Analysis and Design of Hollow Reinforced Concrete Columns

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Abstract:-A hollow concrete section is oftenly used for column design, particularly for very tall bridge columns in earthquake prone areas for reducing the mass and to reduce the self-weight contribution to the inertial mode of vibration during an earthquake. The hollow columns enable to reduce foundation dimensions and thus save the construction cost substantially. Hence, these advantages have promoted the use of hollow columns instead of similar solid members in construction of building structures as well. This study includes analysis of a G+4 commercial building with solid columns analysed in ETABS2016. The analytical data is being used to design a hollow column for the same structure under worst load combinations using software CSICOL9. The best design is being proposed with advantages of hollow columns over solid columns.

Index terms- *Hollow columns, solid columns, comparison, ETABS2016, CSICOL9.*

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I. Introduction

A hollow concrete section is often used for column design, particularly for very tall bridge columns in seismic areas including California, New Zealand, Japan and Italy etc, for reducing the mass and therefore minimizing the self-weight contribution to the inertial mode of vibration during an earthquake. The hollow columns also enable to reduce foundation dimensions and thus save the construction cost substantially. Therefore, these advantages have promoted the use of hollow columns instead of similar solid members. On the other hand, the seismic behavior of the hollow columns has been controversial due to a lack of understanding. The effect of the hollow section should be adequately assessed in the seismic design, because the structural response of the hollow column under seismic loading may be significantly different from that of solid column due to existence of a void section. Based on this concept, incorporation of hollow reinforced concrete columns in buildings can be studied with proper design and analysis to withstand the loads coming on it and performing adequate seismic behavior. This study intends on performing design and analysis of hollow reinforced concrete columns.

II. Review Of Literature

Jun-ichiHoshikuma and M.J.N. Priestley (2000) presented the study of flexural ductility capacity of the hollow circular columns with one layer of longitudinal and transverse reinforcement placed near the outside face of the section. The behaviour of two flexure-dominant circular hollow reinforced concrete columns, with different longitudinal reinforcement ratios, under cyclic loading was investigated through a discussion of experimental studies. They concluded that the inside face concrete compression strain is one of the most important parameters to control the ductility capacity of the hollow columns. Test results inside face concrete was crushed when the compression strain reached nearly 0.005 even though a sufficient amount of transverse steel was placed near outside face.

Y.-K. Yeh et al (2002) performed experimental results for two prototype and four scaled model hollow bridge columns. Primary parameters considered for the specimens were axial load, the amount of lateral reinforcement, and height-to-depth ratio. In this study a specially designed test setup was used to subject the hollow bridge columns to a constant axial load, as well as cyclic transverse shear and bending. An analytical model is also presented that is verified by experimental results. A specimen with greater axial force has less ductility. When the columns are satisfied by the ACI code, their failure mode is flexure due to rupture of longitudinal rebars. When the amount of lateral reinforcement is less than one half of that required by the ACI code, the failure mode may become flexure-shear or shear. The analytical model satisfactorily predicts the moment-curvature relationship and load-displacement relationship of all specimens with acceptable accuracy.

Y. L. Mo et al (2002) investigated the seismic performance of hollow high-strength concrete bridge columns, six specimens were tested under a constant axial load and a cyclically reversed horizontal load. Based on the results of these tests an analytical model was developed in order to predict the moment-curvature curve of sections and the load-displacement relationship of the bridge columns. A specimen with greater axial force has less ductility. When the columns are satisfied by the ACI code, their failure mode is flexure due to rupture of longitudinal rebars. When the amount of lateral reinforcement is less than one half of that required by the ACI code, the failure mode may become flexure-shear or shear. The analytical model satisfactorily predicts the moment-curvature relationship and load-displacement relationship of all specimens with acceptable accuracy.

