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Developments in Manufacture and Assembly

Développements dans la production et l'assemblage

Entwicklungen in Herstellung und Montage

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1. Introduction

In construction of concrete structures of recent, there have been strong demands expressed for shortening of construction periods, saving of labor, and economization. There have also begun to be heard loud clamors for alleviation of public nuisances accompanying construction work such as environmental pollution, noise and obstruction of traffic flow. Minimizing work requiring cast-in-place concrete and effectively utilizing precast concrete elements instead may be cited as an excellent method of complying with these demands. Furthermore, through effective application of precast elements, there will be many cases when other advantages may be gained such as not only construction in cold weather being made easier, but also safety and durability of structural members being improved since concrete of high reliability will come to be used.

Consequently, there has been much research done from the past in countries throughout the world in regard to manufacture of precast concrete elements used in construction of precast structures and methods of assembly using elements, and these have been discussed at a number of international conferences (1)(2)(3)(4)(5)(6)(7).

This paper summarizes the developments seen in manufacture of precast concrete elements and methods of assembly using elements, and discusses the problems involved as well.

2. Developments in Manufacture of Precast Concrete Elements

The conditions required of concrete elements to be used for precast concrete structures may be listed as being (1) accurances within specified limits of shapes, dimensions, and arrangements of reinforcement and jointing steel, (2) concrete possessing the required quality, (3) weights, shapes and dimensions suitable for transport, and (4) economy. These conditions will of course be of varying degree depending on the object for which the concrete elements are to be used.

Of the conditions mentioned above, the condition of (1) is highly important, and since it governs the success of a precast concrete structure, strict limitations on permissible errors are provided in product standards and construction specifications in all countries.

2.1. Improvements in manufacturing facilities for concrete elements

All new manufacturing plants for mass-produced concrete elements indicate that efforts have been made for improvements in facilities for concrete elements, such as for handling and storing aggregates and other materials, for batching and mixing, for fabricating and placing steel, for placing and consolidating concrete, for curing, and for conveyance inside and outside the plant of semi-finished and finished products during and after manufacture. Of the various facilities, the major ones are discussed below.

Among materials for concrete, aggregates require the most careful consideration in handling, and needless to say, it is important for measures to be provided in order to maintain gradations and moisture contents uniform. There are cases of good results being obtained at large-scale precast concrete plants where aggregates are suitably sieved and classified into several fractions according to particle size, with each fraction stored in an individual silo. It is of advantage to do so since it will become unnecessary to add devices to batching equipment for correcting batched quantities of water and aggregates in accordance with variations in surface moisture, while adjustments in concrete mix proportions accompanying variations in aggregate gradation can be almost completely eliminated.

When selecting mix proportions for concrete, it is a basic principle to make the unit water content as low as possible within the limits of obtaining workability suitable for placement, and since it is normal for considerably high-grade placing and consolidating equipment to be available in case of a plant manufacturing precast elements, concretes of dry consistencies having especially low unit water contents are commonly used. For this reason, pan type mixers with mixing blades which revolve inside pans are employed in many cases as mixing efficiencies are improved and mixing times are shortened, while quick discharge of concrete is possible. In particular, mixing efficiencies are good for models with planetary movement of blades.

Equipment for fabrication and placing of steel as well as forms differ greatly according to the kind of concrete element and it can be seen that much attention has been paid to each. At plants manufacturing large quantities of prestressed concrete elements there are many cases where pre-tensioning systems using long-line prestressing beds are employed. Many of these plants have facilities capable of providing curvatures to prestressing tendons as required. Further, the long-line system is also suited to manufacture of long prestressed concrete elements. Prestressed concrete piles of lengths of 60 meters and prestressed concrete girders of lengths of 40 meters or more are being manufactured by this method. Sliding forms are sometimes used in such operations. In case of piles, the hollows parts are formed by using inflated rubber tubes or sliding mandrels and there are cases of these mandrels being equipped with heating units to accelerate hardening of concrete.

When manufacturing prestressed concrete piles and poles by the pre-tensioning system, there are cases when the reactions accompanying prestressing are made to be carried by the forms.

With columns, girders, slabs, railway sleepers, various types of block, piles, etc., there are cases when all or part of a form is immediately removed after thorough consolidation of concrete of dry consistency. This is a rational system for surface finishing and curing also, and is adopted when conveying to the curing apparatus will not be a problem.

