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EXPERIMENTAL STUDY FOR APPLYING ULTRA-HIGH STRENGTH PRESSTRESSING STRANDS TO HIGH STRENGTH CONCRETE

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ABSTRACT: Steel makers have developed a new class of prestressing strands with 20% higher tensile strength than conventional products in terms of both yield strength and tensile strength. The development of ultra-high strength prestressing strands increases freedom in the PC cable arrangement, and when used in combination with high strength concrete, ultra-high strength prestressing strands are expected to result in higher performance in PC structures, and particularly in pretensioning structures. In this research, a design study of the effect of applying ultra-high strength prestressing strands to pretensioning-type slab system PC bridges is carried out, and an experimental investigation of the applicability issues is conducted by performing prestressing tests and bending loading tests with PC beams using 15.2ϕ ultra-high strength prestressing strands. As a result, we confirmed when ultra-high strength prestressing strands are applied to high strength concrete, the inherent high compressive strength possessed by the concrete can be demonstrated to the fullest possible extent, making it possible to reduce the girder height and girder weight in comparison with normal prestressing strands. As the bond-transfer-length of ultra-high strength prestressing strands, it is considered possible to apply the value stipulated in Japanese Specifications for Highway Bridges (hereinafter, JSHB), and as the prestressing strand spacing, it is considered possible to use the minimum PC strand spacing in actual pretensioning girders. It is also found that the effective prestress of pretensioning girders using ultra-high strength prestressing strands can be calculated by the method described in JSHB.

KEYWORDS: Ultra-high strength prestressing strand, High strength concrete, Pretension member, Bond performance, Bond-transfer-length, Effective prestress

1. INTRODUCTION

Recent years have seen progressively higher performance in the component materials in concrete structures. High strength reinforcing bars of the SD670 class are now used, and in the practical application of ultra-high strength concrete, materials with high strength exceeding 100N/mm^2 have also been developed in the field of lightweight concrete [1].

On the other hand, in the field of PC strands, no great progress was seen after the development of low-relaxation materials. Recently, however, steel makers have developed a new class of prestressing strands (hereinafter referred to as ultra-high strength prestressing strands:USP) with 20% higher tensile strength than conventional products (hereinafter, normal prestressing stands:NSP) in terms of both yield strength and tensile strength. The development of USP increases freedom in the PC cable arrangement, and when used in combination with high strength concrete, USP are expected to result in higher performance in PC structures, and particularly in pretensioning structures.

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However, there are issues which must be resolved for application of USP to pretensioning-type structures. These include the development of a calculation method for the bond-transfer-length and effective prestress, and elucidation of the effects of the prestressing strand arrangement and spacing and loading conditions on the performance of PC beams.

In this research, a design study of the effect of applying USP to pretensioning-type slab system PC bridges was carried out, and an experimental investigation of the above-mentioned issues was conducted by performing prestressing tests and bending loading tests with PC beams using 15.2ϕ USP.

2. FEATURES OF USP [2]

USP are a type of product in which high tensile strength is achieved by increasing the contents of C (carbon), Si (silicon), and Cr (chromium) in the chemical composition of the material from those in NSP and adjusting the production process. In comparison with NSP, both yield strength and tensile strength are improved. The characteristics of USP are shown in Table 1. Although the Young's modulus of USP is substantially the same as that of NSP, both the tensile load and yielding load are approximately 20% higher than in NSP. Comparing relaxation characteristics, the relaxation value of USP is 1.0% after 1000 hours, which is superior to the 1.1% of NSP.

Table 1. Characteristics of USP

Name of PC strand	Kind of PC strand	Nominal cross section area (mm^2)	Breaking load (kN)	Load relative to 0.2% permanent elongation (kN)	Elongation (%)	Relaxation value (1000h) (%)
SWPR7BL ϕ15.2	USP	138.7	326	289	7.7	1.0
	NSP	138.7	272	243	7.2	1.1

3. DESIGN STUDY

3.1 DESIGN TRIAL CONDITIONS

The form of the structure used in the design trial was a pretensioning-type slab system PC bridge. The design conditions are shown in Table 2, and the classification of the designs is shown in Table 3. The HFA aggregate in these tables is a high strength artificial lightweight aggregate made from fly ash, using coal ash as the main raw material, and falls under JIS A 5002, "Lightweight aggregate for structural concrete". Unlike conventional artificial lightweight aggregates, although HFA aggregate is light in weight, its performance includes high strength and Young's modulus close to that of ordinary aggregate. When used in concrete, unit mass is approximately 10-15% lower and Young's modulus is about 15% smaller than those with ordinary aggregate, but other physical properties show basically the same values, confirming that this aggregate is fully applicable to PC structures [3].

