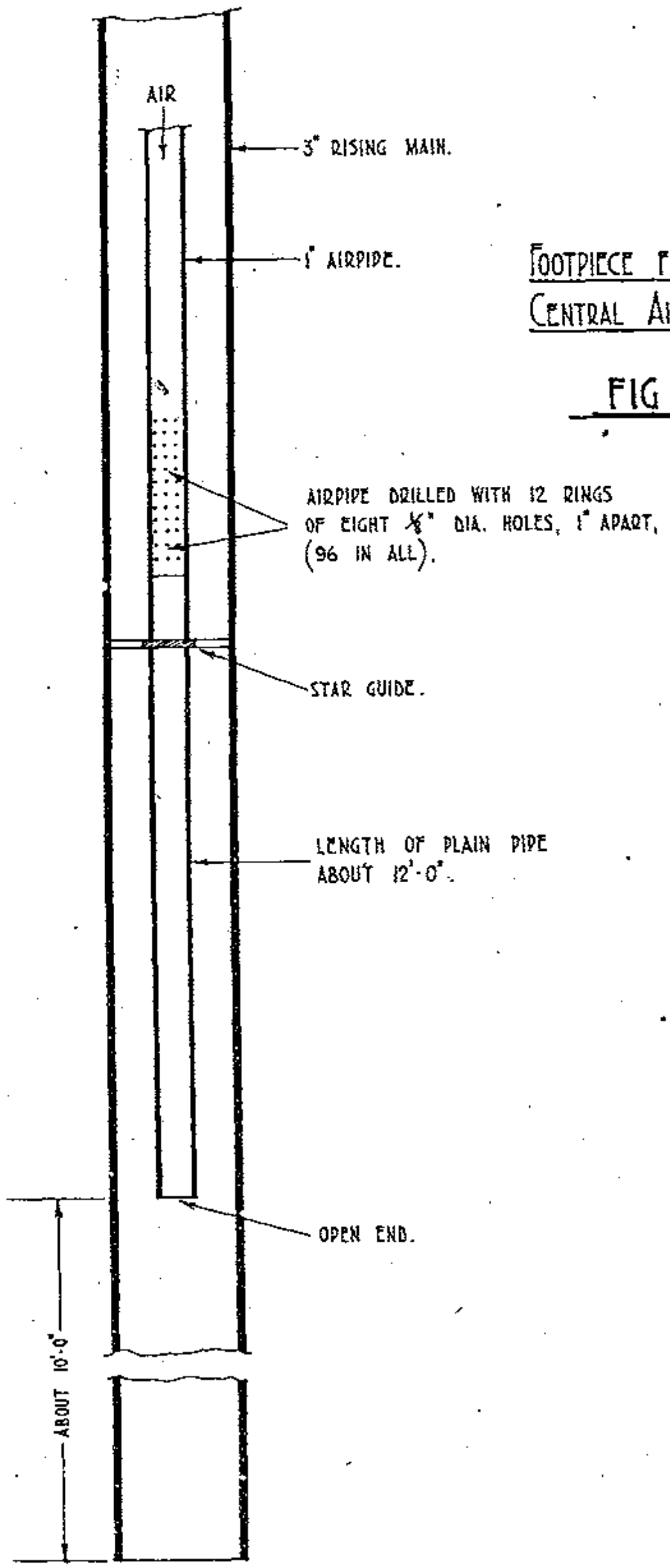
FIG. 5.
AIR LIFT PUMP DELIVERY CURVES.
FROM THIS POINT THE FORMS OF THE CURVE ARE DEDUCED.
SUBMERGENCE RATIO — 2.00 1" AIR PIPE.
D° D° — 1.50 1" D°
D° D° — 2.00 1½" D°
D° D° — 1.00 1" D°
D° D° — 1.50 1½" D°
D° D° — 1.00 1½" D°
D° D° — 2.00 2" D°
CUBIC FEET FREE AIR PER MINUTE.
DELIVERY IN GALLONS PER HOUR.
9,000.
8,000.
7,000.
6,000.
5,000.
4,000.
3,000.
2,000.
1,000.
0.
10.
20.
30.
40.
50.
60.
70.
80.
90.
100.

FIG. 6.

THE "HARRIS" AIRLIFT PUMP.

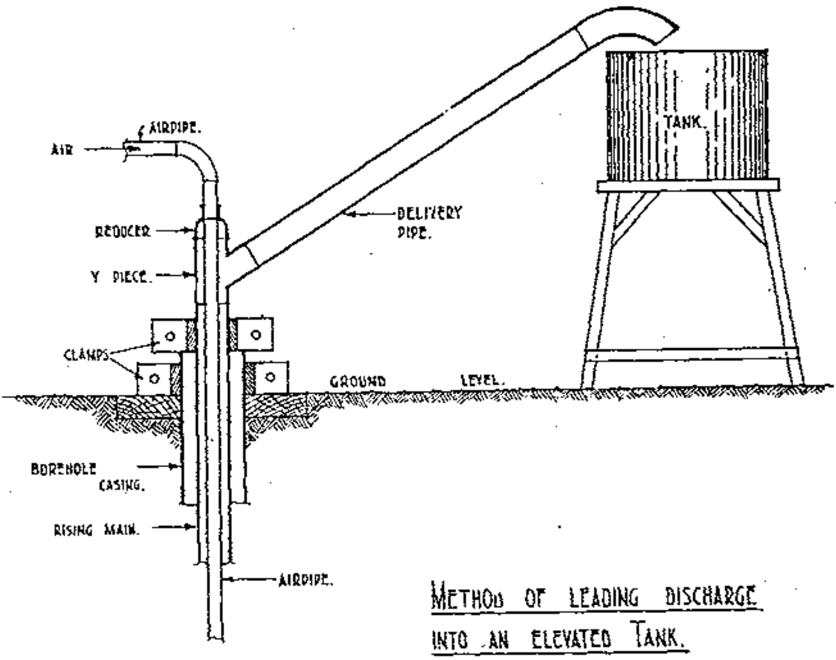


FROM DIAGRAM CONTAINED IN
INGERSOLL-RAND COY'S CATALOGUE Nº 76.