A considerable amount of manual work is generally required when assembly and arrangement of steel used for a concrete element are complex, and many kinds of automatic apparatus have been devised at various large plants to save on the labor cost involved. For example, treatment and fabrication of steel, assembly of spiral reinforcement to be used for piles, pipes and poles, and assembly of reinforcing bars for slabs and wall panels have been automated.

It goes without saying that it is extremely important to have powerful consolidation apparatus capable of thorough compaction in a short period of time when concrete of dry consistency is used. Consequently, precast concrete element manufacturing plants utilize various kinds of consolidation equipment each suited to a certain type of product. The various consolidation apparatus, when classified by principle, would be internal vibration type, external vibration type, vibration table type, tamping type, compression type, roller type and centrifugal type. The internal vibration type is used most widely with frequencies of vibration generally being in the range of 80 to 130 cycles per second. However, since consolidation capability is increased the higher the number of cycles, there are cases when vibrators with frequencies of around 250 cycles per second are used. Tamping types are often used for products like concrete block, roller types for large-diameter pipe, and very widely, centrifugal types for piles, poles and pipes.

When using external vibration types, vibration table types, centrifugal types, etc., there are cases in which good results are not obtained unless consolidation is carried out after first performing preliminary consolidation at low frequency or low speed.

When concrete of dry consistency is to be placed in elements of comparatively narrow cross section or in elements with arrangements of reinforcement which are not simple, there are cases when good results are obtained if the abovementioned methods are used in suitable combinations. For example, in case of placing concrete for pipes and large-diameter poles using vertical-type forms, it would be suitable for application of pressure and external vibration to be used in combination, while the combined use of external vibration would be effective in compression consolidation of sheet piles and slabs. This is because there is a tendency for the transmission of pressure to be hindered by interlocking of aggregate particles when only compression is used. Sometimes, extremely dry concrete of slump of zero is placed in slabs and girders and consolidation is performed using vibro-stampers which combine tamping and vibrating actions. And, to cause concrete of dry consistency to completely fill complex cross sections, there are cases when a special type of concrete placement apparatus equipped with external vibrators is used. This apparatus first applies vibrations to the concrete to make it fluid and then extrudes it into the form by pressure.

The system of transferring prestress in case of manufacturing pre-tensioned prestressed concrete beams, hollow floor panels and other elements by passing electric current through high-tensile steel to heat and expand the steel, fixing the steel to the two ends of a form or to jaws installed in a prestressing bed, and causing the form ends or jaws to bear the reaction accompanying cooling of the steel is used in the Soviet Union, Czechoslovakia and elsewhere[7].

Other than the facilities discussed above, those for curing are also of importance, but since they have a particularly close relationship with concrete quality, they will be discussed in 2.2., "Improvement of concrete quality."

Uniformities of elements are improved and reliabilities increased through advances in manufacturing processes of precast elements at plants, especially automation, but that is not all — labor is saved to bring about economy and the merit of improving plant facilities lies in this effect. For example, at a certain prestressed concrete pile plant in Japan whose production capacity is as much as 480,000 metric tons per year, aggregates were recently separated into fractions while various facilities were automated as much as possible. As a consequence, the results of concrete control tests on specimens which were centrifugally consolidated and high-pressure steam-cured in the same manner as elements were as are shown in Fig. 1. The coefficient of variation of concrete strength during a period of a single month was only 3 percent indicating that the concrete was being controlled in an excellent manner. As for the operating cost after the facilities had been renovated, it is given in Table 1 and is lower than the cost in the past which had included a considerable amount for manual work. Naturally, the investment on the beforementioned apparatus was enormous — as much as 11,900,000 dollars — but the difference with the investment for the old plant can be recovered in about two years, and the benefit of automation can be clearly recognized. This may be only a single example, but is does serve to suggest that new capital investment in accordance with the scale of each plant will lead to economization.

Table 1. Comparison of Prestressed Concrete Pile Manufacturing Costs of New and Old Plants (Manufacturing Costs per Ton of Product)

Manufacturing Cost	New Plant	Old Plant
Principal materials	$24.22	$24.22
Auxiliary materials (fuel, supplies, other)	3.32	3.22
Labor	3.17	6.83
Electric power, repairs, other expenses	1.92	1.74
Depreciation	2.97	2.55
Total	35.60	38.56

Fig. 1 — Example of quality control test of concrete (for month of September, number of days operated, 21).

