General report

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General Report.

Generalreferat

Rapport Général.

F. Campus,
Professeur à l'Université de Liége, Directeur du Laboratoire d'essais du Génie Civil.

The application of concrete and reinforced concrete to hydraulic engineering covers a field so large as to be incapable of complete or even cursory exploration within the limits of a general report. It appears to me, therefore, best not to attempt this, but to take advantage of the programme laid down for the Congress in confining myself to a brief summary of the various reports which have appeared in the Preliminary Publication. Incidentally I shall allow myself to express certain personal opinion in the form of contributions to the discussion, but it is a satisfaction to me to be able to record that generally speaking I find myself in sincere agreement with the eminent authors of the papers. I cannot but attribute this circumstance to the private connections which I have had the honour of maintaining with the majority of these gentlemen ever since our first acquaintance at earlier Congresses. A close reading of the six papers presented has, indeed, served to strengthen me in the opinion, formed at previous Congresses, that the engineering of different countries — at any rate so far as the continent of Europe is concerned — forms a unified whole. This, I like to think, is an outcome of the growth in number of international technical congresses — an outcome which in itself is enough to confound the criticisms sometimes voiced on the subject of these — and it goes to support the view that the meetings ought periodically to be repeated even should they become less arresting in character. I have felt in my perusal of the papers about to be summarised that any lack of the sensational is the result merely of the modesty of the authors concerned and is counterbalanced — to great advantage — by the masterly, fundamental almost perfect, depth of treatment and the interest that derives from these qualities.

Among the hydraulic engineering works to which reinforced concrete is applied it is natural that dams should occupy the most prominent place, having regard to their size, the difficulties attending their construction and the responsibilities involved. Professor *Ludin*, in his paper on the application of concrete to the construction of large dams in Germany, has given us a piece of work characterised by that merit which those who know his treatise „Die Wasserkräfte" — to say nothing of his other writings — have learned to take for granted. Since 1922 ten gravity dams in concrete have been built or begun, three of these exceeding 60 m in height. Only one multiple arch dam, of medium height, has been constructed in reinforced concrete. Several earth and stone dams facing have been provided with internal watertight screens of concrete, including the Sorpe dam which is the highest European structure of this type (62 m depth of retained water). The description of these gravity dams, the details of their execution, the observations made in the course of execution, and the remarks of the author of the paper on the subject of their development, all go to confirm the general tendencies of European practice. These may be summarised as follows:

a) The supersession of liquid concrete by wet concrete which is semi-fluid and very plastic, but not rammed.

b) The tendency in grading to increase the maximum size of stone aggregate and to use a smaller quantity of sand and in general a non-continuous grading of aggregates.

c) An increase in the cement content, the addition of hydraulic materials such as trass and ground furnace slag, or the use of special cements with a view to increased resistance to the aggressive action of water or of atmospheric agencies (on exposed surfaces); also a greater degree of compactness, a smaller development of heat and a smaller amount of shrinkage, etc.

d) The abandonment of stone facings or, indeed, of any kind of linings. But according to the author of this report, German practice has not yet reached a definite decision whether to use a homogeneous concrete or to form facings of richer and more carefully made concrete. The solution to this dilemma may, perhaps, be discerned in the general tendency, in most countries, to give up using excessively weak mixtures (see the paper by M. *Coyne*) but to pay special attention to the treatment of the facings (as by the adoption of vibration).

e) The provision of shrinkage joints, and of drainage both on the upstream face and in the foundation.

f) Mechanisation and modern organisation of plant and installation on site with a view to increasing the rate of progress, even to the extent of cooling thse concrete while poured as done already in America.

