UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES

STATIC AND DYNAMIC ANALYSIS OF MULTISTORY BUILDING INCLUDING P-Δ ANALYSIS

M. Sc. THESIS
IN
CIVIL ENGINEERING

BY
SARDAR ALI
JANUARY2013

Static and Dynamic Analysis of Multistory Building Including P-Δ Analysis

M.Sc. Thesis
In
Civil Engineering
University of Gaziantep

Supervisor
Asst. Prof. Dr. Nildem Tayşi
Co-supervisor
Prof. Dr. Mustafa Özakça

by
Sardar Ali

January 2013

© 2013 [Sardar Ali].

T.C.
UNIVERSITY OF GAZİANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES
CIVIL ENGINEERING DEPARTMENT

Name of the thesis: Static And Dynamic Analysis Of Multistory Building Including P Δ Analysis

Name of the student: Sardar ALI
Exam date: 29 / 01 / 2013

Approval of the Graduate School of Natural and Applied Sciences

Assoc. Prof. Dr. Metin BEDIR
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Mustafa GÜNAL
Head of the Department

I certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. Mustafa ÖZAKÇA
Co-supervisor

Asst. Prof. Dr. Nildem TAYŞI
Major Supervisor

Examining Committee Member	Signature
Asst. Prof. Dr. Nildem TAYŞI	....
Prof. Dr. Ibrahim H. GUZELLBEY	....
Assoc. Prof. Dr. Abdülkadir ÇEVIK.	....

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Sardar Ali

ABSTRACT

STATIC AND DYNAMIC ANALYSIS OF MULTISTORY BUILDING INCLUDING P-Δ ANALYSIS

Ali, Sardar
M.Sc. in Civil Engineering
Supervisor: Associated. Asst. Prof. Dr. Nildem Tayşi
Co-supervisor: Prof. Dr. Mustafa ÖZAKÇA
January 2013, 67 pages

Multistory structures are subjected to different type and form of lateral loadings through its service life. Earthquake, wind and blast loadings are the potential lateral loadings for structures. Lateral displacements caused by these types of loadings necessitate consideration of P-Δ effects, especially for multistory high rise buildings. In this study main attention is focused on the investigation of effects of outrigger frame, end channel, exterior frame tube and exterior diagonal bracing tube systems on the P-Δ behavior of multistory high rise buildings. Staad Pro commercial program which is convenient for this type of investigation is used to simulate P-Δ behavior of multistory structures. 13 to 50 numbers of stories are considered for the investigation. The results suggest that P-Δ affects increases as the number of stories increase. Healing effects of shear walls on P-Δ behavior are also captured through the runs. In following stage, different types of bracings are introduced into models to observe the P-Δ behaviors. In the last stage multistory structures are subjected to different types of dynamic loadings. Free vibration, response spectrum and time history analyses are undertaken to investigate P-Δ behavior of multistory high rise buildings under dynamic loading. Drawbacks obtained in present study generate knowledge and underline critical details to develop safe multi story building designs.

Key Words: Multi story building, P-Δ effects, outriggers, structural systems, static and dynamic analysis

ÖZET

ÇOK KATLI YAPILARIN STATİK VE DİNAMİK YÜKLER ALTINDA P-Δ ANALİZİ

Ali, Sardar
İnşaat Mühendisliği Yüksek Lisans
Danışman: Associated. Asst. Prof. Dr. Nildem Tayşi
Yardımcı tez yöneticisi: Prof. Dr. Mustafa ÖZAKÇA
January 2013, 67 sayfa

Çok katlı yapılar hizmet ettikleri süre içerisinde farklı yapı ve şekillerde yüklere maruz kalmaktadırlar. Deprem, rüzgar ve patlama yüklemeleri yapılar için potansiyel yatay yüklemelerdir. Özellikle çok katlı yüksek binalarda, bu tip yüklerden dolayı oluşan yatay deplasmanlar, P-Δ etkilerinin incelenmesini gerektirmektedir. Bu çalışmada özelliklekafes katlardan oluşan, köşe kanallar, dış çerçeve tüpler ve dış çapraz bağlanmış tüp sistemleri gibi yapı sistemleri üzerinde odaklanılmaktadır. Çok kalı yapıların P-Δ etkilerini simule etmek için,bu tip yapıların analizine uygun olan Staat Pro ticari programı kullanılmıştır. İncelemek için 13-50 kat arası yapılar seçilmiştir. Sonuçlar kat sayısı arttıkça P-Δ etkilerininarttığını önermektedir. Analizlerden perde duvarların P-Δ davranışı üzerindeki etkileri irdelenmiştir. Takip eden aşamada farklı tiplerde yapı modelleri uygulanıp, analiz sonuçları gözlemlenmiştir. Dinamik yükler altında çok katlı yüksek binaların P-Δ davranışı, serbest titreşim, tepki spektrumve zamana bağlı analizler yapılarak da incelenmiştir. Bu çalışmadan elde edilen kazançlar, çok katlı yapıların güvenilir tasarımları için bilgi üretmek ve önemli noktaların altını çizmektir.

Anahtar Kelimeler: Çok katlı binalar, P-Δetkileri, çekirdek sistemler, yapı sistemleri, static ve dinamik analiz.

To My Family, they should receive my greatest appreciation for their enormous love. They always respect what I want to do also give me their full support encouragement over the years.

ACKNOWLEDGEMENTS

I would like to express my respect and regards to my supervisor, Asst. Prof. Dr. Nildem Tayşi and Prof. Dr. Mustafa Özakça, for guidance, advice, encouragement and suggestions during the preparation of this thesis.

My special thanks are reserved for my wife for her encouragement, understanding, patience and great help.

TABLE OF CONTENT

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF SYMBOL

D.L	Dead load
L.L	Live load
W.L	Wind load
E	Modulus of elasticity
ϑ	Density
α	Alpha
D	Damping ratio
M	Moment about axis normal of paper Z
Comb	Combination of loads
F.V	Free vibration
P	Vertical load or gravity
Δ	Displacement
Δx	lateral displacement with x-direction
δ	Small internal displacement for members or columns
P-Δ	Load large displacement effect
P-δ	Large external displacement for frames or structures
V	Horizontal forces
Δ1	Relative displacement for story number 1
Δ2	Relative displacement for story number 2
F_h	Pseudo horizontal load
h	vertical distance between levels (floor to floor)
KG	Geometric stiffness
{Rs}	All external applied nodal forces
{Fs}	All nodal forces correspond to element stress
3D	Three dimension
2D	Two dimension
SET DISP f	Command in staad pro for maximum value of displacement

G.U.I	Graphical user interface
Hz	Frequency unit Hertz
t	Time or period
KN	KeloNewton
SRSS	Square root of summation of squares
Sa/g	Average response acceleration coefficient
Wt	Weight

CHAPTER 1

INTRODUCTION

1.1 Introduction

Increasing in population in most countries, raises land area prices, so tall building has been growth and number of stories increases and reaches 100 to 200 stories and will increase to more for high rise towers. Advanced analysis techniques which depend upon type and bracings are required for multistory structures (more than 20 stories). These techniques are quite different from normal analysis.

First order analysis such as simple equilibrium method assumes undeformed geometry of the structure and these methods are suitable for normal structures. But it is not a complete analysis because it neglects additional loading caused by the deflection of tall structure. One type of second order analysis is P-Δ which exists in all types of structures, but it can be neglected for small displacements. For these structures, an alternative route is available to calculate for P-Δ effects at the analysis stage, thereby, incorporating the additional forces and moments required in the design.