FOOTPIECE FOR AIRPIPE.
CENTRAL AIRPIPE SYSTEM.

FIG 7.



METHOD OF LEADING DISCHARGE INTO AN ELEVATED TANK.

FIG 8.

FIG. 9.

METHOD OF RELEASING AIR FROM RISING MAIN AND TRANSMITTING WATER OVER A DISTANCE HORIZONTALLY FROM WELL-HEAD.

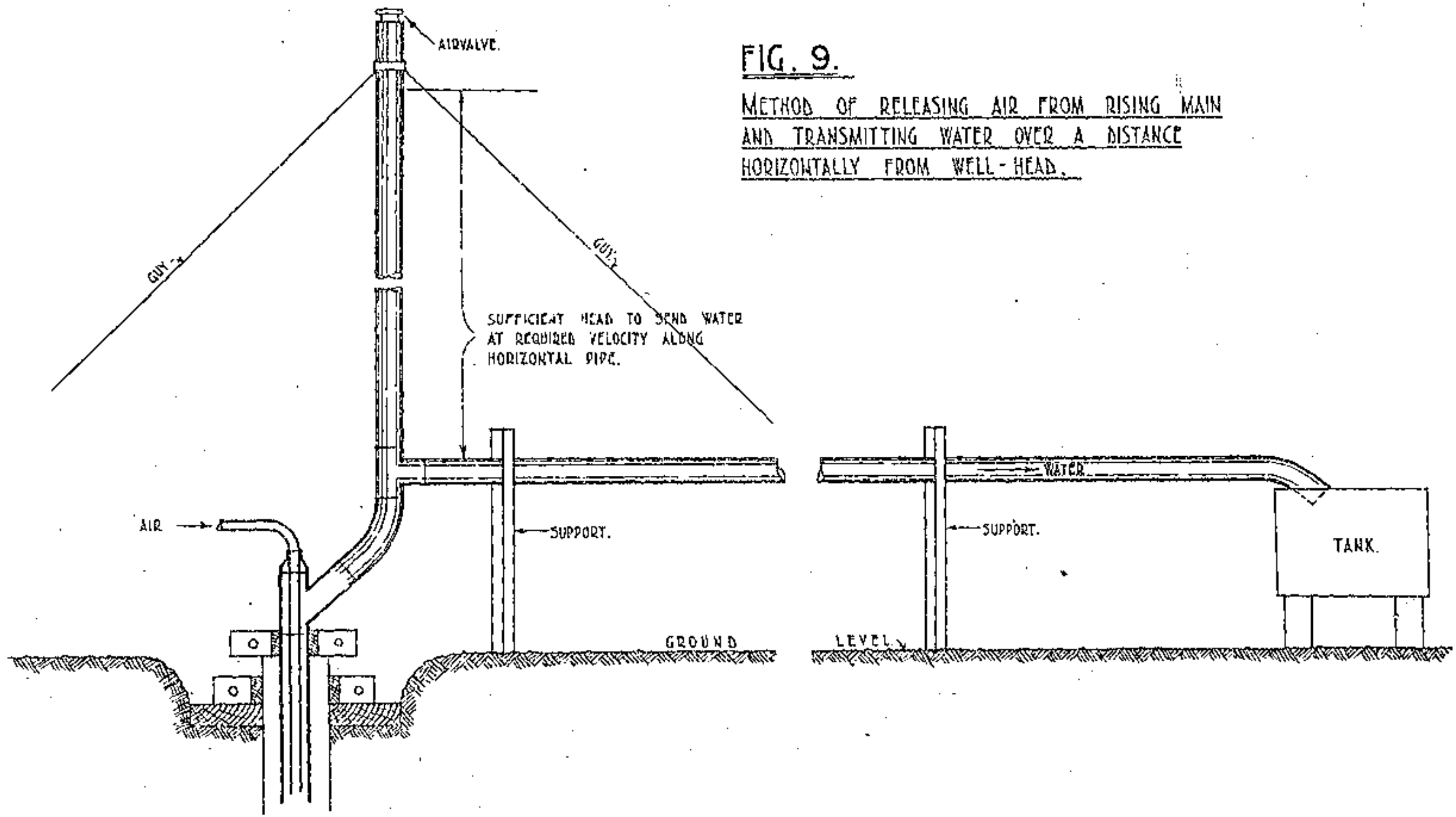
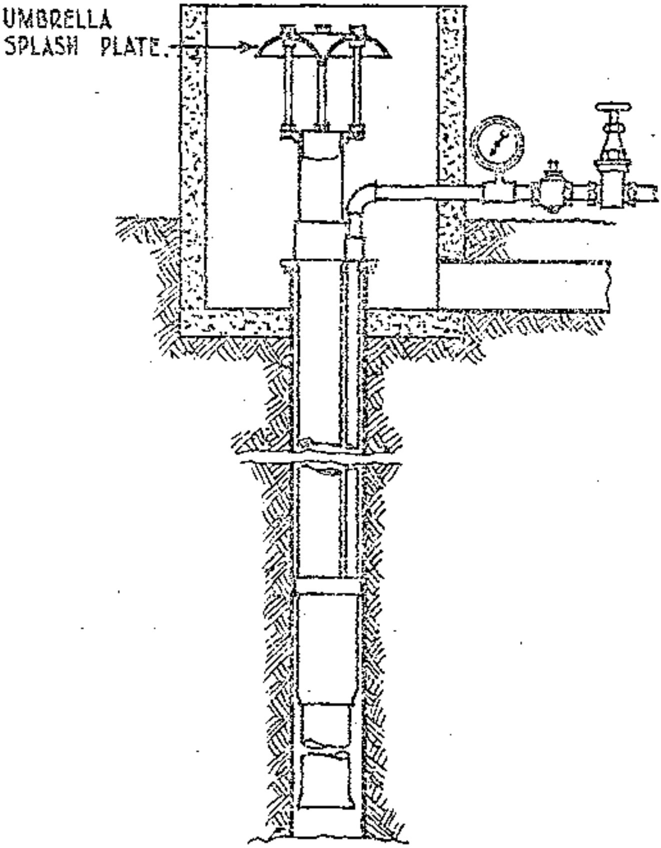


FIG. 10.

