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Seismic Behaviour of Vertically Irregular Reinforced Concrete Buildings with P-Delta Effect

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Abstract – *Irregular building structures are in practice now a day. Architectural aesthetics and functional requirements are the causes for such irregularities. Due to natural hazard like earthquake, these buildings need to be designed earthquake resistant. P-Delta effect is a second order effect. It is also known as geometric nonlinearity effect. P-Delta effect is more important for tall buildings since the increase in deflections and bending moments due to P-Delta effect is generally large for tall structures. The main objective of the current work is to study the influence of P-Delta effect in the structural behaviour of tall RC buildings with vertical irregularity. For this purpose 30 storey buildings having vertical geometric irregularity are modelled and analyzed using ETABS V.16 software and using the Indian standard codes, IS 1893:2002 and IS 456:2000. The buildings modelled are with floor area of (25m x 25m) with 5 bays of 5m span along both directions.*

Key Words: Irregular building, Geometric irregularity, Second order effect, Geometric nonlinearity, P-Delta effect …

1. INTRODUCTION

During an earthquake the failure of structure generally starts from the point of the structural weakness present in the building systems. This weakness arises due to discontinuity in mass, stiffness and geometry of structure. The structural weakness generates further structural deterioration which leads to the structural collapse. The structures having these discontinuities are known as Irregular structures. These irregular structures constitute a large portion of the modern urban infrastructure. Vertical irregularities are one of the major reasons of failures of structures during earthquakes. For example structures with setbacks and step backs are the remarkable structures which collapsed. So, the effect of vertically irregularities in the seismic performance of structures becomes really important. The dynamic characteristics of buildings with vertically irregular configuration differ from the regular building. When such buildings are constructed in high seismic regions the analysis and design becomes more complicated. Hence structural engineer needs to have a thorough understanding of the seismic response of irregular structures.

1.1 P-Delta effect

P- Delta effect is the non-linear (Second order) effect that occurs in every structure, where the elements are subjected to axial loads. P D-delta effect is the genuine effect that is associated with the Magnitude of the applied axial Load (P) and the lateral displacement (Delta). It generates additional shear forces and bending moments in structure because of the deformed shape. P-Delta effect is more prominent in the case of tall structures and it has adverse effect in case of deformation caused by earthquake.

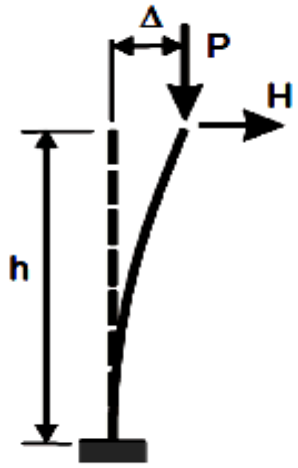

Fig - 1: P-Delta effect

There are two P-Delta effects:-

P-BIG delta (P-Δ) - a structure effect

P-little delta (P-δ) - a member effect

P-δ effect, or P-"small-delta", the member instability effect is related with local deformation relative to the element chord between end nodes. Typically, P-δ only becomes significant at unreasonably large displacement values, or in especially slender columns.

P-Δ (P-Big delta or Large P-delta), the structure instability effect or frame instability effect, has a reference to the effects of the vertical loads acting on the laterally displaced structure.

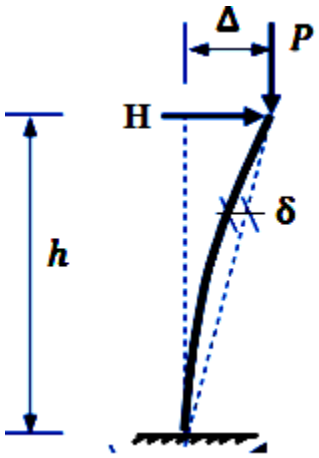

Fig - 2: P-δ-Delta effect

Importance of study

Lateral forces acting on the face of a high-rise building cause lateral deflection of the building. Control of the lateral deflection is very important for the safety of the structure. This is a major challenge before structural engineers now days. P-Delta effect is a secondary effect that associated with the applied load 'P' and the displacement delta (Δ). The P-Delta effects depend on the applied load and material characteristics, in addition to parameters such as height and stiffness of building. Thus P-Delta effect becomes more significant when building height increases.

