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PRECAST CONCRETE FOR WINTER BUILDING

by

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PRECAST CONCRETE FOR WINTER BUILDING

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The protection of freshly placed concrete is one of the problems facing Canadian contractors engaged in winter building. One solution is to use precast concrete which, even in winter, can be manufactured under controlled conditions to ensure maximum strength and durability. There is, however, little experience with such units in Canada because production, although it is increasing rapidly, has been limited. In Europe, on the other hand, precast concrete has been widely used for many years. Experience there indicates that precast concrete can be used in Canada as an aid to winter construction. There are however some practical difficulties to be solved before this practice can gain wide acceptance in the industry. The most serious is that of making connections between members. Although a number of solutions have been suggested, the need for additional research is recognized.

ONE OF THE PROBLEMS facing the Canadian construction industry in wintertime concerns the protection which must be given freshly placed concrete to prevent damage from frost action. This requirement for temporary protection increases the cost of the concreting operation. When added to the increased cost of the concrete itself during the winter months it may raise the final cost in place as much as $5 per yard. There is a natural decrease in labour efficiency if protection is not provided, and a great deal of time can be lost in warming up, and sitting out bad storms.

It is common practice in Canada today to place heated ready-mixed concrete inside a temporary enclosure covered with tarpaulins or plastic, but the whole operation can be very much simplified by mixing, placing, and curing the concrete under the same roof and then assembling the precast components on the site. Protection on the site can then be confined to the joints between the precast parts. It then becomes possible to achieve the valuable economies of factory production.

Fig. 1. The all-important framework can be erected in any weather, and is immediately load-bearing. (Northview Height Collegiate Swimming Pool, Toronto).

The use of precast concrete manufactured in a factory can therefore provide a solution to the problem of winter concreting and at the same time introduce a measure of quality control not usually associated with cast-in-place concrete. The speed with which it is possible to enclose a structure when large precast panels are used promises even further cost savings.

As a part of its research study of winter construction, the N.R.C. Division of Building Research decided to investigate the present status of precast concrete in Canada and to assess the practicability of this practice being more widely used than at present. In the course of this study, an extensive search of American and European technical literature was undertaken followed by visits to engineers, architects, contractors, manufacturers, and research laboratories in the United Kingdom, the United States, and Canada.

Brief History

The practice of precasting concrete is nearly as old as the use of reinforced concrete. Development was slow until World War I when, because of shortages of conventional materials, many nations investigated the possibility of precasting concrete on an industrial basis. By 1930, Germany was producing precast concrete frames, girders, columns, sewers, bridges, fence-posts, lamp-posts, formwork, paving block, and building block, and had already recognized the advantages of precast concrete for winter construction.

In the years following the revolution, much attention was given in the U.S.S.R. to the manufacture and use of precast concrete. So convinced were the authorities of the advantages of this system that by 1934 standard precast concrete structural units were required for all commercial and industrial buildings. By that time precast units weighing 15 metric tons were being fabricated. In contrast to this rapid development in other parts

Fig. 2. Precast concrete roof and frame provide the structural portion of a lightweight enclosure (University of Saskatchewan).

of Europe, little early work was done in the United Kingdom or the United States. Precast floor systems had, however, been developed and were quite widely used, and as early as 1906 American railroads were using some structural precast concrete bridge components. The erection of such large components was no problem to the railroads who could use their heavy wrecking cranes.

The construction industry generally had to wait for the development of the heavy-duty motor truck crane and tower crane before full use of precast building components was possible. The steel shortage brought about by the Second World War resulted in a great increase in the use of reinforced concrete. Much of it was cast *in situ* but with experience came the realization that precast concrete offered a low cost, high quality material that could often replace traditional materials. In the United States the use of precast concrete frames for commercial and industrial buildings increased and large precast girders, which had been used in earlier years, were again used in bridge construction. With the development of prestressing techniques and the introduction of heavy lifting equipment, precasting in the United States began to compete seriously with conventional materials.

Today much use is made of large floor and roofing slabs and tilt-up wall panels, precast on the site and put in place by special erection equipment. At the same time factory precasting is also widely used and has made possible the erection of one factory building at the rate of 7500 sq. ft. per day, with framing and roof decking averaging 10,000 sq. ft. per day.

The precast, prestressed concrete industry in the United States maintains a yearly growth in production of 200 to 300%. At present there are some 200 precast prestressed plants in operation, and a further 150 are under construction or being planned. Girders and beams of I, T, WF, and rectangular sections, roof and floor slabs of double T and channel section, joists of I and T section, rigid frames, trusses, columns, poles, pilings, lintels, bleachers and wall panels are being produced in ever-increasing quantity.

