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論文

EFFECT OF SIZE AND SLENDERNESS RATIO OF SPECIMEN ON STRESS-STRAIN BEHAVIOR OF CONFINED HIGH STRENGTH CONCRETE

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中心圧縮を受けるコンファインド高強度コンクリートの塑性変形性能における形状・寸法効果

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A series of uniaxial compression tests of confined concretes have been carried out to examine the size effects on their compressive behavior. The strength of concrete has been varied from about 300 to 700 kgf/cm2. Based on the test results, discussion has been carried out on the relation between concrete strength and the size effects on the compressive strength, strain at the peak stress, and stress-strain curve of confined concrete.

1. INTRODUCTION

For the analytical discussion of rotation capacity of RC beams, it is very important to understand quantitatively the confining effects of lateral reinforcement on the ductility of concrete in the damaged compressive zone of RC members. The authors have already examined the plastic deformation behaviors of confined concrete under uniaxial compression and RC beams under flexure, and reported that, for both cases, specimens showed more brittle behavior with increasing size of specimen, regardless of the spacing of lateral reinforcement and curing condition [1-3].

Recently, high strength concrete up to 600 kgf/cm^2 is being used practically in high rise building construction in Japan. The discussions in the earlier reports by the authors are, however, limited on the concrete of water-cement ratio of 55% or compressive strength of about 300 kgf/cm^2. The purpose of the present study is to examine the effects of size and slenderness ratio (height -width ratio) of specimen on the stress-strain behavior of confined concrete under compression, taking the compressive strength of concrete into account.

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2. EXPERIMENTAL PROCEDURES

2.1 OUTLINE OF EXPERIMENT

Outline of the uniaxial compression test of confined concrete prisms is shown in Table 1. Testing variables include the section size (bxb, b=9.7, 15, 20, and 30 cm) and the height(H)-width(b) ratio of specimen (H/b=2 and 3), water-cement ratio (W/C=32, 42, and 55 %), and spacing of hoops (S=b/4, b/2, b, and infinity). The size of specimen and the arrangement of hoops are illustrated in Figs. 1 and 2, respectively.

Diameters of hoops were selected for the lateral reinforcement ratio (As/Acv, where, As: cross-sectional area of hoops, Acv: vertical cross-sectional area of core concrete) to be approximately 0.3 % for the specimen with hoops of S=b. The mechanical properties of hoops used are shown in Table 2 with confining stress index (σyAs/Ac). Judging from the index, confining stress on the specimens with 30x30 cm section (ϕ13 mm bar was used as hoops) is assumed to be a little larger than the others. The number of specimens prepared for each combination of parameters was 2, and the total number was 192.

2.2 FABRICATION AND CURING OF SPECIMENS

Ordinary Portland cement, river sand (<5 mm), crushed stone (10-20 mm), and superplasticizer (only for W/C=32 and 42 %) were used for the fabrication of concrete. Slump was designed to be 18 cm. Concrete was cast horizontally for all the specimens. Three batches of concrete for each water-cement ratio were mixed by using the 600 litter Smith type mixer. Variation of the averaged compressive strength of ϕ10x20 cm concrete cylinder was within 3.2 % between the batches. All the specimens were cured in an air conditioned room (20±1℃ and relative humidity of 85±5%) until the tests, which were carried out at the age of 6 weeks.

Table 1 Outline of compression test of concrete prisms

Size of prism			Hoop		Longitudinal bar	Curing condition
Section b×b (cm)	Height H=3b (cm)	Height H=3b (cm)	Diameter ϕ (mm)	Spacing S	Diameter (mm)	
7.3× 7.3	14.5	21.9	3.2	b/4 b/2 b plain	2.7	In air In water
9.7× 9.7	19.4	29.1	3.9			
12.5×12.5	24.9	37.5	4.9			
15.0×15.0	30.0	45.0	5.7			
20.0×20.0	40.0	60.0	8.0			

