SOME INVESTIGATIONS CONCERNING WINTER CONCRETING:
REQUIRED INSULATION AND PRE-HARDENING TIME FOR CONCRETE WITH LOW-HEAT CEMENT
SOME INVESTIGATIONS CONCERNING WINTER CONCRETING: REQUIRED INSULATION AND PREHARDENING TIME FOR CONCRETE WITH LOW-HEAT CEMENT (*)

F. BUO
Lic. Eng. Cement and Concrete Institute

A. ELMROTH
Lic. Eng. Royal Institute of Technology

G. FRISTRÖM
M. Eng. Swedish Water Power Association

S. SÄLLSTRÖM
M. Eng. Swedish State Power Board

SWEDEN

1. — INTRODUCTION

In Sweden hydroelectric power plants to a considerable extent are built also during the wintertime. Normally, winter construction involves a certain increase in building costs, but this is offset by economical and technical advantages, such as:

- lower interest costs because of shorter building time,
- meeting more rapidly the increased power demand,
- uninterrupted employment for personnel and equipment,
- avoidance of seasons when high water levels occur in the rivers.

Note: This report has been drawn up on behalf of the Concrete Committee within the Swedish Committee for the International Dam Commission, and is based on investigations carried out in collaboration between the Swedish Water Power Association and the Swedish State Power Board.

(*) Quelques recherches sur le bétonnage d'hiver.

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Winter construction means that concreting must sometimes be carried out at very low temperatures, in extreme cases lower than — 25 °C. To protect the concrete from cooling and freezing too rapidly, extensive insulating and heating measures have been adopted. A normal practice has been the entire enclosing of the formwork in special heating sheds. These measures have been satisfactory from a concrete-technical point of view but cause a considerable increase — somewhere in the region of 20 % — in costs for winter concreting.

In recent years, investigations have been carried out in order to examine the possibilities of achieving adequate insulation by simpler and less costly means. The investigations have included tests concerning the required prehardening time for concrete with low-heat cement as well as the theoretical and practical study of required form insulation under different conditions when using ordinary wooden forms.

2. — TECHNICAL CONDITIONS

Usual concrete structures in Swedish hydroelectric power plants are buttress dams, retaining walls, intakes and spillways. Considerable parts of the structures consist of walls of more or less even thickness. The concrete generally used has a cement content of 250-300 kg/m³ and a water-cement ratio usually lower than 0.60. A low-heat portland cement is normally used as well as air entraining agents.

Usually wooden forms are used, consisting of 1" boards with 4-5 " struts. As insulation on the forms is used, when a complete heating shed has not been built, sometimes knot paper (a simple and cheap wall board quality, paper thickness about 2 mm) and sometimes mineral wool blankets.

When concrete is to be placed against rock surfaces or old concrete these surfaces are preheated before concreting. The concrete is continuously placed with a minimum of horizontal construction joints. Where structures are exposed to one-sided water pressure, the rate of placement is limited to 25-30 cm per hour. With regard to other structures, higher rates of placement can be used. After the casting has been completed, the fresh concrete surface is covered with a heating shed, when the entire structure has not been covered. The placing temperature of the concrete is kept low to avoid cracking. During the wintertime, the temperature of the concrete when placed in the forms should be +5 to +10 °C.
3. — REQUIRED PREHARDENING TIME

Concrete exposed to freezing at an early age can be permanently damaged. Therefore, an important question is how old the concrete must be to avoid permanent damage when subjected to freezing for the first time. In other words, which is the prehardening time required?

Previous practice in the construction of dams meant that a prehardening time of about one week was required for concrete with low-heat cement. In the Swedish Concrete Regulations of 1965, the required prehardening time for this concrete is 4 days at a temperature of not less than +5°C. For other curing temperatures, the requirement may be given by using the maturity factor according to Saul-Nurse (1951), which gives here 4 · (5 + 10) = 60 days · °C. According

![Diagram](image)

Fig. 1

Temperature development at centre of 15 cm test-cube subjected to freezing temperatures immediately after casting.

(A) Average of three tests.
(B) Air temperature in freezing chamber.

Variations de température au centre d'un cube échantillon de 15 cm de côté, soumis aussitôt après coulage à des températures inférieures à 0°C.

(A) Moyenne de trois essais.
(B) Température de l'air dans la chambre de congélation.
to the international RILEM-recommendations of 1963, a prehardening time of 5.5 days at $+5^\circ C$ is required when using Swedish low-heat cement (corresponding to RILEM-designation Q. 35) with water cement ratio 0.65.

