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Autor: Yoshida, Yojiro / Ueda, Tatsuya

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Composite Steel and Concrete Pier Using Durable Precast Form

Yojiro YOSHIDA
Civil Engineer
Maeda Corporation
Tokyo, Japan

Yojiro Yoshida, born in 1946, received his Bachelor of Civil Engineering Degree from Kanazawa University, Japan. He has extensive experience in the design and construction management of concrete bridges.

Tatsuya UEDA
Civil Engineer
Maeda Corporation
Tokyo, Japan

Tatsuya Ueda, born in 1959, received his Bachelor of Civil Civil Engineering Degree from Tokyo Metropolitan University, Japan. He has wide experience in the design of concrete structures.

Summary

This paper reports on the development and practical application of a new construction method for bridge piers in which H-shaped steel columns with ribbed flanges and durable precast forms with stainless steel fibers are combined.

It was also demonstrated in the practical application that the implementation of the method shortened the construction period by 66% and required 40% less workers, as compared with the conventional method.

1. Introduction

The devastating earthquake that occurred in the Kobe region of Japan in January 1995 caused various forms of damage to reinforced concrete bridge piers. As a country with frequent earthquakes, Japan was awoken again to the fact that it was absolutely crucial to improve the aseismicity of bridge piers.

Meanwhile, highways have increasingly been planned in mountainous regions where the bridge piers are required to have a considerable height. For such highway projects, there has been a demand for the development of a rational and speedy construction method which also saves labour .

The method described in this paper was developed to provide both a new structural configuration of and a new erection system for bridge piers ,with the aim of improving seismic performance and durability, saving labor and speeding up the erection work. The following report gives the outline of this method, describing its development and practical implementation.

2. Outline of the Method and its Features

2.1 Outline of the Method

The method introduces composite reinforced concrete bridge piers which combine durable precast forms and H-shaped steel columns with ribbed flanges instead of the conventional main longitudinal reinforcement (Fig. 1).

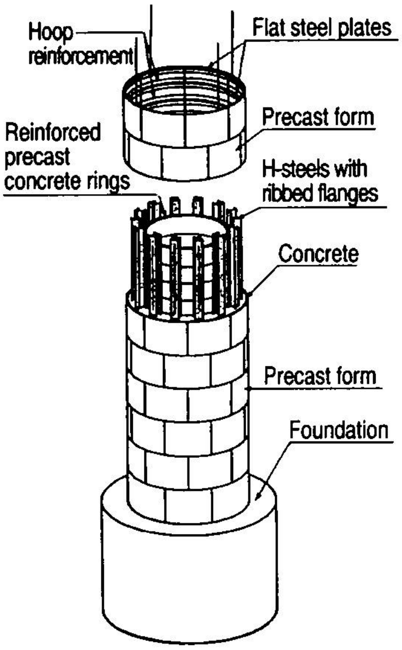


Fig. 1 Steel-concrete composite pier

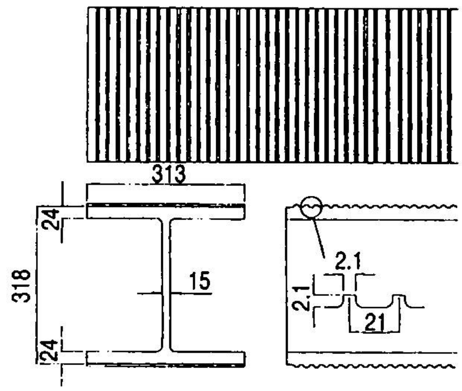


Fig. 2 H-steel with ribbed flanges

2.2 Materials

The H-shaped steel columns with ribbed flanges are H-shaped steel members that have small ribs at a right angle to their flange faces (Fig. 2). These ribs provide the section with a higher concrete bond strength than conventional H-shaped steel members.

The durable precast form is made of mortar with a compressive strength of 700 kgf/cm^2 that contains stainless steel fibers. It works as a form when placing concrete, and functions as part of the structure by acting together with the concrete once the concrete achieves working strength.

2.3 Features of the Method

This method has the following features:

(1) Superior seismic performance is provided by the composite steel and concrete pier which consists of the durable precast forms and H-shaped steel columns with ribbed flanges having enhanced bond strength and higher rigidity than conventional reinforcement bars. This feature is described in detail in 3.2.

(2) Because the precast forms used in the method have stainless steel fibers on their surfaces, the effects which limit both the crack dispersion and the widening of cracks are equivalent to or better than those experienced in reinforced concrete structures. These effects are described in detail in 3.1.

(3) Because the surfaces of the structure are protected by the durable precast forms, the structure becomes highly resistant against salt attack, frost damage and carbonation with much improved durability.