Benjamin Browning et al (2007) experimentally investigated the behavior of circular reinforced columns under reversed cyclic torsion. The columns were reinforced using a new confinement technique which uses two opposing spirals (cross spirals) the passage of concrete during construction. Eighteen reduced scale R/C circular columns with four different length to depth ratios and several spiral spacings and patterns were built and tested. The columns were subjected to reversed cyclic twist to study the behavior of the new confinement technique. The test results concluded that the cross spiral columns were more ductile as compared to single spiral columns with same amount of confining steel. The cross spiral columns rotated a significantly a larger amount before yielding and strength deterioration was greatly reduced by cross spiral confinement.

Dr.Alaa K. Abdal Karim et al (2013) aimed at presenting simplified approach to enable construction of new design charts for hollow section reinforced concrete columns subjected to an axial compressive load and uniaxial bending. These charts can be directly used in design of hollow columns sections, to determine required amount of steel in addition to column dimensions and estimation of column load capacity.

Yan Zhao et al (2013) evaluated seismic performances of the model piers and the factors affecting the seismic performance of the model piers by comparing their failure mechanism, bearing capacity, ductility, energy dissipation capacity, etc. Two large-scale experimental models of the hollow reinforced concrete bridge piers were built to study the seismic performance of the piers subjected to biaxial bending under constant axial load.

Abhay (2014) performed the study of structural behaviour of Hollow (Box- type) and Solid reinforced concrete members in the RCC framed building under Seismic load using ETABS software. He concluded that maximum node displacement of hollow members given by ETABS is less as compared to solid members. 20% to 27% reduction in the storey overturning moment due to hollow members in RCC framed building was observed. Storey shear for RCC framed building having hollow members is decreased by 27% as compared to solid members. 74.1687 ton of M30 concrete is saved by using hollow (Box-type) members in RCC framed building so it leads to economical design without the failure of the structure against seismic loads.

Ho-Young Kim et al (2015) conducted study on different specimens for hollow reinforced concrete bridge piers. They concluded that failure behaviour of circular hollow RC bridge pier was referable to the location of the neutral axis at failure. When the neutral axis was located inside the wall section, i.e. between the inside face and outside face of the wall, the inside face of the wall did not show any damages and the columns showed very ductile behaviour. The section with this type of failure mode may be called “flexure-controlled section”. However, if the neutral axis was located inside the hollow, i.e. the depth of the neutral axis was greater than the wall thickness, relatively brittle failure was observed due to the concrete crushing and spalling of the inside face of the circular wall. The section with this type of failure mode may be called “compression-controlled section”.

III. Experimental Program

A G+4 commercial building is modelled in ETABS2016.

Geometric properties:-

- Height of typical story =3.5 m
- Length of building = 51 m
- Width of building = 21m
- Slab thickness = 125 mm
- Beam size: 300 X 400 mm
- Column size : 600 X 600 mm

Loads :-

- Live Load
  Live load for shops, corridors and staircase = 5 kN/m^2
  Live load for Toilets = 2 kN/m^2
  (IS 875 part 2-1987 Code of practice for design loads for buildings and structures (Imposed loads).
- Masonry Load
  External walls (0.3thk) =18.9 kN/m
  Internal walls (0.15thk) = 9.5 kN/m
- Seismic Loading
  The building comes under Zone-V using the IS 1893 (Part-I) -2002

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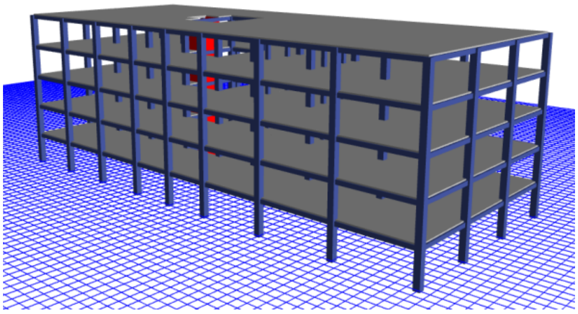

