Effect of Size and Slenderness Ratio of Specimen on Stress-Strain Curve of Confined Concrete under Different Curing Condition

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コンファインドコンクリートの応力－ひずみ関係に及ぼす供試体の形状・寸法の影響

小池狭千朗・畑中重光 *

A series of uniaxial compression tests of confined concretes were carried out to examine the effects of size and slenderness ratio of specimen on stress-strain curve. Based on the test results, not only the effects of the size and slenderness ratio but also relation between the curing condition and size of specimen and between the strain measurement length and slenderness ratio of specimen on the curve were discussed.

1. INTRODUCTION

For the analytical discussion of rotational capacity of RC beams, it is quite important to grasp quantitatively the confining effect of lateral reinforcement on the ductility of compressive concrete in the damaged zone of the RC members. The authors have already examined the plastic deformational 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[1,2].

Size effect on mechanical properties of concrete is considered to be mainly due to the drying of specimen which hinders hydration of cement. Therefore, it is predicted that various size effects may be obtained, depending on curing condition.

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In the previous experiment [1], however, the specimens were cured only in the atmosphere of a laboratory. In addition, concerning the effect of dimension of specimen, measured stress-strain curves of plain concrete are reported to be quite different depending on the slenderness ratio of specimen and strain measurement region [3].

The purpose of the present study is to examine the effects of relations between the size of a specimen and curing condition, and between slenderness ratio (height-width) of specimen and strain measurement region on the stress-strain curves of confined concretes.

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 size (bxbxH) and the height(H)-width(b) ratio of specimen, curing condition, and spacing (S) of hoops. The size of specimen and the arrangement of hoops are illustrated in Figs. 1 and 2, respectively. The prisms are designed to be consistent with the compressive zones of RC beams tested in the previous experiment [1]. Namely, the width (b) of section of prisms and the spacing (S) of hoops are chosen to be equal to the width of section and the spacing of stirrups, respectively, of the RC beams. Screw bolts of φ6mm (φ4mm only for b=7.3cm series) were embedded in prisms at the pitch of b, as shown in Fig. 2. Plain concrete specimens without a screw bolt were also fabricated.

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 height (H) of prisms was chosen to be twice

Table 1 Outline of uniaxial compression test of concrete prisms

Size of prism			Hoop		Longitudinal bar	Curing condition
Section b×b (cm)	Height		Diameter φ (mm)	Spacing S	Diameter (mm)	
	H=3b (cm)	H=3b (cm)				
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

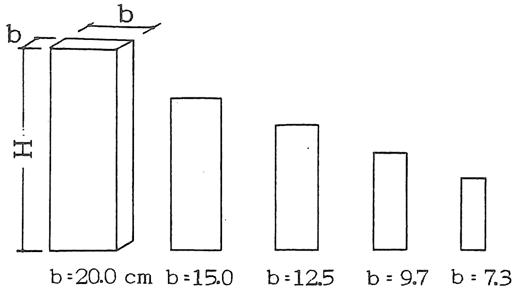
Nominal diameter	Measured diameter (mm)	Yield strength σ_y ($\mathrm{kgf/cm^2}$)	Maximum strength σ_u ($\mathrm{kgf/cm^2}$)	Elongation (%)	$\sigma_y \cdot As/Ac$ ($\mathrm{kgf/cm^2}$)
φ3.2	3.19	2420	3430	29.2	6.37
φ3.9	3.90	2280	3350	40.9	5.04
φ4.9	4.98	1940	3070	41.6	4.19
φ5.7	5.93	2980	3890	31.5	6.34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

[Notes] As:Sectional area of hoop, Ac:Area of horizontal section of core concrete and three times the width(b) of the section i.e. H=2b or 3b. The number of specimens prepared for each combination of parameters was 2, and the total number was 160.