1.2 Objectives

The goal of this research is to investigate various seismic responses of RC framed vertical geometric irregular structure with P-Delta effect. The comparison between various seismic parameters would allow us to propose the best suitable building configuration on the existing condition. More specifically, the main objectives of this study are:

1. To perform a comparative study of the various seismic parameters of different reinforced concrete buildings having vertical geometric irregularity under P-Delta analysis.
2. Comparison between different vertically irregular frames and regular frame on the basis of storey displacement, storey drift, time period etc.
3. To recognize in what way the P Delta effects influence the variation of responses of structure such as displacements, storey drift, and time period against linear static analysis.
4. To suggest the best suitable building configuration on the existing condition.

2. METHODOLOGY

The steps undertaken in the present study to are as follows:

1) Detailed literature review.
2) Select a set of regular and vertical irregular building models with 30 storey, assuming equal storey height of 3m.
3) Perform linear static analysis with and without P-Delta effect for each of the building models taken in this study.
4) Analysis and comparison of the results and outcomes of the seismic analysis.
5) Detailed discussion on the results with the help of graphs and tables for each building models and reaching to the conclusion.

3. STRUCTURAL MODELLING

Building of symmetric plan dimensions of 25m x 25m, bay spacing of 5m along each direction and story height of 3m is selected. All building structures are modeled and analyzed using ETABS 2016 software. Total six different building geometries, one regular and five irregular is considered in the present study. Figure given below presents the plan and elevation of all six different building models. The buildings are three dimensional, with the vertical irregularity in one direction i.e. in X direction. The regular frame is designated as R. Vertical irregular frames are named as S1, S2, S3, S4 and S5 depending on the percentage increase of floor area along the height as shown in the figure below.

