VIIb. Application of steel in hydraulic construction

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VII b

Application of steel in hydraulic construction.

Anwendung des Stahles im Wasserbau.

Application de l'acier dans la construction hydraulique.

VIIb

General Report.

Generalreferat.

Rapport Général.

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During the last few decades the use of steel in hydraulic engineering has increased at a rate which makes it appropriate for this special field of application to be reviewed and assessed, and seeing that steelwork applied to hydraulics has much in common with steelwork in general it has fittingly been included in the programme of the present Congress.

As an amplification of the reports and contributions to the discussion which outline the developments of steel construction in hydraulic work and provide illustrative examples, it is proposed here briefly to summarise those questions of materials which the problems have in common.[1] First and foremost among these is the problem of *corrosion*, which is one of great economic importance even though there is no need to accept the astronomical figures which are frequently (on insufficient grounds) put forward as estimates of the total annual loss by rusting.[2]

The structural engineer who uses steel as a building material will be unable in future to escape the necessity of some attention to the fundamental questions of corrosion, a field in which he has an important contribution to make to the essential collaborative work.

Too much stress should not be laid on the fact that the reports submitted disclose only rare instances of severe damage. In the construction of cofferdams, especially, our experience does not yet extend over a period long enough to be decisive regarding the resistance of steel to corrosion, but the available records appear ample and favourable enough to refute the objections that used

[1] The necessary shortening of this report has been secured by omitting such portions as might be looked upon as partial repetitions of the papers covered.

[2] In the lay and technical press the annual loss through corrosion of iron and steel, in Germany, is frequently put at 2 000 000 000 RM, but the impossibility of the loss reaching this order of magnitude is obvious at once from the fact that in the good year 1929 the total production of steel reached a value of only 2 000 000 000 RM. *Schaper,* working from a sounder foundation, arrives at an estimated value of 120 000 000 RM. (Stahl und Eisen, 1936, p. 1249), and *Daeves* puts the annual loss through rusting of German rolling mill products used in steel building work, bridges, shipbuilding, etc. at a maximum of 18 000 tonnes corresponding to 700 000 RM.

often to be urged against the suitability of steel as a material for hydraulic work. To-day our experience, even in the matter of sheet piling, already covers periods corresponding to the economic life under traffic of most of our works.

The essential point about the difficulties attending the problem of corrosion is that we do not know the order of importance of the diverse and numerous destructive influences that operate together, and as long as we continue to be without a criterion for distinguishing the principal from the incidental circumstances of corrosion we run the risk of neglecting influences which alone can provide the explanation of differences in the behaviour of steel structures similarly situated. The chief lesson to be drawn from this is that whenever practical observations are made it is necessary to insist that as many detailed data as possible be recorded which may throw light on the subject. In this connection it is necessary to take account of distinctive circumstances attending each case under observation even when, so far as our present knowledge goes, they appear to have no connection with the phenomena of deterioration.

Many notable contributions to the research of corrosion (for instance, the copper alloying of steel) are attributable more to chance observations than to planned investigations. Progress depends, therefore, on the co-operation of several different groups of technicians who have at their disposal varying possibilities of observing the phenomena of corrosion. Hence in the field of corrosion research the collection and digestion of experience and observations plays an even more important part than in others, for it is well known that "accelerated tests" to assess the value of a particular kind of paint or the qualities of a particular kind of steel are of very doubtful value. The only means of compressing the process of corrosion into a shorter period of time are by strengthening the corrosive medium, increasing the temperature and increasing the rate of movement of the specimen, and the limited extent that results obtained from laboratory experiments of this kind are suited for practical generalisation is shown by the very fact that indices of resistance to corrosion comparing one metal with another fall in an entirely different sequence according to the particular acid which has been used for the test.

In our special field of work the principal weapons against corrosion are to be found in the further development of paints and of low rusting steels. Metalising processes may be left out of account since they have attained to no significance in hydraulic work.

Underwater paints, exposed as they are to mechanical, chemical, as well as botanical and zoological effects, are made the object of requirements which partly contradict one another. There can, therefore, be no one kind of paint which is equally suitable from all points of view, and it is all the more necessary to ascertain by numerous observations on completed works which points of view are of the greater importance in the choice of such a paint. There is a lack, in all countries, of any suitable principle for the collection of such information. Recently, with a view to filling this need, co-operative work on a generous scale has been begun, such as the discussions and the full sized experiments under natural conditions carried out by the paint committee of the Verein Deutscher Ingenieure; a step which encourages the hope that important progress will be made.

Hydraulic structures should preferably receive a finishing coat based on bitumen or coal tar. In sea water a hot coating (bitumen without a solvent) is used; in fresh water a cold coating of bitumen dissolved in benzol hydrocarbons.[3] For the priming coat red lead continues to be preferred despite the danger of blistering due to the linseed oil it contains, but with hot painting the red lead priming coat is often held to be unnecessary. The red lead must be allowed to harden in order that the benzol of the bitumen coating which follows may not be further dissolved, and the hardening process takes from two to five weeks. This entails great difficulties in the erection and maintenance of hydraulic structures of steel, and these have led to the development of a type of red lead which dries quickly and under unfavourable conditions of weather.[4] Success appears to have been attained even in the use of special combinations of oils and resins to produce a special type of red lead which hardens adequately in a few hours, and is insensitive to bitumen dissolved in benzol.[5] The time required for the drying of the red lead can also be considerably reduced where benzine hydrocarbons can be used as the solvent for the bitumen. Recent experiments with paints based on *chlorinated rubber* (a material which also shows smaller sensitivity to light than the bituminous paint) promise good results with this form of protection, particularly from the point of view of resistance to abrasion, a consideration not negligible in hydraulic work.[6]

Low rusting steels have been obtained chiefly by the addition of *copper* up to 0.3 %,[7] but the increase in corrosion resistance is effective only against atmospheric attack and not against the continuous action of water. Copper-bearing steel rusts almost like ordinary steel, but a surface deposit of copper or copper oxide is gradually formed which combines with the rust to form a dense and strong protective layer, and this greatly retards further deterioration. If kept permanently damp, however, the layer of iron oxide becomes spongey and loses its protective value, this being the explanation of many unsuccessful experiences with copper bearing steel in hydraulic engineering.

Further development has proceeded in the direction of introducing other alloy elements with a view to increasing the corrosion resistance. It was found, for instance, that a relatively high phosphorus content (such as is characteristic of almost all weld iron) when combined with the copper content renders the protective layer very dense and also causes it to form very quickly.[8] The superiority of the more recent low rusting steels is attributable to this discovery. Other researches to determine favourable proportions for alloying copper with phosphorus and also with aluminium, chromium and nickel encourage the hope that economical types of steel may be discovered which possess adequate corrosion resistance in water. The fact that the resistance of different

[3] *Kindscher:* Stahlbau 1935, Nos. 5 and 6, p. 161.

[4] *E. Meier:* Bautechnik 1934, p. 577.

[5] *E. Meier:* Industrie-Lackier-Betrieb 1935, p. 1—6.

[6] *Kappler:* Z.V.D.I. 1936, N° 7, p. 183. — *Ballé:* Der Rhein 1935, N° 2, p. 39.

[7] *O. Carius* and *Schulz:* Mitteilungen aus dem Forschungsinstitut der Vereinigten Stahlwerke Dortmund 1928—1936, p. 177.

[8] *K. Daeves:* Naturwissenschaften 23 (1935); 38, p. 563; idem: Mitteilungen der Kohle- und Eisenforschung G. m. b. H. 1935, p. 186.

kinds of steel is naturally influenced by the composition of the aggressive fluid is reflected in the circumstance that the copper content increases the corrosion resistance of steel in dilute sulphuric acid but not in pure water, while in the presence of nitrates the copper appears, indeed, to operate adversely.[9]

The intermittent immersion tests in artificial sea water carried out by *Eisenstecken* and *Kesting*[10] have indicated, also, the great extent to which the corrosion of the steel depends both on the duration of the experiment and on the period of immersion, and have helped to explain the observation often made in practice that corrosion occurs in the places that are exposed to air and water alternately. The series of experiments represented in Fig. 1 covered a period of 28 weeks, the water being changed at the end of each four weeks. The specimens tested were small plates of mild carbon steel containing 0.08 % copper. A curve is plotted for each four weeks. Heavy corrosion of the specimens is observed only when the period of immersion is increased to about six or seven hours, and after the immersion the loss of weight becomes considerably slower. The effect of the duration of the test is seen in the fact that after four, eight and twelve weeks the heaviest attack was found to occur with 17 hours immersion, whereas at the end of 16 weeks it occurs with an immersion of 15 hours per day, and at the end of 28 weeks with nine hours immersion per day. The displacement of the maximum value in the direction of a shorter immersion period as the length of the experiment increases may be explained by the increasing water content of the rust layer. It may also be concluded from this that it is only with great caution that intermittent immersion tests of the kind frequently practised in the laboratory can be used as a basis for comparing the corrosion resistances of different kinds of steel and protective media. The results also show that the corrosion resistance of one and the same steel in its unprotected condition (as for instance in sheet piling) may vary greatly according to local circumstances.

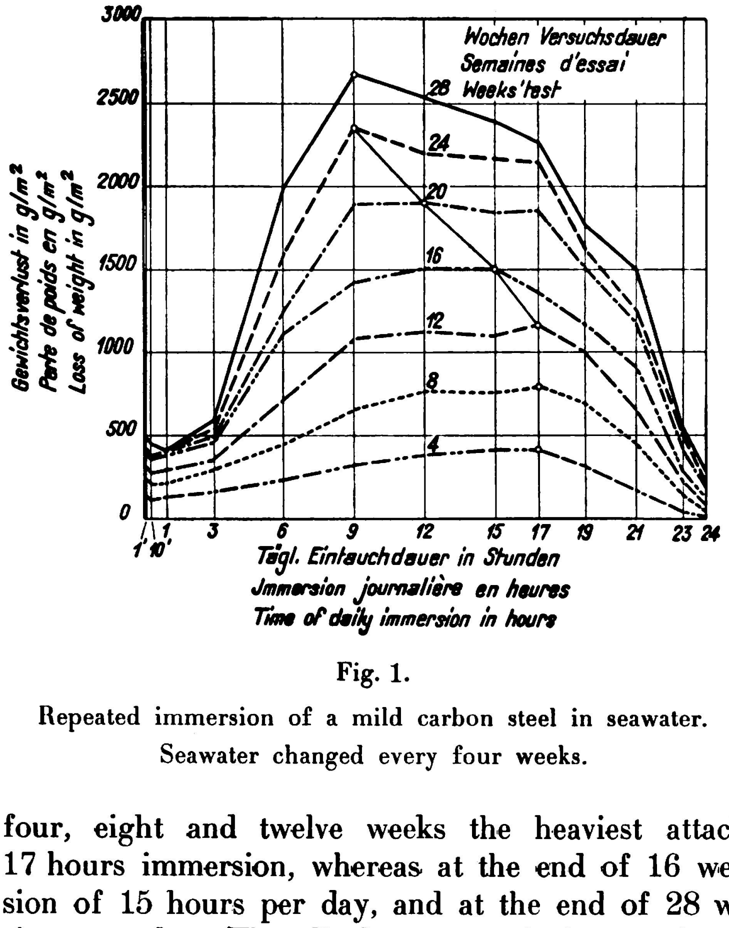

Fig. 1.