Although the general adoption of concrete column-and-beam frameworks in Britain has been slower and is even today less widespread than in the other countries of Europe, precast floors and rigid frames for single-story industrial buildings are now generally accepted as standard forms of construction. Some manufacturers can produce precast concrete frames at the same price as unprotected steel and at half the price of fire-proofed steel. In an effort to conserve steel and provide schools as cheaply and quickly as possible, the British Ministry of Education sponsored the development of a number of proprietary systems. Their success may be illustrated by the fact that one contractor, using a system of precast units prestressed in place, has built between 40 and 50 schools in three years and is now entering the commercial building field.

In the U.S.S.R. today, precast concrete is being used almost exclusively for building construction. In Moscow and Leningrad alone, some 86,000 apartments to be built in this way are planned for 1959, mostly in five-story blocks. The finished buildings have a neat appearance both inside and out, but the precast products are roughly finished and are generally covered by plaster or brick facing. State control and co-ordination of all construction, and the resulting standardization throughout the country, has permitted the complete mechanization of even pretensioning operations, through the development of continuous wire winding machines and rotating casting beds.

Factory Manufacture

Precasting does not automatically imply factory manufacture nor that it cannot be considered beyond the economical hauling distance from an existing factory. On-site manufacture, however, is generally limited to heavier components that are too difficult to transport, or to large jobs where it is economically practicable to erect a temporary factory. A $300,000 job is regarded in Europe as the minimum size for on-site casting, because this will allow recovery of the cost of plant, moulds, and planning during the course of that single job. On-site manufacture in Canada is generally left to the factory manufacturer who can extend his operation in this way. At present, he has the necessary specialized knowledge, and this situation will probably continue until standard specifications for precast concrete are available. There are exceptions to this general rule, but these usually result from very close co-operation with an experienced architect-engineer. At the present time building codes make virtually no distinction between precast concrete and ordinary reinforced concrete cast-in-place, so that they give no indication of the extra care required with precast work.

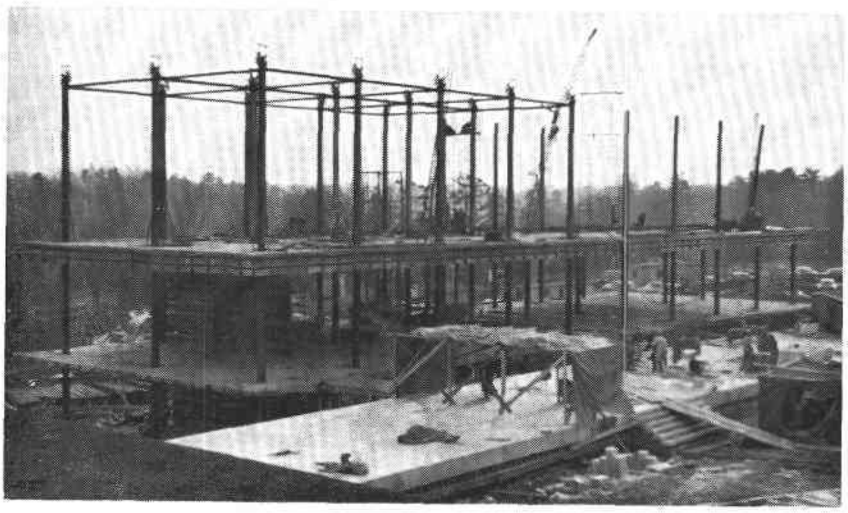
Factory production, whether in a permanent or a temporary factory, permits rigid control of mixing, placing, and curing, as well as being completely independent of weather. Hence it is possible to produce high strengths running as high as 9,000 to 10,000 psi, even with lightweight concretes. The central feature of a precasting factory is the concrete mixing plant, operating on a weight batching principle, and similar in all respects to that commonly used in modern ready-mix concrete plants. Some are electronically controlled. In all cases there is some form of continuous inspection and of random sampling, frequently by an independent testing laboratory.

From the mixing plant the concrete is transferred to the casting bays, which frequently operate on a long-line principle. Here the forms are assembled, the reinforcement placed and possibly prestressed, and the concrete compacted and cured. For smaller units and where rapid production is desired, steam or warm water curing is used; with prestressed units, this permits stress release after as little as 12 hours. Larger units may be air cured, which permits stress release in three days. With either method the side forms are stripped and re-used on a daily basis. For winter operation of outdoor casting bays either on the site or at factories, forms are heated by the circulation of steam, hot water, or hot oil.