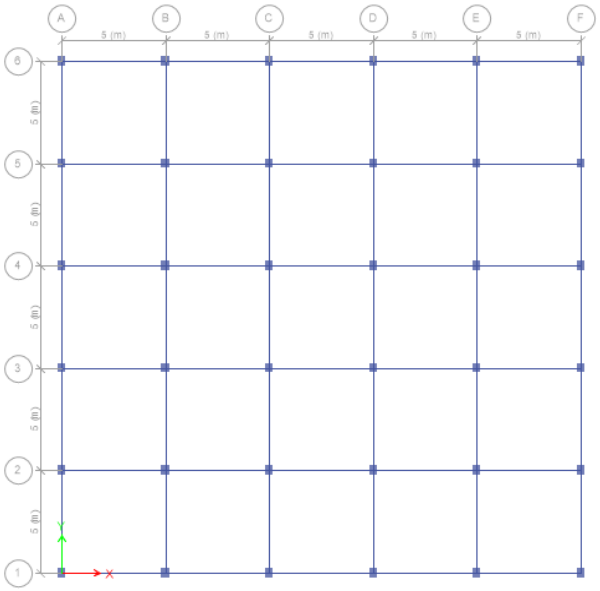

Fig - 3: Typical plan of building model

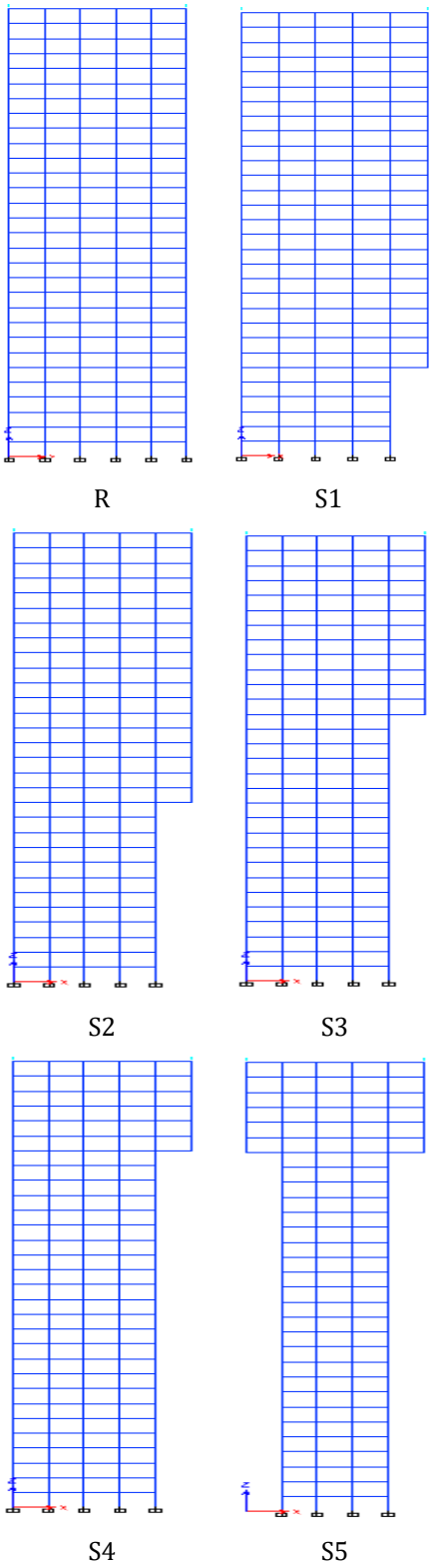

Fig - 4: Configuration of different building models

The method used in this study is equivalent static analysis. Gravity (dead and imposed) load and seismic load corresponding to seismic zone V of IS 1893:2002 are considered for the analysis.

The properties of material and geometric properties are as shown below.

Table – 1: Material Properties

a) Properties of concrete	
Grade of concrete	M25
Elasticity Modulus, Ec	25000Mpa
Poisson's Ratio	0.2
Density of concrete	25 KN/m3
b) Properties of reinforcement steel	
Grade of steel	Fe415
Modulus of elasticity, Es	210000Mpa
Poisson's ratio	0.3
c) Properties of masonry	
Density of brick wall including plaster	20 KN/m3
Poisson's ratio	0.2

a) Dimensions of structural elements

Beam size : 300mm x 475mm
Column dimensions
: 600mm x 800mm (Storey 21 to Storey 30)
: 450mm x 650mm (Storey 11 to Storey 20)
: 450mm x 450mm (Storey 1 to Storey 10)
Slab thickness : 150mm
Brick wall on external beams : 230mm thick
Brick wall on internal beams : 150mm thick
Parapet wall on roof : 150mm thick
Storey height : 3m

b) Seismic Parameters

Zone : V
Importance factor (I) : 1
Building system with response reduction factor (R) :5

c) Loads on Structure

Live load on roof and floor : 3kN/m3
Roof/floor finish : 1.5kN/m3
Load from brick wall on external beams : 13.8kN/m3
Load from brick wall on internal beams : 9kN/m3
Load from parapet wall on roof : 3kN/m3

4. Results and Discussion

Linear static analysis and P-Delta of all the models reveals that P-Delta effects significantly influence the seismic parameters. All the parameters with P-Delta effect have higher value than linear static analysis. Results of all the different types of analysis such as linear static analysis and P-Delta analysis for reinforced concrete structures are obtained and mentioned here.

