iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 10 **Issue:** V **Month of publication:** May 2022

DOI: https://doi.org/10.22214/ijraset.2022.42258

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue V May 2022- Available at www.ijraset.com

Effect of Structural Shape on Seismic Response of Air Traffic Control Tower

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***Abstract:** Air Traffic Control Towers (ATCT) is one of the obligatory infrastructures for the airport to control the takeoff and landing of airplanes. The primary purpose of ATCT is to prevent collisions and shape the flow of air traffic. Due to a lack of adequate information about the seismic analysis, the performance of ATCT is generally considered to be the same as that of normal structures. However, the performance and demands of ATC towers differ significantly from common structures. In the present study, the analysis of ATCT for different structural shapes (viz., Hexagonal, Octagonal, Pentagonal, Square) with a height of 55m has been investigated. The structural performance of these models has been studied by different time history analysis using commercial software ETABs. The results exhibited that the performance of octagonal and hexagonal configurations was effectively better for seismic loads as compared to the pentagonal and square configuration in respect of story displacement, story drifts, story shear, and time periods. The seismic analysis also shows that the octagonal shape attracted larger base shear than pentagonal, hexagonal, and square shaped ATCT. However, due to more lateral resisting capacity, the drifts and displacements are found to be least.*

***Keywords:** Air Traffic Control Tower, Structural shape, Structural configurations, Time history Analysis.*

I. INTRODUCTION

The prime services available at the airports are often the facilities to store and maintain aircraft, and a control tower. Airports are among the most important infrastructures that should keep their serviceability during and after severe earthquakes to manage their crucial workload and critical role. One of the most important facilities at an airport with a direct influence on the serviceability is the air traffic control tower (ATCT). To have organized air traffic, each airport is usually served by one or more control towers. Therefore, no landing or takeoff may take place if the control tower is shut down, and the whole functionality of the airport will be halted temporarily. If the control tower cannot operate properly, due to structural or non-structural damages during earthquakes, the airport may experience some long-term disabilities.

Despite the significant role that ATCT plays in the functionality of airports, only a few researchers have studied the seismic performance of these structures. Mohammadreza Vafaei, Azlan Bin Adnan, Ahmad Baharuddin Abd. Rahman studied the seismic performance of Kuala Lumpur International ATC tower, with a height of 120m was investigated. It was concluded that conventional linear and pushover analysis did not accurately reflect the seismic behavior of the tower investigated over the course of this study. In the future, special care should be paid when using linear and pushover analysis for the seismic evaluation of air traffic control towers.[1]

It was observed by MohammadrezaVafaei and Sophia C. Alih , that records with a low PGA/PGV ratio imposed the highest level of damage to the towers. Results indicated that the intensity of seismic-induced damage to the tallest tower was significantly more than that of the shortest tower. It was concluded that only the shortest tower could satisfy the expected seismic performance objectives.[2]

Sassan Eshghi and Hooman Farrokhi studied the concentrated loads located at the top of the structure, and with increasing these loads, the cracking in the tower was traced. The first cracks initiate in the floor slabs at a very small proportion of the ultimate lateral displacement capacity of the tower and broaden quickly with the increase of the lateral load. The cracking pattern in the pushover analysis showed that the floor diaphragms do not have enough stiffness to connect the wings correctly. By increasing the stiffness of slabs (increasing thickness), the maximum deformation capacity of the structure can be greatly modified. They concluded that it was unwise to consider them as rigid diaphragms which constraint side wings together at specific elevations.[3]

In the present study, the analysis of ATCT for different structural shapes (viz., Hexagonal, Octagonal, Pentagonal, Square) with a height of 55m has been investigated.

II. NUMERICAL STUDY

The analysis of the Air traffic control tower is done using ETABs software (2016). The general sectional elevation for the study is as shown in Fig. 1. The structural system of the tower is a dual system consisting of a steel moment-resisting frame and which is supported on two concrete cores. The outer core is connected to MRF through circular beams. An opening is provided at the bottom for people to enter the ATCT.

