Comparative Seismic Analysis of Conical and Pyramidal Frustum Shaped Commercial Building (G+6) at Janakpuri, Delhi

Sindhu Nachiar S¹, Anandh S², Ajit Kumar³, Abhinav Puskar⁴ and Fardeen Mohammed⁵

¹²Assistant Professor, Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Kanchipuram Dt., Tamilnadu, India.
³⁴⁵UG Student, Department of Civil Engineering, SRM Institute of Science and Technology, Kattankulathur, Kanchipuram Dt., Tamilnadu, India.

Corresponding E-mail: anandhsekar@gmail.com²

Abstract. In the modern building construction, the trend of constructing structures that are economical as well as aesthetically appealing is increasing. These structures often employ ideas and architectural features that are diverse from the emblematic conventional structures. The unconventionally shaped building has irregularities in the distribution of mass, stiffness and strength along the height of the building. Conical and pyramidal frustum shaped building are those structures that have remarkable shape and utilizes both inclined and vertical columns. In these structures, the floor area of the plan changes at each specific storey. With the intensification in complexity and innovation of the building construction, earthquake forces have become an imperative factor to be considered while construction of these avantgarde structures. The Indian Standard code IS-1893: 2002 (Part-I) describes the approach for the structures with irregularities considering the varying mass, floor-area ratio and stiffness of the storeys. The objective of the paper is systematic seismic analysis of a conical and pyramidal frustum shaped commercial building(G+6) at Janakpuri, Delhi using STAAD.Pro V8i. The buildings are located in seismic zone IV. The result of the analysis aids to understand and compare the storey drift, storey displacement and stiffness of the structures subjected to earthquake forces.

Keywords: RCC structures, G+6 Building, Seismic Analysis, Conical, Pyramid, Frustum Comparative analysis.

1. Introduction
Structures are generally built with simple rectangular or regular shape. Irregular structures which have unconventional and unusual shapes generally become an outstanding landmark and icon. The conical frustum is a frustum generated when the top of the cone is sliced parallel to its base and pyramidal frustum is a frustum generated when the top of the pyramid is sliced parallel to its base. The frustum shaped structures are those structures which utilizes both inclined and vertical columns [1]. The multi-storied commercial building can be used for multi purposes like office, library, museum, theatre, conference hall...
and many other. The application of external loads to the inclined column used in these structures give rise to shear and flexure. There will be supplementary moments development because of self-weight. Also due to eccentric loading in column, in addition to direct compressive stresses, it is also subjected to bending stresses. So, it is proposed to design inclined column for the combined axial forces and bending moments. The inclination should be between 10-20% to the vertical of conventional column and placements of stirrups at close spaces are necessary as inclination starts to maintain the stability of the structure [2]. Earthquake forces is very important factor to be considered while construction of these unconventional structures. Seismic analysis of the buildings helps to understand storey drift, storey displacement and stiffness of the structure subjected to earthquake forces [3]. The basic seismic analysis procedure are static analysis and dynamic analysis. By these methods of analysis, we can get the value of beam stresses, axial forces, torsion, displacements and moment at different nodes, columns and beams and use it to design the structure accordingly.

2. Structure Modelling

G+6 conical and square pyramid frustum building is analyzed and compared systematically with the aid of STAAD.Pro V8i.

Table 1 show the planning parameters, materials and member property utilized for analyzing the two buildings.

Table 2 shows the loading condition and seismic parameters utilized for analyzing the two buildings. The dead and live load is taken as per IS 875:1987 Part 1 and Part 2 respectively [4-5]. The seismic loading conditions are taken as per IS 1893:2002[6].

| Description               | Details                           |
|---------------------------|-----------------------------------|
| Area of Land              | 6000 mm²                          |
| No. of Stories            | G+6(7 Storied)                    |
| Each Floor Height         | 3.6 m                             |
| Total Height of Building  | 25.2 m                            |
| Slab Thickness            | 150 mm                            |
| Grade of Concrete         | M 25                              |
| Grade of Steel            | Fe 415                            |
| Beam Size                 | 400 mm x 500 mm                   |
| Inclined Column Size      | 500 mm x 500 mm                   |
| Vertical Column Size      | 600 mm x 600 mm                   |