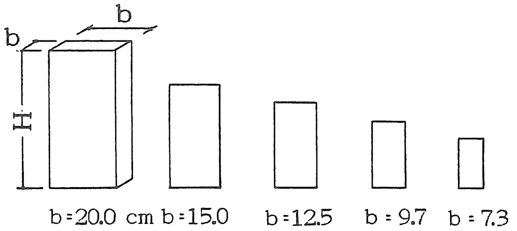
2.2 FABRICATION AND CURING OF SPECIMENS

Ordinary Portland cement, river sand (<5 mm), and river gravel (5-25 mm) were used for the fabrication of concrete. Water-cement ratio of 55% was chosen, and slump was 15 cm. Six batches of concrete was mixed in the 600 litter Smith type mixer. The average of the compressive strength of concrete cylinder of ϕ10x20 cm cured in water was 420 kgf/cm2, and the variation between the batches was within 15 kgf/cm2.

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 12.5x12.5 cm section (ϕ4.9 mm bar was used as hoops) is assumed to be a

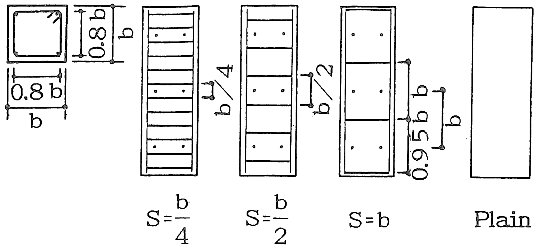


(a) H/b=3

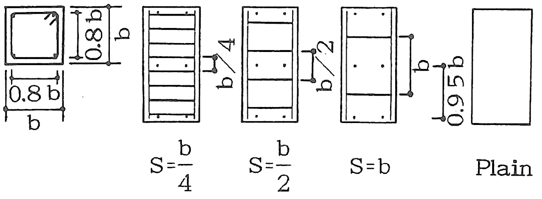


(b) H/b=2

Fig. 1 Size of concrete prisms

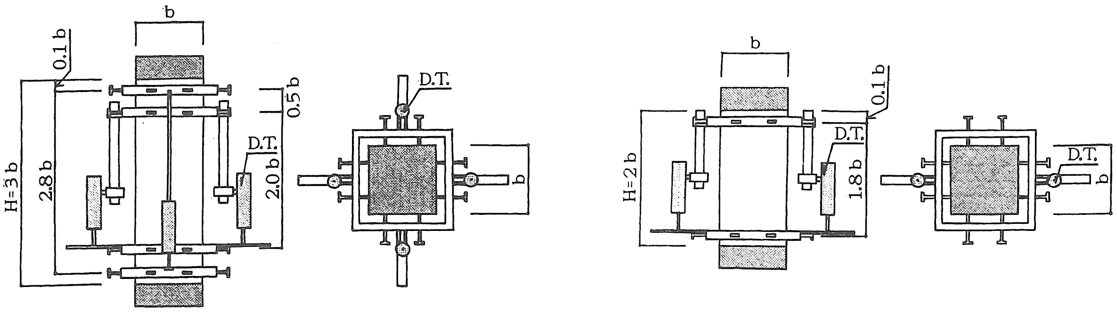


(a) H/b=3



(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

little smaller than the others. Concrete was cast horizontally for all the specimens, and tests were carried out at the age of 24 weeks. A half number of specimens were cured in water (20±1℃) and remaining half were cured in air (20±1℃ and relative humidity (R.H.)= 90±10% till the age of 8 weeks, after that, 20±1℃ and R.H.=85±5% till the age of 24 weeks), hereinafter, referred to as "in a moist room".