As far as is known, these rules have not been based on direct investigations for the type of cement in question. Instead, they have been selected by using results of investigations made for standard portland cement, after a certain recalculation with regard to the slow rate of hydration of the low-heat cement.

To obtain a more reliable evaluation of the necessary prehardening time for low-heat cement, it was therefore, considered essential to make special tests in the laboratory. As test specimens, 15 cm cubes and $7.5 \times 7.5 \times 60$ cm beams were used. The specimens were cast at a temperature of about $+20^\circ C$ and were then placed in a freezing chamber with a temperature of $-10^\circ C$ or $-20^\circ C$ at periods of time varying between 0 and 96 hours after manufacture. The temperature development at the freezing of a test specimen (15 cm cube in steel form) is shown in Fig. 1. The specimens were kept in the chamber for 1-3 days and were then stored at $+20^\circ C$ in moist condition until testing which was normally carried out at 91 days. As a reference test, similar specimens were used which were not exposed to freezing but for the rest treated in the same way. The concrete had a cement content of 280 kg per m$^3$, a maximum aggregate size of

![Fig. 2](image)

Relative strength of frozen test specimens as a function of calculated prehardening time at $+20^\circ C$.

(A) 15 cm cubes.
(B) $7.5 \times 7.5 \times 60$ cm beams.

Résistance relative d'échantillons soumis à des températures inférieures à $0^\circ C$, en fonction d'un pré-durcissement à $+20^\circ C$ d'une durée déterminée.

(A) Cubes de 15 cm de côté.
(B) Barres de $7.5 \times 7.5 \times 60$ cm.
25-32 mm and a water-cement ratio of about 0.60. The water-cement ratio is somewhat higher than that normally used in power plant construction which means that the results obtained include a margin of safety, even if the statistical variations occurring in practice are taken into consideration. Air-entraining agents were used so that the air content was between 4-5% of the concrete volume.

Typical results of these tests are shown in Fig. 2. Really serious damage appears to occur only if the concrete is exposed to freezing within 4-6 hours after curing at +20°C, that is, mainly before it begins to set. If a reduction of 5% in strength is chosen as the criterion that damage has occurred, the results indicate that the required prehardening time at +20°C is about 12 hours. Even with the use of the most unfavourable time-temperature function as given in literature for converting the results from +20°C to +5°C a required prehardening time at +5°C of less than 2 days is obtained.

The results of these investigations, which were carried out in two different laboratories, thus indicate that the required duration of protection is essentially shorter than what was previously assumed. However, further investigations must be considered necessary before a complete answer can be given to the question. The freezing speed and the duration of the freezing time, for example, may be factors of essential importance with regard to the extent of damage when early freezing occurs. While results are awaited from investigations in progress, certain caution should be observed when interpreting test results obtained up to the present moment.

In the examination described below concerning the insulation requirements for forms during winter concreting the required prehardening time was assumed to be 3 1/3 days at +5°C, which implies a good safety margin according to the laboratory results. This corresponds to a requisite maturity factor according to Saul-Nurse of

\[3 \frac{1}{3} \times (5 + 10) = 50 \text{ days} \cdot ^\circ \text{C}.

4. — THEORETICAL DETERMINATION OF INSULATION REQUIREMENTS

The flow of heat from structures has been treated mathematically as diffusion from an internal, divided source. The heat developed as a consequence of the hydration of the cement in an arbitrary point in the was assumed to be a function or the maturity degree (according to Saul-Nurse) of the point in question. As the temperature varies at different places within the structures, this means the heat developed at a certain time is different, for example, in the centre as compared with the surface.

Heat development in and heat emission from the concrete were calculated for a concrete wall of even thickness and for a wall section
at such a large distance from the edges and the foundation that the heat flow is one-dimensional. Certain calculations were also made for edge areas where two-dimensional heat flows occur.

In the calculations, the heat capacity of the forms and of the insulation material were not considered. This simplification only allow for a minor error as far as thick structures are concerned, and the errors are counteracted by the fact that no consideration was given to the influence of the placement rate.

