Concrete in hydraulic constructions

Autor(en): **Killer, J.**

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Concrete in hydraulic constructions.

Beton im Wasserbau.

Le béton dans les constructions hydrauliques.

Dipl. Ing. J. Killer,
Baden (Schweiz).

The design of concrete structures for hydraulic work should follow radically different lines from those customary in work above ground. In the latter the structures are for the most part protected from external influences, so that their cross sections can be determined from statical considerations alone, but below ground or below water the external influences play as important a part as the statical design of the structure. In view of the effects of aggressive water care must be taken to keep the concrete free from any tendency to cracking, and on this account the permissible stresses laid down in the regulations cannot be fully utilised. Above all, in work below ground or below water it is important to build in mass concrete, by contrast with work above ground where the highest of permissible stresses and the newest principles of construction may be exploited. At low levels, however, the principle of mass should predominate. Since every kind of water (but especially water which is poor in lime) attacks concrete, it follows that a greater thickness of construction will resist aggressive water longer than a light concrete member with correspondingly heavier reinforcement; it is of advantage, therefore, to use a larger quantity of concrete and a smaller amount of steel. In hydraulic works the concrete is to a great extent soaked in water, and in course of time, if the workmanship has not been good, this may lead to deterioration. Hence the concrete must be made as dense as possible. Another especially dangerous effect on the concrete is that of frost, and this applies especially at those points which are within the range of fluctuation of the water level.

Experience gained in the construction of dams and weirs in Switzerland has shown that a great deal of importance must be attached to the problem of frost. In the case of the Barberine and Wäggital dams, both constructed between the years 1922 and 1924, concrete made with 300 kg of cement per m^3 proved frost resistant, whereas the concrete containing 190 kg per m^3 used in the dam itself suffered great damage from the effects of frost, with the result that within a few years a lining of natural stone had to be added. In view of this unsuccessful experience in the use of a lean mix of concrete, the more recent dam constructions in Switzerland, those at Dixence and Etzel, are being concreted outside with 250 to 300 kg of cement per m^3, and even so are being lined with natural stone. The core of these dams was made with a mixture of 200 kg of cement per m^3. In the case of the Etzel dam the masonry lining on the water side was carried up to low water level. The practice of concreting from towers has also been completely given up. Whereas at Dixence the practice was maintained of carrying the concrete over a service bridge through a small system of channels to its point of application, the Etzel dam, now in course of construction, is being concreted entirely by means of cranes and buckets with a view to the avoidance of all risk of de-mixing. This dam is situated in the subalpine region and every precaution known to modern engineering is being adopted in order to make the work frost proof. It is an open question, however, whether in the future it will be necessary to go so far as to provide special outer concrete as well as masonry lining; in the interest of the economy of hydraulic power installations the author is of opinion that endeavours should be directed to the production of a concrete that can be counted upon to remain frost proof even at high altitudes — the more so since the stone facing, a mere palliative, prevents any control from being exercised over the concrete within, and since at high altitudes the effects of frost have been detected as far as 2 m into the mass. Stone facings are as a rule not thicker than 70 to 80 cm, so that frost is able to pass through them and enter the mass of concrete. It is possible to ensure frost proof concrete through exceptionally careful workmanship combined with low water content and a high proportion of cement; above all, care is necessary to guarantee that no unmixing takes place on the way from the mixing plant to the point of use. Experience teaches that concrete which has had to travel a considerable distance through channels is not as frost-resistant as concrete in the same job which has had to travel only a short distance through such channels.

It was formerly the standard practice, in Switzerland, to line the piers of weirs with natural stone masonry over the whole of their height, and good results were obtained by so doing. In more recent hydro-electric work the practice has changed to that of carrying the lining up only as far as boulders are liable to be encountered, and to leave the upper portion rough as if comes out of the shuttering. It is mainly within the range of fluctuations of water level, however, that serious frost damage has occurred, and the question has again arisen whether the lining ought not to extend over the whole height liable to be under water. Such a lining, however, is very costly, because the frost proof stone as a rule has to be brought from a great distance, and here again attempts must be made to obtain a concrete which will offer adequate resistance against external effects.

In one instance at a hydro-electric station, frost damage could be observed on the weirs proper while portions of the power house itself exposed to the same influence remained quite free from damage: the aggregates used and the mix adopted had been the same in either case. The heavier reinforcement in the part belonging to the power house entailed more careful concreting. This example clearly shows that provided the workmanship of the concrete is sufficiently careful a great improvement in quality can be ensured. Above all, in the construction of hydro-electric works where various portions are particularly liable to infiltration of water and are exposed to frost, the concreting should no longer be done by using chutes but only be means of cranes and buckets or belt conveyors. The latter method affords the best possibility of ensuring that the concrete will not become unmixed in transport.

Special care is needed in the concreting of pressure tunnels where the in-rush of water through fissures in the rock may give rise to great difficulties. Since the cross section now most commonly adopted for such tunnels is circular, the placing of the concrete becomes a difficult matter, and a very sloppy mixture containing an increased proportion of cement is necessary. Moreover, the concrete easily becomes de-mixed on its long journey through the tunnel, and it is essential to re-mix it immediately before it is placed.

When it is remembered that repair work to a pressure tunnel necessitates the whole of the power plant being put out of action, the importance of perfect treatment and working of the concrete used for such linings will be appreciated.

Good evidence of the fact that heavy frost damage is attributable mainly to the use of liquid concrete may be found in the unimportance of such damage in works built of earth-damp rammed concrete before 1920; before liqued concrete began to be used. Despite the fact that in these early jobs the sand and stone aggregates was, in most cases, taken as it was found near site, the concrete, old as it is, now gives a favourable impression; no doubt the reason for this is that the production of rammed concrete necessitated each layer being consolidated in turn and being free from any excess of water. This is a clear indication that in the future every attention will have to be paid to the working of the concrete — an object not attained merely by the winning of new knowledge through research, but requiring also effort on the part of colleges and institutions to ensure that in course of time engineers and specialist workers are turned out who have apprehended such knowledge and are capable of producing high quality frost-proof concrete on the job.

In view of the heavy vibration to which they are exposed through water shocks and the presence of the turbines, weirs and power houses should not be too lightly and elastically designed. In such works a relatively larger mass and correspondingly less reinforcement is appropriate. Side embankment walls should be provided with some system of drainage to carry water away from the concrete, and the crests of these walls should carry natural stone slabs to protect them against the effects of spalling by frost.

Concrete has been found a suitable material to use in hydraulic work to form those special shapes which modern practice demands — such as inlet spirals, suction pipes, spillways, etc. — at minimum cost. Since, however, these constructions are permanently immersed in water the concrete is very much exposed to frost which may in time damage the work, and the production of concrete for hydraulic jobs makes great demands on the constructing organisation. Concrete mixed with only just enough water to render it workable and containing at least 250 to 300 kg of cement per m^3, carefully mixed and placed has hitherto been found frost resistant. The use of vibrators to increase the density of the concrete serves to increase its surface strength, and may add much to its power of frost resistance.

The great object to be pursued in the future, in making concrete for hydraulic works, must be the attainment of a material which offers adequate resistance to external effects. It is only necessary to remember the large amounts that frequently have to be spent on reconstruction, owing to defects in the original construction of major hydraulic works, to perceive how vital it is that research and practice should combine in doing their utmost towards improving the quality of concrete.