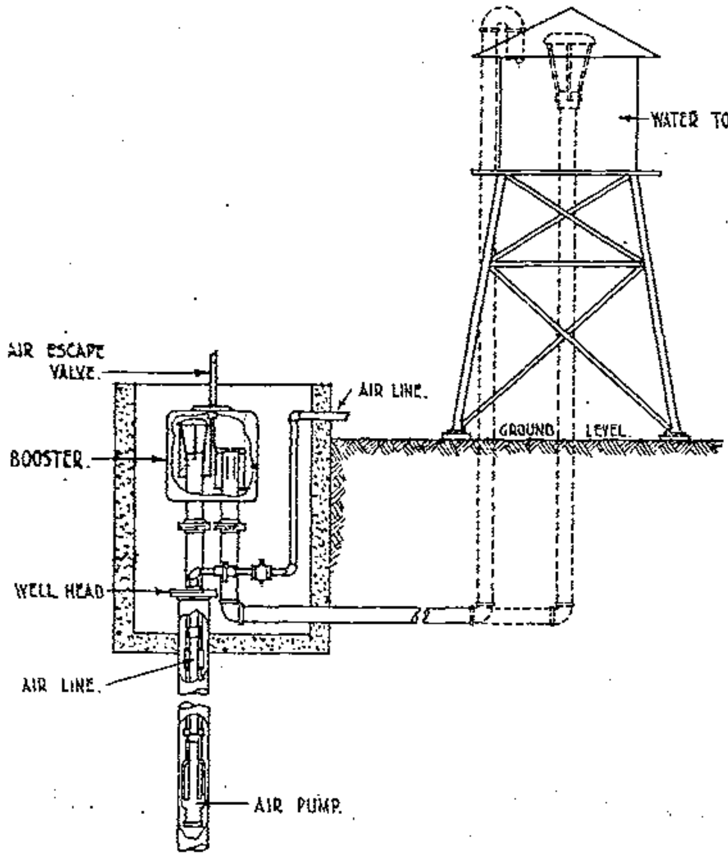
METHOD OF LEADING DISCHARGE AWAY FROM WELL HEAD.



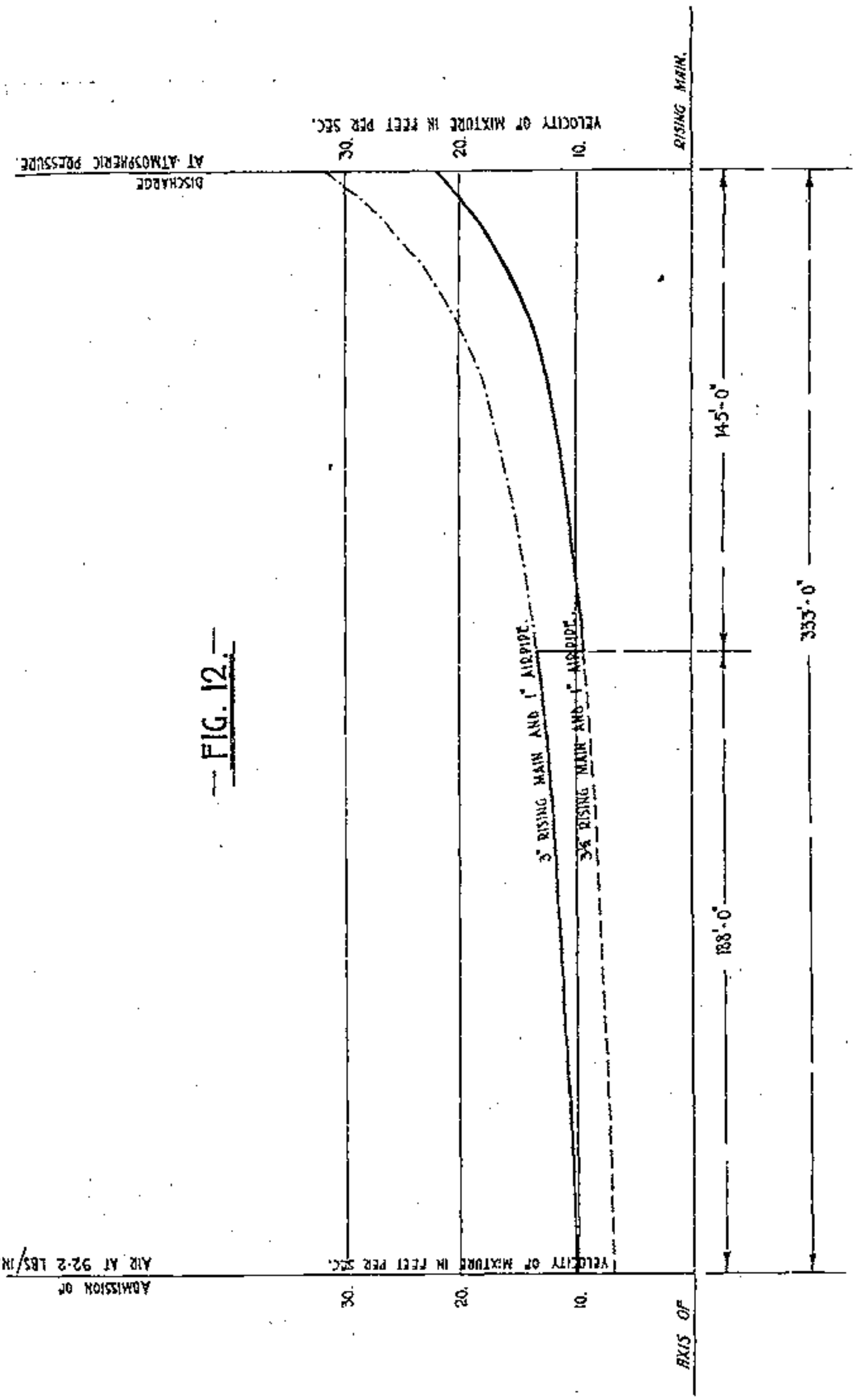
FROM DIAGRAM CONTAINED IN
INGERSOLL-RAND COY'S CATALOGUE Nº 76.

