Low Temperature Curing of Precast Prestressed Concrete Products

Traditionally, low pressure steam has been used to cure plant produced precast prestressed concrete products. Nevertheless, there are some inherent disadvantages associated with this curing method. In this article the author proposes a new curing method for precast products using a low temperature. The method has been applied in New Zealand and preliminary results show that substantial savings in plant operations can be attained without any appreciable loss in concrete strength.

Factory produced precast prestressed concrete depends for its economy on a daily turn-around of molds. This can only be done if a relatively high compressive strength of perhaps 30 MPa (approx. 4300 psi) is achieved not more than 16 hrs after mixing the last concrete of the day. Note that all compressive strengths mentioned in this paper are measured.
on 200 x 100 mm (8 x 4 in.) test cylinders.

There are thus two prerequisites for a successful factory operation. First, concrete made from high quality cement and aggregates with good quality control to insure uniformity and, secondly, a curing procedure which will give a high probability that the required release strength is achieved.

This paper will first review the traditional methods of curing factory produced precast concrete and outline their disadvantages. Then a new method of curing precast products, namely, using low temperature curing, will be described. The experimental program will be discussed together with a comparison of the advantages and economics of the new curing method in relation to the more standard curing methods.

Curing Methods

In the precast industry low pressure steam curing has been the predominant method for curing plant produced concrete products. A variation of this method is known as “closed circuit steam curing.” In the last few years another curing method called “hot concrete” has been used.

The procedures and disadvantages of the above curing methods will now be discussed.*

Low pressure steam curing

Traditionally, this type of curing has been achieved with the aid of low pressure steam injected under covers which contain the products to be cured and test cylinders or cubes which will be used to assess the strength of the unit prior to release of the prestressing force.

It is the pious hope that the concrete in these test specimens will follow the same time-temperature history as the concrete in the product and thus give a reliable indication of the strength of this concrete prior to release.

Unfortunately, this method of curing has some very severe drawbacks:

1. It uses heat very inefficiently due to the large heat losses from the covers and is thus very expensive. This has been made more important by sharp rises in the cost of fuel oil over the last few years.

2. The distribution of the steam is uncertain and curing may not be uniform throughout the product.

3. The strength of the concrete in the test specimen may bear little relation to the strength of the concrete in the product. This, in fact, will usually be the case, as the product is much bulkier than the test specimen and therefore heats up and cools down more slowly and is more affected by the effects of the heat of hydration of the cement.

4. Escaping steam condensing to water poses problems of corrosion of the building structure and, particularly, affects electric equipment in the factory and increases maintenance costs on items such as overhead cranes. It also makes working conditions very unpleasant.

5. Boilers which are to operate overnight unattended are usually equipped with safety devices which lead to occasional cutting off of the steam supply before the curing cycle is completed due to some malfunction. Such occurrences lead to the loss of a day’s production and can be very costly. These occurrences can only be overcome by having an attendant or carrying out a very high standard of

*For more complete details on steam curing methods see MNL-116-77, Manual for Quality Control of Precast Prestressed Concrete Products, published by the Prestressed Concrete Institute.
maintenance, both of which are expensive.

6. The system is usually inflexible as most boilers cannot run efficiently over a wide range of output and thus when only a partial casting is to be made, the heat use becomes even more inefficient.

7. Because the heat is applied about 4 hrs after casting the concrete, the mold tends to heat up ahead of the concrete and its expansion relative to the concrete causes cracking at the ends of the units.

8. It is difficult to control the temperature reached and the rate of increase of temperature. These problems can have a significant effect on the final strength of the concrete.

**Closed circuit steam curing**

The most widely used alternative to steam curing appears to be a system in which steam or oil is recirculated in finned pipes placed under or alongside the molds. The radiant heat from these pipes is used to heat the mold either with or without the use of an insulated enclosure.

This system certainly reduces the heat wasted, but the transfer of heat by radiation with only a relatively small temperature difference does not seem to be very efficient. The system also suffers from four apparent disadvantages:

1. It does not appear to be easy to control the rate of increase of the temperature of the concrete nor the final temperature achieved.

