ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 4, Issue 1, January 2019

Linear Dynamic Response Spectrum Analysis on Different Geometric Plans of Frame Tube Structures

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***Abstract:* --For the purpose of study of geometry of frame tube structures in this report frame tube structure has been modelled in four different geometries namely Square, Rectangular, Triangular and Circular. And each geometry having variation in number of stories namely G+20, G+30, G+40 and G+50 stories are considered to study the effects of variation of height of the structure. All the models having approximately equal area and similar identical member sectional properties and identical loading, The Linear Dynamic Response Spectrum Analysis is performed on a total of sixteen building models. It was observed that the square model shows reduction in top story displacement up to 16.55% of rectangular model, 1.84% of triangular and 6.93% of circular model. As we know that with the increase in height of a structure the displacement of the structure also increases, it is observed that the story displacements are increased in G+30 story by 27%, in G+40 story by 42% and in G+50 story by 50% to that of a G+20 story models. The square model shows reduction in inter story drift up to 15.89% of rectangular model, 2.53% of triangular model and 6.40% of circular model. The square model shows reduction in story shear up to 17.12% of rectangular model, 11.68% of triangular model and 5.06% of circular model.**

Index Terms: — Frame tube structure, Geometric irregularity, Response spectrum analysis, Tall buildings.

I. INTRODUCTION

In Frame tube system, the perimeter of the building consists of closely spaced columns connected by deep spandrels. The system works quite efficiently as a hollow vertical cantilever. In its simplest terms, a framed tube can be defined as a three-dimensional system that engages the entire building perimeter to resist lateral loads. A necessary requirement to create a wall-like three-dimensional structure is to place columns on the building exterior relatively close to each other, joined by deep spandrel girders. In practice, columns are placed 10 ft. (4 m) to as much as 20 ft. (6.l m) apart, with spandrel depths varying from about 3 to 5 ft. (0.90 to 1.52 in.). The economy of the tube system therefore depends on factors such as spacing and size of columns, depth of perimeter spandrels, and the plan aspect ratio of the building[1]. It was the initial system type developed by Fazlur Rahman Khan. This design was first used in Chicago's DeWitt-Chestnut Apartment Building, designed by Khan and finished in 1965, but the most notable examples are the Aon Center and the original World Trade Center towers [2-3].

II. LITERATURE REVIEW

Reza Mahjoub et. al. (2011) studied the methods for evaluating shear lag and suggested two relation groups capable of considering shear lag assuming the tube frame as a web and flange panel and then by considering deformation functions for web and flange frames and proposed a method for numerical analysis[4]. Jahanshahi M. R. et. al. (2012) presented parametric functions for static analysis of tall buildings with combined system of tube-in-tube and outrigger belt truss system subjected to three separate load cases of concentrated load at top of the structure, uniformly and triangularly distributed loads along the height of the structure[5]. It has been shown that results computed by the energy method correlate well with those obtained by means of SAP2000 analysis. Abbas Ali Ibrahim and N. V. Ramana Rao (2015) compared the effect of using framed shear wall system and framed tube system in resisting lateral load for tall buildings with rectangular shapes and to know the much effective system in resisting lateral loads and concluded that for 30, 40, 50 and 60 story structures the Framed Tube is very much effective in resisting lateral loads (both Wind and Earthquake loads) compared to the Shear Wall Structures[6]. Sharadrao Patil and Uttam Kalwane (2015) studied the shear lag phenomenon considering axial force under the action of lateral loading and also the non-dimensional structural parameters governing shear lag phenomenon[7]. Nimmy Dileep and Renjith R (2015) modelled three different tube-in-tube structures by varying the location of the inner tubes. The structures were analyzed using continuum approach in which the horizontal slabs and beams connecting vertical elements were assumed as

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continuous connecting medium having equivalent distributed stiffness properties[8]. Hamid Mirza Hosseini (2015) conducted a parametric study with selected key design variables on the performance of a 40 story building and concluded that the effects of the column depth on the tube action and shear lag behavior were more prominent than the other member dimensions[9]. Arezo Partovi and Jenny Svard (2016) performed comparison of the core, outrigger and perimeter frame system and eight different configurations of Tubed Mega Frame systems was carried out for several different building heights as a main study, based on the tall building 432 Park Avenue, New York. The authors concluded that the Tube Mega Frames Perimeter frame systems had the smallest deflections as the building height was increased and could be increased the most without reaching tension at the base[10]. Hojat Allah Ghasemi (2016) studied the effects of varying design parameters on the tube action and shear lag behavior of a typical reinforced concrete bundled tube building, and propose optimal design approaches for similar structures. The author concluded that increase in column width and beam width reduced overall building drift[11]. Abdul Rafey and Azeem (2018) analysed using linear static method the diagrid and conventional braced structures with symmetric and asymmetric plan geometries. It was observed that the diagrid structures' performance against the lateral loads was much better than that of the conventional braced frame structure[12].

The primary objectives of this study is to investigate the effects of varying plans geometry on the tube action of a typical reinforced concrete framed tube buildings using Linear Dynamic Response Spectrum Analysis and to study the response parameters like displacements, story drifts, base shear and base moment. To specify the optimal type of geometry for similar structures and to see whether this optimal geometry changes with height of the structure.

III. ANALYTICAL MODELS AND METHODOLOGY

A. Building Models used in the Study

Four analytical structures of RC frame structure of different geometry i.e. Square, Rectangle, Triangle and Circle are modeled in ETABS 2015 software. All the structures have approximately equal area with similar identical member sectional properties in all the geometries and each geometry having the variation in story heights namely 20, 30, 40, and 50 story. The material properties, loading details and member sectional properties are shown in Tables 1 and 2. To investigate the effects of varying plans geometry on the tube action of a typical reinforced concrete framed tube building, and propose optimal geometric design approaches for similar structures. And to see whether the optimal geometry changes with height of the structure. The loading is in accordance to the codes as IS 875: Part I and Part II and the Earthquake loads are according to IS 1893: Part I 2002[13][14].

