Geometrically Variations of Steel Frame Structures: P-Delta Analysis

Ajay Agnihotri[1], Raghvendra Singh[2]

[1]M.E. student, UEC Ujjain (MP), [2]Professor, UEC, Ujjain (MP)
[1,2] Dept. of Civil Engineering, UEC, Ujjain, Madhya Pradesh, INDIA

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Abstract - *A method of designing for P-delta effects in 20 storey steel frame buildings is presented. With this approach the strength required to prevent an increase in elastic demand when P-delta effects are included in as analysis, is determined from the performance of different kind of geometrical variation in buildings i.e. rectangular, square, triangular, circular. The tall buildings need high steel frame structure stability for design and safety purposes. This research focused on P-delta effect on Tall steel structures and compared with linear static analysis. In this thesis, a 20 storey steel frame structure with 72m has been modelled by using ETABS (Vr.15) structure analysis software with the consideration of P-delta effect. In all kind geometrical buildings the influence of double diagonal bracing patterns has been investigated. Because lateral loading on a building is reversible, brace will be subjected in turn to both tension and compression, consequently in double diagonal braces the forces in the braces connecting to each beam end are in equilibrium horizontally, with the beam carrying an in signification axial load. The all steel frame structure is analyzed for wind load as per IS 875 (part 3)-1987. After analysis, the comparative study is presented with respective to maximum storey displacement, member displacement, stiffness and base shear, the present work shows the maximum percentage of storey displacement obtained in Circular building. Storey drift increases as no. of storey increases in all kind of steel frame buildings. Maximum column displacement obtained in Square building. Cross bracing system proved to be more stiff and effective with respect to linear analysis and P-delta analysis.*

Key Words: Geometry, Steel Frame Structure, P-Delta Analysis (P-Δ), Wind Load, Double Diagonal Bracing, Displacement, Bending Moment, CSI®ETABS structure analysis software

1. INTRODUCTION

As far as tall building analysis concern, many symmetric and asymmetric tall structures have been analyzed with the consideration of wind and earthquake loading. But at present influence of geometrical variation in the analysis of tall building is included. It is thing to concern that may be much variations among different kind geometric shaped tall buildings i.e. rectangular, square, circular and triangular may be includes in the analysis for the further study to enhance the behavior of tall building. In the tall buildings analysis, wind load is the main influencing parameters related to the stability of tall building. In the case of static analysis of structure, the flow interacts only with the external shape of the structure. When the structure is very stiff deflections under the wind loads will not be significant, and the structure is considered as static structure for the analysis and to resist lateral forces a steel frame of tall building can be strengthened in various types. Braced frames with both pin-jointed and braced frames with pin jointed connections and moment-resisting connections are present. In steel buildings the most widely used method of constructing lateral load resisting system is braced frames. Hence, the main concern is to select the appropriate bracing model and to decide the suitable connection type. Cross bracing structural members are inserted into the rectangular areas so that triangulation is formed and these systems help the structure to reduce the bending of columns and beams and the stiffness of the system is increased. Sometimes because of random nature of wind it takes so destructive form that it can disturb the internal ventilation system when it passes into the building hence, it has become of almost importance to study the effect of wind and air flow on the building and its environment. There are mush advantages of the bracing systems so that they are widely used.

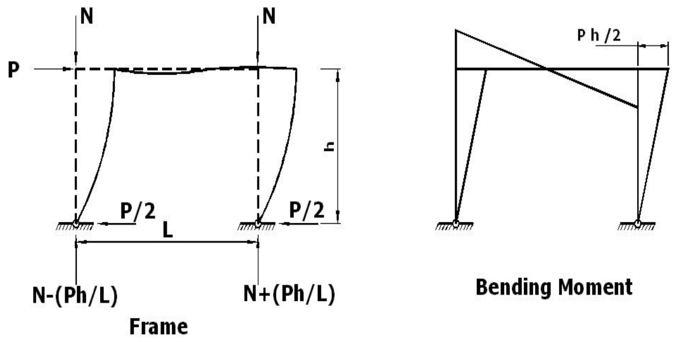
The P-Delta effects are the second order effects seen due to additional moments developed due to excessive lateral sways (Anuj Man Shaky, 2011). The standard elastic design procedures can prove inadequate if the additional destabilizing moments are not taken into account. Current design methods are majorly based on linear elastic, or first order, approach (Dobson, 2002). These design methods do not consider the development of additional internal forces and displacements due to P-Delta effect (Chen and Wang, 1999).

