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BEHAVIORS OF REINFORCED CONCRETE BEAM SUBJECTED TO THE AXIAL RESTRICTION OF DEFORMATION

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SUMMARY

When beams yield, the axial elongation can happen. So the beam tending to yield is considered to be subject to the compressive forces from the surrounding structural members.

In this study, the bending shear experiment of rectangular beam and T-shaped beam was performed to consider the effect of axial restriction of deformation, through a simple analysis.

As a result, experiment and analysis show that the bending strength of reinforced concrete beams increase by 50% to 100% because of axial rigidity. This implies a potential that the structure will not collapse in the assumed mechanism.

INTRODUCTION

It is well known that when beams yield, the axial elongation can happen[1),2)]. Should this state occur at all spans, the horizontal length of the building will comprehensively expand. In an actual building, it is difficult to consider that the whole building expands, as it is restricted by the floors and columns; a further horizontal expansion of the building could be restrained if the structural members such as shear walls, binders and unstructural walls existing parallel to the beams considered as having the potential of restricting the horizontal elongation of the building, are existing. In consideration of such a condition, the beam tending to yield is presumably subject to the compressive forces of the structural members surrounding the beam. Compared with the case where no axial force acts on the beams, it would be possible to consider that these compressive forces cause the bending yield strength to increase, resulting in the column collapse of the structure with the yielding of the beams.

In this study, the bending shear experiment of rectangular beam and a T-shaped beam was performed, followed by a simple analysis, in order to consider the effect in the case of axial restriction of deformation.

METHODS OF EXPERIMENTS

Specimens and Materials Figure 1 shows the dimensions of the specimens and their bar arrangements. In preparing the specimens, a beam of 80cm × 35cm was contemplated with reference to the Example 1 given in the Reinforced Concrete Structural Calculation Standard and its Commentary[3)], the beam was then reduced to a 1/4, with the width of beam being equivalent to as large as 2.3 times and its cross section being 20cm × 20cm. The length of the beam is 1m (2a), and a/D=2.5.

The main reinforcement used are deformed bar having the sizes of D10 and D13. The experiments were carried out at the three stages of the Series A, B and C. In the Series A, a rectangular beam symmetrically was arranged with 3-D10 on top layer and 3-D10 on bottom layer, in the Series B, a rectangular beam asymmetrically was arranged with 3-D13 on top layer and 3-D10 on bottom layer, and in the Series C, a T-shaped beam was arranged with 9-D10 on top layer and 3-D10 on bottom layer. With the above three types of cross sections being used, the potential of restricting the axial deformation was studied on each of the series, and a total of six specimens were experimented. With reference to the effective width derived from the equation (1) on page 11 in bibliography 3), the slab with T-shaped beams was given the width and thickness (60cm × 5.4cm) at which the sectional areas become equivalent to the sectional area on a reduced scale, and bar arrangement was determined similarly as well. Tables 1 and 2 show the mechanical properties of the materials used.

Method for Restricting Axial Deformation Figure 2 shows the jigs with which axial deformation will be restricted. In the Series A and B, the axial deformation restricting jig used is such that the H-steels enclosing the stub in the form of a U-shape are linked to a total of 4 plates, 2 each on top and bottom (Fig.2(a)), and in the Series C, the axial deformation restricting jig was manufactured with the H-steel webs installed on the stub being linked to 4 plates (Fig.2(b)). Table 3 shows the designations and sectional configurations of the specimens, and the stiffness of the whole axial deformation restricting jigs, K (hereafter called the axial deformation restricting stiffness). K is the stiffness derived from the relationship between the axial forces generated due to the experiment on the