FIG. 11.

THE "HARRIS" BOOSTER PUMP.



FROM DIAGRAM CONTAINED IN
INGERSOLL-RAND COY'S CATALOGUE Nº 76.


DISCHARGE AT ATMOSPHERIC PRESSURE.
VELOCITY OF MIXTURE IN FEET PER SEC.
30.
20.
10.
AXIS OF RISING MAIN.
ADMISSION OF AIR AT 92·2 LBS/IN.
3" RISING MAIN AND 1" AIRPIPE.
3¼" RISING MAIN AND 1" AIRPIPE.
145'-0"
188'-0"
333'-0"

— FIG. 12. —

REVIEW.

TELEGRAPHY, AERONAUTICS, AND WAR.

By CHARLES BRIGHT, F.R.S.E.—(Constable & Co. 16s.).

THE author of this volume is a well-known authority on telegraph matters; he has read several papers on the administration of Telegraphs and allied subjects before important bodies and has contributed many articles on similar questions to the leading periodicals. Mr. Bright, it may be remembered, served as a Member of the Committee of Enquiry appointed in 1916 to deal with questions affecting the Administration and Command of the Royal Flying Corps; whilst so engaged he prepared a series of "Additional Recommendations," and some supplementary memoranda on aeroplanes, aero-engines, etc., which are incorporated in the Final Report of the Committee in question. During the War, Mr. Bright has prepared a number of memoranda on cable and "wireless" communications, the censorship and other telegraph matters for the information of the War Office, the Foreign Office, the Colonial Office, etc.

The volume under notice contains reprints of a number of Mr. Bright's more recent papers and articles and also of the memoranda referred to; they are preceded by an "Introduction," separate sections whereof are devoted to War, Aeronautics, and Telegraphy. Addresses, entitled "A Nation's Awakening" and "Nothing as Usual," delivered by Mr. Bright in various parts of the country on behalf of the Victoria League are included in the volume, which is completed by the insertion of a useful table giving approximate cable distances from London to various important centres and the ordinary cable rate thereto, and also of a Telegraph Map of the World.

The papers and articles reprinted in this volume, though mainly devoted to the commercial aspect of our overseas communications, deal also with the strategic aspects of a proposed Inter-Imperial Cable network. Many problems connected with "wireless" telegraphy are discussed by Mr. Bright, who deals, *inter alia*, with the advantages and disadvantages of the submarine cable in comparison with those of "wireless," as a means for providing safe and sure communication with the Overseas Dominions and the outlying portions of the British Empire. The vexed question of the provision of "fixed" defences for localities where mportant British cables are landed is also touched upon. Several of the problems dealt with by Mr. Bright are likely to come up for consideration, with a view to their settlement, in the immediate future. The information contained in the volume under notice will prove of value to all who either take an interest in or are obliged to concern themselves with those questions which affect our overseas communications, whether in war or in peace.

W. A. J. O'MEARA.

NOTICE OF MAGAZINE.

REVUE MILITAIRE SUISSE.

No. 8.—*August*, 1918.

Heavy Field Artillery before the War.

The original article on the above subject is contributed by Lieut.-Colonel E. Mayer (Emile Manceau), who discusses the question therein whether heavy artillery has, in the present War, justified its existence. He tells us that very recently a distinguished French artillery officer remonstrated against the infatuation of the public for the heavy type of field piece. The adoption by Germany of short-range trench guns had provided the officer in question with a pretext for condemning long-range heavy guns, for declaring them to be useless, and even an encumbrance. This condemnation was based on the argument that long-range artillery fire, the effects of which cannot be observed, must be ineffective; the condemnation is summed up in the following terms:—"Long-range artillery fire, the dispersion of which is excessive, should not be resorted to. The example set by the Germans in reducing the range of their 8-in. gun from 10,000 to 2,500 metres should be followed. It is even necessary to go one better. The gun should be placed within a few hundred metres of its target, and the accuracy of its fire increased by this means tenfold. It is further necessary to increase, in a tenfold degree, the rapidity of bringing guns into position and in moving them from place to place; the rapidity of their fire, the explosive force of their ammunition, and its quantity, should be multiplied to as great an extent as possible. In a word, what is wanted is a light short-range gun, with a curved trajectory, capable of affording rapid and accurate fire; its projectile should be a mere container for explosive material and should, therefore, consist of a thin sheet of steel."

The object to be aimed at, it is stated, should be to cover with a rain of explosive matter, propelled from trench guns, the ground over which the waves of attack must pass rather than to employ an armament constructed for other purposes; one therefore which is not particularly suitable, to attain the end in question.

Colonel Mayer points out that there are directions in which long-range artillery can be usefully employed; it is wrong, therefore, to suppose, as some do, that because a particular instrument cannot be used for every purpose, it can have no value for any purpose whatever.

It is true that heavy artillery has not come up to all expectations; on the other hand, it has to be remembered that it could have been usefully employed for many purposes, other than the tasks assigned to it, had a demand been made for further support from this arm. Long-range artillery has "proved in," and, even if new models of trench guns are being designed and manufactured, all the belligerents will still continue to build long-range heavy artillery and are certainly not going to do without its powerful aid.

Examining the origin of heavy field artillery, Colonel Mayer points out that the problem of the introduction of this arm was not approached *a priori* or deliberately; like so many things else heavy field artillery owes its existence to chance. Armies had been provided with light siege trains before the War; there being no immediate use for them after they had accomplished the tasks for which they were originally intended, it was soon recognized that the pieces composing these trains could be utilized for a purpose which was beyond the capabilities of ordinary field artillery. This idea was seized upon and soon put into practice.

Such a use of heavy artillery had been discussed in a prophetic work by Capt. (now Major) Gabriel Glück, entitled *The French Artillery in Contest with Germany Heavy Artillery* (published by Chapelot in 1914). Colonel Mayer gives us an outline of the contents of Capt. Glück's work in the original article.