Multistory structures are subjected to different type and form of lateral loadings through its service life. Earthquake, wind and blast loadings are the potential lateral loadings for structures. Lateral displacements caused by these types of loadings necessitate consideration of P-Δ effects, especially for multistory high rise buildings. These loads produce lateral displacements on structures. The gravity load acting through the structure's lateral displacement is called the P-Δ effect. The influence of gravity loads increases while the lateral displacement increases so, P-Δ effect can start a destructive circle against the structural system at the same time

The lateral displacement is magnified as a consequence of gravity loads acting on them. P-Δ is a non-linear (second order) effect that is exists in any type of structure where the members are subjected to axial load. It is a genuine "affect" that is associated with the magnitude of the applied axial load (P) and a horizontal displacement (Δ).

Economic design of multistory structures depends on more than one factor that includes stiffness, ductility-- ets. P-Δ effect is one of the most important factors that requires in many cases changing dimension or property or system of structures and it is expensive. Choosing the proper solution with economy and good stability and durability to resistance static and dynamic loads for P-Δ effect is the main subject that will be studied in this thesis.

In this study main attention is focused on the investigation of effects of outrigger, frame endchanel, exterior frame tube and exterior diagonal bracing tube systems on the P-Δ behavior of multistory high rise buildings. Four groups of examples has been modeled, loaded and analyzed with two types of analysis, first normal analysis without P-Δ and second analysis with P-Δ. Examples includes different number of stories (13, 25,37 and 50) stories. Static, free vibration and dynamic analysis are done. Staad Pro commercial program which is convenient for this type of investigation is used to simulate P-Δ behavior of multistory structures. Horizontal displacement Δx at the top of structure and base moments Mz at the bottom of structure have been obtained from analysis without and with P-Δ.

1.2 Literature Review

In a first-order analysis, equilibrium and kinematic relationships are based on the undeformed geometry of the structure. Solutions of these analyses are typically simple and straight forward. However when lateral loads are applied to the structure, it is often assumes a configuration which deviates quite noticeably from its undeformed configuration [1]. 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 [2]. These design methods do not consider the development of additional internal forces and displacements due to P-Δ effect [3,4].

Research on inelastic seismic response of structures [5,6,7] has shown that P-Δ effects are significant on flexible structures and amplify the lateral displacements. The additional deformations result in an increase in ductility demand. Seismic provisions, including those in the 2005 National Building Code of Canada [8] , specify limits on the expected interstorey drifts in a structure, with a view to limiting the nonstructural damage, as well as controlling the impact of the P-Δ forces on seismic performance.

Considerable research has been done on how to take P-Δ effects into account. The non-mandatory commentary to NBCC 2005 endorses a method based on the stability approach recommended by [9] to account for P-Δ effects. Analyses were carried out to assess the influence of P-Δ effects on steel plate shear walls. Also, stability approaches proposed in the recommended seismic design provisions of the National Earthquake Hazards Reduction Program [10] and the NBCC 2005 commentary are evaluated.

Simple hand calculations has been used 30 years ago by engineers to determine design forces and moments, in many cases the word analysis was not mentioned even though it was being performed intrinsically [11]. Typically they use linear elastic static (first order) analysis to determine design forces and moments resulting from loads acting on a structure [11].

Chen and Lui [12] reported a second-order analysis which applies equilibrium and kinematic relationships to the deformed structure, it is always necessary for the stability consideration of structures.

Brown D. [13] has explained with great clarity the intended design process for assessing medium sized, orthodox multi-story frames for sway sensitivity in accordance with BS5950-1:2000.

Rathbone A.J. [14] explained second-order effects that need them. The structural engineer takes the issue one step forward to the more general aspect of why P-Δ effects are important in the context of multi-story building design.

All articles focused on multi-story buildings and talk through the methods used. And few research has been done on P-Δ effect in multistory building by the new version of software (Staad Pro v8i), that occupy different systems and type of structures (bracing system with changing number and location).

Calculating P-Δ effects can be ignored because of some times they are small enough, or including them using the k_{amp} method. It is aimed primarily at structures as "medium sized multi-storey buildings.

In the seismic of multi story structures [15] acceptable value should be made for P-Δ effects. These are additional overturning moments applied to the structure resulting from the seismic weight. "P" supported by the structure, acting through the lateral deflections (Δ) which directly result from the horizontal seismic inertia forces. They are second order effects which increase the displacements. The member actions and lengthen the effective fundamental period of the structure.. For design purpose, in most cases seismic induced P-Δ action can be neglected in structures remain elastic throughout the earthquake.

1.3 Objectives of Study

The main objective of this thesis is to investigate and analyze the multi-story buildings including P-Δ effect using Staad Pro program. And then find the best structure type to decrease horizontal displacements or base moments of structures, also to see when P-Δ analysis should be performed or neglected.

Here effect of P-Δ for high rise building is the objective that has to be calculated and learning how the height and other geometry or parameters of the structures influence on P-Δ. So needing for P-Δ calculation will be clear in several structures. The study gives the procedure to know how to solve the problems of high value of P-Δ and lateral drift (or non acceptable value) by choosing different type of structure and seeing that the value of P-Δ will be decrease with modifying the system of structure with choosing the economic and low cost and stable structure.

Staad Pro commercial program which is convenient for this type of investigation is used to simulate P-Δ behavior of multistory structures. The results suggest that P-Δ affects increases as the number of stories increase. Healing effects of shear walls on P-Δ behavior are also captured through the runs. In following stage, different types of bracings are introduced into models to observe the P-Δ behaviors. In the last stage multistory structures are subjected to different types of dynamic loadings. Free vibration, response spectrum and time history analyses are undertaken to investigate P-Δ behavior of multistory high rise buildings under dynamic loading. Drawbacks obtained in present study generate knowledge and underline critical details to develop safe multi story building designs.

1.4 Layout of the Thesis

In present work main attention is focused on analysis of multistory high rise structures for static and dynamic loading condition. Staad Pro is used for these two types (without and with P-Δ analysis). The main goal of the study is to minimize effect of P-Δ so that it will be within the acceptable limit and solving this problem with minimum cost and effort done.

And the layouts of the thesis are now pronounced:

Chapter 2: is consisting of P-Δ analysis information and definition, importance of P-Δ. At last methods for calculating P-Δ using hand calculation (without using software) are explained.

Chapter 3: deals with structural system and bracing. Therefore many selected types of structural systems are mentioned and explained individually with type of bracing and outriggers.

Chapter 4: explains performing P-Δ analysis using computer and softwares, and then comparing it with analysis has been done by hand calculation without computer. And why computer softwares is very important to do P-Δ analysis for large complicated structures that could not be done or impossible without computer. Second it explains how Staad Pro program can do P-Δ analysis, and then explain methods of selection models and procedure required for input parameters data with ability of modifying the data through the work.

Chapter 5: deals with some selected examples with all input parameter. Analysis result tabulated for each group of examples to show the P-Δ effect.

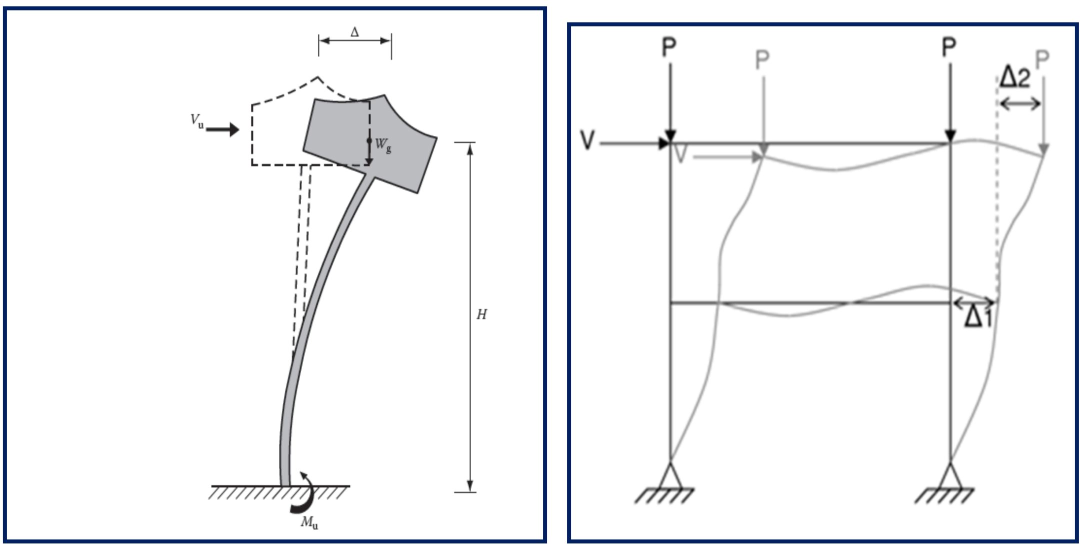
Finally, in Chapter 6, some short conclusions are demonstrated and compared with each other, some proposals for future work are given.

