Concrete in hydraulic works

VI 1

Concrete in Hydraulic Works.

Beton im Wasserbau.

Le béton dans la construction hydraulique.

Hafenbaudirektor a. D. Dr. Ing. A. Agatz,
Professor an der Technischen Hochschule, Berlin.

a) *Introduction.*

The excellent paper on concrete in German dam construction by Professor *Ludin* offers an occasion to complete the treatment of this branch of work by giving an account of German experience in the use of concrete as applied to the engineering of waterways and in the construction of foundations.

The hydraulic engineer, unlike his colleagues engaged in other kinds of construction, is, unfortunately, unable to convey a proper idea of the magnitude of his works since as much as 75 % of this is surrounded by their natural enemies, earth and water. Their true extent can, therefore, be appreciated only from a statement of the quantities involved.

Since the great height of the bridge piers in some of the latest German bridges has several times been quoted, it may be useful as an example to mention here a reinforced concrete gateway of an ocean dock which has a total height of approximately 26 m. When, further, it is stated that plans are now in hand for reinforced concrete works of a similar nature to this, taking the form of a triple frame which is statically indeterminate to the eleventh degree and has a height of 32 m with a ground area of 56 by 65 m, it will at once be apparent not only that reinforced concrete is highly valued by engineers concerned with foundations and hydraulic works, but that if this method of construction were not available, such works would either be quite impossible or could be carried out only with difficulty — a fact which has been brought out, in the last — mentioned instance, by the author's comparative design for massive masonry construction. Moreover, we no longer live in those easy times when such jobs as this could be carried out at leisure, but are required to complete them in half or even one-third of the time previously considered proper.

The very fact, however, that engineers in this field of work are advocates of reinforced concrete for foundations and hydraulic construction, renders it necessary to observe that even yet no such improvement in the quality of concrete (and especially in its binding material) has been achieved as would justify regarding it as adequate in every possible case; and in this connection it must not be forgotten that not only reinforced concrete, but likewise steel, is subject to risks when exposed to aggressive subsoils and waters. The author, proud as he is of works carried out under his direction both in reinforced concrete and in steel yet feels forced, in the light of the stringent and ever recurring examinations which such structures are subjected, to acknowledge that concrete is a material which remains the plaything of human imperfection as well as of the attacks of earth and water.

b) *Experience and observations.*

The material normally adopted as aggregate is the shingle as found in the river beds, but in view of its lack of uniformity it is found desirable to test its granular composition and proportion of voids and to exercise continuous control over deliveries. Some engineers have sought to improve the quality of the aggregate by first sorting it into its components and then adding fine material or broken stone, but the author has not always deemed these measures to be justified, since in his experience the same strength is obtainable at equal cost (or even at a saving in cost and time) by the use of a richer admixture of cement.

The greatest importance is attached, in the first place, to compressive and tensile strength and to density, but on the other hand sufficient attention is not always paid to the life of the concrete and to its resistance against chemical and physical effects at the surface. In the author's opinion the quest of strength, which has been pursued in concrete works for the last fifteen years, is not of such decisive importance where massive hydraulic works and foundations are concerned.

There must always be a definite distinction between the more tenuous types of design appropriate to reinforced concrete structures above ground and the massive concrete work used below ground and in hydraulic structures. In the first case, adopt limits up to 65 and 1500 kg/cm² (for the concrete and steel respectively), and in the second case, for use in hydraulic and foundation works which may undergo later movement or which are exposed to chemical attack, however weak, the corresponding figures may be 30 and 1000 kg/cm².

Moreover, it is necessary to be clear that the strength at 28 days provides no definite criterion for the strength in the completed work, where the latter is of large size. For instance, in the construction of a lock the author found that a portion of the concrete made with 270 kg of blast furnace cement and 30 kg of trass per m³ showed a strength in the job, when 28 days old, of only 80 kg/cm², which ought — according to his interpretation of the regulations — to have entailed its removal; and this applied "only" to 12 000 m³ of concrete. The same concrete, however, after 90 days reached 159 kg/cm², a figure only 9 % below that obtained for another part built with concrete which after 28 days had already reached a breaking strength of approximately 125 kg/cm². The time of year, weather conditions, height and thickness of the blocks concreted, treatment of the concrete within the shuttering, type of shuttering, all exercise an important effect on the 28-day strength.

In massive works below ground or below water the author's practice has been seldom to stress the concrete to more than 30 kg/cm², and in his opinion it is unimportant whether the concrete shows a strength of 150 or 180 kg/cm² at

90 days, but proportionately more important that it should possess endurance. The factor of safety will then always be at a minimum of 5, whereas for other aspects of foundation or hydraulic work, for instance as regards the stress in the steel used in cofferdams, and as regards the carrying capacity of piles, a maximum factor of safety of 2 is accepted.