For a one-dimensional heat flow in the x-direction, the differential equation for the temperature, $\theta$, can be written:

$$\frac{\partial \theta}{\partial t} = a \cdot \frac{\partial^2 \theta}{\partial x^2} + \frac{\dot{q}}{c \cdot \gamma}$$

(1)

where $a$ = the temperature conduction ratio of the concrete,
$\gamma$ = the volume weight of the concrete,
$c$ = the specific heat of the concrete,
$\dot{q}$ = the heat development of the cement per unit of volume and time, function of $TT = \int_0^t (\theta + 10) \, dt$ for the point concerned,
$t$ = time.

At concrete surfaces, the following limit condition applies:

$$\theta_i - \theta_s = \lambda \cdot m \cdot \frac{\partial \theta}{\partial n}$$

(2)

where $\theta_i$ = the temperature of the concrete surface,
$\theta_s$ = the air temperature,
$\lambda$ = the heat conductivity of the concrete,
$m$ = the heat resistance of forms with any supplementary insulation including transition resistance,
$n$ = normal directed outwards from the surface.

With the guidance of the results of previous investigations, the following constant values were assumed to apply for the concrete:

$\lambda = 2.1 \text{ kcal/m h } ^\circ\text{C},$
$a = 3.7 \cdot 10^{-3} \text{ m}^2/\text{h},$
$\gamma = 2.250 \text{ kg/m}^3.$

Furthermore the cement content was assumed to be 250 kg/m$^3$ and the initial temperature of the fresh concrete to be 7 $^\circ$C.

The heat development of the cement was assumed to correspond to that of the RILEM designation Q. 35. As a basis for the calculations the following values of the heat development were assumed to apply, corresponding to average test results using the adiabatic method.

<table>
<thead>
<tr>
<th>Heat development</th>
<th>After 1 day</th>
<th>30 cal/g</th>
</tr>
</thead>
<tbody>
<tr>
<td>» 3 days</td>
<td>44</td>
<td></td>
</tr>
<tr>
<td>» 7 days</td>
<td>53</td>
<td></td>
</tr>
</tbody>
</table>
The differential equations [1] and [2] were solved step by step after conversion to difference equations in time and space. The differential equations valid for two-dimensional heat flow were solved by use of Fourier-series development in space and stepwise solution only in time. The air temperature was assumed to be constant in each calculated case.

Temperature calculations were carried out for different wall thickness and air temperatures, and with several different values for the heat resistance at the surfaces. As an example of a calculated temperature field, Fig. 3 shows the temperature in a 3 metre thick wall at an outside air temperature of \(-1.5\,^\circ\text{C}\) and a heat resistance of the form including insulation of 0.25 \(\text{m}^2\,\text{h}^\circ\text{C}/\text{ kcal}^\circ\text{C}\). The curves concern sections at a good distance from corners and edges. As can be seen in Fig. 3 the concrete temperature in the surface has started to drop soon after placing the concrete. After a certain time, the heat development of the cement has increased which has led to the formation of a minimum temperature point M. Thereafter the temperature has begun to rise. Somewhat later the temperature has started once more to drop and in point N the temperature of the concrete surface has dropped to \(\pm 0\,^\circ\text{C}\).

With the assumed required maturity degree (50 days \(^\circ\text{C}\)), damage from early freezing may occur if either or both of the following conditions are fulfilled concerning the surface temperature of the
concrete:
   a) the temperature is equal to or lower than \( \pm 0 \, ^\circ\text{C} \) in the minimum point M,
   b) the temperature zero point N corresponds to a maturity degree lower than 50 days \( ^\circ\text{C} \).

For thick walls the condition according to a) is determinative, which means that the first 24 hours are critical (point M in Fig. 3). The calculations also show that the form insulation requirement is independent of the wall thickness if this is greater than 1.5 metres.

With regard to thinner walls, the condition according to b) is determinative. With the assumed requisite maturity degree prior to freezing this means that the temperature of the concrete surfaces may drop to \( \pm 0 \, ^\circ\text{C} \) after about 4 days.

By using the temperature curves, the relationship between wall thickness, heat resistance and outside air temperature can be determined so that the prehardening requirement of the concrete prior to freezing is barely met. This means that for a given structure and a certain outside air temperature, the requisite heat resistance of the concrete form including insulation can be determined.

The calculations show that the heat resistance of form and insulation at edges and corners should be about twice as great as that at the side surfaces if the same safety against damage by frost is to be obtained.