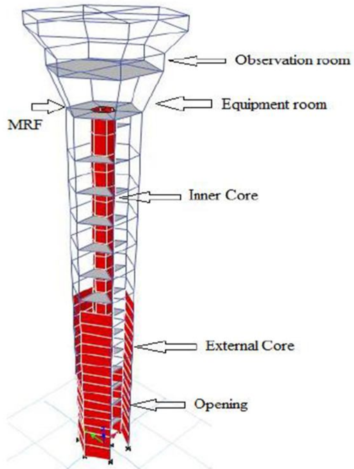


Fig. A

Fig. 1 Elevation of the ATC considered

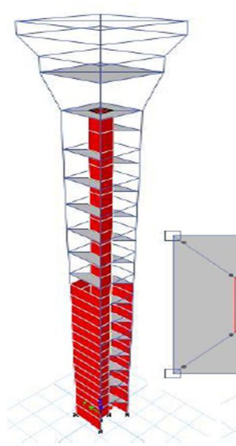
The inner core is connected by radial beams that are designed to support the staircase. All beam to column connections are fixed, while all the radial beams have pin connections. All beams are I sections, and columns are Box sections. It is 1assumed all columns and Cores are fixed at the base.

The following are the shapes of models considered for the analysis of the ATCT.

1) Square
2) Pentagonal
3) Hexagonal
4) Octagonal

The figures for the above are as given below for the height of 55m.

Fig 2 presents Square Elevation and Plan of square shape at a height of 55m. Fig 3 presents Elevation and plan of Pentagonal shape at a height of 55m. Fig 4 presents Elevation and plan of Octagonal shape at a height of 55m. Fig 5 presents Elevation and plan of Hexagonal shape at a height of 55m. For the models as base shear is more at the bottom , the number of shear walls is more at the base and As height is increased the outer shear walls are reduced.



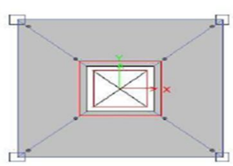


Fig. A Fig. B

Fig. 2 Square Elevation and Plan

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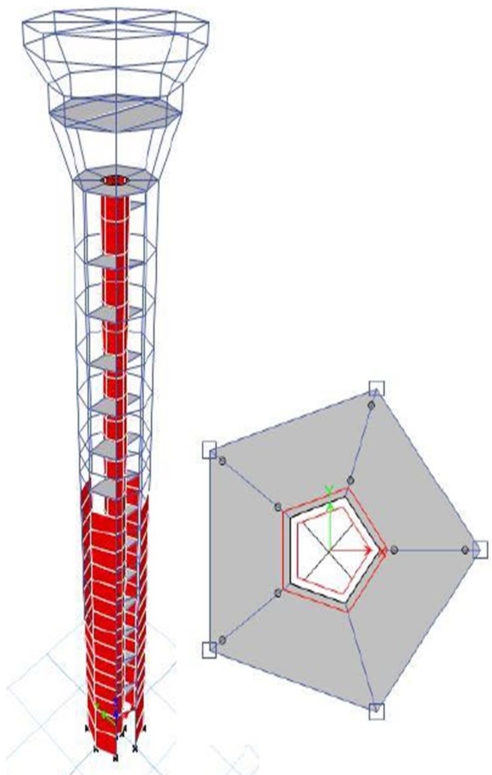

