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Temperature Rise in Concrete Dams.

Temperaturerhöhung in Betonstaumauern.

L'échauffement dans les barrages en béton.

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In large masses of concrete, such as dams, the central portion loses heat very slowly, and the concrete is cured under almost adiabatic conditions; as a result a very high temperature may be reached. The rise in temperature will depend on the type of cement used, as indicated by the figures in Table 1, the mix proportions, the size of mass of the concrete, the rate of placing, the insulation afforded by the shuttering and the external conditions.

Table 1.

Heat Evolved by Different Types of Cement.

Type of cement	Number of consignments tested	Heat evolved in g — calories per g at the end of		
		1 day	2 days	3 days
Normal Portland cement	13	23—42	42—65	47—75
Rapid-hardening Portland cement . .	13	35—71	45—89	51—94
Portland blast-furnace cement . . .	6	18—28	30—51	33—67
High-alumina cement	3	77—93	78—94	78—95

Some attention has been given at the Building Research Station to the effect of heat evolution on the strength and other properties of concrete.

It has been found that the strength is developed more rapidly at the centre of a mass of concrete, where the temperature is higher, than at the edges. In one mass measuring 3 ft. × 4 ft. × 2 ft. 6 in., in which concrete composed of one part of rapid-hardening Portland cement, two parts of river sand and four parts of gravel, and having a water-cement ratio of 0.6 by weight was used, the strength after 3 days of the concrete at the centre was found to be over 50 per cent. greater than that at the corners where the loss of heat through the shuttering was greater.

Since both shrinkage and creep vary with strength it is reasonable to suppose that they also will vary throughout the mass of the concrete. In addition, concrete in large masses hardens at a time when the temperature increase due to beat evolution is considerable and, consequently, the return of the concrete to normal temperature, which in some cases may take many months or even years, must be accompanied by a heat contraction which is additional to any shrinkage effects.

It is particularly desirable that these temperature effects in mass concrete should be reduced to a minimum by the use of selected cement and by the careful design of the concrete mix, and that it should be possible to predict from the results of laboratory tests of the cement the temperature that may be attained in a mass of concrete made with it. The study of the problem at the Building Research Station[1] has therefore been extended with the object of obtaining records of the temperatures attained in the concrete of three large dams, and to compare these records with the time-temperature curves given by laboratory tests of the cements used for these works. Although further tests are needed before an exact correlation can be established, approximate relations can already be given which may be used for the tentative prediction of the temperatures that will be reached in a large mass of concrete made with a given cement.

The observations may be conveniently grouped into two series: one series made on concrete deposited in the Tongland and Clatteringshaws Dams of the Galloway Water Power Works, and the other series on concrete deposited in the Laggan Dam of the Lochaber Water Power Works.

The Tongland Dam, across the River Dee, near Kirkcudbright, is about 850 ft. in length and includes an arch dam in reinforced concrete and a gravity section. The Clatteringshaws Dam is of the gravity type and has a total length of 1450 ft. across the Blackwater of Dee. The Laggan Dam, near Fort William, is approximately 700 ft. long and 138 ft. high, and is of the gravity type. In the Tongland and Clatteringshaws Dams the concrete was placed in lifts varying in depth from 4 ft. 6 in. to 6 ft. 0 in. and in the Laggan Dam from approximately 3 ft. 3 in. to 3 ft. 9 in.

It was possible to observe the temperature rise in masses of concrete placed in the Tongland and Clatteringshaws Dams. The observations were made by inserting a maximum thermometer in a pipe embedded in the mass.

Each mass constituted a lift poured in one operation, the depth of the lift varying from 4 ft. 6 in. to 6 ft. 0 in. Class "0" concrete (3 cwt. cement, 12 cu ft. Gatehouse sand and 20 cu ft. of Porphyrite aggregate) was used in all these masses, except at the Clatteringshaws Dam in which 12 per cent. of displacers were added. Samples of the cement and aggregates were forwarded to the Building Research Station and the temperature rise was measured on completely insulated samples of concrete using the same mix as used in the actual masses.

In the Laggan Dam the temperatures were observed in the central portion of the dam by means of a series of Cambridge resistance thermometers. The concrete was placed in lifts of approximately 3 ft. 6 in. and the mix contained 370 lb. of cement per cu yd. The water added to each batch varied considerably and depended on the amount of moisture present in the sand and aggregate, but the mix was of a stiff consistence. The granite displacers averaged approximately 5 per cent. of the total mass of concrete deposited. The shuttering was

[1] *Davey, N.:* "Correlation between Laboratory Tests and Observed Temperature in Large Dams". Building Research Technical Paper N° 18, 1935.

of tongued and grooved timber 2 in. thick with necessary bracing. The freshly deposited concrete was covered with heavy coconut matting immediately after placing. This matting was kept wet until it was necessary to lift it for placing the succeeding lift.