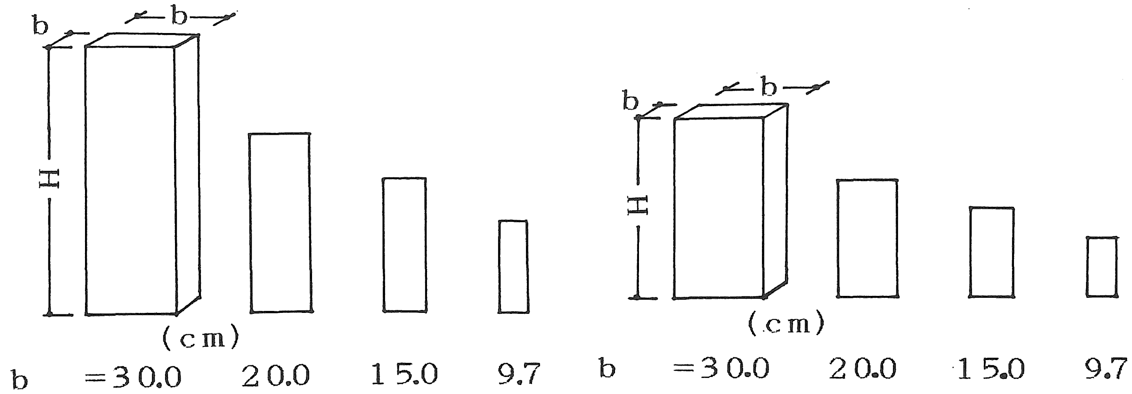
Table 2 Mechanical properties of hoops

Nominal diameter	Measured diameter (mm)	Yield strength σy (kgf/cm^2)	Maximum strength σu (kgf/cm^2)	Elongation (%)	$\sigma y \cdot As/Ac$ (kgf/cm^2)
ϕ3.2	3.19	2420	3430	29.2	6.37
ϕ3.9	3.90	2280	3350	40.9	5.04
ϕ4.9	4.98	1940	3070	41.6	4.19
ϕ5.7	5.93	2980	3890	31.5	6.34
ϕ8.0	7.96	2650	3530	32.5	5.71

[Notes] As:Sectional area of hoop, Ac:Area of horizontal section of core concrete

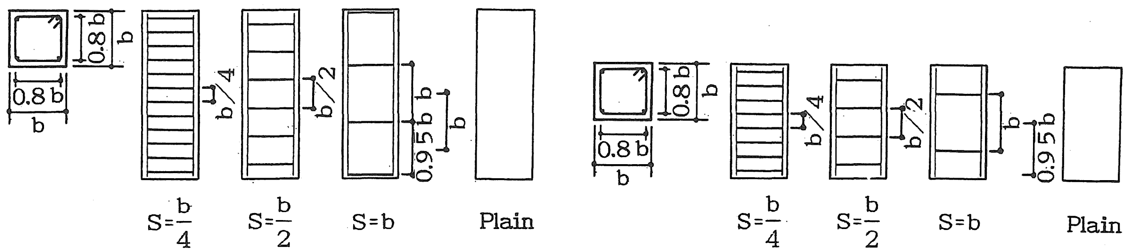
2. 3 METHODS OF LOADING AND MEASUREMENT

The method of strain measurement of concrete prisms is illustrated in Fig. 3. The strain measuring regions (l_o) for the specimens of H/b=3 were 2b and 2. 8b in the middle height of the specimens, while l_o was 1. 8b for the specimens of H/D=2. Most of the specimens were loaded in an actuator (loading capacity: 200 tf) under the constant strain rate of about 1x10-3 /min. till the strain of the 2b region