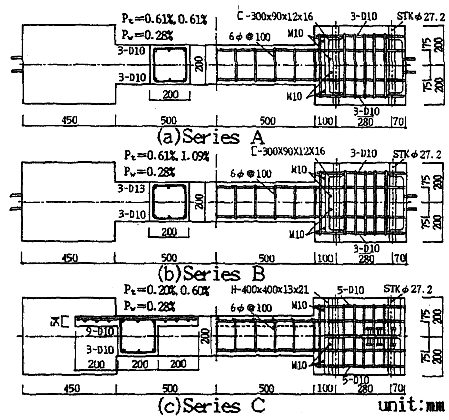

Fig.1 Specimens

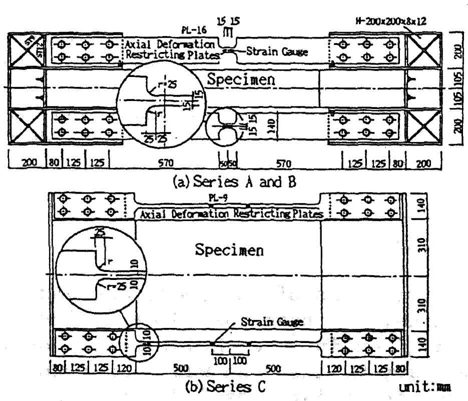

Fig.2 Axial deformation restricting jig

Table 1. Mechanical properties of materials used in Series A and B

Reinforcement

	Yield Strength (kg/cm^2)	Tensile Strength (kg/cm^2)	Elongation (%)
D10	3670	5400	22.8
D13	3520	5210	25.0
6φ	3900	4920	20.5

Concrete

Material Age (Day)	40	44	51
Compressive Strength (kg/cm^2)	310	333	337
Strain at Compressive Strength (10^{-6})	2300	2310	2380
Young's Modulus (t/cm^2)	232	226	226
Tensile Strength (kg/cm^2)	26.1	30.0	23.8

Table 2. Mechanical properties of materials used in Series C

Reinforcement

	Yield Strength (kg/cm^2)	Tensile Strength (kg/cm^2)	Elongation (%)
D10	4000	5990	20.3
6φ	3110	4290	28.4

Concrete

Material Age (Day)	27	36
Compressive Strength (kg/cm^2)	312	309
Strain at Compressive Strength (10^{-6})	2460	2560
Young's Modulus (t/cm^2)	242	225
Tensile Strength (kg/cm^2)	25.0	22.2

Table 3. List of specimens

	without Axial Restriction	with Axial Restriction
Series A	A-1 (3-D10 / 3-D10, 200×200) K = 0 ton/cm	A-2 (PL-16, 3-D10 / 3-D10, 200×200) K=150 ton/cm
Series B	B-1 (3-D13 / 3-D10, 200×200) K = 0 ton/cm	B-2 (PL-16, 3-D13 / 3-D10, 200×200) K=150 ton/cm
Series C	C-1 (9-D10, 3-D10, 200 200 200) K = 0 ton/cm	C-2 (PL-9, 9-D10, 3-D10, 200 200 200) K=148 ton/cm

unit:mm

restricting plates and the elongation of the beam. This experiment was performed of the two cases where the elongation of beam is free and axial deformation is elastically restricted with the stiffness shown on Table 3, this stiffness being 0.16 times the compressive stiffness due to the concrete and reinforcement of the cross section in the Series A.

Methods of Loading As shown on Fig.3, with the use of the parallel crank mechanism, antimetric loading was performed with a 50-ton push-pull double acting oil jack with a loading beam. As shown on Fig.4, incremental cyclic loading was performed such that the initial loop is repeated before and after the yield of the main reinforcement on the tensile side (approx. 3mm of deflection) and, though slightly differing with the specimens, subsequent repetition was controlled with the deflection.