3. Outline of Tests

Having a new structural configuration and erection system, the structural performance of the method had to be confirmed by a variety of tests. The following sections outline the bending tests carried out on beams and the horizontal loading tests using scale models of bridge piers.

3.1 Bending test on beams

3.1.1 Test objective and preparation

The object of this test was to study the structural performance and deformability of the proposed composite steel and concrete pier when it functions as a flexural member. To fulfill this aim, the loading behavior of a composite steel and concrete beam specimen with the durable forms (hereinafter called *SC+PCa* Specimen) was compared with those of a specimen without the durable forms (hereinafter called *SC* Specimen) and a reinforced concrete beam specimen (hereinafter called *RC* Specimen).

3.1.2 Test results

It was found from the test that the width of cracks in the *SC+PCa* Specimen was 50% to 80% of that in the *SC* Specimen. This is because the precast form installed at the extreme tension fibre contributed to the effective restriction of the widening of the cracks.

Furthermore, it was confirmed that the *SC+PCa* Specimen had a higher resisting force at the ultimate state and the best deformability, because of the precast form installed at the extreme compressive fibre.

3.2 Horizontal loading test using scale models

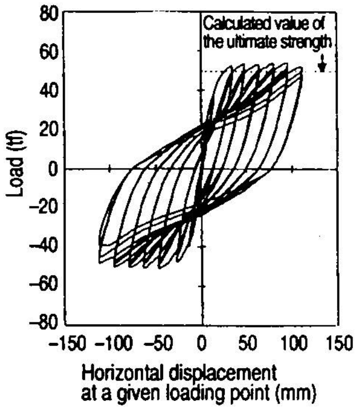
3.2.1 Test objective and preparation

The object of this test was to study the seismic performance (ductility) of the proposed composite steel and concrete bridge pier. It was confirmed by carrying out horizontal loading tests on scale models with alternating positive and negative loads.

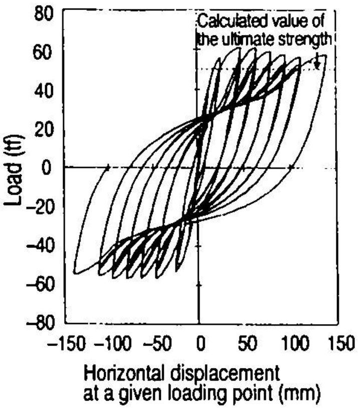
The specimens were 1:5 scale models of the real bridge pier. Two specimens were used: an *SC+PCa* Specimen with the H-shaped steel columns with ribbed flanges and an *RC* Specimen. In consideration of the different types of steel used in each specimen, the amount of the steel was calculated so that the both specimens had an equal bending strength. An equal amount of hoop reinforcement was installed in each specimen. In the *SC+PCa* Specimen, the hoop reinforcement was installed so as not to be in direct contact with the H-shaped steel columns.

3.2.2 Test results

Fig. 3 shows the load-displacement curves of each specimen. Both specimens maintained their strength which was greater than the yield load of the main longitudinal reinforcement until the displacement value of $7\delta y$. In particular, the *SC+PCa* Specimen retained about 57tf of strength which was close to the peak strength and greater than the yield load under the displacement value of $9\delta y$ which was the limit value of the loading instrument.



(a) *RC* Specimen



(b) *SC+PCa* Specimen

Fig. 3 Load–displacement curves

This test confirmed that the composite steel and concrete pier had the following structural performances:

(1) The hoop reinforcement has enough restriction effects on the H-steel columns with ribbed flanges without being in direct contact with them.

(2) The proposed composite structure has better deformability and higher seismic performance ductility than the reinforced concrete structure.

4. Construction Method

So far, three highway bridge projects have adopted the new composite steel and concrete structure. In this chapter, the construction of actual highway bridge piers with a hollow circular section exemplifies the construction method of this new structure. Fig. 4 is the schematic drawing of the bridge, and Fig. 5 is the structural drawing of P_2