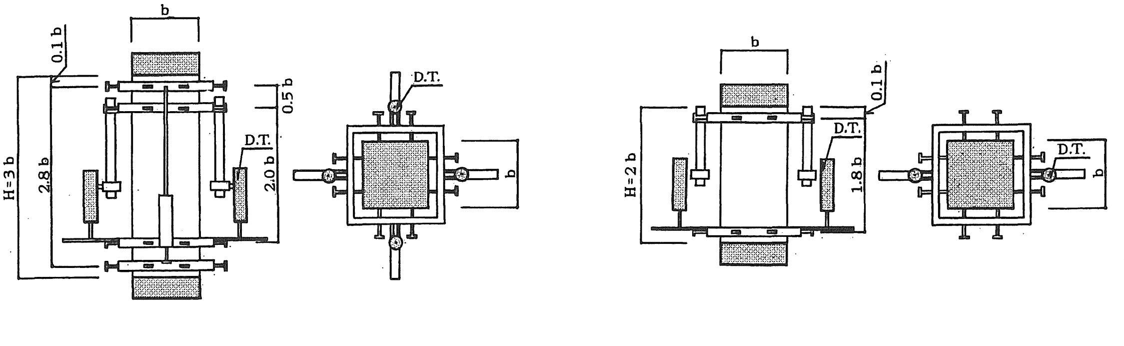
(a) H/b=3 (b) H/b=2

Fig. 1 Size of concrete prisms



(a) H/b=3 (b) H/b=2

Fig. 2 Arrangement of hoops



(a) H/b=3, lo=2b and 2. 8b (b) H/b=2, lo=1. 8b

Fig. 3 Method of strain measurement

reached the specified strain (ε=15x10-3). Large specimens whose load bearing capacity is assumed to be larger than 200 tf were tested in an ordinary type hydraulic compression testing machine (loading capacity: 600 tf).

3. TEST RESULTS AND DISCUSSIONS

3.1 STRESS AND STRAIN AT PEAK POINT

(1)Compressive strength

Figure 4 shows the effect of water-cement ratio (W/C) on the relation between compressive strength and specimen size. The compressive strength is almost constant regardless of the specimen size in case of W/C=55 %. However, in the high strength concrete of W/C=32 %, the compressive strength gradually decreases as the specimen size increases, the compressive strength for the specimens of b=30 cm being smaller than that for the specimens of b=9.7 cm by about 10 % on the average.

(2)Strain at peak stress

Figures 5(a) through (b) show the effect of the pitch of hoops on the relation between strain at the peak stress (ε_m) and specimen size for the case of H/b=2 and l_o=1.8b. It is shown that the value of ε_m generally decreases with increasing size of specimen, regardless of

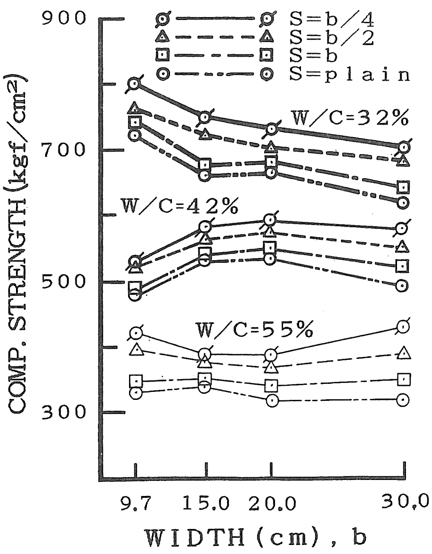


Fig.4 Effect of water-cement ratio on relation between compressive strength and specimen size (H/b=2)