Repeated immersion of a mild carbon steel in seawater. Seawater changed every four weeks.

Metallurgical expedients to increase the corrosion resistance are effective even in steel parts coated with paint. This welcome fact which has been established

[9] *Büttner:* Bücher der Anstrichtechnik 1936, 1. Buch, V.D.I. Verlag 1936, p. 28.

[10] Bericht über die Korrosionstagung 1935, V.D.I. Verlag, p. 48.

in experiments by Daeves[11] may be explained from the consideration that any weak spots in the covering, such as are bound to manifest themselves sooner or later however good it may be, will be countered by a retardation of rust formation at the affected parts because after a short time the thin layer of copper which separates out of the steel will cover them over.

Since the renewal and maintenance of paint coatings in hydraulic structures is particularly wasteful of time and money, there is here even more relevance than usual in the observation that it is uneconomical not to employ high resistance paints merely on account of their high price, for in any case paint represents only about $^1/_5$th of the total cost[12]) and an increase in this item may be balanced by an increase in the life of the treatment relatively several times as valuable.

It is a matter of experience that the preparation of the steel surface to receive the coating of paint exerts a decisive influence on the life of the coating. Any defective places in the rolling skin must of course be dealt with, especially scale and rust, and here again no expense must be spared. It is worth mentioning, however, that a thick rolling skin provides in itself a very useful natural protection against rust. In the further development of low rusting steels — particularly those which are to be used for sheet piling without paint, or are only to be painted at long intervals — special attention should be paid to the systematic production of a dense and effective rolling skin. Fairly pure iron (such as Armco iron) forms a very uniform surface which offers an excellent ground for the application of paint. Apart from metallurgical effects of this kind temperature and the nature of the rolling process may possibly play an important part in the formation of a suitable rolling skin. The results obtained in treating the surfaces of small steel parts by the use of phosphates also offer a stimulus to further exploration of this avenue. The fact that the rolling skin may offer a very good rust protection is seen from a number of favourable experiences on record. For instance, *Hoffmann*[13] reports the good condition of the paint on the North Elbe bridge broken up at Hamburg where, after several decades, the red lead was so firmly bonded to its base (described as a bluish mill scale) that it was impossible to separate it. It cannot be assumed that these steel parts had been pickled. It is difficult, however, to distinguish satisfactorily between the rust protective rolling skin on the one hand and mill scale or layers of rust on the other, and for this reason, in addition to the introduction of the sand blasting process, the tendency is to do away with the rolling skin altogether. Nevertheless the possibility of so developing the rolling skin as to form a natural protection against rust should not be neglected. Moreover, in sanded steel parts, the transition zone between the oxide layer and the steel is not usually eliminated; hence no metallically clean surface is ensured, and as the surface is known to be particularly susceptible to corrosion rapid painting or other measures to prevent rust formation are necessary though not always successful.

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11 *Daeves:* Farbe und Lack 1931, N° 21, p. 242.

12 *Klöppel:* Unterhaltungskosten von Stahlbauwerken, Noske, Leipzig.

13 Dissertation, Technische Hochschule, Hannover 1921.

The further development of structural steels in the direction of increasing the permissible stresses is a matter of relatively small importance in hydraulic engineering by contrast with bridge work, since only small spans have to be covered. Indeed in many cases it is desirable to counter the dynamic effect of the water by means of a heavier mass of steel, and this explains why *high tensile steel* finds only exceptional application in hydraulic work. For sheet piling, again, according te Professor *Agatz*, ordinary structural steel is preferred, because a uniform thickness of the rusting layer weakens the cross sections of ordinary steel relatively less than that of high tensile steel, while moreover a greater resisting moment is presented and smaller deflection occurs in the sheet pile wall, and it is easier to maintain the alignment of the piles in driving them. Increased strength is, however, essential in overcoming heavy driving resistance and is desirable where heavy surface abrasion is encountered.

The *conditions of acceptance* for sheet piling are in general the same as those for steelwork in general, but it is difficult to say how far this practice is justifiable in view of the very different conditions of stress arising. Experience shows, indeed, that the criteria of quality hitherto imposed are in no way defective, but that is not to deny the possibility that other test values for steels might provide a better indication of their suitability for sheet piling. On this account, if the conditions of acceptance which have hitherto operated be found a hindrance to the further development of steel sheet piles it would be wrong to hesitate too much in departing from them.

Hydraulic engineering provides yet another field in which *welding* offers great advantages, as may be seen particularly in the movable hydraulic structures on the Albert Canal in Belgium. The monolithic character of welded steel structures tends to confer on them a greater degree of stiffness by comparison with heavy riveted work, and this is of great advantage especially in the case of flat constructions such as lock gates, where these are built of steel. The greater watertightness and the more convenient maintenance due to freedom from gaps and joints are great advantages, as is also the simplified design by this means of torsionally rigid structures, which are of great importance in hydraulic work.

To the steel engineer, the determination of the pressure and suction of water and the devising of measures to overcome vibration present additional difficulties. In order to solve these problems, as illustrated in examples by *Burkowitz*, a knowledge of the physics of stream flow is necessary, and this is obtainable from the theory of hydraulics. It would be in the best interests of hydraulic engineering — and particularly of the education of engineers for work in this field — that co-operative work between the structural steel and the hydraulic departments should be undertaken in the Universities.

VIIb 1

Steel in Hydraulic Engineering, and Model Experiments.

Stahlwasserbau und Modellversuche.

Constructions hydrauliques en acier et essais sur modèles.

Dr. Ing. e. h. Th. Becher,
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In the paper by *Burkowitz* and in all the contributions to the discussion on "Application of Steel in Hydraulic Construction — Movable Plant" reference is made to hydro-dynamical effects, vibration, etc. It is proposed here to develop that section of the subject which relates to the design of steel hydraulic structures on the basis of model experiments for studying the hydro-dynamical effects.

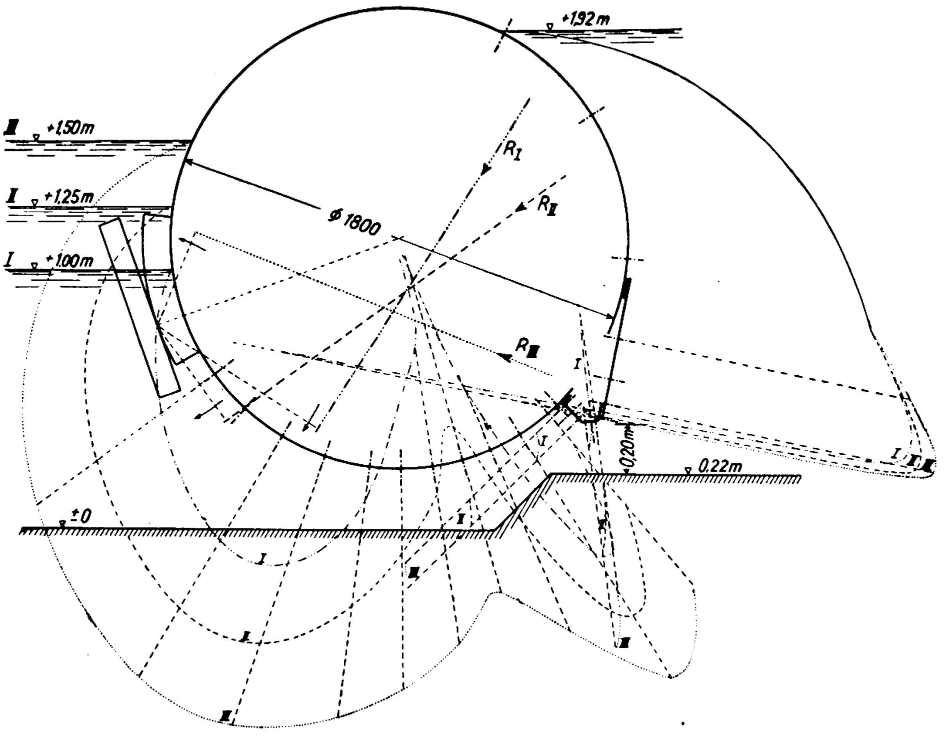

Fig. 1.

This study was first embarked upon as the result of certain diseases of infancy in the hydraulic plants which had to be cleared up by experiments on models, and the second phase was to use such experiments as a means of deducing principles capable of application for measuring the forces and dimensioning the openings and operating gear in plant designed in the ordinary way. From this it was easy to pass to the next stage, namely that of using model experiments to develop forms which would offer the most favourable possible hydro-dynamical qualities. A few examples will now be given.

Among the earliest roller weirs there were some which consisted merely of a supporting cylinder with a small attachment for stop planks. On one occasion such a weir was seen to be in a vigorous dancing motion, which finally led to the destruction of the whole gauge house and to the roller coming out of its guides. As it was difficult to explain this occurrence otherwise than on the assumption of some outstanding fault in operation, experiments on models were undertaken (Fig. 1). These showed that with a roller and crest of that shape the current of water shooting over the top experienced violent variations of pressure with the result that the roller was subjected alternately to pressure and suction effects. As a result of this knowledge all rollers were subsequently made with larger shields (Fig. 2). The most favourable relationship between the diameter of the roller and the height of the inlet was also experimentally determined.

