Evaluation of Best Multistoried Building Case of Vertical Mass Irregularity under Seismic Loading

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Abstract — The phenomenon of out-of-plane offset in multistoried buildings has emerged as a topic of considerable interest in the field of structural engineering. Out-of-plane offset pertains to the vertical displacement or misalignment of structural components, such as walls or columns, relative to the primary vertical load-bearing elements of a building. This research paper aims to explore the most effective strategies for managing out-of-plane offset in multistoried buildings. To achieve this objective, a comprehensive analysis was conducted on a series of six model cases from case OPO case 1 to OPO Case 6, with an additional case of OPO 1.1, resulting in a total of seven cases being examined. The comparative analysis revealed that possibility case 6 exhibited the most favorable outcomes among all scenarios, indicating its potential as the recommended approach, highlighting the benefits of implementing out-of-plane offset selectively at the upper floor levels, to enhance the structural integrity and performance of multistoried buildings.

Keywords: Multistory Building, Seismic Activities, Response Spectrum Method, Plan Irregularities, Out of Plane Offset

I. Introduction

In the construction of multistoried buildings, it is customary for the columns to be designed as perfectly vertical and the beams as perfectly horizontal. Nevertheless, deviations from these ideal positions can occur due to factors like construction tolerances, fabrication errors, and foundation settlement. Minor deviations might have negligible impacts on the building's structural integrity. However, substantial deviations can lead to a range of issues, including:

1) Reduced structural strength: When columns and beams experience out-of-plane offsets, their structural strength can be compromised as they become susceptible to bending stresses.
2) Structural instability: Significant out-of-plane offsets can result in the tilting or buckling of columns or beams, exposing the overall stability of the structure.
3) Impaired aesthetic appearance: Out-of-plane offsets can lead to misalignment with finishes like plaster, tiles, or drywall, causing damage and hindering the proper alignment of these elements.

To avoid these problems, it is important to carefully assess and control the out of plane offsets during the design and construction phases. This can be achieved by:

1) Consistent quality inspections: It is crucial to perform regular quality inspections throughout the construction phase to verify that out-of-plane offsets fall within acceptable limits.
2) Provision of sufficient structural reinforcement: To guarantee the columns and beams can withstand anticipated loads, it is essential to provide adequate structural reinforcement.
3) Enforcing proper construction methodologies: Builders must employ appropriate construction methodologies to ensure the precise installation of columns and beams in accordance with the designated design specifications.

To summarize, the presence of out-of-plane offsets can greatly influence the structural performance and stability of multistory buildings. Hence, it is crucial to thoroughly evaluate and manage these offsets throughout the design and construction stages in order to guarantee the safety and longevity of the structure.

II. Procedure and 3D Modelling of the Structure

Seismic analysis of a ten-story commercial building is conducted using a software-based approach. The earthquake data is collected according to the IS 1893(PART1):2016 standards. The analysis of the building is performed utilizing the response spectrum analysis method. Detailed information about the model and input parameters is provided below.

Models	Description
OPO Case 1	Residential Apartment having out of plane offset provided at foundation level
OPO Case 1.1	Residential Apartment having out of plane offset provided at ground floor level
OPO Case 2	Residential Apartment having out of plane offset provided at 1st floor level
OPO Case 3	Residential Apartment having out of plane offset provided at 3rd floor level
OPO Case 4	Residential Apartment having out of plane offset provided at 5th floor level
OPO Case 5	Residential Apartment having out of plane offset provided at 7th floor level
OPO Case 6	Residential Apartment having out of plane offset provided at 9th floor level

Table 1: Model Description

Constraint	Assumed data for all buildings
Soil type	Actual soil data used
Seismic zone	III (Z = 0.16)
Response reduction factor (ordinary shear wall with SMRF)	4
Importance factor (For all commercial building)	1.5
Damping ratio	5%
Fundamental natural period of vibration (T_a)	$0.09*h/(d)^{0.5}$ For X direction = 0.8625 sec

	For Z direction = 0.7874 sec
Plinth area of building	575 sq. m
Floors configuration	G + 10
Structural type	Commercial Building
Height of building	47.92 m
Floor to floor height	3.66 m
Depth of foundation	4 m
Beam sizes	650 mm X 550 mm
	550 mm X 350 mm
	450 mm X 300 mm
Column sizes	750 mm X 650 mm
	650 mm X 550 mm
	500 mm X 400 mm
Slab thickness	135 mm (0.135 m)
Shear wall thickness	150 mm (0.15 m)
Stair case waist slab thickness	135 mm (0.135 m)
Material properties	M 30 Concrete and Fe 550 grade steel

Table 2: Input details for Commercial Building for all cases

III. RESEARCH OBJECTIVES

On keeping in mind the above problem statement outline for new research work is proposed in the form of conclusive outcomes given below :-

1) To study the various cases of Out of plane offset provided in the multi-storey building at different floor levels and comparing them by using Response Spectrum Method of dynamic analysis using Staad pro software.
2) To calculate Maximum displacement, Base Shear and Drift values and then comparing all the cases.
3) To determine maximum Axial Forces in columns at base level for various cases.
4) To study the variation of maximum Bending Moments & Shear Forces in columns of all cases for commercial building.
5) To study and compare maximum Bending Moments & Shear Forces in beams parallel to X and Z directions.
6) To evaluate maximum Torsional Moments in beams along X and Z directions.