Attention may be drawn to the following points of detail:

a) The desirability of taking uplift into consideration, as long proved in Germany by measurements of pressures in the foundations of structures, measurements of percolation, etc.

b) The occurrence of shrinkage cracks in the lower portions of the dams at Agger, Bleiloch and Schluchsee, where the shrinkage joints although relatively close together did not reach down to the base of the work. These structures are slightly curved in plan, as is true of most German dams except that at Zillierbach. Here confirmation may be found for the opinion (which I have already maintained) that the slight curvature frequently conferred upon gravity dams does not, as regards their thicker portions, possess all those virtues which are apt to be claimed for it without sufficient reason, and that it offers no justification for relaxing the precautions required in this type of structure. On the other hand the fact that the crack in the Agger dam extended only half way up from the base[1] shows that the curvature may be effective in the thinner portions of the structure.

c) The use of stone dust which has the effect of weakening the cement is recognised as being undesirable, but on the other hand the addition of pozzolanic material such as trass, or hydraulic materials like ground slags, may be advantageous. An admixture of this material has been adopted in the most recent of the dams under construction, that at Hohenwarte in Thuringia. At the International Congress on the Testing of Materials in 1931, I took the occasion to point out the advantages of these admixtures, having myself made use of them in foundations exposed to aggressive waters; since then, however, I have abandoned this system in view of the production of metallurgical cement, which is in fact a ready made mixture of Portland and slag. In Germany, moreover, the use of special cements (such as trass and metallurgical cement) appears to be increasing, and there is a general tendency towards increased fineness in grinding which has the result of accelerating the rate of setting of these cements, and of increasing their workability and the watertightness of the concrete.

d) The mixtures employed in the most recent dams (such as that at Sorpe) are expressed by weight, and no longer, as has been the customary practice in Germany, by volume. The present writer favours specification by weight in order to ensure regularity in the quality of the concrete, and he presumes that the change in Germany has been made for the same reason.

M. *Coyne*, Ingénieur en Chef des Ponts et Chaussées, of Paris, is in charge of the work on the dam at Marèges in France, which is the largest European arch dam (90 m high and 247 m length of the crest); he modestly entitles his report "Observations on the use of concrete in solid dams". Actually his paper forms a general report such as the present writer would have liked to make, and the difficulty of summarising it will be obvious. It is a remarkably lucid exposition by an engineer whose mastery stands out against a background of great attainments. Confining himself to the question of concrete as a material for making dams, M. *Coyne* expounds its use as would a master sculptor his clay. He explains, discusses and formulates rules; and according to the preceding paper some of them appear to embody the same lessons as emerge from German experience. They include the adoption of a concrete which is plastic but not fluid; recognition of the importance of workability, to ensure the faultless placing of the concrete in the job; the use of mixtures sufficiently rich to ensure durability; the adoption of special cements with low evolution of heat and not susceptible to attack by aggressive waters; the employment of vibration — especially on the upstream face — as the finishing touch to the use of good plastic concrete; the use of correct grading of aggregates and in certain cases the adoption of artificial cooling these are the principal measures which M. *Coyne* recommends. Proportioning by weight, also, is favoured by him. In my own humble opinion I can only emphasise the danger inherent in discontinuities in the work, and the care necessary to ensure adequate bond of working joints.

[1] Preliminary Publication, Fig. 8, p. 1198.

At the International Congress on Testing Materials at Zurich in 1931 I have already supported his advise as to the exercise of control on the job by taking specimens from the work itself; likewise as to control over the density of fresh concrete and over the strength of mortar taken from the concrete (according to Bolomey).

Importance attaches also to his penetrating remarks, which are the fruit of well digested experience, on the danger of longitudinal cracks; on the mechanism of watertightness and stanching (especially that due to biological causes), on the deterioration of concrete; and on the subject of the considerable resistance offered against erosion when the concrete is dense and smooth. M. *Coyne* is a strong partisan of arch dams, and while not concerning himself in the present work with the question of design of dams he points out incidentally a defect of gravity dams: namely the deterioration of the concrete from climatic causes, which is the result of the low cement content in the mixtures usually adopted for plain concrete dams.