The French having, after the War of 1870, fortified their Eastern frontier in order to bar the routes leading into the interior of France from the Rhine, the Germans, imbued with the doctrines of Clausewitz, felt that, in the event of their attempting another invasion of the territories of their Western neighbour, their best plan would be to strike quickly at the heart of France and to attempt to reach it as soon as possible, without waiting to reduce the entrenched camps intended to impede their progress to their main objective. These camps they proposed merely to invest. The Germans had, however, to reckon in addition with the *forts d'arrêt* which the French Engineers had built in such positions that they could not be similarly turned. The Great General Staff hoped that by means of the *attaque brusquée,* delivered with extreme violence, and with engines of War specially designed for the purpose, it would be possible to readily reduce the last-mentioned forts and thus quickly to open a route for Germany's invading columns. With this object in view the German Army was provided with parks of light siege guns consisting of 15-cm. (approximately 6-in.) howitzers and 21-cm. (approximately 8-in.) mortars.

Major Glück, discussing the question of the employment of these light siege guns in the work referred to above, pointed out that, after the principal task for which they had been introduced had been accomplished, a further opportunity for their employment would be found against the enemy's strong points and field entrenchments. The possibility of utilizing the parks of light siege guns as heavy field artillery was facilitated by the fact that the Great General Staff had, in 1892, provided horse-transport for the garrison artillery batteries armed with the siege guns and had, subsequently, year by year brought about an assimilation of this branch of the artillery to the other field troops. By degrees, the *rôle* originally assigned to the light siege guns was enlarged and steps were consequently taken to enable them to undertake wider duties on the field of battle. Major Glück refers to the subject in the following terms:—"The organization of the units, the increase in their establishments, the improvements in their equipment, all tend towards this object. The garrison artillery takes part in the combined manœuvres with the other arms; the brilliant part played by the garrison artillery of the Guard at the Imperial Manœuvres of 1900, caused the Kaiser, at the Conference, to award to the 15-cm. howitzer, the title of *heavy field howitzer*, a title which it still retains. To-day (1914) the heavy batteries of the field army have become an important factor with which the High Command must reckon from the moment a campaign begins."

After the experiments carried out at Thorn, shortly before the War, were completed, General von Dulitz, Inspector-General of Garrison Artillery, claimed the premier *rôle* for the arm which he officially represented; he urged that heavy batteries should be organized and that they should be at once brought into action in the initial stages of a battle owing to their greater range. Naturally, General von Schubert, the Inspector-General of Field Artillery, was unable to accept such a claim; his views on the subject were expressed in the following terms:—

"An arm as powerful as the garrison artillery should be reserved for the destruction of defined objects. It would be wasteful to bring it into action before the situation has been cleared up. Besides, one cannot be blind to the fact that its presence at the head of the columns would be an impediment to their progress and the coming into action of the heavies at the beginning of an engagement could only delay the entrance into the fray of the field artillery."

The divergent views of the two Inspectors-General are mirrored in the German regulations relating to the employment of the new artillery arm. The first of these regulations was at first kept secret and only became public property in June, 1906; the text therefore was revised and modified in November, 1908. The participation of battalions of 15-cm. howitzers in a field campaign was definitely provided for in this revised text and units of heavy howitzers have since formed an integral part of the German Army Corps. The regulations relating to the use of this arm issued in June, 1911, and in March, 1912, were only amplifications of those promulgated earlier. It is not the text of the regulations but the comments thereon by German officers that gave a true indication of the intentions of the High Command concerning the part this arm would play in the theatre of operations.

In the preface to the latest regulations, it is stated that reliance is placed on this arm "to open the road to victory for the infantry," and, in paragraph 358, it is laid down that the heavy artillery "shall act in co-operation with field artillery" in support of the infantry; the regulations are so framed that they meet, to some extent, the conflicting claims of the two Inspectors-General.

Paragraph 365 of the regulations of March, 1908, had decreed that the heavy batteries were to march in rear of the regimental trains of the field artillery. This decision gave rise, at the time, to lively polemics; it was held to be illogical. The value of the heavy pieces was soon recognized and a modification of the regulations immediately followed.

Paragraph 417 of the new regulations ran as follows:—" If an Army

Corps marches on a single road, the heavy artillery should, as a rule, be attached to the leading division; its place in the column should, under ordinary circumstances, be immediately in rear of the infantry. If the possibility of bringing it into action early in an engagement is foreseen, it should occupy a more forward position in the column; under certain circumstances it may even be necessary for it to march in front of the main body of the field artillery. It will be necessary to consider, in such a case, whether the forward position to be assigned to the heavy artillery is likely to prejudicially delay the field artillery, and, above all, the infantry in coming into action."

In the battle, it was intended to employ the German heavy batteries grouped; they were to come into action by whole battalions, under the orders of the Divisional General to whom they were temporarily assigned. It was contemplated that the employment of these batteries as Corps Artillery would be exceptional.

The heavy batteries were enjoined to come into action in invisible and masked positions, so that hostile artillery would find them a difficult target; these positions were, as a rule, to be in rear of those required by the field artillery.

Such an arrangement provides two tiers of fire, but in the case of artillery is inconvenient, owing to the difficulty in observing the effects of the fire. The German regulations lay stress on the importance of having a properly organized chain of observation posts to meet the situation, and instructions are set out for the guidance of the infantry and cavalry for the purpose of preventing undue interference with these observation posts. The necessity of providing uninterrupted communication between the positions of the batteries and the advanced infantry fighting line is also insisted upon. (There are some French writers who are of opinion that it is almost impossible to provide communications of this nature with certainty and have argued from this assumption against the employment of heavy field artillery).

Summing up the position of affairs before the War, Colonel Mayer states that the Germans reckoned on employing their battalions of mortars against the French *forts d'arrêt* and strongly fortified positions; whilst the long heavy guns were intended for use against the enemy's billeting areas and for long-range fire against advancing columns, in order to bring about their premature deployment, thus to cause the enemy to advance for a greater distance across the fields instead of along the highways. It was expected that his *morale* would thereby be lowered. Heavy guns stationed on the flanks of a position would, it was further argued, deter an attack against those flanks and compel an enemy to make wide turning movements for the purpose of effecting the capture of such a position.

