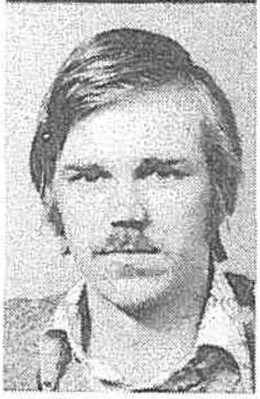

PROPERTIES OF HOT CONCRETE AND ITS USE IN WINTER CONCRETING

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Synopsis

The use of hot concrete in winter concreting has been started in Finland two years ago. During this period research work concerned with the utilization of hot concrete has been carried out. The results of this research have been introduced in this paper. According to these results hot concrete is a useful method in winter concreting. It makes possible a rapid turn-over of the forms, provided that concreting is rapid, concrete is protected with heat insulation as early as possible and additional heating at the edges of the structure is used.

Hot concrete
Winter concreting

1. INTRODUCTION

By reason of productivity and efficiency of construction work a rapid turn-over of the forms is also used in winter concreting. Due to cold weather a rapid 1- to 3-day turn-over of the forms during the winter requires, however, that concrete is heated efficiently. The heating of concrete has traditionally been carried out first after the compaction of concrete, but it is also possible before casting. This new method is called hot concrete.

With an increase in a temperature of fresh concrete the hydration reactions between water and cement are accelerated. High temperature accelerates the development of strength, but at the same time it speeds up the stiffening of fresh concrete thus causing difficulties in workability and exerts generally a harmful effect from the point of view of late strength.

The most frequently used temperatures of the hot concrete are between 40° and 60°C. In several cases an appropriate temperature is around 50°C. The use of temperatures higher than 60° can be considered only when extra high early strengths are desired to achieve, because difficulties in workability of fresh concrete and the loss of strength greatly increase.

The object of using hot concrete is to reduce heating of the concrete on the jobsite and costs induced by it. It is based on more efficient use of heating energy as well as on savings in heating equipment and labour costs due to its installation.

The use of hot-mixed concrete is more wellknown in precast factories than on jobsite. On site hot concrete is used both in the Soviet Union and Norway. In Norway the utilization of hot concrete started in 1974. The temperature of hot concrete is 60°C, the cement used is a rapid hardening Portland cement and the concrete is produced by steam-injection. Experiences of hot concrete have been favourable.
In Finland hot concrete has been used in in-situ concreting during winter for two years. During this period research work concerned with the utilization of hot concrete has been carried out as a joint project between the Concrete and Silicate Laboratory of the Technical Research Centre of Finland (VTT) and the manufacturers of hot concrete. After study of literature laboratory and site investigations have been carried out.

In the laboratory tests, main emphasis was laid on the elimination of workability problems of the hot concrete and on the examination of strength development, whereas in field investigation temperature development of hot concrete after casting, a need for heat insulation and strength development were studied.

2. LABORATORY TESTS

2.1 Performance of tests

The laboratory tests on hot concrete were performed by using separately heated aggregate and water. The cement used was rapid hardening Portland cement. Since different admixtures made possible a reduction of water in different amounts, the concrete mixes were designed for constant consistency by changing the water/cement ratio. The ratio of cement to aggregate was always 1:5.23 and the average cement content 330 kg/m^3.

In the tests, two different mixing procedures were found to be necessary. In the first mixing procedure hot aggregate and cement were placed directly into a mixer. Subsequently, used admixture and water were added and the mixing was started. In mixing the concrete mix this way, a retarding admixture failed in any dosage to have a retarding effect. The concrete mix could stiffen more rapidly than usual. Eventually, the reason for this was a very rapid start of hydration, which the retarder could not sufficiently prevent when batched in this way.

In order to give the retarder enough time to exert an effect on cement immediately in the initial phase of reactions, the mixing procedure was changed. The retarder and hot water were first batched into the mixer. The cement was added after that during mixing. Subsequently, aggregate was added to the cement paste and the actual mixing period was started.

After mixing, slump of each concrete mix was measured and the mix covered to prevent the evaporation of moisture. It was proceeded in this way also at intervals of the following slump measurements. The 150 mm cubes were used as test specimens. They were made about 45 min. after the addition of water. The test specimen moulds were heated in advance to the temperature of the concrete mix. The test specimens were protected against heat and moisture losses in such a way that their temperature remained as even as possible and no rise of temperature occured as a result of heat of hydration. At the age of 1 day the heat insulation was removed and the test specimens were transferred to water curing.