Elements used in various kinds of precast structures are not necessarily mass-produced articles which are sold in the market. In such case it would be difficult to install superior machinery and equipment as previously described, but it is thought necessary at least for concrete manufacturing facilities to be fully equipped for securing the required uniformity. Since it will be possible to assume smaller influence of strength variation and lower reduction coefficients when using precast elements made with such concrete, design strength will be improved to offer an advantage to the designer.

2.2. Improvement of concrete quality

2.2.1. Improvement of concrete strength

The design strength of a concrete element will differ depending on the purpose for which the element is to be used, and although cases of about 200 to 350 kilograms per square centimeter are greatest in number, there are also cases of about 400 kilograms per square centimeter, and recently, there have even been elements with high strengths of 800 kilograms per square centimeter or more which have come into practical use.

Increasing concrete strength markedly above present levels has been called for to a maximum degree in concrete engineering circles and this has been studied from the past by an extremely large number of researchers. According to the reports of these researchers, compressive strengths of 1,000 to 1,500 kilograms per square centimeter have been obtained, but most of these strengths were gained with small specimens of cement pastes and there have been very few studies which have progressed to the extent of practical use in concrete.

Yoshida reported in 1940 that compressive strength of 700 kilograms per square centimeter was obtained at the age of 6 hours and 1,040 kilograms per square centimeter at 28 days(8). This was achieved using strong, hard aggregates and ordinary portland cement to make concrete of dry consistency and filling it in cylinder molds of 15-centimeter diameter. Pressure of 100 kilograms per square centimeter was applied to squeeze out excess water and air, and the concrete which had then become of water-cement ratio of about 0.23 was cured for three hours immersed in boiling water while still under pressure. This technology was first put into practical use in part of the shield segments for the Kanmon Undersea Railway Tunnel (completed in 1942) of Japan, while recently, it is being widely utilized in manufacture of reinforced concrete segments for subway projects in urban areas of the country and of concrete sheet piles. In case of products being sold on the market, compressive strengths of around 400 kilograms per square centimeter at the age of 5 hours and 750 kilograms per square centimeter at the age of 28 days are being obtained by steam-curing under pressure after pressurizing for 6 to 8 minutes at 8 to 10 kilograms per square centimeter while employing simultaneous external vibration.

Roy and Gouda have reported that compressive strength of 6,700 kilograms per square centimeter and tensile strength of 650 kilograms per square centimeter were obtained with cement paste at the age of 28 days on application of pressure of 3,500 kilograms per square centimeter while maintaining the paste at a temperature of 250°C(9). The water-cement ratio was 0.09 with the minimum value of paste porosity a mere 1.8 percent. The paste consisted of the outer sides of extremely compacted unhydrated cement particle groups surrounded by dense cement gel. In any case, such high strengths are very much worthy of attention.

Short-term strengths also comprise an important factor of concrete elements for shortening periods of time required for stripping forms, for transferring prestress, and for making possible handling, conveying and assembling at an early time. With elements which are mass-produced, there is a strong tendency for rise in strength over the long term to be sacrificed and increase in short-term strength to be aimed for.

As means of increasing short-term strengths of concrete elements, use of high early-strength cement, use of admixtures, reduction in water-cement ratio, utilization of high-performance consolidation apparatus, atmospheric-pressure steam curing, high-pressure steam curing, etc. are conceivable. However, since most manufacturing plants already have accelerated curing facilities, ultra-rapid-hardening cements and set-regulated cements are not used very much from the standpoint of running costs. A method of heating concrete during mixing to 65 to 75°C using a special type of mixer which is heated with steam has been adopted in some cases(10). Such concrete is said to attain approximately 60 percent of 28-day compressive strength at the age of three hours. In attempting to gain strengths as intended by this method, there are such drawbacks as the difficulty of controlling temperature and the necessity of placing concrete within 10 minutes after finishing mixing. However, in case of continuing with steam curing, there is no trouble even if the temperature were to fall to about 50 to 40°C, and for the reasons that the time for surface finishing is shortened and labor costs are saved, this method is being used to a considerable extent.