Paragraph 358 of the regulations of 1908 contained an instruction that the German heavy artillery should engage *all* enemy artillery, even guns in invisible or masked positions; every means, *e.g.*, aerial reconnaissances, etc., were to be adopted, for locating such masked guns as early as possible.

Major Glück states in his work that the German Army Corps, in addition to its complement of 144 field pieces (*i.e.*, 108 77-mm. guns and

36 light howitzers), had a number of heavy pieces, manned by garrison artillerymen, viz., 15-cm. howitzers, 21-cm. and 28-cm. mortars and 10-cm. and 13-cm. guns.

The German garrison artillery, like the other branches of the German Army, had had its establishment largely increased by recent legislation. In the spring of 1914, it consisted of 25 regiments, or 50 battalions, comprising 193 batteries. At the beginning of the War the Germans had, in round numbers, 700 heavy guns ready to take the field.

Normally, each German Army Corps had attached to it a battalion, *i.e.*, 4 batteries of 15-cm. howitzers.

The remainder of the garrison artillery, attached to the field army, consisted of about 30 batteries (125 pieces) of 21-cm. mortars and of 80 to 90 batteries of 10-cm. and 13-cm. guns.

In the original article many details regarding the German heavy artillery and its ammunition are furnished by Colonel Mayer.

THE GERMAN ATTACK ON LIEGE.

The original article, which is accompanied by a sketch-map of E. Belgium, is written by Colonel Feyler, who has obtained his materials mainly from German official sources—principally from Part I. of the publication *Der grosse Krieg in Enizeldarstellungen*, prepared by the Great General Staff, entitled "Lüttich-Namur" (Mittler & Sohn, Berlin). The Great General Staff's publication has been prepared for propaganda purposes rather than from the point of view of a military historian; many of the statements contained therein are deliberately false.

Colonel Feyler points out that the German *coup de main* against Liège is one of the pieces of evidence pointing to the fact that the present War had for some time been premeditated by Germany. A short description is given in the original article of the defences of Liège; these consisted of 12 detached forts with unfortified intervals between them—five of these forts were situated on the right bank of the Meuse and the remaining seven on the left bank of this river.

The *coup de main* was directed by General von Emmich, Commanding the X. A.C.; his troops advanced to the attack on the morning of the 4th August, 1914. Two cavalry columns, under the command of General von Marwitz, formed the covering screen of the force detailed for this purpose; one of these columns, consisting of the 2nd and 4th Cavalry Divisions, advanced along the Dutch frontier, whilst the 9th Cavalry Division, constituting the second column, was directed on to the lower course of the R. Ourthe.

The above cavalry force was followed by six mixed brigades; they crossed the Belgian frontier at 9 a.m. on the date named and marched concentrically towards the Belgian fortress. Three of these brigades, the 34th, 27th and 14th advanced from Aix-la-Chapelle; one, the 11th, from Eupen; and two, the 38th and 43rd, from Malmedy. The 34th Brigade, after crossing the Meuse at Lixhé, on the 5th August, wheeled to the left and deployed against the N.W. forts of Liège. The 27th and 14th Brigades advanced against the N.E. forts; the 11th Brigade formed up on the left of the 14th Brigade; at the same time, the two brigades from Malmedy were directed, astride the R. Ourthe, against the S.E. forts of Liège.

The attack on Liège was delivered on the night of 5th–6th August. The bombardment of the N.W. forts by 21-c.m. mortars began at 2 p.m. on the 5th *idem*.

At daybreak of the 6th *idem*, the Germans found that their attack had failed at all points except one, where the results were, however, still indecisive. The troops of the 14th Brigade had passed through the interval between two of the E. forts and had reached the outskirts of the town, under the old citadel of *La Chartreuse*. The other brigades had been obliged to retire. The 14th Brigade had broken off the fight; it was reduced to 1,500 men and its ammunition supply was nearly exhausted. It approached the town with caution; it met with no resistance, the Belgians had abandoned the portion of Liège situated on the E. bank of the Meuse.

The 14th Brigade uncertain as to its communications was in a most uncomfortable position. However, on the morning of the 7th August, as the Belgians did not counter-attack, the decision was arrived at to enter the town; the bridges over the Meuse were, in consequence, crossed and it was then found that Liège had been completely evacuated. The 3rd Belgian Division, detailed to defend the town during the concentration of the Belgian Main Army, had been ordered to fall back on the Gette where it joined up with this main army, which had completed its mobilization and had taken up its assigned position on the river.

Meanwhile, all the detached forts at Liège were still held by their original garrisons; they commanded all the approaches to the river crossings. General von Einem was directed to reduce these forts, as a matter of urgency; the IX., VII. and X. A.C., also parts of the VIII. and IX. A.C. and some heavy guns and siege artillery were placed under his command to effect this purpose.

The intention had been to capture the N. forts first of all, and as early as possible, in order to permit the German I. Army to continue its advance westward, along the Dutch frontier. The first of these forts—viz., Barchon on E. bank of the Meuse—surrendered on the 8th August, and two others—both on W. bank of the river—were taken on the 13th and 14th *idem*.

In order to secure the river crossings completely, it was necessary to capture the W. forts, as well as those on the N. and E. of the town. The last of the Liège defences fell into German hands on the 15th and 16th August, and on the 17th *idem* the advance of the German Army on Brussels was recommenced.

