International Journal of Multidisciplinary Engineering in Current Research
Volume 1, Issue 1, September 2016, http://ijmec.com/

Evaluation of Suitability of Non-Rectangular Specially Shaped Thin Columns in Multi Storeyed Buildings using E-TABS Software

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***Abstract*— Now-a-days, the architects often restrict the widths of the columns so that more free space is available and for the good aesthetic look of the building without columns protruding out of the walls and corners. This is structurally not advisable and economically feasible most of the time hence an alternate solution is required to overcome this difficulty which every structural design engineer faces every day.**

Concrete structures with non-rectangular specially shaped thin columns has been studied and found out as an alternative to the above said problem and it is found out that non-rectangular specially shaped thin columns performs well structurally with all analysis results within acceptable limits.

This thesis is carried out by considering a rectangular plan building with total width of 21m (Y-direction) and total length of 54m (X-direction). The same building is analysed with specially shaped (L,T,+ plus) columns with four different models of 5,10,15,20 storeys and the economical sizes of columns are determined by trial and error with E-Tabs software. Again the same building is analysed with conventional rectangular columns of sizes with same equivalent moment of inertia as of special shaped columns.

After detailed analysis and comparison it is concluded that the building with non-rectangular specially shaped thin columns performs better under seismic and wind load conditions than the building with conventional rectangular columns under the same loadings.

The outcome of this project is that the cost of construction of multi-storeyed buildings like apartments, hotels, offices etc., would be less with more free space and column free look is available for the dwellings

***Index Terms*— E-TABS, specially shaped thin columns, Seismic load, Wind load, storey displacement, storey shear, Storey drift and base shear.**

I. Introduction

There has been a drastic change and rapid development of urban construction and various design requirements of architects, different types of structural design of constructions have taken into shape now-a-days .However, customers need more than fundamental housing function from the building since people's living standards improve greatly. They need their houses to be as perfect as possible in terms of aesthetic. So frame structure with specially shaped columns is suitable blooms, especially for villa and multi-storey buildings. This kind of structure satisfies spatial requirements of corners and intersection of the wall, as well as intersection of corners so that no visible edges or prominent column would appear in the buildings and thus expands the actual usable floor area and more furniture can be placed into the buildings.

II. SPECIALLY SHAPED COLUMNS

In the RCC buildings, columns are structural elements which are predominantly subjected to axial compressive forces, moments, and transfers total load from the super structure to sub-structure. Various shapes of the columns are used. Some common shapes are square, rectangular, circular columns and some special shapes of columns are L-shaped, T- shaped and plus (+) shaped columns as shown in figure 1 which are not commonly used but gives more indoor space than commonly used shapes of columns. Special shaped columns avoid prominent corners in a room which increases usable floor area.

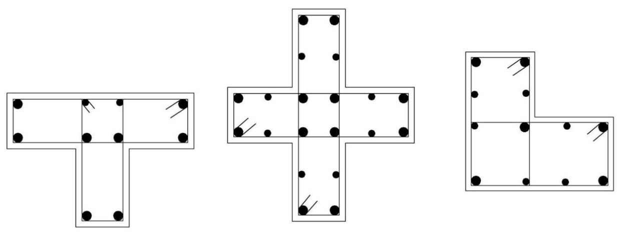

Fig.1. Specially shaped (T,+,L) columns with longitudinal and lateral reinforcement

Concrete structures with non-rectangular specially shaped thin columns have many advantages such as:

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- Stiffness in both the axes unlikely of rectangular columns.
- Increasing usable floor area
- Avoiding prominent corners in the rooms
- Reduce dead load of the structure etc.

These columns combined with the use of light weight concrete bricks and light infilled walls can be widely used in multi-storeyed and high rise building construction.
The better performance of the buildings in seismic and wind loads conditions can be achieved by using high strength steel bars and high strength concrete in construction. The reinforced concrete structure system with specially shaped columns is a system widely adopted in residential structures due to no exposed beams and columns in the room. The feasibility and convenience of reinforced concrete (RC) frame with special shaped columns in structural design and its favorable service make it widely used in construction industry.
Frame structure with specially shaped RC columns has been increasing used in multi-storey dwelling buildings over recent decades in China. The thickness of specially shaped column leg is the same as a wall, so the edges of columns are invisible and the structure with specially shaped columns is beautiful in aesthetics and appearance. But the section of specially shaped column is irregular and its behavior is different from that of rectangular column. Sometimes, the specially shaped columns with different limb lengths may be adopted in actual engineering.