Prof. *Bažant*, of the Czechoslovak Polytechnic School of Prague, has contributed a masterly exposition under the title of "The Development of Design for Arch Dams". Considerations regarding the application of concrete, while not paramount in this particular study, are not absent therefrom, for when deciding upon the design of arch dams it is necessary to take account of the conditions of construction and of the mechanical and physical properties of the material such as shrinkage, low resistance to tension, the need for local reinforcement, contraction joints, etc. The author of this paper shows that modern arch dams originated in Europe, and justifies their points of superiority over gravity dams in a way which the author of the previous paper, M. *Coyne*, would be unable to contradict; he then proceeds to analyse the assumptions underlying the methods of design which have followed one another in the following sequence:

a) The arch is considered to be built up of independent arched elements each of which separately resists the hydrostatic pressure.
b) The foregoing action is supplemented by a resisting action due to the weight of the vertical elements of the dam, considered to be built in at the base.
c) The barrel arch is assumed to form a curved elastic shell.

This last concept, while theoretically the most accurate, has scarcely passed beyond the stage of infinitesimal equations, and in the opinion of the writer of the paper is not practicable. The two earlier ideas may take very varied forms from the simplest (in case *a*, the theory of a thin cylindrical shell) to the most complicated (in case *b*, the "trial load method" of the Americans). In theory, all these methods are inaccurate, or rather are to be described as approximate. The writer of the paper confines himself, very properly, to a clear and detailed explanation of the details of this development. Here M. *Coyne* will allow me to refer to his opinion as to these theories and, at the same time, as to a method worked out by him which is different again (though related to method *a* above) in which the resisting arch elements are not independent of another but are bound by isostatic surfaces, generally having the character of inclined arches, and offering resistance to the hydrostatic pressure both as arches and as buttresses.

This method, which I believe to be unpublished — and for that reason, I suppose, unknown to M. *Bažant* — has been applied as a check for the large dam at Marèges. I hope that my indiscretion in referring to it here will induce M. *Coyne* to report on this matter in due course.

It is to one of M. *Coyne*'s principal colleagues, M. *Mary*, Ingénieur des Ponts et Chaussées, of Paris, that we owe a paper of very great interest both in itself and for its documentary value, entitled "The Hoop Reinforcement of Pressure Conduits for the Hydro-Electric Plant at Marèges". In this he has described one of the most remarkable items of the work at Marèges, in which concrete has been applied with marvellous ingenuity. The essential requirement was that of constructing pressure conduits in reinforced concrete with an internal diameter of 4.40 m to withstand an internal hydraulic pressure equivalent to a head of 102.50 m of water (10.25 atmospheres), without the thickness exceeding 0.40 m, while guaranteeing complete safety and, of course, complete watertightness. The solution adopted was to surround the concrete pipes by cables forming a circumferential reinforcement which was placed in tension beforehand. The idea of pre-stressing was not in itself original, but its application to a pipe-line constructed underground was so. Its boldness called for preliminary experiments, and the effect of these was both to indicate the aptness of the solution and to suggest how it could best be put into practice in the actual job. The cables, spaced longitudinally at intervals of 0.50 m, were given a pre-imposed tension of 135 tonnes after the envelope had been concreted, this being done by increasing the diameter of the ring of cable through the agency of two opposed jacks which were affixed to the concrete wall of the pipe. The cables when deformed in this way were secured in a mortar, made by filling ciment fondu into gaps left for the purpose. Apart from this the pipes are provided only with some local reinforcement.[1] Measurements of internal stresses, carried out with the acoustic string measuring instruments of M. *Coyne*, have served to confirm the success of this work. All the various phases of its design and execution, together with the results obtained, are explained in the paper with that meticulous care which reflects the personality of the author and which entitles him to the reader's gratitude.

Leaving the subject of dams and works connected therewith, we now pass on to those other prodigies of engineering, rendered equally formidable to the engineer by difficulties of quite another order, due to construction having to be carried out under water at great depth. These are represented in the paper by Professor *G. Krall* and Mr. *H. Straub* on "New Dry Docks in the Ports of Genoa and Naples".

Italy is a country renowned not only for large dams, but as one where nature has forced the attainment of mastery in maritime engineering. The works described and explained by the authors of the paper are remarkable modern examples of this, reflecting credit on them as much for the science displayed, the accuracy of the investigation, and the assurance with which the work has been carried into effect. As regards width the two dry docks are identical; 40 m in width, 14 m depth of water below mean water level, 9 m thickness of side walls,

[2] Preliminary Report, Fig. 10, p. 1218.