Fig. A Fig. B

Fig. 3 Pentagonal Elevation and Plan

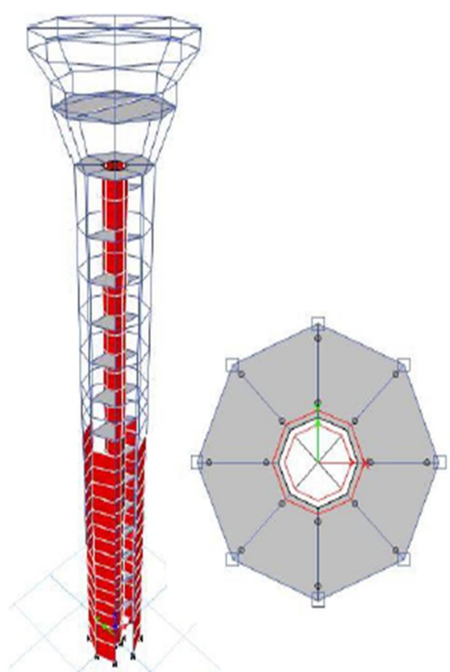

Fig. A Fig. B

Fig. 4 Octagonal Elevation and Plan

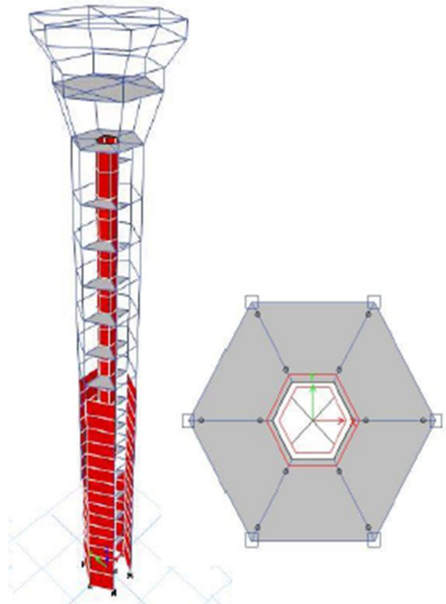

Fig. A Fig. B

Fig. 5 Hexagonal Elevation and Plan

III. DESIGN DATA

Linear time history analysis is carried out on all the structures. In the elastic analysis, the stiffness characteristics of the structure are assumed to be constant for the whole duration of the earthquake. The different peak ground acceleration time histories that are used for the study are given in Table 1. Table 2 presents the design data of ATCT. Details of the column sizes are given in Table 3, whereas the details of the sizes of the beams are presented in Table 4.

Table 1 Time History of different peak ground acceleration

Name	Year	Station	PGA m/s^2
Indian Burma	1988	Berlongfer	3.37 m/s^2
Bhuj	2001	Ahmedabad	0.78 m/s^2
Chamoli	1999	Gopeshwar	1.95 m/s^2
Uttarkashi	1991	Bhatwari	2.48 m/s^2
Koyna	1967	1A Gallery	4.80 m/s^2

Table 2 Design Data of ATCT

PARAMETERS	VALUE
Reinforcement	Fe415
Steel	Fe345
Inner Radius	0.87m
Outer Radius	2.56m
Height of Outer Core	11.68m
Height of Inner Core	22.21m
Shear wall	300 mm
Slab	100 mm
Importance factor	1.4
Zone factor	IV
Response Reduction Factor	5

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Table 3 Size of Column

Height	Height×Flange Width×Thickness (mm)
5.2	300x200x15
8.44	300x200x8
11.68	300x200x15
44.08	350x250x12
48.13	350x250x15
53.16	300x200x8
56.09	350x250x15

Table 4 Size of Circular Beam

Levels		Width x height x Thickness (mm)
From	To	
0	48.13	300x300x15
48.13	51.76	300x300x25
51.76	54.99	200x200x12
54.99	56.09	300x200x8

IV. RESULTS AND DISCUSSION

The analysis of the results is presented by the bar charts in this section, which explain the structural behaviour of ATCT in terms of the natural time period, story displacements, story drifts, and story shears.

Table 5 shows the natural time periods for the first three mode shapes obtained for all the considered ATCTs. It is observed that as the shape varies, the time period varies too. It can be seen that the octagonal shape has the least time period whereas the square shape has the maximum time period.

Table 5 Comparison of Time Periods of Different Shapes of ATCTs.

	Period(Sec)			
Mode Shape	Squ	Penta	Hexa	Octa
1	1.619	1.684	1.584	1.480
2	1.521	1.478	1.515	1.472
3	0.794	0.691	0.636	0.573

Table 6 Story Stiffness

Shapes	Seismic Stiffness (KN/mm)
Square	1303066
Pentagonal	1628535
Hexagonal	1799261
Octagonal	2505926

The stiffness obtained for each structural configuration is given in Table 6. As time period is inversely proportional to the stiffness of the structure, due to larger stiffness, the octagonal shape has the least time period compared to the other structures.

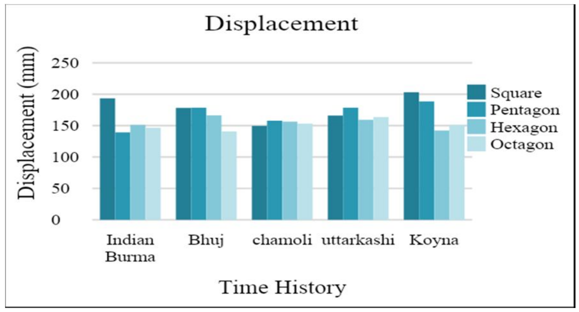

Fig. 6 Story Displacement of different shapes of ATCTs

Fig. 6 shows the graph for comparison of story displacements for different shapes of the ATCTs. It is found that the square and pentagonal have maximum displacement than the other two configurations. It is observed that the displacement at the top story increased drastically than that of the bottom stories. This is due to the less stiffness in the moment-resisting frame at the top panels than the shear walls at the bottom stories. As the opening is needed, it can be seen that the square has shear walls only on three sides, which causes the least stiffness.