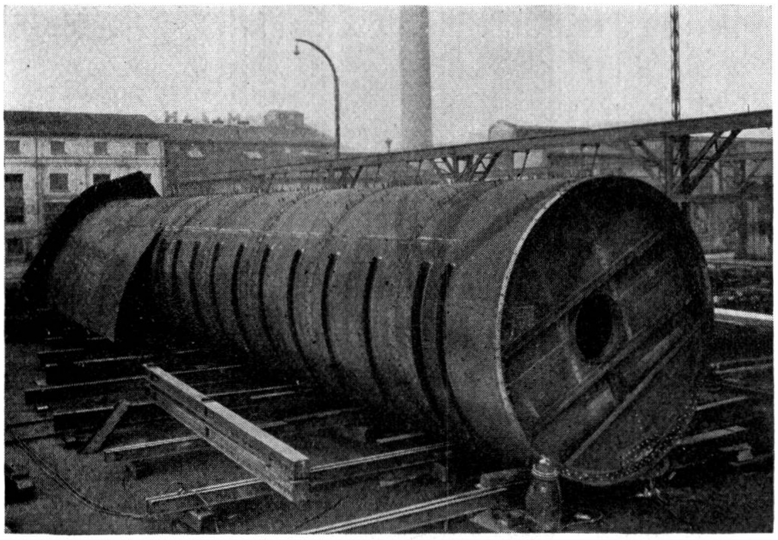

Fig. 2.

In the double gates of a large weir the upper gates were provided with a cover which the overflow water was discharged when the upper shields (upstream) were lowered. This cover consisted as shown on the left of Fig. 3 of a flat wooden sill inclined downstream. After every period of high water it was found that these overflow sills were to some extent damaged and required renewal. The wooden sill was replaced by a steel sill, but before doing so experiments were carried out to a scale of 1 in 5 to determine the proper shape for the plate, whereby a curved shape was decided upon, as shown on the right. The original inclined shape was found to cause an entirely irregular distribution of pressure, with numerous suction hollows, and the form finally decided upon for the overflow plates gives a harmonic distribution of pressure without any such suction hollows. At the same time it was found possible to incorporate two further impor-

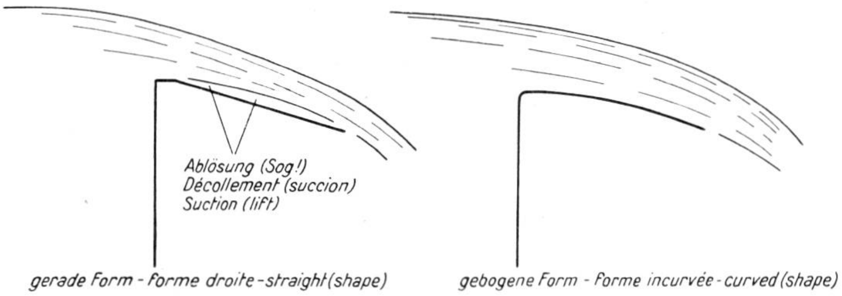

Fig. 3.

tant improvements in the new design: the water pressure load on the wall was reduced from 82 tonnes in the old to 38 tonnes in the new form, with a corresponding reduction in the power required for operation, and at the same time the discharge capacity was increased by some 20 %, showing that with the aid

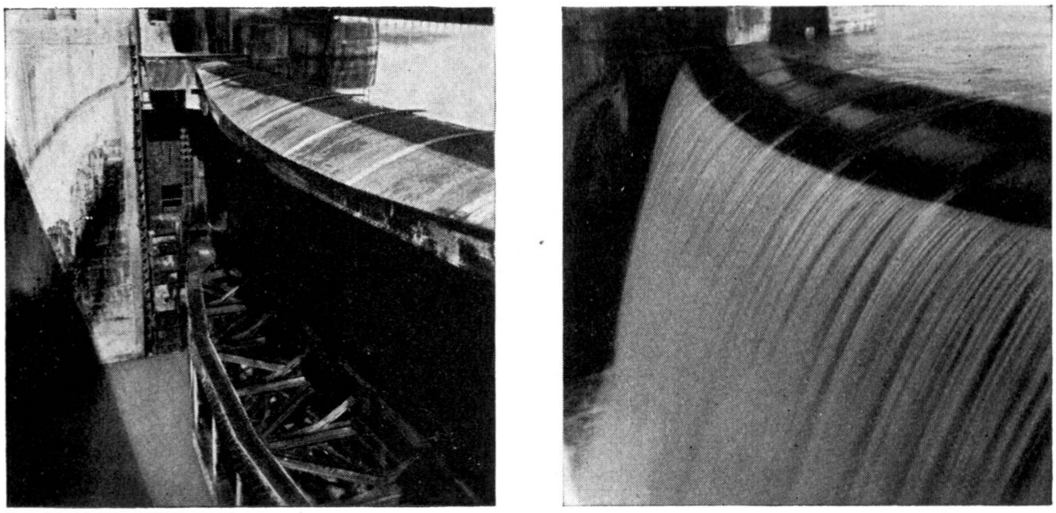

Fig. 4.

of a suitable overflow sill it is possible to economise in the length of the weir. Fig. 4 shows the constructional arrangement of a weir with one of the M.A.N. "hook gates" at Ryburg-Schwörstadt with the overflow shutter of the upper stoney-sluice. With a total height of 12.5 m these gates allow the upper gate to be dropped by 4.5 m. Their dynamical behaviour thus calls for very careful study.

A further problem was that of the vibration experienced by weirs when water flows underneath where only a small opening exists, an effect which was apt to lead to damage when the retained head became large. It was soon found by experiment that the cause of these vibrations lay in the design of the wooden sill and that by taking suitable measures the trouble could be mitigated (Fig. 5). Here again it is a question of obtaining a positive and stable line of pressure.

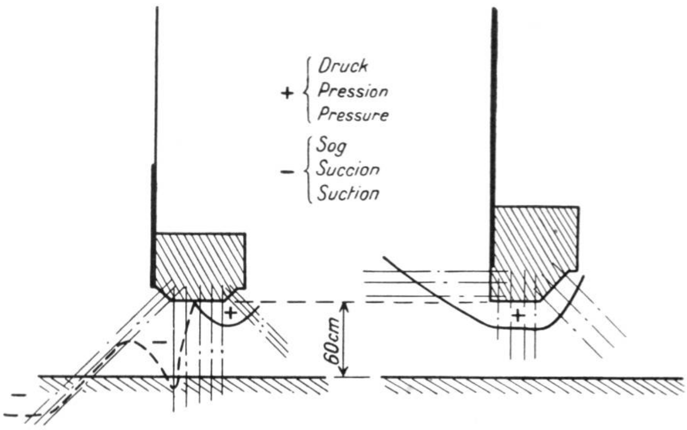

Fig. 5.

In yet other weirs of the stoney-sluice or bear-trap type vibrations were found to occur where there was an excess flow, especially where the height was limited. First of all, by experiment, ample ventilation of the space between the gate and the overflow was ensured, but this did not always cure the trouble, for it was found that the thin, coherent stream of water flowing over the flat sill was extremely sensitive to every impulse, and thus in itself tended to cause vibration. The experiments also showed however that this sensitiveness of the water stream is destroyed if cohesion is disturbed throughout its length, as by cutting it up or making it wavy (Fig. 6). This was accomplished by the introduction of

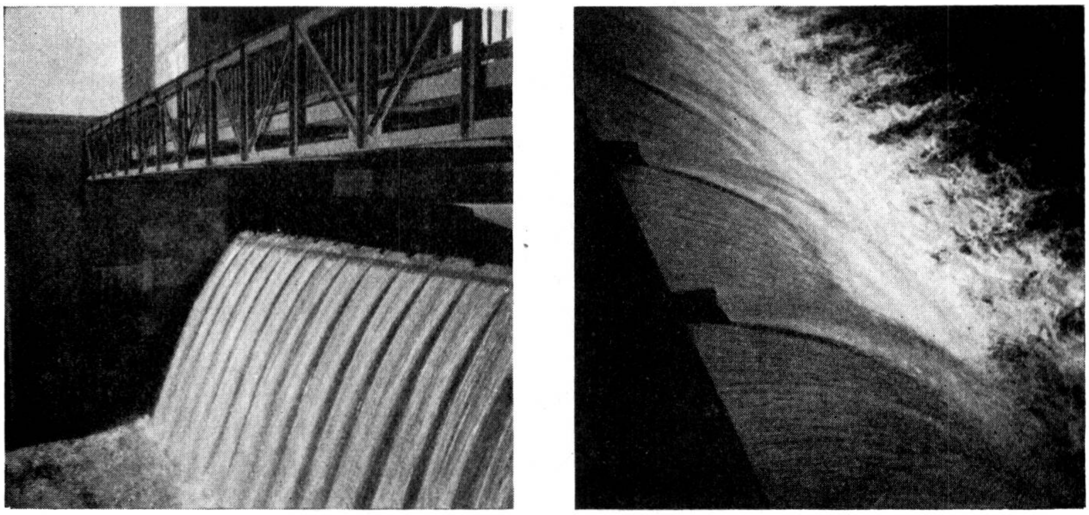

Fig. 6.

dovetailed strips of plate on the sill of the weir, and the illustration shows the stream flowing over the gate after this had been done.

Again, in the M.A.N. "fish bellied shutter", the chief feature of which is the operation from one side (Fig. 7), a current interrupter of this kind has been introduced. The example shows a sill of this kind in the weir at Heinbach measuring 18.0 × 4.0 m.

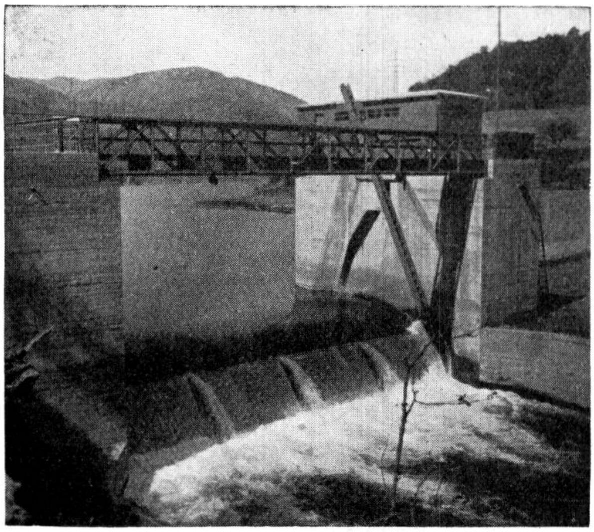

Fig. 7.