2.3 METHODS OF LOADING AND MEASUREMENT

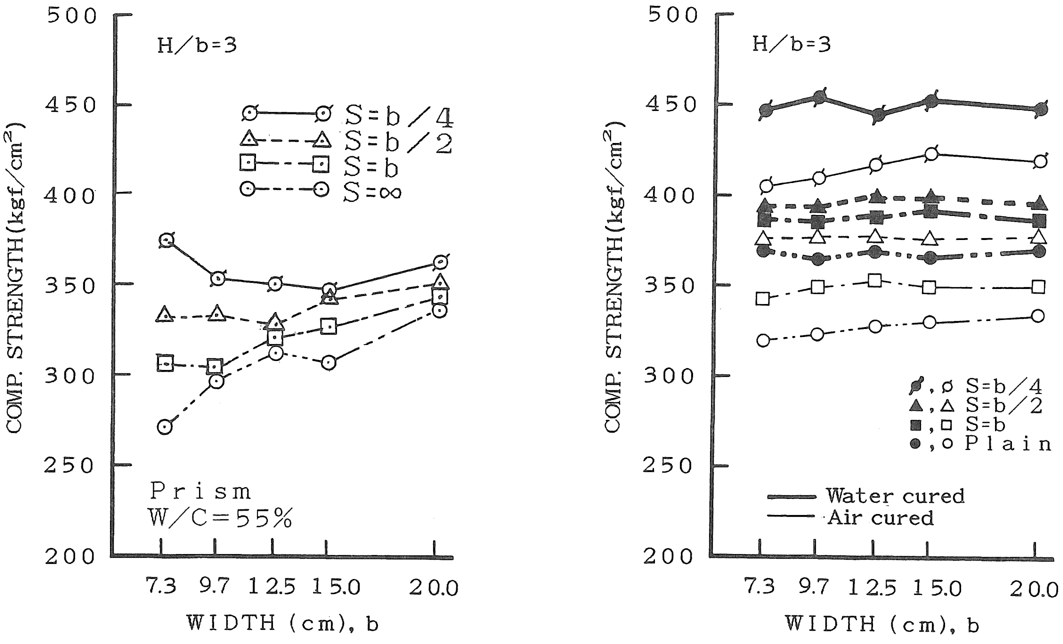
The method of strain measurement of concrete prisms is illustrated in Fig.3. The strain measuring regions (lo) for specimens of H/b=3 were 2b and 2.8b in the middle height of the specimens. Specimens were loaded in an actuator (loading capacity: 200 tf) under the constant strain rate of about 1x10-3/min. till the strain of the 2b region reached the specified strain (ε=15x10-3).

3. TEST RESULTS AND DISCUSSIONS

3.1 STRESS AND STRAIN AT PEAK POINT

(1)Compressive strength

Figures 4(a) and (b) show the effect of curing condition on the relation between the compressive strength and specimen size for various spacing (S) of hoops. Previous experimental data shown in Fig.4(a) was obtained from the specimens cured in a laboratory where relative humidity (R.H.) varied in 60±20%. It is shown, for plain concrete (S=∞) and confined concrete with hoops of large spacing (S=b), that the compressive strength increases with increasing size of



(a) Cured in a laboratory

(b) Present experiment

Fig.4 Effect of curing condition on relation between compressive strength and specimen size specimen. This tendency, however, is not recognized for confined concrete with hoops of small spacing (S=b/4, b/2).

As shown in Fig. 4(b), the size effect is hardly recognized for the concrete cured in a moist room (R.H. ≒90%) and in water. Such difference in the effect of curing condition on the compressive strength shown in Figs. 4(a) and (b) is considered due to the fact that drying of specimen at early ages affects the compressive strength to a large extent.

(2) Strain at peak stress

Figure 5 shows the effect of curing condition on the relation between the strain (ε_m) at the peak stress and specimen size for various spacing of hoops. It is shown that the value of ε_m generally decreases with increasing size of a specimen, regardless of curing condition, which is different tendency from the compressive strength. Also, the values of ε_m of specimens cured in air are larger than those cured in water, which is a similar tendency to plain concrete [4]. The increment of the value generally becomes large with the decrease in specimen size and in spacing of hoops. The size effect of the specimens cured in a moist room is very similar to that of the specimens cured in a laboratory obtained in the previous experiment [1]. Almost the same tendency was obtained for the specimens of H/b=2.

Figure 6 shows the effect of height-width ratio (H/b) of specimen on relation between ε_m and specimen size for various spacing of hoops. Strain measurement lengths are almost equal to the whole height of specimens. It is shown that the values of ε_m of specimens of H/b=2 are larger than those of H/b=3, regardless of the pitch of hoops and specimen size. Note that in specimens of H/b=3, as shown in