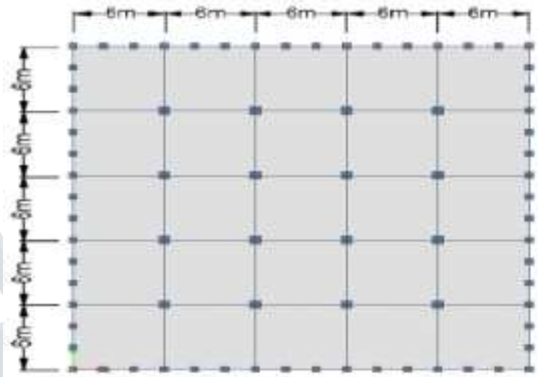

Fig. 1 Plan view of a square building model

Fig. 1 shows the plan view of square model with the plan dimensions 30 m x 30 m and the area 900m2. Fig. 2 shows the plan view of rectangular model with plan dimensions 42 m x 22 m and the area of the building 924m2. Fig. 3 shows the plan view of triangular model having the equilateral side of 46 meters and the area of the building is 916m2. Fig. 4 shows the plan view of circular model having the radius of 17 meters and the area of the building is 907m2.

Table 1: Material Properties and loading details

Parameter	Value
Height of ground story	4m.
Height of the remaining stories	3m.
Grade of concrete	M40 and M50
Grade of steel	Fe500
Floor finish load	1 KN/m^2
Live load	2.5 KN/m^2
Partition wall load (inner wall)	8 KN/m
Partition wall load (exterior wall)	10 KN/m
External columns spacing c/c	2m.
Internal columns spacing c/c	6m.
Response reduction factor (R)	5
Zone factor (Z)	0.24
Site type	II
Importance factor	1

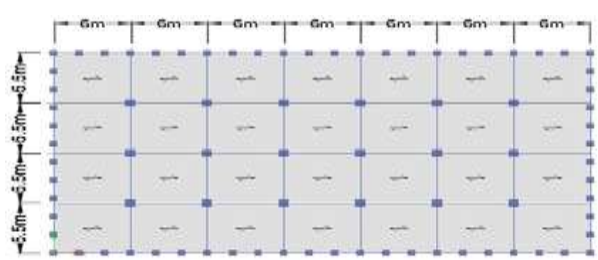

Fig. 2 Plan and 3d view of a rectangular building mode

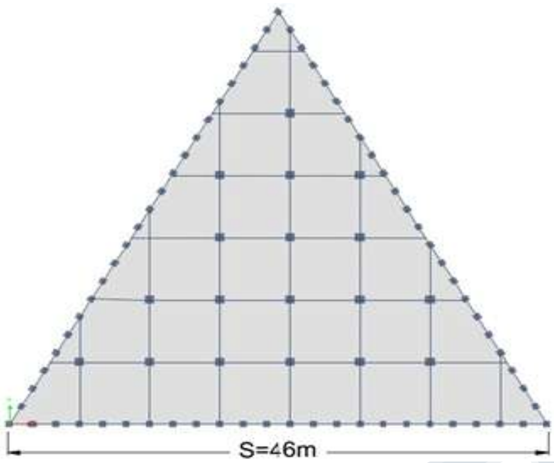

Fig. 3 Plan and 3d view of a triangular building model

<table>
<tr><th rowspan="3">Storey No's</th><th colspan="8">Square, Rectangle, Triangular, circular</th></tr>
<tr><th colspan="2">20 Storey Column sizes (mm)</th><th colspan="2">30 Storey Column sizes (mm)</th><th colspan="2">40 Storey Column sizes (mm)</th><th colspan="2">50 Storey Column sizes (mm)</th></tr>
<tr><th>External</th><th>Internal</th><th>External</th><th>Internal</th><th>External</th><th>Internal</th><th>External</th><th>Internal</th></tr>
<tr><td>0-10</td><td>500 X 500</td><td>800 X 800</td><td rowspan="2">600 X 600</td><td rowspan="2">900 X 900</td><td rowspan="2">800 X 800</td><td rowspan="2">1000 X 1000</td><td rowspan="2">1000 X 1000</td><td rowspan="2">1200 X 1200</td></tr>
<tr><td>11-15</td><td rowspan="2">400 X 400</td><td rowspan="2">600 X 600</td></tr>
<tr><td>16-20</td><td rowspan="3">500 X 500</td><td rowspan="3">600 X 600</td><td rowspan="4">500 X 500</td><td rowspan="2">800 X 800</td><td rowspan="5">600 X 600</td><td rowspan="5">800 X 800</td></tr>
<tr><td>21-22</td><td colspan="2">—</td></tr>
<tr><td>23-30</td><td colspan="2">—</td><td rowspan="2">600 X 600</td></tr>
<tr><td>31-40</td><td colspan="4">—</td></tr>
<tr><td>41-50</td><td colspan="6">—</td></tr>
<tr><td colspan="9">Beams- all main beams (in outer-periphery) = 600 mm X 800 mm</td></tr>
<tr><td colspan="9">Beams- all secondary beams (in inner-periphery) = 600 mm X 1200 mm</td></tr>
<tr><td colspan="9">Slabs- all slabs = 300 mm (Thick)</td></tr>
</table>

Table 2 Member sectional properties

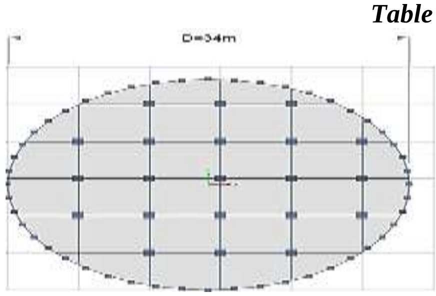

Fig. 4 Plan and 3d view of a circular building model

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
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IV. RESULTS AND DISCUSSIONS

A. Time Period

Table 3 Fundamental Time Periods of the building models

Story/ Geometry	Square	Rectangular	Triangular	Circular
20	1.75	1.81	1.75	1.76
30	2.34	2.51	2.31	2.41
40	2.94	3.22	2.91	3.08
50	3.47	3.89	3.39	3.67

The fundamental time periods of the building models considered are shown in Table 3. It was observed that with the time period increases with the increase in height of the structure. The square model shows reduction in time period up to 11% when compared to rectangular model, 6% when compared to circular model and increment in time period by 3 % when compared to triangular model.