The continual re-use of standard forms makes it possible to use steel forms. Besides reducing form maintenance costs and producing accurate castings, steel forms produce a smooth finished surface ready for painting. The savings involved in factory production of an integral surface finish are very real and can reduce the construction time very considerably. The exposed face of a wall panel, for example, may be tiled, trowelled smooth, brushed, polished, or treated with an acid solution or water spray to expose the aggregate. It is possible to achieve almost any desired texture or colour, and at the same time to produce a finished surface that requires little or no maintenance. The application of special finishes of this type to a cast-in-place panel would be costly, if not impossible, and would require additional winter protection.

The precast units are easily handled in the factory, usually with gantry cranes. Some factories that use a vacuum process to remove surplus water from the compacted concrete also use a vacuum mat pick-up for handling precast components, particularly wall panels. The finished units can be stored under cover if necessary, and standard units can be stockpiled during periods of low demand so that factory production can be maintained at a uniform year-round level. Most units, however, are produced to order and stored until they have reached the required strength, which incidentally means that they have undergone most of their shrinkage. They can be delivered to the construction site in sequence of erection. On well-planned jobs they can be lifted directly from the delivery truck to their final positions. This eliminates on-site storage completely and is a great advantage in wintertime. Erection of precast concrete may depend on solid ground conditions for heavy erection equipment; in this respect it is also more suited to winter than to summer construction.

Fig. 3. The lift slab method is an ideal winter construction method because the concrete slabs can be placed with a single enclosure at ground level (Carleton University Arts Building, Ottawa).



Simplification of Construction Operations

The quality of precast work and the possibility of using prestressing techniques with it are not the only reasons for its increasing acceptance. Simplified construction procedures result in major time and labour savings, which can in turn reduce building costs considerably. The elimination of framework on the construction site is a big factor in reducing costs. Forms must be used, of course, in the precasting plant, but through re-use their number may be greatly reduced. The amount of formwork is also reduced by casting the units in the most advantageous position. A concrete staircase, for example, is best cast upside down in a horizontal form. A vertical wall panel with a double grid or reinforcement is a difficult section to place on the job, but in a precasting plant the concrete can easily be placed in the open face of a simple horizontal form.

In Europe, savings of two to three hours per cubic yard have been recorded for panels of this type. The over-all saving made by using precast concrete for a French apartment building amounted to 50 per cent of the formwork, or from 10 to 15 per cent of the total cost of the building. Construction times are commonly cut in half. One British contractor has found that it pays to redesign cast-in-place buildings as precast structures simply to take advantage of modern methods and equipment. He has achieved such results as being seven months ahead on a 30-month schedule with a job little more than half finished. Such time savings can greatly reduce overhead expenses and interest on capital. They can result in earlier occupancy, and hence in earlier receipt of rents. In the construction of an apartment building in Europe, four months were saved by using precast concrete instead of concrete cast-in-place. The resulting savings, together with the earlier receipt of rents, more than offsets the cost of 30,000 miles of trucking from factory to job-site and of importing and setting up a special crane to handle the precast units. In Canada, because of the long winter season and the desire to close in buildings in the shortest possible time, saving of construction time is of great importance. Precasting avoids cold weather delays. It can eliminate the need for temporary enclosures of any kind and can provide, in itself, an immediate and permanent shell to shelter the work of sub-trades.

Although the labour force required to erect precast concrete is small, it must be highly skilled. In the United States a trained crew of six men erected the frame of a two-story, 17,000-sq. ft. building in four 8-hour working days. In another case, six men erected the frame of 64,000-sq. ft. single-story building in ten working days. Factory processes make best use of less skilled labour and make it possible to build up experienced teams that benefit from year round employment. Experience in the U.S.S.R. has shown that the use of precast concrete leads to an over-all labour saving of as much as 48% for the individual components, compared with monolithic members. In housing, where large precast wall and floor panels are used, labour on the building site has been reduced by as much as 55%, compared with cast-in-place construction.