As mentioned before, the calculations were carried out assuming a cement content of 250 \( \text{kg/m}^3 \). A 10% increase or decrease in the cement content will roughly have the same effect upon the protection required as that of a 10% increase or decrease in the wall thickness. The effect is thus rather insignificant.

The calculations were carried out assuming a required prehardening time of 3 1/3 days at \( +5 \, ^\circ\text{C} \), which is considerably longer than what was indicated by the laboratory test results (about 2 days at \( +5 \, ^\circ\text{C} \)). If the required prehardening time is assumed to be 2 days at \( +5 \, ^\circ\text{C} \) this would approximately have the same effect upon the calculated insulation requirement as that of a 20% increase in the wall thickness. Thus, the requirement in the previously established criterion b) would be considerably reduced. However, for thick walls the criterion a) would still be determinative and the calculated insulation requirement thus relatively unaffected.

It is obvious that the heat resistance of the form including any supplementary insulation is one of the most important factors, which influence the surface temperature of the concrete. In order to determine the heat resistance of a number of wooden forms with different types of insulation some laboratory investigations were carried out as described below.
5. — LABORATORY DETERMINATION OF THE HEAT RESISTANCE OF WOODEN FORMS WITH DIFFERENT SUPPLEMENTARY INSULATION

The heat resistance, \( m \), of a structure can be calculated according to

\[
m = \frac{A \cdot (\theta_1 - \theta_2) \cdot t}{Q}
\]

where
- \( A \) = surface area, \( \text{m}^2 \),
- \( \theta \) = temperature, °C,
- \( t \) = time, h,
- \( Q \) = heat quantity, kcal.

If \( \theta_1 \) denotes the temperature of the surface on the warmer side, in this case the concrete surface, that is, the inside of the form surface, and \( \theta_2 \) outside air temperature, \( m \) includes the total heat resistance from the inside surface of the form to the outside air.

The investigations were carried out principally in accordance with "The Guarded Hot Box Method", ASTM Standards (1962). This method is based on the equation [3] by measuring at a stationary, one-dimensional heat flow, the heat quantity \( Q \) which passes through an element with surface area \( A \) and determining at the same time the temperature, \( \theta \), on both sides of the element, after which the heat resistance, \( m \), can be calculated.

The size of the form elements was \( 120 \times 150 \text{ cm} \) with \( 2'' \times 4'' \) struts at a spacing of \( 50 \text{ cm} \). The actual measuring area was \( 80 \times 100 \text{ cm} \) and was so positioned on the form element that it included a strut surface corresponding to the strut spacing of \( 50 \text{ cm} \). The form consisted of 22 mm rough boards. The measuring area contained no tie bolts. To prevent air leakage through the form, the fissures between the boards were sealed with tape.

The investigations included determining the heat resistance of uninsulated form as well as form with supplementary insulation. As insulation, knot paper or 3 cm mineral wool blanket was used. The insulation material was carefully applied with good contact against the form to avoid leakages and ventilated air spaces. Dry as well as wet wooden forms were tested separately. The moisture content of the dry form amounted to 15-18 weight-% and for the wet form to 55-60 weight %. The tests were carried out partly in calm air and partly with a strong air stream flowing parallel to the surface.

The heat resistances determined in this way are compiled in Table 1. These heat resistances include only the outside transition resistance as temperature was determined for the inside of the form.
Table 1

Determined heat resistances, m² h °C/kcal, for a 22 mm wooden form under different conditions and with different supplementary insulation. The heat resistance includes the outside heat transition resistance.

<table>
<thead>
<tr>
<th>22 mm wooden form moisture content weight-%</th>
<th>supplementary insulation</th>
<th>HEAT RESISTANCE IN CALM OUTSIDE AIR</th>
<th>HEAT RESISTANCE IN POWERFUL AIR STREAM PARALLEL TO SURFACE</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 - 18</td>
<td>—</td>
<td>0.38</td>
<td>0.24</td>
</tr>
<tr>
<td>55 - 60</td>
<td>—</td>
<td>0.32</td>
<td>0.21</td>
</tr>
<tr>
<td>15 - 18</td>
<td>knot paper</td>
<td>0.50</td>
<td>0.36</td>
</tr>
<tr>
<td>55 - 60</td>
<td>3 cm mineral wool blanket</td>
<td>0.98</td>
<td>0.82</td>
</tr>
<tr>
<td>55 - 60</td>
<td>9</td>
<td>0.92 (1)</td>
<td>0.76 (10)</td>
</tr>
</tbody>
</table>

(1) Heat resistance calculated with the use of test results for dry form.

surface and in the outside air. Maximum errors in the determinated heat resistances can be estimated to approximately 5%.