III. Data to be Used

Grade of steel used is Fe 500 N/mm^2
Grade of concrete used for columns is M40
(fck = 40 N/m m^2)
Grade of concrete used for beams and slabs is M30
(fck = 30 N/mm^2)
Young's Modulus of M30 concrete, E = 27.386x103N/mm^2 (5000x√fck)
Young's Modulus of M40 concrete, E= 31.623x103 N/mm^2
Density of reinforced concrete = 25 KN/ m3

Building model details:

The model details are given below:
No. of stories 5, 10, 15 & 20

Floor to floor height	=3.2m (Typical)
Longitudinal beam size	=300mmx600mm
Transverse beam size	=300mmx450mm
Thickness of slab	=150mm
Thickness of external walls	=230mm
Thickness of internal walls	=150mm
Grade of concrete for columns	=M40
Grade of concrete for beams and slab	=M30
Grade of steel	=Fe500

IV. Loading

Dead Loads:

Dead loads are calculated as per IS 875 (part-1)-1987 Table2

Self-weight of slab (150mm thick slab)	=3.75KN/ m^2
Suspended metal lath and gypsum plaster	= 0.5KN/ m^2

Wall Loads:

Taking density of brick wall	=18KN/ m^2
External walls are considered 230mm thick	
Internal walls are considered 150mm thick	
Floor finishes	=2.0KN/m^2
Roof finishes	=2.0KN/m^2

Live Loads:

Live loads are calculated as per IS 875 (part-2)-1987 from Table 1
Flat roof with access provided Imposed load =1.5KN/m^2
Considering residential building i.e., dwelling houses

Live load for all rooms and kitchen	=2.0kn/m^2
Live load for toilet and bathrooms	=2.0KN/m^2
Live load for passage and staircase	=3.0KN/m^2
Live load for balconies	=3.0KN/m^2

Seismic Loads:

Seismic loads are calculated as per IS 1893 (part-1) 2002.
For various zones, zone factors are given in Table 2 of IS 1893(part-1)-2002
From Annex E of IS 1893 (part-1) 2002, Hyderabad comes under zone II and the zone factor Z=0.1

Note: We have considered Zone III with Z = 0.16 hence this building evaluation study is applicable to buildings in Hyderabad as well as any other building in moderate seismic zone.
In Seismic analysis, three factors are to be considered, they are:-

A. Response Reduction Factor (R)
B. Zone factor (Z)
C. Importance factor (I)

The eccentricity of the loads is considered as 5%
The Response Reduction factor is taken from Table 7 of IS 1893(part-1) 2002

Considering the building as Ordinary RC moment resisting frame (OMRF), R=3.0

Considering the soil type II Medium soil as per table 1of IS 1893 (part-1) 2002.
The Importance Factor (I) is taken from Table 6 of IS 1893 (part-1) 2002

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For important buildings like hospitals, schools, large community halls, I=1.5
For other buildings I=1.0

Considering the building as residential, the Importance factor I=1.0
The seismic load is calculated by the software itself from the above given input data.

Wind Loads:

Wind loads care calculated as per IS 875(part-3)-1987
Basic wind speed for Hyderabad Vb= 44 Km/s
Design wind speed Vz= VbK1K2K3
K1 = risk coefficient obtained from Table 1 of IS 875 (part-3) 1987
K2 = terrain height and structure size factor is obtained from Table 2 of IS 875(part-3)
Assuming the terrain category as 3 and class C
K3= topography factor from clause 5.3.3 of IS 875(part3)1987
K1 = 1.0, K2 = 1.0, K3 = 1.0

V. GOAL AND OBJECTIVES OF THE STUDY

The present thesis work is aimed at evaluating hypothetical existing RC framed buildings with the following objectives:

- Generation of 3D building models with conventional rectangular columns and special shaped (L,T,+) columns.
- Determination of deflections, storey drifts and base shear of the buildings under wind and seismic conditions.
- To find whether non-rectangular specially shaped thin columns are suitable and economical compared to conventional rectangular columns for the given loads.
- To study the behavior of the building under lateral loads like seismic and wind loads.

