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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.

Prof. Dr. K. Dantscher,
Oberbaudirektor der Rhein-Main-Donau A.G., München.

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.