CHAPTER 2

P-Δ ANALYSIS

2.1 Introduction

Multistory structures may be subjected to different types and forms of lateral loadings through its life period. Examples of these loads are earthquake, wind or blast loading. The displacements or base moments causes by these mentioned loads with vertical gravity loads (self weight, other dead loads and live loads) are calculated. So this new displacement add new forces to the system because axes of effecting of gravity has been changed from its original cases this procedure will be repeated until value reaches non reasonable value that can be neglected, where it is minimum or the difference is less than 5 %. This can be explained in simple model as shown in Figure 2.1(a) and Figure 2.1(b).



(a) (b)

Figure 2.1 P-Δ explanations (a) simple elevated tank pole, (b) simple frame

P-Δ effects, also known as ‘big’ P-Δ, refer to the increase in moment experienced by a fixed connection at the ith end of a member when the jth end is loaded axially while simultaneously undergoing lateral translation. It can be imagined as a cantilever beam with both axial and transverse loading. Simple static analysis tells us that the fixed end only experiences a moment equal to the magnitude of the transverse loading multiplied by the length of the member. However, P-Δ analysis reveals that an additional moment is created due to the application of the axial load no longer lining up with the support; it is displaced by an amount Δ. This can be seen in Figure 2.2.

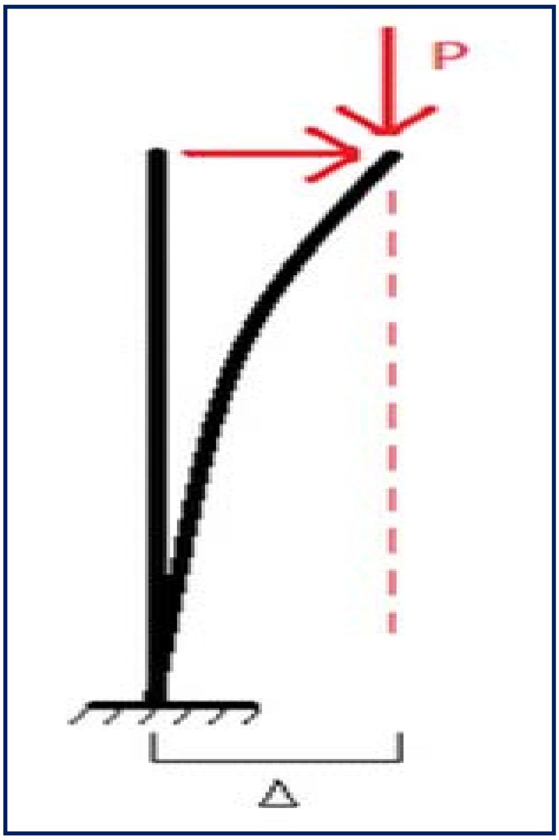


Figure 2.2 Single columns P-Δ

The structural behaviors of tall buildings under static and dynamic loadings are different and these can be seen easily in analysis results. It can be said that the main load which affect P-Δ analysis is lateral loads, especially dynamic loads with exist of gravity in high-rise building due to its height are important. Stability of structures due to the shifting of resultant gravity loads distance from original center of gravity to the ground level allows the center of gravity to be out from the base area of structure.

2.2 Importance of P-Δ Analysis

Economic design of multi story structures depends on more than one factor that includes property, stiffness, ductility, --- ets. P-Δ effect is one of the important factors that requires in many cases changing dimension or property or system of structures and this is money expense. Choosing the proper solution with economy, good stability and durability to resistance static and dynamic loads is the main subject that will be studied here for P-Δ effect. As structure becomes more slender or has small cross section area for the base plan and less resistant to deformation, or it is exposed to high intensity lateral load (such as wind load or seismic) then the need to consider the P-Δ effect increases. Recent studies show that P–Δ effects are reasonable and have to be included to design calculations of high rise building for safe and stable structures. The structural engineer deals with the importance of P-Δ effects on multi-story building design. Research on structural inelastic response has shown that P–Δ effects are significant on flexible structures and amplify the lateral displacements [15,6]. The additional deformations result in an increase in ductility demand. [16].

Beginning with the publication of the Tentative Provisions for the Development of Seismic Regulation for Buildings [17] in United State, most building codes have intended to take into account the P–Δ effect. The ACI code indicates that in the design of column, the slenderness effect can be accounted for using two different methods. One method is called the moment magnifier approach, which uses some code-based equations to approximate these second order effects. The other method is to perform a P–Δ analysis.

In most cases of high-rise buildings (more than 25 stories) horizontal displacement is high and thus P-Δ effect value is important and neglecting it may cause collapse or damage to the structure as it is shown in Figure 2.3.

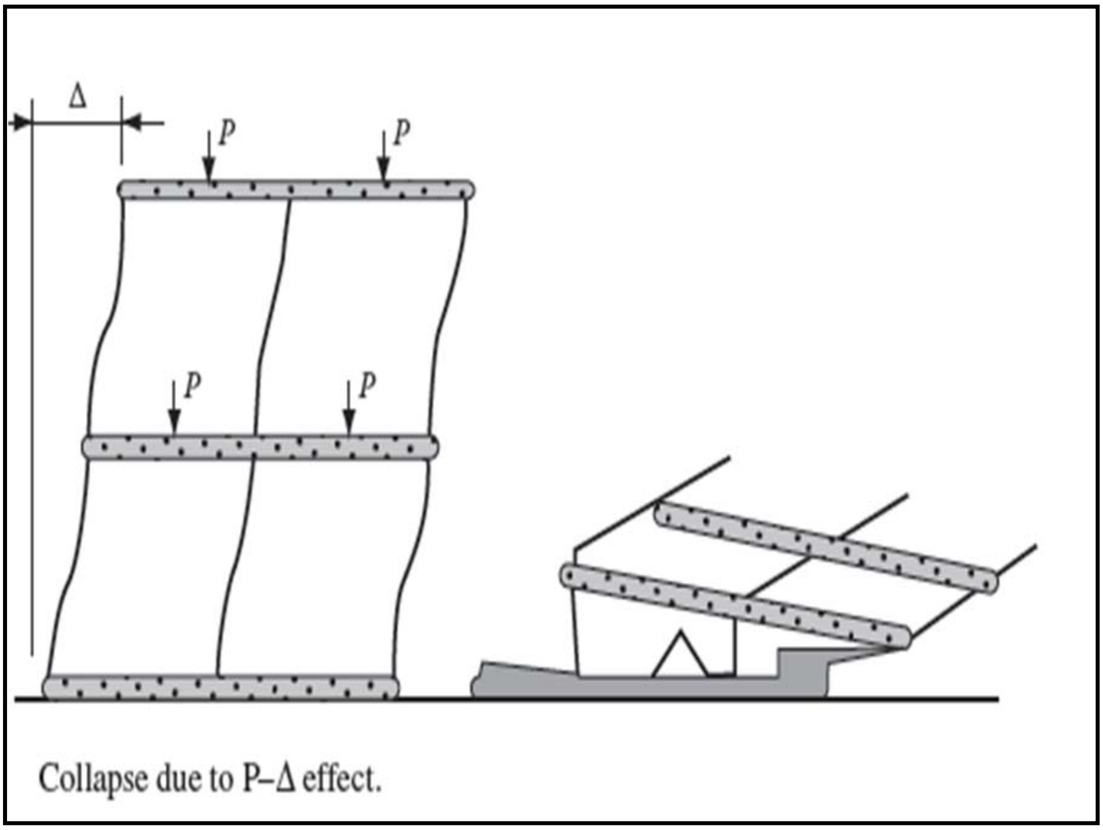


Figure 2.3 Collapse due to p-Δ effect

However, if the weight of the structure is high in proportion to the lateral stiffness of the structure, the contributions from the P-Δ effects are highly amplified and, under certain circumstances, can change the displacements and member forces by 25 percent or more. Excessive P-Δ effects will eventually introduce singularities into the solution, indicating physical structure instability. Such behavior is clearly indicative of a poorly designed structure that is in need of additional stiffness [18].