The goal of this project is to find out whether non-rectangular specially shaped thin columns are suitable and economical solution compared to conventional rectangular columns for the given loads and also to study the behavior of the building under lateral loads like seismic and wind loads (static and dynamic analysis).

Parametric Studies:

The different parameters like displacement, storey drift, base shear and the overall behavior of the structures when subjected to different loads is studied and compared with reference to the columns.

VI. CASE STUDY AND METHODOLOGY

For this study, a rectangular plan building is considered with total width of 21m (Y-direction) and total length of 54m (X-direction). The span (column to column distance) in X-direction is taken as 6m and in Y-direction is 4.5m with a corridor of width 3m in between. The same building is analysed with specially shaped (L,T,+ plus) columns with four different models of 5,10,15,20 storeys and the economical sizes of columns are determined by trial and error with E-Tabs software.
Again the same building is analysed with conventional rectangular columns of sizes with same equivalent moment of inertia as of special shaped columns. Four different models of 5,10,15,20 storeys are generated and analysed for the study.

The height of each floor is taken as 3.2m and the buildings are designed in compliance with the Indian codes of Practice. The buildings are assumed to be fixed at base and floors act as rigid diaphragms. The sections of structural elements are rectangular, L, T, + (plus) shaped and their sizes vary depending on the total number of storeys. The foundation depth is taken as 2.5m and all other storey heights are taken constant including ground storey. All external walls are taken 230mm thick and all internal walls are taken 150 mm thick. Beams in X-direction are 230x600 mm size and beams in Y-direction are 230x450mm size. Slab thickness is taken as 150mm thick.

The buildings are modeled using E-TABS. The location of building is considered in Hyderabad i.e., seismic zone III and the type of the buildings are considered as residential apartment. In seismic analysis only 25% of the floor live load is considered as per IS1893-2000 for Live Load ≤ 3.0 KN/M^2
Ground Floor has been considered as stilt floor to use as car parking area with slab on grade without any infilled brick walls, hence no slab or wall load has been modeled at ground floor level.

E-TABS software has been used for the analysis and design of building models. Multi-storeyed building models with different floors has been analysed and designed using conventional rectangular columns and the same buildings has been designed using non-rectangular specially shaped (L, T &plus + shapes) thin columns and a comparative study of both type of buildings has been done.

The buildings of 5, 10, 15 and 20 storeys are modeled, analysed and designed for static and dynamic loading and the detailed comparison of the results has been performed.

A span of nearly 4.5m to 6m c/c between columns has been chosen for the present study. Lateral loads like seismic and wind loads has also been applied as per requirements of IS codes and a comparative study of storey displacement, storey

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shear, storey drift, base shear, overturning moment and building drift has been done using seismic analysis.