The main and foremost objective is to determination of the best Possibility case after comparison of various result parameters that will be recommended for construction in the similar field.

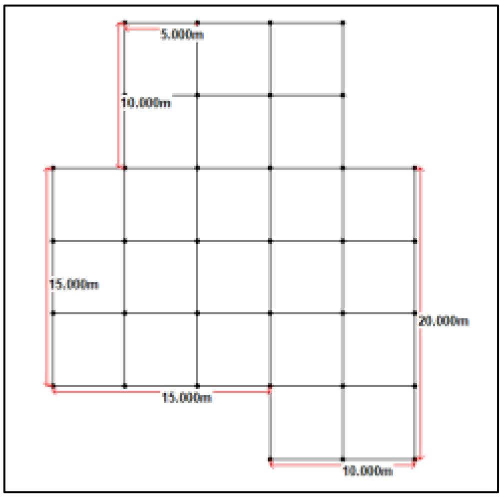


Fig. 1: Plan of Structure

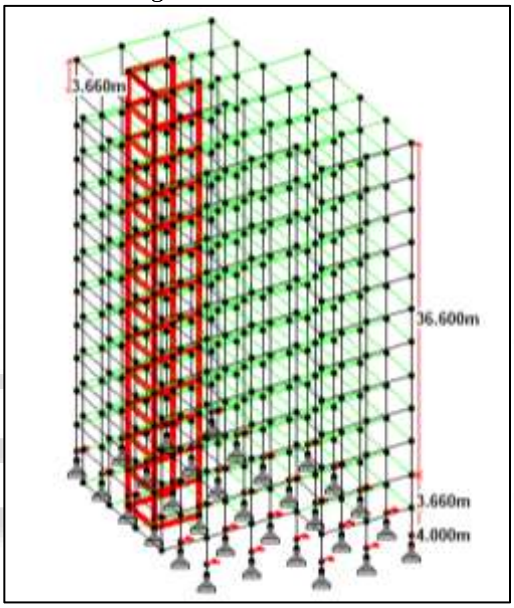


Fig. 2: 3- D view of all buildings

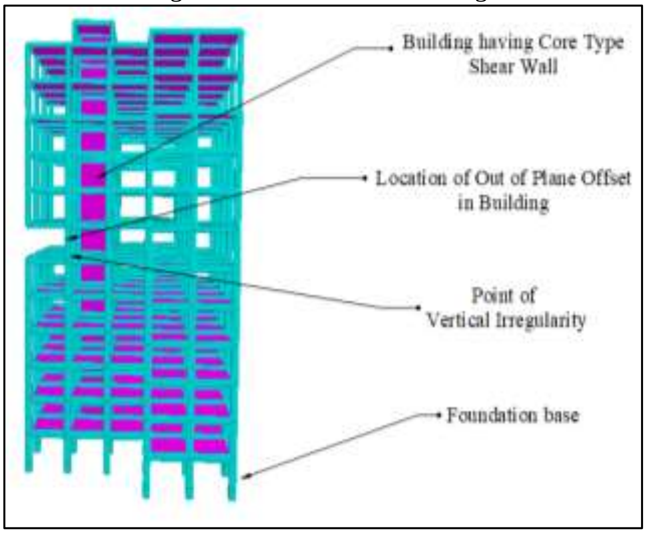


Fig. 3: Out of plane offset in multistoried building

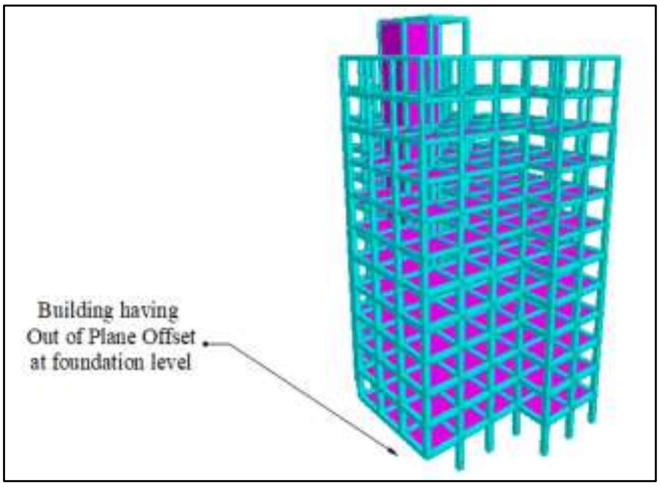


Fig. 4: OPO Case 1 - Residential Apartment having out of plane offset provided at foundation level.

