Behavior of Laterally Loaded RC Columns with Thick Cover under Axial Compression

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Abstract: This study aims to bring into information the behavior of laterally loaded reinforced concrete cantilever columns with high cover thickness under axial compression. An experiment was conducted and nonlinear analysis was performed using a finite element analysis package, COM3. It was found that the residual deformation during lateral unloading and reloading is considerably small in such cases. The load resisting mechanism by reinforcement and concrete is separated and discussion is made to explain the cause of small residual deformation.

Introduction: In underground reinforced concrete piles, comparatively thicker cover is used and significant axial load exists. Comparatively fewer studies have been done in the past about reinforced concrete columns with large cover and high axial compression. To understand the behavior of such structures, a cantilever column with thick cover under axial compression is studied here.

Experiment: The experimental setup is shown in figure 1 and experimental parameters are given in table 1. In order to make the column function as a cantilever beam, the footing was tightly fixed to the base slab using prestressed tendon. Constant axial compression of 25 tf was applied at the top of the column and cyclic lateral displacement was applied at a height of 120 cm from the top of the footing.

Table 1. Experimental parameters

Column cross section	25cm*25cm
Main reinforcement	6 no. D10 bars
Reinforcement ratio	0.69%
Stirrups	D6 @10cm c/c
Cover thickness	7.5 cm
Shear span	1.2 meter
Compressive strength, f_c'	380 kgf/cm^2
Tensile strength, f_t	25 kgf/cm^2
Young's Modulus, E_s	1950000 kgf/cm^2
Yield strength, f_y	3700 kgf/cm^2

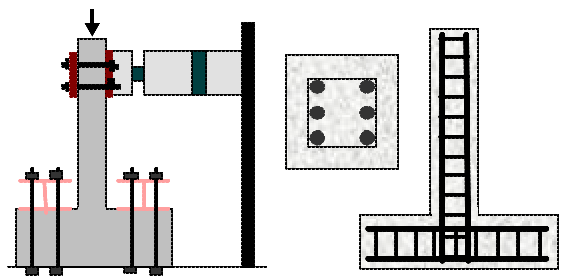

Fig. 1. Experimental Setup and Specimen

Analysis: Analysis of the same structure was performed using fiber model [1]. In fiber model, the member cross section is divided into a mesh of cells or sub-elements. Within each sub-element, the strain is assumed constant and equal to the strain at the center of gravity of that sub-element. Non-linear path-dependent constitutive models, as shown in figure 2, are used for concrete and steel existing in each cell. Those models have been verified in the element and member levels with satisfactory results, and have been incorporated in COM3 for three-dimensional analysis of reinforced concrete under monotonic and cyclic loading [2]. In order to consider the phenomenon of localization of tension stiffening, effective RC zoning method proposed by An et al [3] is used, in which the concrete fibers are divided into RC and PL zones depending on the distance of the fiber from nearby reinforcing bar. The tensile response of the two zones is different as shown in figure 3.

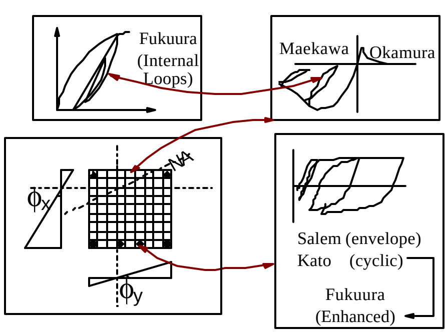

Fig. 2. Constitutive Relationships Used in Fiber Model

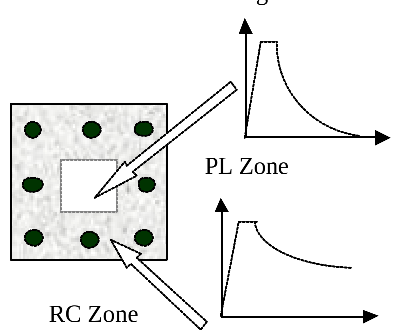

Fig. 3. RC zoning (An et al, 1996)

Results and discussions: The load-displacement relationship is shown in figure 4. Due to some technical problems, the experiment had to be stopped after applying lateral displacement equal to 15 mm. It can be observed that unlike the response of normal structures, the load-displacement curve nearly passes through the origin during unloading and reloading. In order to understand the cause of this behavior, nonlinear finite element

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analysis using fiber model was carried out. It can be observed in figure 4 that in spite of small differences in the initial stiffness and residual deformation between analytical and experimental results, the maximum loads in both cases are found to be nearly same. The stress-strain history of one of the steel fibers is shown in figure 5. In spite of the yielding of reinforcement, the cyclic loop of the load displacement curve (both in experiment and analysis) is found to be very narrow.