Fig. 1 3D model of commercial building modelled in ETABS2016

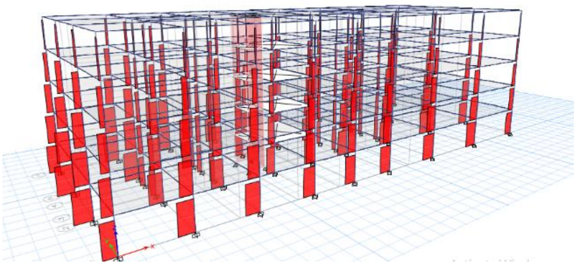

Fig.2 Axial forces acting on columns in ETABS2016

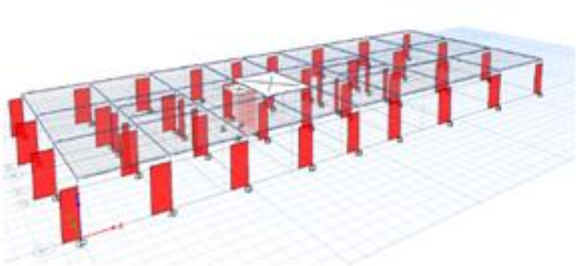

Fig. 3 Maximum values of axial forces acting on bottom story columns in ETABS2016

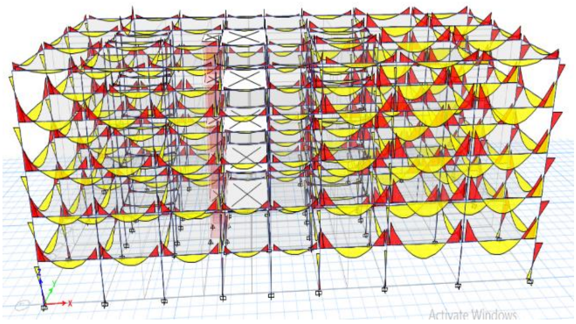

Fig.4 Bending moments acting on the building

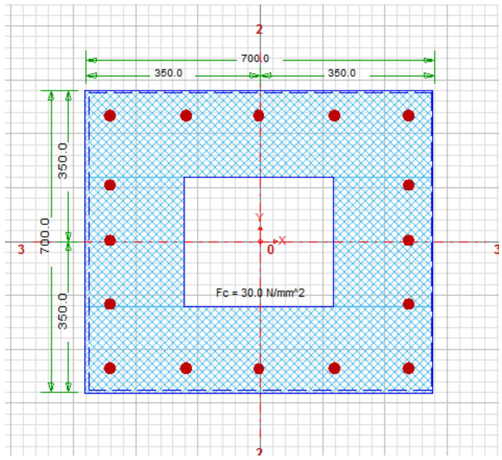

Fig.5 Cross section of hollow column in CSICOL9

Table 1. Forces acting on C16 column in the bottom story

Story	Column	Load Case/Combo	P	M2	M3
			kN	kN-m	kN-m
Story1	C16	Dead	1239.51	-0.025	-0.2956
Story1	C16	Live	1400.04	0.1707	-0.5983
Story1	C16	EQX 1	0.7864	-0.006	118.5397
Story1	C16	EQX 2	0.131	181.9535	-10.6514
Story1	C16	EQX 3	0.7651	-2.9135	35.2135
Story1	C16	EQX 4	0.2005	225.7642	-17.3792
Story1	C16	EQX 5	0.8078	2.9178	34.1833
Story1	C16	EQX 6	0.0615	138.1428	-3.9235
Story1	C16	EQY 1	0.7864	-0.006	118.5397
Story1	C16	EQY 2	0.131	181.9535	-10.6514
Story1	C16	EQY 3	0.7651	-13.4638	120.6064
Story1	C16	EQY 4	0.2005	225.7642	-17.3792
Story1	C16	EQY 5	0.8078	13.4518	116.4731
Story1	C16	EQY 6	0.0615	138.1428	-3.9235
Story1	C16	Masonry	572.41	0.2277	-0.1796
Story1	C16	DCon1	2717.88	-0.1461	0.2209
Story1	C16	DCon2	4817.95	-0.1841	-0.8905
Story1	C16	DCon3 Max	3853.39	270.7698	144.0153
Story1	C16	DCon3 Min	3820.81	-2.8415	-7.2453
Story1	C16	DCon4 Max	3854.43	16.0093	20.1427
Story1	C16	DCon4 Min	3855.33	-271.064	-145.44
Story1	C16	DCon5 Max	3853.39	270.7698	144.0153
Story1	C16	DCon5 Min	3854.28	-16.3038	-21.5675
Story1	C16	DCon6 Max	3854.43	16.0093	20.1427
Story1	C16	DCon6 Min	3855.33	-271.064	-145.44
Story1	C16	DCon7 Max	2716.67	338.5003	181.1305