P-Δ will create additional base moment as from its definition it is:

$$M = P * \Delta \qquad (2.1)$$

As Δ increases the amount of P-Δ moment will be increased and with repeating the iteration P-Δ will be increased and this is clear in Figure 2.4. Δ1, Δ2, Δ3----- Δn and iteration has to be repeated until relative Δ will reach small and negligible value.

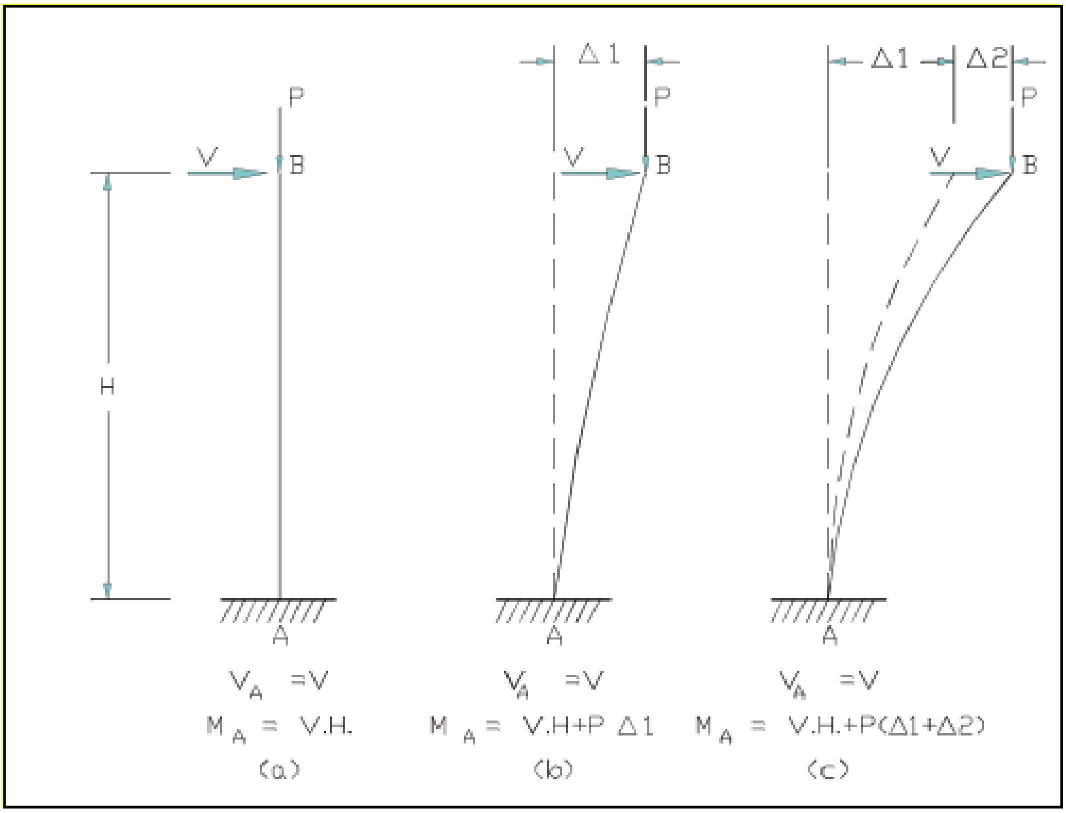


Figure 2.4 P-Δ displacement changes and repetition

P-Δ can be calculated to see if it is within the limit or not more than 5 %, if it is not it means P-Δ has to be considered and neglecting it may cause damage. If not it can be controlled by changing the system of structure or adding some additional members to increase the stiffness or distributing the mass to decrease the tensional affect that produce additional P-Δ effect .

Research that has been done on P-Δ in multi story building and advises the designer to choose new system of structure and using advance calculations for determining P-Δ is very important to get the exact value that is important to get economic structures with high resistance. Andrews [19] suggested that by increasing the stiffness of the frame and by limiting its drift, the influence of P–Δ effects could be ignored. Contrasting to Andrews' suggestion, Paulay [20] considered it more practical to control excessive displacement in frame structures suffering important P–Δ effects by increasing strength instead of stiffness [1].

This is an important subject to decide when P-Δ has to be considered in structural designing. Also it depends upon experience of engineer that more than one points influence on it. So the structures which P-Δ to be included is:

1- High rise building with more than or equal to 25 story with normal story height and member stiffness.

2- Structure that will be constructed in high intensity earthquake or max ground motion that may be occurred concurrently with the other stresses (such as gravity), at a particular instant the stresses may all be additive and this is shown in Figure 2.5.

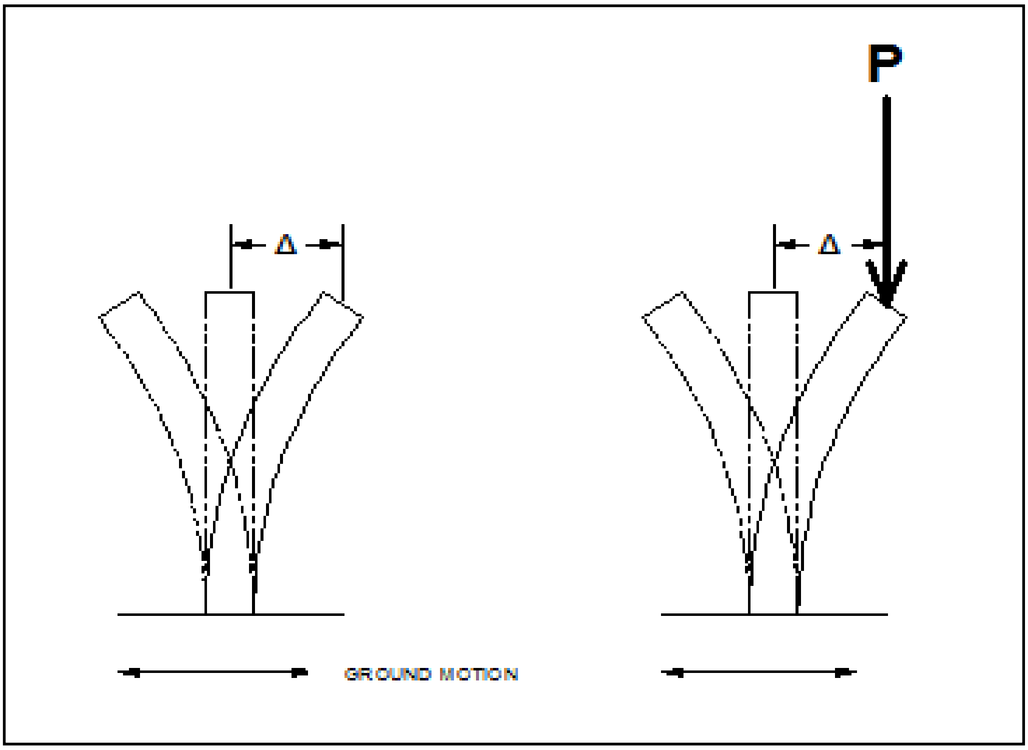


Figure 2.5 The stress caused by the P-Δ moment occurred concurrently with gravity

3- Weak structure with low stiffness or stability due to large spans and story height or with not enough shear wall or bad arranged shear walls causing large displacement and then large P-Δ will occur as in Figure 2.6.