280 m length at Genoa and approximately 350 m length at Naples. But while the appearance is the same the design in the two cases is essentially different, in view of the rocky nature of the ground at Genoa and the soft ground at Naples. The problems to be solved in the two respective cases were not, therefore, questions of the use of concrete but questions arising from the nature of the ground — for here as in the case of the dams discussed by M. *Coyne* that is the governing condition. The use of concrete confers flexibility on the ideas of the engineer, and this, in combination with highly developed constructional technique, has allowed of a perfect solution being obtained.

The paper by Messrs. *Krall* and *Straub* provides a striking and up-to-date demonstration of the advantage — indeed necessity — of close correlation between design and construction. In the two dry docks under consideration the stresses were at least as high during the various stages of construction as in normal operation afterwards. It is the acceptance of this principle which constitutes one of the greatest advances ever made in constructional work, and the examples described by the authors are an admirable instance of its application. The principle is explained consisely but very clearly in the paper, but does not lend itself very well to summarising without going to excessive length. In the case of the Genoa dry dock, founded under compressed air on rocky ground, the main hyperstatic problem arising in this design was solved by an ingenious mode of construction. The side walls were built first with the aid of reinforced concrete caissons sunk by compressed air, and the end wall was constructed in the same way. The enclosure thus formed was closed at the open end by a caisson gate and was pumped dry to allow/of concreting the bottom. During this phase of construction the enclosure had to withstand a water pressure equal to nearly 20 m a greater head than would be imposed on it later in actual service, and in order to provide for this without the use of heavy permanent reinforcement a temporary arrangement was adopted in which the side walls were caused to act as multiple arch dams between piers strutted against one another across the width of the dock. This gave rise to a statical problem analogous with that arising in arch dams, but with certain additional complications, which were solved in a neat and original way by Professor *Krall*.[3] It is to be noted that the deformations of the ground were taken into account the same way as the deformations of all structural parts. The procedure of the calculation is clearly explained. After the construction of the floor the temporary counterforts were demolished.

In the case of the dry dock at Naples, which was founded on soft ground, the problem was different and had reference to the structure in its final form. The walls and the floor were constructed separately by means of caissons, the latter being handled from travelling gantries of 68 m span running on two reinforced concrete bridges built parallel to the side walls of the dock. After the walls and the floor had undergone settlement independently, the joints between them were closed up with the aid of a diving bell. The static problem to be solved related to the stresses arising in the structure after the joint had been closed, taking due account of the deformability of the ground below: this problem is one of

[3] Preliminary Report, Figs. 5 and 6, pp. 1172—1173.

long standing which admits of solution by ordinary methods based on the strength of materials, as applied, for instance, in a recent investigation by one of my pupils (*F. Szeps:* Etude des constructions reposant sur un sol élastique. Revue Universelle des Mines, March 1936).

Professor *Krall* explains the principle of a very interesting method based on the use of ellipses of elasticity, due to *W. Ritter*. The confident application of this method to the dry dock at Naples was rendered possible through observations carried out on the dry dock at Venice under usual conditions of service, with a view to determining the "coefficient of soil elasticity" or of deformability of the ground. The instances in which an experiment has been carried out on so large a scale with so excellent a result must be rare.

The execution of the work was on a par with the design explained above. Points of interest include the use of a plastic concrete containing 300 kg of pozzolanic cement per cubic metre with a view to resisting the aggressive action of the sea water; the general adoption of concrete for the compressed air caissons reaching to depths of more than 23 m; the construction of what was in effect an auxiliary dry dock of reinforced concrete for the purpose of constructing the caissons at Genoa; and the reinforced concrete service bridges used ab Naples. In short, the paper by Messrs. *Krall* and *Straub* affords a striking proof of the utility of concrete and reinforced concrete for solving problems in hydraulic and maritime work; but emphasis should also be laid on the lesson it affords of the potency, to engineers, of a combination of the science of structural design with experiment, and with experience gained on actual works.