In the case of trap weirs it is also found that when the tail-race water rises, with the barrage down, alternating forces are set up therein, and in the lowest position these may easily tend to develop vibrations. The idea arose of so forming the barrage that in all cases its weight, together with the pressure of the water, would produce a positive moment in the direction of overturning on the body of the weir thus holding it steady (Fig. 8). The curves in the diagram give the turning moment due to the water pressure in the different positions of the gate, the small negative portion below the abscissae being compensated by the moment due to the own weight of the structure which always acts in a positive direction. The problem was solved only after numerous measurements of pressure had been carried out in the testing laboratory. Indeed it is essential, if accurate work is required, to carry out a fresh set of experiments for each new weir, since the shape of the fixed portion of the weir and of the tailrace, the depth of water in the latter, and the possible height of water over the sill, are always different and all affect the result. In the course of these experiments accurate determinations were also made of the turning moment due to the pressure of the water to be carried by the body of the barrage, and also of the operating pressure on the turning gear; at the same time the installation was calibrated, that is to say the discharge over the weir was measured for each stage of water level.

A particularly difficult problem arises in the design of under water closures (Fig. 9). Here the M.A.N., with the aid of their laboratory resources, have achieved several successful new solution during the past few years. This entailed

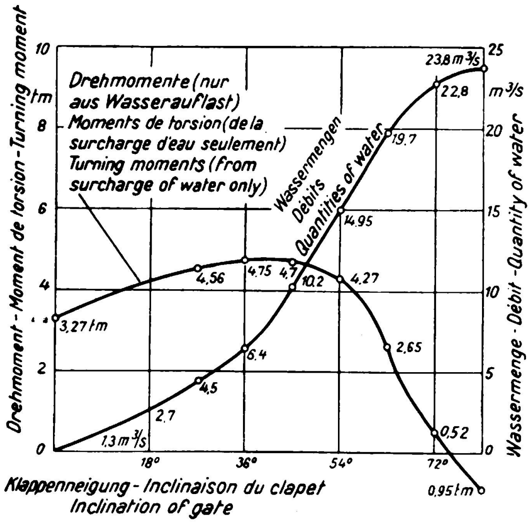

Fig. 8.

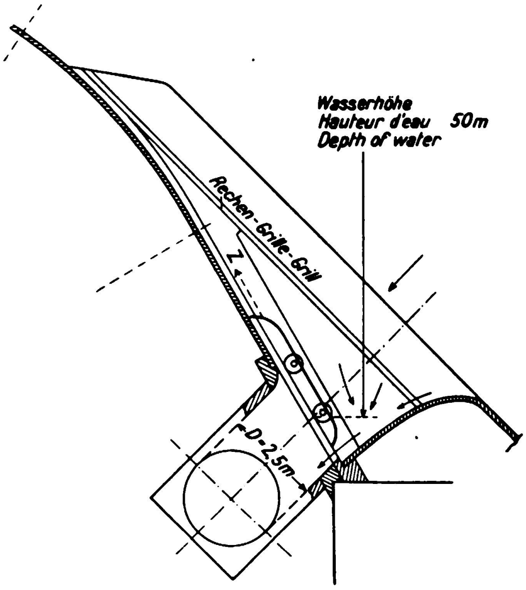

Fig. 9.

working in the laboratory with very considerable pressures in order to enable the transition to be made to full scale. The illustration (Fig. 10) shows the under water gate used in the Odertal dam in the Harz mountains, which is designed to withstand a head of water of some 50 m. As the weir is required closed under its own weight when subject to the full pressure of water, very extensive experiments were necessary to determine the design of the weir and of the structure as a whole.

The contest with vibration, and the study of the effects of moving water which it entailed, has had yet other repercussions on design, for these are factors which influence not only outward arrangement of the design but also its detailed dimensions. Flowing water must always be opposed by a definite mass, but the possibility suggests itself of reducing the moving masses in movable weirs by more suitable construction or by the use of high grade materials. Considerations of cost either of the construction or of the electric current required for operating the weirs should not be allowed to interfere with such developments, for in weirs where such operation is seldom required this factor is of no importance, and in the cases of sluices or lifting gear the same consideration applies. The choice of St. 52 as a material would not appear to be very appropriate in the construction of weirs unless special local considerations make it necessary, for the elasticity and therefore the tendency to vibration become greater in structures where this is used. The permissible stresses, moreover, should not be as high as in ordinary steel work, having regard to corrosion. For instance in steel applied to hydraulic engineering St. 37 should not be stressed in excess of 1200 kg/cm^2.

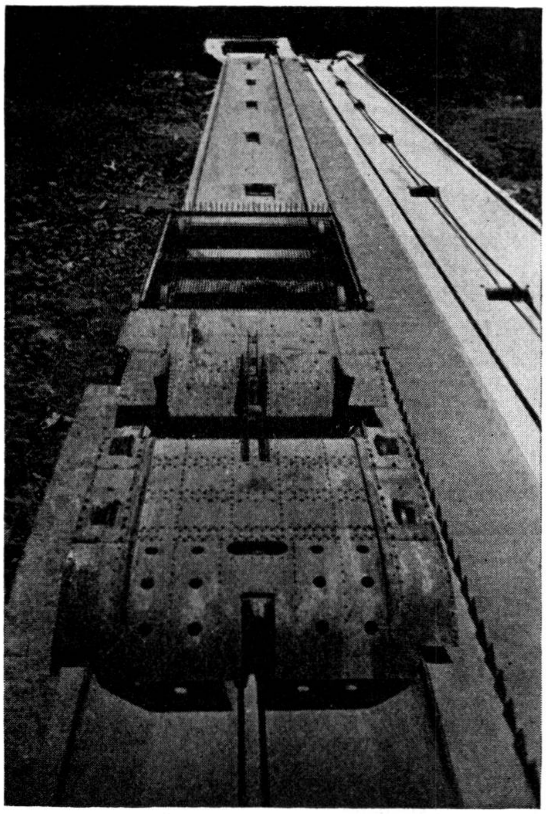

Fig. 10.

Finally, a few illustrations from workshops and finished weirs may be given as indications of the magnitude now attained by steel structures in application to hydraulic work. Two of these examples will be drawn from the numerous large weirs on the Main and Neckar canalisation. Firstly Fig. 11 shows a barrage with three-boom framing and fish-bellied shutter for the installation of Faulbach in the Main-River during the process of erection. This barrage 35.0 m weir width and 6.7 m high, of which 1.60 m is taken up by the movable member. Among the Neckar weirs the installation at Heidelberg (Fig. 12) is especially notable, both on account of the pleasing way in which it has been incorporated in the landscape of the

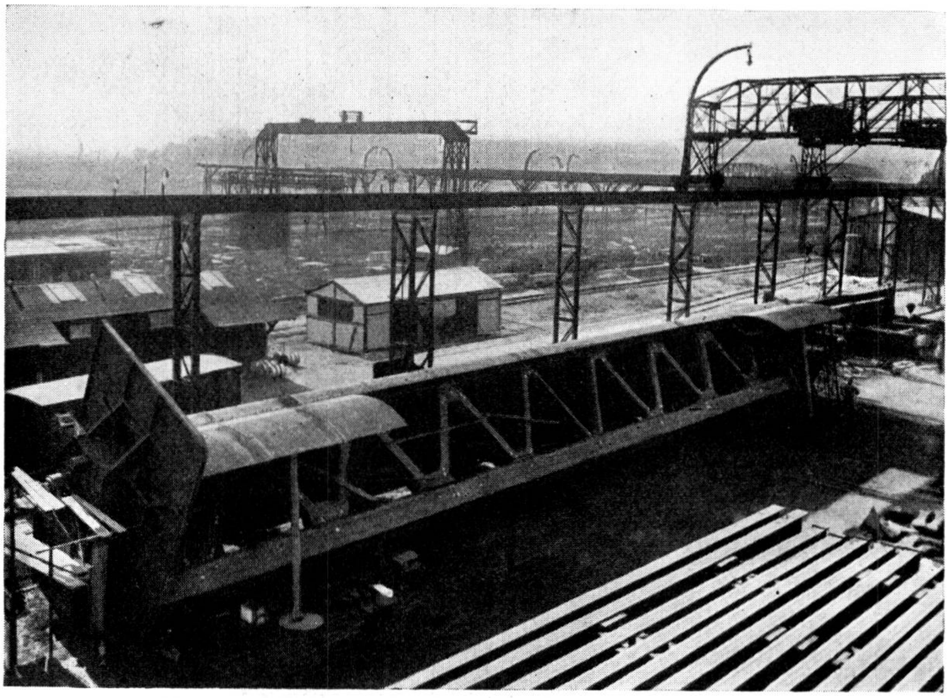

Fig. 11.

town — here so important — and on account of its dimensions. The three rollers at Heidelberg, for a retained head of only 4.10 m, have a clear width of 40.0 m and can be dropped through a depth of 0.60 m.

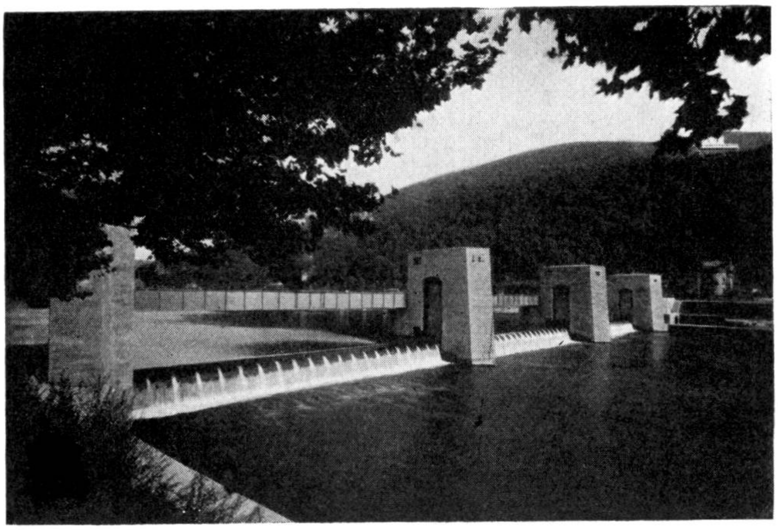

Fig. 12.

