Defective concrete

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Defective Concrete.

Mangelhafter Beton.

Béton défectueux.

Ministerialrat D. Arp,
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Great as the advances in concrete and reinforced concrete construction have been during the last few decades, we must not delude ourselves into thinking that perfection in the use of this material is anywhere near being reached. Reports of damage to concrete work from frost or the attack of acid waters or acid subsoils are often made, brought about by an insufficient quantity of the binding medium, incorrect granulation of the aggregates resulting in lack of density, or lack of uniformity in their distribution through carelessness in placing the mixture. Too often we see jobs in which the water has percolated through numerous horizontal working joints to cause hideous stains and efflorescence. Renderings, even if applied by means of compressed air, may show deterioration in places through flacking, and blistering, and so confer a tumble-down appearance on the structure as a whole. What large job in concrete or reinforced concrete is completely free from cracks? The observant visitor is apt to see only these and his impressions are formed accordingly; and it is a false consolation to suppose that most of the cracks do not go far into the concrete mass, for it is extraordinarily difficult to fix with certainty the depth of a crack. Most cracks go much deeper than is generally believed.

It is often said that the cracks in the tension zone of reinforced concrete structures do not impair the stability of the steel, provided the width of such cracks does not exceed a certain limit at the surface; the author, however, is of opinion that all cracks are an evil, and that their presence points to errors in design or in execution which must be avoided whatever the circumstances. Often, when inspecting handsome reinforced concrete bridges only a few years old, he has noticed with regret how the concrete has already begun to flake off here and there, because of rusting at stirrups which have not been held at a sufficient distance from the shuttering.

The defects thus outlined would be of rarer occurrence if the existing regulations were observed with more understanding and if every supervisor and worker on the job were impressed with the delicacy of the work and the meaning of carefulness in his duties. It might well indeed be desirable to fix somewhat stricter limits in these regulations — as, for instance, in regard to the minimum concrete cover for reinforcing bars, the screening curves for the aggregates, and the maximum and minimum limits of water content.

In considering the danger of rusting of reinforcing bars in delicate structures, it appears to the author a matter of regret that up to the present so little attention has been paid to the question of galvanising the steel, an expedient which provides excellent protection. It has long been established that galvanising does not reduce the bonding quality.

On the question of consistency we ought in no circumstances to allow ourselves to be led back, on the strength of laboratory results and theoretical considerations of plasticity, to the use of "earth-damp" concrete. The concrete must always be soft enough to make it fill the shuttering under its own weight as densely as possible, even if the supervisor and workers have occasionally been remiss in their care. In Germany the placing of concrete by means of pumping has rightly attained to a considerable development during the last few years; the great viscosity of mixture has proved an advantage in this method, and the mixture requires no more than 9 % of water in proportion to the dry mix. Unfortunately the concrete pump up to the present has required the exclusive use of stone aggregate measuring not more than 80 mm in any direction. In all the larger concrete and reinforced concrete jobs constructed on the Mittelland Canal during the last few years the whole of the concrete — whether conveyed by pump, conveyor belts, channels or in any other way — has been introduced into the shuttering by means of fixed funnels according to the "Kontraktor" system, which was actually devised for placing concrete under water. The characteristic of this system is that the funnels in question are raised with the concrete in such a way as to keep the lower edge of the funnel always at a certain depth within the fresh concrete. The number of funnels is determined by the size and shape of the plan of the construction. In all these jobs without exception it has been found that concrete poured in this way, so as to cause it to pile up uniformly around the pipe in the dry, is remarkably uniform and dense, and no laitance appears either inside or on the surface. In these jobs horizontal working joints have been as far as possible avoided altogether, so that the whole mass is in fact made monolithic. In the doublelift lock at Allerbüttel, for instance, two walls each 14.2 m high and 9.3 m wide at the bottom were built in this way, in blocks about 15 m long, each block being completed in one non-stop working operation from the bottom to the top without the introduction of any horizontal joint. All fittings in these walls, such as the foot plates, horizontal and vertical edge protectors, ladders and bollards were erected within the shuttering beforehand and so cast into the concrete; waterproof joints and guide rails for the lock gates, roller-sluices, etc. in the lock-heads were installed in the same way.

Despite the successful results obtained in these works a few parts of them exhibit the defects indicated above, namely cracks; some of these being very fine surface cracks, others deeper and even extending right through the mass. At any rate the appearance of such cracks in the blocks constructed during the colder seasons of the year afford an indication of the important part played by temperature effects. In large masses of concrete cracks are apt to be produced at places wherever the stresses from live load, shrinkage and temperature combine to make up a maximum which exceeds the tensile strength of the concrete. In massive concrete works such as lock walls, dams and the like, the shrinkage stresses which result from drying are relatively unimportant (except as regards a thin surface layer) because there is always sufficient moisture present in the interior of the concrete mass to mitigate this effect. It is chiefly the temperature stresses that are responsible for the cracks occurring in the cross-walls. These temperature influences give rise to considerable secondary stresses which have not, as a rule been taken into account when calculating the stability of the work, and they endanger the concrete at a time when its strength has not yet reached an appreciable value.