2.2 Workability

A rapid reduction in workability is one of the greatest problems encountered in the use of hot concrete. The stiffening of the hot concrete mix starts as early as in the mixing phase. After mixing, the stiffening of hot concrete proceeds at a rate depending on the consistency and temperature of the concrete mix as well as on the cement used. The reduction in workability is due to evaporation and decrease of free water in the concrete mix caused by hydration reactions. Furthermore, the stiffening of the concrete mix is partly a result of an increase in internal friction of the mix produced by hydration products.

Workability of hot concrete can be improved by using additional water, retarders and plasticizers. As these cannot prevent the water from evaporating, also the stiffening of the mix cannot be prevented completely. The use of concrete mixes of high workability is therefore required in practise.

In the tests performed the retarders appeared to be most effective in lowering the stiffening rate of hot concrete. However, the water content of the concrete mix could not be reduced markedly by retarders. By means of retarders workability time can also be regulated and by the use of a sufficiently large dosage of retarders hardening of the mix can also be completely prevented. The effect of retarder on the stiffening of the hot concrete mix is described in Fig. 1 when a small dosage of a mononatrium-phosphate-based retarder (0.1 %) is used.

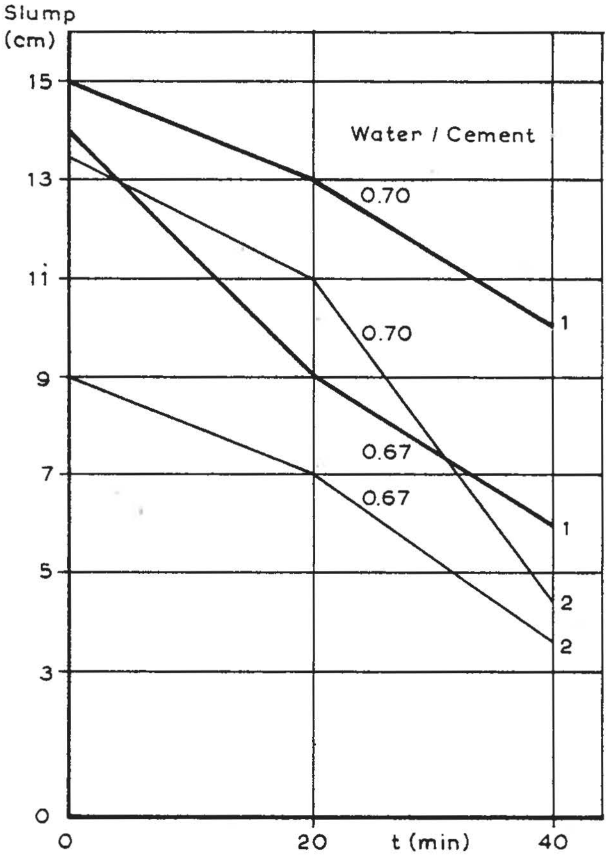

Fig. 1. Effect of the retarder on workability of the hot concrete mix.
1. With retarder
2. Without admixture

The tests made with plasticizer indicated that the time at which the plasticizer exerts an effect on the hot concrete is short. The time of this effect could be increased by using also retarder in the concrete mix. Results of the tests with the melamineformaldehyde-based plasticizer are given in Fig. 2. By using only plasticizers a great water reduction and a high slump value were achieved but the stiffening of the mix remained rapid. When the retarder (mononatriumphosphate-based) was used it was possible to reduce the dosage of the plasticizer, and simultaneously with it a great reduction of the water content as well as a long workability time were achieved.