Fig. 13 shows an example of a roller weir in course of construction, intended for Solbergfoos in Norway; one of the three rollers is shown in course of being

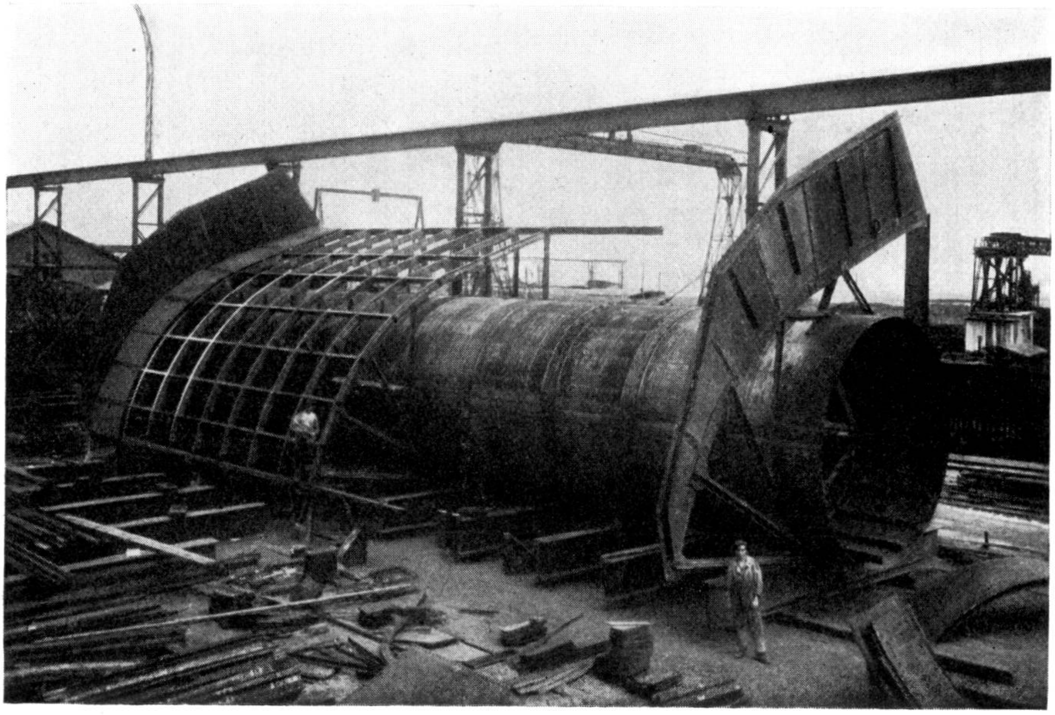

Fig. 13.

erected in the workshop. This method is economical as in the case of all roller weirs where large heads of water are to be retained and where the widths are relatively small. For instance the installation at Solbergfoos will have three rollers each of 20.0 m clear width with 8.75 m retained depth (Fig. 14).

The Ryburg-Schwörstadt installation has already been cited as an example of large weirs with double shutters or "hook gates". The M.A.N. double gate has

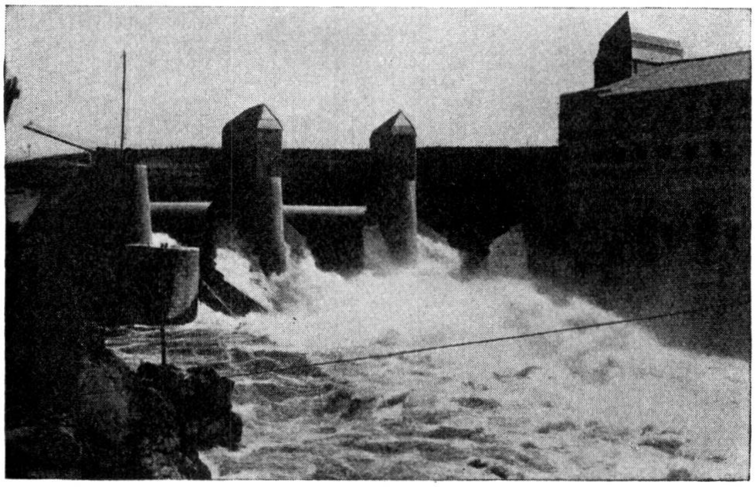

Fig. 14.

also been adopted in the large weir installation at Donau-Kachlet, which has six such gates of 25 m clear width and 11.5 m height, this being one of the largest installations anywhere in the world. Finally Fig. 15 shows the installation at

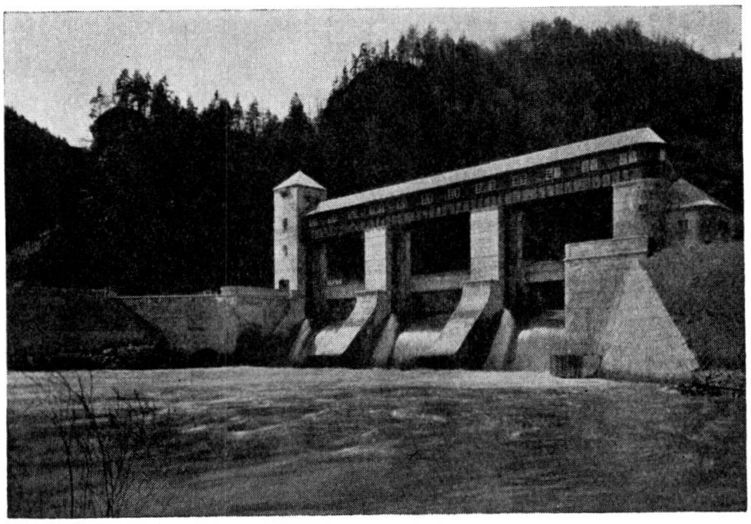

Fig. 15.

Pernegg in the Mur district, which again is a good example of the way that modern barrages are made to blend with the landscape. This includes three double openings measuring 15.0 m by 11.60 m. The extent that the double gates can be dropped amounts, as a rule, to one quarter of the total height, but the "hook gates" can be sunk as much as one third of the total height.

VIIb 2

The Use of Steel in Hydraulic Engineering, General Remarks and Details.

Anwendung des Stahles im Wasserbau, Allgemeines und Einzelheiten.

Application de l'acier dans la construction hydraulique, généralités et détails.

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In the two German reports by Messrs. *Agatz* and *Burkowitz* respectively reference is made to the use of steel in hydraulic engineering under the two headings of fixed and movable structures, the properties of this material being treated with special regard to the requirements of hydraulic work and its performance in such construction being dealt with at some length. Contributions to the discussion will serve to amplify these reports by describing the developments of steel construction in hydraulic engineering and by giving relevant examples from German practice.

The materials in use for hydraulic engineering over 100 years ago were stone of all kinds, concrete, fascines, certain kinds of earth and timber. The last mentioned has been applied mainly to the movable parts of hydraulic works such as sluice gates, weirs and piled and other foundations. There was an almost complete absence of iron and steel work in hydraulic engineering, this material being used only in conjunction with timber construction in the form of screws, nails and binding pieces. At a later stage large cast or wrought iron pieces came into use as supports or load bearing members, and these conditions generally held good until the end of the century. Only now that steel is produced in large quantities, and is available in rolled sections of the greatest variety of shapes and sizes, is the picture changing. Steel in this form is making remarkable progress as a material for hydraulic work and is almost completely replacing timber, even to some extent replacing masonry, a change attended by many new methods of work and forms of construction. A brief description of this development will be given in reference to hydraulic engineering classified under the following heads: —

1) Works serving for purposes of navigation.
2) Weirs.
3) Works connected with the exploitation of hydraulic power.
4) Foundations.

I. Works Connected with Navigation.

In reference to navigation the first point to be noticed is that the vessel itself has been in process of change from timber to iron or steel for as long as fifty years. In marine work this transition is by now almost completed and in inland navigation, in Germany, it has run the greater part of its course. As a material for ship construction iron or steel offered greater stability and strength and led to an increase in dimensions, such as would have been quite unthinkable using the earlier material, namely timber. A corresponding development has taken place in all forms of construction appertaining to navigation, and an example may be found in one of the basic elements of navigational engineering — namely, the lock. Until about fifty years ago lock gates continued nearly always to be made of timber, except for occasional iron parts of the frames. A clear width of six to eight metres was normal, and heads of this dimension were regarded as large. The introduction of 600 ton vessels called for a clear width of 10 m in the locks, and that of 1500 ton vessels a width of 12 m, while in the case of marine locks the requirements gradually increased up to 40 or 50 m. It was not feasible to construct locks of these dimensions in timber, and nothing but steel would solve the problem; hence the transition from the timber to the iron gate in inland navigation. This particular type of lock gate has been in use for centuries, and its design has developed so effectively from long experience in handicraft, informed by so perfect an appreciation of the forces arising, that up to to-day the ironwork has been unable to do better than imitate the old timber gate with its hinge and jamb uprights, its transoms, back struts and tie.

The introduction of iron work brought with it elaborate methods of statical analysis, and there followed a period in which attempts were made to free the design of such gates from statical indeterminacy, to eliminate bending moment from them by introducing curvature, and so on; later, however, a reversion took place to the typical form of lock gate. In the meantime, the dimensions have grown considerably greater and a lock gate of 12 m clear width is now the normal type. The gates for the lock at Kachlet on the Danube are of 24 m clear width, corresponding to the dimensions of the first North East Sea Canal. Even with these large dimensions the stiffness so necessary in lock gates is easily attained through the adoption of a strong and well riveted skin, if necessary of double thickness.