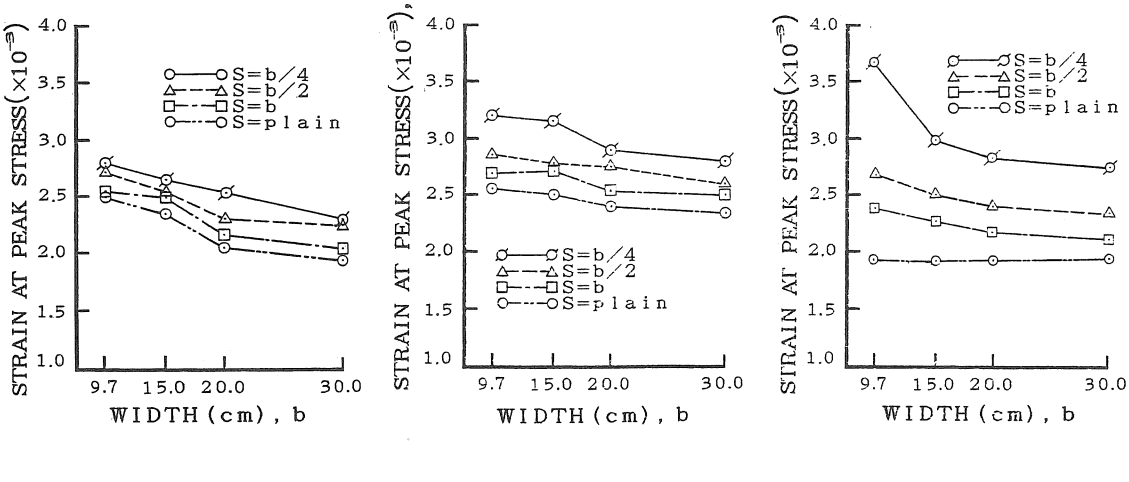
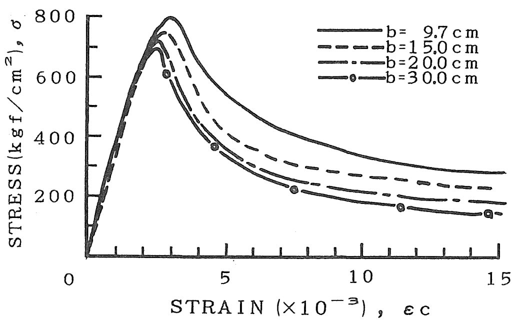


Fig.5 Effect of pitch of hoops on relation between ε_m and specimen size (H/b=2, l_o=1.8b)

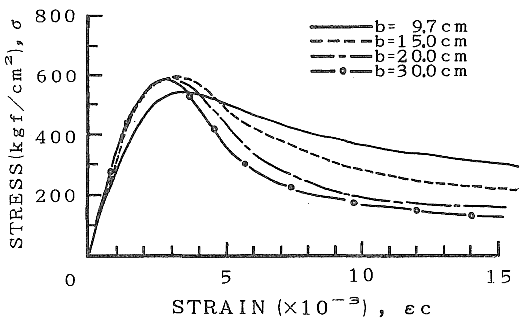
W/C ratio. The value of εm for the specimens of b=30 cm is smaller than that for the specimens of b=9.7 cm by about 15 %, which is the same tendency in the earlier experiment of normal strength concrete [3]. Note that the increment of εm due to hoop reinforcement decreases as W/C ratio becomes small. Almost the same tendency is obtained for the specimens of H/b=3.

3.2 STRESS-STRAIN CURVES OF SPECIMENS WITH DIFFERENT SIZES

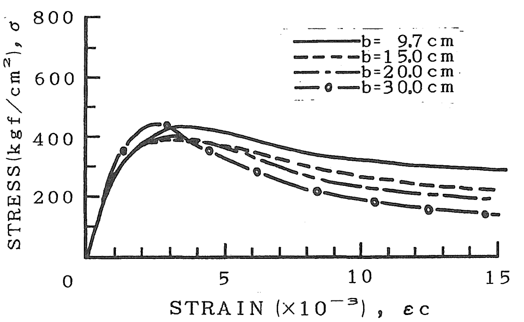
Figures 6(a) through (c) show the effect of the specimen size on the stress-