The Great General Staff asserts that everything in connection with the attack on Liège worked out according to plan. According to the Berlin authorities their scheme was as follows:—

Weak brigades, at peace establishment, were detailed for the *coup de main* against Liège. Owing to the success, with which they met, it was possible immediately to bring them up to War establishment. At the same time, the German Main Army was being concentrated in the Liège region. When, thanks to the success of the *coup de main* whereby the War, and thus France might not have taken steps to bring about, in time, a redistribution of her armies to meet the attack against her N. frontier. If a battle on the 22nd day of mobilization had been foreseen by the Berlin authorities, it is evident the *coup de main* against Liège on the third day of mobilization constituted a benevolent warning to France, affording her three weeks in which to make her preparations to meet the serious dangers threatening her. Colonel Feyler is of opinion that an act implying such kindly consideration on Germany's part towards her foe requires for its acceptance as a fact a good deal of credulity.

The maintenance of the utmost secrecy in the arrangements being made by Germany for the invasion of France was essential in order to promote the success of the German plan of campaign. However, the Belgians early became aware of the presence of five German A.C. on their frontiers and having received information that two more A.C. (the III. and IV.) were mobilizing at Malmedy and St. Vith, they concluded, not without reason, that "seven A.C., 300,000 men approximately, were being concentrated on the roads leading into Belgium, which were barred by the fortress of Liège." (*Vide* Report of Army Commander at page 11 of *L'action de l'armée belge*).

Liège and Namur lie about 19 miles apart. Brussels is only some 47 miles distant from Liège, say three days' march; as soon as the forts of Liège fell it became possible for the Germans to advance to and take up a position on the line Brussels-Namur in four days, as actually occurred. Von Klück's Army, beginning its advance on the 17th August, entered Brussels on the 20th *idem*, whilst von Bülow's Army delivered an attack on the Sambre on the 21st *idem*.

Colonel Feyler points out that the attack on Liège on the 4th August—the third day of mobilization—which brought about a disclosure of the German plans does not fit in with a scheme which provided for a general deployment to begin on the 17th *idem*—the 16th day of mobilization—nor with the collision at Mons on the 23rd *idem*—the 22nd day of mobilization. For the surprise to have been a complete success, the order and dates of the events in question should have been as follows:—*Coup de main* securing passages of Meuse, 5th to 7th August; general deployment of the German Army, 8th *idem*; occupation of Brussels, 11th *idem*; arrival of von Klück in Lille region, 14th or 15th *idem*, *i.e.*, a week before arrival of British Army in the neighbourhood of Maubeuge.

It is stated in the original article that the dates just set out are those contained in the programme which had been drawn up by the Great General Staff.

Colonel Feyler points out that having regard to the facts that the two battalions of 21-cm. mortars attached to the attacking German columns had to be brought into action against the N.E. forts of Liège, and that the 34th Brigade (the one on the most northernly route) had to lend a battalion to the 27th Brigade, it is evident that the *coup de main* against Liège was not so successful as the Berlin authorities have claimed it to be. That the stroke against Liège miscarried is also to be gathered from the fact that the German right wing was not set into motion for the

the forts were taken in reverse, the last of these forts fell the concentration of the Main Army was already completed; consequently, the German I. Army was able at once to take up, on the left bank of the Meuse, the line from which it was to advance westward. The general deployment, according to programme, was therefore proceeded with.

Colonel Feyler points out that if the above statement accurately represents the German scheme a period of fifteen days was occupied by the German Main Army in its concentration, within one day's march only from the Belgian frontier defences, and that its advance into the interior of Belgium began on the sixteenth day after the orders to mobilize were issued.

It is necessary to assume that the *coup de main* against Liège was an essential element in the German plan of campaign. This plan, as is well known, involved the march of seven German Armies on the N.E. and N. frontiers of France, *i.e.*, towards the front extending from the Donon region to the Lille region. The left wing of the German Army, consisting of 8 A.C., marked time, whilst the right wing, consisting of 28½ A.C., pivoting its left flank on Thionville, was swinging round, so as to form front on a line west of the Moselle. A line drawn from a point of the Meuse just below Liège to a point on the Scheldt just below Tournai measures 170 km. (approximately 105 miles) *i.e.*, a 7-days' march. It was intended by the Germans that the invasion of France along the whole line should take place simultaneously.

In the main, the German advance did actually take place as outlined above, with the exception that the German right wing extended slightly beyond the limit mentioned. The collision of the German forces with the British Army at Mons occurred at midday on the 23rd August.

In order to determine the real value of the attack against Liège and to settle the point whether it was successful or not, it is necessary to know whether the Great General Staff had reckoned with the possibility of the German Armies being heavily engaged on the 21st and 22nd days after the order to mobilize was issued, and, if so, whether it was contemplated that such engagements would take place on the Namur heights, or on the N. frontier of France (towards Lille). Colonel Feyler points out that if the Great General Staff did anticipate that a battle would take place at so late a date, the course adopted in sending an ultimatum to Belgium as early as the 2nd August and the attempted *coup de main* with *non-mobilized* forces on the 4th, 5th and 6th *idem* require a good deal of explanation. Germany's wiser course, from all points of view, would have been to complete all her arrangements and then to strike with united forces. If the Great General Staff reckoned on capturing Liège with six weak brigades and two battalions of heavy artillery, the success of such an operation could not have been made less certain by employing a similar number of formations on a War establishment. Namur was captured by von Bülow's Army in three days.

By adopting the course suggested by Colonel Feyler Germany would have gained the further advantage that her intention to advance through Belgium would not have been disclosed from the first day of invasion of Northern France immediately on the completion of the concentration of the German left wing in Lorraine. It has to be borne in mind that, in spite of the difficulties caused to the French 7th A.C. by reason of the want of success attending its operations in Alsace, General Pau's Army was ready to strike on the 13th August. In Lorraine, Dubail was ready on the evening of the 12th *idem*, and Castlenau's Army actually began its offensive movement on the 14th *idem*. The German Armies in Lorraine must have been ready to meet the French on the above dates. In view of the foregoing situation, it would indeed have been a singular thing if, in spite of the fact that the German right wing had to advance from 100 to 170 km. (*i.e.* about 60 to 100 miles) to come on to the same strategic front as the left wing, the plans of the Great General Staff had not provided for the mobilization of the German right wing being completed at least as early as that of the left wing. Indeed, if the German Armies in Lorraine were ready to assume the offensive on the 13th or 14th August, as were the French Armies, then the German Armies intended to march into Belgium should have been ready to commence their advance on the 8th or 9th *idem* at latest.