2. It is difficult to make test cylinders representative of the strength of the concrete in the product.

3. The problem of mold expansion relative to the unit on initially turning on the heat is even worse than with free steam as all the heat is transferred through the mold.

4. The system only lends itself to boilers with their attendant problems, and the simplicity of control offered by warm water electrically heated is not possible.

**Hot concrete**

Because of all these disadvantages, other methods of curing have been sought over the last few years and one apparently successful method has been the use of hot concrete. Here, steam is injected into the mixer to supply part of the mixing water and the resultant concrete at a temperature of perhaps 50-60 C (122-140 F) is placed in molds which are usually insulated.

The disadvantage of this method is that only a very limited time is available to handle the concrete, whose initial set may take place within 15 minutes of mixing. For this reason, a sophisticated method of distributing concrete is essential and hot concrete is really only possible in a new factory set-up, specially designed to deal with this problem.

**Research Program**

In New Zealand we operate 18 existing precasting factories, all using steam curing. About 3 years ago we began development work to look into other possible curing methods. We wanted a method which could be introduced into existing factories without substantially altering the factory layout or the concrete distribution methods.

**Use of accelerators**

At first the work was aimed at assessing the use of accelerators in the concrete. With calcium chloride not being acceptable for prestressed concrete and most other forms of accelerators being relatively expensive,
the work was concentrated on accelerators based on calcium formate.

It soon became clear that, under New Zealand conditions, an accelerator alone would be insufficient, but we found that the application of quite modest amounts of heat when combined with accelerators gave spectacular results.

**Insulated molds**

We investigated the use of insulated molds together with an accelerator and obtained very promising results except when the freshly mixed concrete was particularly cold. However, the warming of the mold gave such large increases in strength that in most cases, we have been able to eliminate the accelerator completely.

Instead, we rely on a system which consists of placing concrete mixed at normal temperature in a mold which has been previously warmed to a predetermined temperature and which is insulated so that modest inputs of heat will maintain this temperature overnight. The concrete generally takes about 4 hrs to achieve the mold temperature and is then held at this temperature for a further 12 hrs.

In larger products, the heat of hydration of the cement is often sufficient to maintain the required temperature without the addition of further heat. The molds are insulated by spraying on polyurethane foam of a relatively high density which produces a surface that is not damaged by normal factory handling.

This foam layer is usually about 30 mm (a little over an inch) thick and can be applied to most types of mold. In some cases, it is only necessary to insulate the part of the mold containing the prestressing strands, but, in most cases, the whole mold is insulated.

Before this sprayed-on insulation is applied, the mold is provided with facilities for heating the skin plate. This can be in the form of steel pipes through which hot water or hot oil can be passed or can be provided by electrical resistance elements or heating tape. Our research program has established the amount of heat necessary for various types of units and this turns out to be relatively modest.

**NZCRA research program**

A parallel research program has been carried out by the New Zealand Concrete Research Association to determine the effects of different brands of cement, different aggregates, and day-to-day variations in the composition of each cement.

In each case, it has been possible to determine the temperature necessary for obtaining suitable release strengths with a concrete of given workability, containing a fixed proportion of a particular cement, allowing for the likely variation of the cement from batch to batch. In the case of some ordinary grade cements, it has been necessary to incorporate a small percentage of accelerator to keep this temperature to a reasonable value—usually around 50 C (122 F).

This program has also related release strengths to 28-day strengths for concrete cured as described and both these strengths to the strength of standard cured cylinders. Tests are continuing to see if the method has any effect on the long-term concrete strength, although this appears to be unlikely.

**Test results**

Some test results obtained during the New Zealand Concrete Research Association study are summarized in Figs. 1 and 2 and Table 1.