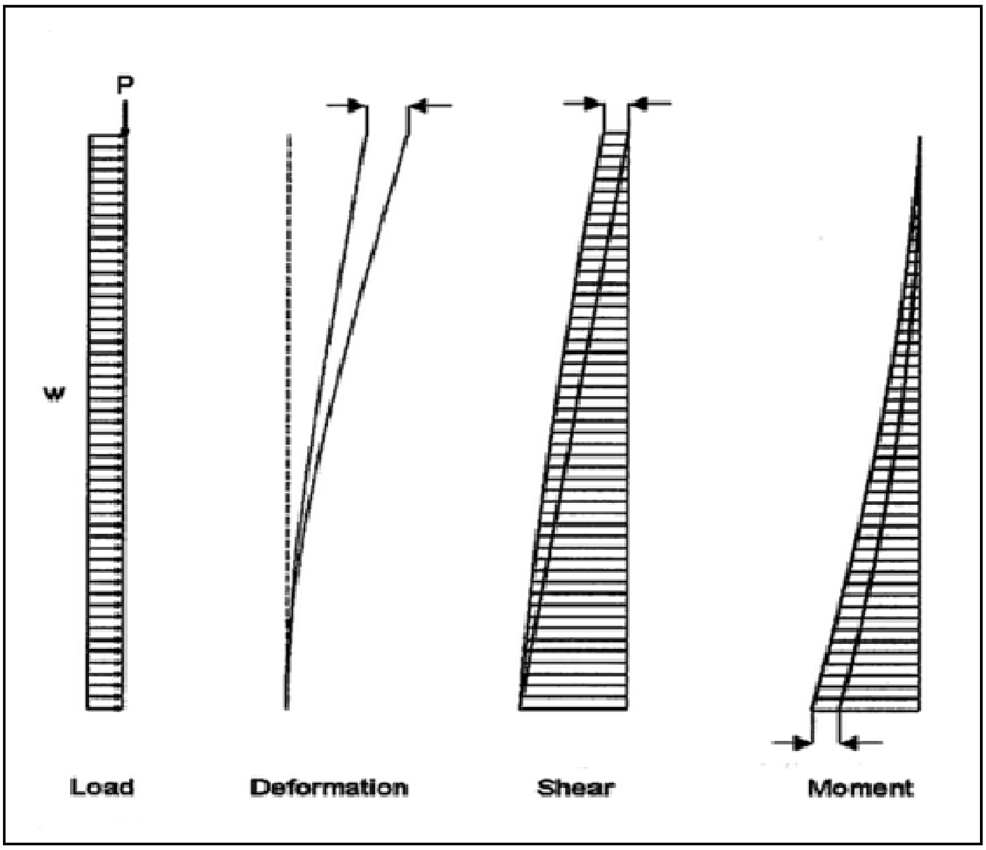


Figure 2.6 The P-Δ effect, large displacement modifies structural stiffness and generates additional force and displacements

4- Multi story building exposed to very strong winds and especially in open area and as with increasing the height of structure the intensity will increase in addition that the resultant of lateral loads will be increased as in Figure 2.7.

5- Multi story or high rise building with very small width due to its length and lateral force is perpendicular to its width.

6- Type of support and rigidity (fixed, pin, spring).

7- Ratio of whole horizontal cross dimension to the height of structure.

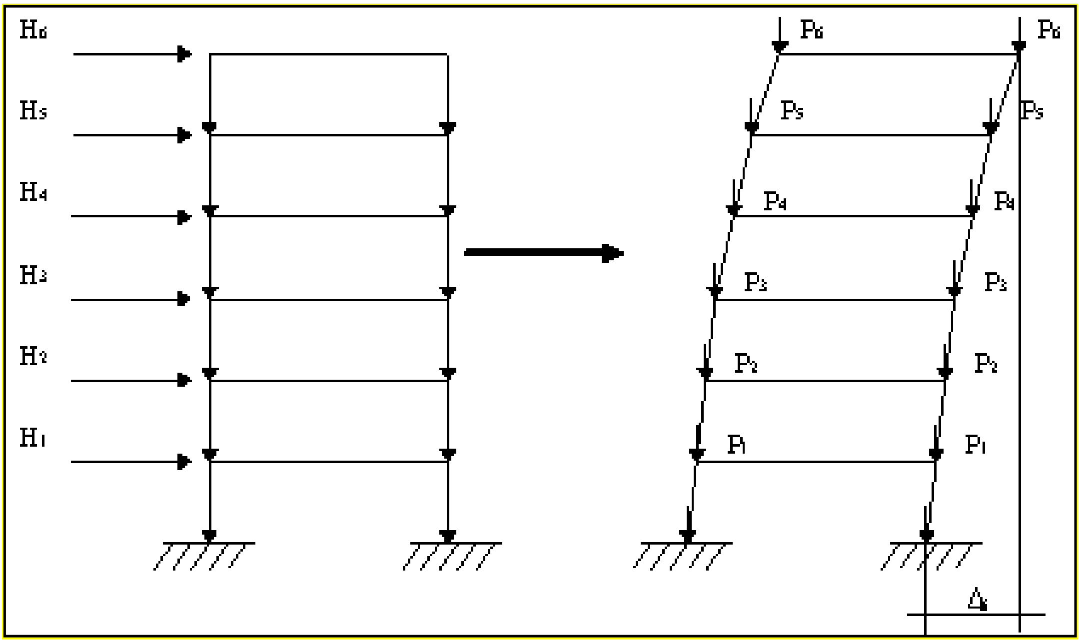


Figure 2.7 Distribution of gravity and lateral loads with P-Δ in multistory buildings

2.3 P-Δ Analysis Methods

Many techniques have been proposed for evaluating this second-order behavior. Rotenberg [21] summarized the publications on this topic and presents a simplified method to include these second-order effects. Some methods consider the problem as one of geometric non-linearity and propose iterative solution techniques that can be numerically inefficient. Also, these iterative methods are not appropriate for dynamic analysis where the P-Δ effect causes lengthening of the periods of vibration.

There are several simplified methods available for completing a second-order analysis by hand calculation, without using structural analysis softwares. Many of the procedures include only P-Δ effects, which is acceptable since, the member instability P-Δ effects are not significant in most structures. But for tall buildings P-Δ effects are significant and relatively complex methods are require. There are many commercially available software packages capable of computing the second-order effects in structures such as Staad Pro, SAP 2000 ---- etc. Some of P-Δ analysis methods are explained here.

2.3.1 A “Pseudo-Load” approach

Structure here is subjected to main gravity (vertical) loading. Additional (Pseudo) horizontal load (F_h) at each level can be estimated as:

$$F_h = (P * d) / h \tag{2.2}$$

P = the vertical external load at that floor level

d = the relative horizontal deflection between two level

h = the distance between floor levels

To find (d) value requires an initial analysis and then the structure is re-analyzed with the added loads F_h. The process can be repeated for further iterations of Pseudo load.

If the structure fits the limitations (for this method) the result could be exactly accurate, but there will be forces within the structure and base reactions that relate to entirely artificial loading.

This method only deals with the P-Δ effect of structures which are predominantly gravity loaded. [22]

2.3.2 A “Pseudo-Displacement” approach

Initial elastic analysis has to be run to establish nodal deflections, and then modification will be done on the structural model due to the deflection occurred and is re-analyzed elastically. This process can be repeated more than one time but since “stress stiffening” is not taken into account then solutions may not converge. It is a simple approximation. Inaccuracies increase as “second order” effects increase. This method will not give a good approximation to the P-Δ effect as it takes no account of the ‘work done’ to move the structure. This method is only approximate since “stress stiffening” is not taken into account and it only deals with the P-Δ effect [12].