The German statement that von Emmich's Brigades were sent against Liège at their peace establishment cannot, says Colonel Feyler, be accepted as true merely because it appears in an official document. Had these brigades been pushed forward, as stated, before being made up to War establishment, they would have been lacking not only in their full complement of men, but also in certain details of equipment. It should not have proved beyond the capacity of the Great General Staff to make up six brigades to War stablishment in *personnel* and to provide them with the necessary additional equipment and transport *in an emergency* in a locality such as Aix-la-Chapelle.

In making the statement that the *coup de main* against Liège was undertaken by brigades at peace strength, the Great General Staff, Colonel Feyler points out, lays itself open to severe criticism. In acting thus, it not only ran the risk of prematurely disclosing the German plan of campaign, but it failed to adopt the most adequate measures to secure the success of the enterprise contemplated. The Germans had the choice of alternatives; they could either have attacked with a sufficient force, and thereby disclosed the importance of the task assigned to the right wing of their army, but with the advantage that they would have broken through the obstacle in their way with the minimum loss of time, or, on the other hand, they could have attempted to conceal their plans by pushing forward a relatively small force only, but in this case they ran a serious risk of the failure of their plans. They adopted the latter course; they do not appear to have appreciated, at their true value, the risks involved in the plan of campaign prepared by the Great General Staff. The German plan for the invasion of France was faulty in conception both from the point of view of strategy, as well as that of diplomacy; the German armies had to mark time, whilst a way was being opened for them into Belgium, and the measures taken to conceal Germany's war-like intentions provide ample evidence to prove the bankruptcy of her diplomacy.

TRAINING CENTRE OF THE SWISS 1ST DIVISION.

A brief description is given in the original article of the six weeks' course of training provided for the 1917 and 1918 recruits called up for service with the Swiss 1st Division during the current year. The training given to these recruits is based on the methods adopted in the French Army. The author of the original article states that, although good results are being obtained, much has still to be done to put the training of the infantry of the Swiss 1st Division on a thoroughly sound footing. Sufficient is not being done, it is suggested, for providing instruction for the specialists, in the case of officers as well as of other ranks. The formation of musketry and bombing schools, and the institution of courses in gymnastics and bayonet fighting for the specialists is strongly advocated in the original article. It is urged that the period of instruction at the training centre should be extended to sixty-five days.

THE PEACE QUESTION.

Colonel Feyler contributed an article on "A Durable and Immediate Peace" to the number of the *Revue* for May last (*vide R.E. Journal* for July, 1918). The article in question was based on a pamphlet by the late M. Ragnar Paijkull-Sturzenbecker, entitled *Droit au but. Les conditions essentiels pour une paix durable.* The number of the *Revue* under notice contains a reply to Colonel Feyler written by M. Paijkull-Sturzenbecker very shortly before his death, which occurred suddenly. The author of *Droit au but*, in his reply, states that although he is flattered that the issue of his pamphlet had prompted Colonel Feyler to contribute a long article to the *Revue*, still he much regrets that the Colonel did not review this pamphlet. He expresses the opinion that he and Colonel Feyler have approached the same subject from different points of view; there is nothing remarkable therefore in the two writers having arrived at conclusions which do not agree.

M. Paijkull-Sturzenbecker states that, although, in his pamphlet, he does not take the side of either of the belligerent groups, he has made it clear that he in no way seeks to minimize the enormity of the crimes committed by Germany, nor does he make any attempt to excuse her immoral acts. His object was merely to look for some common ground, which would afford a suitable starting point for an agreement whereon the foundations of a future peace could begin at once to be laid.

It is clear from M. Paijkull-Sturzenbecker's reply to Colonel Feyler that the conflict in the views held by these two gentlemen on the subject of the present War and the means for securing a permanent and durable peace was sharp, and probably irreconcilable. The reply is too long to reproduce here *in extenso* and it, unfortunately, does not lend itself to condensation.

NOTES AND NEWS.

Switzerland.—The somewhat heavy mortality among the young soldiers, who have succumbed during the influenza epidemic prevalent in Switzerland during last spring, has unfortunately resulted in an extremely violent Press campaign being directed against the Director-General of the Swiss Army Medical Service.

A spirit of unrest seems to be prevalent everywhere. Switzerland has been, in recent times, troubled by the formation of "*fédérations de soldats*." A general order has recently been issued forbidding the formation of such associations; fear is expressed, however, that professional agitators and the "enemies" of Swiss military institutions will not be deterred from carrying on, clandestinely, their nefarious work of undermining the discipline of the Swiss soldier. This danger can best be combated, it is urged, if the military authorities are watchful and take the necessary steps to prevent the many petty annoyances to which soldiers have been subject, and which were the true cause of the "*fédération de soldats*" coming into existence.

It is stated that the Swiss cavalry is living in a state of "splendid isolation"; the War and its lessons seem to have no existence for this arm of the Swiss Army. No Cavalry Brigade Commander has, it is said, taken any official part in the tactical exercises of the combined arms which have been carried out since the Swiss Army was mobilized. The modern conditions of war, it is suggested, still require to be brought home to the Swiss Cavalry.

Portugal.—A special correspondent contributes notes from the Portuguese front in France. During the recent German offensive the Portuguese troops held a part of the line in the neighbourhood of Neuve Chapelle and were forced back to the Lys.

A special reference is made to the work of the Portuguese Artillery, which suffered somewhat heavily during the German advance.

What was known as the *secteur calme*, part whereof was held by the Portuguese, was during the German offensive the scene of much strenuous fighting. The Portuguese troops are naturally proud that it fell to their lot to bear their share of the brunt of the German attack.

A *Bulletin Bibliographique* concludes this number of the *Revue*. Notices are published relating to works, which deal with certain important Belgian questions; *inter alia*, M. Passelecq's *La question flamande et l'Allemagne*, M. Passelecq's *Le testament politique du Général von Bissing* and M. von Langenhove's *La volonté nationale belge en* 1830.

W. A. J. O'MEARA.