Fig. 4

Winter concreting of intake structure at the Moforsen power plant.
Coulage, en hiver, d'un ouvrage d'aménée en béton, à la centrale hydroélectrique de Moforsen.
The results show that the wooden form in itself has a heat resistance which is not negligible, even in wet condition. The heat resistance was improved when the form was insulated with knot-paper. This improvement should principally depend on the fact that between the paper and the form there is an air space the heat resistance of which is considerable. The great improvement, however, was obtained when the form was insulated with a 3 cm thick mineral wool blanket carefully applied against the form.

6. — FIELD TESTS ON WOODEN FORMS WITH SUPPLEMENTARY INSULATION

In order to verify the laboratory test results and the theoretical calculations, concrete temperatures were measured during the erection of a dam pillar at the Moforsens hydroelectric power plant, Fig. 4. In this case the wooden forms were entirely insulated with 3 cm mineral wool.

![Diagram of dam pillar](image)

**Fig. 5**
Horizontal section through end of dam pillar showing insulated form and positions of thermistors used for temperature measurements.
(A) 22 mm wooden form.
(B) 30 mm mineral wool blanket.

*Coupe horizontale à l'extrémité d'une pile de barrage, montrant l'isolation thermique du coffrage et la position des thermistors utilisés pour mesurer la température.*
(A) Coffrage en bois de 22 mm.
(B) Tapie de laine minérale de 30 mm.
wool blanket with impregnated kraft paper or plastic folio on both sides. The temperatures were registered with thermistors in sections situated at different distance from edges according to Fig. 5. In each section the temperature was registered at four points: at 10 cm depth in the concrete, in the concrete surface, between the wooden form and insulation and on the outside surface of the insulation. The temperatures were recorded during a period of about 10 days. Reading were made every 30 minutes at the beginning of the period. The time between reading was then gradually increased. The concrete in the dam pillar contained approx. 270 kg low-heat cement per m³. The water-cement ratio was between 0.50 and 0.55.

The outside air temperature, which was registered with a thermo-hydrograph at the testing site was between −10 °C and −15 °C for the greater part of the 10-day period. During the 2nd night of the period, however, the temperature dropped to −22 °C.

Figure 6 shows an example of the temperature development in the surface of the concrete at different distances from an edge. With the exception of the edge itself, the temperature at the various measuring points reached a maximum value of approx. 20° to 30 °C. A lower temperature was registered near to the edge, but even here the temper-
ature was always well above 0 °C. It is obvious that a 3 cm mineral wool blanket would have provided fully satisfactory insulation also at considerably lower air temperatures than those occurring during the test. For comparison, the temperature development was also calculated assuming actual conditions. The calculated temperatures showed very good agreement with the measured temperatures except at the beginning which was probably owing to the fact that the heat capacity of the forms was overlooked in the calculations.

![Graph](image-url)

**Fig. 7**

Temperature in concrete surface at different periods of time after casting as a function of distance to edge.

Temperatur de la couche superficielle du béton plus ou moins longtemps après le coulage, en fonction de la distance à laquelle on se trouve d'un bord.

As can be seen in Fig. 7, the temperature development in the concrete surface is influenced by the distance to the edge. For those periods of time which are of interest here, i.e. less than 100 hours, this influence seems, however, to be relatively local. Already at a distance of 15 cm from the edge, the temperature was considerably higher than at the edge itself. At a distance of 50 cm, the temperature was almost the same as that at a large distance from the edge.
7. — PRACTICAL RECOMMENDATIONS

In order to make possible an easy and practical application of the calculations and test results obtained, simple charts for required insulation have been drawn up in Figs. 8 and 9. Consideration has then been given to the fact that the wooden form, through wetting prior to concreting, can acquire a relatively high moisture content. Furthermore the long-wavy net radiation from a vertical surface, especially during clear nights, may result in the lowering of the outer transition resistance almost to zero. Strong winds may have a similar effect on the transition resistance. (Brown, 1956).

Therefore, to obtain a sufficient margin of safety, the recommendations given in Figures 8 and 9 are based upon the assumption that the heat resistance corresponds to that of wet forms exposed to strong

![Diagram](image)

**Fig. 8**

Recommended insulation of wooden forms for side surfaces of concrete walls at different air temperatures.