Fig. 1 shows the strengths obtained in one series of tests with a particular rapid hardening cement using cement samples obtained over a 6-month period. It will be seen that low temperature curing [in this case at 50 C
Fig. 1. Compressive strength of 20 samples of concrete subject to three different types of curing conditions.

Table 1. Effects of curing temperature on compressive strength of two types of concrete (ordinary and rapid hardening cement).

<table>
<thead>
<tr>
<th>Brand of cement</th>
<th>Temperature, deg C (deg F)</th>
<th>28-day standard cured</th>
<th>28-day low temperature cured and standard cured</th>
<th>5-month standard cured</th>
<th>5-month low temperature cured and standard cured</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golden Bay cement (ordinary)</td>
<td>55 (131)</td>
<td>62.4 (8920)</td>
<td>57.3 (8200)</td>
<td>73.1 (10470)</td>
<td>69.0 (9860)</td>
</tr>
<tr>
<td></td>
<td>60 (140)</td>
<td>63.9 (9120)</td>
<td>59.4 (8600)</td>
<td>75.2 (10740)</td>
<td>72.2 (10300)</td>
</tr>
<tr>
<td></td>
<td>65 (149)</td>
<td>62.6 (8930)</td>
<td>59.9 (8570)</td>
<td>75.0 (10700)</td>
<td>70.8 (10100)</td>
</tr>
<tr>
<td>Wilsonite cement (rapid hardening)</td>
<td>50 (122)</td>
<td>64.4 (9210)</td>
<td>56.4 (8080)</td>
<td>73.1 (10470)</td>
<td>65.9 (9410)</td>
</tr>
<tr>
<td></td>
<td>55 (131)</td>
<td>63.2 (9030)</td>
<td>57.1 (8170)</td>
<td>71.3 (10200)</td>
<td>66.5 (9500)</td>
</tr>
<tr>
<td></td>
<td>60 (140)</td>
<td>67.7 (9670)</td>
<td>56.1 (8300)</td>
<td>73.6 (10520)</td>
<td>66.9 (9560)</td>
</tr>
<tr>
<td></td>
<td>65 (149)</td>
<td>63.3 (9070)</td>
<td>56.5 (8090)</td>
<td>73.8 (10570)</td>
<td>66.7 (9530)</td>
</tr>
</tbody>
</table>
Fig. 2. Compressive strength of two types of concrete subject to three different types of curing conditions.

NOTE: CURING PERIOD MEASURED FROM END OF DELAY PERIOD
LOW-TEMPERATURE CURING AT 55°C (131°F)

- 16-HOUR LOW-TEMPERATURE CURED
- 28-DAY STANDARD CURED
- 28-DAY LOW-TEMPERATURE CURED AND FOG (ORDINARY)

- 16-HOUR LOW-TEMPERATURE CURED
- 28-DAY STANDARD CURED
- 28-DAY LOW-TEMPERATURE CURED AND FOG (RAPID HARDENING)
(122 F) depresses the 28-day strength relative to standard curing by about 10 percent. This is not usually significant as the specified 28-day strength is normally considerably less than that achieved by concrete designed to reach the required release strength.

Fig. 2 shows that delay time is not necessary, as it is with steam curing, since delays up to 5 hrs have no significant effect on either the 28-day strengths or the strength after 16 hrs curing at 55 C (131 F).

Table 1 shows that the actual curing temperature used over a fairly wide range has little effect on the 28-day or 5-month strengths, although it will, of course, have a significant effect on the 16-hr strength.

**Low temperature curing**

The heat source is turned on about an hour before concreting so that the mold is warm when the concrete is placed and is left on until the desired curing temperature is achieved. From then on, it is thermostatically controlled so that this temperature is maintained and whether this requires additional heat input depends on the size of the unit.

With steam curing, it is necessary to observe a delay period before applying the steam so that the initial set has taken place. If this is not done, a decrease in concrete strength results, probably through micro-cracking of the concrete caused by its expansion during the setting process.

With the alternative system, which we might call “low temperature curing,” this does not appear to be necessary and the fact that heat is applied from the moment the concrete is placed does not appear to depress the 28-day concrete strength significantly.