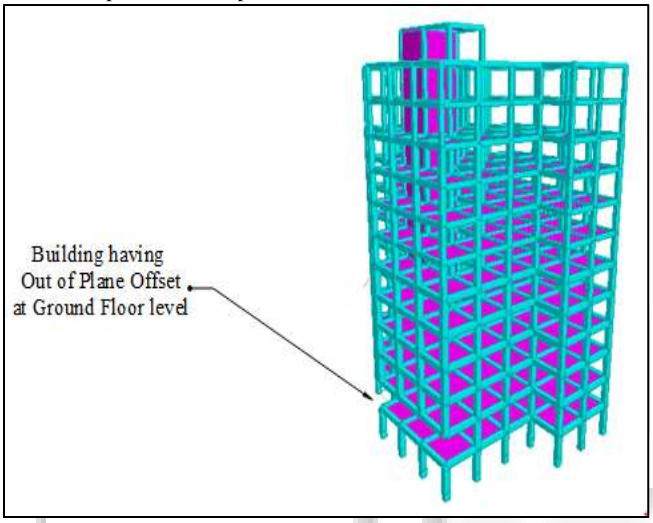


Fig. 5: OPO Case 1.1 - Residential Apartment having out of plane offset provided at ground floor level.

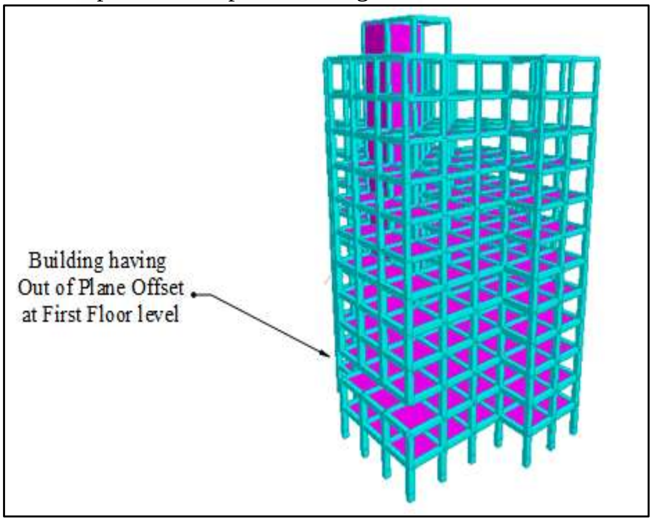


Fig. 6: OPO Case 2 - Residential Apartment having out of plane offset provided at 1st floor level

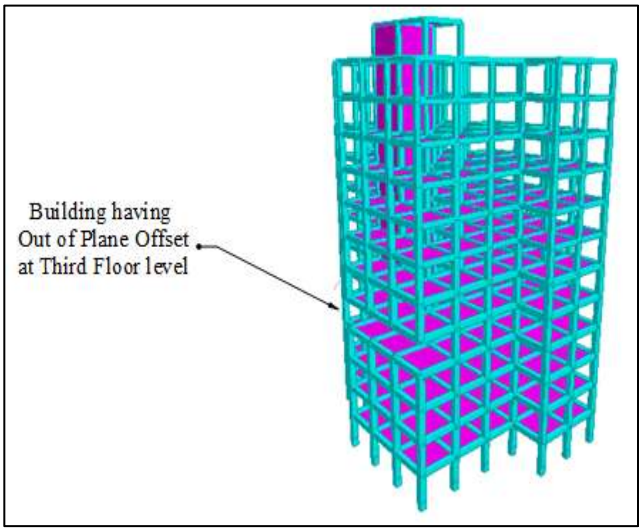


Fig. 7: OPO Case 3 - Residential Apartment having out of plane offset provided at 3rd floor level

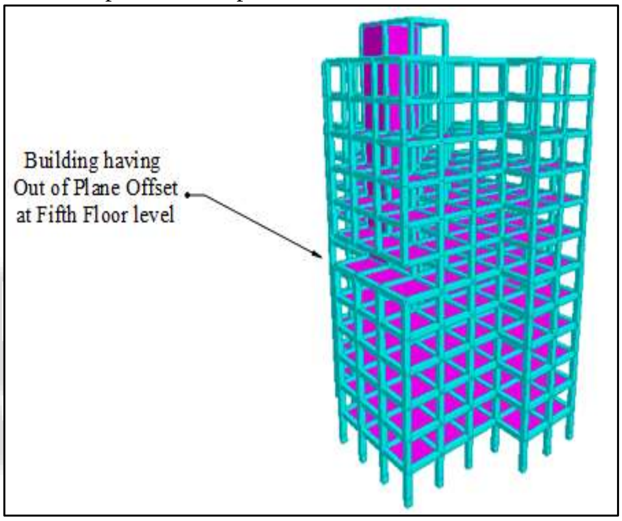


Fig. 8: OPO Case 4 - Residential Apartment having out of plane offset provided at 5th floor level