In regard to utilization of various admixtures, the development of the technique of economically producing extremely high-strength concrete through large-quantity use of high-performance water-reducing agents may be cited as being especially noteworthy. Such water-reducing agents are mainly constituted of polyaromatic sulfonates and all of them cause hardly any air to be entrained, while retarding effects are comparatively minor. When these water-reducing admixtures are added at rates of about double the standard quantities and concrete is mixed, prominent water-reducing effects are demonstrated and unit water content of concrete can be reduced by approximately 30 percent.

This type of technology was developed in manufacture of prestressed concrete piles with the purposes of increasing resistance through high strength and eliminating damage accompanying driving of piles. Compressive strengths higher than 900 kilograms per square centimeter have been attained using combined atmospheric-pressure and high-pressure steam curing on hollow piles which had been made with concrete using large quantities of water-reducing agent thoroughly compacted by applying high-speed revolutions at centrifugal acceleration of approximately 30g(11). In case of using good-quality aggregates, it is easy for strength at one day to be raised to around 1,300 kilograms per square centimeter. Approximately 2,200,000 tons of this type of concrete pile were manufactured at numerous plants in Japan in 1973 and were used in various construction projects. This technology has begun to be utilized not only for prestressed concrete piles, but also in manufacture of other types of precast elements such as members of trusses, and a concrete truss railway bridge with a span of 45 meters has recently been erected by assembling such concrete members.

In basic research carried out by Yamamoto at the University of Tokyo, it was shown that in case of concrete using ordinary portland cement at unit cement content of 500 kilograms per cubic meter, admixture of water-reducing agent at a rate of one percent by weight of cement, and curing at 21°C, high strengths of 430 kilograms per square centimeter at the age of one day and 950 kilograms per square centimeter at 28 days could be obtained. The water-cement ratio of the concrete was only 0.27, but the slump was approximately 12 centimeters.

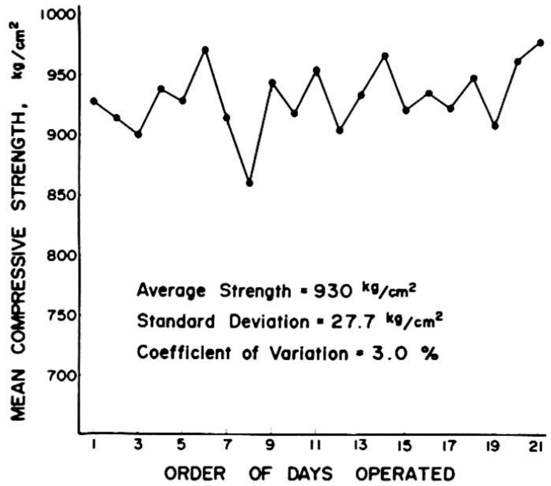

Fig. 2 — Truss railway bridge of Sanyo Super-express Line.

Furthermore, it was found that there were practical limits to unit cement content and dosage of water-reducing admixture; in this case, when making comparisons on the basis of concretes with equal workabilities, there was little gain in strength even if unit cement content were raised above 500 kilograms per cubic meter, unit water content was also a minimum when unit cement content was roughly around 500 kilograms per cubic meter, there was not very much effect of increasing water-reducing admixture beyond a certain extent (1 percent in this case), etc., and it is suggested that there would necessarily be an appropriate mix design in using such an admixture(12).

Concrete with unit cement content above a certain degree and with addition of a large quantity of a water-reducing admixture which is thoroughly mixed, besides indicating high strength of about the level mentioned above without any special curing, will demonstrate prominent mobility under the action of a vibrator even though the outward appearance of the concrete may be that of dry consistency, and therefore, will be easy to consolidate with very little segregation of materials. Consequently, this type of high-strength concrete can be used widely for various kinds of elements and it is expected to become widely utilized. Fig. 2 shows a double-track railway bridge truss for a new super-express line using reinforced concrete members cast with this type of high-strength concrete, cured at outdoor temperature, and assembled by prestressing. The two examples of railway bridge trusses, including the one of 45-meter span previously cited, may be noted as cases of lightening dead weight through the use of slender members of high-strength concrete in structures subjected to extremely frequent repetitions of live loading. The decisions to use slender members were made after careful studies of fatigue resistance properties.