1.1 P –Delta Effects

In building structures the calculation of P-delta effects is an iterative process in which a horizontal displacement, caused by an initial misalignment or horizontal load, causes an increasing eccentricity of the gravity load. This process continues until the compression member is in equilibrium or collapses.

Engineers have been aware of the P-Delta for many years. However, it is only relatively recently that the computational power aided to provide analytical approximations to this effect, which has become widely available. It is an engineer's judgment as to how accurately the second order effect needs to be accounted for in determining design forces and moments.

In second-order elastic analysis, the material is assumed to have a linear elastic relationship. However, the equilibrium is calculated on the deformed geometry of the structure. A rigorous second-order analysis includes both the member curvature (P-Δ) and side-sway (P-δ) stability effects. This is because the deformed geometry of the structure is not known during the formation of the equilibrium and kinematic relationship. Thus, the analysis proceeds in a step-by-step incremental manner, using the deformed geometry of the structure obtained form a preceding cycle of calculation. For most practical case, accurate second–order design forces can be obtained by applying the loads in one or two increments, and only a few iterations are required to converge to an accurate solution.



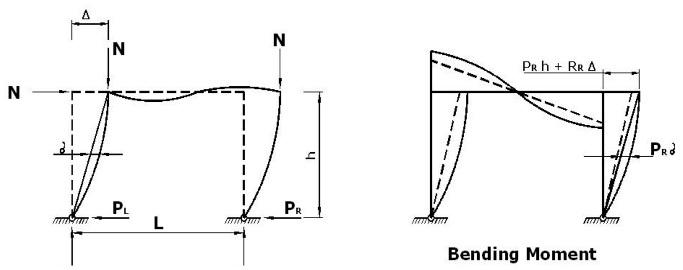


Fig 3.12-c Fig. 3.12-d

Second order Analysis

Considering the portal frame as shown in fig.3.12-a, first order analysis does not consider the second order moments, the bending moment distribution given by first order elastic analysis is linear as shown in fig. 3.12-b Elastic analysis assumes linear-elastic material behavior and may be done based on the equilibrium in the unreformed geometry of the structure (First-order elastic analysis). In the deformed geometry of the structure (Second-order analysis) structure become even more slender and less resistant to deformation the need to consider the P-Delta effect increases. To reflect this, codes of practices and engineers refers to the use second order analysis in order that P-Delta and stress stiffening effects are accounted. P-Delta effect should be considered in all types of loadings.

2. DETAILS OF STRUCUTURES

A. Modelling and Analysis

The main objective of the analysis is to study the different kind of geometric shaped buildings. The analysis is carried out in ETABS (Vr.2015) software. Different types of geometric steel frame buildings are discussed below. The comparison is made among rectangular building, square building, triangular building and circular building.

B. Assumptions

The following are the assumptions made:

Description	**Rectangular building**	**Square building**	**Triangular Building**	**Circular building**
Plan size	36m x 20m	25m x 25m	½ (30m x 25m)	Dia. = 30m
Height of storey	3.6m	3.6m	3.6m	3.6m
Seismic zone	III	III	III	III
Wall thickness	100 mm	100 mm	100 mm	100 mm
Type of soil	Type-I hard as per Is :- 1893-2002	Type-I hard as per Is :- 1893-2002	Type-I hard as per Is :- 1893-2002	Type-I hard as per Is :- 1893-2002

C. Section Properties

Description	Rectangular Building	Square Building	Triangle Building	Circular Building
Beam	ISMB 600	ISMB 600	ISMB 600	ISMB 600
Column	ISWB 550	ISWB 550	ISWB 550	ISWB 550
Brace	ISMB 350	ISMB 350	ISMB 350	ISMB 350
Material	Fe250	Fe250	Fe250	Fe250