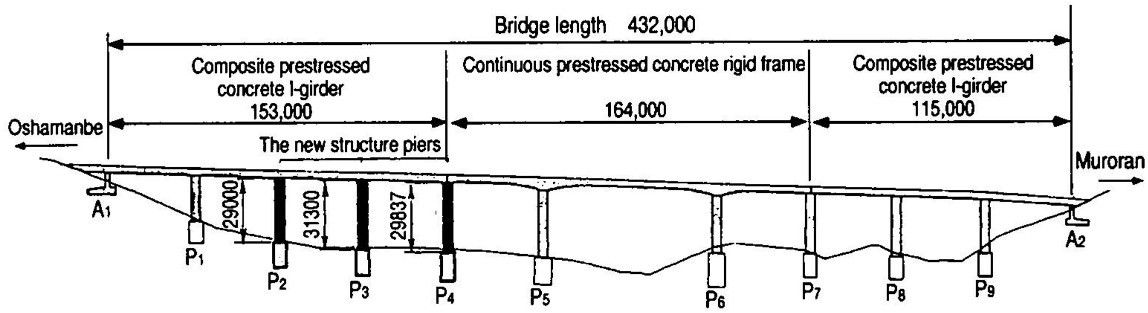


Fig. 4 Schematic drawing of the bridge

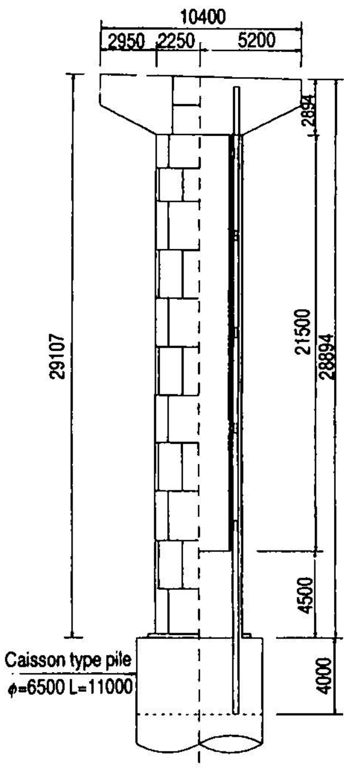
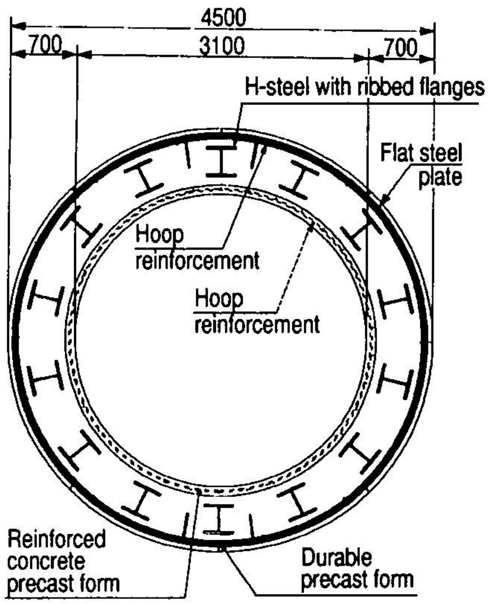


Fig. 5a Structural drawing of the pier 2



H-steel with ribbed flanges	H-318×313×15×24
Durable precast form	t= 50 mm thick
Reinforced concrete precast form	t=100 mm thick
Outer hoop reinforcement	D19@150
Inner hoop reinforcement	D19@250

Fig. 5b Standard cross section

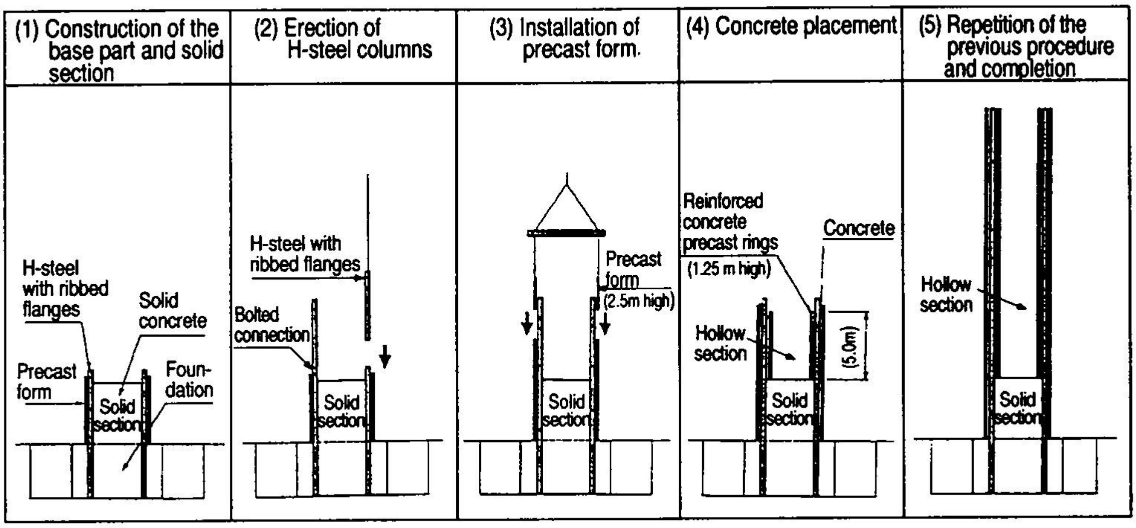


Fig. 6 Construction procedure

4.1 Construction procedure

Fig. 6 gives the conceptual drawings of the construction procedure.