2.2.2. Accelerated hardening of concrete

There are various drawbacks to steam curing which are conceivable such as that hardly any strength gain of concrete at long-term age can be expected, that there is risk of microcracks being formed due to internal strains produced by the differences in thermal coefficients of expansion of the various materials used for elements such as cement, aggregates, water, air bubbles and steel, and that there is danger of cracks being produced during the process of temperature change, especially from temperature and moisture differences between interiors and surfaces of elements occurring with falling temperature, but it is being very widely used in manufacture of various kinds of concrete elements since the economic effects are prominent. Both drying shrinkage and creep are smaller for steam-cured concrete elements compared with cast-in-place concrete. For example, even in case of atmospheric-pressure steam curing, drying shrinkage is about 30 percent and creep about 50 percent smaller. This would be of advantage for a structural member.

Venuat showed that the cement hydration products of cement steam-cured at atmospheric pressure are of practically the same kinds as the hydration products in case of curing at 20°C, but that differences can be recognized in the morphologies of the hydrates, sizes of crystals and porosities, and that the features of the various physical properties of steam-cured concrete can be explained from these differences(13).

The important conditions in case of performing atmospheric-pressure steam curing are such as the presteaming period, rate of temperature rise, maximum temperature and duration of maximum temperature period, and rate of temperature fall, with the quality of a concrete element varying greatly according to these conditions, and it is necessary for these four conditions to be selected as suited in order that the purpose of curing can be achieved economically in accordance with the purposes of use, shapes and dimensions, materials used, and mix proportions. If maximum temperature were to be raised and duration of maximum temperature period prolonged within suitable limits, strengths would naturally be increased. Consequently, the curing cycle for achieving the desired purpose will differ according to the case. However, there are many countries where standards for these conditions have been established considering concrete elements marketed in general, among which there are cases requiring moist curing for several days after having performed steam curing. The recommendations of the American Concrete Institute on steam curing(14) are very good and there are many other countries which are utilizing them. These recommendations provide that maximum temperature in general should be between 66 and 82°C with rise in temperature not more than 22°C per hour in case of presteaming period of 3 hours and not more than 33°C per hour in case of 5 hours.

In case of concrete made by hot mixing, steam curing may be performed raising the temperature immediately to 80 to 90°C since the temperature of the concrete will already be up to a level of 40 to 50°C. The curing period will therefore be extremely short and in most cases this will be economical.

With high-pressure steam curing, compared with atmospheric-pressure steam curing, high strength of concrete is obtained at an earlier age, drying shrinkage is reduced, chemical resistance is increased, and efflorescence is reduced. This is said to be because the tobermorite formed during curing by this method is more dense than the tobermorite gels produced in the cases of atmospheric-pressure steam curing and normal moist curing. In case of performing moist-air curing or atmospheric-pressure steam curing, the aggregates in concrete are inert except for special kinds, while in case of curing in high-pressure steam of pressure of approximately 7 kilograms per square centimeter or higher, tobermorite of high silica content is produced in which lime and silica in the cement, water, and even silica in silicate admixtures and aggregates are combined. The previously mentioned superior properties are imparted because this tobermorite is hydrous calcium silicate which is strong and dense. In the event that high-pressure steam curing is to be performed on cement paste, it is necessary for a silicate admixture to be included. However, there are also cases which differ and the use of silicate admixtures will not be necessary when performing high-pressure steam-curing concrete. In essence, there are cases when the silicate in aggregates alone will be adequate(11).

The cycles of high-pressure steam curing must be determined suitably in accordance with the specified strengths, dimensions, materials used, concrete mix proportions of elements, etc., while steam curing is divided into two stages in most cases. In effect, presteaming is omitted with atmospheric-pressure steam curing performed as first-stage curing and high-pressure steam curing as the second stage. The various properties of concrete subjected to high-pressure steam curing are governed according to the second-stage curing while it appears the influences of the various conditions at the first-stage curing are small(15).

