STUDY ON CYCLICALLY AND BI-AXIALLY LOADED RC COLUMNS BASED ON FLEXIBILITY METHOD

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1. INTRODUCTION

In case of earthquake loadings, some RC members are subjected to bi-axial bending due to the location of structural members and due to the configuration of structures. Under bi-axial bending, it is observed that increments of deflection in fixed loaded direction grow larger as orthogonal deflection increases. In this study, we applied flexibility method, which is force-based formulation, to this analysis, and we could get an analytical simulation for this phenomenon.

2. FORCE BASED ELEMENT FORMULATION [1]

In the force-based formulation, the internal forces **D(x)** are written from equilibrium as functions for the element forces **P**,

$$\mathbf{D}(\mathbf{x}) = \mathbf{N}_P(\mathbf{x}) \cdot \mathbf{P} . \quad (1)$$

Where $\mathbf{N}_p(\mathbf{x})$ are the interpolation functions of forces. To apply this equation to constitutive relation, introducing Eq.(2).

$$\mathbf{d}(\mathbf{x}) = \mathbf{f}(\mathbf{x}) \cdot \mathbf{D}(\mathbf{x}) . \quad (2)$$

Application of the principle of virtual forces leads to the element flexibility matrix,

$$\mathbf{F} = \int_0^L \mathbf{N}_P^T(\mathbf{x})\,\mathbf{f}(\mathbf{x})\,\mathbf{N}_P(\mathbf{x})\,d\mathbf{x} . \quad (3)$$

These formulations are based on the equilibrium of forces. Therefore this method can estimate the accurate moment and curvature distribution by just one element so long as force distribution is linear, which are usual cases in real column structures. The differences of internal moment and curvature distributions between force- and displacement-based element are shown in Fig.1.

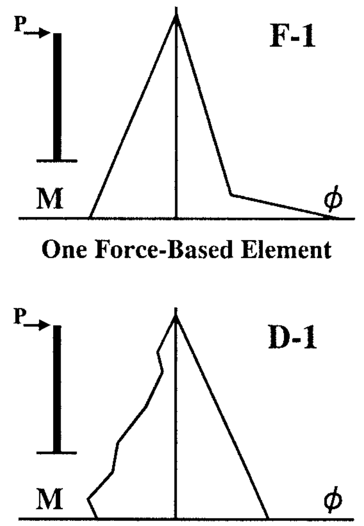

Fig.1 Differences between Force- and Displacement-based Element

3. TEST SPECIMENS [2]

To show the availability of flexibility method, the cyclic analysis under bi-axial bending which was tested by Sato et al. was carried out in this paper. Summary of the specimen is shown in Fig.2. In this experiment, the cyclic horizontal displacement in the x-direction and fixed horizontal force in the y-direction is controlled. Material properties are shown in Table.1.

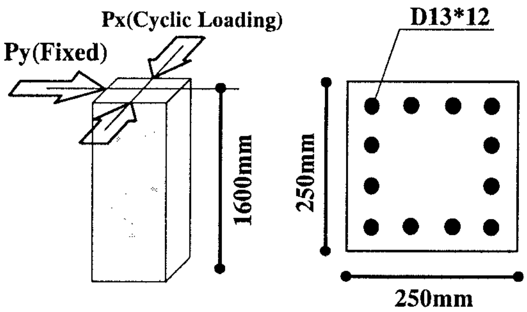

Fig.2 Summary of Specimen

4. ANALYSIS MODEL AND ANALYTICAL RESULTS

In case of the above-mentioned specimen, the RC column can be modeled by one element in flexibility method. To analyze this specimen, we take fiber-model to obtain section stiffness and hysteresis. In fiber-model, constitutive relation of concrete and steel were Darwin-Pecknold model and Menegotto-Pinto model, respectively.

Table.1 Material Properties

Concrete	
Compressive strength	31.4 [MPa]
Initial Young's Modulus	21.0 [GPa]
Main Bars	
Yield Stress	371.4 [MPa]
Young's Modulus	184.2 [Gpa]

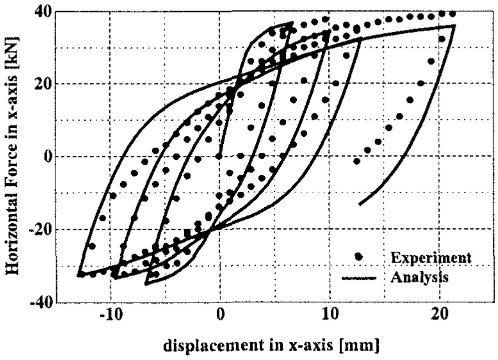

Fig.3 Comparison of load-deflection curve (x-dir)