B. Story Displacement

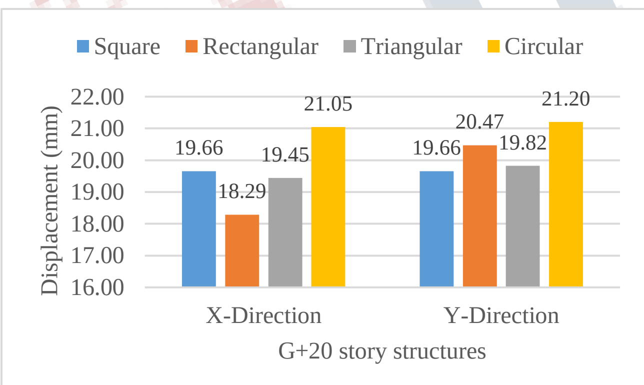

Fig. 5 Story displacement for 20 story structures of different geometries

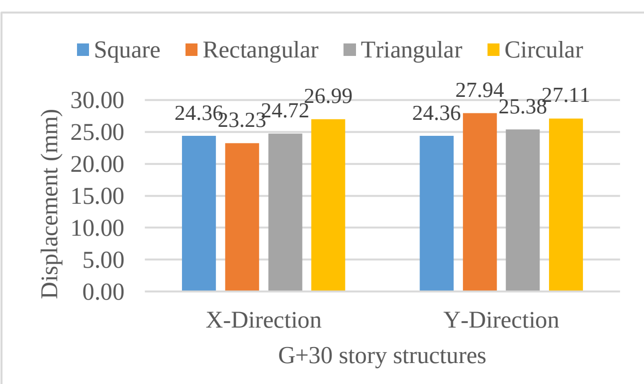

Fig. 6 Story displacement for 30 story structures of different geometries

Fig. 5 shows the maximum displacement of 20 story models. It can be seen that for square model there is an increase in maximum displacement of about 7% and 1.08% when compared to rectangular model and triangular model, and reduction of about 7.1% when compared circular model in X direction. In Y direction, it can be seen that the square model shows reduction in top story displacement of about 0.82%, 4.14% and 7.85% when compared to triangular model, rectangular model circular model respectively.

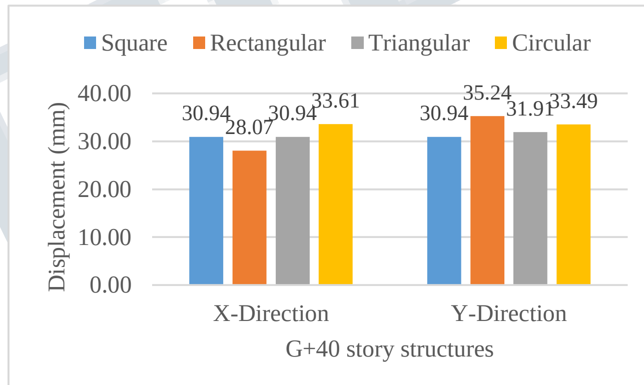

Fig. 7 Story displacement for 40 story structures of different geometries

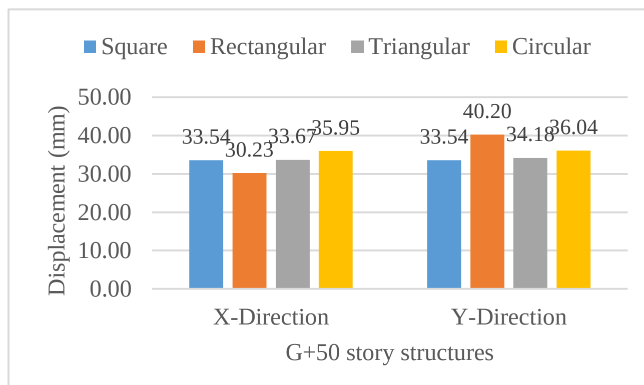

Fig. 8 Story displacement for 50 story structures of different geometry

In Fig. 6, the square model shows an increase in top story displacement in X direction of about 4.66% when compared to rectangular model, and reduction in top story displacement of about 1.45% and 10.79% when compared to triangular and circular models respectively. The square model shows reduction in top story displacement of about 4.15%, 11.28% and 14.67% when compared to triangular, circular and rectangular models respectively in Y direction.

The top story displacement for 40 story structures in X direction is as shown in Fig. 7. The square model shows an increase in top story displacement in X direction of about 9.27% when compared to rectangular model and decrease of about 0.01% and 8.26% when compared to triangular and circular models. The square model shows reduction in top story displacement of about 3.13%, 8.64% and 13.91% when compared to triangular, circular and rectangular models in Y direction

Fig. 8 illustrates the story displacement for 50 story structures in X direction. It is observed that the square model shows increment in top story displacement in X direction of about 9.87% when compared to rectangular model and reduction in top story displacement of about 0.38% and 7.18% when compared to triangular and circular models. In Y direction, the square model shows reduction in top story displacement of about 19.83%, 1.88% and 7.46% when compared to rectangular, triangular and circular models.

It can be observed from the roof displacement results that the displacements are minimum in square geometric structure for G+30, G+40 and G+50 stories. For G+20 structure the minimum roof displacement is observed in triangular structure, with a slight variation when compared to square structure. One of the main reason for the variation of the results could be due to the placement of coordinate axes with respect to the structure especially in case of triangular and rectangular structures, which in turn leads to the change in the stiffness of the structure in that particular direction resulting in the variation of the results.

C. Story Drift

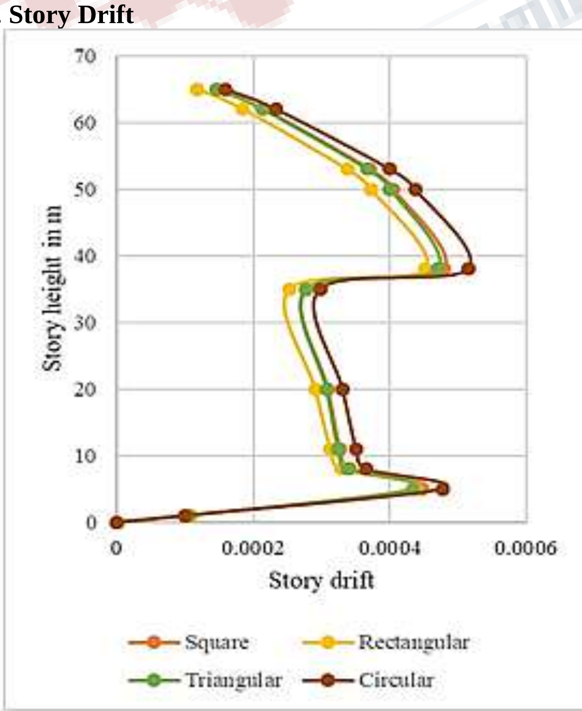

Fig. 9 Story drift for 20 story structures of different geometry in X direction

Fig. 9 shows the story drift for 20 story structures in X direction, it was observed that the square model shows an increment in inter story drift of about 5.43% and 1.67% when compared to rectangular and triangular models and a reduction of about 7.74% when compared to circular model.