According to IS 1893: 2016, Part1, permissible story displacement should be equal to or less than h/500 of total building height. For a 55 m structure, the maximum allowable displacement is 110 mm. For square shape, it is more than the limit (203 mm at roof level), as shown in Fig. 6.

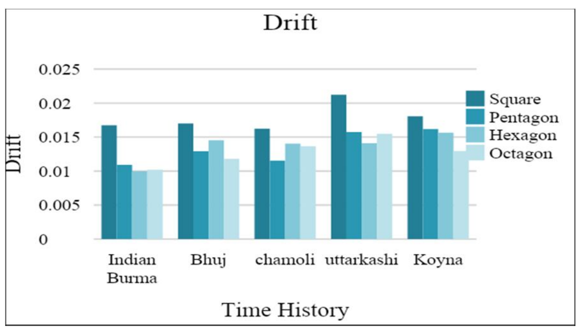

Fig. 7 Story Drift of different shapes of ATCTs

Fig. 7 illustrates the variation of story drifts between different floors of the models. Story drift is the drift of one level of a multi-story building relative to the level below. Here the story drifts in a similar manner for different shapes of structures. Maximum story drift is observed at square shape (0.0212) more than the permissible limit of 0.004 which is given by IS 1893.[4]

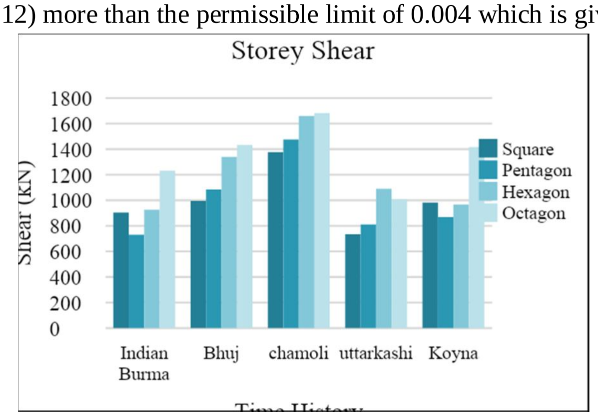

Fig. 8 Story Shear of different shapes of ATCTs

Fig. 8 shows the shear force acting at different story levels. Story shear is a force that acts on any story in a direction perpendicular to its extension and is measured in ‘kN’. Story shear is highest at the bottom (base shear), and it decreases towards the top. For octagonal shape maximum story shear is 1682.20 kN. The weights of the structures where we can see octagonal has the maximum weight, thus attracting more story shear than the rest of the shapes.

Table 7 Shape Factors

Shapes	Shape factors
Square	1.5
Pentagon	1.56
Hexagon	1.60
Octagon	1.78

From Table 7, it is seen that square shape has the least shape factor. It is observed from Figure 6 that maximum story displacement (203 mm). For most of the considered earthquakes, displacement is found to be the maximum for square shape ATCTs. It can be concluded that this poor performance of square shape ATCT is due to the least shape factor. Similarly, for other earthquakes considered the displacements are minimum for octagonal shape due to its maximum shape factor, and thus, it performs better.

The drift ratio is mostly dependent on the story stiffness of the structure. From Table 6, it is seen that octagonal shape has maximum story stiffness, thus has the least drift ratio. On the other hand, as the square has the least story stiffness, it tends to have a maximum drift ratio.

The story shear, as seen in Fig. 8, is maximum for octagonal shape in all cases. This is due to the maximum weight of the structure as compared to the other considered shapes. The square shape ATCT has the least weight among all four shapes resulting in minimum base shear.

