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RESTORING FORCE CHARACTERISTICS OF A [STEEL-HOOP-CONCRETE] COMPOSITE COLUMN

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SUMMARY

[Steel-Hoop-Concrete] composite is the steel encased reinforced concrete (SRC) composite without longitudinal reinforcements. It is a new composite system developed by the authors.[1][2] This paper discusses the estimation of the restoring force characteristics of this new composite column with two degrees of deformation freedom through some experimental and analytical examinations. It was clarified that the behavior of SHC column with two degrees of deformation freedom was roughly estimated by degrading stiffness tri-linear model and Giberson's end spring model. SHC column has a quite good aseismic performance.

INTRODUCTION

The authors have been developing the new composite system, [Steel-Hoop-Concrete](SHC) composite and have been studying the fundamental characteristics ofthis new composite for recent several years. In the previous papers,[1][2] mechanical properties of SHC member were examined through compression test, cyclic bending test under constant axial load and cyclic shear bending test under constant axial load. In the cyclic shear bending test,both end rotations of member were controlled to be equal. But end rotations of member are not equal generally during earthquake. Therefore it is hard to say that restoring force characteristics of SHC members have been grasped sufficiently without the investingation of behavior of members in asymmetrical curvature. This paper deals with the restoring force characteristics of SHC column with asymmetrical end rotation histories.

EXPERIMENT

The typical specimen is illustrated in Fig.-1. All the specimens have square cross section of 21cm × 21cm and 80cm length. They are about 1/3 scale models of actual column. Steel encased is H-shaped full-web steel, and it's standard classification is SS41. 6ϕ steel bars were used as the hoop reinforcements. Mechanical properties of steel, hoop reinforcement and concrete are shown in Table - 1 and Table - 2. Compressive strength of concrete is about 450kg/cm^2.

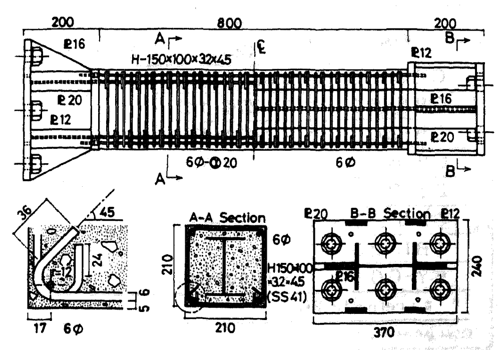


Fig.-1 Details of a typical specimen

Table-1 Mechanical properties of steel and reinforcing bar

	Steel Plate (PL-4.5)	Steel Plate (PL-3.2)	Hoop Reinforcement (6Φ)	
Standard Classification	SS41	SS41	SR24	
Actual Thickness or Size (mm)	4.32	3.07	5.24	
Yield Strength (t/cm²)	3.07	3.99	upper	3.37(4.10)*
			lower	3.32(4.09)*
Tensile Strength	4.23	4.69	4.27	
Strain at the Onset of Stress Hardning (%)	----	----	1.4~1.6	
Elongation (%)	28.3	18.0	29.2	
Classification of test Piese (JIS Z 2201)	No.1(A)	No.1(A)	No.2	

.* Data outside or inside of parenthesis were caluculated with nominal or actual area respectively

Table-2 Mechanical properties of concrete

Age (day)	28	47	62
Compressive Strength σ_B (kg/cm²)	455(453)	452(548)	475(583)
Splitting Tensile Strength (kg/cm²)	32.2(34.4)	28.0(29.1)	34.4(40.7)
σ_B /3 Secant Modulus ($\times 10^5$ kg/cm²)	3.66	3.77	3.63
Strain at the Maximum Stress (%)	1.7~2.2	1.8~2.1	1.8~2.2
Date of Placing	Jun 5,1987		
Slump (cm)	14 ~ 19		

Diameter and Height of Cylinder : 10cm × 20cm (for Compression Strength Test)
10cm × 10cm (for Splitting Tensile Strength Test)

Curing : in Air (Data inside parenthesis ····· in Water)

Table-3 List of specimens

Name	R_w (%)	Compelled End Rotation*
CBS-20	1.35(6Φ-@20)	1
CBS-60	0.45(6Φ-@60)	
CB-20	1.35(6Φ-@20)	3
CB-60	0.45(6Φ-@60)	
BT-20	1.35(6Φ-@20)	2
CBSL-20		5
CBL-20		6
BY-60	0.45(6Φ-@60)	4

