ANALYSIS OF STRUCTURES WITH RESPECT TO LINEAR STATIC ANALYSIS USING P-DELTA EFFECT

Rupali Bondre , Sandeep gaikwad

Student, M-Tech. str., civil Enginrreing , Tulsiramji Gaikwad Patil college of Engineering and Technology, Maharashtra, India.
Asst. prof. Civil Engneering, Tulsiramji Gaikwad Patil college of Engineering and Technology, Maharashtra, India.

ABSTRACT

A first-order analysis, in which equilibrium and kinematic relationships are taken with respect to the undeformed geometry of the structure, is simple to perform but is not a thorough analysis since it neglects additional loading caused by the deflection of the structure. For most structures, a second-order analysis, which imposes equilibrium and kinematic relationships on the deformed geometry of the structure, is required for stability design In the traditional first order analysis or linear static analysis of structures, the effects of change in the structure actions due to structure deformations are neglected. However, when a structure deforms, the applied loads may cause additional actions in the structure that are called second order or P-Delta effects. 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 present study Seismic analysis of a multi-storey RC building with and without P-Delta effects is analysed by using STAAD structural analysis software.

Keywords — *p-delta, structure deformation ,seismic analysis ,STAAD structural analysis software*

1.INTRODUCTION

P- Delta Effect in Reinforced Concrete Structures of Rigid joint six storey group in two different analyses is performed. During study, total 12 models were analyzed and 12 cases, or geometrical possibilities, were simulated through both Linear Static and P-Delta analysis When horizontal loading acts on a building, causing it to deflect, the resulting eccentricity of the gravity loading from the inclined axes of the structure's vertical members causes the lateral displacements of the structure and the moments in the members to increase. This second-order effect is termed the P-delta effect. In heavily clad low- and medium-rise structures, the P-delta effects are small enough to be neglected. However, with the trend toward taller and lightly clad buildings with greater lateral flexibility. the P-delta effects become more significant. In the modern era the demands of high-rise are greater than earlier due to the provision that the number of satisfactory people can be accommodated in that but the inappropriate design may lead to catastrophic demolition or destruction of the structure which is obvious from the earlier few decades. In some cases, the P-delta effects are large enough to require an increase in the designed member sizes. In an extreme case of a very flexible structure with a large gravity loading, the P-delta effects could, if not accounted for, be severe enough to initiate collapse. Thus, in the design of any high-rise building, it is important to assess whether these second-order effects are significant

1.1 p-δ effect

In the traditional first order analysis of structures, the effects of change in the structure actions due to structure deformations are neglected. However, when a structure deforms, the applied loads may cause additional actions in the structure that are called second order or P-Delta effects. P-Δ effect in structure mainly arises from the direct action of lateral forces and expiry the structure in a state of equilibrium where the deformed structure shape is a more determining factor. This kind of effect is made in the analysis of second order, where the geometry of the elements is come from their warped condition. Gravitational loads (especially in high buildings, they reach a very high order of their values) on their way through the construction elements, where this one are deformed they produce additional forces, which are not taken into account during calculations of structures in unreformed shape as shown in fig1.1. The given gravitational loads are the loads, more precisely defined, in the group of action forces in a structure, we cannot say that their change from project values, will be the determining factor in the effect of P-Δ, but in defining order remains the geometry of the structure. More precise the geometry is defined as the correct second order effects could be considered in structures.

1.2 Objective

The aim of project is. a) To reviewed and compared different methods in terms of their efficiency and accuracy. b) To recognize in what way the P Delta effects influence the variation of responses of structure such as bending moments, displacements and shear forces against linear static analysis. [3]

2.LITERATURE REVIEW

1. Mallikarjuna B.N, Ranjith A **(Aug 2014)**

2. Yousuf Dinar, Nazim Uddin Rahi2, Pronob Das **(2013)** Variation of Deflection of Steel High-Rise Structure Due to P- Delta Effect considering Global Slenderness Ratio.