Story1	C16	DCon7 Min	2717.79	-20.3418	-25.8479
Story1	C16	DCon8 Max	2717.98	20.0497	26.2897
Story1	C16	DCon8 Min	2719.1	-338.792	-180.689
Story1	C16	DCon9 Max	2716.67	338.5003	181.1305
Story1	C16	DCon9 Min	2717.79	-20.3418	-25.8479
Story1	C16	DCon10 Max	2717.98	20.0497	26.2897
Story1	C16	DCon10 Min	2719.1	-338.792	-180.689
Story1	C16	DCon11 Max	1629.52	338.5587	181.0422
Story1	C16	DCon11 Min	1630.64	-20.2834	-25.9363
Story1	C16	DCon12 Max	1630.82	20.1081	26.2014
Story1	C16	DCon12 Min	1631.94	-338.734	-180.777
Story1	C16	DCon13 Max	1629.52	338.5587	181.0422
Story1	C16	DCon13 Min	1630.64	-20.2834	-25.9363

IV. TESTING PROCEDURES

Considering the maximum values of axial force, moment 2-2 and moment 3-3, the hollow column is designed in CSICOL9

1) Maximum Axial Force= 3855 kN

Moment 2-2= 271 kN/m

Moment 3-3= 145 kN/m

2) Maximum Axial Force= 2716.67 kN

Moment 2-2= 338.5 kN/m

Moment 3-3= 181.13 kN/m

3) Maximum Axial Force= 4818 kN

Moment 2-2= 0.18 kN/m

Moment 3-3= 0.9 kN/m

Sr. No	Load Comb	Load-Pu (kN)	Mux-Bot (kN-m)	Muy-Bot (kN-m)	Mux-Top (kN-m)	Muy-Top (kN-m)
1	combination 1	4818	0.0	0.0	0.18	0.9
2	combination 2	2716.67	0	0	338	181.13
3	combination 3	3855	0	0	271	145
4						
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Fig.6 Load combinations assigned on hollow column in CSICOL9