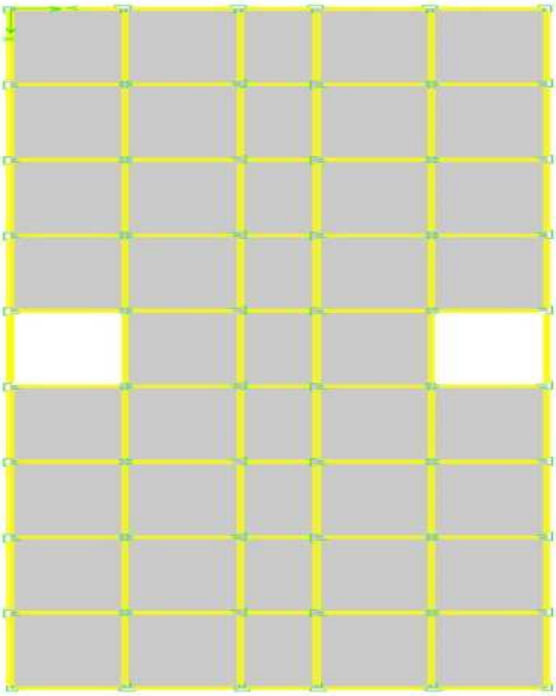

Fig. 1.2. PLAN VIEW

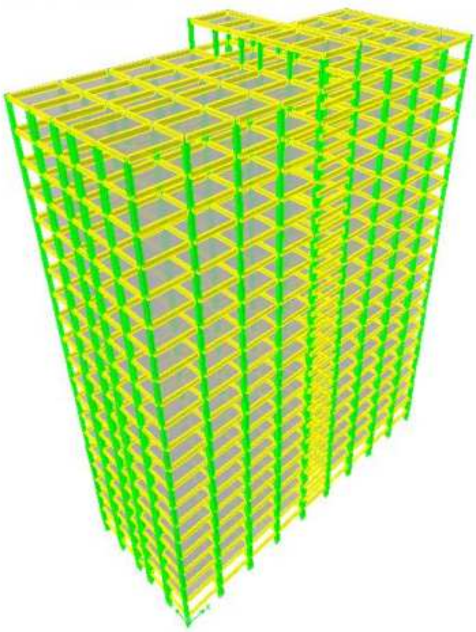

Fig. 1.3. ISOMATRIC VIEW

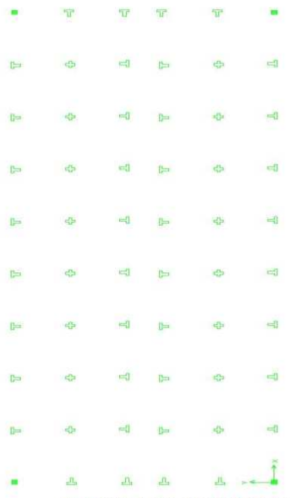

Fig. 1.4. COLUMN LAYOUT FDN-5F

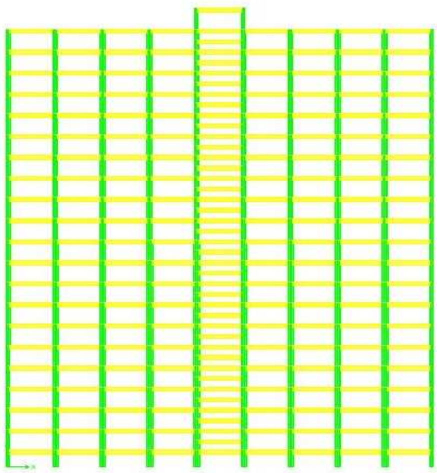

Fig. 1.5. FRONT ELEVATION

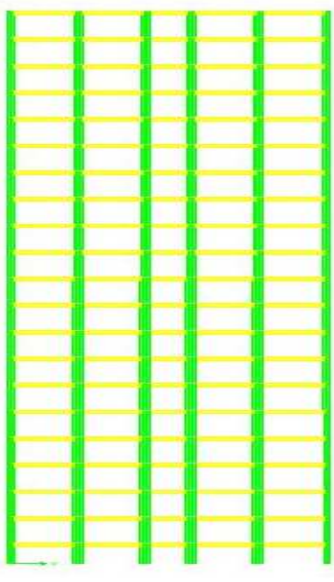

Fig. 1.6. SIDE ELEVATION

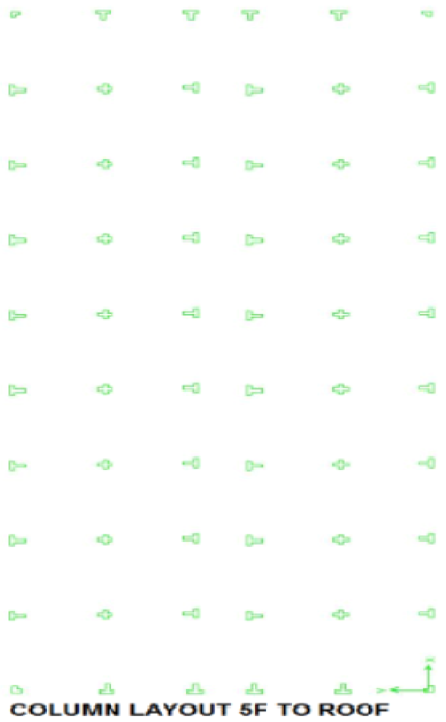

Fig. 1.7. COLUMN LAYOUT 5F-ROOF

VII. RESULTS AND DISCUSSION

After study of analysis results tabulated below, it has been found that maximum storey displacements of all building models i.e. 20, 15, 10 and 5 storeys are under acceptable limits.