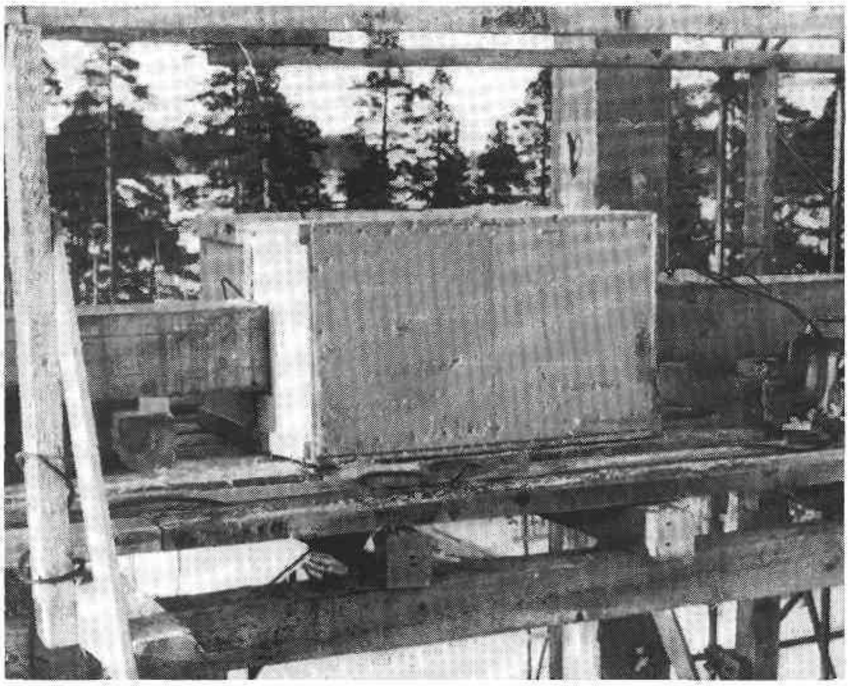


Fig. 4. Joints made with cast-in-place concrete require winter protection. This fibreboard box could be heated with a single electric light bulb.

Connections Between Precast Units

The advantages of using precast concrete are often offset by the difficulty of producing satisfactory connections between precast units. A number of special systems of jointing have, however, been developed. Some are well suited for winter construction, but others require cast-in-place concrete which must then be protected by portable shelters or other means.

There are *four main types of joints* in common use:

(1) Welded reinforcement joints;
(2) Rigid metal joints;
(3) Prestressed joints;
(4) Cast joints.

The welded joint connects reinforcing bars which have been left exposed during manufacture of the precast units. Only a small space is left between units and this space is later grouted. Rigid metal joints are made by steel connectors consisting of short lengths of structural steel, anchored into the ends of the units to be joined and tied into the main reinforcing by welding. The joint is made by bolting, riveting, or welding the connectors.

Prestressed joints are made by precasting steel reinforcement which is anchored in both units being connected or by using prestressed bolts. This system, which is considered by some experts to be the best one, gives a joint which is able to resist the bending moments as well as the shearing forces which must be carried. Cast joints are made by splicing the ends to be joined with reinforced concrete which is cast-in-place. In such a joint the compressive loads are carried by the concrete filling, while the tensile loads are transferred through the reinforcement which is spliced, or by bond between the reinforced concrete splice and the precast units.

An ideal joint design for precast concrete framing should satisfy three major requirements:

(1) The joint should provide bending moment strength to the maximum possible extent;
(2) It should be economical, with the least possible use of extra steel and labour; and
(3) The joint should allow exact plumbing of a column after it has been erected.

Maximum moment resistance is particularly desirable for large warehouses and industrial buildings, because it is most often very difficult to obtain lateral stability in any other way than by fixing the columns to their foundations. To obtain this maximum rigidity, the reinforcing steel over and under the joint should be made continuous as far as possible. This is most easily achieved by means of welding; it is easier to obtain the desired quality when all of the steel reinforcement is marked according to steel type and yield strength.

To reduce the amount of extra steel required, footplates, for example, should be made as thin as possible and should not be depended on to transfer bending stresses except in the initial stages before final welds are made or filling concrete added. In wintertime, it is a definite advantage to have a rigid metal joint which is capable of taking the construction loads without the assistance of the filling concrete. This concrete can be added at a later more convenient time after the building is closed in. In most instances, the labour involved in making the joint is more significant than the extra material used. Erection time is very expensive and should be kept to an absolute minimum.

For most parts of Canada the rigid metal joint is the most attractive for winter construction projects, but it is also the most expensive. For this reason, one of the other joint systems is generally used and provision made to ensure that no frost damage occurs to the grout around the joints. A good grouted joint is often harder to achieve than generally believed. Frozen members must be heated before the grout is applied. Some engineers believe that porous members can absorb even the water required for hydration of the cement. Temperature, shrinkage, and loading movements are often ignored. Early failures of grouted systems have been attributed to one or other of these conditions. Some designers find it an advantage to use a cast-in-place core for stability. This eliminates any uncertainties about joints between the precast members, and has been shown to fit in particularly well with the general contractor's operation.