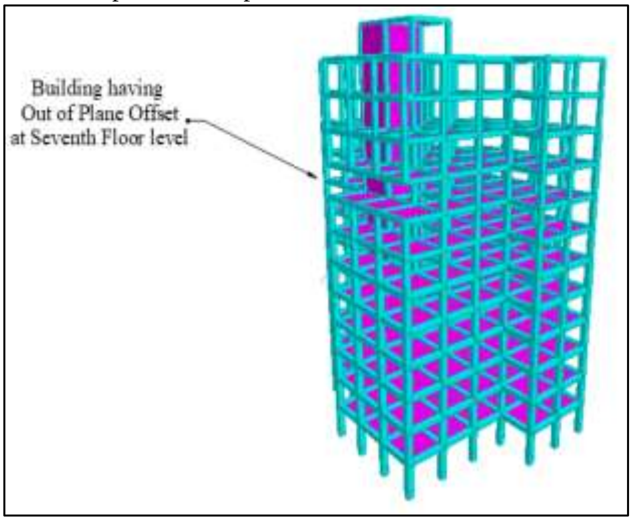


Fig. 9: OPO Case 5 - Residential Apartment having out of plane offset provided at 7th floor level

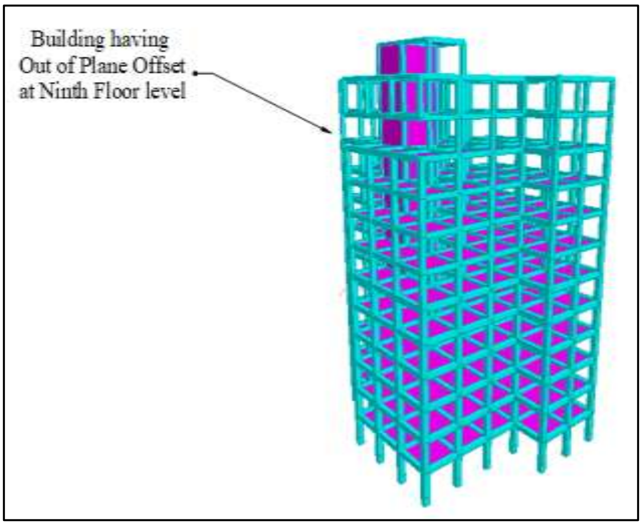


Fig. 10: OPO Case 6- Residential Apartment having out of plane offset provided at 9th floor level

IV. RESULTS ANALYSIS

The application of loads and their combinations on different cases as per the Indian Standard 1893:2016 code of practice yield result parameters:-