2.3.3 The two cycle iterative method

The two-cycle iterative method (Chen and Lui) [12] requires a two-pass analysis procedure. In the first analysis, the linear static analysis of system equilibrium equations are solved to find the nodal displacements for the entire load cases including load combinations. The nodal displacements are then obtained; the element end forces are calculated and used to find the element geometric stiffness matrices. The element geometric (stress) stiffness matrix includes both the P-Δ and P-δ as shown in Figure 2.8. Effects as well as accounting for "stress stiffness". Because a general geometric stiffness matrix is used in the method, there are no significant limitations on its use or applicability.

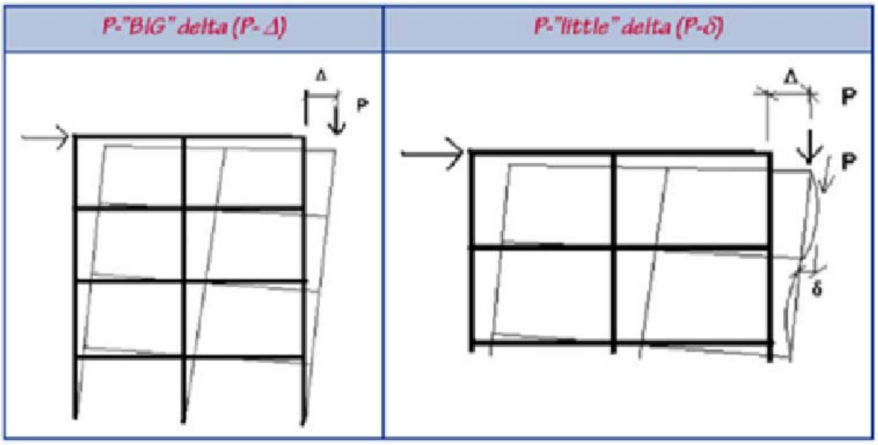


Figure 2.8 P-Δ and P-δ definition in simple frame

2.3.4 Nonlinear static (full Newton Raphson) analysis method

It is a full nonlinear iterative solution allowing all sorts of other non-linear conditions to be accounted for simultaneously [12], in addition to both the P-Δ and P-Δ effects as shown in Figure 2.8. The system equilibrium equations for the non-linear static analysis are

$$\{F\}_s - \{R\}_s = 0 \qquad (2.3)$$

Where the system load vector $\{R\}_s$ includes all externally applied nodal forces or loads. Such as applied nodal loads, loading due to static acceleration fields (such as gravity) and element thermal/pressure loads.

And vector $\{F\}_s$ includes the nodal forces that correspond to the element stresses in this configuration. This vector is known as the internal load vector.

Non-linear equation can be solved and carry out in an incremental step-by-step analysis with the total applied loads divided into a number of load steps (n). The best method of solution for non-linear equations is the Newton Raphson method. When a general geometric stiffness matrix is used in the method, there are no significant limitations on its use or applicability.

2.3.5 Fictitious lateral load method

This includes only frame P-Δ effects. In this method first-order analysis is done to find the first order deflections. Then the fictitious loads will be found and applied to the frame to simulate P-Δ effects. Then other first-order analysis is run to find new deflections. However, it has been shown that the P-Δ effects can be included relatively easily by modifying the moment of inertia.

The procedure is repeated until the member end moments do not change significantly or the difference can be neglected. This method is simple, since, only load matrix changes and stiffness matrix stay same. It converges good results for frames with not too slender members and small number of bays. Slender members result in significant P-Δ effects, this method does not consider a large number of bays can lead to varying axial forces that can either over-predict or under-predict the member end moments [2].

CHAPTER 3

STRUCTURAL SYSTEM AND BRACING

3.1 Introduction

Choosing the proper structural system for high rise multistory buildings is very important to carry loads and transfer them to the foundation safely and to be able to resist the lateral loads.

Controlling P-Δ analysis of structures can affect capacity and also type of structure is very active to increase or decrease value or amount. Choosing the type of system for multistory or high rise buildings depend on number of stories or the whole size of structure (means horizontal dimensions or number of bays for each of horizontal direction). Type and intensity of loads property of material, geometry and other architectural requirement also forced to change the system.

3.2 Types of structural system

The most commonly used structural systems have been classified by Khan [23]. They are broadly defined as follows and shown in Figure3.1

a- Moment resisting frames
b- Shear wall-frame systems
c- Shear truss-outrigger braced systems
d- Framed-tubes
e- Tube-in-tube systems with interior columns
f- Bundled tubes and modular tubes

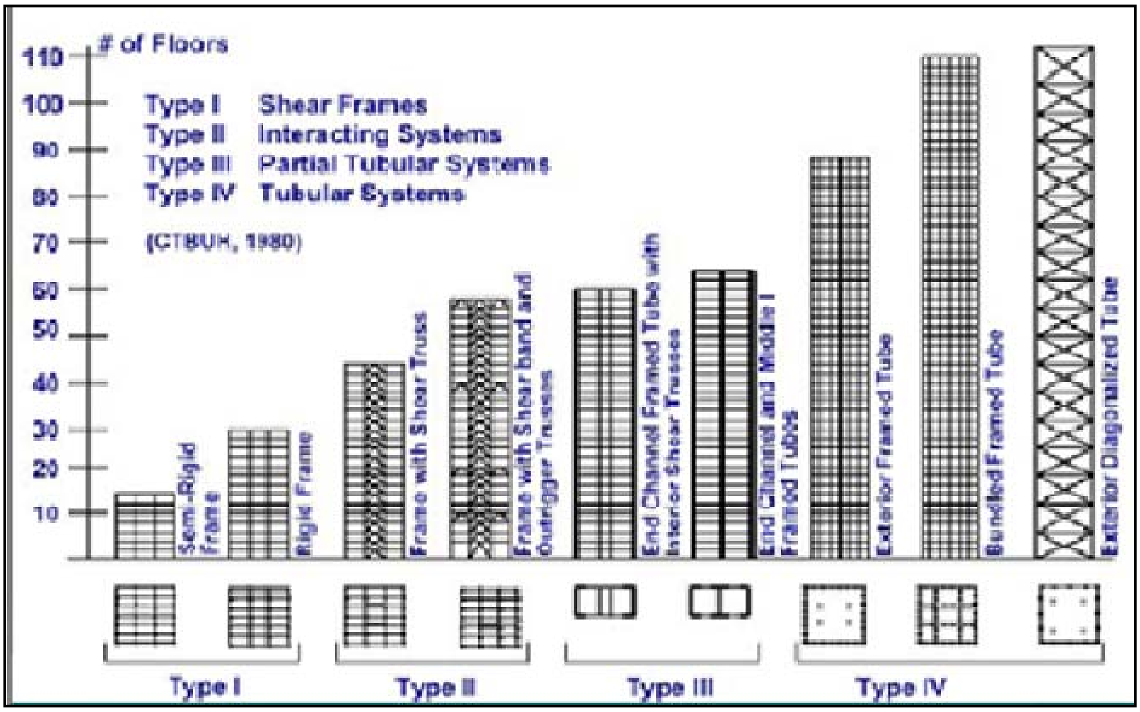


Figure 3.1 Structural systems have been classified by Khan.

3.2.1 Moment resisting frames

Moment resisting frames are normal frame with beams, columns and fixed or semi-rigid connections as in Figure 3.2. The stiffness and strength are proportional to the height of story and column spacing. Steel and concrete moment resisting frames and concrete encased steel columns can be used.

Steel beams can be covered by concrete and connected to slabs by shear connections. Moment resisting frames could also be built with columns connected to flat slab or flat plate. Slab and walls could also be designed as moment resisting frames. Steel moment frames could be fabricated using 3 story panels of beam-column sub assemblies. This type is without shear walls so the number of stories are limited depending on the bay spans between columns and story height and preferred to be not more than five stories and if need for increasing number of story shear wall has to be added.