* refer to Fig.2

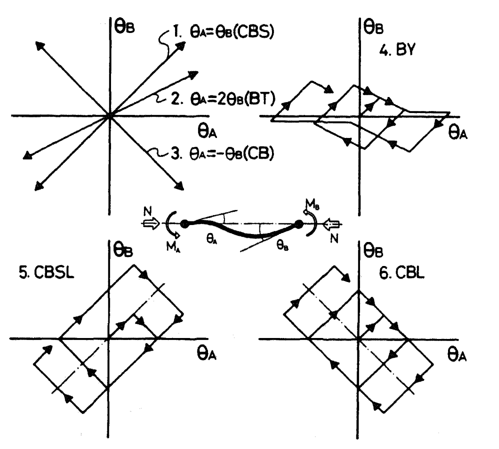


Fig.-2 Compelled end rotation histories

Eight tested specimens are listed in Table-3. Experimental paramaters were the amount of hoop reinforcements and compelled end rotation hislories shown in Fig.-2. Loading system and measuring system is illustrated in Fig.-3. Axial force was loaded through PC bars by two hydraulic jacks installed at the pin end in the axial direction. The axial force loaded was 60 ton which was about 25% of ultimate compressive strength of the specimen. End rotations were imposed on the specimen by two hydraulic jacks through two loading beams installed at both ends of the specimen. Axial deformation and end rotations were measured by dial gages set at both sides of the specimen.

Experimental results of CBS, CB and BT specimens are shown in Fig.-4, Fig.-5 and Fig.-6. Ultimate flexual strength calMu was calculated based on the additional theorem. It was confirmed that hoop reinforcements made the behavior of the SHC column stable.

MOMENT RESPONSE ANALISYS OF SHC COLUMN WITH ASYMMETRICAL END ROTATION HISTORIES USING END SPRING MODEL

With respect to the hysteretic behaviors of the specimens subject to looped $\theta_A - \theta_B$ end rotation histories, namely CBSL-20, CBL-20 and BY-60, experimental results were compared with the analytical results using Gibeson's end spring model.

The fundamental moment-rotation hysteretic characteristics of member model was defined from the test results of the specimen in symmetric double curvature (CBS specimens), and the degrading stiffness tri-linear model [3] was assumed. A typical moment-rotation hysteretic hoop of degrading stiffness tri-linear model is illustrated in Fig.-7. The rules of the hysteretic loop are as follows;

a)The skeleton moment-rotation curve is tri-linear defined by initial slope K_1, second slope K_2, third slope K_3, moments as the stiffness dgrades, Mc and My.

b)As the load reverses, the first stiffness and second stiffness decrease to $\alpha \cdot K_1$ and $\alpha \cdot K_2$; in which α is the ratio of stiffness degradation, follows the next eguation,