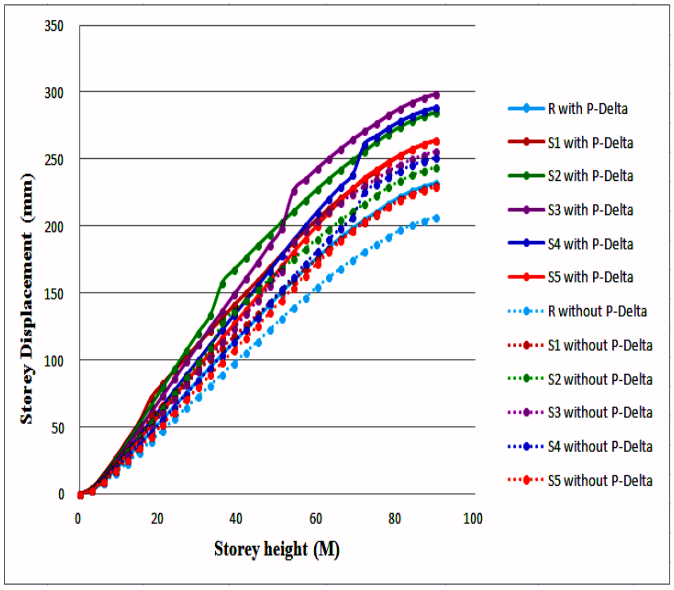

Chart -1: Variation of Storey Displacement

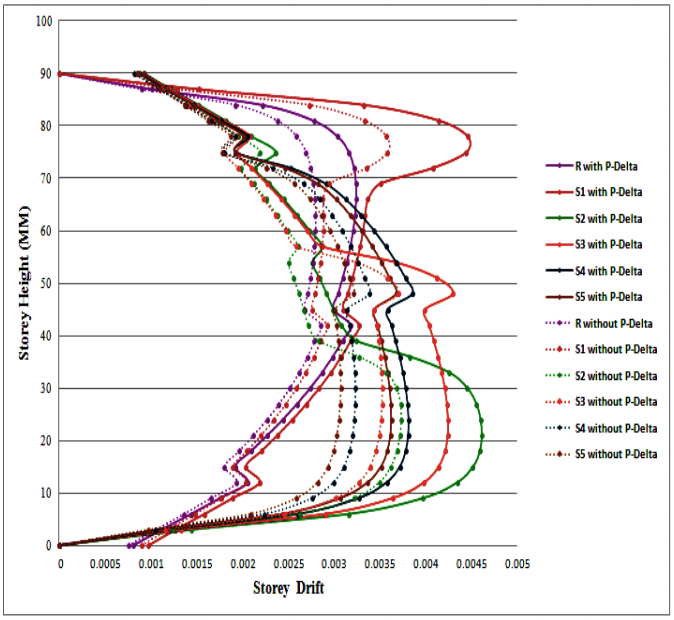

Chart -2: Variation of Storey Drift

Table – 2: Comparison of Time period

Time Period (Sec)			
Model	Without P-Delta	With P-Delta	% Increase In Period
R	4.891	5.228	6.45
S1	5.499	5.982	8.07
S2	5.436	5.9	7.86
S3	5.402	5.847	7.61
S4	5.252	5.655	7.13
S5	5.854	6.394	8.45

Table – 3: Comparison of Displacement

Max. Displacement (mm)			
Model	Without P-Delta	With P-Delta	% Increase In Displacement
R	206.98	232.11	10.83
S1	229.94	263.82	12.84
S2	244.11	285.2	14.41
S3	256	298.44	14.22
S4	251.61	288.65	12.83
S5	229.46	263.74	13.00

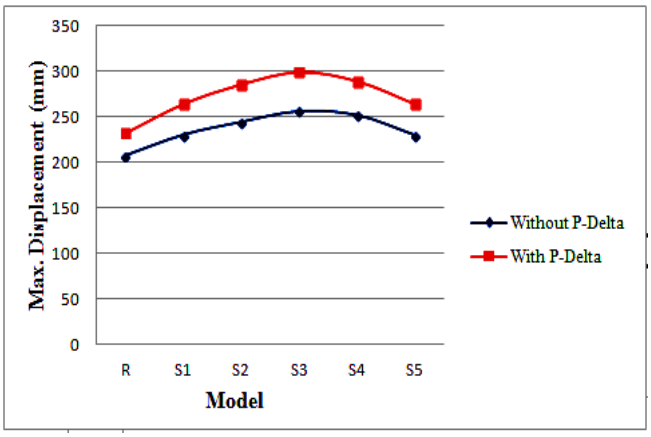

Chart -3: Comparison of Displacement

Table – 4: Comparison of Drift

Max. Storey Drift			
Model	Without P-Delta	With P-Delta	% Increase In Drift
R	0.002857	0.00325	12.09
S1	0.003587	0.004463	19.63
S2	0.004	0.004618	13.38
S3	0.003708	0.004304	13.85
S4	0.003392	0.003865	12.24
S5	0.003222	0.003685	12.56

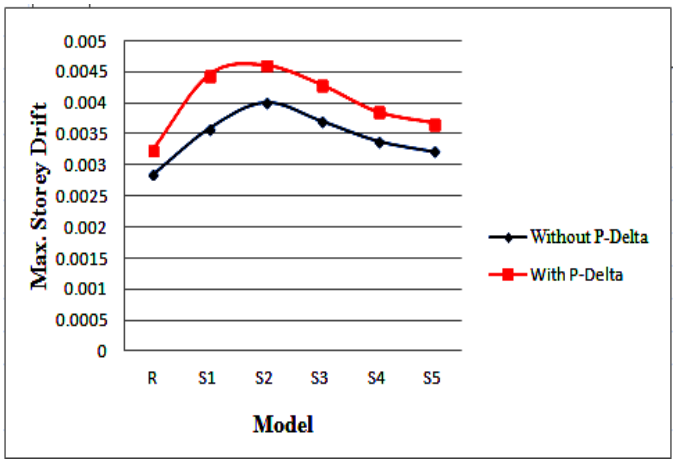

Chart -4: Comparison of Drift

Table – 5: Comparison of Stiffness

Stiffness (Kn/M)			
Model	Without P-Delta	With P-Delta	% Decrease In Stiffness
R	1779022	1597300	10.21
S1	1478134	1287561	12.89
S2	1475603	1293071	12.37
S3	1475091	1304498	11.56
S4	1474861	1315347	10.82
S5	1170828	1039905	11.18