The introduction of iron and steel work has, however, also led to other developments such as entirely new forms of gates. Examples of gates on horizontal hinges and of sliding gates may, indeed, have occurred at earlier times where the conditions were easy, but it would be true to say that these types of gate have become really practicable only with the introduction of steel. This applies to the lifting and the segmental types of gates of which the second contributor to the discussion, *Dr. Becher*, has given examples. The sliding gates adopted in recent large locks which afford entrance to inland harbours would be altogether impossible without steel construction, and for the development of these large harbours, as at Bremerhaven, Antwerp, Amsterdam, or in the German North East Sea Canal, large locks of this kind are essential. There is no need here to elaborate the statement that all the operating arrangements increase in size with the gates and that all such equipment is made of steel; one point appertaining to steel construction must, however, be noticed — it has given rise to yet another method of filling locks. In the small locks of primitive design the filling was effected through a small opening in the timber gate; later the practice grew up of providing diversion channels in the side walls. The considerably greater stiffnes of a steel gate makes it possible, however, to arrange a large opening in the gate itself, and the result is that in, for example, the Neckar canalisation the filling of the lock takes place through openings in the steel gate, which can be closed by means of segments. Either the lifting or the segmental type of gate, which can be constructed only in steel, enable the lock to be filled and emptied without the need for side channels, as they can be operated against the pressure of the water. Where large heads have to be overcome the shaft form of lock, as favoured in Germany, would not be feasible in large dimensions were it not for the availability of steel lock gates.

In the case of ship lifts the inclined plane is a form of construction in which steel is not necessary to any great extent in the smaller dimensions, but other types of lift involve very notable amounts of steel construction, and this is a field in which German engineering has made great progress, as exemplified in the ship lifts at Henrichenburg and Niederfinow.

So far reference has been confined to the substitution of steel for timber construction, but it should also be mentioned that in the field of navigation steelwork is beginning to compete with concrete, for building locks, quays and canal walls. The steel sheet piles exhaustively treated in Prof. *Agatz*'s paper have been found particularly suitable for this purpose, and in Germany a number of locks have been constructed entirely in the form of sheet piling, the largest examples being those at Griesheim and Eddersheim on Main, which are 350 m long by 14 m wide. In these works the steel piling takes the place of ordinary walls to the locks, and where the ground is such that piles can readily be driven the advantages of this type of construction are evident. Numerous examples of this application exist along the edges of harbours, and there is evidence also that the system of using sheet piles with anchorage in the ground behind is one which gives good results. A noteworthy example of the adaptability of steel piling is provided by the widening of the Dortmund-Ems canal to accomodate a larger type of vessel; here long sections of the widening work were carried out by first driving sheet piles in the solid ground on either bank, and then excavating the material in front of them, a method which allows the cross-section of the canal to be enlarged by a very simple procedure without interrupting traffic. With good pile driving the watertightness of canal walls formed in this way is very great.

II. Weirs.

The weirs needed for various purposes in hydraulic engineering were at first mainly of the fixed type and in many cases the body of the weir itself was built of timber, openings for the removal of detritus and ice being always protected by small timber screens. The canalisation of rivers, which began to be undertaken about a hundred years ago, called for a type of weir capable of movement across the whole of the stream, and to meet this need there were developed needle weirs, the hinged barrage and the drum barrage. In these forms the needles or shutters were made of timber and were of small dimensions, only the supporting portions of iron, usually either cast or wrought. Poirée's type of service bridge as adopted in such weirs provide a notable example of the limitations of iron construction at that time. Improvements in the art of forging led to somewhat better solutions as, for instance, in the needle weir. The reason why Chanoine's shutter weir did not prove a success at the time lay partly in these constructional limitations of iron; the revial of this type by Pasqueau in the eighties was the result of improved possibilities in iron construction, and of making supports of cast steel. The favour it is experiencing at the present time is due entirely to the improved lifting gear made possible by the use of steel.

Formerly the commonest type of sluice in hydraulic work was the gate weir which nearly always was used in conjunction with a fixed weir. For instance, the weirs used for hydraulic power stations and on rivers with heavy gradients were almost invariably fixed weirs, as the gate type could be built only in limited dimensions. This form of construction gradually increased in size until finally the movable part became so large that in the latest developments the fixed portions has entirely disappeared and movable weirs are being adopted even in power plants, a development made possible by the use of steel to construct large and reliable opening gear. In regard to regulating the rise of a flood and diverting boulders and ice this constitutes a great advance.

With the normal forms of gate construction using timber it is not possible to exceed a clear width of 8 m. Greater widths than this were, however, always being demanded, as for instance on the Main at Schweinfurt where a clear opening of 30 m was required in the weir on account of the heaviness of the ice formation. This particular problem led to the leading Bavarian engineer, *Eickemeyer,* proposing the use of a steel cylinder in view of its large resisting moment, and from this suggestion *Carstanjen,* the managing director of the Gustavsburg bridge construction works near Mainz, was enabled to develop the roller type of weir which is feasible only in steel construction, and which makes it possible to build a movable weir with a clear width quite impossible with other forms of gate, while at the same time it is simple and strong and is, therefore, exactly what is required in hydraulic engineering. In weirs for the canalisation of rivers the roller type was soon adopted, and its most notable examples are in this field. In canalisation work ice, flotsam and dirt must be capable of release from storage without lowering the water level, and from this point of view the old forms of weir were at a disadvantage. By the development of the submersion roller, and of the roller with additional shutters, the roller type of weir was enabled to answer these requirements also. As already mentioned the earlier types of movable weir could not be made to exceed 6—8 m, and the large widths required to cope with rising floods were obtainable only by the use of movable uprights; this clumsy form of construction, however, soon had to be superseded, and by adopting steel as a material, it was found possible to enlarge the gate itself to a greater clear width, resulting in the design where a screen of steel plates is used to transfer the pressure of the water onto a horizontal framing. This form of construction enabled considerable progress as regards width, but the forces required for lifting the weir became very heavy. A solution to this problem was provided by the Stoney sluice in which the raising and lowering motion takes the form of rolling in addition to sliding; here the roller carriages necessitated a new form of staunching, which was supplied in the Stoney sluice by a staunching rod, and in the steel sluice developed by the Maschinenfabrik Augsburg-Nürnberg (M.A.N.) by an elastic packing plate.

In Germany, particularly in the South German water power plants, further development has been given to the gate type of weir, and the M.A.N. firm have introduced the double sluice and the hook sluice which allow the upper portions of the construction to be lowered; the Dortmunder Union have produced the three-boom gate and the gate with shutters. Clear spans of 40 m and more have already been obtained, and were it not for the problem of coping with the vibrations that are encountered in still larger widths, weirs of more than 50 m clear opening would now be in existence.

Those forms of sluice which are operated by the water pressure, known as automatic weirs, have derived great advantages from the introduction of steel as a material of construction. The old bear trap barrage introduced by the American, White, a hundred years ago has been revided as the "roofed weir" using many different kinds of gate constructed in steel, providing for the automatic regulation of the water level in reservoirs and at the spillways of dams, and, when made to the fish-bellied type of design, enabling great widths to be spanned. The sector weir has been applied in Germany on the Weser by the M.A.N. for a sluice of 54 m clear opening, with 4.5 m retained height, which is the largest sluice actually in existence. The drum barrage invented by Desfontaines and originally constructed only in small sizes has been built as large as 12 m by the use of steel, and has provided an exceptionally useful form of weir for use on the Main canalisation work. Finally the segmental weir should be mentioned, a type which is possible only in steel, and which have been carried out in Germany up to 30 m clear opening.

Thus iron and steel have entirely taken the place of timber in the field of weir construction also, enabling much larger widths and heights than were hitherto feasible, and leading to the developments of quite new forms of sluice.

III. Power Plants.

The part played by steel in the construction of weirs for hydraulic power plants has already been discussed but a few words will now be added on the changes that have arisen in the power plants themselves. Not long ago the water wheel, the head race and the tail race and the whole of the substructure of the power house were constructed of timber. Turbines, possible only in steel construction, were introduced in the eighties of the last century. The more recent practice has been to build the power house of concrete, and, with the high heads now in use, the water is fed to the turbines through pipes. These pipes, on suitable pedestals, are an important part of the high pressure installation and provide a field of use for steel in which it is practically without competitors. It is true that pressure pipes have been constructed in timber and in reinforced concrete, but only for limited heads and discharges, and in all the larger water power plants built to-day the pipe line is of steel. The constructional requirements of pressure piping for water power plant are by no means simple, for the regulation of the turbines entails continual variations of pressure in the pipe and a sudden closing down is liable to cause very notable increases in pressure and, therefore, in the stresses present in the pipe walls. In addition there are temperature effects which become very important in large pipes, and the reactions imposed by the supports. Cast iron pipes are found here and there in small installations, but in modern practice their place is invariably being taken by steel. In the Mannesmann seamless rolled pipe the German metallurgical industry has produced a constructional element almost without rival for high pressures, but if the discharges to be handled are great it becomes necessary to use piping of larger diameter built up from rolled steel plates. The usual method of forming the longitudinal and transverse joints continues to be riveting, but welding is being applied to an increasing extent.

For pipelines in power plants such as the Walchensee and Schluchsee, and also in pumping installations where the pipes have to operate under pressure, nothing but steel comes into question, and in such pipe lines an important part is played by the various forms of valves such as butterfly valves, high pressure slide valves, etc. (see the report by *Burkowitz*). Yet another new development has resulted from the requirements of hydraulic power practice. In works of this kind attention must always be paid to the maintenance of the water level, since if this is lost the wastage of energy becomes excessive. In order to be able to keep the sluices in order and to carry out necessary repairs, forms of auxiliary cofferdams have been developed, especially in the case of power plants, and these represent notable types of construction. The old timber stop planks not being suitable for large widths were replaced by iron beams; the procedure for laying these in position and for transporting, inserting, removing and maintaining them exerts an important influence on the design of a modern power plant, but even so these iron stop planks are not suitable for unlimited widths as they become too heavy to handle. Hence for use at large weirs, as in canalisation of rivers, forms of temporary cofferdam have been developed which can be put together on the site under water. There is, for instance, the type introduced by *Schön* which is constructed by the firm of *Noell* of Würzburg, in which the watertight wall is carried on iron supports consisting either of slabs or of Larssen sheet piles which are arranged like the needles of a needle weir.

Mention should also be made of floating cofferdams, which are hollow iron vessels which can be floated into position and sunk. At the Kachlet weir these have been built for 24 m clear width.

IV. Foundations.

Dr. Agatz has given a very full account of the use of steel for the purpose of foundations. This takes two forms, since either steel may be used as sheet piling to form a cofferdam around the excavation, or it may be used as a permanent part of the construction of the foundation to prevent scour and to resist pressure.