This has two beneficial effects: it greatly extends the curing time at elevated temperature and hence reduces the temperature required to produce a given maturity, and it eliminates one of the problems of steam curing, namely, the relative expansion of mold and unit which often causes cracking at the ends of units.

We now use low temperature curing in some of our factories while most others are changing to it.

**Test cylinders**

The major problem that became apparent very early in the research program was that of obtaining a concrete test cylinder that has undergone a time-temperature history similar to the concrete in the product and hence representing the strength of this concrete.

The early research into the method was, of course, carried out purely on test cylinders. We soon found that with concrete of a particular water-cement ratio using a particular rapid hardening cement and aggregates, a temperature of 50 C (122 F) reached about 4 hrs after casting and maintained for a further 12 hrs, gives a reliable release strength of more than 30 MPa (approx. 4300 psi). However, before the method can be applied to actual products, some method must be found of forcing test cylinders to follow the same time-temperature history as the product so that the release strength can be obtained.

This problem has been overcome by constructing curing enclosures in which test cylinders are placed and forced by a heater to follow the temperature in the product. The heater is controlled by an electronic controller, using two thermocouples—one in one of the test cylinders, and the other in the product. The controller senses when the temperature in the test cylinder drops below the temperature in the product and turns on the heater, turning if off as soon as the temperatures are equal.

We have found that, with suitable
positioning of the thermocouple in the test cylinder and with a suitable design of curing enclosure, we are able to produce traces on a recording thermometer whose probes have been placed close to the thermocouples which do not differ by more than about 1 deg C (about 2 deg F).

**Advantages of using low temperature curing**

One major advantage of low temperature curing is that the thermocouple in the unit can be placed where the concrete strength at release is really of interest, i.e., in the most critically stressed area in the concrete—and, for the first time, we can be confident that the concrete in the test cylinder is of similar strength to concrete in the selected part of the product.

Perhaps, we could summarize the advantages of low-temperature curing by looking again at the eight disadvantages that were listed for steam curing:

1. The heat input required is quite small and is nearly all used to heat the concrete.
2. Curing can be as uniform as the design of the heating arrangements on the mold cause it to be.
3. The test cylinders exactly represent concrete in any desired position in the unit.
4. The factory is dry and so no special maintenance problems arise.
5. The equipment is simple and trouble-free and no failures have been experienced to date.
6. With thermostatic control of the heating medium, only as much fuel or power is used as is needed for the particular situation.
7. Cracking at the ends of units is eliminated.
8. The temperature and rate of temperature rise are easily controlled.

**Disadvantages and solutions**

It is thus clear that low temperature curing eliminates most of the disadvantages listed for steam curing. One drawback is, however, obvious. Wet steam provides free water to insure adequate hydration of the cement, both in the product and in the test blocks.

The dry heat of low temperature curing means that a waterproof cover must be provided to prevent evaporation of water from the product and that the test cylinders must be made in test molds with end caps or placed in plastic bags during curing.

We are now using horizontally cured test cylinders which do not require capping before testing and which are made in molds with end caps which largely prevent evaporation of water.

In certain cases, where highly stressed regions of concrete occur near the top of a product, it is desirable to provide an insulated cover and this can also act as the vapor seal.

The system outlined is satisfactory for cases where aggregates are of high quality, a good quality rapid hardening cement is available and concrete can be placed with fairly low water-cement ratio. In other cases, two further possibilities exist for increasing the release strength in conjunction with low temperature curing, although both add significantly to the cost of the concrete.

First, an accelerating admixture based on calcium formate can be added to the concrete. This will give a substantial increase in strength or a reduction in the required curing temperature and, in the example mentioned above, it was possible to reduce the curing temperature to 35 C (95 F) by the addition of 2 percent of the weight of cement of accelerator.