(1) H-steel columns with ribbed flanges were positioned inside a caisson type pile to become the bottom section columns into which concrete was placed. The base part was then completed.

(2) The H-steel columns (5 m long) for the next section were erected, and then connected to the bottom section columns by high tension bolts.

(3) Precast forms were installed after being fabricated in the assembly yard on the ground (Photograph 1). The joints were bonded with resin mortar and sealing rubber which enabled both the transmission of compressive forces and sealing against water penetration under a tensile load.

(4) Cylindrical reinforced concrete precast rings were installed to become the inner form, and concrete was placed into the annulus.

(5) The procedure from (2) to (4) was repeated. After the pier shaft was finished, the pier head was erected and the construction was completed (Photograph 2).

4.2 Erection cycle

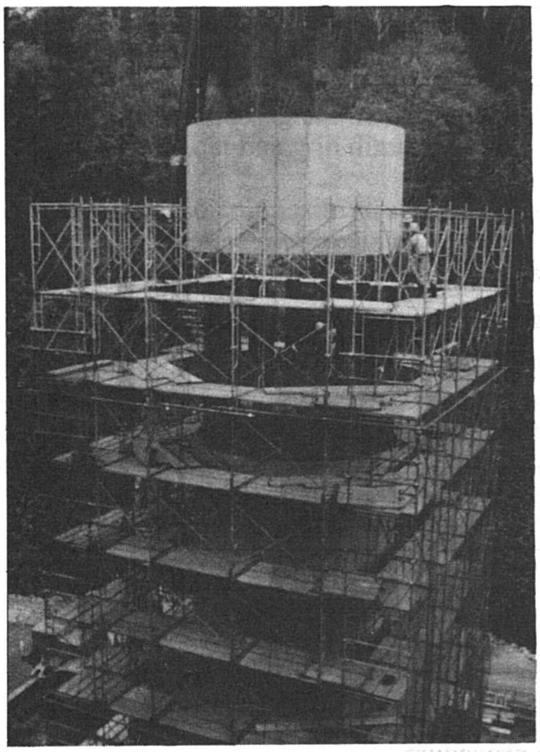
Table 1 shows the erection cycle of a unit lift (5 m), which was adopted when constructing P2, 3 and 4 piers in the project.

4.3 Results

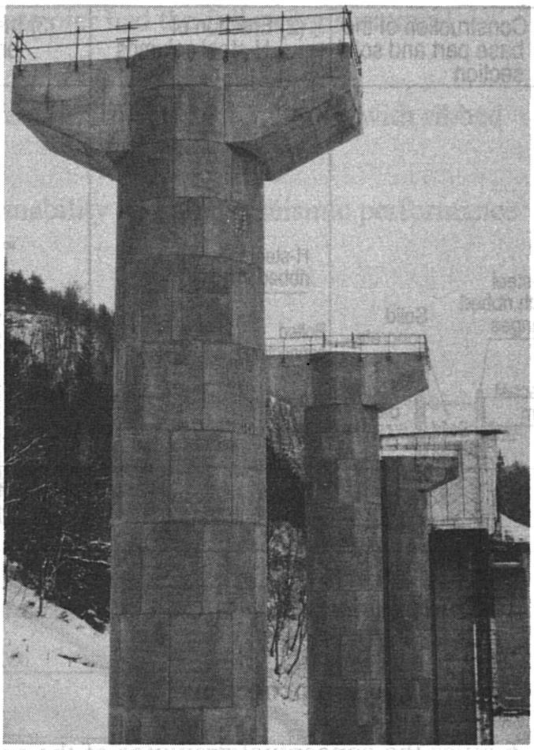
The following results were obtained by comparing the piers constructed in the new method with P8 pier erected in the conventional method:

(1) The construction of piers was 2.8 times faster in the new method than in the conventional method when comparing the average construction periods.

(2) Labor was reduced by about 40% as compared with the conventional construction method.



Photograph 1 Installation of precast form



Photograph 2 Completed bridge pier

Table 1 Construction cycle of the hollow part of the bridge pier (for one erection cycle of 5m)

		Day one	Day two	Day three	Day four
1	Fabrication of scaffolding				
2	Erection of H-steel columns				
3	Erection of precast forms				
4	Erection of inner reinforced concrete rings				
5	Concrete placement				
6	Clearing of laitance				

5. Future Objectives

In respect of the initial objectives, the shortening of the construction period by 66% has been achieved. With regard to the saving of labour, the following improvements can be made:

(1) To reduce the number of bolted connections by extending the unit of the H-steel columns with ribbed flanges to over 10 m.

(2) To rationalize the fabrication work of the precast forms, which occupies 33% of the total labour requirement to achieve a higher efficiency.

(3) To reduce the number of workers and time needed for scaffolding works as much as possible by systematizing the falsework, such as by employing travelling stages.