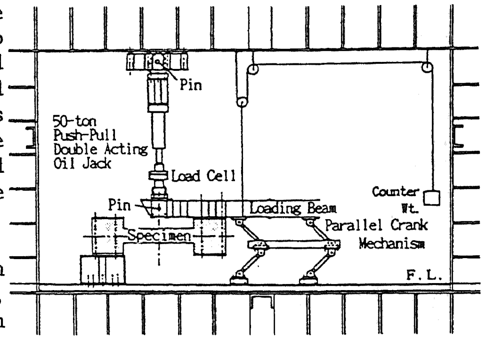

Fig.3 Loading arrangement

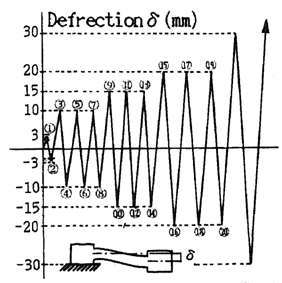

Fig.4 Loading path

EXPERIMENTAL RESULTS

Relationship Between Shear Forces and Deflections Figure 5 shows the relationships between the shear forces and deflections of each specimen. In the figure, the straight line shown with the broken line represents the shear force derived assuming that the both ends of beam reach the maximum bending moment simultaneously derived by the exponential function method when the axial force is zero. The case where axial deformation is unrestricted is denoted with the solid line, and where restricted, with the broken line. In the case of axial deformation being unrestricted, in both the A-1 and B-1, a decrease in the strength did not occur until the rotation angle of member has not exceeded 1/20 (the value derived by dividing δ=50mm with the length of beam, 1,000mm), but in the case of C-1, a decrease in the load due to the compressive failure and shear cracking of the concrete from near the rotation angle of member, 1/50 (δ=20mm), and the load sharply decreased with the rotation angle of member at 1/25 (δ=40mm). When, regarding loads, comparing the cases where axial deformation is restricted and unrestricted, in the Series A, B and C, load increased to approximately 2 times, 1.5 times and 1.5 times, respectively, with the rotation angle of member at 1/50. With the axial deformation being restricted, A-2 and B-2 gently decreased their strengths after the maximum strength, while a decrease in the strength of C-2 was great after the rotation

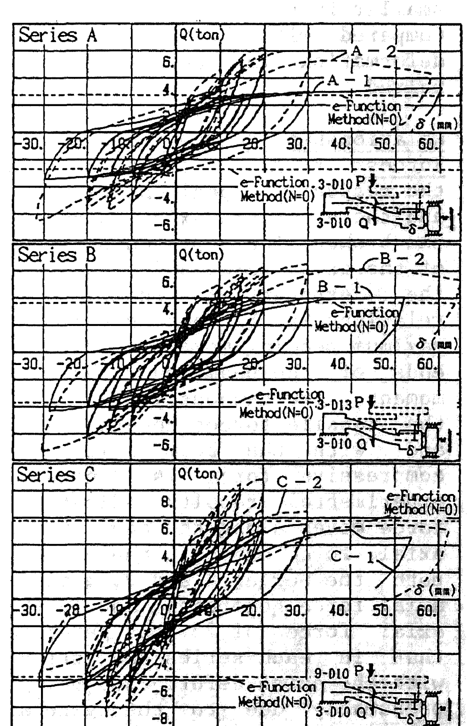

Fig.5 Shear force – Deflection relationships

angle of member at 1/50. Although in the respective repeated loops, load decreased in the order of the 1st cycle, the 2nd cycle and the 3rd cycle, a decrease in load decreased more greatly when axial deformation is restricted, than when unrestricted, suggesting that the strength decreased due to the compressive failure and shear cracking of the concrete, resulting in the decreased axial force.

<u>Relationship Between Shear Forces and Axial Deformation</u> Figure 6 shows the relationships in the respective specimens between shear forces and axial deformation. In the figure, the axial deformation is the average of the sum of the axial deformation in the upper portion of beam, Δ_1 and that in the lower portion of beam, Δ_2. In all series, with axial deformation being restricted, elongation at last cycle was approximately 1/3 of the case where unrestricted, suggesting the effective working of the axial deformation restricting jig. It is apparent that as each cycle increased the axial deformation, plastic strain accumulated. With load released from the peak of each repeated cycle, the axial deformation decreased, much greater in the Series C than in the Series A and B, and smaller in the Series B than in the Series A. Compared with the Series A and B, the axial deformation in the Series C approximately halved.

<u>Relationship Between Shear Forces and Axial Forces</u> Figure 7 shows the relationships in the respective specimens between shear forces and the generated axial foroes. In the figure, the broken line represents the envelope curves of the axial force and shear force derived by the exponential function method the relationship between shear force and the maximum bending moment assuming that the both ends of the beam reach the maximum bending moment simultaneously. The axial force with the tensile forces generating in the plates and with the beam being subject to a compressive force is denoted as (+). The experimental results indicate that the axial force moves along the envelope curve when the axial force once hit the envelope curve. In both the Series A and B, a maximum of 35 ton axial force generated, and in the Series C, an axial force of 25 tons generated. The fact that in each series the strength increased with the axial deformation being restricted is presumably due to the generation of this restricting axial force.