In case of prestressed concrete piles (made by a pre-tensioning system with diameters not more than 0.6 meter and lengths not more than 15 meters) in Japan using the concrete described previously, compressive strength of 900 kilograms per square centimeter are being secured on completion of curing. Atmospheric-pressure steam curing is performed for approximately 10 hours at temperature between 60 and 70°C. Prestress is transferred, forms stripped, the piles are placed in an autoclave and the temperature is raised to 180°C in 3 to 5 hours. High-pressure steam curing is then carried out again for 3 to 5 hours at a temperature of 180°C and pressure of 10 kilograms per square centimeter. The rate of temperature drop is made to be as small as possible in accordance with the cross-sectional area of the pile. The report(15) that when high-pressure steam curing is carried out on concrete using a large dosage of high-performance water-reducing admixture, the tobermorite produced is particularly dense due to the dispersion effect on cement particles is of special interest.

2.2.3. Weight-reduction of concrete

When high-strength concrete is appropriately utilized, the cross sections of structural concrete members can be made smaller and the dead weight of a concrete structure can thus be lightened. However, a more effective means of reducing dead weight is the utilization of lightweight concrete. An advantage brought about by reduction in the weight of a structure other than lightening of the superstructure is simplification of the foundation, and this advantage becomes greater especially when bearing capacity of the ground is small. Furthermore, with a long-spanned concrete bridge, there will additionally be simplification of piers, abutments and shoes. In case of precast concrete elements, lightweight concrete will be of still more advantage as the costs of transporting and assembling will be reduced. Since the cost of artificial lightweight aggregate is much higher than that of normal-weight aggregate, the economy of the case of using lightweight concrete elements should be judged upon careful comparison of the abovementioned advantages and materials costs, but it is felt there will be many cases when the use of lightweight elements will be economical(16). Lightweight concrete elements are excellent in the properties of heat insulation and sound absorption, and are being used to a considerable extent as wall, floor and roof materials of various types of buildings.

The variety of lightweight aggregates used for lightweight concrete is very great. Not only do the qualities vary, but also the properties differ with each country and each region even for aggregates belonging to the same classification. Therefore, to attempt to clearly outline what will be the unit weights, strengths, durabilities and other physical characters of concretes using these lightweight aggregates is a difficult matter. However, when lightweight aggregates of comparatively good qualities are used, concretes of unit weights between 1.6 to 2.0 tons per cubic meter and compressive strengths between 350 to 500 kilograms per square centimeter can readily be obtained so that they are even used in prestressed concrete bridges. The modulus of elasticity of a lightweight concrete will naturally be low, but with regard to the amounts of shrinkage and creep, whereas there are reports that these were as much as 1.5 to 2.0 times those of normal-weight concrete, there are reports on the other hand stating that for practical purposes there were no significant differences. This discrepancy is probably due chiefly to differences in the qualities of the aggregates. Since it is inconceivable for drying of civil structures standing outdoors to progress in the same manner as drying in the laboratory, there will be cases when it will be unrealistic to consider laboratory values of shrinkage and creep for design. However, as cracking due to difference in moisture content between surface and interior portions of concrete is liable to occur, it would be proper to provide additional reinforcement or combined use of natural aggregates to a suitable degree in case of precast elements to be employed in an important structure. Also, it is suitable for more thorough reinforcement to be provided than for normal concrete at places where stress concentration will be produced.

2.2.4. Self-stressing concrete

The method of transferring prestress to concrete through restraint of expansion of concrete containing expansive cement by forms or steel is beginning to come into practical use for various structures such as floor and roof slabs of buildings, water tanks, pressure pipes and pavement slabs. This method is being actively used especially in the Soviet Union, but in most cases, the prestress transferred is not more than 40 kilograms per square centimeter.

Prestressed pressure pipes are representative of precast concrete elements utilizing self-stressing concrete and have found widespread practical use. In order for self-stressing concrete to be extensively used in other types of precast elements, there will be accurate control of prestress needed, while problems requiring clarification still remain such as loss of prestress accompanying shrinkage and creep of concrete, but this is a material which is important for saving labor and economizing in construction of precast structures. Moreover, as will be described later, this is without any doubt an extremely useful material for joining precast elements.

2.3. Standardization of concrete elements

All industrial products will show remarkable development as a result of standardization, and precast concrete elements are not exceptions. As they have become standardized in various countries, mass production has progressed to make possible lowering of product costs, and general use and development have been realized. Although the details of standardization differ with each country, materials, manufacturing methods, testing methods, etc., are specified for many kinds of concrete elements.