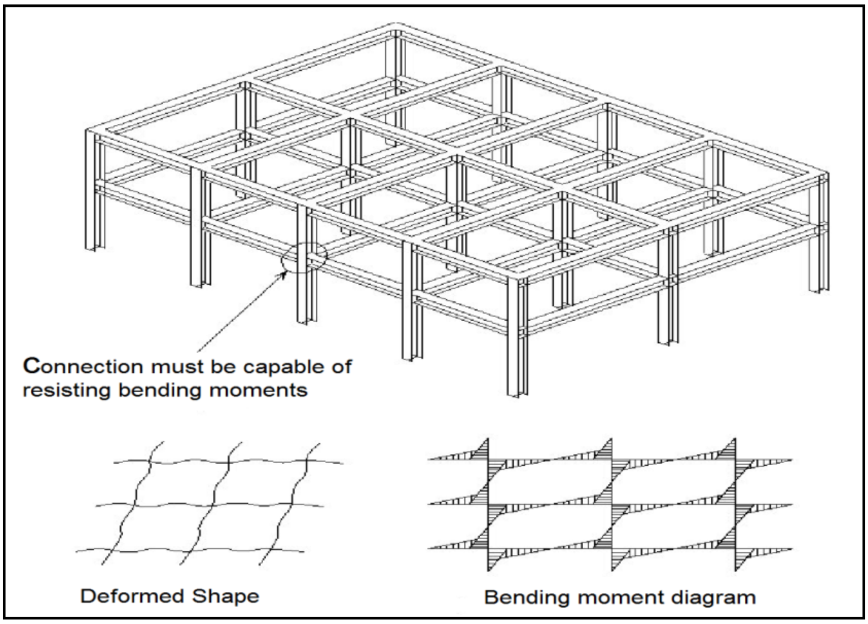


Figure 3.2 Moment resisting frame

3.2.2 Shear wall-frame systems

Its normal frame with columns, beams, girder like the type shown in section 3.2.1 and Figure3.3, shear walls will be added in number and type due to the structural type, size, amount and type of loads and number of stories. And depend on property of material, geometry, stiffness, symmetry and center of rigidity. Choosing the best location for shear wall is the important point that affect on the stability of structure in most design procedure to give the economical structure.

Normally the rigid shear wall will sustain the shears and moments at the base. At the top of building, the frame will tend to pull back on the wall and hence a point of contra flexure develops in the shear wall and it is shown in Figure 3.3.

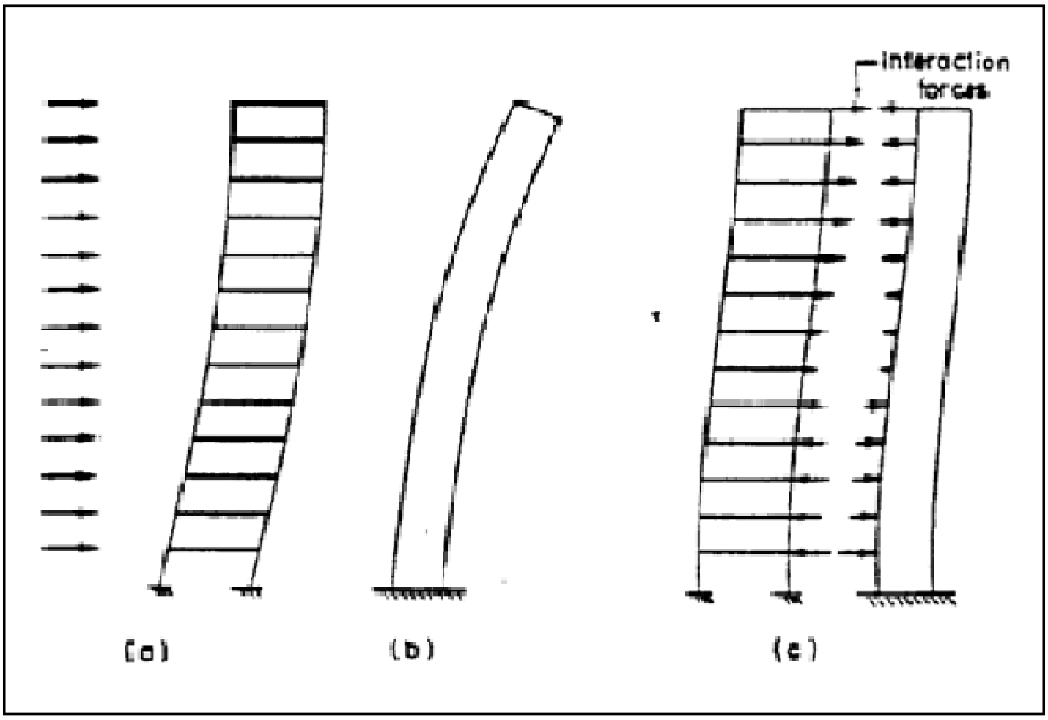


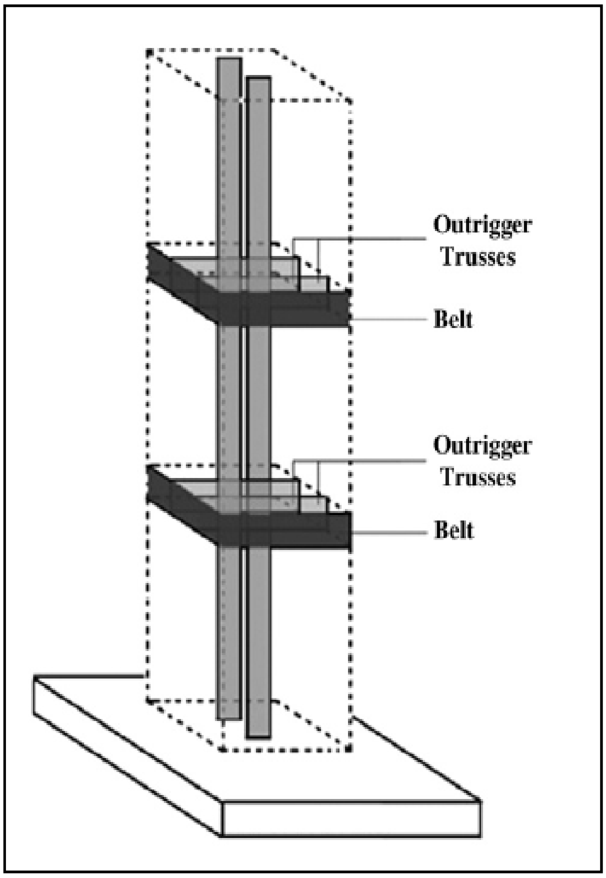
Figure 3.3 Shear wall frame system with (a) rigid frame shear mode, (b) shear wall bending mode deformation, (c) interconnected and shear wall deflections story level

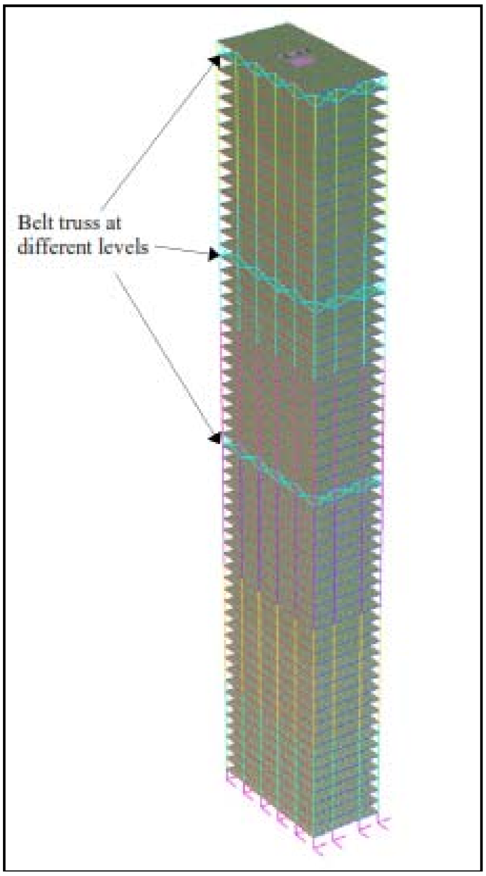
3.2.3 Shear truss outrigger braced systems

Shear truss outrigger braced systems is very effective when used with the composite structures and especially in tall buildings.