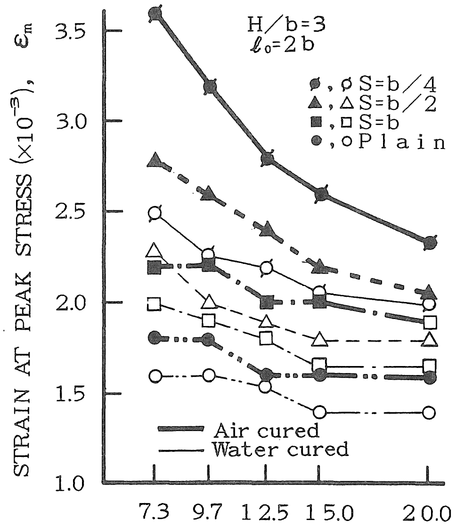


Fig. 5 Effect of curing condition on relation between ε_m and specimen size

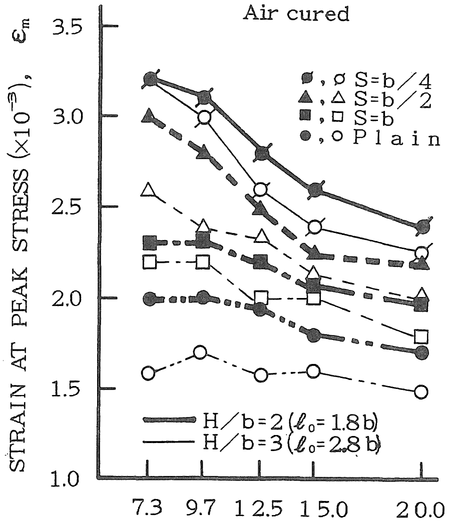


Fig. 6 Effect of height-width ratio of specimen on relation between ε_m and specimen size

Fig. 3(a), concrete is subjected to the confining stress to some extent by the steel frames attached to a specimen to measure the strain in l_o=2b region. Taking the confining effect into consideration, it is predicted that the difference in the value of ε_m between specimens of H/b=2 and 3 without the steel frames is a little larger than that in the figure.

Figure 7 shows the effect of height-width ratio (H/b) of specimen on relation between ε_m and specimen size, where specimens were cured in a moist room and strain measurement lengths (l_o) were 1.8b and 2.0b for H/b=2 and H/b=3, respectively. It is shown that the values of ε_m from specimens of H/b=2 are a little larger than those from specimens of H/b=3, except the specimens of S=b/4. Almost the same tendency was obtained for specimens cured in water although all the

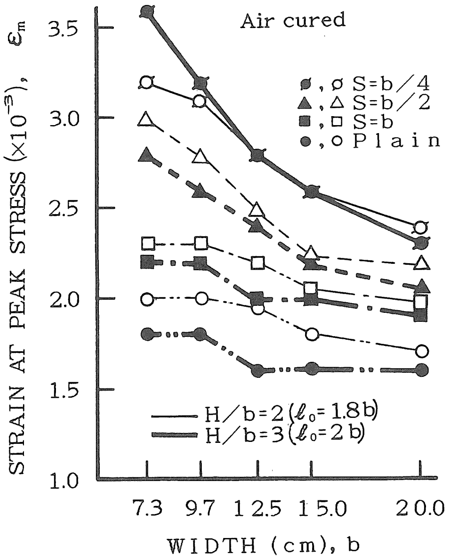
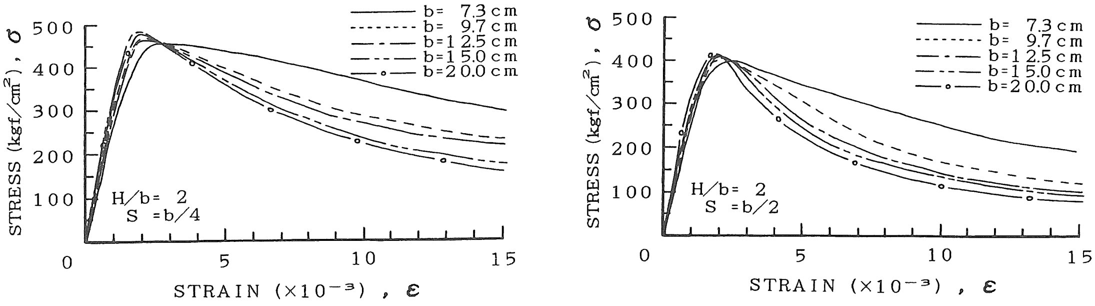
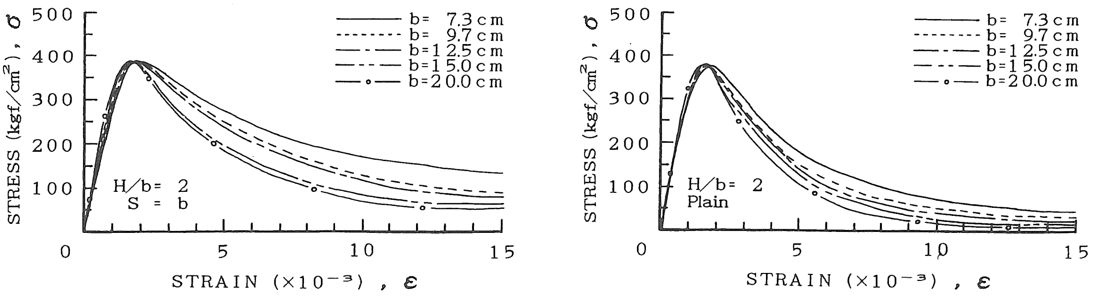