It is observed that the deflection of buildings with equivalent rectangular columns are 1.5 to 2 times more than the buildings with specially shaped columns with little reduction in base shear and overturning moment for different lateral forces.

Hence it is quite desirable to have lesser deflection of the building as per serviceability point of view hence the performance of specially shaped columns is superior to rectangular columns.

After study of column design results tabulated below, it is concluded that average column reinforcement of all building models i.e. 20, 15, 10 and 5 storeys with specially shaped columns are under acceptable limits.

It is also observed that the columns from 15 to 20 storeys has only minimum 0.8% reinforcement requirement.

All the equivalent rectangular columns have failed in the reinforcement designed criteria between foundations to 15 floor level and columns satisfy the reinforcement design requirement criteria between 15 to 20 floors only that to with higher percentage of steel in the range of 2.2 % to 5.96% although the reinforcement requirement of specially shaped columns is only 0.8%

Hence it is concluded that equivalent Rectangular columns are not suitable for the 20 storey building structure at the same time specially shaped columns are performing fantastically, hence specially shaped columns performance is far superior to rectangular columns.

TABLE I Base Shear, Storey Drift, Storey Displacement and Overturning Moments (20 Storey Building Model)

20 STOREYS BUILDING RESULTS- SPECIALLY SHAPED COLUMNS (E-TABS Results)					
Sl. No	**Load**	**Base Shear (KN)**	**Max. Storey Displacement (MM)**	**Max. Storey drift (MM)**	**Overturn -ing Moment KN-M**
1	Wx	1560	20	0.003	60500
2	Wy	3280	72	0.004	127000
3	EQx	3160	56	0.004	160000
4	EQy	2540	88	0.004	128000
5	Spec-1	3190	47	0.004	128000
6	Spec-2	2540	80	0.004	101000

TABLE II Base Shear, Storey Drift, Storey Displacement and Overturning Moments (20 Storey Building Model)

20 STOREYS BUILDING RESULTS- EQUIVALENT RECT. COLUMNS (E-TABS Results)					
Sl. No	**Load**	**Base Shear (KN)**	**Max. Storey Displacement (MM)**	**Max. Storey drift (MM)**	**Overturn -ing Moment KN-M**
1	Wx	1560	19.5	0.003	60500
2	Wy	3280	**145.55****	0.004	127000
3	EQx	3150	57	0.004	159000
4	EQy	2480	**167****	0.004	125000
5	Spec-1	3170	49	0.004	128000
6	Spec-2	2380	**143****	0.004	99800

** Excessive Deflection

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TABLE III COLUMN REINFORCEMENT
20 Floors Building Models (E-TABS Results)