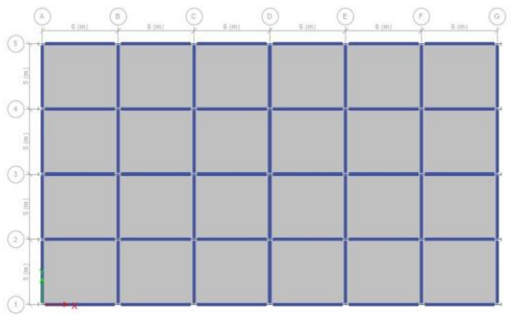


Fig.-1: Plan of rectangular building

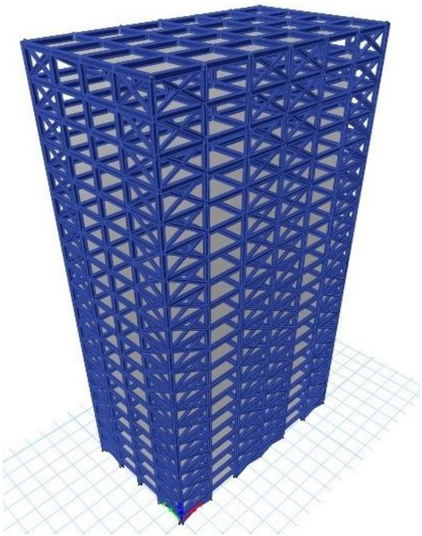


Fig.-2: 3D Model of Rectangular Building

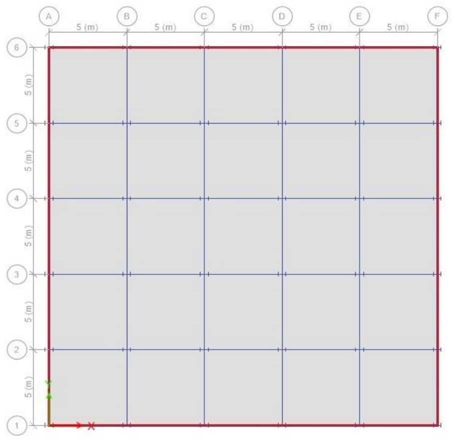


Fig.-3: Plan of Square Building

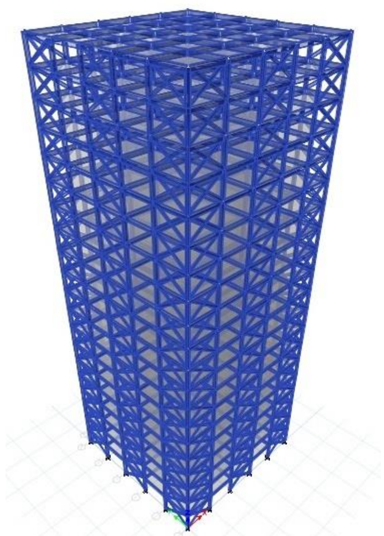


Fig.-4: 3D Model of Square Building

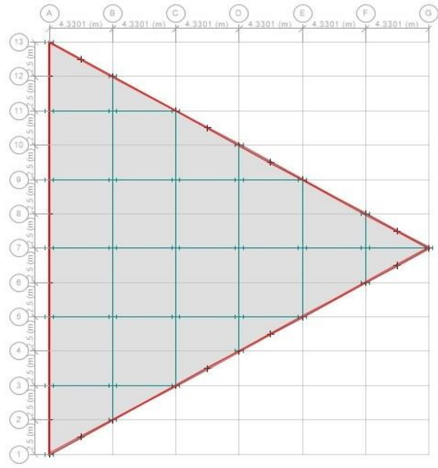


Fig.-5: Plan of Triangular Building

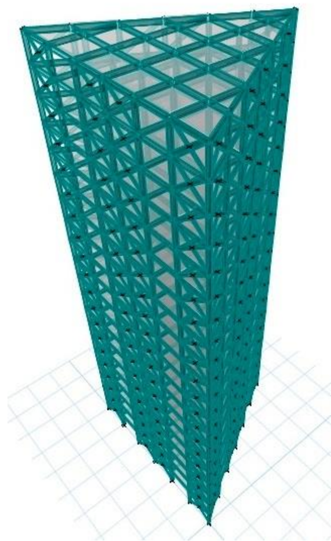


Fig.-6: 3D Model of Triangular Building

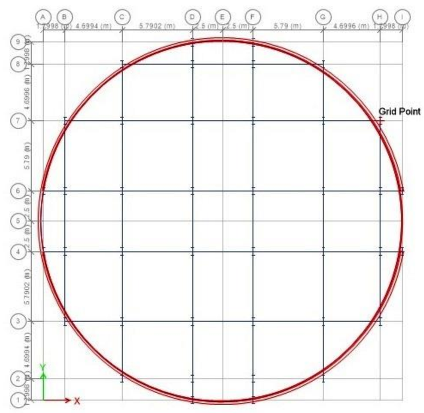


Fig.-7: Plan of Circular Building

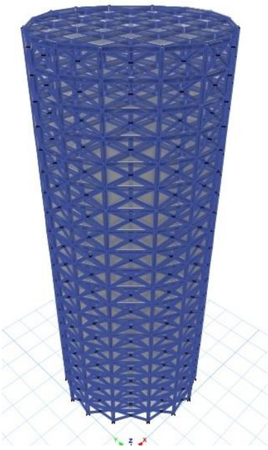


Fig.-8: 3D model of Circular Building

3. LOAD CALCULATION

3.1 Gravity Loading:-

1. Dead Load: The self weight and floor load of the structure are calculated as per general considerations of IS 875:1987 (part-1).
2. Live Load: As per IS 875:1987 (part-2) taken for commercial building. Intermediate floors is $3kN/m^2$ and roof is $1.5kN/m^2$

3.2 Wind Loading:-

Static wind load is given as per IS 875:1987 (part-3). Following assumptions are used for calculations.

Location : Indore
Wind speed : 36m/s
Terrain category: 1
Class : A
K1 : 1.06
K2 : Depending upon the variations of height
K3 : 1.0 (flat topography)

3.3 Earthquake Loading:-

The earthquake loads are calculated as per IS 1893:2002 (part-1)

Design seismic base shear

$$Vb = Ah*W$$

Where,