The variations in strength obtained when concrete specimens of identical composition are tested go to show that concrete must continue to be looked upon as a very rough kind of material, so that an adequate margin of safety in its use is essential.

Further, there is a difference between the compressive strength of cement at 450 to 550 kg/cm^2 and that of granite at 800 to 2700 kg/cm^2 or of sandstone at 1500 kg/cm^2, which means that we have not yet attained to the possibility of equalising the strengths of the binder and the aggregate. Then there is the question of the chemical attacks to which the steel within the concrete is exposed in works below ground or below water; and the importance of the resistance offered by materials against chemical attack is appreciated by all who have had occasion to observe the damage suffered by steel or concrete works exposed to aggressive waters. Since this quality is determined not only by strength, but, more particulary, by density, which, in turn, depends upon the methods of concreting adopted — methods which are still comparatively rough and ready — it must henceforth be an object of endeavour on the part of cement manufacturers to improve the quality of the cement, and on the part of the contracting industry to improve the quality of the concrete.

In works constructed for purporses of water transport, the use of trass has been found advantageous as an addition to the aggregates and binders, and in the author's opinion, having regard to the available qualities of binders, this advantage will be retained in the future.

What is of great importance is that the addition of trass certainly does confer upon the concrete the density essential to it. Earlier misgivings as to the addition of trass to blast furnace cement have happily been allayed since such material had proved successful in large harbour works. The amount of trass added must, however, always be regulated according both to local conditions and to the purpose of the concrete, and in the author's opinion it would be a mistake to set up any definite standards in this matter. On the question of water content the author is in agreement with Professor *Ludin* in regarding any excess, producing too fluid a concrete, as harmful to density and strength. The middle way between stamped and poured concrete should always be taken, according to conditions within the shuttering. Whether the result be described as soft concrete or plastic concrete is really more a question of name than of limit to the water content. Where the reinforcing steel is very crowded, the concrete must necessarily be introduced in a somewhat softer condition than where only a small amount of reinforcement, or none at all, is present.

The author is unable to understand the occasional tendency to return to the use of stamped concrete. Sufficient should have been learnt from earlier experience in this respect, as well as from recent research, to show that "earth-damp" concrete has its use only where the vibration process is applied; or for very thin-walled constructions, but not with usual methods of working or in jobs of large dimensions. As regards the mixing and placing of concrete, all methods of placing, whether by the use of channels, chutes, conveyor belts, funnels, pipes or pumps, are to be regarded as of approximately equal merit. Whatever the process adopted, however, it is essential that concrete with the proper water content should arrive in the shuttering without having become unmixed. In many cases the choice of method will be governed by local conditions and by those peculiar to the job. It is true that the adoption, for instance, of either the pump or the conveyor-belt method places a definite upper limit on the water content, but so far as the properties of the resulting concrete are concerned, the methods of placing and mixing are less important than the proper treatment of the concrete within the shuttering. Here the vibration process, provided the dimensions of the work and the water content are suitable for its use, offers the likelihood of considerably increasing the strength and density of the concrete-qualities which, it must be remembered, are in the end dependent not on machines but on the human factor.

In the matter of division into blocks and keying, the mistake is still made of arranging horizontal and vertical working joints from considerations of design and statics alone, without due regard to the exigencies of construction, such as, for instance, adaptation to suit the sizes and numbers of the mixing and placing plants, and according to whether the concrete is to be deposited in one or more layers.

Since every working joint implies an interruption in the monolithic character of the concrete its statical repurcussions cannot always be left out of account-quite apart from the fact that chemical and physical attack usually has its origin in a working joint (more often horizontal than vertical). Endeavours should, therefore, be made to increase the height of the layers to a maximum by the use of "silo" or sliding shuttering, and to adopt vertical joints in preference to horizontal, with suitable precautions. When horizontal joints are unavoidable their roughening to provide a key should never be neglected. In structures which are to be watertight — as, for instance, dry docks — the joints must be carefully filled. The type of such filling adopted in the extension to the Kaiser Dock in Bremerhaven has proved itself entirely successful in six years service, and the author would be ready to use it again, especially since it possesses the advantage that the lead-wool caulking used can, at any time, be easily reconditioned if required; though in the work named above this has not yet been necessary.