3 .Prashant Dhadve, Alok Rao, Atul Rupanvar, Deokate K., Dr. Nemade. P.D **(May-2015)** ' Assessment of P-Delta Effect on High Rise Buildings'

4 .Dr S.K. Dubey Prakash Sangamnerkar, Deepak Soni (**2014)** 'Dynamic Behavior of ReinforcedConcreteFramed Buildings under Non Linear Analysis'

5 Rafael Shehu, **(Feb-2014) '**The P-Δ-Ductility Effect: Overview The Effect of The Second Order in The Ductile Structures'

6 Prof. C. G. Konapure, Mr. P. V. Dhanshetti **(Jan-2015) '**Effect of P-Delta Action on Multi-Storey Buildings'

This research focused on P-delta analysis to be compared with linear static analysis. In this study, a 18 storey steel frame structure with 68.9 m has been selected to be idealized as multi storey steel building model. The model is analyzed by using STAAD. Pro 2007 structural analysis software with the consideration of P-delta effect. At the same time the influence of different bracing patterns has been investigated. For this reason five types of bracing systems including X, V, Single Diagonal, Double X, K bracing with unbraced model of same configuration are modeled and analyzed. The framed 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 and Axial Force. The present work showed that the 'X' bracing in continuous bracing pattern is proved to be more effective with respect to both Static and P-delta analysis.

3. METHODOLOGY FOR STATIC ANALYSIS

The static analysis of multistory buildings for the gravity loads or vertical loads and horizontal loads can be done as followings:

1. Portal frame method
2. Substitute frame method
3. Cantilever method
4. Kani's method

In this method only a part of the frame is considered, called a substitute frame. The moment's for each floor is separately computed. It will be assumed that the moment transferred from one floor to another is small. Each floor will be taken as connected to columns above and below with their far end fixed.

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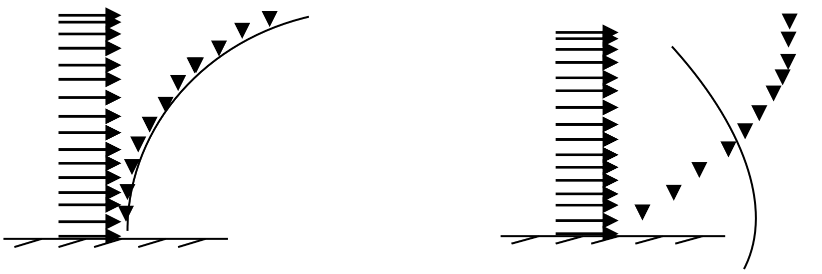

Fig. 1: Cantilevers with Uniformly Distributed Gravity Load: (a) Flexural; and (b) Shear

4. MODEL DESCRIPTION

In the present study the method of P-Delta (structure deformation) effect in multi-storied structures are identified floor wise and the significance of building responses like displacement, column moment, beam moment, column shear and beam shear are studied in detail. Seismic analysis is carried out as per IS-1893 (Part-I) 2002 guidelines. Equivalent static force method is adopted.
The stress resultants are displacement, bending moment and corresponding shear force. Linear elastic plane frame analysis is performed for the different models of the building using STAAD software. The frame members are modelled with rigid end zones.
In present study six different storey cases is taken where storey variation starts from storey 5 to storey 30, Making 5 storey intervals from each makes a gradual but less time consuming analysis. Storey cases are: 5, 10, 15, 20, 25 and 30. Each of the storey case is performed Linear Static and P-Delta analysis separately with appropriate command. Each storey is 3 meter in height makes Storey 5, Storey 10, Storey 15, Storey 20, Storey 25 and Storey 30 in total height of 15 m, 30 m, 45 m, 60 m, 75 m and 90 m. As storey increases so the slenderness increases. Bay length of buildings in both directions is 5 m.