Ah = Design horizontal acceleration spectrum
W = Seismic weight of building

$$Ah = \frac{Z}{2} * \frac{I}{R} * \frac{Sa}{g}$$

Z = Zone factor as per 1893:2002 (part-1) = 0.16
I = Importance factor = 1
R = Response reduction factor = 5

4. RESULT AND DISCUSSIONS

P-Delta analysis is carried out for different kind of geometric steel frame buildings. After the analysis significant change in parameters such as storey displacement, storey drift, base shear of the structures is noticed.

Table 4.1 Maximum Displacement (mm) at 20 Storey for Linear and Second order analysis

Types Of Building	Without P-Delta	With P-Delta	Percentage Variation
Rectangular	81.32	83.42	
Square	79.01	80.91	
Triangular	86.14	88.24	
Circular	73.25	75.15	

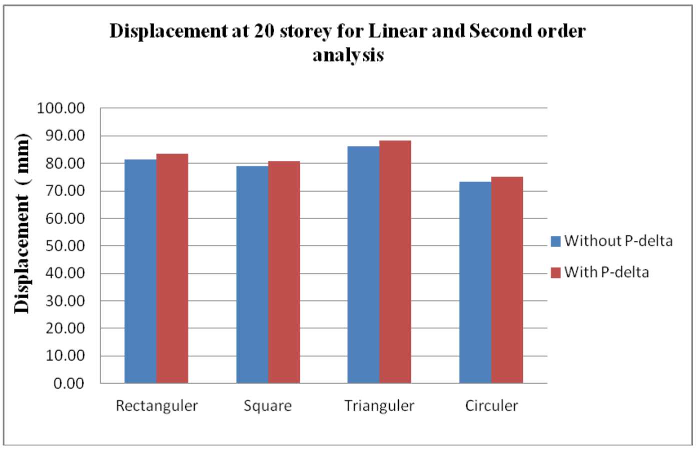


Fig.-9: Storey displacement in X-direction

Table 4.2 Maximum Storey drifts for 20 Storey for Linear analysis.

Storey	Rectangular	Square	Triangular	Circular
1	0.00	0.00	0.00	0.00
2	6.60	3.90	2.3	1.8
3	11.70	7.80	11.1	6.7
4	18.80	10.60	17.9	9.1
5	21.1	12.7	21.9	11.7
6	26.2	16.3	27.4	16.3
7	29.8	18.4	29.7	19.8
8	35.8	21.3	36.2	20.7
9	38.6	23.5	39.2	24.3

10	41.6	26.5	41.8	29.9
11	44.3	29.3	43.5	33.1
12	47.6	30.2	46.3	35.3
13	50.3	32.6	50.5	37.2
14	52.8	34.4	51.3	40.2
15	54.9	38.7	53.1	44.7
16	56.3	40.1	54.8	49.6
17	57.6	43.4	56.2	51.4
18	55.2	49.9	59.8	55.8
19	60.2	56.9	60.8	57.3
20	62.3	58.3	61.6	58.9