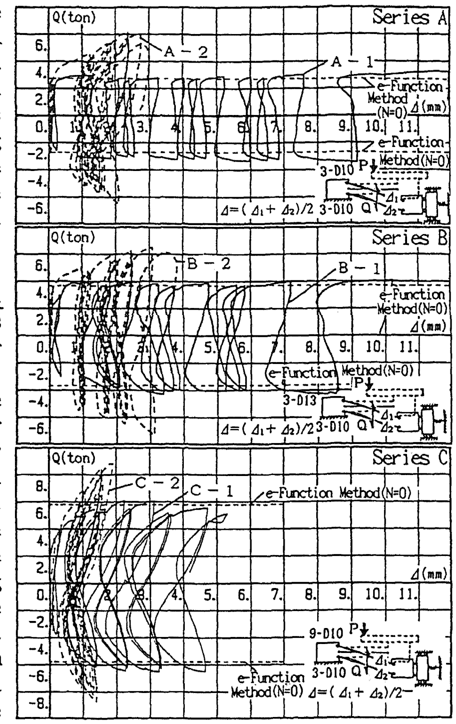

Fig.6 Shear force - Axial deformation relationships

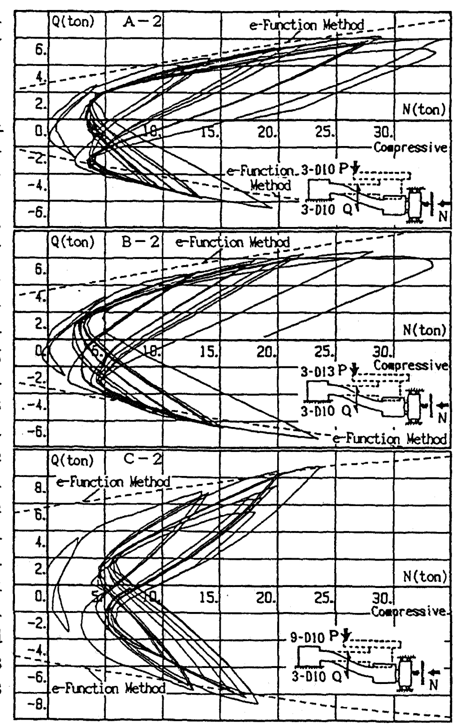

Fig.7 Shear force - Axial force relationships

ANALYTICAL METHOD

<u>Models of Elastic and Plastic Members</u> In order to analyze the beam member being subject to a bending shear force and with consideration given to the restriction of axial deformation, an elastic and plastic member model having several elastic and plastic axial springs at its ends, for which the interaction between shear force and bending moment can be considered, will be used. In Fig.8, the a-b portion and e-f portion are the rigid zones respectively, and the c-d portion is the elastic member for which the deformation due to bending shear is considered. The center of the axis of this elastic member will be located where the center of gravity of the member's cross section is. Several elastic and plastic axial springs will be provided between b and c, and d and e.

<u>Models of The Relationship Between The Loads and Displacement of Elastic and Plastic Axial Springs</u> The relationship between the stresses and strains of concrete and that between the stresses and strains of reinforcement will be as shown on Fig.9 and 10. These stress-strain relationships will be replaced with the relationships with the axial forces and displacement of the respective axial spring, attached to the ends of members.

CONSIDERATIONS THROUGH ANALYSIS

For the purpose of making considerations on an increase in the strengths of the specimens and a decrease in the axial deformation when restricting the axial deformation in this experiment, a simple analysis was made.

An analysis of one-way loading was made of the six specimens. Figure 11 shows the idealization. Based on the state of final rupture, the length of elastic and plastic axial springs was determined to be 2/15 of the beam length. Reinforcement is represented with two axial springs, unconfined concrete is represented with twenty axial springs, and confined concrete is represented with fourteen axial springs. The left end of the member is fixed, while the right end is provided with an axial restrictive spring.