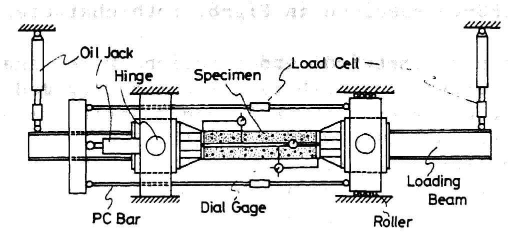


Fig.-3 Loading apparatus and measuring system of end rotations

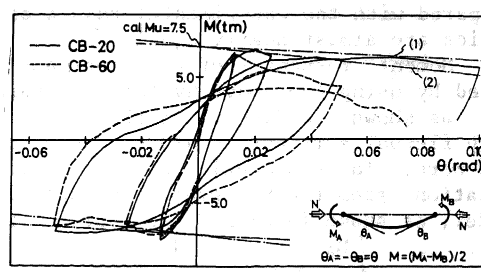


Fig.-5 M - θ relation of CB specimens

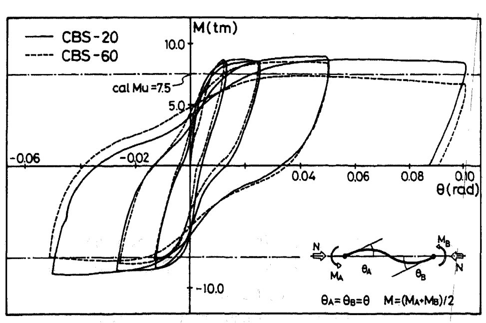


Fig.-4 M - θ relation of CBS specimens

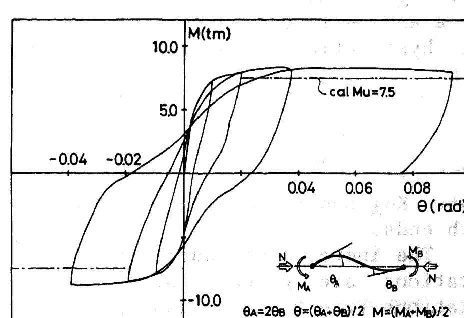


Fig.-6 M - θ relation of BT specimen

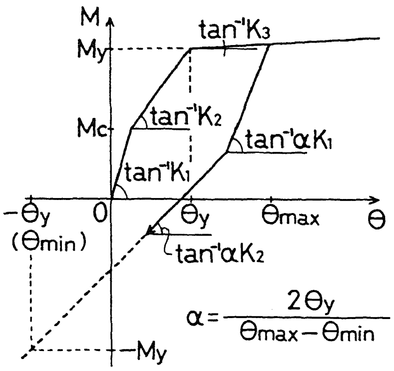


Fig.-7 A typical hysteretic loop of Degrading Stiffness Tri-linear model

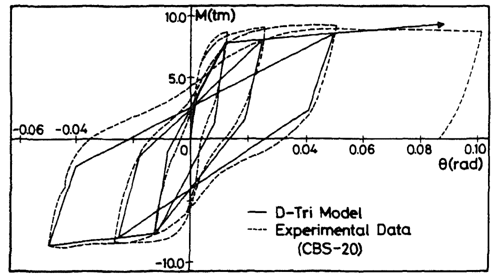


Fig.-8 Hysteretic characteristics of the experimental result and the analytical model

$$\alpha = \frac{2\theta y}{\theta max - \theta min} \quad (1)$$

in which θy is the yield rotation, θmax and θmin are maximum and minimum rotation histories. In case the absolute value of θmax or θmin is smaller than θy, θmax or θmin is θy.

c)The relationship of moment and rotation in the second stiffness stage aims at the past maximum deformation point (θmax or θmin , Mmax or Mmin). When K_1, K_2, K_3, Mc and My are given, the hysteretic loop are determined. In this paper, the above constants were defined as follows; My was caluculated based on the additional theorem. Mc, which is moment when flexual cracks occurs, was desided by Ref.5. K_1 was the addition of stiffness of concrete and steel. K_2 was decided by Ref.5. K_3 was 0.1% for the specimen with hoop reinforcements of Pw=1.35%, and 0.05% for of Pw=0.45%, respectively, considering the effect of hoop reinforcements.

The hysteretic characteristic of the degrading stiffness tri-linear model was compared with the experimental result of CBS-20 specimen in Fig-8. Both characteristics are almost nearly equal.

Moment responses of the specimens with asymmetrical end rotations were analyzed by using the above hysteretic characteristic and Giberson's end spring model [4] as shown in Fig-9. In this model, end springs, a and b, and elastic spring with flexual stiffness K are connected in series. The actual length of $\overline{Aa}$ and $\overline{Bb}$ are zero. The hysteretic characteristic of both end springs are taken the elastic rotation from the hysteretic characteristic of the degrading stiffness tri-linear model, as shown in Fig-10. In Fig-10, end moments, M_A and M_B is given by

$$\begin{Bmatrix} M_A \\ M_B \end{Bmatrix} = K \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{Bmatrix} \theta_A - \alpha_A \\ \theta_B - \alpha_B \end{Bmatrix} = \begin{Bmatrix} g(\alpha A) \\ g(\theta B) \end{Bmatrix} \quad (2)$$

where θ_A is end rotation at A, θ_B is end rotation at B, θ_A is end spring rotation at a and θ_B is end spring rotation at b. K is the flexual stiffness and $g(\alpha)$ is the hysteretic characteristics of the end spring. Representing in incremental form,

$$\begin{Bmatrix} \Delta M_A \\ \Delta M_B \end{Bmatrix} = K \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix} \begin{Bmatrix} \Delta\theta_A - \Delta\alpha_A \\ \Delta\theta_B - \Delta\alpha_A \end{Bmatrix} = \begin{Bmatrix} K\alpha_A \ \ \Delta\alpha_A \\ K\alpha_B \ \ \Delta\alpha_B \end{Bmatrix} \quad (3)$$

where $K\alpha_A$ and $K\alpha_B$ are the stiffness of the end spring described in Fig-10 at the both ends.

