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General Report.

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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.

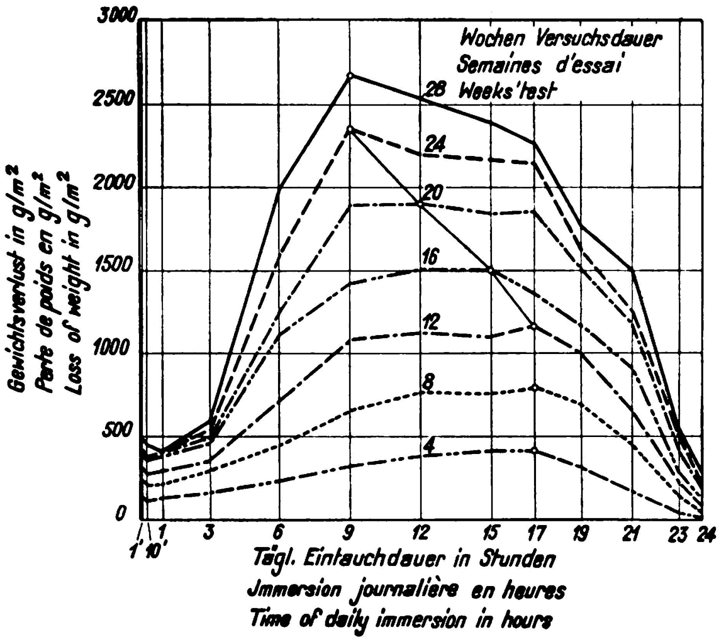

Fig. 1.

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.