Figure 12 shows the relationships in the respective specimens between shear forces and deflections and Fig.13 shows the relationships between shear forces and axial deformation. The experimental result is denoted with the

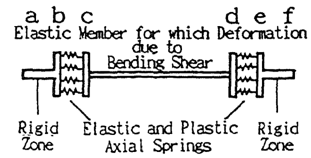

Fig.8 Elastic and Plastic model

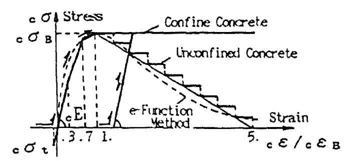

Fig.9 Stress-strain relationships of concrete

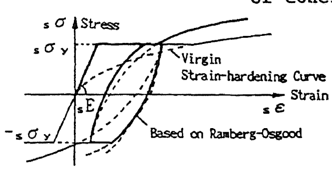

Fig.10 Stress-strain relationships of reinforcement [4]

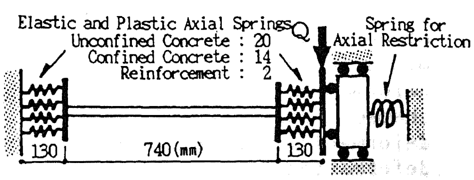

Fig.11 Idealization

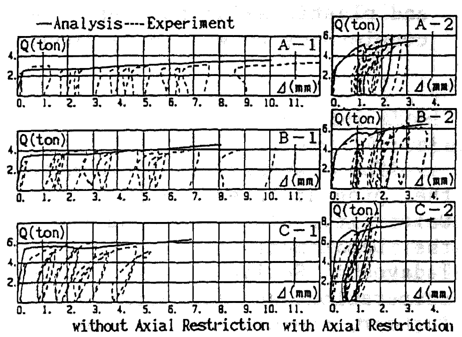

Fig.12 Shear force - Deflection relationships

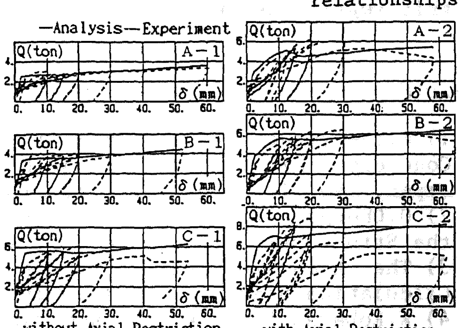

Fig.13 Shear force - Axial deformation relationships

broken line, while the analytical result is denoted with the solid line. A-1, B-1 and C-1 all show good consistency between analytical results and experimental results except for the decreased strength region of C-1. In A-2, B-2 and C-2, analysis indicates a trend to generate a strength increase, but the ratio of strength increase is greater in experiment than in analysis, specifically in C-2 the consistency of the analytical results with the experimental results after the maximum strength is not favorable.

CONCLUSION

Based on the concept that the reinforced concrete beam tending to yield to bending in an actual structure has a potential of being subject to an axial restriction of deformation from the surrounding structural members, an experiment on the bending shear of the reinforced concrete beam being subject to an axial restriction of deformation was carried out. And an analysis was made by means of a Simple model having several elastic and plastic axial springs in the ends of members. The following conclusion was attained.

(1) When the beam being subject to an axial restriction of deformation deforms when subjected to a bending shear force, a compressive force acts on the beam, causing the strength of the beam to increase at a greater ratio than in the case of an unrestricted beam. In the case of the specimens used for the present experiment, this increase ratio ranged from 1.5 to 2 times.

(2) Compared with a reinforced concrete beam not subject to an axial restriction of deformation, a reinforced concrete beam being subject to an axial restriction of deformation has the collapse of the concrete occurring earlier, causing the deformation capacity to decrease, specifically remarkable in the case of a T-shaped beam. Therefore, it would be necessary not to expect an excess deformation capacity with a beam being subject to an axial restriction of deformation.

(3) The analytical results by means of a analytical model having several elastic and plastic axial springs located in the ends of member indicate an approximate consistency between experiment and analysis.

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