V. CONCLUSIONS

Based on the analytical results of the study, the following conclusions were drawn:

1) For all the models that are considered, the maximum displacement is for the square plan, which is 203 mm and the least for the octagonal, which is about 140.7 mm.
2) The maximum drift found to be for the Square shape is 0.0212 and minimum for the octagonal shape.
3) Considering all the time histories, it can be concluded that the octagonal shape is most efficient.
4) The seismic analysis octagonal shape attracted large lateral shear (10% – 25% higher than square and pentagonal for seismic analysis), but due to more lateral resisting capacity, the drifts and displacement are found to be least.
5) It can also be concluded that as an important structure, advanced nonlinear analysis is recommended for the analysis and design of an Air Traffic Control tower.

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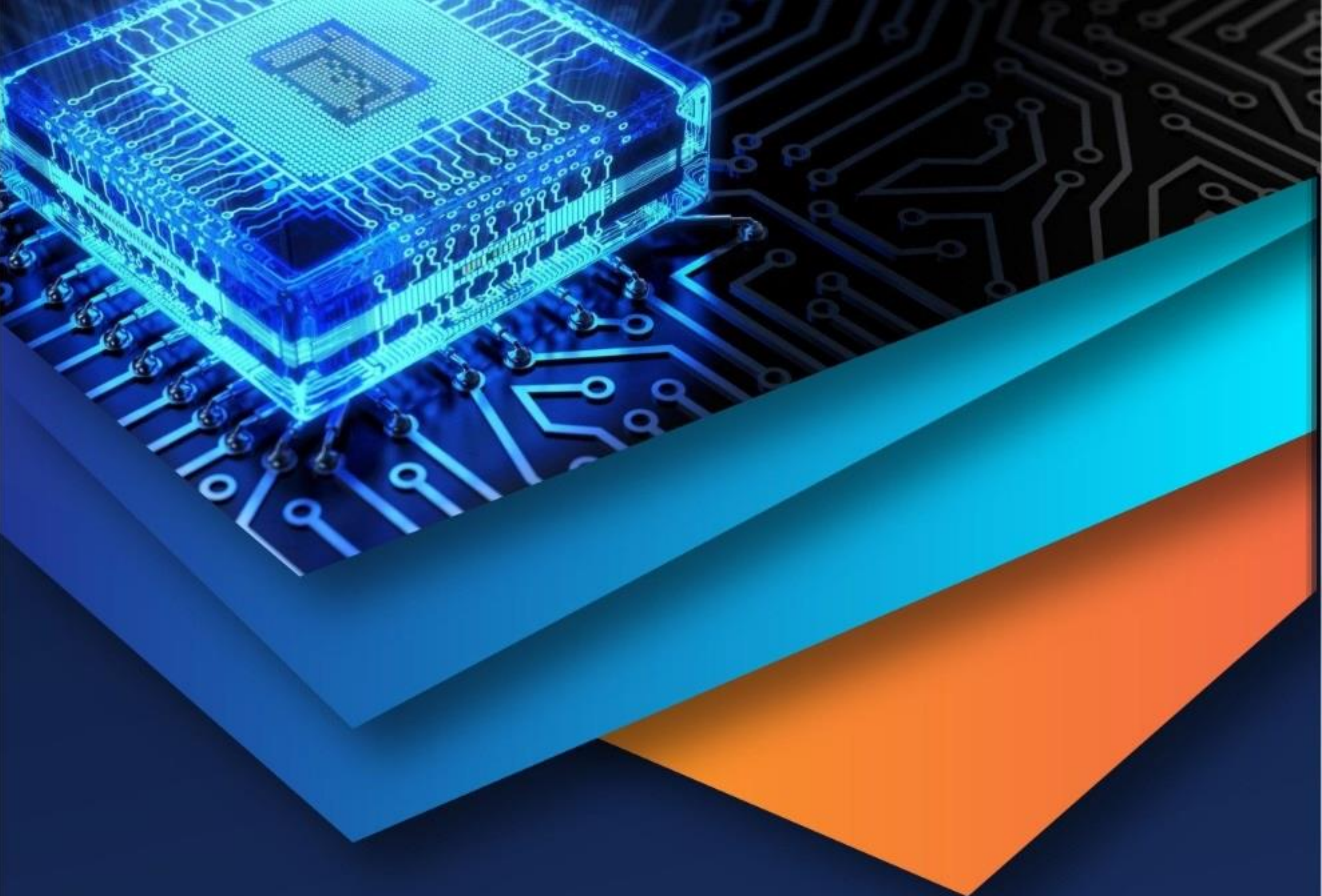

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