An examination of the rise in temperature at the interior of lifts of concrete showed that in the majority of instances, particularly in the Laggan tests, two peaks were reached. The first rise in temperature is very rapid and in actual practice may exceed in rapidity the rise recorded on samples of similar concrete placed at the same temperature and cured in the laboratory under adiabatic conditions; the reason being that a certain amount of heat is received from the preceding lift. The first rise is followed by a less rapid fall in temperature, but

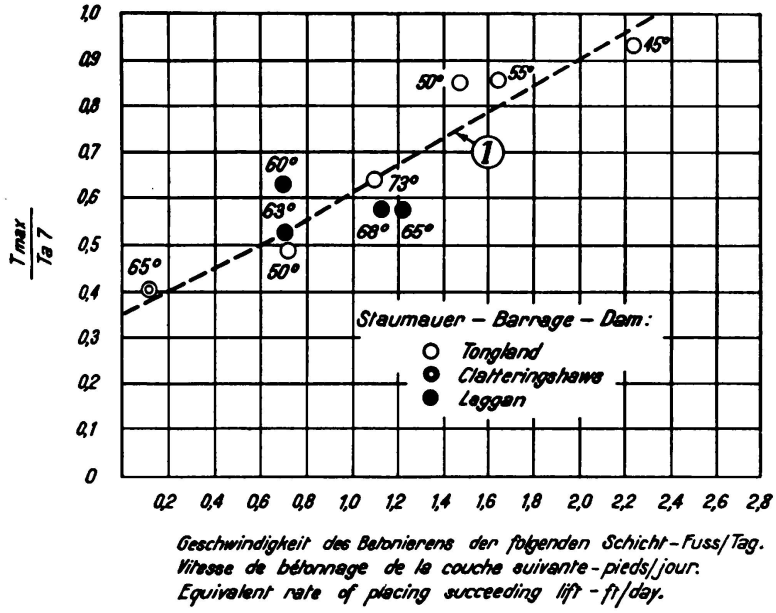

Fig. 1.

Temperature rise in mass concrete.
(The placing temperatures are indicated.)

this fall is arrested by the heat received from the succeeding lift of concrete and a second peak temperature is experienced.

As a general conclusion it may be stated that in placing concrete in lifts of equal thickness and of the same proportions of mix the first peak temperature T_{max} in any particular lift is dependent upon the age of the preceding lift, and the second peak temperature T'_{max} is dependent upon the time interval before the succeeding lift is placed.

Figure 1 gives the relation between the ratio $\frac{T_{max}}{T_{a7}}$ and the equivalent rate of placing the preceding lift, T_{a7} being the temperature rise in a completely insulated sample after 7 days; in Figure 2 is given the relation between the ratio $\frac{T'_{max} - T_{max}}{T_{max}}$ and the rate of placing the succeeding lift. If, then, the value T_{a7} is known it is possible to determine with very fair accuracy the temperature rise likely to occur in a mass of concrete of similar thickness and placed under similar temperature conditions as those recorded here.

The existence of high temperatures in the heart of the dam with a much lower temperature at the surface must result in the development of high stresses near the surface. It is therefore essential that some idea of the maximum temperature rise that can be allowed without the formation of cracking, due to temperature, should be obtained. Observations made on the Laggan Dam have

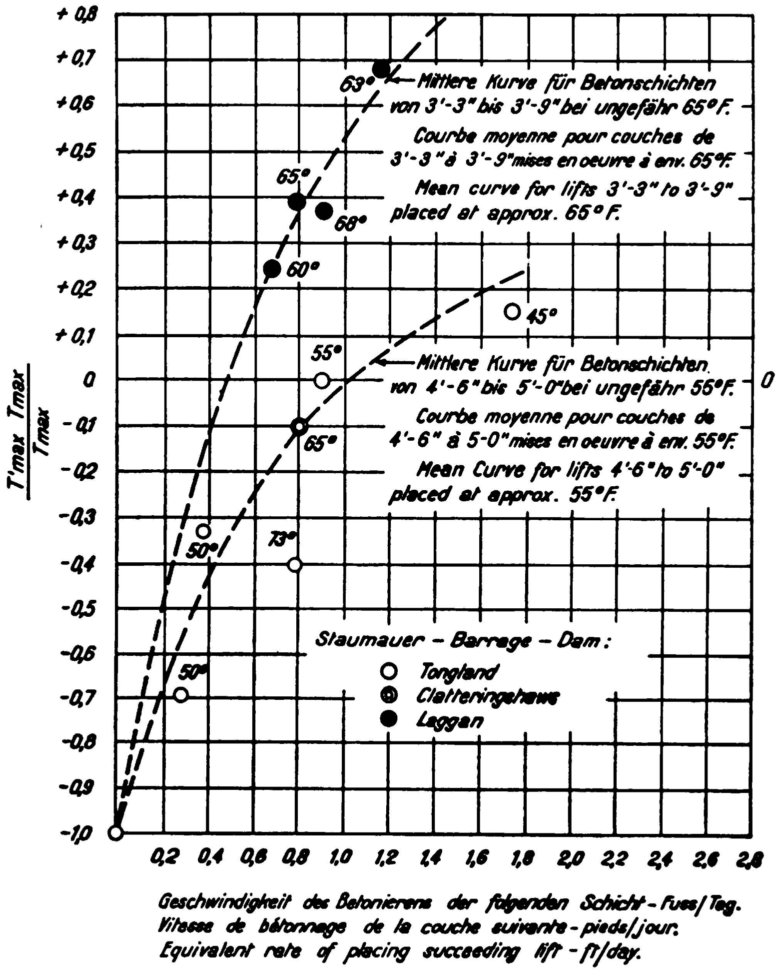

Fig. 2.