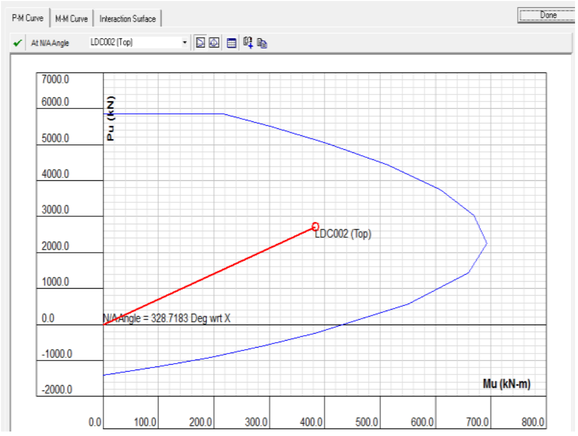

Fig.7 Interaction diagram of results for hollow column in CSICOL9

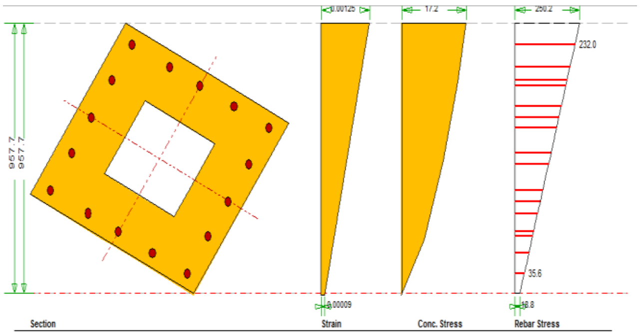

Fig.8 Stress and Strain diagram of results for hollow column in CSICOL9

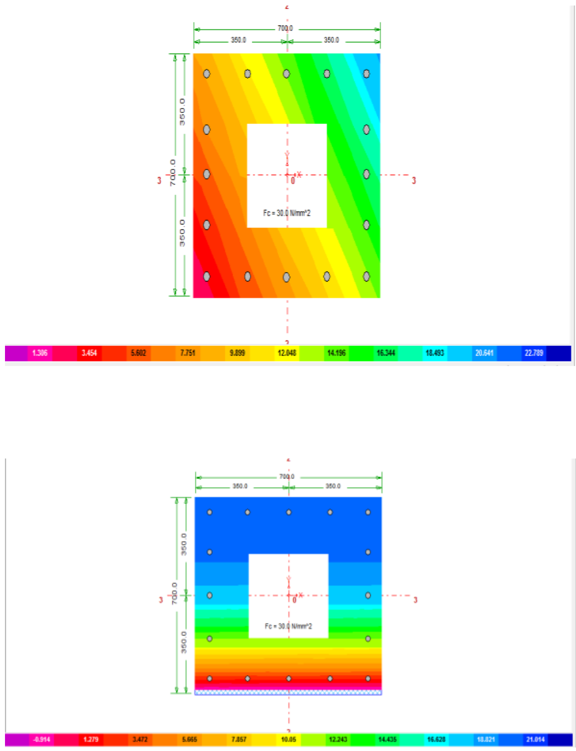

Fig.9 Stress variation diagram of results for hollow column in CSICOL9

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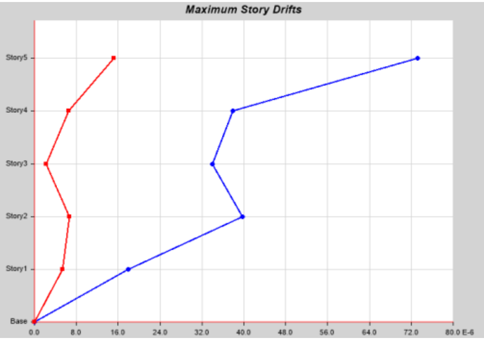

Fig 10 Maximum story drift in solid columns

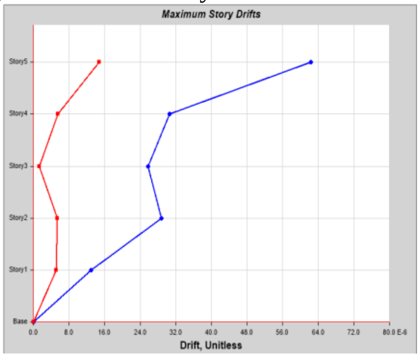

Fig. 11 Maximum story drift in hollow columns

V. RESULTS AND DISCUSSIONS

The present study indicated the feasibility of using hollow concrete columns instead of solid columns in building constructions. The following conclusions can be drawn out:

- There is 20-27% reduction in storey overturning moment in RCC framed building with hollow columns.However the storey overturning moment decreases with increase in storeys for hollow as well as solid columns.
- The results showed that the storey shear decreased in case of hollow columns as compared to solid columns. Approximately 25% decrease in storey shear was observed.
- A maximum of 15% reduction in storey drift was noted in case hollow columned structure.
- Use of hollow structure was estimated as an economical method under seismic loading without failure. It showed reduction in construction cost as compared to solid columns.

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