

DUCTILITY OF HOLLOW RC SHORT COLUMNS IN COMPRESSION REGION

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ABSTRACT

Five reinforced concrete short rectangular columns with hollow made from PVC pipe that placed in the center of cross section were tested under eccentrically axial loading in compression region with load eccentricity of 60mm ($e < e_b$). The hollow ratio was taken from 3.63% up to 20.28%, and concrete strength used was 34.52MPa. The columns had four longitudinal steel reinforcements of 12mm diameter were symmetrically placed in both sides of the square column section with average yield strength of 323.06MPa, and average modulus of elasticity of 257411.49MPa. The objective of this research is to study the ductility of hollow RC short columns with square cross section of 150mm x 150mm. The results show that generally all columns give significant difference in ductility escalation. The maximum ductility escalation was occurred at column with maximum hollow ratio (20.28%), that is 16.38%, compared relatively to the solid column. It could be stated that PVC pipe installation in column will improve the ductility.

Keywords: ductility, hollow ratio, RC short column, square cross section, compression region

INTRODUCTION

In high-rise buildings, it is often to provide a different diameter of pipe in a column for plumbing system. Hollow due to pipe installation has an effect on the strength degradation and stiffness of structural elements such as column. Generally, column failure in compression will affect to another structure component that connected with. For this reason, strength reduction factor for column is taken to be less than that of beam in order to give more spare strength.

Previous study related to the present study had been observing the flexural strength and ductility of circular hollow reinforced concrete columns without confinement on inside face (Zahn et al., 1990). Suprabowo (1996) had developed an analysis for hollow RC column with square cross section based on circular column analysis method. The hollow effect toward ultimate strength of RC column with hollow ratio less than 10% had been investigated (Supriyadi, 1997).

The current code such as the ACI Building Code in the section of 6.3.4, it is stated that conduits and pipes, with their fitting, embedded within a column shall no displace more than 4 percent of the area of cross section in which strength is calculated or which is required for fire protection. The Indonesia National Standard (SNI 1991), it is stated same as the ACI Building Code that hollow ratio is less than 4 percent.

This paper is aimed to study the ductility of hollow RC short columns subjected to eccentrically axial compressive loading in compression region. An offered concept was optimizing the hollow ratio to take a portion of an effective column area and give the significant ductility escalation.

RESEARCH SIGNIFICANCE

Building codes implicitly guarantee an acceptable factor of safety on member design for conventional strength concretes. For the design of hollow RC columns, it is essential that this accepted factor of safety be maintained by modifying design capacities. This research aims to study the ductility of hollow RC short columns with square cross section subjected to eccentrically axial loading in compression region with variation of hollow ratio. The diameter of pipe were taken from 32.25mm up to 76.25mm and made from PVC that placed in the center of column cross section. This research provides the information about the escalation of ductility of the column subjected to eccentrically axial loading in compression region.

DESCRIPTION OF EXPERIMENTAL PROGRAM

Test Specimens

A total of five tie reinforced concrete columns with square cross section, having dimensions of 150mm high, 150mm width and 800mm length were tested under eccentric axial

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compressive loading with eccentricity of 100mm. Four of them were hollow columns with hollow ratio were (C2) 3.63%, (C3) 7.95%, (C4) 12.50%, and (C5) 20.28%, while the rest was solid column (C1) representing control specimen. Four longitudinal steel reinforcements of 12mm diameter were

symmetrically placed in both sides of the square column section. Tie reinforcements of 6mm diameter with 100mm spacing were used along the column. The dimension of tests specimen were shown in Figure 1.

