Behavior of Prestressed Concrete Beams with Artificial Lightweight Aggregate

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1.Introduction

Recently, several artificial lightweight aggregates (hereinafter called ALA) made from coal ash which is industrial waste have been developed[1), 2)]. Distinctive features of these aggregates are lightweight, low water absorption, high strength and free from alkali-aggregate reaction. By using these aggregates for prestressed concrete (hereinafter called PC) bridges, which is recycling of waste, it is made possible to lighten self-weight of superstructure, and lightened superstructure will lead to rationalization of the execution, and reduction of the cost of bridges. However, modulus of elasticity, tensile strength, and bond strength of concrete with these aggregates are small as compared with those of normal concrete. Therefore, it is necessary to check the properties of PC such as transfer length and effective stress of prestressing strand. So we prepared several PC beams and measured such properties. Aggregates used in this experiment were two types of ALA (hereinafter called TL and UL) with different density and natural gravel (hereinafter called N). The absolute dry density of TL, UL and N were 1.81kg/l, 1.32kg/l and 2.78kg/l, respectively.

2.Experimental program

2.1Transfer length

Fig. 1 and Table 1 show the details and characteristics of beams, respectively. Each beam was pretensioned with 15.2 mm strands in diameter. Stirrups are arranged so as to prevent shear failure. In order to investigate the transfer lengths with different spacings, spaces of prestressing steels of the specimens were 50.00mm, 61.25mm, and 70.00mm. 61.25mm is same as JIS beam. Fig. 2 shows the location of gauges. In order to investigate the transfer lengths of strands and effective stresses of prestressing strands, we measured stresses of strands at release and time dependent loss of strands during 3 months. After the measurements, we carried out loading tests with each specimen to confirm the strength. In loading tests, all specimens were simply supported and loaded with two points.

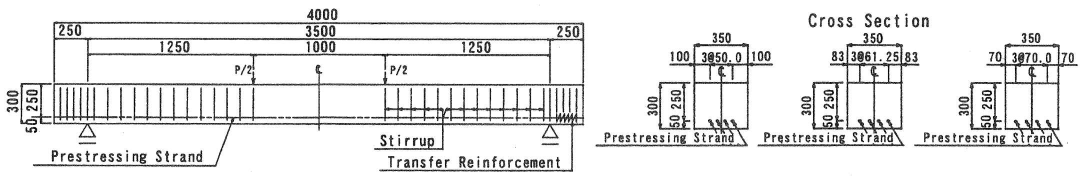


Fig. 1 Details of test beam

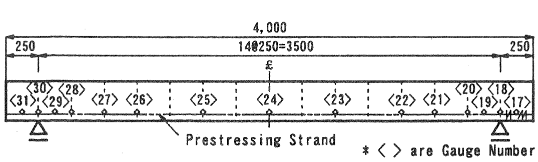


Fig. 2 Location of electric strain gauges on strand

Table 1　Characteristics of test beams

Name of Specimen	Name of Aggregate	Size of Cross Section		Space of Prestressing Steel (mm)	Effective Stress of Prestressing Strand* Pe (kN)	Calculated Value at Cracking	Calculated Value at Ultimate Bending
		Width b (m)	Height h (m)				
S-1	TL	0.35	0.30	61.25	845	148	316
S-2	UL				836		
S-3	N				866		
S-4	TL			50.00	845		
S-5	N				866		
S-6	TL			70.00	845		

* Effective stress of prestressing strand is after 3 months from at release.

2.2Material Properties

Table 2, Table 3 and Table 4 show the material properties, the strength properties of concrete at just before loading tests and the mix design of concrete, respectively. The aimed compressive strength of concrete was 60MPa. Natural sand was used as fine aggregate.

Table 2　Material properties

Cement (C)			High-Early-Strength Portland Cement, Density: 3.14g/cm^3
Water (W)			Running Water
Fine Aggregate (S)			Density:2.61 kg/l, Water Absorption Ratio:3.0%
Coarse Aggregate (G)	ALA	TL	Absolute Dry Density: 1.81 kg/l, Water Absorption Ratio: 2.4% Solid Content: 63.0%, Maximum Size: 15mm
		UL	Absolute Dry Density: 1.32 kg/l, Water Absorption Ratio: 0.9% Solid Content: 62.6%, Maximum Size: 15mm
	Natural Gravel	N	Surface Dry Density: 2.80 kg/l, Water Absorption Ratio: 0.7% Solid Content: 63.0%, Maximum Size: 20mm
Prestressing Strand (SWPR7BL)			Yield Strength: 1570N/mm^2 Ultimate Tensile Strength: 1860N/mm^2
Steel Bar (SD345)			Yield Strength: 345N/mm^2