Canadian Practice

There are approximately 20 manufacturers in Canada who produce structural precast and prestressed concrete. Over half of them are to be found in or near Montreal or Toronto. Although the greater part of their business is still done in hollow cored and double T floor and roof slabs, a few have now increased their regular production to structural frameworks, sandwich panel walls, and large architectural facing slabs. Some extend their field of operations by site-casting and post-tensioning outside their own area. Precasting is now a $25 million a year business. All the companies report that each year's production is higher than that for the previous year. One company has increased its production six-fold in three years.

A lack of standardization has kept the industry from enjoying the full benefits of factory precasting. Competition is keen, and because of this manufacturers are forced to work very close to design limits. These problems are recognized by the industry but there is some reluctance to establish standard sections on the grounds that such action may restrict the development of this relatively young, rapidly expanding industry.

Canadian designers confirm the advantages of precast concrete for winter construction. In order to make the best use of the precasting method, a designer should be able to co-ordinate architecture and structure. He should have a basic knowledge of the manufacturing processes as well as the construction operations and the equipment used to handle precast components. Better than average supervision of the job must be provided. In short, all the problems facing architect, engineer, manufacturer, and contractor must be considered in the very early design stages. This collaboration encourages new thinking; in many cases the savings resulting from a new method of approach have exceeded those forecast for the precasting method itself.

Conclusion

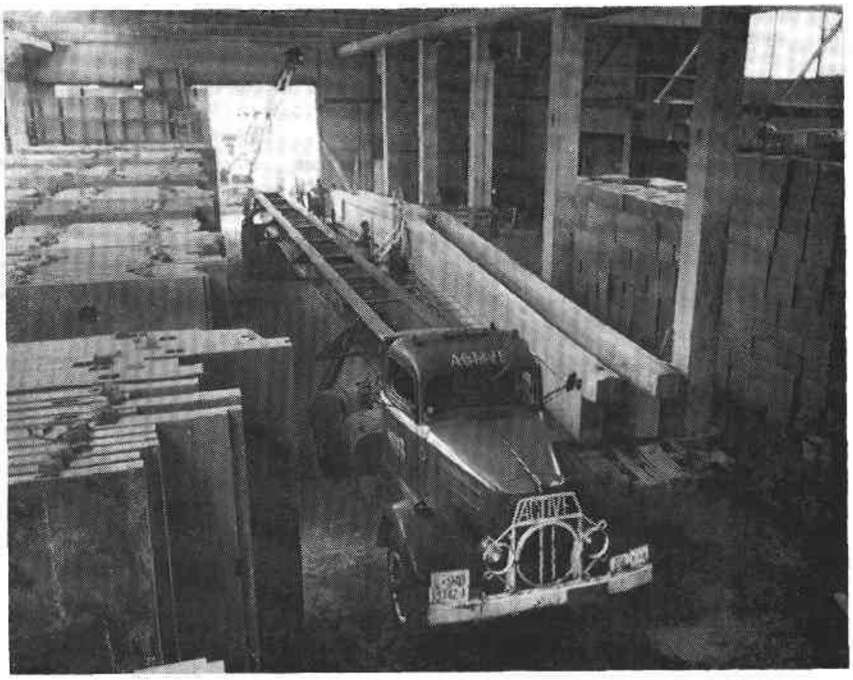
The use of precasting can limit on-site concreting operations in wintertime to the making of the joints between the precast parts. It can halve construction time and ensure top quality products. Not unnaturally its use is expanding rapidly in Canada. Much of the production of Canadian plants is still restricted to floor and roof panels, but to an increasing extent structural members such as beams, columns, arches, purlins, and load-bearing wall sections are being produced. Full development of this new industry would seem to be restricted by the lack of information in the offices of engineers and architects, and by some hesitation on the part of designers and contractors to full consideration of this new method and the necessary techniques.

As with all building materials, there is still a great deal to learn about precast concrete but this need has been recognized. The American Society of Civil Engineers and the American Concrete Institute have formed a joint committee to study it. One of the first projects to be undertaken by this new "Committee 712" will be an investigation of joint systems for use between structural precast members. From such studies, an increasing fund of knowledge will be accumulated for the use of designers in this country. In the meantime, there is sufficient evidence already available to show that precast concrete has an important place in Canadian wintertime construction, a place long established in northern Europe and Russia.

Acknowledgements

The authors wish to express their thanks to all the engineers, architects, contractors and manufacturers in Canada, the United States, and Great Britain who gave so generously of their time and experience in discussions and whose comments are summarized in this paper.

Fig. 5. Factory storage under cover avoids on-site storage problems in winter and allows complete curing in controlled conditions.



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