Temperature rise in mass concrete.

(The placing temperatures are indicated.)

been helpful on this point. The time at which the maximum difference in temperature occurred between the concrete in the heart of the dam and at the surface has been recorded. This corresponded with the date at which the concrete in the heart attained its second maximum temperature (T'_{max}). In the case of block IV south of the dam this date was 4 to 5 weeks after depositing the concrete in the heart of the block.

An examination of the temperatures recorded at points Nos. 5, 4 and 3 — 3 ft., 23 ft. and 43 ft. respectively, from the upstream face of the dam during the

10 days following 27th July, 1933 — is interesting in that it shows how quickly the gradient changed near the surface of the dam.

date	Thermometer No. 3	Thermometer No. 4	Thermometer No. 5	Air Temperature
27. 7. 33	109° F	106.5° F	108° F	62° F
29. 7. 33	109	107	97	54
31. 7. 33	108.5	107	90	60
2. 8. 33	108	107	88	54
4. 8. 33	108.5	108	84	55
6. 8. 33	108.5	108	83	55

The gradient observed on 6th August, 1933 is shown in Figure 3. From a point about 10 ft. in the mass to the exposed surface the gradient is seen to be about 50° F. The difference in temperature between the heart of the dam and the air at the exposed surface approached 55° F. This amount is not entirely

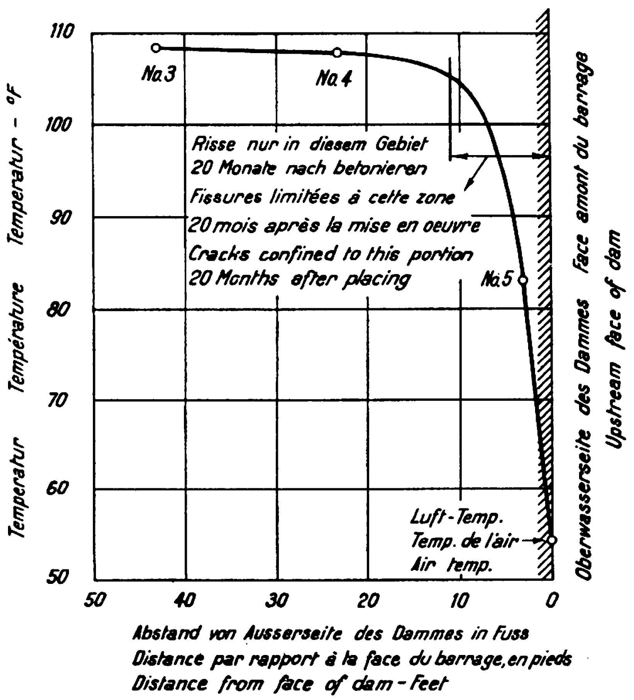

Fig. 3.

Temperature gradient in Laggan Dam, 6th Aug. 1933.

due to the rise in temperature of the concrete due to the heat of hydration (approximately 45° F) but also to a fall in the average air temperature of about 10° F. Cracks became visible in the concrete by the end of the month, but the cracks had not penetrated as far as the inspection gallery, situated 8 to 11 ft. from the upstream face of the dam, at the end of 20 months. The cracks are therefore confined to the surface and seem to be definitely accounted for by the development of the sharp temperature gradient in this region.

Taking a value for the effective modulus of elasticity of 1×10^6 lb. per sq. in. for the concrete which had an average compressive strength of approximately 2,800 lb. per sq. in. at 28 days, and a coefficient of thermal expansion of 6×10^{-6} per 1^0 F, the tensile stress set up due to the temperature gradient alone would probably exceed 300 lb. per sq. in. This value is excessive and would result in cracking. If the risk of cracking is to be reduced to within reasonable limits the tensile stress in the concrete (due to temperature) should not be allowed to exceed at the most 150 lb. per sq. in. This in turn means that the temperature difference between the centre and the surface of a mass should not exceed about 25^0 F. To achieve this the rate of placing of a concrete similar to and placed at the same temperature as that used in the Laggan Dam, with a cement which generates 65 calories per gram at 7 days, would have to be restricted to 0.5 ft. per day i. e. lifts of 3 ft. 6 in. placed at intervals of not less than 7 days. This figure assumes that the average air temperature from the time of depositing the concrete to the time when the maximum gradient occurs does not change appreciably. Seasonal temperature fluctuations will have the effect of increasing or decreasing the gradient through the dam. With a rising air temperature the gradient would tend to be less steep and the reverse effect would be anticipated if the air temperature was steadily falling. If cement which generated only 55 calories per gram after 7 days were used, the rate of placing could be increased by about 20 per cent. without incurring additional risk of cracking.

It cannot be claimed that finality has been reached in this investigation, which must be extended to cover conditions of placing other than those of the Laggan and Galloway Dams.