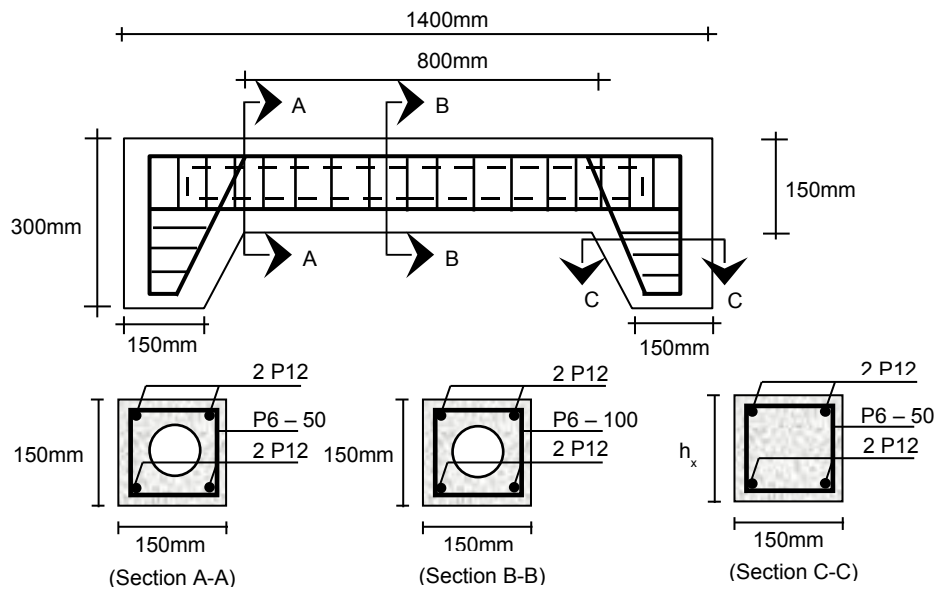


Figure 1. Geometric details and configuration of test columns

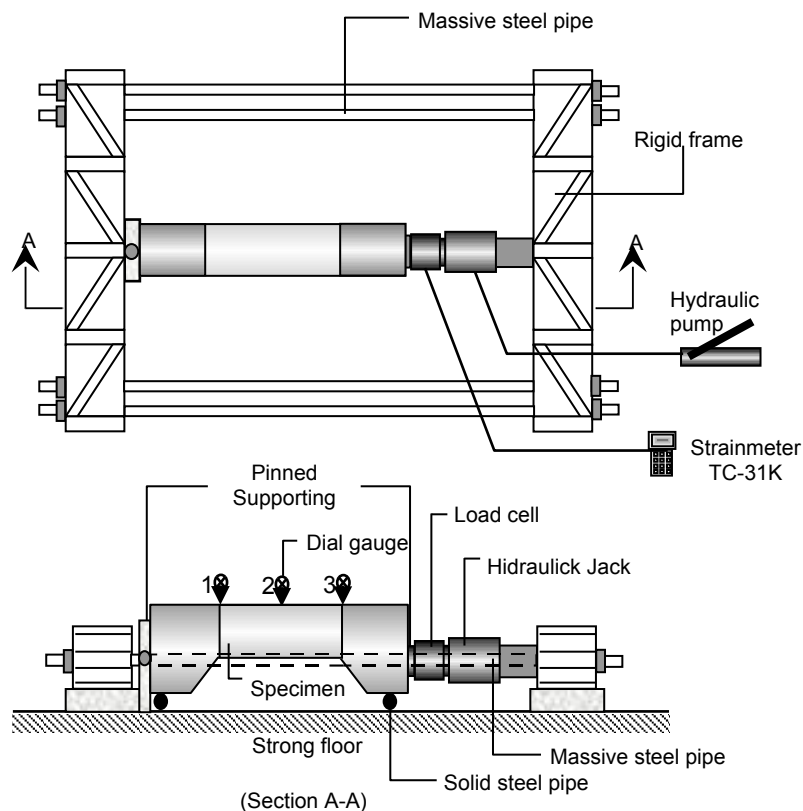


Figure 2. Loading set up

Material Properties

The specimens were made using concrete with mix proportion of 1:1.65:2.01 and water-cement ratio of 0.5. The concrete used was a mixture of PPC (type A), crushed sand, and aggregate with maximum size of 20mm that gave an average compressive strength of standard cylindrical samples of 34.52MPa. The longitudinal reinforcements of column were mild steel bars with average yield strength of 323.06MPa, and average modulus of elasticity of 257411.49MPa.

Test Setup and Procedure

The test were conducted to all specimens after 28 days with static load which applied using a hydraulic jack and the load intensity was monitored from load cell which equipped by transducer indicator. Three dial gauges were used for displacement monitoring. Each test specimens were placed on the pinned supporting structure.

Load and displacement reading are conducted in stage with loading step, started from zero up to maximum loading. Variation of loading step is from 4kN up to 10kN. Static load was applied until the test specimens fail. Load and displacement, that occurred during the test were observed and recorded. The loading set up was illustrated in Figure 2.