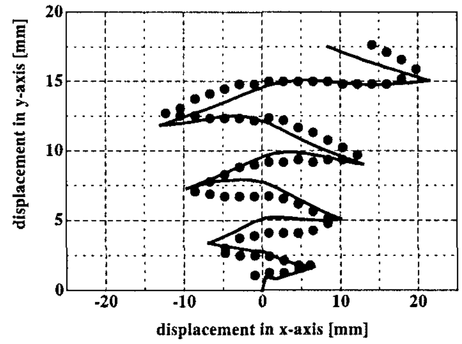

Fig.4 Comparison of deflection of x-dir and y-dir

Analytical results and experimental results are shown in Figs.3-4. As a whole, these results show that the analysis is reasonable.

These results also shows that the deflection of the y-direction get larger though the horizontal force in the y-direction keeps constant. To consider these phenomena, the displacement increment ratio between x-direction and y-direction are introduced (Fig.5). According to Fig.5, increment of displacement increment ratio is taken place at two places (A, B in Fig.5).

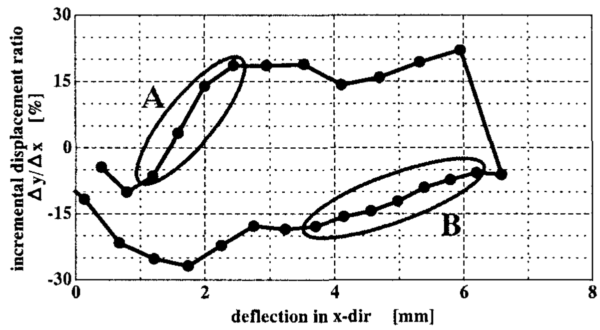

Fig.5 displacement increment ratio between x-dir and y-dir

Fig.6 shows the constitutive relations of concrete and steel in yield section. In point A in Fig.5, the upper right side of steels enters into yield plateau. However, in point B in Fig.5, the crack of the upper left side of concrete, which had been closed due to horizontal force in the x-direction, opens and this caused the section stiffness degradation to occur. Consequently, the causes of increment of deflection in fixed loaded direction is made up of two primary factors, that is, steel yielding and concrete crack opening.

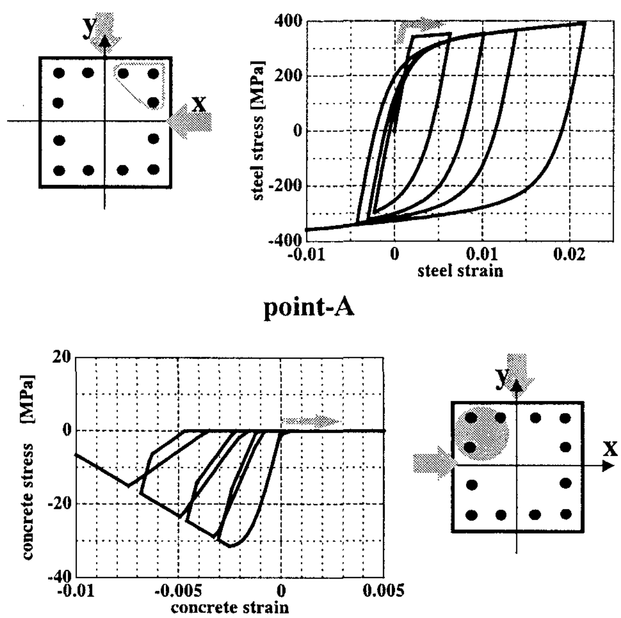

Fig.6 Hysteresis loops of steel and concrete

5. CONCLUSIONS

Based on the above consideration, the following conclusions can be extracted.

1) The comparisons between the predicted and experimental results of the bi-axial column test show that the flexibility method can reasonably describe the behavior of RC analysis under bi-axial bending.

2) The causes of increment of deflection in fixed loaded direction are composed of steel yielding and concrete crack opening. These two different mechanisms make the stiffness in fixed loaded direction degrade.

REFERENCES

1) Spacone,E.,Ciampi,V. and Filippou, F.C., : "Mixed Formulation of Nonlinear Beam Finite Element," Computers & Sciences, Vol.58,pp.71-83,1996

2) Sato,Y., Yoshimura,M., and Tsumura,K., : "Displacement Response of R/C Columns Subjected to Bi-Axial Lateral Loads," Proceedings of the JCI, Vol.16, No.2, pp.653-658, 1994 (in Japanese)