Simplification of concrete structure shape and utilization of precast concrete for robotization

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Abstract

With an aim of automating and streamlining construction work as well as securing safety, the Ministry of Construction has been striving from 1990 to 1994, for the accomplishment of a general technology development project, 'Development of new construction process technology', that covered an extensive field of construction. The primary objective of the project was to develop new construction equipment and technology that enable the automation of construction work and laborsaving. The project was also aimed to develop new design and construction methods that facilitate the automation of concrete structure construction work through the simplification of concrete structure shapes, pre-assembling of reinforcement (bars are prefabricated in units in specialized factories) and the development of a large-scale structure prefabrication method. This paper reports the results of the study efforts.

1. Preface

Existing criteria and guidelines for reinforced concrete construction assume skilled laborer expertise as a prerequisite. This becomes a serious hindrance when it comes to the automation of construction work. For this reason, in order to develop and attain the widespread use of construction robots, as well as streamline construction work by employing prefabricated structural members, the establishment of new criteria and design is essential. Public Works Research Institute (PWRI) of the Ministry of Construction proposed in the 'Development of new construction process technology (1990-1994)' measures for streamlining construction work that were considered viable from the standpoint of reinforced concrete structure design, and established new designing procedures to ensure the smooth adoption of such measures at the job site. In addition, in order to attain the ultimate goal of automating and streamlining construction work, PWRI developed a method for prefabricating large-scale structural members and precast form erection.

This paper reports the pursuit of the project by PWRI to achieve the goal of automating construction work and laborsaving.

2. Designing of concrete structures suitable for automation

Conventionally material cost took up the major portion of construction cost. Because of this, attaining a shape that can minimize the quantity of materials to be used was a primary design objective. In order to expedite laborsaving and the automation of construction work, this perspective must be turned around toward a 'minimum possible labor' design principle, although within a range that the functions expected from a structure are properly served. By attaining this, reduction of labor and the robotization of construction work become possible through the simplification of structure shapes and standardization of dimensions, although with an associated slight increase in the quantity of materials to be used. The study focused attention on the simplification of structure shapes , standardization of dimensions, standardization of bar arrangement , which led up to the establishment of design criteria (proposed) and compilation of standard design drawings (proposed).

(1) Simplification of shapes and standardization of dimensions

One of the study objectives was the standardization of retaining walls and culverts having a haunchless or taperless structure. In order to attain simplified geometry, tapered sections were eliminated from the walls and bottom slabs, as shown in Fig.1. The simplified shape enabled not only the use of large form panel, as illustrated by Photo.1. Experimental construction, but the automatic erection of forms with such equipment as truck crane. As a result, as far as form erection is concerned, labor can be reduced by 15%, and an overall reduction rate of approximately 7% can be attained.

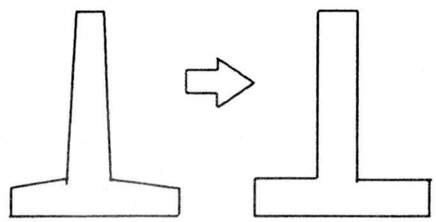


Fig. 1 Simplification of the shape of an inverted T-shaped retaining wall

Photo.1 Erection of large form panels

In the case of the standardization of dimensions, broader spacing of standardized dimensions expedites the automatic fabrication of reinforcement and forms in specialized factories and facilitates the introduction of robotization. The newly established design criteria provide minimum and maximum thickness and length values for structural members along with spacing, as listed in Table 1.

Table 1 Standardization of dimensions (m)