One key to making design of a precast concrete structure economical may be said to be in suitably joining together standard concrete elements which are widely being marketed or making composite members out of elements and cast-in-place concrete. For the designer, in such case, it will be desirable for an element to be usable for several other purposes besides its main purpose. For example, a prestressed concrete foundation pile can be used as all or part of a bridge pier, or as a structural column of a building. Consequently, there will be cases when it would be advantageous to slightly modify designs of structures in accordance with the shapes and dimensions of elements available on the market.

It is desirable for standardization of precast elements to be done not on a mere national basis but on an international scale. This will be extremely difficult to accomplish, but at the least, it is wished to internationally unify standards for materials used in construction of structures and testing methods of elements. However, if standardization of elements were to go ahead, a trend to hinder revolutionary progress may be produced because the natures of manufacturing facilities, materials and practices will tend to become fixed, and it will be absolutely necessary to take precautions that such a bad effect will not result.

3. Developments in Assembly of Precast Concrete Elements

3.1. Joining of precast elements

It is not an overstatement to say that design and construction of joints between precast concrete elements, connections between precast concrete members, and connections between precast concrete elements and cast-in-place concrete members comprise the most important problem in construction of precast structures. All of these joints and connections must be such that the required precisions will be possessed, that there will be no overstressing under design load, and that the required safety factors against failure will be secured. Also, it is necessary that construction of joints and connections can be done quickly and economically.

Materials used for joints in making prestressed concrete members by connecting precast elements may be broadly divided into the three varieties of concrete, mortar and epoxy compound, the last being in essence a mixture of epoxy resin and hardening agent. Joint construction using concrete or mortar is a method which has been widely employed from the past. The work is easy, and generally, it is the most economical method. However, since prestress cannot be transferred until the concrete or mortar has hardened to a certain extent, there is the great shortcoming that the construction period will be prolonged. Nevertheless, it is possible to transfer prestress immediately even when using mortar in case elements are to be joined one on top of another, and there have been cases of good results obtained by setting the upper element on stiff mortar thinly spread across the top of the lower element, vibrating the elements to transmit vibrations to the mortar to increase its mobility and make it spread uniformly throughout the joint surface, stopping the vibration when the thickness of the mortar had become reduced to a specified amount, and immediately transferring prestress. The method of using an epoxy compound has been devised to shorten construction periods, but since epoxy is an expensive material, in addition to which its deformation is large, it is desirable for joint thickness to be small. However, if the joint thickness is to be made very small, it will be necessary to finish end surfaces of elements to be joined so that they will fit together perfectly, but this would be almost impossible to accomplish. Therefore, a method using epoxy compound mixed with filler of fine sand or cement has come into use with joint thickness being one to two centimeters, but in case of this method also, transfer of prestress must wait until the epoxy has hardened.

The coming into practical use of a jointing method using only epoxy compound and no filler may be cited as one of the remarkable advances made in recent prestressed concrete bridge construction. In this case, in order to cause the ends of two elements to be joined to fit perfectly, when manufacturing the elements, separating material was coated on the end of one element to be joined and concrete was cast up against this to use it as a form. Consequently, elements were required to be manufactured on a precasting bed matching the intrados line of a bridge, and the operations involved were troublesome in such a case as when the intrados profile of a long bridge happened to vary. However, since there were perfect fits between elements at the joint portions, the thickness of epoxy could be made extremely thin, and upon fitting, it was possible to transfer prestress immediately. Accordingly, the construction period required for jointing was shortened to about one fifth of that for the ordinary case of using mortar joints. Subsequently, it has been devised so that adjustments could be made even if the intrados or some other feature of a bridge should vary, or in case an error should be produced in erection, by referring to the results of computer calculations and using one fixed mold and two movable molds. Thus, success has been achieved in simplifying the abovementioned troublesome work. Cantilever erection without using shoring is facilitated going by the method of using epoxy only.

There is an extremely great variety of joints and connections being used which do not rely on mechanical prestressing, and broadly divided, they are those utilizing welding, bolting or other means of connection between steel provided at ends of elements or members, those depending on bond or anchorage in concrete of steel protruding from ends of elements or members, those employing sleeves, those using the likes of epoxy compound, those embedding ends of members in cast-in-place concrete, and others, with various innovations provided depending on the respective purposes. There are also cases of good results having been obtained by filling self-stressing concrete or mortar between members to be joined.