Table 2. Design conditions

Structure type	Pretensioning type slab system PC bridge
Length of the girder	24.7 m
Span of the bridge	24.0 m
Width of the bridge	0.6 m + 9.5 m + 0.6 m
Angle of the bridge	90°00′00″
Design load	B live load in JSHB

Table 3. Classification of the designs

Symbol	Specified design strength	Type of concrete	Class of PC strand
NS50	$50N/mm^2$	Ordinary aggregate	NSP
NH50		HFA aggregate	
NS80	$80N/mm^2$	Ordinary aggregate	
US80			USP
NH80		HFA aggregate	NSP
UH80			USP

3.2 STUDY RESULTS

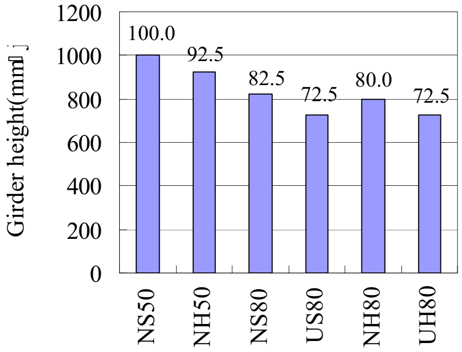

Figure 1. Study results for girder height

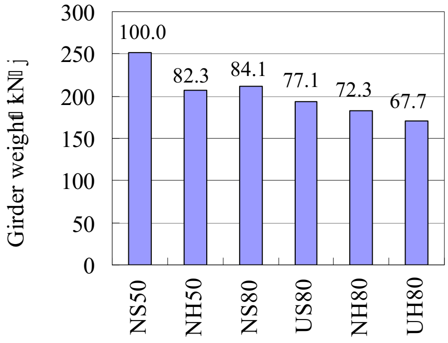

Figure 2. Study results for girder weight

The study results for girder height and girder weight are shown in Figure 1 and Figure 2, respectively. When HFA aggregate is used, at a specified concrete strength of 50N/mm^2, a 75mm (7.5%) reduction in girder height and 44.6kN (17.7%) reduction in girder weight can be seen in comparison with the ordinary aggregate. Moreover, even at 80N/mm^2, the reduction effect is 25mm (3.0%) in girder height and 29.6kN (14.0%) in girder weight. However, with a specified concrete strength of 80N/mm^2, arrangement of the prestressing strands becomes difficult due to the increased amount of PC strand material relative to the decrease in girder height. Thus, considering the relationship with the space available for arrangement of the PC strands, there are physical limitations on the reduction in girder height and weight. This problem can be overcome by applying USP, as the same prestressing force as with NSP can be obtained with a smaller number of strands. When USP are applied to a girder with a specified concrete strength of 80N/mm^2 using ordinary aggregate, a reduction effect of 100mm (12.1%) in girder height and 17.7kN (8.4%) in girder weight can be achieved in comparison with NSP. Under the same conditions, the reduction effect with HFA aggregate is 75mm (9.4%) in girder height and 11.7kN (6.4%) in girder weight.

Based on these design trial results, when USP are applied to high strength concrete, the high compressive strength possessed by the concrete can be demonstrated to the fullest possible extent. Moreover, combined use with HFA aggregate concrete can be expected to result in even higher PC structure performance.

4. OUTLINE OF EXPERIMENTS

4.1 SPECIMENS FOR BENDING LOADING TEST

Table 4. List of specimens

Specimens	Class of PC strand	Type of concrete	Specified design strength
NS50	NSP	Ordinary aggregate	50N/mm^2
US50	USP		
US80			80N/mm^2
UH80		HFA aggregate	

A list of the specimens prepared in this research is shown in Table 4. The configuration and dimensions of the specimens are shown in Figure 3. The specimen parameters were the specified design strength and type of concrete and the class of prestressing strand. Two prestressing strands were arranged in the specimens, and the strand spacing was set at 61.25mm, which is the minimum spacing of the strands used in actual pretensioning girders.