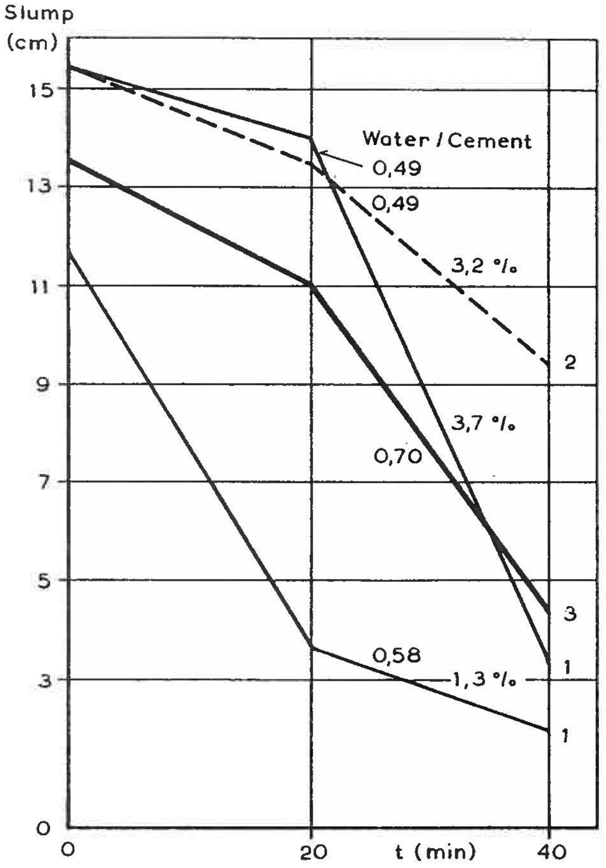

Fig. 2. Effect of plasticizer on workability of the hot concrete mix. Dosage of plasticizer is given in the figure. Temperature of concrete from 55 to 60°C.

1. Plasticizer
2. Plasticizer plus retarder (0.1 %)
3. Without admixture

In practice, additional water is to be used in the hot concrete mix. A disadvantage of the use of additional water is that the concrete strength decreases as the result of a gain in the water/cement ratio. In case the strength properties of concrete are desired to maintain then cement has to be added to the concrete mix. The addition of cement together with water increases the amount of cement paste of the mix, which intensifies shrinkage of the mix. The use of additional water and the addition of the cement amount required by this use will lead in practice to the use of quality classes ranging only from K 20 to K 30.

2.3 Strength development

The strength development of concrete is accelerated with an increase in temperature of the mix. The benefit derived from the high initial temperature of the mix is at its highest at the beginning of hardening. On the other hand the importance of the initial temperature (40 to 60°C) of the hot concrete even as early as at the age of one day is slight. The variation of 1-day strengths due to different initial temperatures has no practical significance.

The strength development of concrete is also dependant on the temperature development of concrete. The influence of different hardening temperatures (>20°C) is also weakening before the 1-day strength is resched. The tests performed indicated that the most profitable heat protection was the one that made possible to maintain an even temperature or a slowly decreasing one. On the other hand by a combination of heat treatment and hot concrete very high strengths in a few hours were attained.

The loss of strength occurring as a result of the high hardening temperature at early age has an effect on the later strength development of concrete. As a result of strength loss the strength of hot concrete remains usually lower than that of a corresponding concrete made at a normal temperature. The strength loss of hot concrete is the higher, the higher the initial temperature of concrete, the higher the curing temperature and the longer the time the concrete has been kept at a high temperature. The amount of the strength loss is difficult to evaluate as it is not appropriate to use the same mix design at room temperatures.

In the tests, 50 to 75 % of the 28-day strength was achieved with hot concrete (55 to 60°C) at 1 day; the strength at 28 days varied correspondingly between 30 and 50 MN/m^2 depending on the admixtures employed.

3. FIELD TESTS

3.1 Performance of field tests

In the field tests, temperature and workability of the concrete mix, temperature development of hardening concrete as well as strength development of concrete were followed. Main attention was paid to the temperature development. The temperature measurements were made by thermocouples placed in a structure before concreting and a 12-channel recorder. The thermocouples were placed for the purpose of studying the minimum and maximum temperatures existing in the structure. The temperature measurement was interrupted at the time of form removal or during the drilling of test specimens from the structure. The strength development of hot concrete was monitored using the 150 mm standard cubes and test specimens from the structures. The standard cubes were stored at a precast concrete plant and they were left to cool spontaneously to a temperature of +20°C. Half of the test specimens from the structure and the standard cubes were tested at the time of form removal and half of them at the age of 28 days after moist curing (RH 100 %).

3.2 Temperature measurements

Temperature measurements of hot concrete were carried out both in wall and slab structures. The aim was to study the need for heat insulation and additional heating at the edges of the structure.