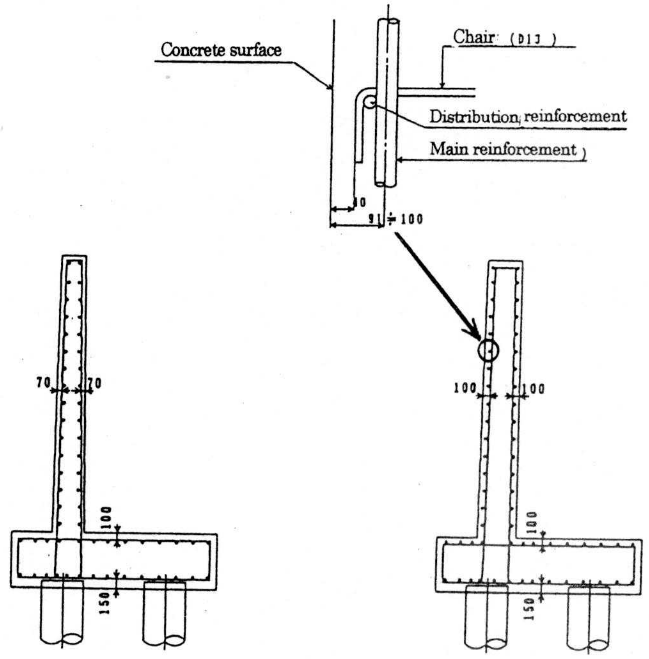
	Min. dimension	Max. dimension	Spacing of dimensions
Structural member thickness	0.40	1.00	0.10
Structural member length	2.00	7.00	0.50

(2) Alteration of bar arrangement specifications; Standardization of bar arrangement procedures

In the conventional practice of bar arrangement, distribution bars have been arranged inside main reinforcement out of expediency in stress computations. However, when the erection sequence is taken into consideration, some alterations has to be made in the arrangement procedures. It was decided that in the case of walls, distribution bars were to be placed outside its main reinforcement, and above the main reinforcement in the case of bottom slabs. The uniform concrete cover length was set at 10 cm.

Conventional bar diameter - spacing combination was diverse, and the selection was often left in the hands of the designers, which has always been a hindrance to the process of streamlining bar processing and erection work. The standardization of bar arrangement procedures can be attained by reducing the number of bars to be used, and with this in mind, ten possible arrangement patterns were established, as shown in Table 2.

The laborsaving effect expected as a result of the alterations in bar arrangement specifications and the standardization of bar arrangement procedures is 2 to 3%.



1. Conventional design

2. Altered bar arrangement specifications

Fig.2 Alterations in bar arrangement specifications resulted from the improvement of distribution bar placement design

Table 2 Combination of main and distribution re-bars obtained from the standardization of bar arrangement

Distribution reinforcement \ Main reinforcement		D15	D19	D22	D25	D29	D32	D25	D29	D32
		250mm pitch						125mm pitch		
D13	250mm pitch	○	○	○	○	○				
D15							○	○		
D19									○	○

3. Pre-assembling of reinforcement and associated technology

The concept behind this approach is that reinforcing bar pre-assembled in units in specialized factories are transported to the job site, where they are erected with truck cranes, as shown in Photo.2. Shop-assembling of reinforcement using robots realizes labor saving and highly accurate reinforcement erection. Since pre-assembled reinforcement is subjected to considerable load during its erection, all points of intersection must be bound securely. In order to attain this efficiently, spot welding is indispensable. However, existing criteria strictly limit the use of spot welding due in part to the fact that it impairs the quality of re-bars and greatly affects their fatigue strength, and in part to the fact that field erection causes the concentration of joints on a single cross section.

In order to cope with the situation,a series of tests was carried out, including tensile strength, fatigue strength, bending, and shear and tear, to determine the strength of spot welded reinforcement (Photo.3). It is considered that the problem of joint concentration can be overcome by adopting helpful devices in the splicing mechanism, or restricting the application to specific structure types or limiting the location of splicing.

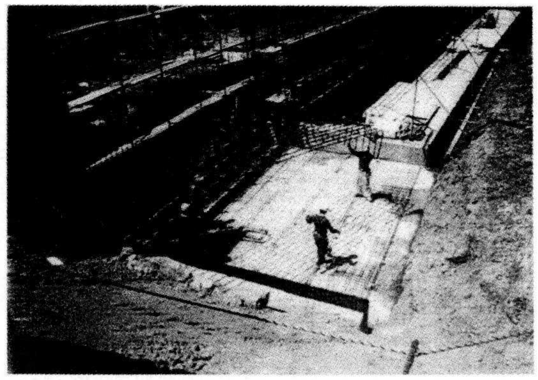


Photo.2 Field erection of pre-assembled reinforcement

To verify the strength of a point of splicing, a cut-off position was subjected to loading tests (Photo.4). From the test results, pre-assembled reinforcement design and erection requirements can be proposed as follows:

- Applicable structures : Retaining walls and culverts which are subject to low magnitudes of shear stress and fatigue.
- Lap length : For main reinforcement, 1.3 times that required by the Specifications for Highway Bridges, Part VI 'Substructure'. Horizontal reinforcement is necessary for additional strength.
- Points of splicing : In accordance with cut-off requirements.
- Fabrication procedure : Shop-spot welding is recommended.