The cracks most frequently observed are vertical transverse cracks in the walls. These are the least dangerous kind, since, when all is said, they merely represent an addition to the number of joints purposely provided, and their disadvantage lies mainly in impairing the water tightness. Horizontal cracks also occur, and these are more serious. The worst of all are longitudinal cracks which destroy the assumed integrity of the cross section. In the finished work they can be detected only if there are internal passages such as for instance the circulating channel in a lock or the inspection shaft and galleries in dams. *Vogt*,[1] who has made an investigation of practically all dams existing in the world built up to 1930, gives many examples of vertical, horizontal and longitudinal cracks in such structures, and very few dams are mentioned by him as being completely free from any kind of cracks. Similar experience has been recorded in concrete dams since constructed in Germany, regarding which Professor *Ludin* has given an account before the Congress.

The fact that stresses in the concrete may attain considerable values on account of temperature changes alone is brought home when one considers the magnitude of the heat changes to which large concrete masses are exposed, and the movements to which they are compelled through the effect of such changes. Concrete which has been placed at a mixing temperature of $+ 25^0$ C will thereupon harden in accordance with the dimensions of the shuttering, but in the course of time its volume must diminish to correspond with the mean annual temperature, which may be a matter of $+ 10^0$ C. Assuming a coefficient of thermal expansion of 0.000012 a wall block 15 m long constructed in this way must suffer a contraction of 2.7 mm in cooling to the mean annual temperature, if its movement is not restrained.

The most far reaching effects are those which result from the increase in temperature which the concrete in large blocks undergoes in the course of setting. With the usual conditions of mixing, the increase in temperature of the concrete in usually medium sized walls of ship canal locks may reach 35 to 40^0 C in the interior of the concrete. In large gravity dams the difference between the internal and external temperature may be even greater, since the escape of heat from one block is hindered by the construction of its neighbour immediately or soon afterwards. The magnitude of the stresses imposed by the gradual cooling before the final temperature is reached may be gathered from the consideration that the volume of a block of approximately 1000 m^3 content, which has been formed at

[1] Prof. Dr. *Fredrik Vogt:* Shrinkage and cracks in concrete of dams. D.K.N.V.S. Skrifters, Trondheim, 1930, N° 4.

a mixing temperature of + 25° C and has its temperature increased to 40° C in setting, must shrink approximately 2 m³ smaller than its maximum size in the process of reaching a temperature of + 10° C.

The firm rock foundation below a dam participates in the expansion and contraction of the concrete only to a small extent, and in the same way the lower blocks of a large gravity dam, which have already partly cooled off, hinder the movements of the fresh blocks formed above them. It is clear that in a concrete dam many movements to and fro must take place, giving rise to considerable stresses before any load from water pressure has been imposed. The result is that the true conditions of stress in such a dam are exceptionally difficult to determine, especially so in the first few years after filling with water.

What, then, are the measures which can and should be taken to minimise the formation of cracks in concrete? Of course an eminently suitable cement should be chosen, which besides having as high a tensile strength and elongation as possible, shows very low shrinkage and, above all, produces a minimum amount of heat. In Germany it has been sought to promote these qualities in nearly all the newer dam works by making additions to the cement, particularly the additions of trass, or alternatively in a few cases certain other lime-binding materials such as "Thurament" which is a basic blast furnace slag cement which has been merely ground but not otherwise specially treated. In the Saaletal dam near Hohenwarte, now under construction, a mixture of three components — Portland cement, trass and Thurament — is being used in the proportions of 36 parts by weight of the first mentioned, 40 of the second and 24 of the third. It must always be borne in mind, however, that whatever care may be exercised in the choice and composition of the binding material the secondary stresses, which may give rise to the formation of cracks, are diminished only to a small extent.

Further, the water cement ratio should be kept as low as possible, in order that no reduction in strength may occur. Should one, from fear of cracking, return to the use of "earth-damp" concrete placed in thin layers and rammed or vibrated, in order that the setting heat may to a great extent escape into the air? In the author's opinion concrete so made is the worst kind of all and, moreover, in a dam containing several hundred thousand cubic metres of concrete there is not time to delay the sequence of layers to such an extent that the accumulation of setting heat may be avoided.