Fig. 10 shows story drift for 20 story structures in Y direction, it was observed that the square model shows reduction in inter story drift of about 1.68% and 8.57% when compared to rectangular and circular models and increment of about 0.20% when compared to triangular model.

The least amount of story drift in 20 story structures is observed in the square geometric structure having same values of drift in both the (X, Y) directions. In rectangular geometric structure it is observed that the structure having least story drift in X direction but also having the maximum story drift in Y direction but less than that of circular geometric structure. In circular geometric structure the story drift is maximum in both the (X, Y) directions. And the story drift for triangular geometric structure are having the moderate and approximately equal story drift in both the (X, Y) directions. The sudden change in the profile of the story drift at level 10th is due to the change in member sectional properties thereafter.

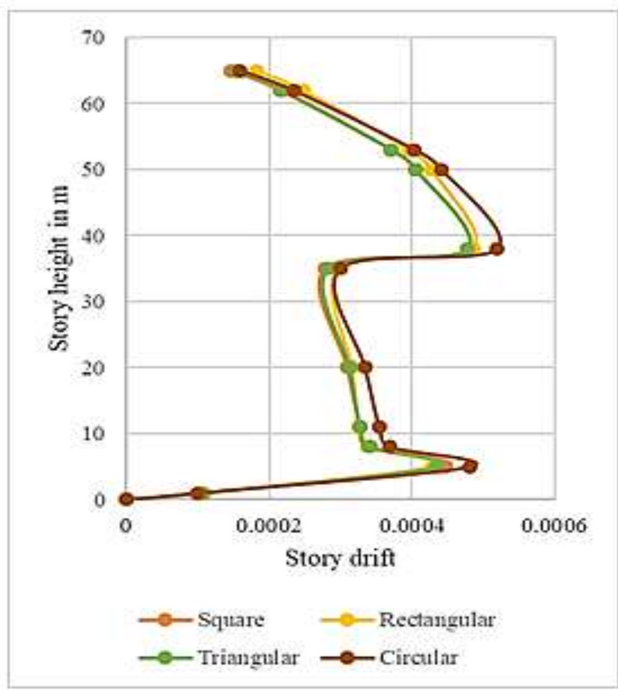

Fig. 10 Story drift for 20 story structures of different geometry in Y direction

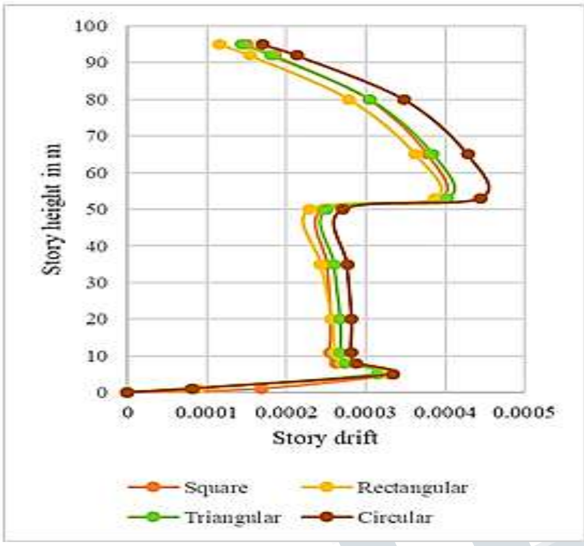

Fig. 11 Story drift for 30 story structures of different geometry in X direction

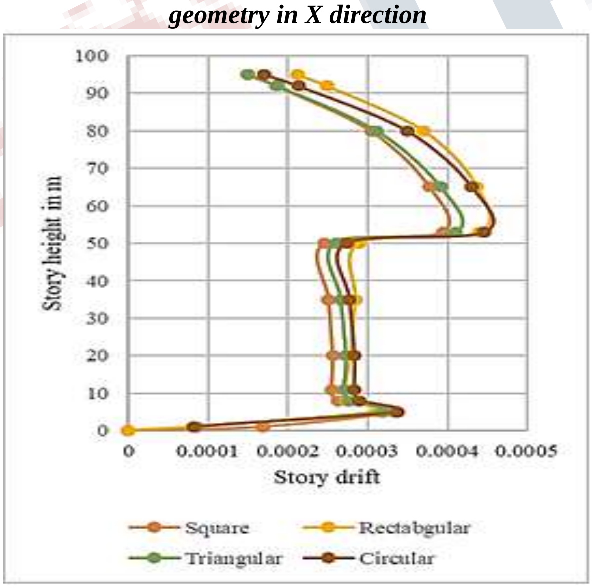

Fig. 12 Story drift for 30 story structures of different geometry in Y direction

The story drift for 30 story structures in X direction is shown in Fig. 11. It is observed that the the square model shows increment in inter story drift up to 1.77% when compared to rectangular model and reduction in inter story drift up to 2% and 13.19% when compared to triangular and circular models. The story drift for 30 story structures in Y direction is shown in Fig. 12. It was observed that the square model shows reduction in inter story drift of about 11.67%, 13.19% and 4.06% when compared to rectangular, circular and triangular models.