The incremental end moments can be solved by eq.(3), When the incremental end rotations are given. The effect of axial force is ignored. The actual end rotations θ_A - θ_B relationship and end moments M_A - M_B relationship of the experimental and analytical results of the specimens with asymmetric end rotation histories are shown in Fig-11, Fig-12 and Fig-13. BY specimen was assumed the

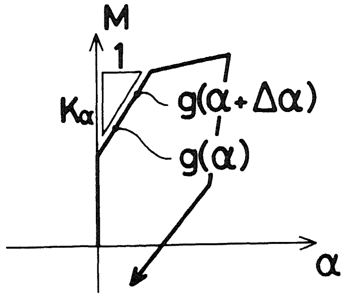


Fig.-10 Hysteretic characteristics of end springs

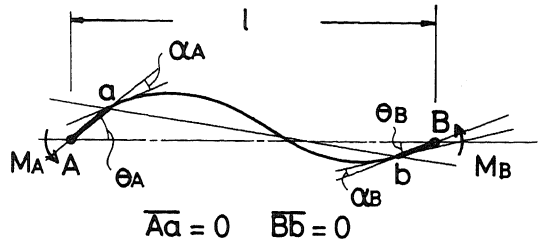


Fig.-9 Giberson's end spring model

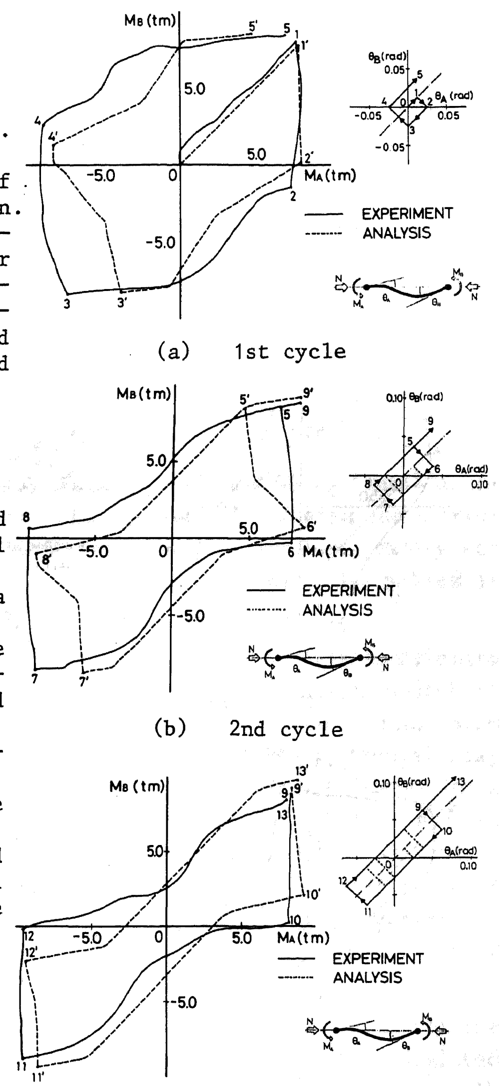
actual column at the base story of the frame. The moment at one end was controlled not to go over 5.0t·m, which is the yieled moment of the beam connected with the end of the column. According to Fig.-11 - Fig.-13, The moment response of [Steel-Hoop-Concrete] column under cyclic loading and under asymmetrical deflection can be roughly estimated using the degrading stiffness tri-linear model for the end moment-rotation hysteretic characteristic and using Giberson's end spring model.

CONCLUSIONS

The following conclusions were obtained through the experimental and analytical examinations.