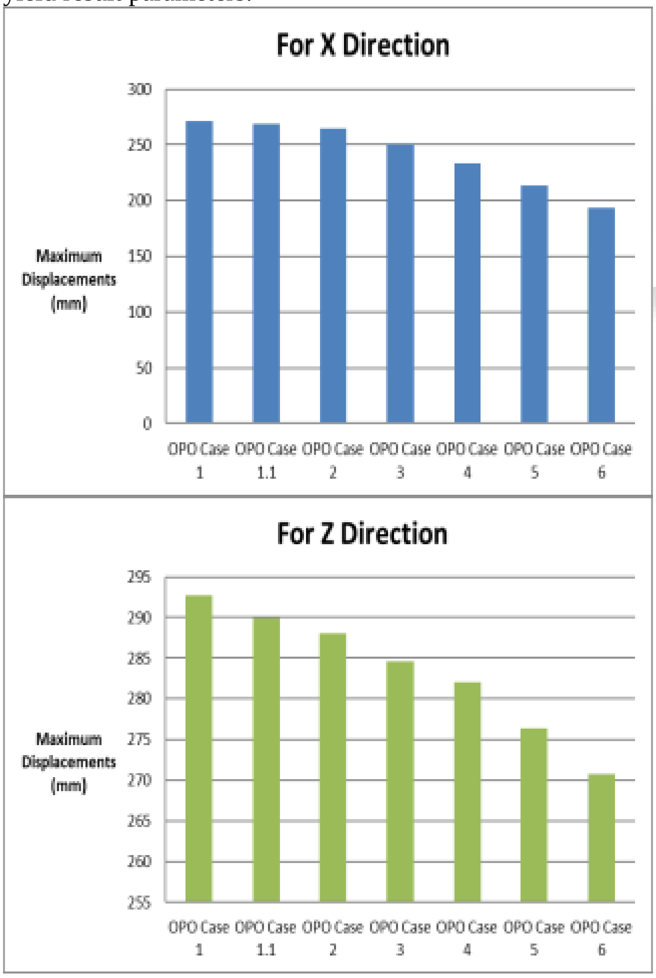


Fig. 11: Maximum Displacement in X and Z direction

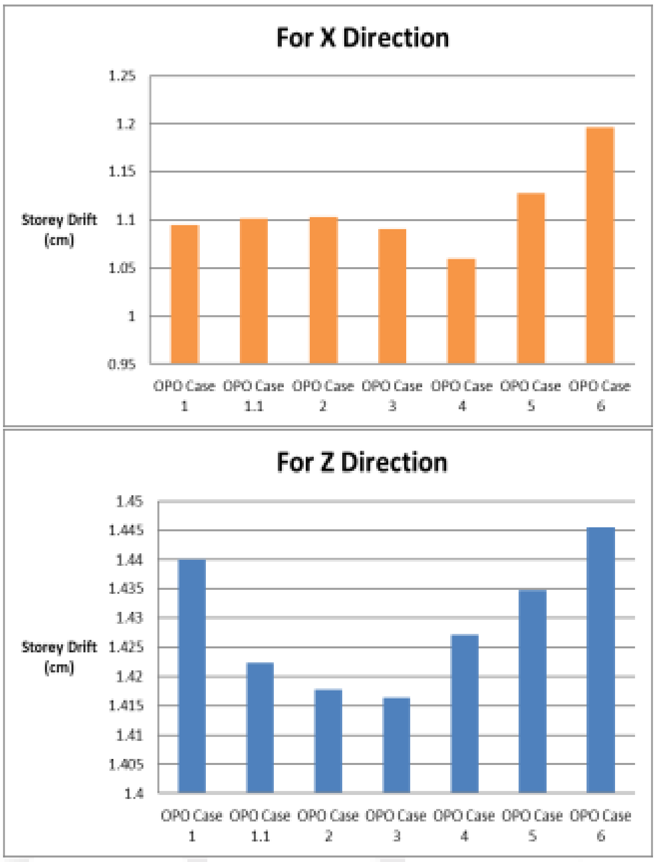


Fig. 12: Storey Drift in X and Z direction

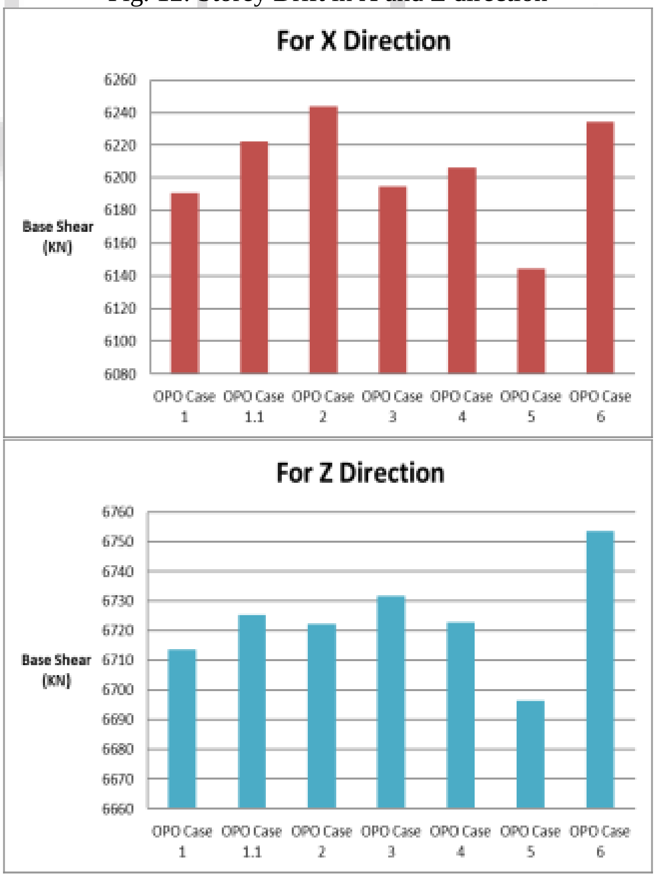


Fig. 13: Base Shear in X and Z direction

