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

Rajesh Prasad Dhakal¹, Koichi Maekawa²

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Column cross section</td>
<td>25cm*25cm</td>
</tr>
<tr>
<td>Main reinforcement</td>
<td>6 no. D10 bars</td>
</tr>
<tr>
<td>Reinforcement ratio</td>
<td>0.69%</td>
</tr>
<tr>
<td>Stirrups</td>
<td>D6 @10cm c/c</td>
</tr>
<tr>
<td>Cover thickness</td>
<td>7.5 cm</td>
</tr>
<tr>
<td>Shear span</td>
<td>1.2 meter</td>
</tr>
<tr>
<td>Compressive strength</td>
<td>380 kgf/cm²</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>25 kgf/cm²</td>
</tr>
<tr>
<td>Young's Modulus, E</td>
<td>1950000 kgf/cm²</td>
</tr>
<tr>
<td>Yield strength, fy</td>
<td>3700 kgf/cm²</td>
</tr>
</tbody>
</table>

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.

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

¹ Graduate Student, Dept. of Civil Engineering, University of Tokyo.
² Professor, Dept. of Civil Engineering, University of Tokyo.
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

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:
Concrete Structures, Pavements, JSCE, 35(564), 1997, pp.297316.