I have kept for last, but not least, the paper by Dr. *W. H. Glanville* and Mr. *G. Grime* dealing with the "Behaviour of Reinforced Concrete Piles in Driving", on account of its very special character which is less directly relevant to hydraulic work in the sense that, although reinforced concrete piles are very frequent and very valuable adjuncts to hydraulic construction, the question as treated by the authors is not directly related to works of this kind. The paper is none the less of very special interest both intrinsically and on account of the practical conclusions reached through the masterly scientific way in which the question is handled — a mastery which is characteristic of Dr. *Glanville,* well known for his researches on "creep strains" in concrete, and equally characteristic of the Building Research Station to whose higher staff he belongs.

The paper forms a very detailed summary of the investigations carried out for several years past at the Building Research Station dealing with the behaviour of reinforced concrete piles under the effects of driving. It differs only slightly from a more complete paper to which the authors refer, which appeared in the Journal of the Institution of Civil Engineers in December 1935, the only difference being the omission of a mathematical treatment of the question of the propagation of impact waves in the piles. Partial reports have already appeared in British journals and in the annual reports of the Building Research Station, and an official report on the investigation is to be published. The investigation was carried out theoretically on the basis of certain definite assumptions which agree well enough with practice, and later experimentally, first of all at the Research Station and then on actual works. Special mention should be made of the employment of a dynamic stress measuring instrument of extreme sensitivity which made use of piezo-electric quartz and oscillographic recording instrument in conjunction with a special form of accelerometer for controlling the maximum stresses at the head of the pile during the process of driving. Practical engineers are well aware how, in certain circumstances, the driving of reinforced concrete piles may give rise to difficulties, and I have myself given an account of such difficulties recently in Annales des Travaux Publics de Belgique, February 1935. The research undertaken by Dr. *Glanville* and Mr. *Grime* amounts to little less than a revelation as regards the magnitude of the mechanical phenomena produced in piles under the action of the impact of the pile driving hammer and as regards the resulting instantaneous stresses. The theoretical and related experimental steps disclose a whole range of details on which no exact information, it appears, has hitherto been available. Practically, an old rule is confirmed: heavy hammers are the best and it is advisable not to exceed a certain height of fall. Another rule, of no less importance, would appear to be new: if the maximum instantaneous stress in the pile is to be limited with a view to the preservation of the latter while driving, and it is desired to ensure maximum penetration, the head of the pile should be covered with a cushion as elastic as possible without reducing the efficiency of the energy transfer so as to be inconsistent with the conditions under which the pile driving is being done.

The essential practical outcome, therefore, is that which relates to the cushioning of the pile heads. The scientific question of how the dynamic stresses vary in their distribution may be regarded as solved; most often these stresses are at a maximum in the head and are independent of the nature of the ground, but sometimes, where the driving is very hard, they are at their maximum at the point. Rules are laid down for the composition of the concrete and the arrangement of reinforcement. These rules are in agreement with good practice, but it is certain that many contractors would benefit by considering the sound advice here given in reference to precautions in driving. In any case the strength of the concrete used in piles should not be less than 350 to 500 kg/cm^2 at the time of driving. Diagrams (dimensioned in British units) accompany the paper for the purpose of rapidly determining the optimum conditions for driving the piles in any given case, but in their present form these do not appear to be applicable to Continental conditions.

To conclude this general report it only remains for me to express the great pleasure which I have felt in reading the remarkable works which it has been my honour to analyse here, not only because of their high quality and great interest, but also because I have felt flattered to find in them a confirmation of the optimistic opinions I have expressed in earlier general reports on the subject of the unceasing progress which is occurring in the application of reinforced concrete; more particularly in that field of engineering construction which is acknowledged to be one of the most difficult of all. Nor has this progress by any means come to an end. In any case the future scope of reinforced concrete leaves no room for doubt. The extent of its applications continually gives rise to new and important problems; in reference to these the old dogmas appear relatively insignificant, and have no effect on development.