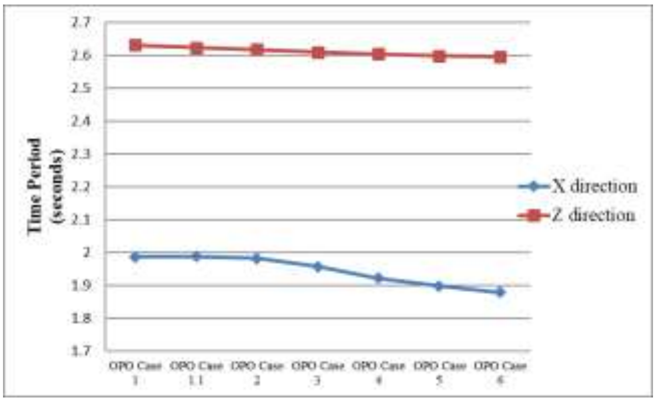


Fig. 14: Maximum Time Period

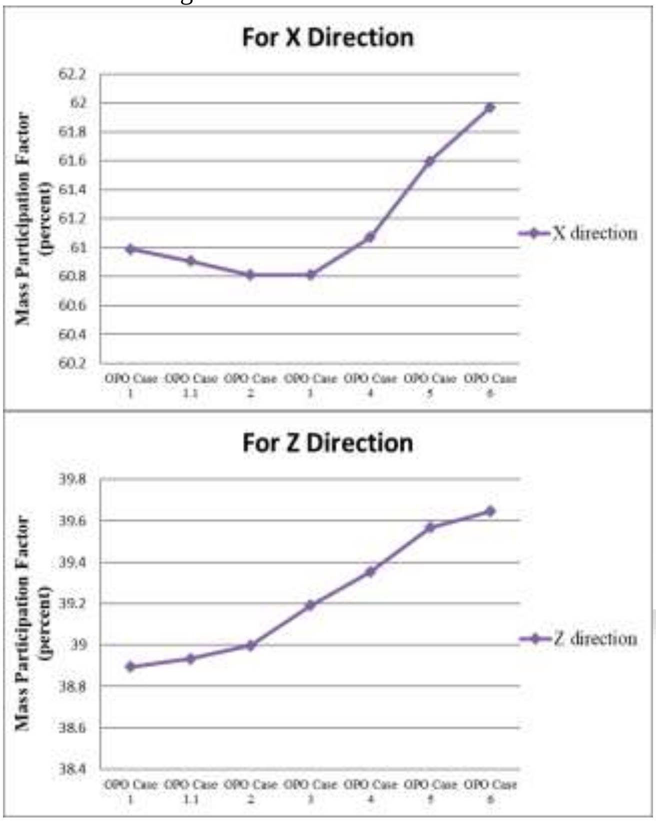


Fig. 15: Mass Participation Factor in X and Z direction

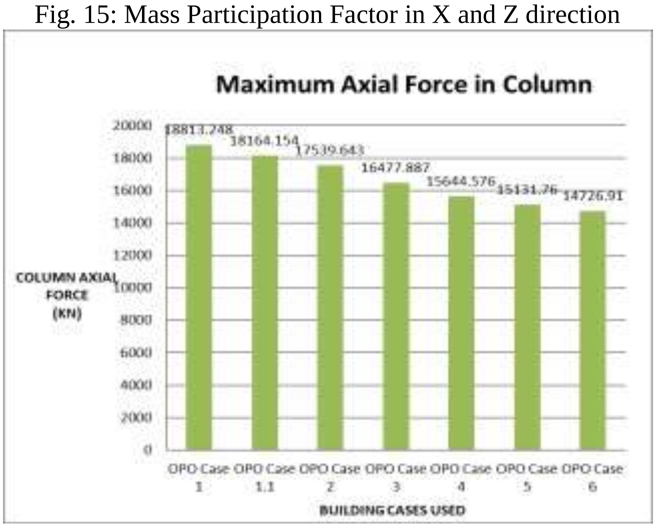


Fig. 16: Maximum Axial Forces in Column

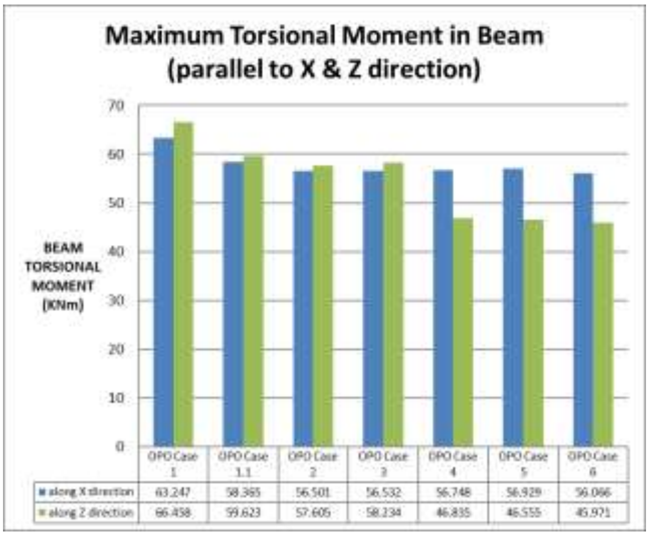