The richer the mix the greater the shrinkage and hence the greater the setting heat. Let us, then — it is sometimes suggested — adopt the leanest possible concrete; but a lean concrete cannot be expected to be watertight or to resist chemical and atmospheric effects. In view of these considerations a few recent dams have been built with a thick core of lean concrete and the outer layer, both on the water and on the dry sides of the dam, of rich concrete, the expectation being that in this way the dam as a whole will undergo smaller amounts of movement from shrinkage and temperature changes. Where is the guarantee, however, that the stresses in the contact zone between the rich and the lean concrete will not exceed the permissible amount, with a consequent risk of crack formation in course of time — cracks which may run along the length of the dam and endanger its stability? Again, how will it be possible to prevent water from percolating in course of time to the lean core, where it may bring about chemical changes? The author would not advise such a method of construction. He is entirely of the opinion that nowhere in hydraulic construction should a lean concrete be used in a position where the water may penetrate in any way. The expressions "lean concrete" and "economy concrete" should be struck right out of the technical vocabulary.

He looks upon these devices for avoiding cracks as being of little or no use, and sees only one possibility of serving the desired purpose, which is by cooling the concrete.

The components of the concrete may be cooled before or during the mixing process, or the concrete may be cooled after its introduction into the shuttering, or these methods may be combined. The cooling of the ingredients of the mix

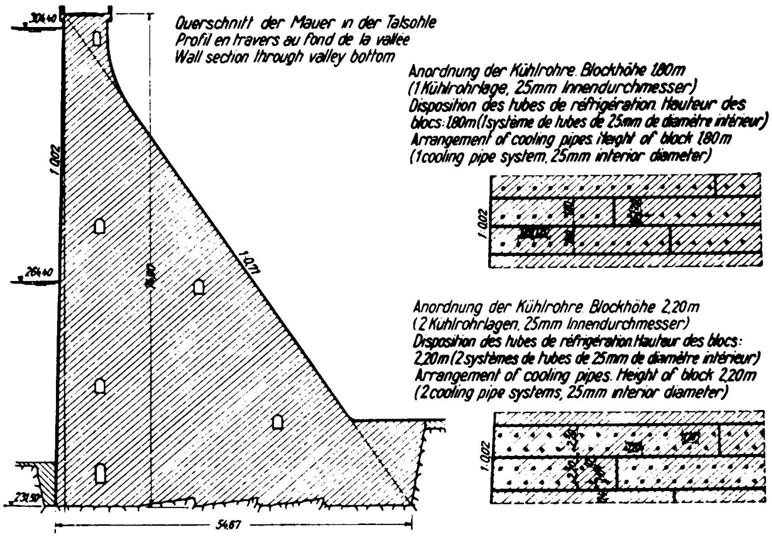

Fig. 1.

Cross section of upper Saale river barrage near Hohenwarte, showing arrangement of internal cooling tubes.

is very effective during the hot part of the year and enables the heat curve to be considerably lowered, but in this way no direct influence can be exerted over the development of the harmful setting heat. That can be done only by cooling the concrete actually placed.

By spraying all concrete which is fresh and has not yet fully hardened with water for a long time, with the object of rendering the drying process more uniform and of providing an adequate supply of water to the surface layers for the continuation of the setting process, a considerable reduction in the excess heat from the concrete mass may, of course, be secured, but this effect cannot penetrate right into the interior of large blocks.

In the case of the Grimsel Dam in Switzerland, and also in other dams, large slots have been allowed to remain open for a long period between the individual large constructional blocks and also at certain of the vertical working joints, before being filled up with concrete, the idea being that in the meantime the air might serve as a means of escape for the heat within the concrete, which would thus be more rapidly drawn away. The author has no exact information as to the success of these measures, but it is clear that no extensive and uniform effects in preventing the formation of temperature cracks can be expected from them.

The only rational method appears to him to lie in the internal cooling of the concrete wall by a system of cooling pipes uniformly distributed through the cross section at not too great intervals. Such cooling is being applied with success by the American engineers in the Boulder Dam in Colorado now approaching completion, though in that instance the reason for the adoption of cooling was not the question of temperature cracks, but the desire to use this means of bringing various sectors of the arc dam to their final dimensions as quickly as possible so that the gaps separating the elements of the arch might be filled with cement grout under pressure, in time to enable the dam to stand the water