4.1 METHODOLOGY FOR P-DELTA ANALYSIS

The methods are -

1. Amplification factor method
2. Direct method
3. Negative property fictitious member methods
4. Iterative method[6]

4.2.1 AMPLIFICATION FACTOR METHOD

This is an approximate method in which a factor is applied to the transverse displacements and moments of a first-order lateral force analysis. The amplification factor is derived by considering the action of any axially loaded member with an initial transverse displacement such as the horizontally loaded cantilever in Fig. 1. From the solution of the differential equation of the deflection curve, the final deflection at the free end, including the P-delta effect, can be approximated by the expression (Timoshenko and Gere 1961):

$$\Delta * = \Delta\left(\frac{1}{1-\frac{P}{Pcr}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Where,
Δ*= Final deflection at free end, including the P-delta effect;
Δ = First order deflection;
P = axial load at the free end of the cantilever and
Pcr = elastic buckling load of the cantilever.
Eq. 1 indicates that, when an axial load P is present, the free end deflection due to a uniform lateral load only is increased by an approximate amplification factor.

$$F=\left(\frac{1}{1-\frac{P}{Pcr}}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Δi = First order deflection at level i in the structure;
P = Total gravity load at the base of the structure;
Pcr = elastic buckling load at the base of the structure.

The amplification factor in this method is a constant over the height of the structure.

In a P-delta analysis, the relationship between the displacements and the Gravity loading is nonlinear; hence it is necessary that the loads corresponding to the failure state be used in the analysis. Factored loads must be used when checking ultimate limit states, while specified loads are used when checking serviceability limit states. Further, the stiffness of members to be used should correspond to the assumed failure state.

By using the appropriate elastic buckling load, Pocr, at the base of the structure, Eq. 3 can be applied to uniform shear wall structures at one extreme, rigid frame structures at the other and, more approximately, to any combination of shear walls and rigid frames in between. For structures buckling as a flexural cantilever under distributed axial loads, the elastic buckling load is given by (Goldberg 1973):

$$Pcr=\left(\frac{7.83EI}{L^2}\right)(1\text{-}0.3\beta) \quad \ldots\ldots(4)$$

Where
EI0 = flexural stiffness at the base of the structure;
EI0(1 — β) = flexural stiffness at the top of the structure;
and *L* = full height of the structure.
For rigid frames deforming primarily in the shear mode, when the columns of the frame have rigid base connections, the buckling load can be derived from Eq. 13 and Goldberg (1947) as

$$Pcr=\left(\frac{12E(1+\frac{C1}{6G1})}{h1(\frac{1}{c1}+\frac{2}{3G1})}\right) \quad \ldots\ldots(5a)$$

And, when the columns have a pinned base connection

$$Pcr=\left(\frac{12E}{h1(\frac{4}{c1}+\frac{3}{2G1})}\right) \quad \ldots\ldots(5b)$$

Where,
E = modulus of elasticity;
h1 = first-storey height;
C1 = $\sum(I_c/h)1$ for which the summation is carried out over all columns in the first storey; And
G1 = $\sum(I_g/l)1$ for which the summation includes all the girders (of length *l*) in the floor above the first storey.
For cases in which a combination of shear and flexural modes may contribute to buckling, *Pcr* may be determined very approximately from the interaction formula (Goldberg 1973)

$$\frac{1}{Pcr}=\frac{1}{Pof}+\frac{1}{Pos} \quad \ldots\ldots(6)$$

Where
Pcr = buckling load for the combined modes of buckling;
Pof = buckling load for the flexural mode of buckling; and
Pos = buckling load for the shear mode of buckling.
The P-delta effect causes an increase not only in transverse displacements but also in internal moments. It has been demonstrated (Timoshenko and Gere 1961) that the amplification factor for the internal moments is the same as for the deflections, thus

$$Mi^*=Mi\left(\frac{1}{1-\frac{Po}{Pocr}}\right) \quad \ldots\ldots(7)$$

Where
Mi*= final moment, including the P-delta effect at level i; in the structure; and

Mi = first-order moment at level i in the structure.

The amplification factor method is a rapid but approximate method for obtaining P-delta effects. However, rather than being a practical method for determining the magnitude of the F-delta effects, it serves more as a guide to whether or not the effects may be significant.

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The floors are assumed to be rigid in their plane. The maximum response in building Model had been studied. Lateral load for the selected frame has been carried out as per IS-1893 (Part-I) 2002. The analysis has been carried out for without P-Delta effect and then same has been analyzed for P-Delta effect with number of iterations. The maximum response values are compared to notify the P-Delta effect.