According to the temperature measurements the use of hot concrete is simpliest in lagre moulds provided with heat insulation. For large moulds a heat insulating layer, which has the efficiency equal to that of a 50 mm mineral wool insulating layer commonly used in Finland, protects sufficiently hot concrete in the middle parts of the structure. In general, at the edges of the walls additional heating is, however, necessary. Additional heating is necessary at the point at which the lower part of the wall and the previously cast concrete slab join each other. Fig. 3 shows temperatures measured in large moulds provided with heat insulation when the lower part of the wall is additionally heated. The additional heating has been carried out by means of wire heating cables. An adequate stripping strength has been achieved after 18-hour hardening. On the other hand Fig. 4 gives temperatures measured in large moulds with heat insulation when there is no additional heating either in the lower part of the wall or at the joining point of the wall. In addition to low hardening temperature also great temperature differences are brought about, which may produce heat cracks.

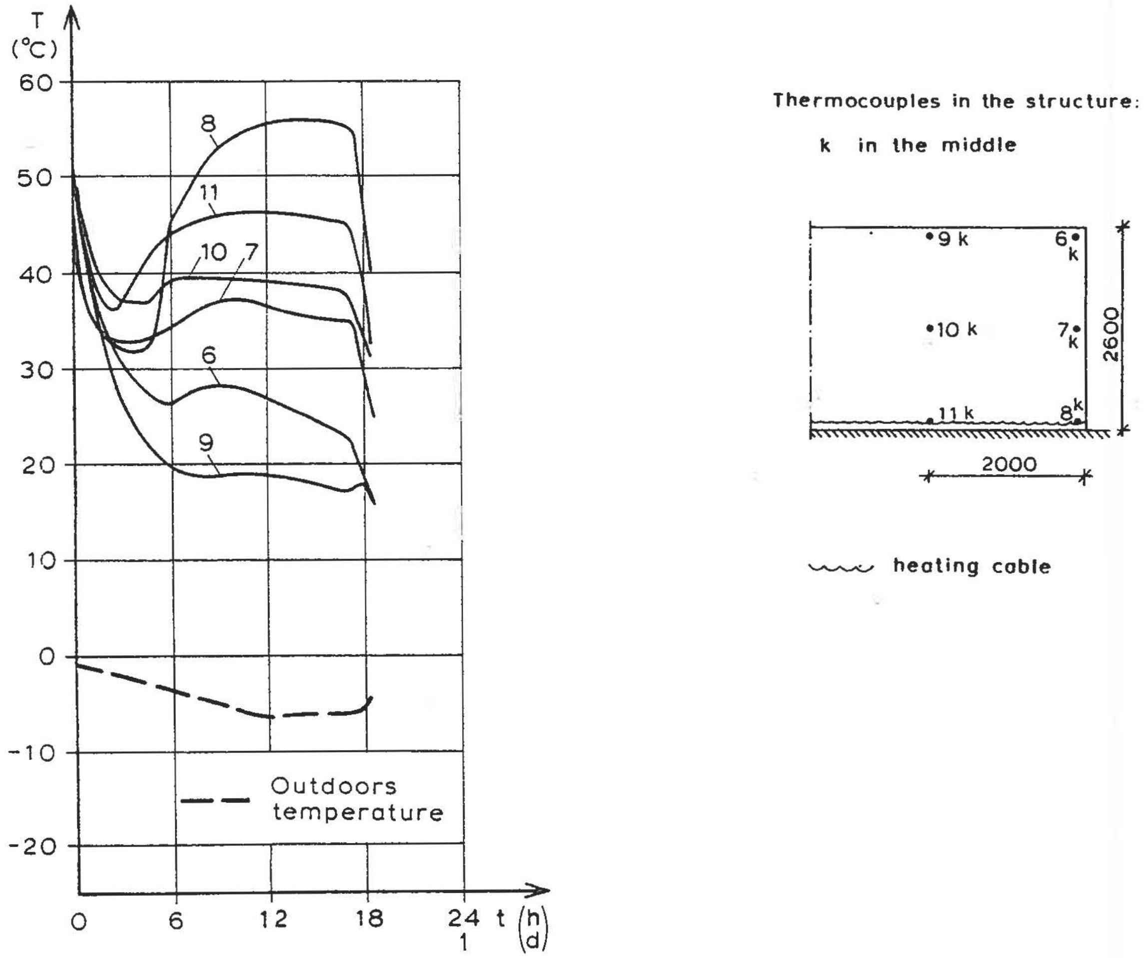

Fig. 3. Measurements of concrete temperature taken in the large mould, and placing of thermocouples.