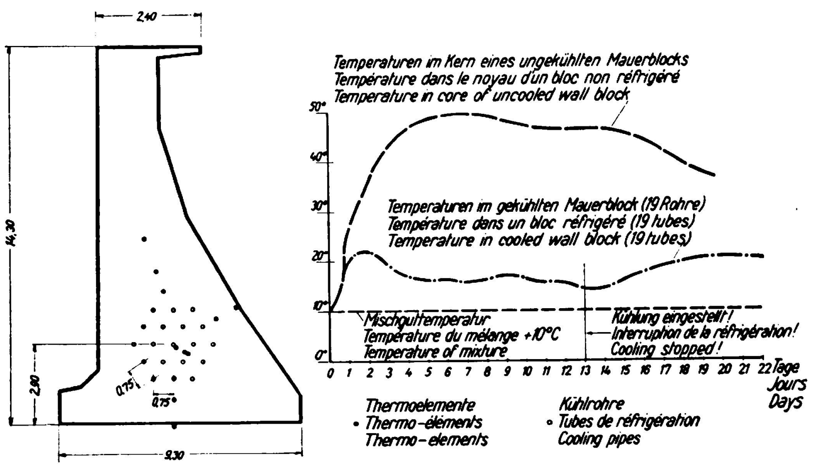

Fig. 2.

Artificial cooling of the concrete wall of the Allerbüttel double barrage (German Midlandcanal).

pressure. But the un-sought for absence of cracks in the concrete was an additional advantage of the cooling system not originally intended.

This example of the Boulder Dam serves to bring out the advantage of the internal cooling of the concrete applied to the German dam, already mentioned, in the upper Saale near Hohenwarte, in which the concreting was begun in the late autumn of 1936. Here it is a question not of an arch but of a gravity dam, so that the grouting of the gaps under pressure is of secondary importance and the only purpose of the cooling is to carry away the heat of setting at such a rate that no harmful stresses will arise and entail the risk of crack formation. It may be seen from Fig. 1 how the cooling pipes are distributed over the whole cross section within any of the working blocks. The bore of the iron pipes is 25 mm and the horizontal interval 1.2 m, the vertical interval depending on the thickness of the layers in the blocks, which is not yet fixed. If this is taken as 1.8 m then that dimension will also correspond to the vertical spacing of the cooling pipes; where layers more than 2.20 m high are adopted two rows of cooling pipes will be used having an interval equal to half the height of the block, that is to say, 1.10 m. The pipes will carry a slow circulation of water which has been cooled down to between + 6 and + 9° C, until the working block in question has reached the mean annual temperature, and then, as was done at the Boulder Dam, the pipes will be filled with cement grout under pressure. The Hohenwarte dam is approximately 400 m long at the crown and is 75 m high at the deepest part, and the total volume of concrete will be approximately 450,000 m^3; altogether some 200,000 m of cooling pipe will be necessary apart from the supply and return connections. The additional cost due to the provision of cooling will be about 3.5 % of the total cost of the work not including the power station, or approximately 6 % of the cost of the dam by itself.

In addition to the internal cooling of the concrete blocks, provision has here been made for cooling the mixture in the mixing plant during the summer months.

At Hohenwarte the cooling through the water pipes is not, as in the case of the Boulder Dam, to be delayed for some weeks after a block has been concreted, but is to be begun immediately after the concreting, with a view to cutting off the peak of the heat curve in advance. Criticisms to the effect that the setting heat is being removed are not valid, since it is a question of removing the heat which has already been set free by the chemical process, and the slowing down of the hardening process of the concrete by the application of cooling to reduce the temperature can be regarded only as an advantage.

The fact that the proposed cooling process is attended by no disadvantages is shown by experiments carried out on large concrete blocks in the Institute for Frost Investigation at Magdeburg—Glindenberg, and also in actual practice in the double lift lock at Allerbüttel to which reference has already been made. In the latter a number of the blocks the lock walls were provided with cooling water pipes arranged in different ways, one such arrangement being that shown in Fig. 2 which also serves to indicate the remaining measurements of the wall. The temperature of the cooling water in this experiment was 7° to 9° C. In other experiments it was higher, as the water from the neighbouring canal was taken during the warmer part of the year. The variation in temperature in these, as well as in a few blocks which were not cooled and in the ground below, was measured by means of electrical thermometers and automatically recorded. The curves of temperature reproduced in the figures indicate that the cooling was effective in carrying away a considerable amount of the heat of setting, the height of the cooling curve being reduced by some two-thirds. In other wall blocks at Allerbüttel, in which the spacing and diameter of the pipes was varied, the results obtained corresponded to these variations. In none of the cooled blocks did any cracks arise, though the pipes were provided only in the core.

These experiments at the Allerbüttel lock serve at the same time to indicate the possibility of applying the concrete cooling process even in works of smaller dimensions, making use of relatively simple means, and in this way to protect the work from the cracking which might otherwise occur. The small expense of cooling is out of all proportion to the great value thereby obtained.