Buildings having planned dimensions 20 m x 20 m with bay width 5 m both sides are selected. The building is located in Zone III as per IS 1893 (Part-I) – 2002). [7]

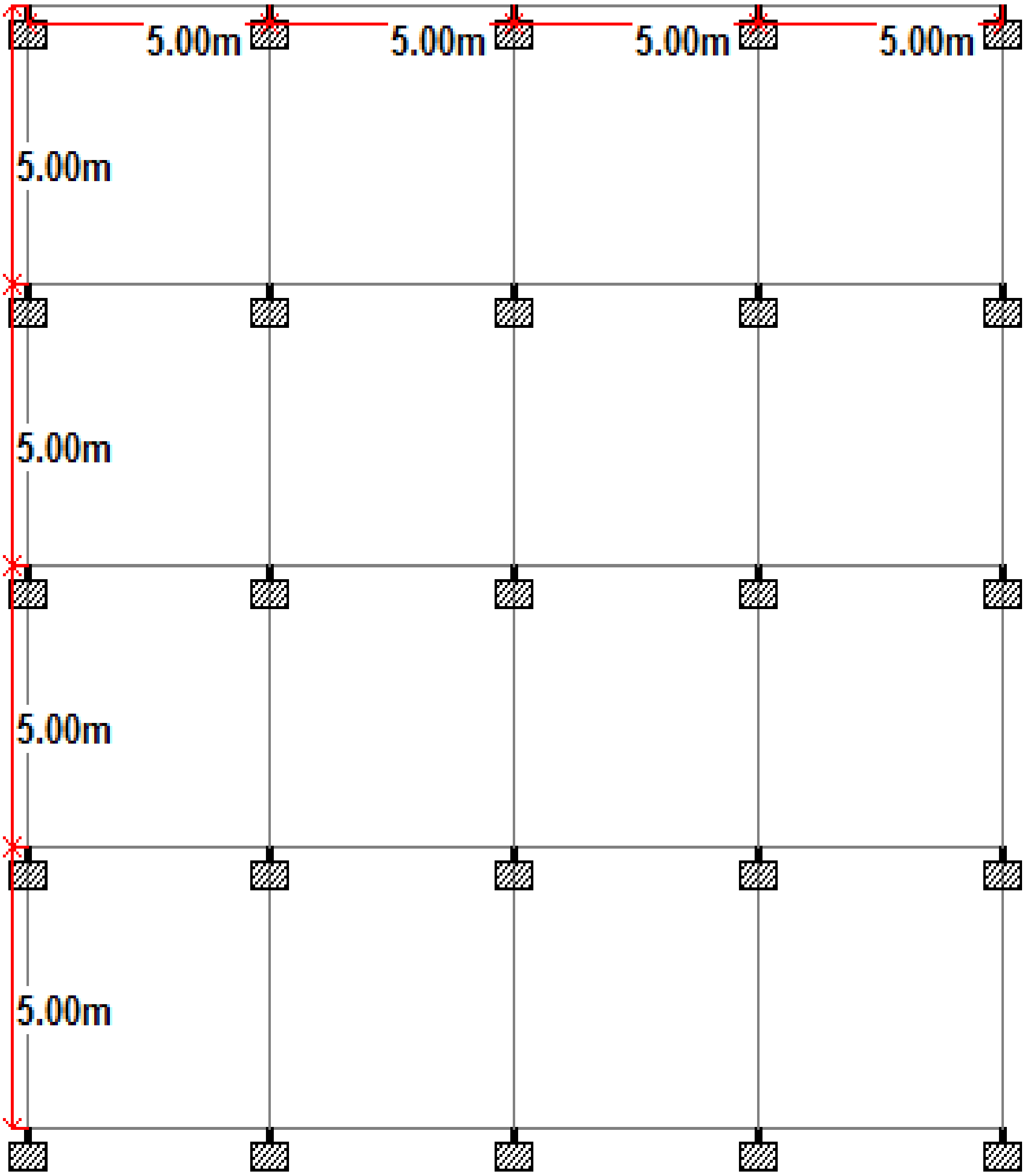

Fig. 4.1: Typical plan of Building [7]