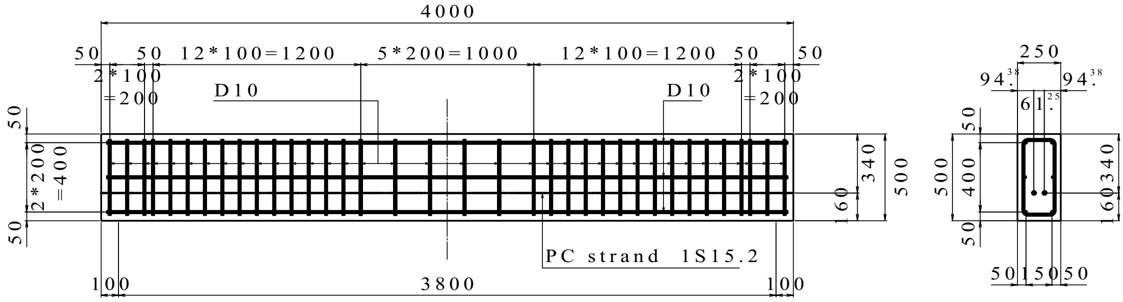

Figure 3. Configuration and dimensions of specimens

4.2 EXPERIMENTAL METHOD

In this research, the following three types of experiments were performed in order to investigate the applicability of USP to the pretensioning construction method.

4.2.1 Measurement of Bond-transfer-length

As shown in Figure 4, concrete strain gauges were attached to the side of the specimens at the positions of the steel strands to measure the concrete stain when tensioning force was introduced. The bond-transfer-length was then estimated by the method of least squares.

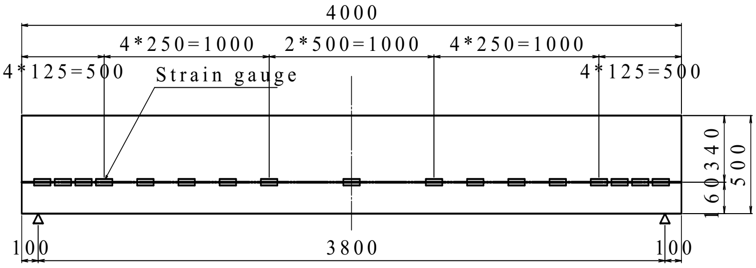

Figure 4. Attaching positions of strain gauges

4.2.2 Measurement of Stress Change on Prestressing Strands

The changes over time in the concrete strain at three points in the central part of the specimens were measured 30 days after introduction of tensioning force, and the change in stress on the prestressing strands was calculated assuming that the change in the strain in the prestressing strands is equal to the change in concrete strain.

4.2.3 Bending Loading Test

The measured and calculated values of the cracking load and ultimate load of PC girders using USP were compared, and differences in the fracture shape were observed.

5. EXPERIMENTAL RESULTS

5.1 BOND-TRANSFER-LENGTH EXPERIMENT

The measured results of the bond-transfer-length experiment are shown in Table 5. When NS50 and the other three specimens are compared, the introduced tensioning force was smallest in NS50, but the bond-transfer-length was largest. Thus, the bond-transfer-length showed a tendency to decrease with increasing concrete strength when tensioning force was introduced, and this was independent of the class of prestressing strand.

Moreover, with all of the specimens, the bond-transfer-length was 65ϕ or less, which is the value stipulated in Japanese Specifications for Highway Bridges (JSHB). This means that it is possible to apply the conventional provision for the bond-transfer-length given in JSHB and a prestressing strand spacing of 61.25mm, which is the minimum strand spacing in actual pretensioning girders with USP, which enable an approximate 20% increase in the introduced tensioning force.

Table 5. Measured results of bond-transfer-length experiment

Specimens	**Mechanical properties of concrete at prestressing**		**Bond-transfer-length (mm)**
	Compressive strength (N/mm^2)	**Young's modulus (kN/mm^2)**	
NS50	44.6	2.93	723 (48ϕ)
US50	46.2	3.00	641 (42ϕ)
US80	64.4	3.42	588 (39ϕ)
UH80	63.3	2.59	610 (40ϕ)

5.2 PRESTRESSING STRAND TENSION CHANGE EXPERIMENT

The change over time in prestressing strand stress is shown in Figure 5; a list of the measured results of stress changes in the prestressing strands is shown in Table 6. The calculated values of the stress on prestressing strands 30 days after introduction of tensioning force were obtained using a calculation method in accordance with JSHB, and considered creep, drying shrinkage, and relaxation of the pretensioning strands. The measured values of stress on the prestressing strands were obtained from the amount of change in strain at three points in the central part of the specimens with the concrete strain gauge used in the bond-transfer length experiment, based on the assumption that the strain in the prestressing strands is equal to that in the concrete.