The least amount of story drift in 30 story structures is observed in the square geometric structure having same values of drift in both the (X, Y) directions. In rectangular geometric structure it is observed that the structure having least most story drift in X direction but also having the maximum story drift in Y direction. And the story drift for triangular and circular geometric structures are having the moderate and approximately equal story drift in both the (X, Y) directions. The sudden change in the profile of the story drift at level 15th is due to the change in member sectional properties there after (i.e. different member sectional properties below and over the 15th story)

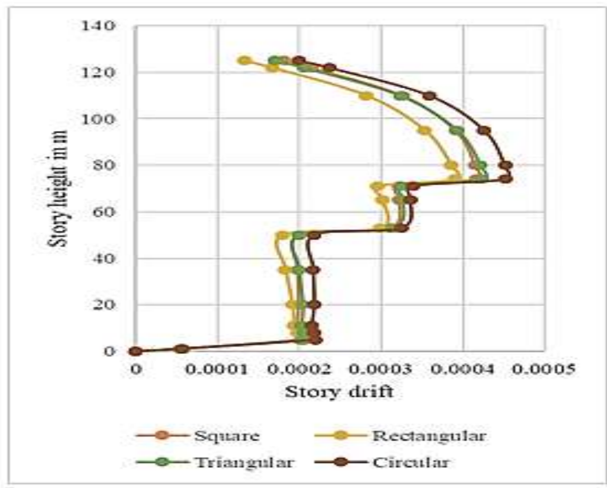

Fig. 13 Story drift for 40 story structures of different geometry in X direction

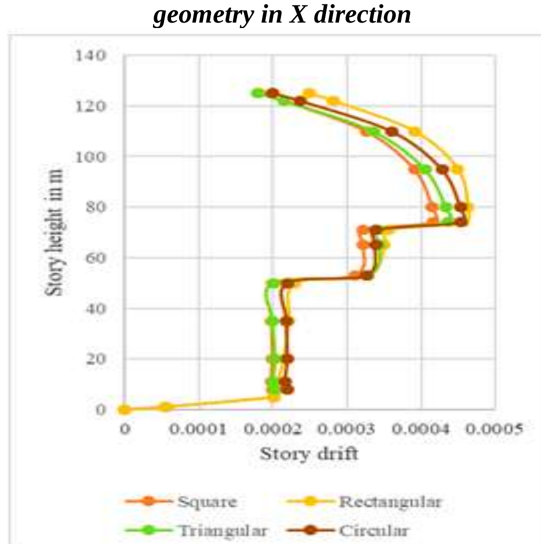

Fig. 14 Story drift for 40 story structures of different geometry in Y direction

Fig. 13 shows the story drift for 40 story structures in X direction, it was observed that the square model shows increment in inter story drift up to 6.25% when compared to rectangular model and reduction of about 1.65% and 8.41 % when compared to triangular and circular models. Fig. 14

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shows the story drift for 40 story structures in Y direction, it was observed that the square model shows reduction in inter story drift of about 9.61%, 4.81% and 8.9% when compared to rectangular, triangular and circular models.

The least amount of story drift in 40 story structures is observed in the square geometric structure having same values of drift in both the (X, Y) directions. In rectangular geometric structure it is observed that the structure having least most story drift in X direction but also having the maximum story drift in Y direction. And the story drift for triangular and circular geometric structures are having the moderate and approximately equal story drift in both the (X, Y) directions. The sudden change in the profile of the story drift at level 22nd and 15th is due to the change in member sectional properties there after (i.e. different member sectional properties below and over the 22nd and 16th story)

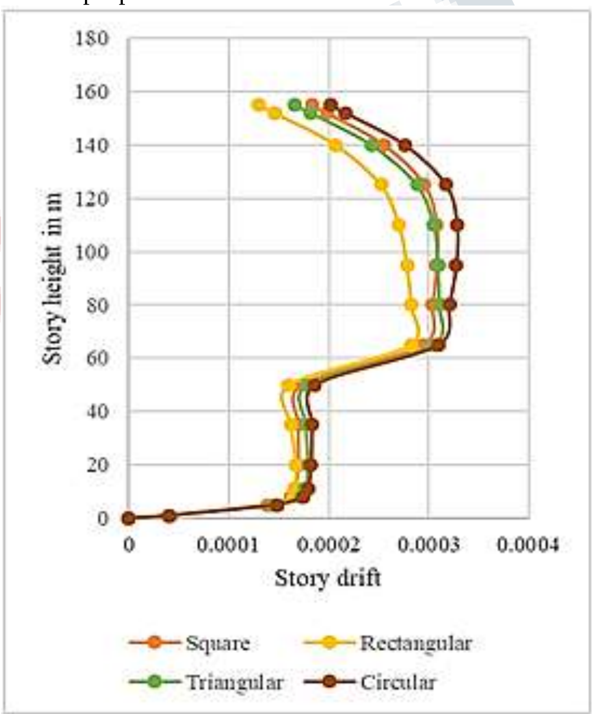

Fig. 15 Story drift for 50 story structures of different geometry in X direction

Fig. 15 depicts the story drift for 50 story structures in X direction. It was observed that the square model shows reduction in inter story drift up to 2.6% of triangular model, 5.31% of circular model and increment in inter story drift up to 6.93% of rectangular model. Fig. 16 shows the story drift for 50 story structures in Y direction. It was observed that the square model shows reduction in inter story drift up to15.89% of rectangular model, 2.53% of triangular model and 6.40% of circular model.

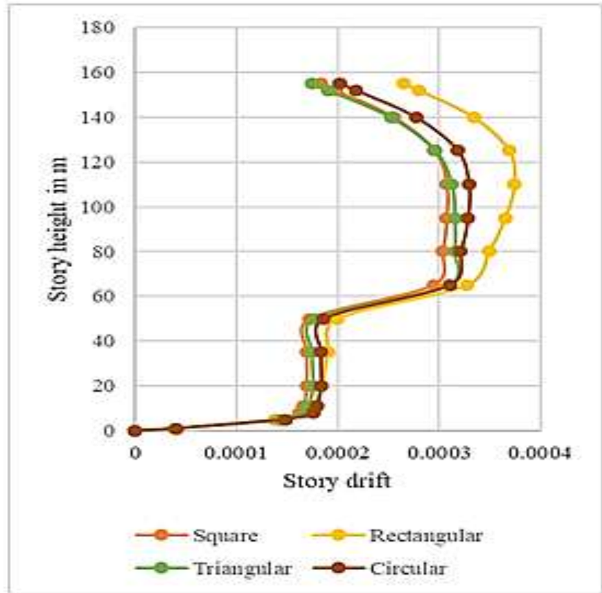

Fig. 16 Story drift for 50 story structures of different geometry in Y direction

The least amount of story drift in 50 story structures is observed in the square geometric structure having same values of drift in both the (X, Y) directions. In rectangular geometric structure it is observed that the structure having least most story drift in X direction but also having the maximum story drift in Y direction. And the story drift for triangular and circular geometric structures are having the moderate and approximately equal story drift in both the (X, Y) directions. The sudden change in the profile of the story drift at level 15 is due to the change in member sectional properties there after (i.e. different member sectional properties below and over the 15th story)