(A) No extra insulation.  
(B) One layer of knotted paper.  
(C) 30 mm mineral wool blanket.  
(D) 2 × 30 mm mineral wool blanket.

Recommandations en matière d'isolation des coffrages en bois utilisés pour les surfaces latérales de murs en béton, selon la température ambiante.

(A) Aucune isolation supplémentaire.  
(B) Une couche de carton.  
(C) Tapis de laine minérale de 30 mm.  
(D) 2 tapis de laine minérale de 30 mm.
winds. Furthermore, the recommendations presuppose a cement content and initial concrete temperature which are not considerably lower than 250 kg/m³ or +7 °C respectively.

The diagrams show that the outside air temperature and the thickness of the structure are the only factors which determine the insulation required, providing the cement content and the initial concrete temperature are given. Insulation requirements are inconsiderable at thicknesses exceeding 1.5 metres which, according to the diagram, can be cast at temperatures as low as —23 °C without the need of supplementary insulation except at corners, edges and foundations. The diagrams also show that if the wooden form is insulated with a 3 cm mineral wool blanket, thin concrete structures may also be cast at low temperatures without risk of frost damage to the green concrete.

Fig. 9
Recommended insulation of wooden forms for corners and edges of concrete walls at different air temperatures.

(A) No extra insulation.  (D) 2 × 30 mm mineral wool blanket.
(B) One layer of knot paper.  (T) Wall thickness.
(C) 30 mm mineral wool blanket.

Recommandations en matière d'isolation des coffrages en bois utilisés pour les angles et les bords de murs en béton, selon la température ambiante.

(A) Aucune isolation supplémentaire.  (D) 2 tapis de laine minérale de
(B) Une couche de carton.  (T) Épaisseur du mur
(C) Tapis de laine minérale de 30 mm.
SUMMARY

Economical and technical reasons normally motivate winter concreting in the construction of hydroelectric power plants in Sweden. The temperatures may then be as low as — 25 °C or in extreme cases even lower. To protect the concrete from damage caused by early freezing, comprehensive and costly protective measures have normally been employed such as, for example, the complete housing of the form in a heating shed.

In recent years, investigations have been carried out with a view to establishing the possibilities of achieving adequate insulation by simpler and less costly means. The investigations have included tests concerning the required prehardening time for concrete with low-heat-cement as well as the theoretical and practical study of the requisite insulation of wooden forms under different conditions.

The results of the investigations have led to the conclusion that the required prehardening time for the concrete is essentially shorter than what previously assumed. Moreover, a simplified type of form insulation consisting of an insulation blanket directly applied to the wooden form seems to be sufficient, even at very low temperatures and for relatively thin structures. Where massive structures are concerned, supplementary insulation above that provided by the wooden form itself is often not required. On the basis of the results obtained, practical recommendations are given in simple diagrams.

RÉSUMÉ

Des raisons économiques et techniques motivent le coulage du béton pendant l’hiver et la saison froide pour la construction des centrales électriques. Les températures peuvent donc tomber jusqu’à 25 °C au-dessous de zéro et dans des cas extrêmes encore plus bas. Pour protéger le béton contre les détériorations causées par un refroidissement trop rapide on prend habituellement des mesures de protection très rigoureuses et très couteuses, comme par exemple un enveloppement complet des parties coulées dans une barraque pour éviter les pertes de chaleur.

Des recherches ont été faites ces dernières années pour trouver des mesures de protection satisfaisantes, plus simples et moins coûteuses. Ces recherches ont inclu des essais sur le temps nécessaire à la solidification de béton comprenant du ciment LH, ainsi que des études théoriques et pratiques sur l’isolation nécessaire des moules sous différentes conditions.
Les résultats des recherches indiquent, entre autre, que le temps nécessaire au durcissement du béton est beaucoup plus court que ce que l'on a cru auparavant. Il semble ensuite qu'une isolation simplifiée, se composant d'un revêtement isolant autour du moule en bois, est suffisante, même en cas de températures très basses et de constructions relativement minces. Lors de constructions plus robustes une isolation supplémentaire en plus de celle qui est donnée par le moule de bois lui-même, n'est pas du tout nécessaire dans la plupart des cas. — On a dressé des recommandations pratiques sous forme de simple diagrammes dimensionnels, basés, sur les résultats obtenus.

LITERATURE