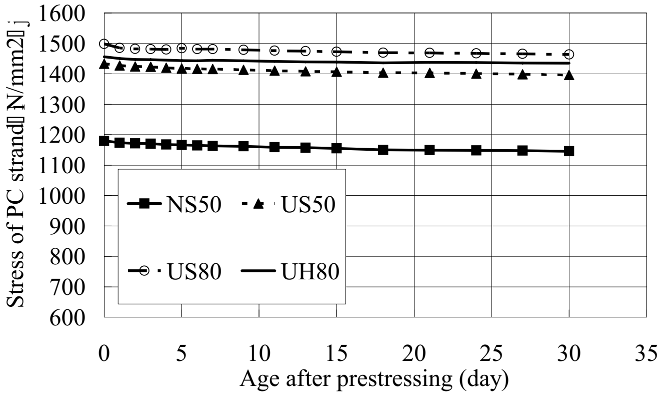

Figure 5. Stress changes in strands after prestressing

Table 6. Results of stress changes in prestressing strands

Specimens	**Stress of PC strand (initial prestressing) (N/mm^2)**	**Stress of PC strand (30 days after prestressing)**	
		Measured value (N/mm^2)	**Calculated value (N/mm^2)**
NS50	1179.57	1145.39	1139.25
US50	1433.54	1396.13	1384.43
US80	1497.93	1462.48	1448.99
UH80	1456.00	1434.61	1400.75

From these results, the stress on the prestressing strands 30 days after introduction of prestress is larger than the calculated values in all of the specimens, clarifying the fact that calculations of effective prestress by the conventional method can also be applied to pretensioning girders using USP.

5.3 BENDING LOADING EXPERIMENT

The results of the bending loading experiment are shown in Table 7. The relationship between loading and displacement in each of the specimens is shown in Figure 6. With all of the specimens, the measured values of the cracking load and ultimate load exceed the calculated values. Looking at the relationship between loading and displacement, the two specimens which consist of a combination of USP and ordinary aggregate concrete all possess flexural rigidity equal to or greater than that of NS50. The flexural rigidity of UH80 is slightly lower than that of the other specimens. This difference is attributed to the fact that HFA aggregate concrete is used, and as a result, Young's modulus is smaller than that of the specimens using ordinary aggregate concrete.

Table 7. Results of the bending loading experiment

Specimens	**Mechanical properties of concrete**			**Cracking load**		**Ultimate load**	
	Compressive strength	**Tensile strength**	**Young's modulus**	**Calculated value**	**Measured value**	**Calculated value**	**Measured value**
	(N/mm^2)	**(N/mm^2)**	**(kN/mm^2)**	**(kN)**	**(kN)**	**(kN)**	**(kN)**
NS50	60.4	4.0	3.49	129.0	140	259	327
US50	67.2	4.4	3.55	152.0	170	296	360
US80	87.0	5.1	3.87	167.0	200	302	380
UH80	88.0	4.0	2.93	145.0	160	301	370

6. CONCLUSIONS

The knowledge obtained within the scope of this research may be summarized as follows.

(1) When USP are applied to high strength concrete, the inherent high compressive strength possessed by the concrete can be demonstrated to the fullest possible extent, making it possible to reduce the girder height and girder weight in comparison with NSP. Moreover, further reductions in girder height and weight can be achieved by combined used of USP and HFA aggregate concrete.

(2) As the bond-transfer-length of USP, it is considered possible to apply the value (65ϕ) stipulated in Japanese Specifications for Highway Bridges, and as the prestressing strand spacing, it is considered possible to use 61.25mm, which is the minimum PC strand spacing in actual pretensioning girders.

(3) The effective prestress of pretensioning girders using USP can be calculated by the method described in Japanese Specifications for Highway Bridges.

(4) Pretensioning girders in which USP are applied show no change in bond performance due to loading, and the cracking load and ultimate load also exceed the calculated values. Based on these results, it can be concluded that USP possess bond performance equal to that of the NSP which are currently in use.

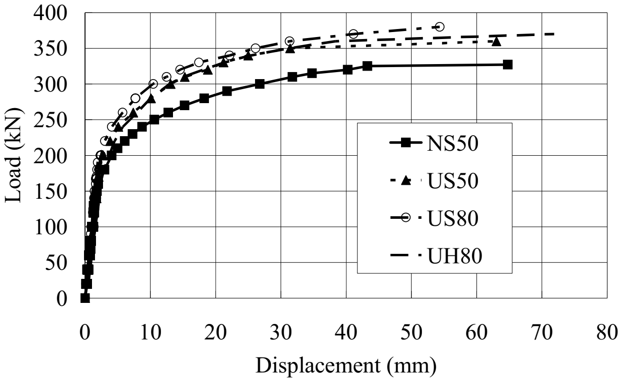

Figure 6. Relationship between loading and displacement

7. REFERRENCES

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