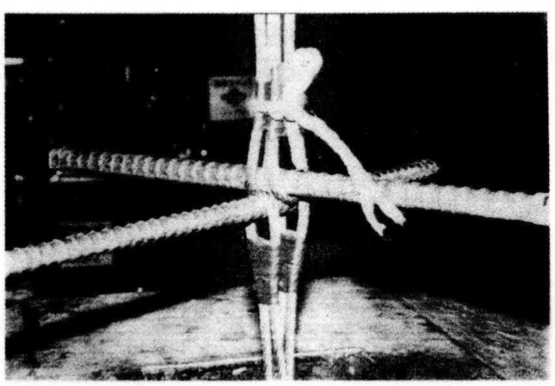


Photo.3 Tensile tests of spot-welded reinforcement

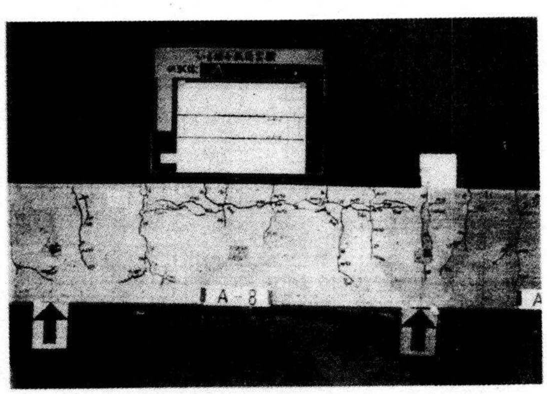


Photo.4 Loading tests on joint concentration

The results of the experimental construction revealed that a laborsaving effect of approximately 50% could be attained in field erection, and an overall laborsaving rate of 13% or so could be expected.

The final results of the study are summarized in "Pre-assembled reinforcement design and erection manual (proposed)" . They are also incorporated in the proposed design criteria and standard design drawings.

4. Prefabrication of structural members and associated technology

(1) Large-scale structural member prefabrication method

One way of streamlining and robotizing concrete structure construction work is to erect shop-prefabricated products at the job site. However, since most civil engineering structures are large in scale, the dimensions of these products tend to increase accordingly. It is therefore important, from the point of transportation efficiency and workability, to develop a technology that enables the field erection and jointing of prefabricated structural members.

The study focused on the development of new methods that streamline the construction of large-scale concrete structures, such as box culverts and inversed T- or L-shaped retaining walls. Primary development objectives include methods for dividing and jointing large prefabricated structural members, joint connection and waterproofing design methods, and field erection methods. Since joint connections are often vulnerable parts of a structure, special consideration was given to these parts during discussion of points and methods of splicing (that employed mortar joints). Bending and shear testing was carried out on a point of splicing to verify the structural performance. The test results revealed no significant difference between the point of splicing and an unjointed section in terms of flexural rigidity, cracking load, maximum load, and shear strength. From this it can be concluded that both the point of splicing and the unjointed section have an equal level of performance.

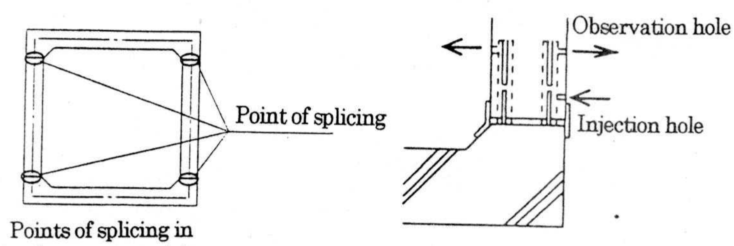


Fig.3 Splicing mechanism

Prior to launching out into actual box culvert construction, full-scale model testing was carried out to verify the work performance (the propriety of the erection sequence and method, work efficiency at individual construction phases, quality and safety) (Photo. 5).