The plan of the building is made abiding the National Building Code of India [7]. Since, both conical and square pyramid frustum building utilizes inclined column, the dimension of each floor changes. So, it is proposed that the angle of inclination of inclined column is at 10° to the vertical column in both building. Also, that the diameter of each respective floor in conical frustum building is kept equivalent to side of each floor. The diameter and side of terrace of respective buildings will be 52.91 m. The use of these similar parameters will aid to systematic comparison of the buildings.
The plan view of the Conical and Square Pyramid Frustum Building are shown in Figure 1.

![Plan View of Conical and Square Pyramid Frustum Building](image1)

**Figure 1.** Plan View of Conical and Square Pyramid Frustum Building

The 3D view of the Conical and Square Pyramid Frustum Building are shown in Figure 2.

![3D View of Conical and Square Pyramid Frustum Building](image2)

**Figure 2.** 3D view of Conical and Square Pyramid Frustum Building
Table 2. Loading Condition and Seismic Parameters for Conical and Square Pyramid Frustum Building

| Description                  | Details                  |
|------------------------------|--------------------------|
| Dead Load                    | 3.75 kN/m²               |
| Beam Size                    | 400 mm x 500 mm          |
| Inclined Column Size         | 500 mm x 500 mm          |
| Site Location                | Zone-IV                  |
| Zone Factor                  | 0.24                     |
| Response Reduction Factor    | 5                        |
| Importance Factor            | 1                        |
| Soil Type                    | Medium Soil              |
| Damping Ratio                | 5 %                      |
| Code                         | IS 1893 : 2002           |
| Combination Method           | Complete Quadratic Combination |
| Spectrum Type                | Acceleration             |
| Interpolation Type           | Linear                   |

3. Analysis, Results and Discussion
The structural modelling of the two building viz. conical and square pyramid frustum building is done using STAAD.Pro V8i. Both buildings have 7 stories. The moments, shear forces and deflection of the beam and column are analyzed, studied and compared. The seismic analysis is done and the results are studied and compared.

3.1 Critical Beam and Critical Column
The elements with highest moment are considered to be critical element. The Critical Beam (2237) of Conical Frustum Building and Critical Beam (514) of Square Pyramid Frustum Building is shown in Figure 3. The Critical Column (2391) of Conical Frustum Building and Critical Column (2112) of Square Pyramid Frustum Building is shown in Figure 4.

Figure 3. Red Position shows the Critical Beam (2237) of Conical Frustum Building and Critical Beam (514) of Square Pyramid Frustum Building respectively
Figure 4. Red Position shows the Critical Column (2391) of Conical Frustum Building and Critical Column (2112) of Square Pyramid Frustum Building respectively

The Bending Moment (BM), Shear Force (SF) and Deflection values of the respective critical column and column beam of conical and square pyramid frustum building is shown in Table 3.

Table 3. Bending Moment (BM), Shear Force (SF) and Deflection values of the respective critical column and column beam of conical and square pyramid frustum building

| Critical beam | Critical column |
|---------------|----------------|
|               | Conical Frustum Building | Square Pyramid Frustum Building | Conical Frustum Building | Square Pyramid Frustum Building |
| BM (kNm)      | 374.25 | 372.38 | 280.83 | 144.70 |
| SF (kN)       | 254.51 | 193.77 | 17.11  | 25.39  |
| Deflection (mm)| 13.41 | 22.36 | 4.53  | 5.51  |

The values of the bending moment, shear and deflection values of the respective critical column and column beam of conical and square pyramid frustum building aids in the manual structural design of the structure. The obtained values help to comprehend, analyze and compare the relative stability of the structures.