Fig. 17: Maximum Torsional Moment in beams along X and Z direction

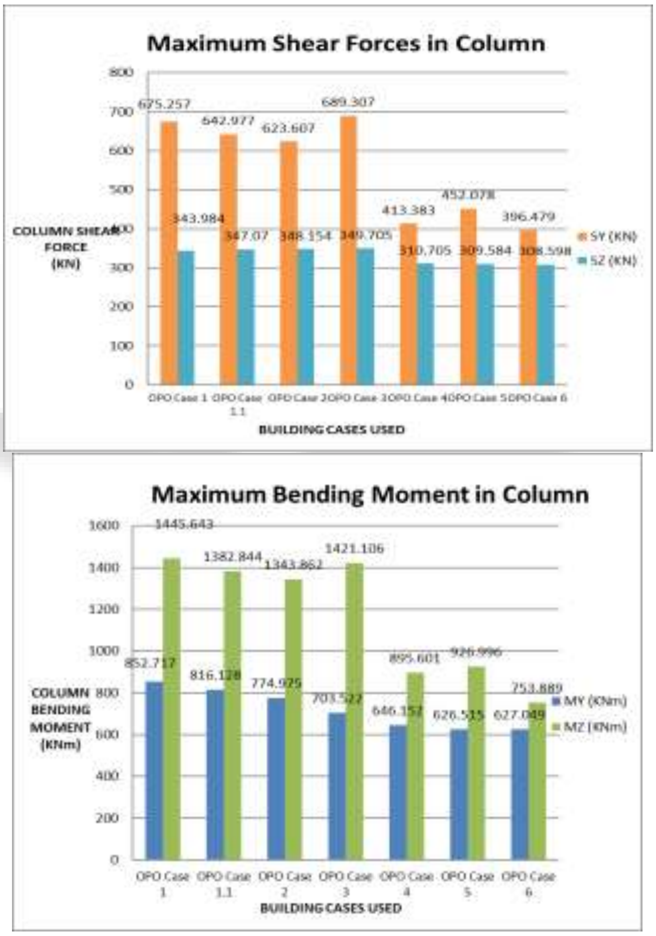


Fig. 18: Maximum Shear Forces and Bending Moments in Columns

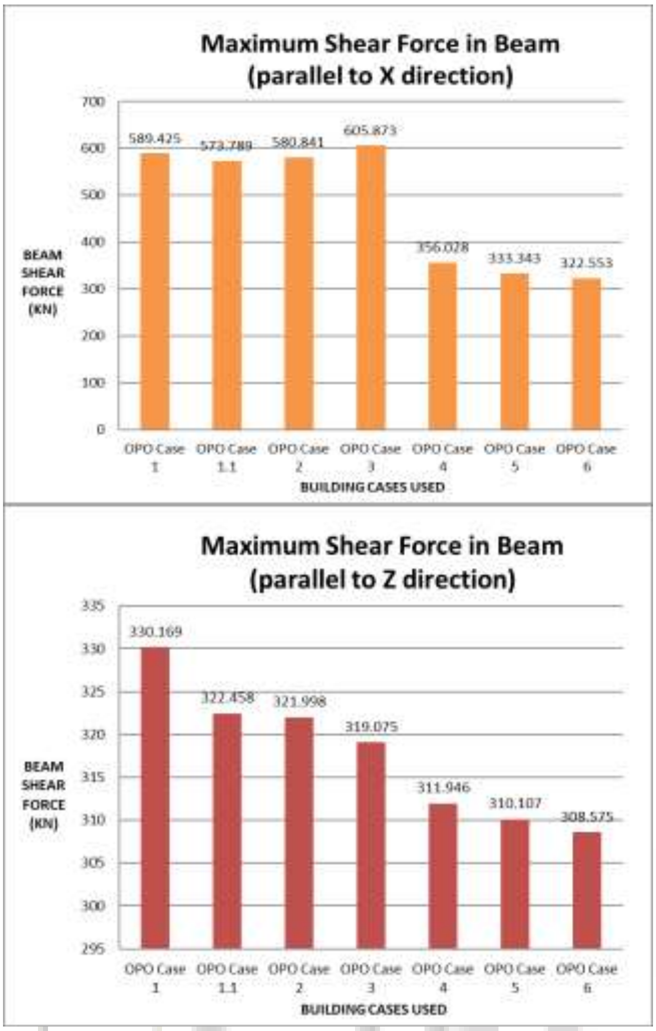
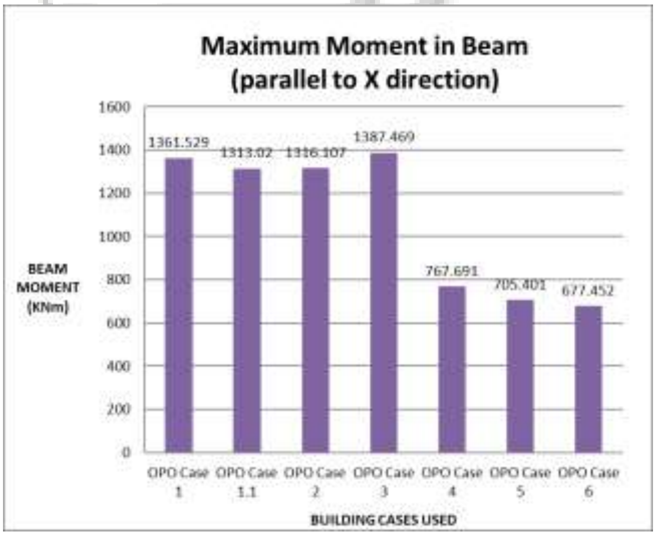