The results of the testing are summarized and titled "Technical data concerning the design and construction of concrete structures using precast concrete" for future

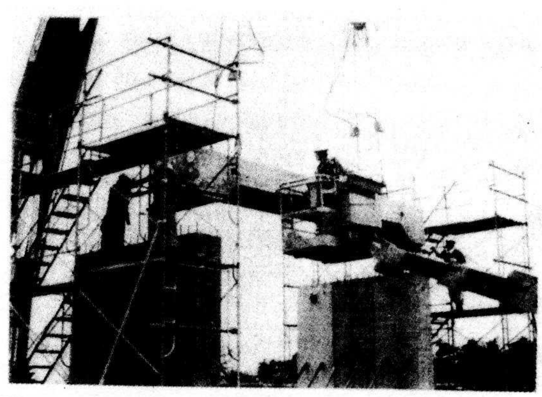


Photo.5 Workability tests using a full-scale model

reference in accurate designing and construction operations.

(2) Precast concrete form erection method

The study was aimed also at the development of a precast form erection method. In this method, form members are assembled along the circumference of a structure, into which concrete is poured. The erected form will remain in place to serve as the exterior wall of the structure. Intended application of this method is to structures larger in scale than retaining walls, such as bridge piers. The method eliminates the need for manual labor in field form and reinforcement erection.

In this method, the precast concrete form that contains main reinforcement is treated during designing operations as integral part of the structure system itself. To maintain the monolithic quality of the structure, structural requirements, the structure's load carrying capacity, and precast form jointing methods were examined. The results confirmed the need for placing shear cotters and dowels. It was decided that mortar joints were to be employed for precast concrete form connection.

In order to perfect the study and validate the applicability of the method, experimental construction was carried out at a national highway bridge substructure construction site in the Hokuriku districts. Data obtained from the construction confirmed the viability of the method and labor saving effect.

The study results are summarized in the "Technical data concerning the design and construction of concrete structures using precast concrete forms" .

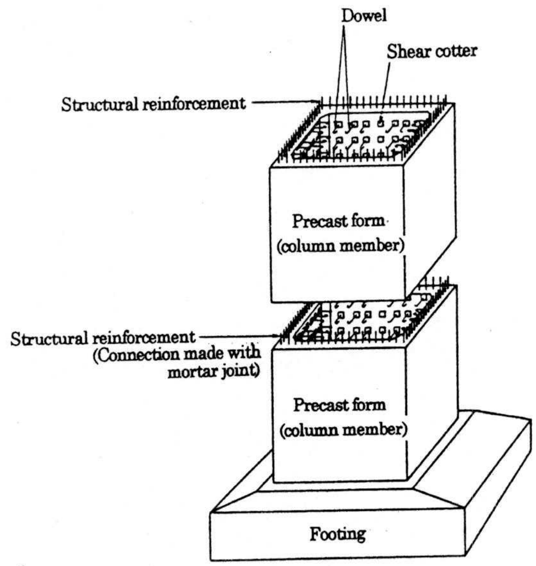


Fig.4 Sketch of the precast concrete form erection method

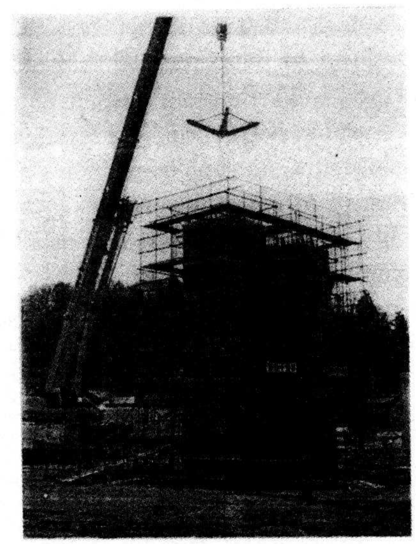


Photo.6 Precast form installation

5. Concluding remarks

In the field of reinforced concrete structure construction, the major portion of work is carried out manually by skilled workers. For this reason, the field lags behind in robotization. In view of the situation, the authors performed the study from the adpect design and construction methodd with an aim to expediting the automation and robotization of construction work.

The authors hope that the study results will be of service in facilitating the development of automation technologies specifically intended for individual work categories involved in reinforced concrete structure.