SL. No.	Floors	Column Location	Column Shape	Column Sizes (mm)	% Steel Reinforcement (Shaped columns)	% Steel Reinforcement (Equivalent Rectangular columns)
1	0 to 5	Grid-1 Exterior Col.	**Square**	450x450	3.52	5.2
2	5 to 10	Grid-1 Exterior Col.	**L**	230x450x450	5.88	O/S
3	10 to 15	Grid-1 Exterior Col.	**L**	230x450x450	3.46	5.92
4	15 to 20	Grid-1 Exterior Col.	**L**	230x450x450	0.8	2.73
5	0 to 5	Grid-1 Interior Col.	**T**	230x750x750	5.83	O/S
6	5 to 10	Grid-1 Interior Col.	**T**	230x750x750	3.37	O/S
7	10 to 15	Grid-1 Interior Col.	**T**	230x600x600	2.04	O/S
8	15 to 20	Grid-1 Interior Col.	**T**	230x600x600	0.8	5.5
9	0 to 5	Grid-1 Lift Lobby	**T**	230x750x750	5.9	O/S
10	5 to 10	Grid-1 Lift Lobby	**T**	230x750x750	3.53	O/S
11	10 to 15	Grid-1 Lift Lobby	**T**	230x600x600	2.29	O/S
12	15 to 20	Grid-1 Lift Lobby	**T**	230x600x600	0.8	5.96
13	0 to 5	Grid-2 Exterior Col.	**T**	230x750x750	5.42	O/S
14	5 to 10	Grid-2 Exterior Col.	**T**	230x750x750	2.96	O/S
15	10 to 15	Grid-2 Exterior Col.	**T**	230x600x600	1.86	5.88
16	15 to 20	Grid-2 Exterior Col.	**T**	230x600x600	0.8	2.2
17	0 to 5	Grid-2 Interior Col.	+	230x750x750	5.2	O/S
18	5 to 10	Grid-2 Interior Col.	+	230x750x750	2.65	O/S
19	10 to 15	Grid-2 Interior Col.	+	230x600x600	1.51	O/S
20	15 to 20	Grid-2 Interior Col.	+	230x600x600	0.8	2.68
21	0 to 5	Grid-2 Lift Lobby	+	230x750x750	5.08	O/S
22	5 to 10	Grid-2 Lift Lobby	+	230x750x750	2.63	O/S
23	10 to 15	Grid-2 Lift Lobby	+	230x600x600	1.62	O/S
24	15 to 20	Grid-2 Lift Lobby	+	230x600x600	0.8	3.67
25	0 to 5	Grid-3 Exterior Col.	**T**	230x750x750	4.69	O/S
26	5 to 10	Grid-3 Exterior Col.	**T**	230x750x750	2.31	O/S
27	10 to 15	Grid-3 Exterior Col.	**T**	230x600x600	1.46	5.88
28	15 to 20	Grid-3 Exterior Col.	**T**	230x600x600	0.8	2.47
29	0 to 5	Grid-3 Interior Col.	**T**	230x750x750	5.39	O/S
30	5 to 10	Grid-3 Interior Col.	**T**	230x750x750	2.75	O/S
31	10 to 15	Grid-3 Interior Col.	**T**	230x600x600	1.69	O/S
32	15 to 20	Grid-3 Interior Col.	**T**	230x600x600	0.8	3.12

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VIII. CONCLUSION

After the detailed comparative study, as per engineering knowledge and best practices it is been established that the building with non-rectangular specially shaped thin columns performs better under seismic and wind load conditions than the building with conventional rectangular columns under the same loadings.

It is also been concluded that buildings with non-rectangular columns will be more economical and user friendly with good aesthetics.

The outcome of this project is that the cost of construction of multi-storeyed buildings like apartments, hotels, offices etc., would be less with more free space with column free look is available for the dwellings.

The specially shaped columns are not suitable for low rise buildings i.e. Five storeys and less height. It is advantageous to use for buildings from 6 to 20 stories.

It is been found that the reinforcement requirement in columns are minimum i.e. 0.8% in half of the height of the buildings, 3-4 storeys from foundation have little high steel consumption but comparable to conventional rectangular columns.

IX. SCOPE OF FURTHER STUDY AND LIMITATIONS

Scope of Further Study

There are many areas where work need to be done to use the shaped thin columns in the buildings which are summarized as below:

1. Building models need to be analysed and designed for Severe and Very severe seismic zone (Zone IV and V) and study the behavior.
2. Effect of infilled walls has been ignored for the present study and need to be considered under further study.
3. Effect of shear wall and core wall need to be studied together with thin specially shaped columns.
4. The behavior of the thin shaped columns needs to be studied for un-symmetric building structures; present study covers only symmetrical buildings which are most common in apartment structures.

Limitations and disadvantages of the thin specially shaped columns:

There are few limitations and disadvantages of specially shaped thin columns in the buildings which are summarized as below:

1. It has been concluded that till 5 storied buildings standard rectangular columns works more efficiently than shaped columns, hence it should not be used for buildings of height five storeys or less.
2. Shuttering is non-standard and not available easily in the market and to be custom made hence suitable for large construction only. High shuttering cost can be advantageous in case of large construction and multiple time usage of this custom made shuttering.
3. Skilled and trained manpower is needed to install the shuttering and reinforcement as it is not conventional rebar work.
4. Specially shaped thin column do not work for buildings above 20 storeys.

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