Steel has long been used in foundation work in the form of diving bells and caissons, and in special cases steel pipes have been used as piles. Since *Larssen*, in co-operation with the Dortmunder Union, brought out the first sheet piling section, the whole conceptions of foundations in hydraulic construction has altered. Foundations built within an open excavation have always been the desideratum of engineers. The excavation was enclosed in a wooden cofferdam and was pumped dry, but a depth in excess of 5 to 6 m great difficulties were encountered. In the steel cofferdams engineers have a method of reaching more deeply into the ground and of obtaining a more watertight wall, and in addition such a wall was found to be considerably stiffer than a wooden cofferdam. Whereas, about thirty years ago, it was necessary to contemplate compressed air foundations as soon as depths of 6 to 7 m were reached, it is now possible to obtain depths of 12 to 14 m by open excavation within a steel cofferdam, and depths of 20 m have already been reached in this way. For excavations of large size and great depth as, for instance, those required for founding piers in large rivers, it is no longer customary when using this method to enclose the whole area of the site but only to enclose small sections in which adequate stiffening can be provided, after the manner of shafts, and in this way considerable depths may be reached. The use of closing piles and corner piles enables a high degree of watertightness to be obtained.

In weirs and dams it is always the case that percolations of water may tend to occur underneath the structure which, in the course of time, may impair the subsoil. It is necessary, therefore, that an impermeable stratum should be reached, either by the foundation itself or by apron walls, and in many weirs this has involved the use of pneumatic methods of foundation at great expense in time and money. In this respect the introduction of the steel cofferdam has been of great assistance, since in most cases it enables the impermeable subsoil to be reached even at considerable depth, and with good driving of the piles such a cofferdam is more watertight than a concrete wall sunk by pneumatic methods. The introduction of the steel sheet pile in foundation work has therefore made it possible to hold up dangerous precolations of water underneath the foundations of weirs much more easily, and the weirs can be founded more effectively than was previously possible.

Dr. Agatz has also referred to the use of rolled sections as bearing and retaining piles. Here we are at the beginning of a development, for this is an application in which timber still remains supreme; the reinforced concrete pile has not yet been able to displace it, and it remains to be seen how far the steel pile will succeed in doing so.

For the construction of high dams it has become a favourite method during the last ten years to make use of an earth dam, which is rendered watertight by the provision of a reinforced concrete wall at the core. Lately steel sheet piling has been adopted as a means of forming this impermeable wall, the core being enclosed between two lines of such piling. The stresses liable to be imposed upon this core during the placing and settlement of the earth dam may be very large, and if the risk of cracking is to be avoided can properly be carried only by a material which has the elastic properties of steel.

V. The Durability of Steelwork as applied to Hydraulic Engineering.

The transition to the use of steel in hydraulic work raises the important question of the length of life to be expected from this form of construction.

This matter has been dealt with in the paper by *Agatz,* who concludes that experience is as yet too short for any definite pronouncement to be made. It is scarcely to be expected that steel structures under water will have as long a life as the Roman aqueducts or of timber piles which are permanently under water, but the life that may reasonably be attributed to them should be about equal to that of concrete structures, and certainly equal to that of reinforced concrete. The measures necessary to ensure durability of steel when applied to hydraulic engineering are stated at length in the German report. The question of painting is one to which considerable attention has been paid in German hydraulic practice, and one on which no definite conclusion has as yet been drawn.

VIIb3

Welding in Hydraulic Engineering.

Schweißkonstruktionen im Stahlwasserbau.

La soudure dans les travaux hydrauliques.

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Hitherto welding has found relatively little application in hydraulic engineering by contrast with building work and bridges, but it may safely be said that in this special field, also, the engineer is making increasing endeavours to utilise the obvious constructional, technical and economic advantages which welding offers.

In steelwork applied to hydraulic construction there are, for instance, emergency closures, stop beams, lock gates, etc. which are mainly exposed to stresses of a purely statical character, and in this kind of work, as in building, welding is very suitable and is also economical.

In movable weirs, however, dynamic forces play a predominant part, and the phenomena which arise are even more difficult to follow than those occurring in bridges which, likewise, are exposed mainly to dynamical stresses. The dynamic forces in weirs are difficult to calculate and have not yet been fully cleared up from a scientific point of view. The barrage must be capable of being operated against the full water pressure according to requirements, and the water may flow either under or over. The whirling and rolling which attends the movement of the water, and the variations in pneumatic pressure, promote vibration which may under some conditions be dangerous. So long as the cause of these vibrations and the measures suitable for overcoming them are not fully understood it would appear advisable to make the body of the barrage as rigid and as heavy as possible.

It is true that the leading constructors of weirs, in close co-operation with universities and laboratories, have for some years been carrying out exhaustive experiments and scientific researches with a view to determining the origin of these vibrations and the means whereby they can be avoided. The results already obtained are very satisfactory. They show that by suitable design and shape and other measures it is indeed possible to avoid at least those vibrations which are likely to endanger the structure, but no complete clarification of this important problem has hitherto been obtained. The fact remains that despite all care in design and construction vibrations arise in operation, the effect of which has however, been reduced sufficiently to remove any risk of damage to the structure. In order to render these vibrations which are not yet theoretically understood as harmless as possible, the designer is compelled for the present to aim at combining a high degree of rigidity with the maximum possible inertia. Hence that reduction in dead weight which is attainable through the use of welding is not a possibility of which the engineer is at present enabled to take much advantage. For the same reason the present tendency is to avoid the adoption of high tensile structural steel in weirs, however desirable it may otherwise be on economic grounds.

For the present, then, there is no intention of constructing weirs entirely by welding, but there remain at least a few detailed members which may advantageously be constructed by this means. For instance in most of the three-boom barrages constructed in the last few years by the Dortmunder Union the end wall, booms and shutters have been welded, the remainder riveted.

The end wall if built to a welded design can easily be adapted to the cross section of the weir, and the resulting saving in weight has no effect on vibration as the wall is supported on piers.

The welded construction of the booms and gusset plates simplifies the design and gives convenient connection and simple arrangement of the staunching timbers.

For large widths the shutters must be made rigid against torsion. With welded construction the joints in the pipe provided to take up the torsional forces can easily be made and this can be connected to the remaining portions of the structure so as to be stiff against torsion. The curved form of plate covering which is necessary in order to avoid vibration can be made cheaper by welding than by riveting and in a welded plate the presence of projecting rivet heads is avoided; these would be exposed to a risk of abrasion by sand.

Apart from these dynamically stressed weir structures, welding is, as mentioned above, employed with special advantage in hydraulic constructions subject mainly to statical stresses.

The simplest statical conditions are those which arise in stop beams, and the Dortmunder Union have adopted welded construction for the stop beams in the machine house of the Albbruck-Dogern installation. These "beams" consist mainly of nosed plates with web plates. The saving in weight by comparison with riveted work was found to be about 14 % and this reduction has a very favourable effect on the design of the lifting gear.

A further example of the advantageous use of welding occurs in the lifting gate for the Niegripp lock, recently constructed by the Dortmunder Union. The main girders and the end posts are welded plate web girders built up from nosed plates and the site joints in the skin plate are riveted. The saving in weight achieved in this way by comparison with all-riveted construction amounts to about 11 %, and the counterweights are, of course, lightened by a corresponding amount, thereby imposing smaller loads on the winches and on the operating frame.

A new and particularly interesting application of welding in steel hydraulic work is provided in the floats, 10 m in diameter by 35 m high, now under construction for the ship lifting gear at Rothensee forming part of the Elbe connection on the Mittelland canal. The first of these floats is now being erected. Here again the saving in weight is considerable, amounting to abt. 10 to 12 %.

The results obtained by the application of welding to steel structures used in hydraulic engineering may not hitherto have been as conspicuous as those in bridge and building work but they are neverthess notable, for the difficulties with which this branch of engineering has to contend are particularly great.

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Steel Dams.

Stahldamm.

Barrages d'acier.

Prof. G. Krivochéine,
Ing., General-Major, Prag.

A field of application which offers great scope for the use of steel as a constructional material is that of dams. It is known that in North America there are thousands of dams constructed in masonry, concrete and reinforced concrete, but only four or five steel dams; but whereas dams built of stone, concrete or reinforced concrete are not completely watertight, steel dams can be made completely so.

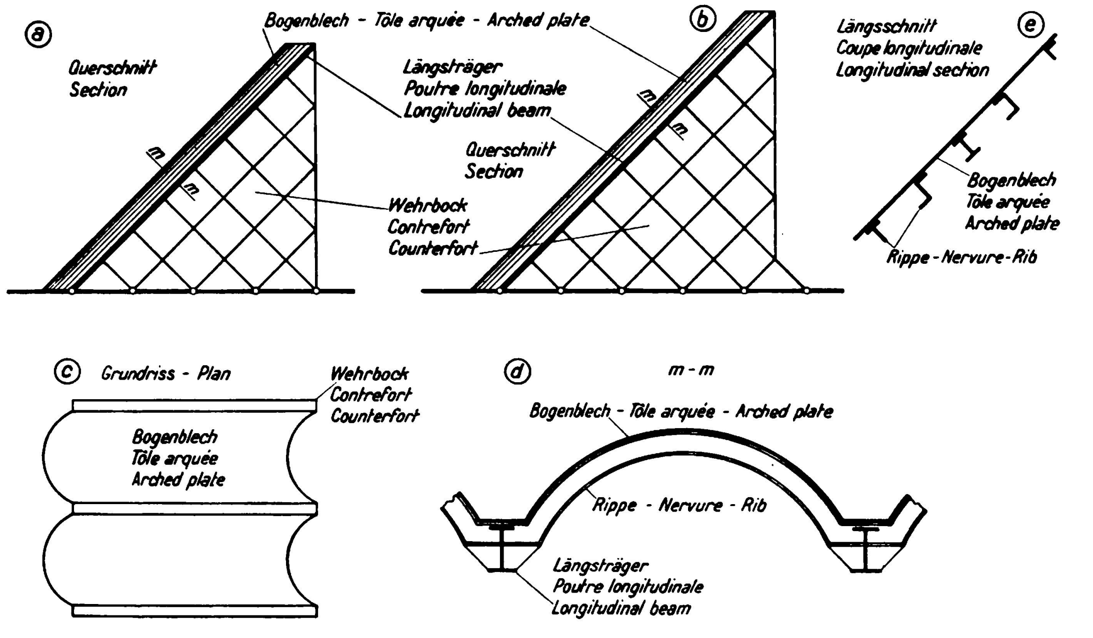

Fig. 1.