The critical beam and critical column of conical frustum building is shown in Figure 5 and Figure 7 respectively. The critical beam and critical column of square pyramid frustum building is shown in Figure 6 and Figure 8 respectively.
Figure 5. BM, SF and Deflection of Critical Beam (2237) of Conical Frustum Building

Figure 6. BM, SF and Deflection of Critical Beam (514) of Square Pyramid Frustum Building

Figure 7. BM, SF and Deflection of Critical Column (2391) of Conical Frustum Building

Figure 8. BM, SF and Deflection of Critical Column (2112) of Square Pyramid Frustum Building
3.2 Seismic Analysis
The proposed buildings are located in seismic Zone IV of India. The soil type at site is medium soil. The Response Reduction Factor of 5 and Importance Factor of 1 is considered. The seismic analysis is done systematically using the STAAD.Pro adhering to the IS code 1893:2002 as standard. The results from the systematic analysis has been tabulated and arranged graphically for the competent comparison between the two buildings on the basis of the parameters viz. average displacement, drift, time period and base shear.

The displacement of the conical and square pyramid frustum building due to seismic load is shown in Figure 9.

The maximum absolute stress on floor in the conical and square pyramid frustum building is shown in Figure 10.

Figure 9. Displacement of Conical and Square Pyramid Frustum Building due to Seismic Load

Figure 10. Maximum Absolute Stress on Floor in Conical and Square Pyramid Frustum Building
3.2.1 Average Displacement

Storey displacement is the displacement of a storey with respect to the base of the structure. The maximum top storey displacement should not exceed $H/500$ as per IS 456:2000, whereas ‘$H$’ is the total height of the structure [8]. The displacement results are within permissible limit. The comparison between the average displacement in the conical and square pyramid frustum building is shown in Figure 11.

![Average Displacement Graph](image)

**Figure 11.** Variation of Average Displacement in Conical and Square Pyramid Frustum Building

3.2.2 Drift

Storey drift is the displacement of one storey with respect to another storey. The storey drift should not exceed 0.004 times of storey height. Hence storey drift values are within permissible limit as per IS 1893:2002. The comparison between the drift in the conical and square pyramid frustum building is shown in Figure 12.

![Drift Graph](image)

**Figure 12.** Variation of Drift in Conical and Square Pyramid Frustum Building
3.2.3 Time Period
Time period increases with increase in height of the building. More the time period means structure is considered as less stiff. The comparison between the time period in the conical and square pyramid frustum building is shown in Figure 13.

![Figure 13. Variation of Time Period in Conical and Square Pyramid Frustum Building](image)

3.2.4 Base Shear
Base shear is an estimate of maximum lateral force at the base of the structure due to seismic ground motion. It also explains the inertial tendency of building to resist the seismic forces. The comparison between the base shear in the conical and square pyramid frustum building is shown in Figure 14.

![Figure 14. Variation of Base Shear in Conical and Square Pyramid Frustum Building](image)
4. Conclusion
The proposed project of the conical and square pyramid frustum shaped building is efficaciously modelled and analysed and its summary of results and comparison is concluded in following-

- The G+6 building is constructed in Janakpuri, Delhi over a land area of 6000 m$^2$.
- For the beam, the bending moment is reduced by 0.498 %, shear force is reduced by 23.86 % and deflection is increased by 66.73 % in square pyramid frustum building when compared to conical frustum building.
- For the column, the bending moment is reduced by 48.47 %, shear force is increased by 48.37 % and deflection is increased by 21.66 % in square pyramid frustum building when compared to conical frustum building.
- The average displacement is reduced by 15.39 % in square pyramid frustum building when compared to conical frustum building.
- The drift is reduced by 13.92 % in square pyramid frustum building when compared to conical frustum building.
- The time period is reduced by 13.55 % in square pyramid frustum building when compared to conical frustum building.
- The square pyramid frustum building has more base shear compared to conical frustum building. Here, the base shear is increased by 26.96 %. Hence it is good for seismic design.

Square pyramid frustum building will have better seismic performance.

5. References
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