Secondly, one of the recently introduced super-plasticizers based on melamine formaldehyde resin or a
similar long-chain polymer can be used to reduce the water-cement ratio while maintaining workability. While early strength gains with these materials do not appear to be as spectacular as the reduction in the water-cement ratio would suggest, they nevertheless give an appreciable increase in strength for a given workability and maturity.

Either of these materials, together with low temperature curing, will still provide a curing method appreciably cheaper in operating costs than steam curing and more certain and uniform in its action.

Economics of system

The economics of the system can now be summarized, but it must be borne in mind that, even if no substantial direct economy can be shown, there are indirect savings in the elimination of the effects of condensed steam on the factory structure and electrical equipment and in the elimination of loss of production due to failure of the steam curing cycle to give acceptable release strengths.

Further, the proposed system is technically superior in that test cylinders give a much more reliable indication of the strength of the product and that curing of the product is much more uniform and hence better control of characteristics such as camber can be achieved. In most cases, a direct cost saving is apparent as well.

The capital cost of setting up equipment to heat water and to circulate it, together with the control system for low temperature curing, is rather less than a steam curing boiler and controls for the same curing capacity. Experience so far suggests that repairs and maintenance will be considerably less.

However, the cost of molds for use with low temperature curing is appreciably more than those for steam curing as they must incorporate heating pipes and must be insulated. The running costs of low temperature curing are very much less than steam curing, typically being of the order of one-fifth.

Cost analysis in actual case

An example of an actual case might be of interest. A particular factory producing about 4000 cu. metres (5200 cu yds) of precast concrete a year when changed from steam curing to low temperature curing gave the following results:

Costs have been updated to 1976 New Zealand costs and the figures given are for one year's operation. It has been assumed that depreciation of the capital cost of the two systems is similar.

1. Steam curing
Cost of 200 second oil fuel ..$36,000
Repairs and maintenance on boiler ...................... 8,000
Total actual cost ............$44,000 or $11 per cu metre ($8.5 per cu yd)

2. Low temperature curing using hot water heated by electricity
Cost of electric power .........$5,000
Repairs and maintenance and additional cost of covering products .......... 3,000 $8,000
or $2 per cu metre ($1.54 per cu yd)

There is thus a saving in running costs for this particular factory of $36,000 against which must be offset the additional costs of molds used during the year in the factory. Obviously, if the factory is producing standard units, a substantial cost saving is made by changing to low temperature curing. However, under New Zealand conditions, this is rarely the case and the factory would be producing a mixture of standard and special products.

Taking a range of the type of products produced, it would appear that about 8 sq metres (86 sq ft) of
formwork are required per cu metre of concrete in the product. Assume that the total cost of insulation is $8 per sq metre ($0.74 per sq ft) and the cost of insulation and pipe work as $25 per sq metre ($2.32 per sq ft). Take the cost of an accelerator as $2.50 per cu metre ($1.82 per cu yd).

From the above, it follows that cost savings will be made using low temperature curing if there are 22 uses of a mold and that cost savings relative to steam curing can be made by the use of insulation and an accelerator if there are 10 uses for a mold. For fewer than 10 uses, steam curing would be more economical. However, very few jobs have fewer than 10 castings and they can probably be dealt with by using a 2-day cycle if necessary.

It is clear that substantial cost savings follow in the case of standard concrete products and that most special products will show some cost savings which will more than offset the occasional small job which could be more economically cured by steam.

Of course, the above figures are based on average products and the actual shape of the unit would have to be considered in any particular case.

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Concluding Remarks

Based on the results of the experimental work and the practical experience already gained in the precasting plants, I believe that the proposed curing method is a considerable technical improvement on present curing methods. The proposed technique will result in better quality precast products as well as help stabilize prices in the current inflationary situation.

We are continuing to develop the curing method but it has now been operating for nearly 2 years in one factory without any failure to reach release strength and without requiring any maintenance or repairs. I believe that it is now sufficiently developed for commercial application.

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References


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Acknowledgment

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Discussion of this paper is invited.
Please forward your comments to PCI Headquarters by January 1, 1978.