(a) W/C=32%

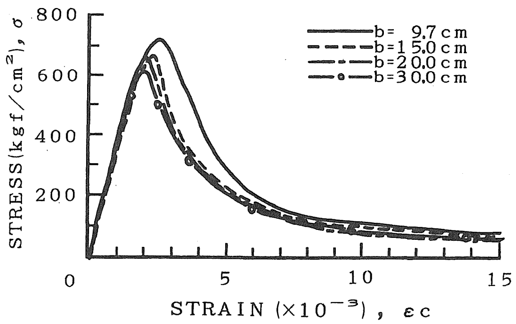


(b) W/C=42%

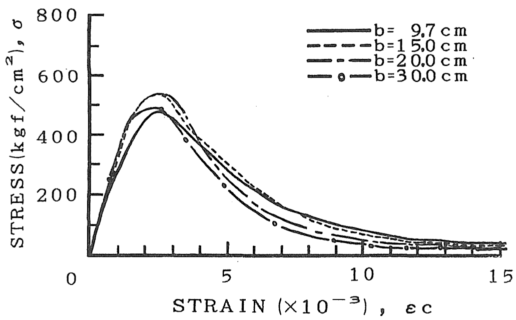


(c) W/C=55%

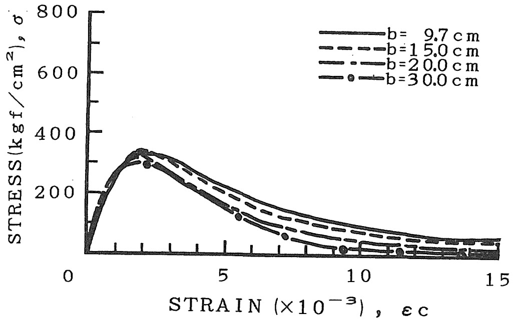
Fig. 6 Effect of specimen size on stress-strain curve (H/b=2, S=b/4)



(a) W/C=32%



(b) W/C=42%



(c) W/C=55%

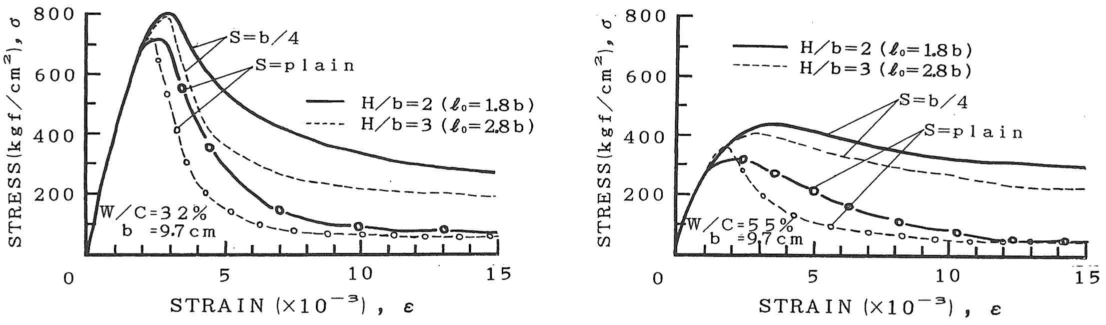
Fig. 7 Effect of specimen size on stress-strain curve (H/b=2, plain) strain curve for the case of H/b=2 and S=b/4. It is shown that the shape of stress descending portion becomes steeper with increasing size of specimen, independently of W/C ratio. The amount of reduction of compressive toughness (area under the stress-strain curve) due to the increase in the specimen size is not so different from each other set of the curves of Figs. 6(a) to (c).

As is obvious from the comparison between the curves in Figs. 6 and 7, such size effect on the stress-strain curve is more remarkable for the specimens with densely arranged hoops. This is considered due to the fact that the confining effect by hoops is affected by the magnitude of spacing itself between hoops, as well as S/b ratio. Note that all the specimens are made of the same concrete with the same size of aggregate.