D. Base Shear

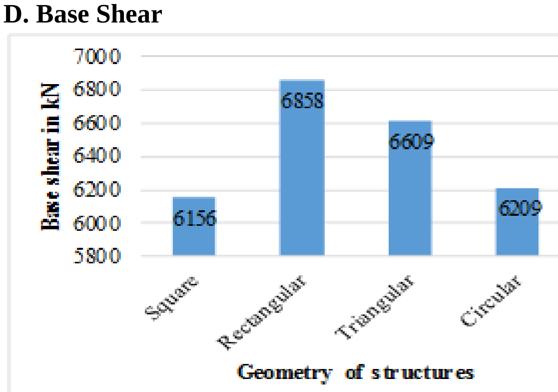

Fig. 17 Base shear for 20 story structures of different geometry in X direction

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ISSN (Online) 2456-1290

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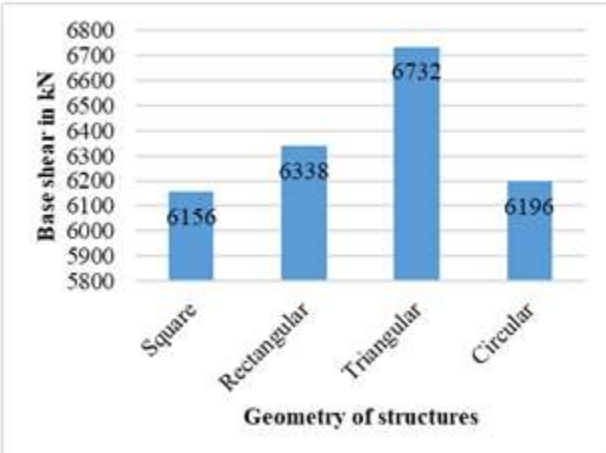

Fig. 18 Base shear for 20 story structures of different geometry in X direction

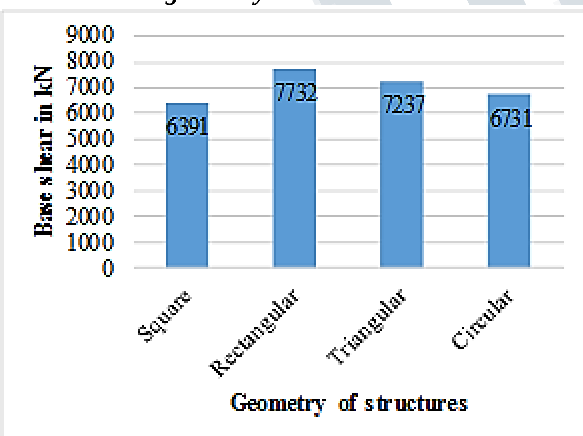

Fig. 19 Base shear for 30 story structures of different geometry in X direction

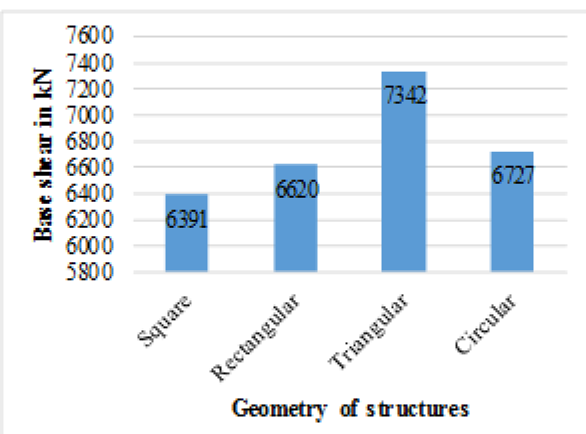

Fig. 20 Base shear for 30 story structures of different geometry in Y direction

From Fig. 17, it was observed that the square model shows reduction in base shear up to 10.23%, 6.85% and 0.85% when compared to rectangular, triangular and circular models. From Fig. 18, it was observed that the square model shows reduction in base shear of about 2.87%, 8.55% and 0.64% when compared to rectangular, triangular and circular models.

It can be seen in Fig. 19 that the square model shows reduction in base shear of about 17.34%, 11.68% and 5.05% when compared to rectangular, triangular and circular models. From Fig. 20, it is observed that the square model shows reduction in base shear up to 3.46%, 12.95% and 5% when compared to rectangular, triangular and circular models.

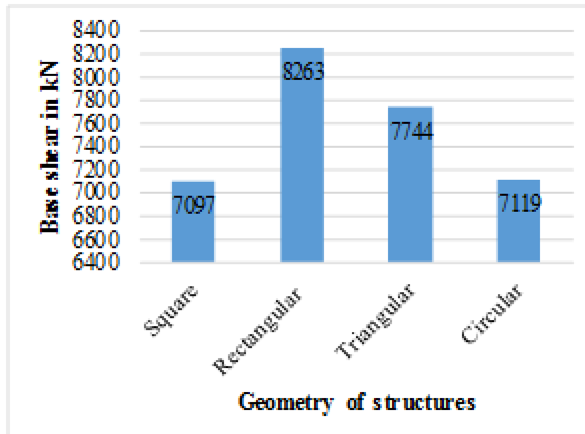

Fig. 21 Base shear for 40 story structures of different geometry in X direction

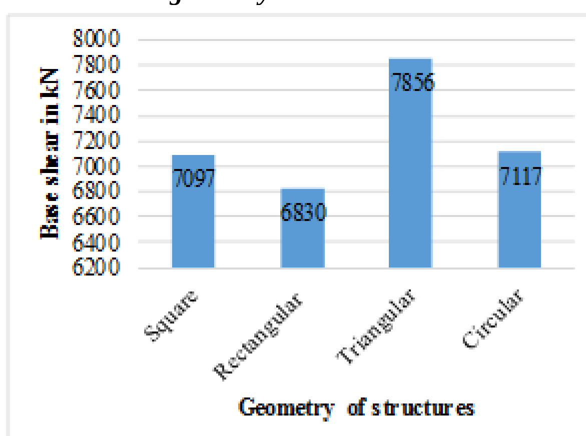

Fig. 22 Base shear for 40 story structures of different geometry in Y direction

From Fig. 21, it was observed that the square model shows reduction in base shear up to 14.11%, 8.35% and 0.31% when compared to rectangular, triangular and circular models. Fig. 22, it can be observed that the square model shows reduction in base shear of about 9.66%, 0.28% and 3.76% when compared to triangular, circular and

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rectangular models.