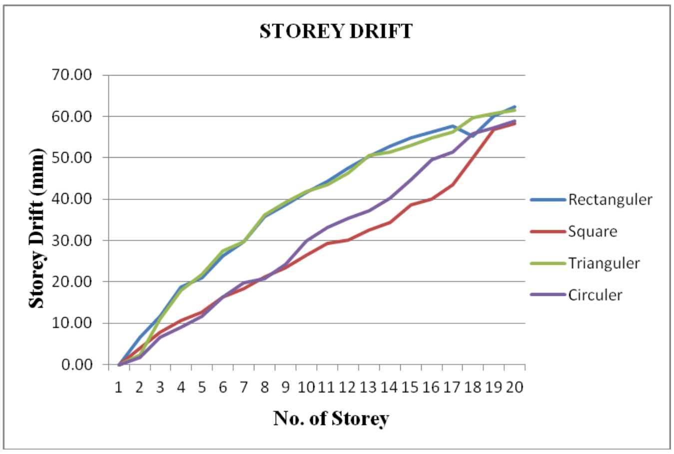


Fig. 10 Storey drifts without P-delta.

Table 4.3 Maximum Storey drifts for 20 Storey with P-delta analysis.

Storey	Rectangular	Square	Triangular	Circular
1	0.00	0.00	0.00	0.00
2	7.48	4.78	3.18	2.68
3	12.23	8.33	11.63	7.23
4	19.68	11.48	18.78	9.98
5	21.98	13.58	22.78	12.58
6	26.73	16.83	27.93	16.83
7	30.68	19.28	30.58	20.68
8	36.68	22.18	37.08	21.58
9	39.13	24.03	39.73	24.83
10	42.48	27.38	42.68	30.78
11	45.18	30.18	44.38	33.98
12	48.13	30.73	46.83	35.83
13	51.18	33.48	51.38	38.08
14	53.68	35.28	52.18	41.08
15	55.43	39.23	53.63	45.23
16	56.68	40.48	55.18	49.98
17	58.48	44.28	57.08	52.28
18	55.73	50.43	60.33	56.33
19	60.58	57.28	60.92	57.42
20	63.18	59.18	62.48	59.78

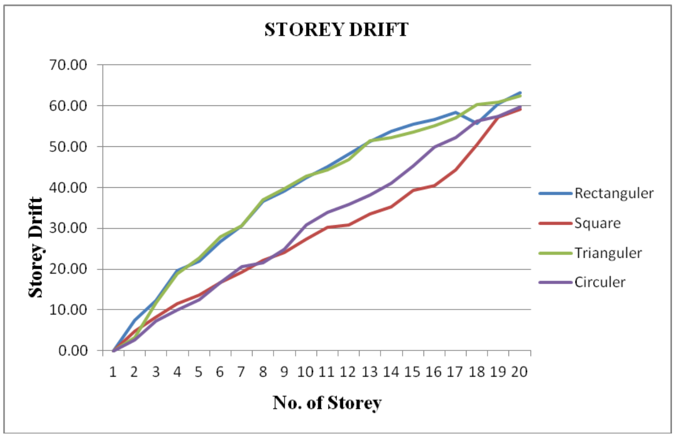


Fig. 11 Storey drifts with P-delta.

Table 4.4 Maximum displacement (mm) in Column at 20th storey

Types Of Building	Without P-Delta	With P-Delta
Rectangular	178.02	179.32
Square	181.78	183.08
Triangular	180.23	181.53
Circular	179.15	180.45

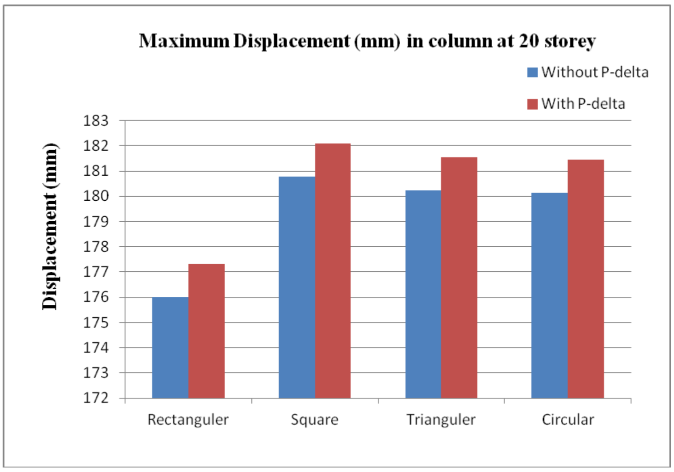


Fig. 12 Column displacement in X-direction

Table 4.5 Maximum Storey Stiffness variations (kN/m)