3.3 STRESS-STRAIN CURVES OF SPECIMENS OF DIFFERENT SLENDERNESS RATIOS

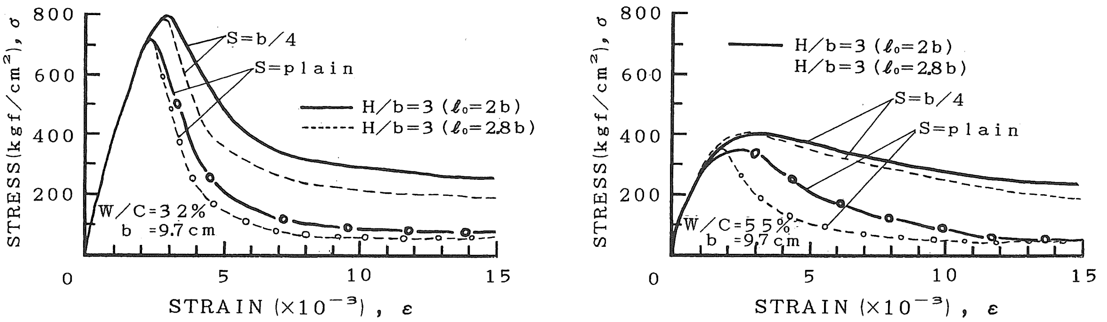
(1) Effect of height-width ratio

Figures 8(a) and (b) show the effect of height-width ratio (H/b) of specimen on the stress-strain curve for the case of b=9.7 cm. Strain measurement length (l_o) is 1.8b for specimens of H/b=2, and 2.8b for specimens of H/b=3. It is observed that, independently of W/C ratio, the descending portions of stress-strain curves of specimens of H/b=2 are much less steep than those of specimens of H/b=3.



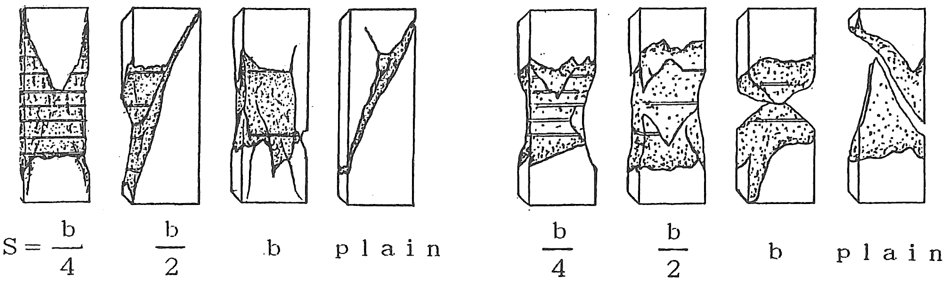
(a) W/C=32% (b) W/C=42%

Fig. 8 Effect of height-width ratio (H/b) on stress-strain curve (b=9.7 cm)



(a) W/C=32% (b) W/C=42%

Fig. 9 Effect of strain measurement length (l_o) on stress-strain curve (H/b=3, b=9.7 cm)



(a) W/C=32%　　(b) W/C=42%

Fig. 10 Failure pattern (b=20 cm)

(2) Effect of strain measurement length

Figures 9(a) and (b) show the effect of strain measurement length (l_e) on the stress-strain curve for the case of H/b=3 and b=9.7 cm. The stress descending portions of stress-strain curves of l_e=2b are less steep than those of l_e=2.8b, regardless of W/C ratio. This is considered due to the fact that the occupying ratio of undamaged zone within the strain measurement region is larger for l_e=2.8b than that for l_e=1.8b. Figures 10(a) and (b) show examples of failure pattern of the specimens of b=20 cm.

Note that this tendency becomes a little less remarkable as specimen size increases. Further, the stress descending portions of stress-strain curves measured between the loading plates were a little steeper than those from both l_e=2.8b of H/b=3 and l_e=1.8b of H/b=2, independently of W/C ratio.

4. CONCLUSIONS

The following conclusions can be drawn from the present study.

1) The compressive strength is almost constant regardless of the specimen size in case of W/C=55 %. However, in the high strength concrete of W/C=32 %, the compressive strength gradually decreases as the specimen size increases, the compressive strength for the specimens of b=30 cm being smaller than that for the specimens of b=9.7 cm by about 10 % on the average.

2) The strain of the peak stress (ε_m) for the specimens of b=30 cm is smaller than that for the specimens of b=9.7 cm by about 15 %, regardless of W/C ratio, which is the same tendency in the earlier experiment of normal strength concrete [3]. Note that the increment of ε_m due to hoop reinforcement decreases as W/C ratio becomes small.

3) The shape of stress descending portion becomes steeper with increasing size of specimen, independently of W/C ratio.

4) The size effect on the stress-strain curve is more remarkable for the specimens with densely arranged hoops. It is considered due to the fact that the confining effect by hoops is affected by the magnitude of spacing itself between hoops.

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