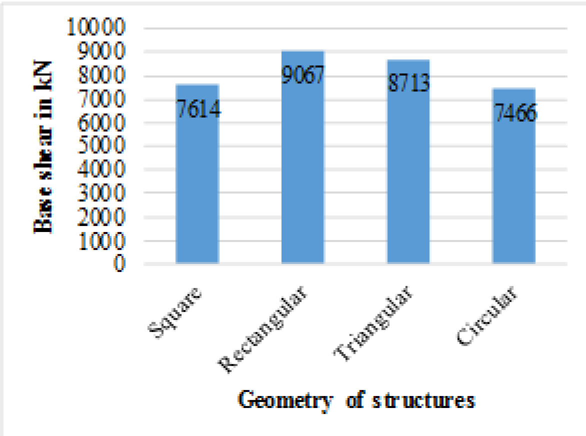

Fig. 23 Base shear for 50 story structures of different geometry in X direction

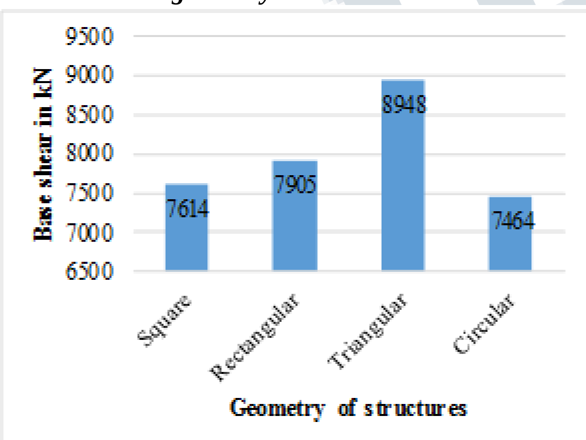

Fig. 24 Base shear for 50 story structures of different geometry in Y direction

From Fig. 23, it was observed that the square model shows reduction in base shear of about 16.01%, 12.65% and 1.94% when compared to rectangular, triangular and circular models. From Fig. 24, it was observed that the square model shows reduction in base shear of about 3.68%, 14.9% and 1.97% when compared to rectangular, triangular and circular models. In models G+20, G+30 and G+40 stories the minimum of all the base shear is observed in square model and in G+50 story it is observed in circular model.

E. Base Moments

From Fig. 25, it can be observed that the square model shows reduction in overturning moment MX of about 1.08%, 7.87% and 0.34% when compared to rectangular, triangular and 0.34% circular models. The square model shows reduction in overturning moment MY of about 11.24%, 6.9% and 0.54% when compared to rectangular, triangular and circular models. The square model shows reduction in torsional moment MZ of about 8.00%, 26.34% and 87% when compared to rectangular, triangular and circular models.

In 20 story structures of different geometry the lowest MX value is recorded in circular geometric structure and the highest value of MX is recorded in the triangular geometric structure. And the lowest MY value is recorded in circular geometric structure and the highest value of MY is recorded in rectangular geometric structure. The moment MX and MY are exactly and approximately equal to each other in square and circular geometric structures, and they slightly change in triangular geometric structures.

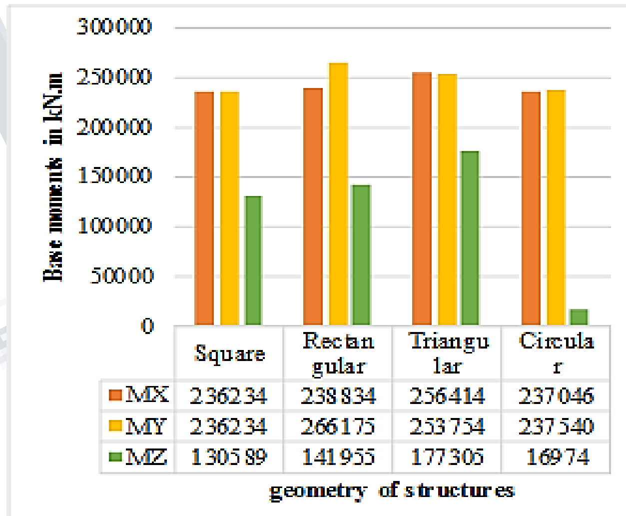

Fig. 25 Base moment for 20 story structures of different geometry

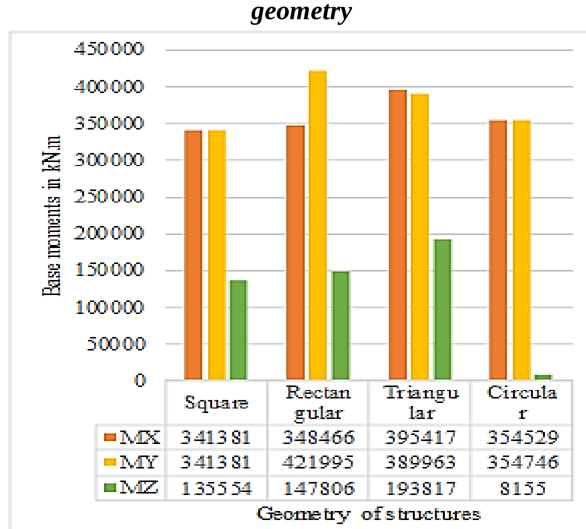

Fig. 26 Base moment for 30 story structures of different geometry

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 4, Issue 1, January 2019

From Fig. 26, can be observed that the square model shows reduction in overturning moment MX of about 2.03%, 13.66% and 3.70% when compared to rectangular, triangular and circular models. The square model shows reduction in overturning moment MY of about 19.10%, 12.45% and 3.76% when compared to rectangular, triangular and circular models. The square model shows reduction in torsional moments MZ of about 8.28%, 30.06% and 93.98% when compared to rectangular, triangular and circular models.