Table 3　Strength properties of concrete

Type of Concrete	Type of Aggregate	Compressive Strength σ_c'(N/mm^2)	Modulus of Elasticity E_c(kN/mm^2)	Tensile Strength σ_t(N/mm^2)
S-1	TL	67.4	28.4	3.7
S-2	UL	67.8	26.1	3.9
S-3	N	60.4	32.2	4.1
S-4	TL	67.4	28.4	3.7
S-5	N	60.4	32.2	4.1
S-6	TL	67.4	28.4	3.7

Table 4　Mix design of concrete

Type of Concrete	Type of Aggregate	Air (%)	W/C (%)	Unit Weight (kg/m^3)				Unit Weight of Concrete* (kg/l)
				W	C	S	G	
TL60	TL	4.5	40	160	400	837	642	2.04 (0.86)
UL60	UL		36	160	444	801	458	1.86 (0.78)
N60	N		40	160	400	837	972	2.37 (1.00)

( ) are ratio to N60

3.Test result and consideration

3.1The investigation of transfer length

(1) Influence of type of aggregates

Fig. 3 shows the stress change of PC strands at release. The calculated value was obtained with normal calculation method, taking pull in strand, relaxation and elastic deformation of beam into consideration. Modulus of elasticity for calculation was the actual value of concrete. In all aggregates, the measured transfer lengths were almost equal and were approximately 65 times the

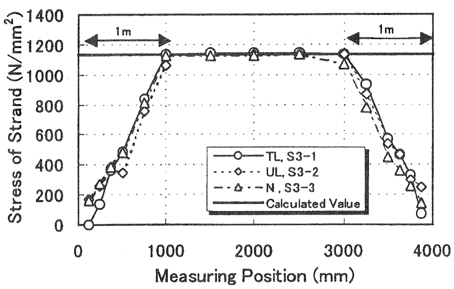
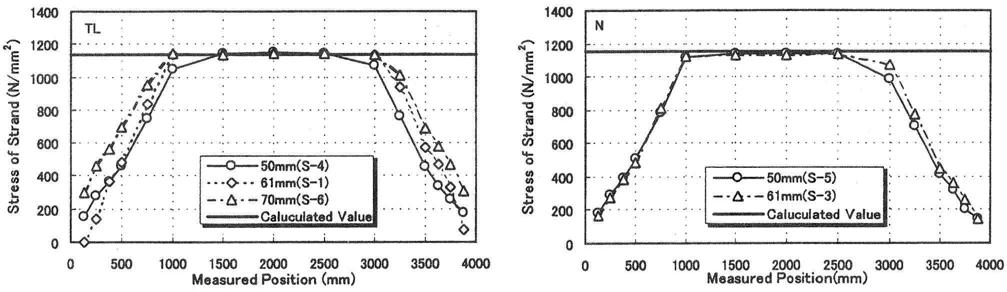


Fig. 3 Stress change of PC strands at release

strand diameter (=988mm). The transfer lengths of strands which made from ALA are almost equal to that of made from normal aggregates.

(2) Influence of pitch of prestressing steels

Fig.4 shows the influence of pitch of prestressing steels on transfer lengths. In the case of pitch of prestressing steels 50.00mm, the stresses of strands at 1m from the end of the beam are smaller than the calculated values for both in TL and N. It is realized that transfer lengths tend to be a little longer. In Concrete with TL as well as N, spaces of prestressing steels need more than 3 times of the strand diameter.



a) HFA (TL)　　b) natural aggregate

Fig.4 Influence of pitch of prestressing steels on transfer lengths

3.2 Investigation into effective stress of prestressing strand

Fig.5 and Table 5 show time dependent loss of strands at center of span. Numbers on legend in figures show location of gauges. Calculated values of effective stresses after 3 months from casting, were obtained with the similar calculation method used for normal JIS beam taking influences of creep and shrinkage on concrete into consideration. In all specimens, measured values of strands have been more than calculated values for 3 months from at release. It is realized that specified prestressing forces were introduced. The stress of strand in concrete with TL or UL after 3 months from at release is bigger than N. This reason is that creep and shrinkage on concrete with lightweight aggregates are smaller than those on concrete with normal aggregates[3].