Fig. 7 Effect of height-width ratio of specimen on relation between ε_m and specimen size (for almost equal strain measurement lengths)



(a) S=b/4 (b) S=b/2



(c) S=b (d) Plain

Fig. 8 Effect of specimen size on stress-strain curve (H/b=2, Water cured) values of εm are smaller than those in Fig. 7.

3.2 STRESS-STRAIN CURVES OF SPECIMENS OF DIFFERENT SIZES

(1) Effect of size of specimen

Figures 8(a) through (d) show the effect of the specimen size on the stress-strain curve of confined concrete cured in water for various spacing (S) of hoops. It is shown that the shape of stress descending portion becomes steeper with increasing size of specimen, independently of spacing of hoops. This tendency is similar to that of confined concrete cured in air [1]. However, the size effect is not so large for the specimens of b=10 cm to 20 cm, especially when hoops are densely arranged, e.g. S=b/4 and b/2.

(2) Effect of curing condition

Figure 9 shows the effect of curing condition on the size effect of stress-strain curves. Generally, the compressive strength and the descending portions of stress-strain curves of concrete cured in a moist room are smaller and less steep, respectively, than those of concrete cured in water.

3.3 STRESS-STRAIN CURVES OF SPECIMENS OF DIFFERENT SLENDERNESS RATIOS

(1)Effect of height-width ratio

Figures 10(a) and (b) show the effect of height-width ratio (H/b) of specimen on stress-strain curves. 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 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.

Figure 11 shows comparison between stress-strain curves of experiment and calculation with the idealized damaged zone model proposed earlier [3]. Fairly good agreement is observed in general for all the specimens.

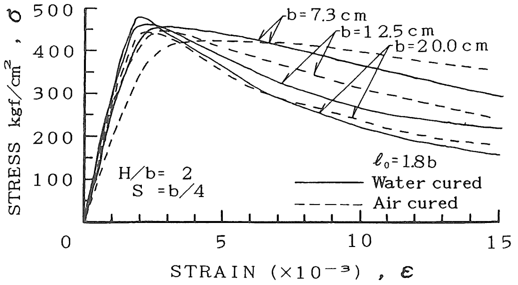
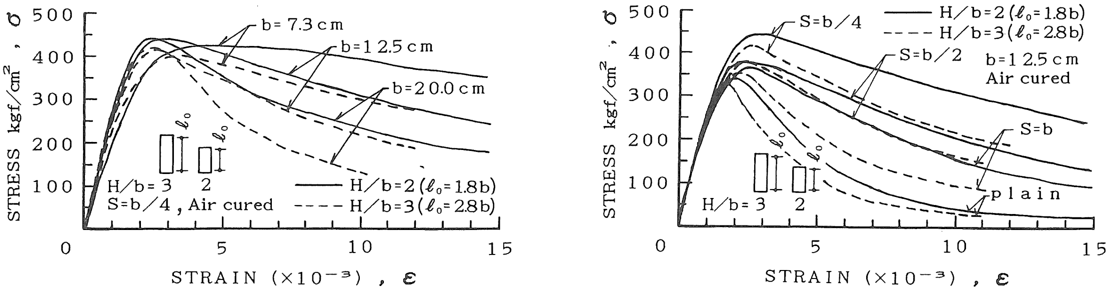