In 30 story structures of different geometry the lowest MX value is recorded in circular geometric structure and the highest value of MX is recorded in the triangular geometric structure. And the lowest MY value is recorded in circular geometric structure and the highest value of MY is recorded in rectangular geometric structure. The moment MX and MY are exactly and approximately equal to each other in square and circular geometric structures, and they slightly change in triangular geometric structures.

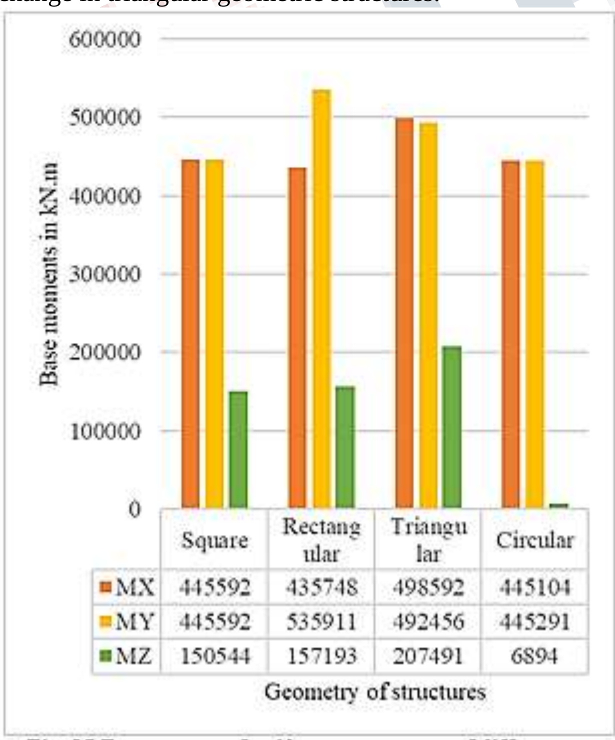

Fig. 27 Base moment for 40 story structures of different geometry

From Fig. 27 it can be seem that the square model shows increment in overturning moment MX of about 2.20%, 0.10% and 10.62% when compared to rectangular, circular and triangular models. The square model shows reduction in overturning moments MY of about 16.85%, 9.51% and 0.07% when compared to rectangular, triangular and circular models. The square model shows reduction in torsional moment MZ up to 4.22%, 27.44% and 95.42% when compared to rectangular, triangular and circular models.

In 40 story structures of different geometry the lowest MX value is recorded in rectangular geometric structure and the highest value of MX is recorded in the triangular geometric structure. And the lowest MY value is recorded in circular geometric structure and the highest value of MY is recorded in rectangular geometric structure. The moment MX and MY are exactly and approximately equal to each other in square and circular geometric structures, and they slightly change in triangular geometric structures.

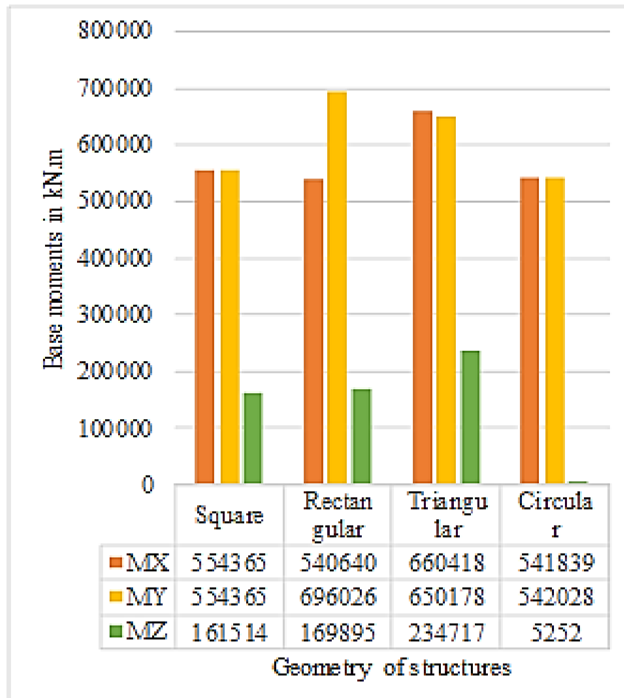

Fig. 28 Base moment for 50 story structures of different geometry

From Fig. 28 it can be noted that the square model shows increment in overturning moments MX up to 2.47%, 2.25% and 16.05% when compared to rectangular, circular and triangular models. The square model shows reduction in overturning moments MY of about 20.35%, 14.73% and 2.22% when compared to rectangular, triangular and circular models. The square model shows reduction in torsional moments MZ of about 4.93%, 31.18% and 96.74% when compared to rectangular, triangular and circular models.

In 50 story structures of different geometry the lowest MX value is recorded in rectangular geometric structure and the highest value of MX is recorded in the triangular geometric structure. And the lowest MY value is recorded in circular geometric structure and the highest value of MY is recorded in rectangular geometric structure. The moment MX and MY are exactly and approximately equal to each other in square and circular geometric structures, and they slightly change in triangular geometric structures.

V. CONCLUSIONS

The results shown by the square geometric structure are the optimal results and they do very much slightly vary from the results of triangular geometric structure, the rectangular geometric structure are not much suitable for this type of structural system because of height strength required in the shorter side of the rectangle and the circular geometric structures shows an average results than that of square and rectangular geometric structure. Though the data of all the structures kept constant the no of columns could not be maintained constant due to tube constant. The no of columns in triangular structure in each story being 87 No's and in the square being 76 No's. The best/optimal and economic geometry to be concluded in this report be square geometric structure. The geometry and displacement profiles of the structures are such that there is no torsional irregularity observed in any of the structures. The changes in responses of the structures are mainly due to the stiffness consideration, due to the change of stiffness along the tapering portions of the geometry. The volume of concrete required for the different structures considered are also calculated and it was found that the square geometric structure requires least amount of concrete.

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