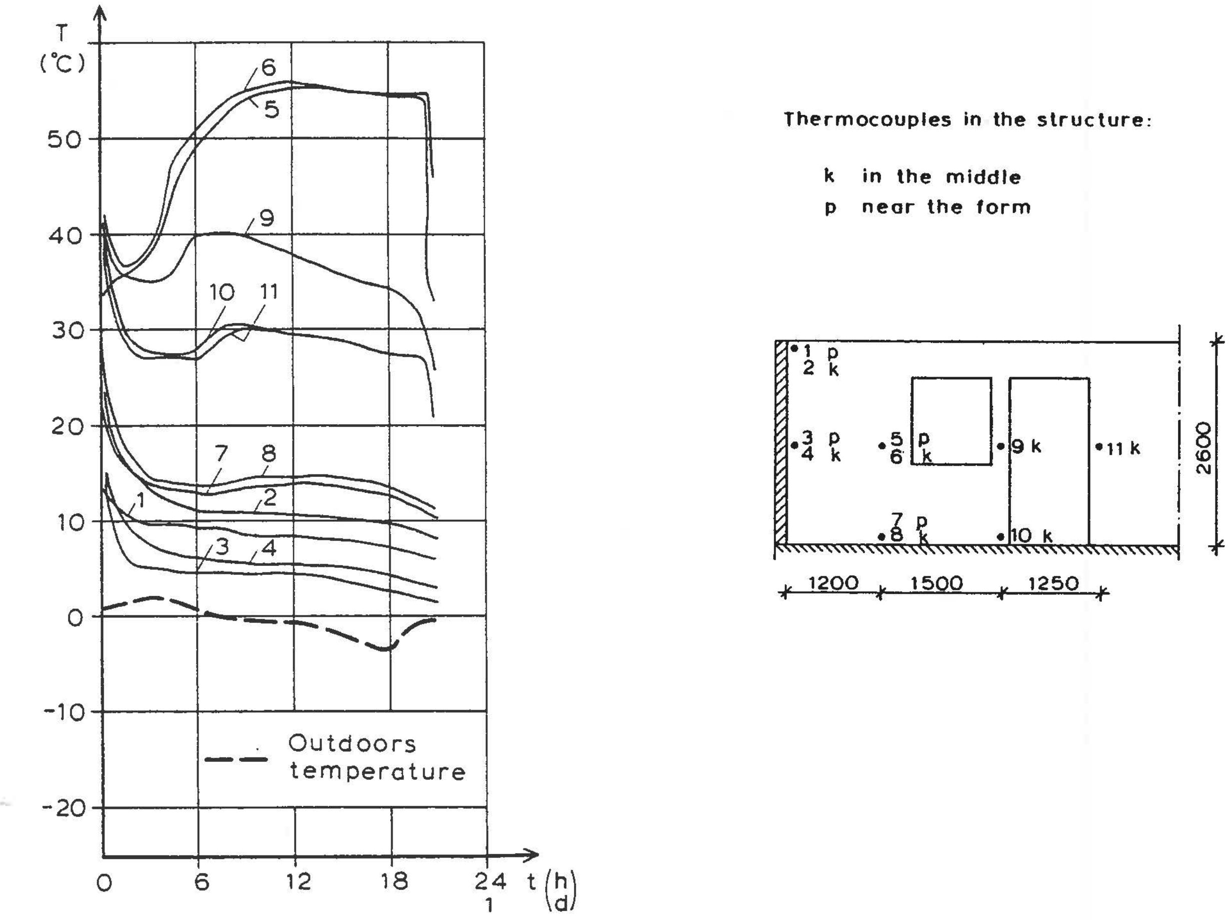

Fig. 4. Measurements of concrete temperature taken in the large mould, and placing of thermocouples.