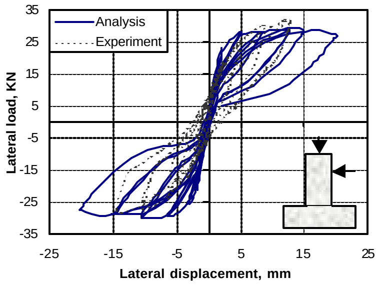

Fig. 4. Load -Displacement Relationship

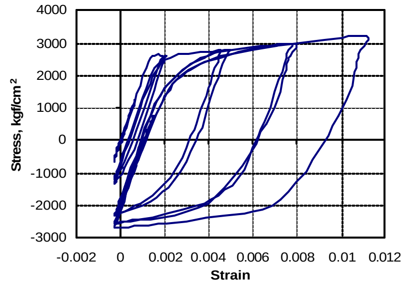

Fig. 5. Steel Stress Strain History

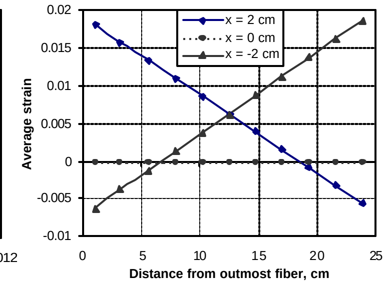

Fig. 6. Strain Distribution in Fibers

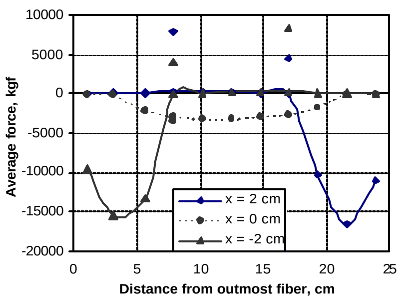

Fig. 7. Force Distribution in Fibers

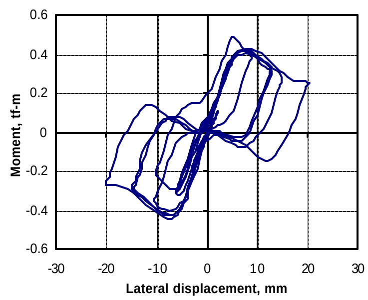

Fig. 8. Moment Carried by Steel Fibers

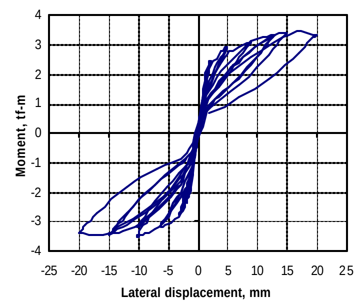

Fig. 9. Moment Carried by Concrete Fibers

For more detailed investigation, the last loop (applied displacement from 2 cm to –2 cm) is considered here. The average strain distribution and force carried by the fibers along the cross section at three instants (at two opposite peaks and at zero displacement) are shown in figures 6 and 7 respectively. As expected, the strain distribution is linear and nothing unusual was observed. The forces carried by fibers show general behavior for the extreme cases, but at zero displacement, all the fibers are in compression because of the applied axial compression. Interestingly, the force distributions (both in concrete and steel fibers) in this case are nearly symmetric resulting in very small moment at the section and consequently, the lateral load is nearly zero. In every loop, similar tendency can be observed. Next, as shown in figures 8 and 9 respectively, the moment at the fixed support is divided into two parts; moment carried by steel fibers and by concrete fibers. As discussed earlier, the moment carried at around zero displacement during reloading and unloading is very small due to the symmetric nature of the force distribution. It is well known that the residual displacement and wider cyclic loops in the load displacement relationship of such structures come mainly from the reinforcement. But, in this case, unlike the usual structures, the contribution of steel is around 1/10 of that of concrete. This fact can be attributed mainly to the small reinforcement ratio and small arm length due to large cover. That's why the overall response is following nearly the cyclic path of concrete fibers. For comparison, some more analyses were carried out with larger reinforcement ratio and smaller cover thickness. The results are not shown here because of space limitation. It was found that the contribution of reinforcement is higher than that of concrete and there exists some residual deformation during loading and unloading. Hence, it is verified that axial compression, reinforcement ratio and cover thickness are the governing factors for the shape of cyclic response of RC columns.

Conclusion: The behavior of a reinforced concrete column with large cover under axial compression is studied experimentally and analytically. It is found that unlike the normal structures, the cyclic load-displacement response of such structure form a neck around the origin. It is understood that the contribution of reinforcement in the overall response of such structures is relatively very small and hence the concrete fibers govern the overall behavior. Moreover, it is observed that the shape of the cyclic behavior of reinforced concrete column is mainly governed by three factors; axial compression level, reinforcement ratio and the thickness of cover concrete.

References:

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