Fig. 19: Maximum Shear Forces in beams parallel to X and Z direction



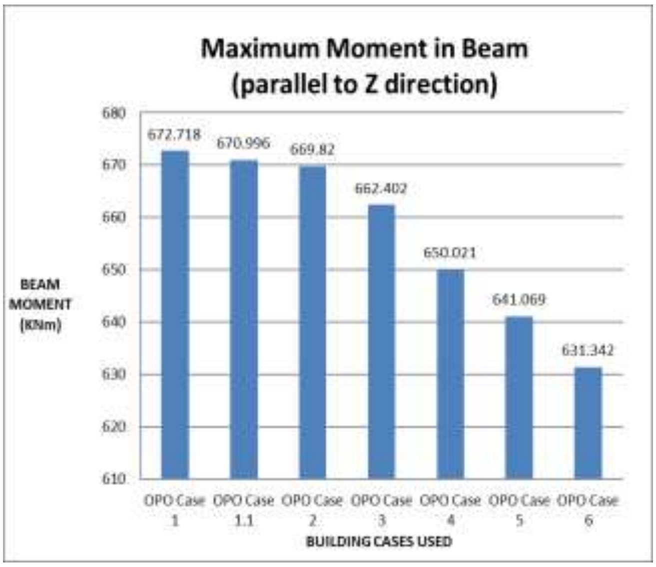


Fig. 20: Maximum Bending Moment in beams parallel to X and Z direction

V. CONCLUSIONS

Based on the analysis of seven different cases involving out-of-plane offsets in multistorey buildings at various floor levels, the following conclusions can be drawn:

1) Among the compared models, OPO Case 6 consistently exhibits better performance in terms of maximum displacement in the X direction across all cases.
2) Similarly, OPO Case 6 outperforms OPO Case 1 in terms of maximum displacement in the Z direction for all cases.
3) The calculation of storey drift, as per IS codal provisions, reveals that OPO Case 1 model exhibits lowest values in the X and in the Z direction. These conclusions highlight the varying outcomes obtained from the comparative analysis of the mentioned cases in the structure.

For General case:

The IS codal provision recommend the storey drift limitation as in any direction, it shall not exceed 0.004 times the storey height. i.e. $\frac{L}{250}$.

Therefore, for out of plane offset type, the IS codal provision recommend the storey drift limitation as in any direction, it shall not exceed 0.2% i.e. 0.002 which comes out to be $\frac{L}{500}$ (with stories having offset and stories below)

Hence, structural provision for best case of storey drift will be out of plane offset provided upto 7.66m from foundation level.

Therefore, safe limit for drift obtained is (%) $= \frac{\text{Safe height}}{\text{Total Height}} = \frac{7.660}{47.920} \text{X } 100 = 15.98\%$, i.e. OPO Case 1.1 model.

4) OPO Case 5 model demonstrates lower base shear values in both the X and Z directions.
5) Shifting the out-of-plane offset to the top floors results in a decrease in the time period for OPO Case 6 models in both directions.
6) According to IS 1893:2016, Table 6, vii, point a, the mass participation factor should not be less than 65% in

each principal plan direction to avoid lateral storey irregularity. None of the models exhibit such behavior.

7) Comparing axial forces in columns, OPO Case 6 model shows lower values.
8) The minimum values for maximum shear forces in columns are observed in OPO Case 6 model, making it the best case.
9) Among the compared models, OPO Case 6 model demonstrates the lowest values for maximum bending moment in columns, making it the best case.
10) OPO Case 6 model exhibits the minimum values for maximum shear forces in beams parallel to both the X and Z directions, making it the best case.
11) Again on comparing maximum moment in beam parallel to X and Z direction, again OPO Case 6 model proved to be the best case with least values.
12) The torsional moment in beam parallel to X and Z direction seems to be less in OPO Case 6 model, when out of plane offset shifted to top floors.

Based on the comparison of all the result parameters, this project concludes that in the majority of cases, the OPO Case 6 model emerged as the best case. Therefore, it is recommended to adopt this construction procedure, specifically utilizing out-of-plane offset at the top floors. This approach has shown favorable outcomes across various parameters and can be recommended as the preferred method.

ACKNOWLEDGEMENTS

I, *Sapana Rawat*, M. Tech. Scholar, would like to thank *Prof. Prachi Chincholikar*, Assistant Professor, Department of Civil Engineering, Vikrant Institute of Technology and Management, Indore (M.P.), India, for her valuable guidance from the commencement of the work up to the completion of the work along with his encouraging thoughts.

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