Table 5　Stresses of Strands

Name of Specimen	Type of Concrete	Stress of Strand: Just after release σ_{pt}(N/mm^2) Measured Value	Calculated Value	Ratio※	After 3 months σ_{pe}(N/mm^2) Measured Value	Calculated Value	Ratio※
S-1	TL	1141	1134	1.01	1082	1015	1.07
S-2	UL	1135	1126	1.01	1064	1004	1.06
S-3	N	1142	1156	0.99	1141	1041	1.01

※Ratio is measured value to calculated value

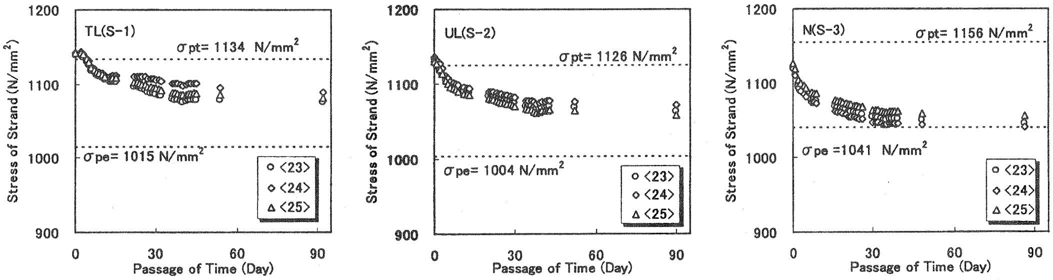


Fig.5 Time dependent loss of strands

3.3 Loading test

Fig. 6 shows load-displacement curves for different pitches of prestressing steels. The calculated value of cracking load is the load by which the stress of bottom of the beam reaches tensile strength, and that of flexural breaking load is calculated from ultimate resistant bending moment. In the case of over 61.25mm pitches of prestressing steels, cracking and breaking loads are equal or bigger than calculated values. On the other hand, in the case of 50.00mm pitch of prestressing steels, flexural breaking load is less than the calculated value and that isn't satisfied with the required condition of beam. Because of small pitch, bond between strand and concrete was gone. Pitches of prestressing steels need to be more than 61.25mm in view of flexural strength of PC beam.

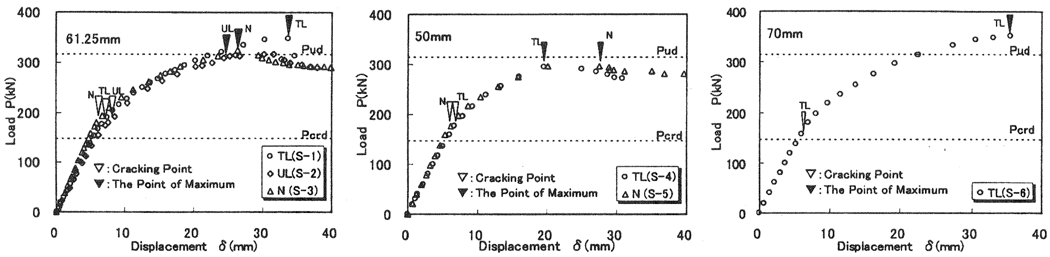


Fig. 6 Load-displacement curves

4.Conclusions

Based on the results of this investigation about PC beams made from artificial lightweight aggregates, following conclusions are drawn.

1. Transfer lengths of strands in concrete with ALA are almost equal to those in concrete with natural aggregates.
2. If pitches of prestressing steels are small, transfer lengths tend to be big. Spaces of prestressing steels need more than 3 times the strand diameter in concrete with TL as well as concrete with normal aggregates.
3. Effective stresses of prestressing strands from at release through 3 months later exceeded the calculated values, so it is said that specified prestressing forces were introduced.
4. Measured stresses of strands in concrete with ALA on 3 months later from at release tend to be bigger than that in concrete with normal aggregates. This reason is that influences of creep and shrinkage on concrete with artificial lightweight aggregates are smaller than that on concrete with normal.
5. If the pitches of prestressing steels are small, flexural strengths are also small. This reason is that bond between strand and concrete is small, so pitches of prestressing steels need to be more than 61.25mm which is equal to JIS beam.

Acknowledgement

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