3.2. Assembly

With the recent advances made in concrete technology and the rapid progress evidenced in cranes, trucks and other machinery, precast concrete elements and their assembly have become of extremely large scale. This is in response to the demands of society for rapid construction and saving of labor. To take a bridge using precast concrete elements as an example, Tiel Bridge in the Netherlands is a cable-stayed concrete bridge of a total length of 612 meters having a center span of 267 meters. The approach viaduct of this bridge is a continuous structure consisting of ten spans each of 78.5 meters and a cantilever of 22 meters. The viaduct was constructed by cantilever erection of precast elements using epoxy compound, and each element had a length one fifteenth of span length and a weight of 120 tons. It is said the stays of the main bridge were made of prestressed concrete assembled by connecting precast concrete elements 5.15-meter long with joints of cast-in-place concrete. This was for protection of prestressing cables and for increasing rigidities of stays.

Precast concrete bridges built by cantilever erection of precast elements are being constructed at many places throughout the world and it is not unusual for center spans to exceed 100 meters in length. When rivers or sea routes can be utilized for transportation, the use of much larger elements is permissible, and for the center of Tiel Bridge, four suspended lightweight concrete girders each of length of 65 meters and weight of 425 tons were used, and these were erected on hauling by barge.

The reason cantilever erection is recommended is because there are such advantages as suitability for construction across deep canyons and over sea-waters, no obstruction of river water flows or highway and railway traffic flows since shoring can be omitted, and because rapid erection is possible. However, when only direct construction costs are compared, cantilever erection is generally more expensive than cases of providing shores and making connections on top of falsework on the shores with joints of concrete or mortar, or cases of elements connected at some other site with joints of concrete or mortar and installed using erection trusses or other equipment, and it is particularly more expensive in case of a short bridge. On the other hand, the shortness of the construction period results in the benefits of earlier opening for use and reduction of interest on investment, while the benefit accompanying reduction in obstruction of traffic flow is also substantial. Therefore, in selecting the method of construction, the true economics cannot be judged unless careful study is made of the net result of these benefits and the direct construction costs.

The discussion above is on only one example — there is much research activity going on in many fields on design and execution of assembly according to the type of precast structure, and these studies are unquestionably making steady advances. Namely, research is being conducted on methods of rapid yet safe assembly according to type of project, conditions of work site, period of construction, and construction cost and construction equipment as well. If circumstances should permit, it will naturally be advantageous to reduce the number of joints by using large-sized elements. Accordingly, elements have increased in size as advances have been made in equipment for their erection, particularly cranes, and there has even been a case of a precast reinforced concrete well weighing approximately 1,800 tons used for the pier of a marine bridge.

It is thought that offshore structures will be important precast concrete structures to be developed from here on, and besides marine bridges already mentioned, marine airports, marine power stations and marine petrochemical complexes can be cited as not-too-distant examples for development which come to mind. It may be said that construction of these types of structures will be impossible unless precast concrete is utilized since work on these structures must proceed while protecting the ocean environment. It is thus thought that even more development of precast structures will be seen in the future.

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SUMMARY

Recent facilities and practices for manufacturing precast concrete elements and new developments in assembly of elements are summarized and the problems involved are discussed. It is pointed out that extra-high-strength concrete can be readily obtained through use of a high-quality water-reducing admixture and the performance in actual use is described.

RESUME

La contribution présente les développements récents dans la production d'éléments préfabriqués en béton ainsi que dans l'assemblage de ces éléments. Les problèmes soulevés par cette évolution sont discutés. On souligne qu'une résistance exceptionnellement élevée du béton peut être facilement réalisée par l'utilisation d'un produit de haute qualité diminuant la quantité d'eau nécessaire. Les résultats obtenus sont décrits.

ZUSAMMENFASSUNG

Im vorliegenden Beitrag werden die neuesten Möglichkeiten und Verfahren zur Herstellung vorfabrizierter Betonelemente und neue Entwicklungen in Bezug auf die Montage zusammengefasst und die damit verbundenen Probleme diskutiert. Es wird hervorgehoben, dass extrem hohe Betonfestigkeiten leicht durch den Wasseranspruch reduzierende Rezepte erzielbar sind. Entsprechende Ergebnisse bei der praktischen Anwendung werden beschrieben.