Shuttering lined with steel — or iron shuts has the undoubted advantage that it can be stripped from the concrete without damaging the surface of the latter, and that a smooth surface is left. The author, therefore, attaches as great a value to this as to the placing of a framework of rolled steel sections within the concrete to allow of careful and easy arrangement of the reinforcing bars. The additional costs thus involved are relatively small since the rolled sections can be utilised in the statical design of the structure, apart from the fact that they facilitate rapid concreting even where the work is of great height.

The author's observations on finished works have not led him to attach fundamental importance to the question whether mass concrete is to be kept permanently damp. It is true that a great difference between external and internal temperatures may lead to cracking, but this cannot be avoided even if such structures could be permanently kept damp. But the risk can be minimised if the dimensions of the structure and of its component blocks are suitably chosen.

As regards the question of whether or not concrete should be faced with masonry, the author is in favour of *unfaced* concrete, because the presence of a facing necessitates thin layers of the blocks themselves and thus impairs the monolithic character of the concrete, throwing away the chief advantage of this material. If concrete is used in conjunction with steel reinforcement, the facing militates against the full utilisation of the cross section from a statical point of view. Of course, however, the size and slape of the structure will influence the decision to be taken in this respect.

Where the concrete is exposed to external attack the reinforcing bars should be placed further in than usual, 10 cm being regarded as the minimum depth of cover, but the amount depends on the shape of the work. In certain cases a thin wire netting should be embedded at 3 to 4 cm from the surface in order to avoid surface cracking. There would be no objection to a special facing concrete if it could be placed in a single run together with the main concrete and intimately connected to the latter.

Supervision of the execution of the work can never be too careful and conscientious. By this means alone, having regard to the comparative novelty of this material and shortness of experience in its use, is it possible to extend the use of concrete in large works connected with water transport.

In purely reinforced concrete structures it is, of course, necessary to attach much greater importance to the quality of aggregates and binders, the water content, the reinforcement and the preparation of the concrete, because the relative thinness of the structural members and the high stresses imposed upon the material in them entail very careful preparation of the concrete. In construction for water transport, and in foundation work, however, any excessive thinness of reinforced concrete structures are normally avoided for the reasons already given, because, by contrast with bridges and building structures, the statical and chemical demands made upon them are less easy to evaluate and less accurately known. This is not to say that a return should be made to the practice of using excessively massive structures, but only that the mistake should be avoided of replacing the predominantly block-like construction appropriate to water transport by a network of posts and beams. It must always be left to the discretion of the engineer to find a middle way, satisfying on the one hand the statical leanings of the designer and on the other hand taking due account of the susceptibility of purely reinforced concrete work to damage when used below ground or below water.

c) *Conclusion.*

If, in conclusion, the author may be allowed to compare his experience of works below ground and below water with structural engineering above ground he must once again affirm — despite the boldness of his colleagues in that field, which is a matter of continual wonder to him — that it is those engaged on foundation work and in hydraulic engineering who have to contend with greater difficulties. It is impossible for them to adopt finely articulated structures, because the magnitude and manner of incidence of the attack to be apprehended from their enemies, earth and water, are not known — and, moreover, despite the valued mathematical activity of soil mechanists, never can be fully known, because it is not a question of one definite material but rather of a conjunction of conditions, more or less complicated in each particular case.

It appears necessary, therefore, to emphasize the danger of overvaluing a purely theoretical and mathematical conception of the agencies earth and water when from time to time the theorists offer us, who have to design and execute, a basis for our calculations. Construction below ground and under water remains first and foremost a science of experience, though it imposes upon its practitioners the high demand to master theory also so as to be able to evaluate it correctly. A practical engineer "without" theory appears, to the writer, as dangerous as a theorist "without" extended practice.

Colleagues in the field of structural engineering should remember, when drawing up their regulations for concrete and reinforced concrete, that while the knowledge they possess is fully valid for their kind of work it cannot always have the same validity when applied to the subject matter of this paper.

Merely as an example, it may be mentioned that in the reinforced concrete and steel structures designed by the author the permissible stresses laid down for structural engineering above ground were not binding, because to the author the final criterion was the limit of elasticity, always assuming the possibility of assessing the magnitude and direction of the forces in the least favourable case. In other cases, where the structure undergoes movement the amount of which cannot be estimated, stresses must be kept within such limits which are far below those adopted as criteria in normal structural engineering.

The governing factor in the treatment of works below ground and below water is not the values of the stresses, but the correctness of the assumptions as regards incidence of load and as regards movement of the work and its component parts.

One more point may be made. In structural engineering above ground relatively small quantities of concrete and thin sizes are involved, whereas construction below ground and in water is a mass problem. To produce 300 000 m^3 of reinforced concrete in one year in a single job demands an altogether different scale of appraisal than, for instance, 10 000 m^3 of high grade reinforced concrete.