Type Of Building	Without P-Delta	With P-Delta
Rectangular	149412.5	149872.9
Square	135207.02	135972.85
Triangular	124008.77	125060.16
Circular	150124.81	155117.53

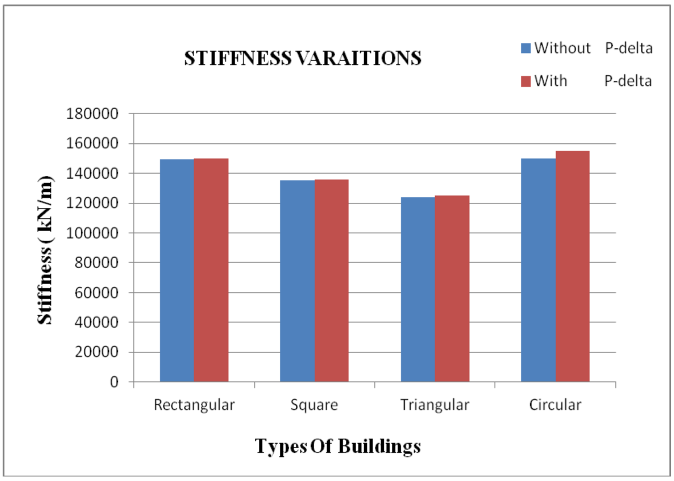


Fig. 13 Storey Stiffness

Table 5.6 Maximum Base shear in buildings.

Type Of Building	Unit (kN)
Rectangular	2325.312
Square	2186.294
Triangular	1988.63
Circular	2386.716

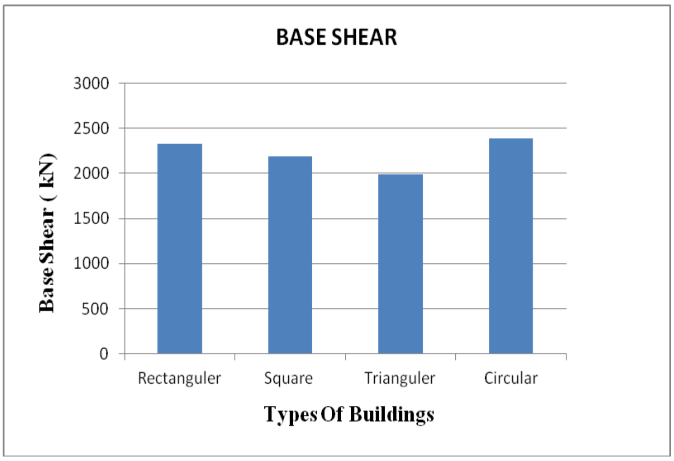


Fig. 14 Base Shear

5. CONCLUSIONS

To investigate the linear behavior of the all types of geometric steel frame buildings of the P-Delta effects is very simple way to use. The storey displacement, storey drift, column displacement, stiffness and base shear is found out by considering both earthquake an wind loading considering and with and without P-delta effects from different kind of steel frame geometry of buildings in ETABS (Vr.2015) software.

On the basis of the present study, following conclusions are made:

1. The P-delta effects found to increase the storey displacement at all type of the steel frame structure.
2. The maximum percentage of storey displacement obtained in circular building.
3. In the all type of steel frame buildings, the results show the storey drift increases as storey of building increases.
4. The storey drift found higher at the top storey when compared to with and without P-Delta analysis.
5. The cross bracings are more stiff and they are effective in linear static and P-Delta analysis. As results obtained the P-Delta analysis, stiffness increases in all type of steel frame buildings.
6. Cross bracing systems are adequate for linear and P-Delta analysis for all types of buildings.
7. The P-delta analysis must be done for the structure, because second order analysis increases the displacement and bending moment. So as a structure engineer must consider the second order analysis

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