The column sizes are 450X 450 mm and. All beams are of same size 300X450 mm. On the other hand, slab thickness is 125 mm reinforced concrete having 21 MPa compressive strength. [7]

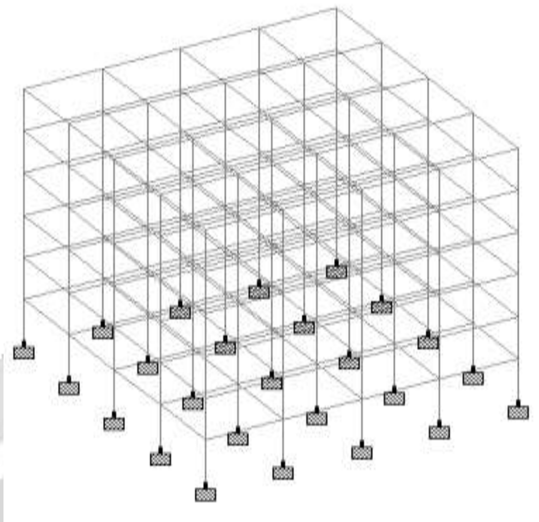

Fig. 4.2-Dimension view of Building

Finite element models are developed to notice the variation of responses due to the effects obtained from P-Delta analysis against linear static analysis using STAAD Pro v8i Software. STAAD- Pro also has the capability to perform a second-order, P-Delta analysis. The simplified solution procedure uses a revised load vector to include secondary effects. First, the deflections are calculated based on the original applied loads. Next, the deflections are combined with the original applied loads to create secondary loading. Based on the new loading, the load vector is revised to include secondary effects. Finally, the revised load vector is used in a new stiffness analysis and new member forces and reactions are calculated based on the new deflections. This solution procedure accounts for frame effects (P-Δ) only and is not able to evaluate individual member effects (P-δ).

4.3.1 P-Delta & Buckling –In STAAD-Pro

By Staad-Pro, leading structural engineering software, complete effects could be identified using appropriate command. In Staad-Pro, a unique procedure has been adopted to incorporate the P-Delta effect into the analysis. The procedure consists of the following steps:

1. First, the primary deflections are calculated based on the provided external loading.
2. Primary deflections are then combined with the originally applied loading to create the secondary loadings. The load vector is then revised to include the secondary effects. Lateral loading must be present concurrently with the vertical loading for consideration of the P-Delta effect. The Repeat Load facility has been created with this requirement in mind. This facility allows the user to combine previously defined primary load cases to create a new primary load case.
3. A new stiffness analysis is carried out based on the revised load vector to generate new deflections.
4. Element/Member forces and support reactions are calculated based on the new deflections.

P-Delta effects are calculated for frame members only not for finite elements or solid elements. So outcomes are compares against frame members only.

When **non-linear situations are not involved**, a load combination type would be adequate.

The following PERFORM ANALYSIS facilities are available in STAAD.

1) Stiffness Analysis / Linear Static Analysis
2) Second Order Static Analysis

a) P-Delta Analysis
b) Non-Linear Analysis
c) Multi Linear Spring Support
d) Member/Spring Tension/Compression only

3) Dynamic Analysis
a) Time History
b) Response Spectrum.

A regular STAAD P-Delta Analysis performs a first order linear analysis and obtains a set of joint forces from member/plates based on the large P-Delta effect. 5 to 10 iterations will usually be sufficient. In the new P-Delta KG Analysis that is with the Kg option selected the effect of the axial stress after the first analysis is used to modify the stiffness of the member/plates. A second analysis is then performed using the original load vector. Large & small P-Delta effects are always included (1 or 2 iterations will usually be sufficient). [2]

5 RESULT AND DISCUSSION

The trend towards slender and more efficient building structures has resulted in more significant P-delta effects, which has led to the demand for simple and accurate methods of P-delta analysis. In present study P-Delta and Linear Static analysis of 12 cases, in total 12 models reveals that P-Delta effects significantly influence the axial, moment and displacement of the structural components and get higher value than the Linear Static analysis. The variation particularly identified when the slenderness ratio is comparatively increasing by increasing the storey. Variation is observed in several sections: variation of storey displacement between linear static analysis and P-Delta analysis, Variation of storey drift, Variation of axial force in column, Variation of moment in column and percentage of variation against slenderness ratio to systematically scrutinize the response characteristics of the structure due to P-Delta effects with respect to slenderness.