TEST RESULTS AND DISCUSSION

Strength of Column

Figure 3 shows the relationship between load and mid-span deflection for solid column (C1E1) and hollow columns (C2E1, C3E1, C4E1, and C5E1) with load eccentricity of 60mm. For compression region ($e < e_b$), it is shown that the strength of column decrease as hollow ratio increase. The strength degradation is followed by a larger displacement that occurred at the mid of column.

Flexural Capacity of Column

Figure 4 shows the relationship between moment and mid-span curvature for solid column (C1E1) and hollow columns (C2E1, C3E1, C4E1, and C5E1) with load eccentricity of 60mm. For compression region ($e < e_b$), it is shown that the flexural capacities of column decrease as hollow ratio increase. The flexural capacity degradation is

followed by a larger curvature that occurred at the mid of column.

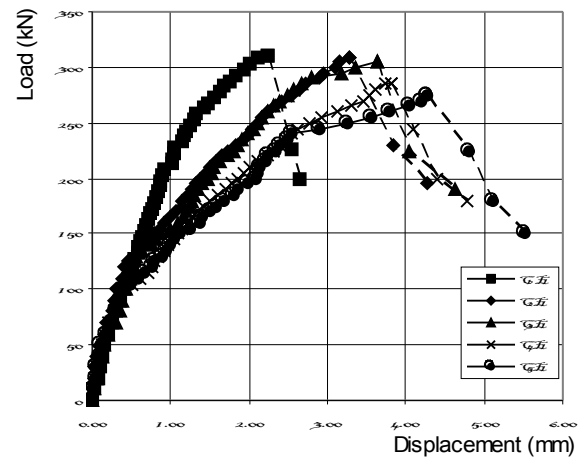


Figure 3. Load versus mid-span deflection

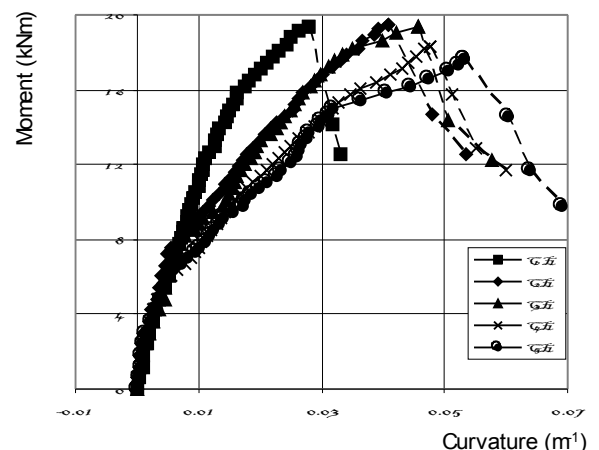


Figure 4. Moment versus mid-span curvature

Ductility of Column

Park and Paulay (1975) have defined that ductility of column could be observed by using moment-curvature diagram that known as curvature ductility factor, that is ratio between ultimate curvature (ϕ_u) and yield curvature (ϕ_y). El-Tawil and Deierlein (1999) have defined that ultimate curvature (ϕ_u) could be obtained when moment was 0.80% of the maximum moment (M_{max}) in the slope part of diagram.

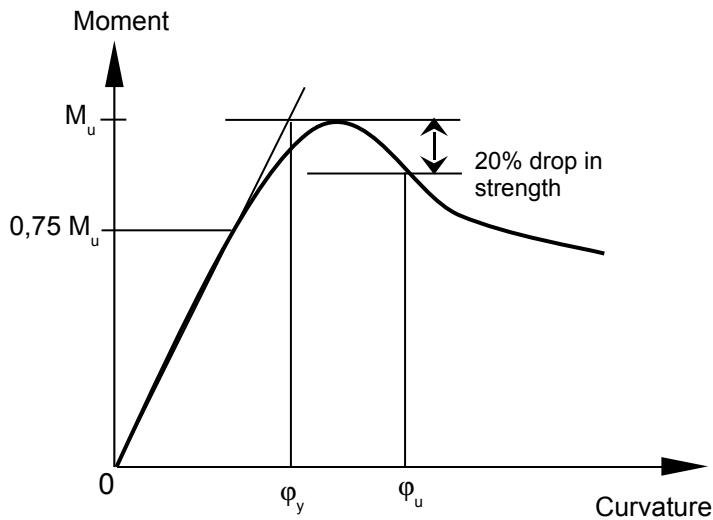


Figure 5. Definition of curvature ductility ratio (El-Tawil & Deierlein, 1999)