In slab structures, chances for using hot concrete successfully are greatly improved if the cast concrete slab is provided with heat insulation as soon as concreting proceeds. Otherwise possible changes in the weather,e.g. its turning rapidly colder or rising of the wind, may result in strong cooling of cast concrete with the result that hardening of concrete retards. The edges of the slab and the cold upper parts of the walls forming the form face are heated additionally, for example using heating cables. In the space below the forms it is advisable to reduce also air circulation. Plywood is most practical of the form materials, because its thermal conductivity is quite low. It is difficult to carry out heat insulation of slab forms in practice. Fig. 5 shows temperatures measured in the slab structure. At the edges of the structure a cooling effect of the cold concrete surface can be clearly noticed. Due to additional heating the temperatures in these areas have been high enough. The slab was covered with 3 cm thick mineral wool insulation as soon as concreting proceeded. The sufficient stripping strength was achieved in one day.

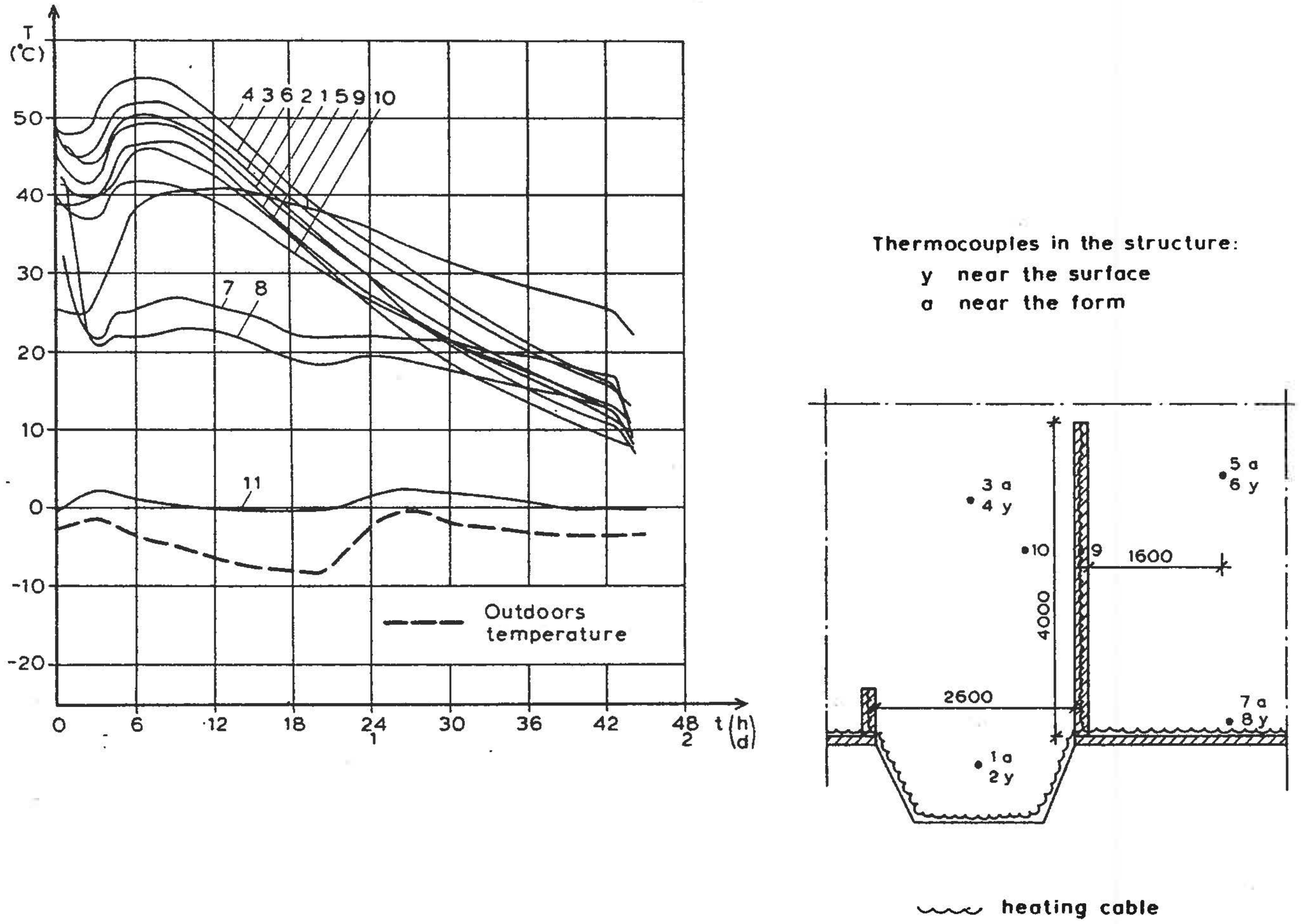

Fig. 5. Temperatures of concrete measured in the slab structure and placing of thermocouples. Thermocouple 11 was placed in the space below the forms.