5.1 VARIATION OF HORIZONTAL DISPLACEMENT IN TOP

All 12 models and 6 storey case are studied to describe how the structure generate difference with height which represent the slenderness and obviously to present the priority of P-Delta analysis over Linear Static analysis. To establish the object top displacement is studied and found that structure analyzed under P-Delta effect causes much displacement in top then the structure analyzed by Linear Static analysis. The variation is following an upward trend with increasing storey. Following Figure 5.1 shows that after P-Delta analysis displacement increased exponentially with increment of storey over the simple analysis, "Linear Static analysis". [4]

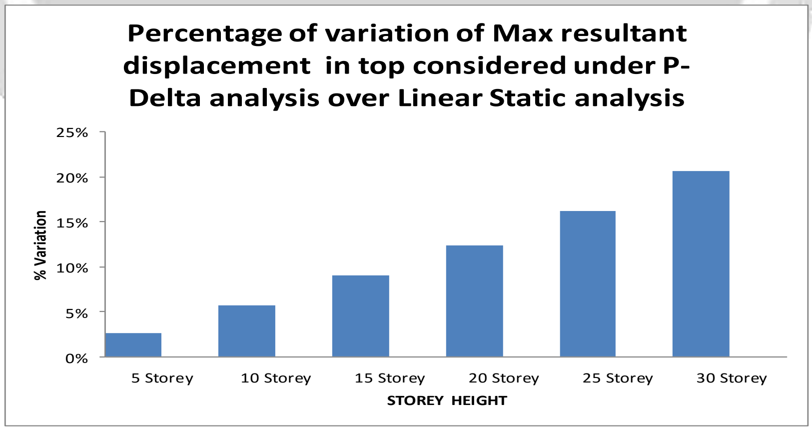

Fig. 5.1 Percentage of variation of Max resultant displacement in top considered under P-Delta analysis over Linear Static analysis [4]

Storey Percentage of variation must be seen keeping Linear Static analysis outcomes as base. After P-Delta analysis storey 5, storey 10, storey 15, storey 20, storey 25 and storey 30 the top displacement increased by 3.0 %, 6.0 %, 9.0 %, 12.0 %, 16.0 % and 21.0 % respectively which represent the variations do not follow any linear trend. It seems with increasing slenderness variation between Linear Static and P-Delta will be maximized and vice-versa so proper understanding and strategy should be taken when designing a high-rise. [4]

6 CONCLUSION

This chapter presents the major conclusions and future scope of the assessment of P-delta effect for high rise buildings. Based on the second order analysis using STAAD-Pro and verification with other authors following conclusions can be drawn.

1) As number of storey increases P-delta effect becomes more important.

2) Generally, P-delta effects are negligible up to 10 storey buildings where only gravity loads are governing load combinations. But having significant effects in high-rise structure.

3) The iterative method, in which the gravity load is transformed to an equivalent additional horizontal load, gives very accurate results for both shear and flexurally deforming structures.

4) It could be summarized that analyzing and designing RC high-rise structure needs expert observation and understanding. Analysis found was versatile in characteristics but it could be said, displacement varies exponentially under P-Delta analysis with increasing height or increment in storey and so the axial force too.

5) Axial force changes in positive side rapidly over the Linear Static analysis, if P-Delta is performed to find it. For moments P-delta effect is only observed in some of the beams and columns (Exterior columns and their adjacent beams) in some load cases. If these load cases are governing load cases for design of member, then only we can say that it is considerable.
6) So, Linear Static and P-Delta both are necessary for RC structures and have to use after proper understanding to prevent any catastrophic. Hence we can say that, at least it is necessary to check the results of analysis with and without considering P-delta effect for the buildings.
7) Axial and displacement could be observed by P-Delta analysis while keeping the moment section to the Linear Static analysis. All these outcomes were for reinforced concrete structure of rigid joint which is very common in society.

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