Table 1. Ductility of column

Test Specimen	Eccentricity (mm)	Diameter of Pipe (mm)	Yield Curvature, ϕ_y (m^{-1})	Ultimate Curvature, ϕ_u (m^{-1})	Ductility, μ
C1	60	0	0,021	0,031	1,48
C2	60	3,63	0,031	0,049	1,58
C3	60	7,95	0,031	0,051	1,65
C4	60	12,50	0,033	0,056	1,70
C5	60	20,28	0,035	0,062	1,77

While for yield curvature (ϕ_y) could be obtained by making a straight line from zero point and trough point of contact where diagram have reached $0,75M_{max}$ and horizontal line from M_{max} , and from this point could be made a vertical line beneath curvature axis to get a yield curvature (see Figure 5).

The ductility shown in Table 1 was based on the ultimate curvature (ϕ_u) and the yield curvature (ϕ_y). The ductility can be calculated by dividing ϕ_u with ϕ_y .

For compression region ($e < e_b$) with load eccentricity of 60mm, it is shown that ductility of column increase as hollow ratio increase. From Table 1, it could be observed that maximum escalation was occurred at column with maximum hollow ratio (C5E1), that is 16.38%, compared relatively to the solid column (C1E1). It could be stated that PVC pipe installation in column will improve the ductility.

Mode of Failure

In general, cracks are started from critical region where subjected to maximum flexural moment and weakness dimension. The cracks occurred are flexural crack that indicated by vertical crack direction to column height and always found on tension side. In average, the first crack occurred when applied load is 30% from maximum load with crack width observed are between 0.01 to 0.02mm.

Cracking patterns of the hollow and solid columns, in general, follow similar patterns. The modes of failure was started by hairlines cracks appeared at tension side followed by the widening and elongating of several cracks as the load increased, and finally concrete spalled off from the concrete surface at compression side.

All columns with load eccentricity of 60mm were exhibited modes of failure that were similar to that of compression failure. Spalling that occurred is getting bigger as hollow ratio increase.

Comparison of Test Results with Theoretical Predictions

Table 2 summarizes the experimental and analytical maximum loads for all five-columns being tested. It is evident from Table 2 that all five-columns do not exceed the theoretical predictions of the maximum load, but this value is still larger than the

requirements for column with tie reinforcement as $0.80P_n$. It could be stated that columns are comply with the requirements. The differences of maximum load between theoretical and experimental were not significant. The average difference is 2.89% with load eccentricity of 60mm.

Table 2. Capacity of column (experimental and theoretical)

Test Specimen	Eccentricity (mm)	Diameter of Pipe (mm)	Maximum Load		P_{max}/P_n
			Theoretical (P_n)	Experimental (P_{max})	
C1	60	0	320,22	311	0,97
C2	60	3,63	314,47	308	0,98
C3	60	7,95	307,44	305	0,99
C4	60	12,50	299,78	286	0,95
C5	60	20,28	285,82	274	0,96

CONCLUSION AND RECOMMENDATION

Conclusion

1. With load eccentricity of 60mm, the maximum load capacity of the hollow column with hollow ratio of 20.28% decrease 11.90%, compared relatively to the solid column.
2. Ductility of the hollow columns with hollow ratio of 20.28% had maximum increase 16.38 %, compared relatively to the solid column.
3. The PVC pipe installation can make the columns more ductile as diameter of pipe increase.
4. All columns with load eccentricity of 60mm were exhibited modes of failure that were similar to that of compression failure.
5. Cracking patterns of the hollow and solid columns, in general, follows similar patterns. The modes of failure was started by hairlines cracks appeared at tension side followed by the widening and elongating of several cracks as the load increase, and finally concrete spalled off from the concrete surface at compression side.
6. The differences of maximum load between theoretical and experimental were not significant. The average difference is 2.89% with load eccentricity of 60mm.

Recommendation

1. More tests need to be conducted to verify the accuracy of the test results.
2. It is recommended to examine the hollow RC column in the different type of cross section and the slender column.
3. Other environmental exposure test under dynamic loading also recommended examining the hollow RC column.

4. Field monitoring project are also recommended to further study the hollow effect under actual field conditions.

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