The system of dam construction patented[1] by Eng. *Fultner, Dr. Sekla* and Professor *Krivochéine* (Figs. 1a, b, c, d) consists of a series of curved and inclined steel plates of wide span (8 to 15 m) strengthened by ribs. The arched steel plates formed in this way are carried on inclined longitudinal girders without any cross girders, and supported directly on counterforts of open frame

[1] Amer. patent, U.S.A. N° 2, 033.027.

construction. The latter are built in an original shape, being made triangular without diagonals; a form of structure which possesses theoretical hinges at the intersections, and which is both rigid and statically determinate.

An arched form of dam in accordance with this invention is completely elastic, and allows expansion to take place under variations in temperatures although no gaps are left. Another very important advantage, from a technical point of view, is the reduction in width of the base.

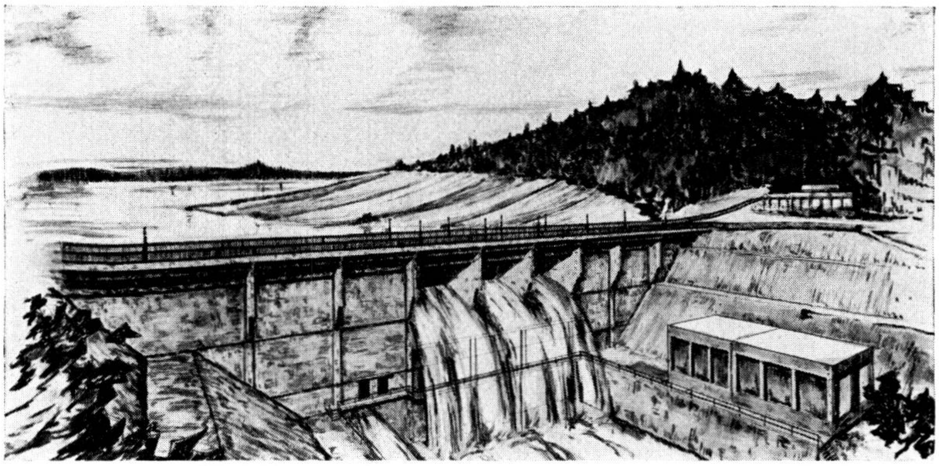

Fig. 2.

Design of steel multiple-arch dam on the Svratka River at Kniničky, Czechoslovakia. Patented by J. Fultner, Prof. G. Krivochéine and Dr. J. Sekla.

In a competition in Czechoslovakia the author had an opportunity of proposing a steel dam of this kind for Kninicky in the neighbourhood of Brno (Fig. 2)[2] and the tender put forward by the Witkowitz works, according to the patent mentioned, worked out same 22 to 53 % lower than the respective fifteen tenders for masonry or concrete dams.

[2] The steel dam at Brno was covered with Monier reinforced concrete slabs.

VIIb 5

The Thickness and Rusting of Steel Sheet Piles.

Wandstärke und Abrostung bei stählernen Spundwänden.

L'épaisseur et l'oxydation des palplanches métalliques.

Dipl.-Ing. W. Pellny,
Hamburg.

The wide usage and numerous applications to which steel sheet piling is put has led to the development, in the course of a few years, of a special science in their use which may now be regarded as an important branch of hydraulic engineering. The variety of technical knowledge has become so great that it is no longer possible for the engineer to follow developments in all branches and to be aware of the latest position in technology, or even to know what is being treated in the literature. For this reason alone, quite apart from the importance of such knowledge in public economy, everything technical ought to be expressed in a clear and simple form so as to relieve the engineer of the need for unnecessary and time-wasting cogitation.

It was, therefore, a matter for congratulation when the four leading German rolling mills agreed to adopt the same series of rolled sections for steel sheet piling. To-day the corresponding sheet piles are of the same cross section wherever produced; they have the same resisting moments and are of the same weight and quality. Likewise the freight on them is the same.

There is, however, one point which continues to cause the conscientious engineer a good deal of worry, and that is the question of the thickness of the piles in relation to rusting. There is no doubt, of course, that in the greater number of cases where engineering works have had to be renewed up to the present it has been for technical operating reasons — because the arrangement was out of date, the capacity had become insufficient, or the operating costs were too high — and seldom because the structure of the works had, in fact, become dangerous. It has always been sought to eliminate this last contingency, or at least to delay it as long as possible, and for this reason it is easy to understand why the thicker sections of piles should have been preferred.

There are many who profess to see a difference in this respect between the different sections, basing their arguments on the listed information of the producers who specify, for instance, 13 mm thickness in one case and 11 mm in another. It would, however, be a serious mistake to assume that on this account alone the first mentioned sheet pile would withstand heavy corrosion better than the second. This should be pointed out clearly once and for all, because there are many engineers who, having to deal with sheet piling and reasoning very naturally in this way, have apprehended difficulties which were in fact non-existent.

When reference is made to the thickness of the pile it is apt to be forgotten that the flanges of these Z sections are made up of not only the listed thickness but also a large additional cross section at the interlock. If the latter were to be recalculated as redistributed uniformly over the whole width of the flange it would correspond to a strip approximately 5 mm thick, and if similar calculations were to be made for the corresponding sections of different types it would be found that this calculated or *virtual thickness is approximately the same in the corresponding sections produced by the different mills.* In order to simplify the matter it is sufficiently accurate to regard the resisting moment as being equal to the area of the flange multiplied by its distance from the neutral axis.

However, the criteria for examining or evaluating a steel sheet pile wall at the end of a life of 50 or 100 years is not the original thickness and the amount of rusting, but the *residual resisting moment* at the end of that time.

A rusting of 1 mm means the same reduction in resisting moment in *any* of the corresponding rolled sections, those rollings which are of small constructional depth being somewhat more favourably situated in this respect. The heaviest amount of rusting which is at all possible corresponds to the thinnest place in the web and if the rusting should become deeper still the sheet pile must fail at the interlock.

Fortunately the maximum bending stress which sheet piling is designed to withstand occurs in most cases at a point which lies considerably deeper than the part exposed to the heaviest rusting, so that it is possible for extensive weakening through rust to take place before the piling is in fact endangered.

Careful measurements have shown that under ordinary conditions in Europe the amount of rusting that is to be expected in the course of 100 years may be about 2 mm at the places most affected. (Compare Professor *Agatz* in the Preliminary Report.)

Knowing the smallest resisting moment that must be retained at the heavily rusted place in order that the prescribed degree of safety may be counted upon, the life of the sheet piling can very quickly be calculated, or the proper thickness of piling to give a desired length of life can be determined, thus fixing the section to be adopted. But even if the rate of rusting were in fact assumed too high this would be to the advantage of the steel.

In the course of years a consolidation of the ground occurs in the backfill, with the result that the *true* earth pressure falls off and becomes distinctly smaller than the *calculated* earth pressure which was taken as a basis for the design. This affords no justification for any great reduction in the additional margin of safety to be demanded in an old structure, in view of special circumstances, but it does mean that one need be a little less apprehensive — always provided that the load bearing members are accessible to inspection and that the material itself does not alter in its properties. In the case of steel both these conditions are usually fulfilled.

As regards the rusting itself, a clear distinction should be drawn between apparent and true rusting. Very often the flaking which is wrongly described as rust is merely thick layers of dross or other suspensions which the rusty water causes to adhere to the sheet pile, and if their thickness is recalculated as metallic iron it amounts to only a fraction of a millimetre. If, therefore, it is desired to observe the rusting on an actual job, it is essential to measure both the original and the remaining thickness.

VIIb 6

Steel Pipes of Large Diameter Subject to Heavy Internal Pressure.

Stahlrohre für Druckleitungen mit großem Durchmesser und hohem Innendruck.

Tuyaux en acier pour conduites forcées de grand diamètre, sous de hautes pressions intérieures.

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It has been found possible to obtain valuable information as to the distribution of stresses and strains, and to arrive at the factors of safety enumerated below, by means of tests carried out in the Swiss Federal Laboratory for Testing Materials during the years 1930 to 1935. The tests were carried through until the pipes burst under the effect of the internal pressure and they were correlated with extensive tests and investigations of actual pipe lines as well as of the materials employed. Diameter D = 1.8 — 4.6 m; pressure head H up to 1750 m; coefficient of capacity $H \cdot D^2 = 1500 — 3000$:

Type	Factors of safety as calculated		
	for static failure	for yield	fatigue rupture
1. Welded pipes with normal or helical welds, "Sulzer Winterthur"			
Normal quality steel, tensile strength $\beta_z = 38—42$ kg/mm²	3.5	2.4	1.6
High quality steel, tensile strength $\beta_z = 42—48$ kg/mm²	3.5	2.4	1.4
2. Hot bound pipes, "Ferrum" Katowice Tensile strengths $\beta_z \cong 38$ kg/mm² in pipes $\beta_z \cong 60$ kg/mm² in binding	3.4	2.3	—
3. Cold drawn, previously bound pipes, "Autofrettage G. Ferrand" by Bouchayer et Viallet, Grenoble Tensile strengths $\beta_z \cong 38$ kg/mm² in pipes $\beta_z \cong 94$ kg/mm² in binding	3.9	2.0	—
4. Pipes bound with steel wire from a reel, "Monteux", Paris Tensile strengths $\beta_z \cong 42$ kg/mm² in pipes $\beta_z \cong 197$ kg/mm² in binding	4.5	2.0	—

The four types which were subjected to close investigation are found to compete with one another technically and economically, and the helical welding is seen to make the competition keener. Each type offers technical and economic advantages of its own — whether with respect to weight, freedom from rusting, maintenance or safety — which require to be established by careful comparative experiments in each particular case.

As regards complicated shapes such as branches, junctions, inlets to turbines, large manholes, and sockets an accurate estimate of the true conditions of stress and safety can be obtained merely by measuring the stresses and strains under a multi-axial system of loading. Further valuable information can be obtained from a study of crack formation and lines of flow in specially applied coatings of lacquer. Fatigue tests and photo-elastic experiments offer means of estimating reductions in concentrations of stress.

The system of stresses and strains corresponding to the operating pressure must nowhere reach the yield value. Nothing but a combined application of all these methods of testing, in a perfected form, will allow the effective degree of safety of pressure pipe lines to be correctly assessed.

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