(1) The restoring force characterisics of a [Steel-Hoop-Concrete] composite column with sufficient hoop reinforcements are stable and can be roughly estimated using the degrading stiffness tri-linear model and Giberson's end spring model.

(2) Because the restoring force characteristics of [Steel-Hoop-Concrete] composite column in asymmetrical deflection can be expected by the above analytical model, cyclic shear-bending test in which both end rotations of member controlled to be equal is apposite as the experiment to examine the restoring force characteristics of [Steel-Hoop-Concrete] composite column.



(a) 1st cycle

(b) 2nd cycle

(c) 3rd cycle

Fig.-11 Moment response of CBSL specimen

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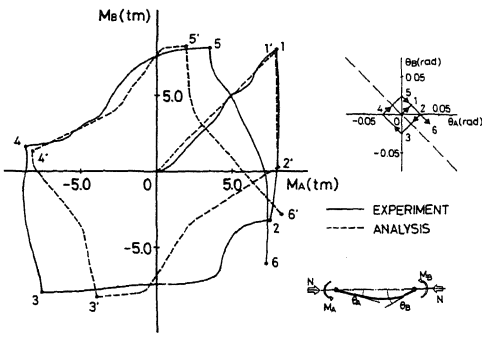
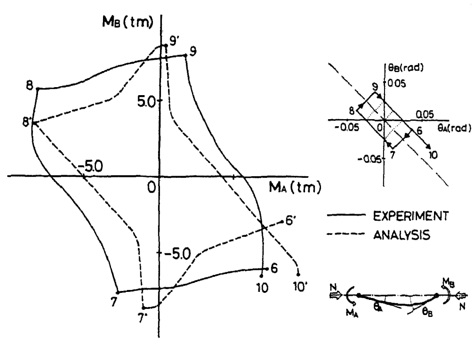
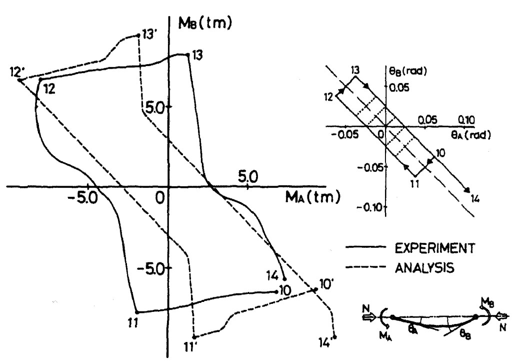


(a) 1st cycle

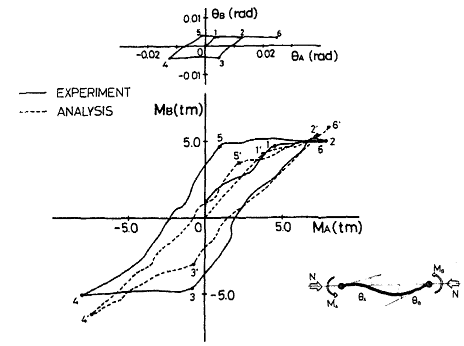


(b) 2nd cycle

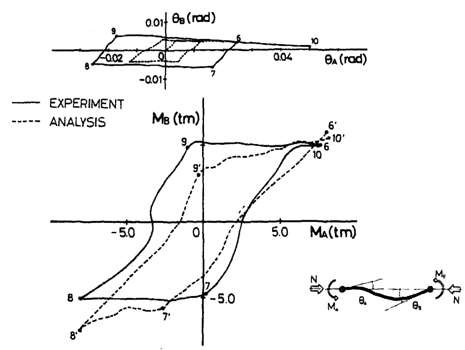


(c) 3rd cycle

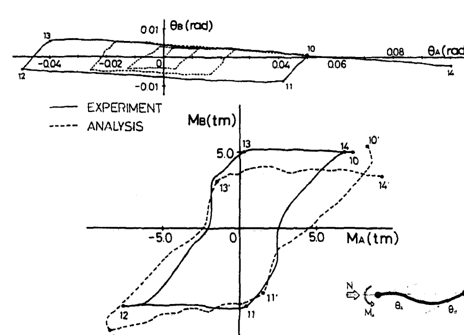
Fig.-12 Moment response of CBL specimen



(a) 1st cycle



(b) 2nd cycle



(c) 3rd cycle

Fig.-13 Moment response of BY specimen