3.3 Strength development in jobsite tests

The demoulding strengths achieved in the wall structures were determined from the samples drilled from the structure. They were on the average 40 to 50 % of the average 28-day standard strengths of the cubes manufactured on a mixing plant and 50 to 60 % of the 28-day strengths of the drilled samples. The variation of strength of the samples drilled from the structure was greater in slab structures than in the wall structures. This may result from changeable hardening conditions and possible differences in compaction. In favourable conditions, however, the strength level equal to that of the wall structures was achieved.

The variation of the strength of hot concrete is estimated on the basis of the standard cubes left freely to cool on the plant and of the test specimens drilled from the structure. In estimating variation of strength account must be taken of possible differences in compaction of the test specimens. On the basis of test results the loss of strength of hot concrete seems to be quite small generally when the above-mentioned factor is taken into account.

On the basis of the results from the strength development of hot concrete the following conclusions can be drawn:

- In slab structures, to ensure above all the development of early strength it is recommended to use the nominal strength of fresh concrete which is one strength class (5 MN/m^2) greater than required in plans.
- In wall structures the nominal strength of concrete required of the structure in plans may be used.

3.4 Temperature and workability of fresh concrete

The temperature of hot concrete after mixing was on an average 50°C. Temperature was monitored and it indicated that the cooling of concrete during transport was slight. True, the transport times within the city limits remained usually below 20 min. The cooling during transport was in the order of 1 to 4°C depending on the transport conditions. A noticeable cooling of fresh concrete before protection of compacted concrete is effected by cold concrete and form faces as well as by the wind and cold weather. The consistency of fresh concrete at the mixing plant is usually fluid (slump 10 to 15 cm). Observation of the consistency indicated that the concrete mix stiffened, measured as slump, about 2 cm in 15 min. The observations made on the jobsite supported the measurements made in the laboratory. The stiffer the initial consistency of the mix,the more rapidly the workability of the mix decreases. The required initial consistency for about 1 hour working time is fluid.

4. INSTRUCTIONS FOR USE OF HOT CONCRETE IN SLAB AND WALL STRUCTURES

The use of hot concrete should be planned carefully beforehand. In plans, the limited heat quantity of hot concrete and the cooling of hardening concrete shall be taken into account. The heat loss in concreting and during hardening can be replaced only by additional heating. In the temperature measurements made in slab structures the temperature of concrete at the age of 2 days was, on an average, only +10°C when the ambient temperature was between -5 and +5°C. As the strength at this temperature develops rather slowly the required stripping strength usually is to be achieved earlier. Thus a one- to two-day turn-over of forms is most profitable for hot concrete, in which case concreting is planned according to the rapid turn-over requirements of forms /1/.

To avoid heat losses in casting hot concrete it is advisable by means of preliminary preparations to secure a rapid concreting and heat insulation of cast concrete as early as possible. Before concreting the form faces and the previously cast concrete surfaces acting as a form face as well as the surfaces of rock and soil shall be preheated /2/.

To ensure the strength development of hot concrete and to balance the differences in temperature additional heating at the edges of the structure is used.

A sufficiently long maintenance of hardening temperature of hot concrete is based on heat insulation. Additionally, with good heat insulation the hardening temperature can be made even in the middle parts and higher at the edges of the structure.The recommended heat insulation for hot concrete when using wood forms is 3 to 5 cm thick mineral wool and in the case of steel forms 5 cm thick mineral wool or insulation material of corresponding kind.

Temperature measurements are made to monitor the hardening temperature of hot concrete. By means of these measurements the strength development of hot concrete is evaluated. For the reason that the evaluation of strength development would be reliable enough measuring points are fixed in the middle of the structure and at its edges.

Before form stripping, the temperature of the wall structure at least is recommended to let reach almost the same level as the surrounding temperature, so that too great temperature stresses could be avoided.

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