Fig. 9 Effect of curing condition on stress-strain curve



(a) For different specimen size

(b) For different spacing of hoops

Fig. 10 Effect of height-width ratio (H/b) on stress-strain curve

(2)Effect of strain measurement length

Figure 12 shows the effect of strain measurement length (l_o) on stress-strain curves of specimens of different sizes. In specimen of H/b=3, the stress descending portions of stress-strain curves of l_o=2b are much less steep than those of l_o=2.8b, regardless of specimen size. This is considered due to the fact that the occupying ratio of undamaged zone within the strain measurement region is larger for l_o=2.8b than for l_o=1.8b. Further, the stress descending portions of stress-strain curves measured between the loading plates were a little steeper than those from both 10=2.8b of H/b=3 and l_o=1.8b of H/b=2.

Figure 13 shows the effect of height-width (H/b) ratio of specimen on stress-strain curve, where strain measurement length (l_o) are almost the same. According to the figure, the stress descending portions of H/b=2 are a little less steep than those of H/b=3, independently of specimen size. For plain concrete cylinder cast vertically it has been reported that, for the same strain measurement length in the middle height of specimen, measured stress-strain curves are almost the same [5]. The result of the present experiment is different from the report. This is considered partly because of the difference in casting direction of concrete, in failure pattern due to the confining effect by hoops.

4. CONCLUSIONS

The following conclusions can be drawn from the present study.

1)The compressive strength of confined concrete decreases with decreasing size of specimen when cured in air. The size effect is more remarkable for the lower humidity of curing atmosphere. On the other hand, the size effect is almost

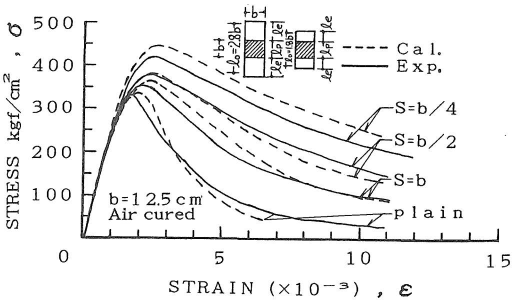


Fig. 11 Applicability of idealized damaged zone model

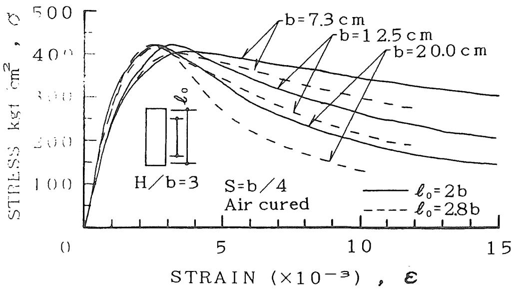


Fig. 12 Effect of strain measurement length on stress-strain curve

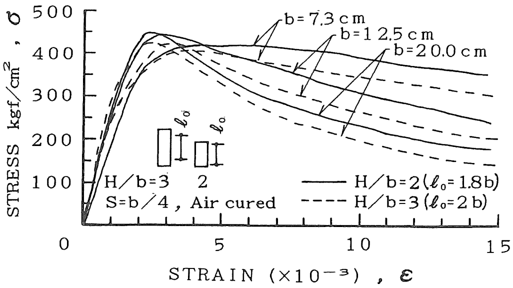


Fig. 13 Effect of height-width (H/b) ratio of specimen (for almost equal strain measurement lengths)

negligible in water cured specimens.

2) The strain (εm) at peak stress of confined concrete increases with decreasing size of specimen. Such size effect is more remarkable for smaller spacing of hoops. The value of εm of specimens cured in air is larger by 10 to 40 % than those cured in water.

3) The stress-strain curve of confined concrete shows more brittle behavior with increasing size of specimen. The stress descending portion of stress- strain curve of concrete cured in air is less steep than those cured in water.

4) The size effect in confined concrete above stated is qualitatively consistent with that in plain concrete reported earlier [1,2]. Quantitatively, however, degree of the size effect depends on the spacing of hoops.

5) The stress-strain curves of confined concrete is influenced by the height-width (H/b) ratio of specimen. For strain measurement length of almost the total height of specimen, the measured curve becomes steeper after the peak point with increasing value of H/b. The relation between the stress-strain curves from different regions are successfully predicted by an idealized damaged zone model proposed earlier [3].

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