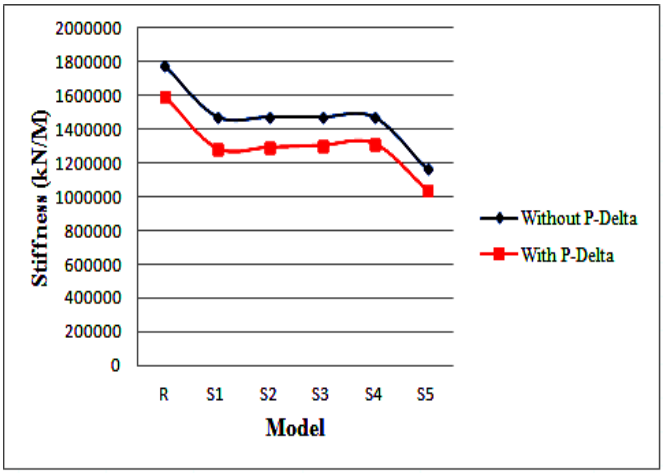

Chart -5: Comparison of Stiffness

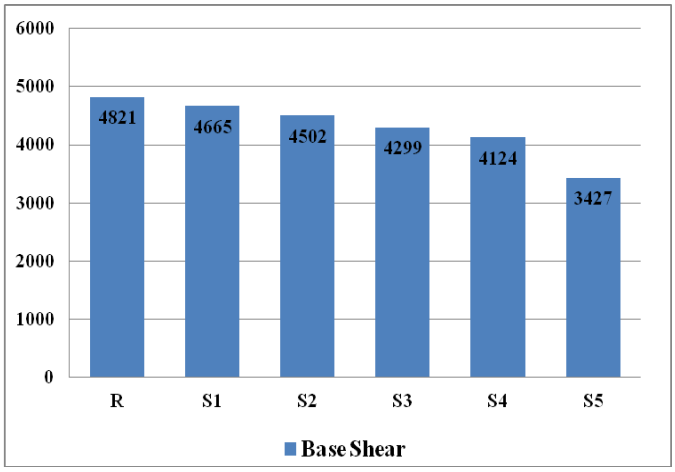

Chart -6: Comparison of Base Shear

From the above results it can be seen that building models with P-Delta effect have higher value than building models without P-Delta effect. In model R the percentage increase in maximum Displacement and Storey Drift due to P-Delta effect is 10.83% and 12.09%, while these increment values of irregular models are more as compared to Model R. For model S1 the percentage increase in displacement and storey drift values are 12.84 and 19.63, and 13 and which is 12.56 for model S5. For all models the change in displacement and drift is more than 10%. In case of all irregular building models the change in displacement values are from 11% to 14.5%. The maximum value for change in drift value is 19.63 (model S1) while the minimum value is 12.09 (model R). Value of Base Shear is reduced for both cases (models with and without P-Delta effect) as Seismic weight of building is reduced. All buildings models (Both regular and irregular) with P-Delta effect have high time period value as compared with models without P-Delta effect. Considering P-Delta effect, the minimum value of fundamental period is 5.228sec which is for model R and the maximum value of fundamental period is 6.394sec which is for model S5. The magnitude of stiffness decreases with P-Delta effect. Comparing with

regular building model there is a decrease in stiffness value for irregular building models.

5. CONCLUSIONS

From above study, it is clear that for all building models, values of the seismic parameters increase with P-Delta effect. The comparison of results has been done for each building model. It is concluded that as the amount of vertical irregularity increases the displacement also increases. Also there is increase in values of time period, displacement, and storey drift due to P-Delta effect. Based on the result analysis the following conclusions are drawn:

1. It is concluded that as the amount of irregularity increases, the displacement also increases.
2. The regular building frames have low displacement compared to irregular frames.
3. It is seen that the seismic parameter of building models without P-Delta is less than corresponding building models with P-Delta effect.
4. The seismic performance of regular frame R is found to be better than other irregular frames for all the cases.
5. Presence of irregularities in buildings is harmful, but in some cases building irregularities are unavoidable. Therefore irregular buildings should be constructed to minimize the seismic effects.
6. Designer should include P-Delta effect while designing both regular and irregular buildings.

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