Gunel and Ilgin [24], documented that belt truss and outrigger is basically an evolution of braced frame or shear wall framed system. Iyengar [25], demonstrated the deflection control on a two dimensional model with the use of outriggers trusses. A 25 % reduction is achieved by the use of this system as well as 32 % reduction is attained with steel exterior column.

The belt truss located at the top floor is sometimes called a “hat-truss’. Belt trusses can improve system stiffness by as much as twenty five percent [26]. A large number of strong rigid moment connections will be wanted by shear truss-frame interaction in steel buildings. In order to increase the interaction between the core and exterior columns thereby improving cantilever action and reducing shear deflection horizontal outrigger trusses can be introduced to “link” the core and exterior as in Figure3.4.





(a) (b)

Figure 3.4 (a) Two shear truss outrigger bracing system with detail, (b) Three shear truss outrigger bracing system outside view

Frequently belt trusses are used to engage a greater number of exterior columns to reduce vertical deflection and improve action due to thermal effects. These trusses most often are located at special levels to be best in the building show the plan of the outrigger-belt truss system.

The outrigger trusses have to be fixed with the core and pinned to the exterior columns to improve bending efficiency as in Figure3.5 and Figure3.6. When the core bends outrigger trusses act as lever arms that transfer vertical shears and transfer direct axial stresses into the perimeter columns.

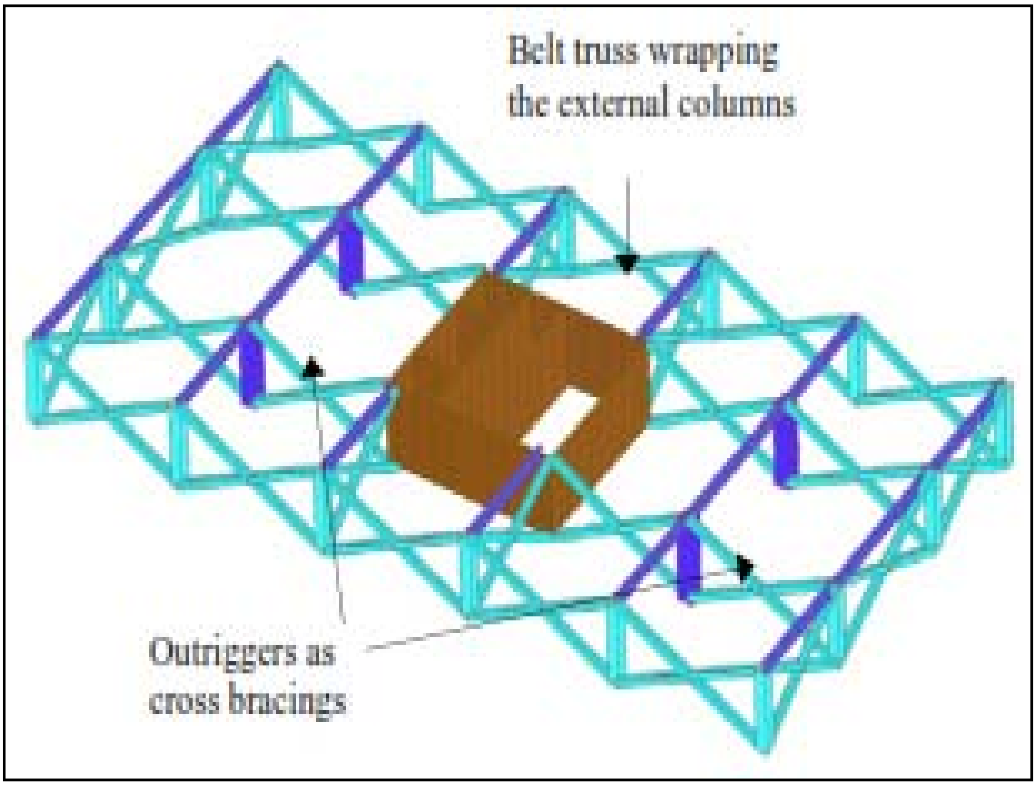


Figure 3.5 Shear truss outrigger bracing system connection with core shear in detail

The columns act as struts to resist bending and the core moment is reduced due to the transfer of overturning moment to axial loads. States that apart from economy of material and speed of construction, composite structures due to being light weight inflict less severe foundation conditions hence results in greater cost savings. Moreover; stiffness of concrete is more effective in controlling the horizontal displacement caused by lateral loads.

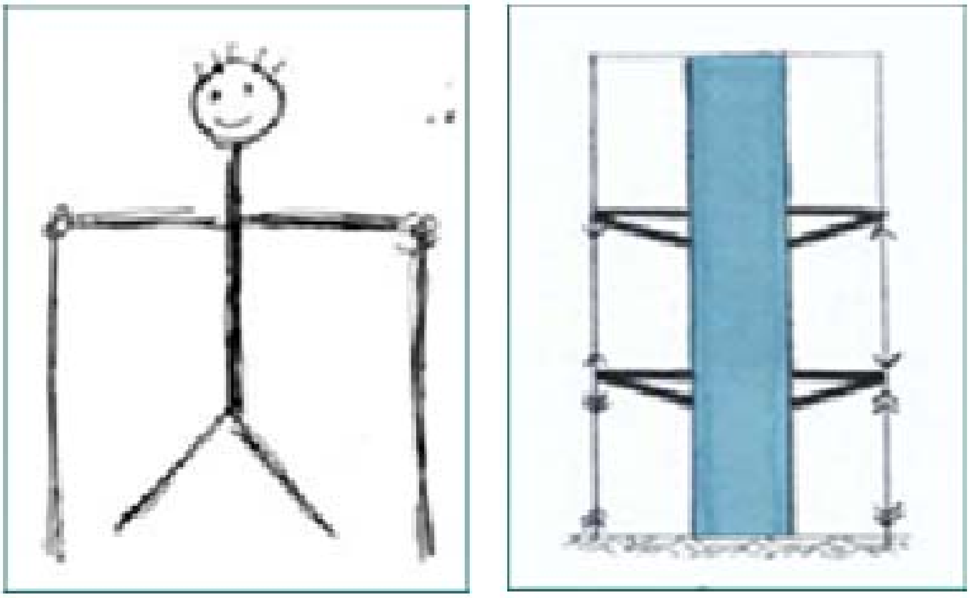


Figure 3.6 Shear truss outrigger bracing system frame example

3.2.4 Framed tubes

The framed tube structural system shown in Figure 3.7 is the most modern type developments in high-rise structural buildings. The framed tube system consists of very closely spaced (between 2-3 meters) exterior columns are joined in each floor level with deep edge beams (with depth usually 0.5-1.5meters). Like other structure of this form, the exterior tube or columns is designed to resist the entire lateral loading. The frames parallel to the wind act as the webs of the perforated tube cantilever, while the frames normal to the wind act as the "flanges". Vertical gravitational forces are resisted partly by the exterior frames and partly by some inner structure such as interior columns or an interior core. Tubular structures can be commonly square or rectangular in shape, or sometimes circular, triangular and trapezoidal shaped cross– sections can also be chosen. Sometimes the closely spaced column arrangement makes access difficult to the public area at the base. It can be avoided by using a large transfer girder to collect the vertical loads from the closely spaced columns and distribute them to a smaller number of larger more widely spaced columns at the base [27]. The framed tube allows the core framing to be constructed independently therefore the exterior can be constructed while the interior layout is being finalized.

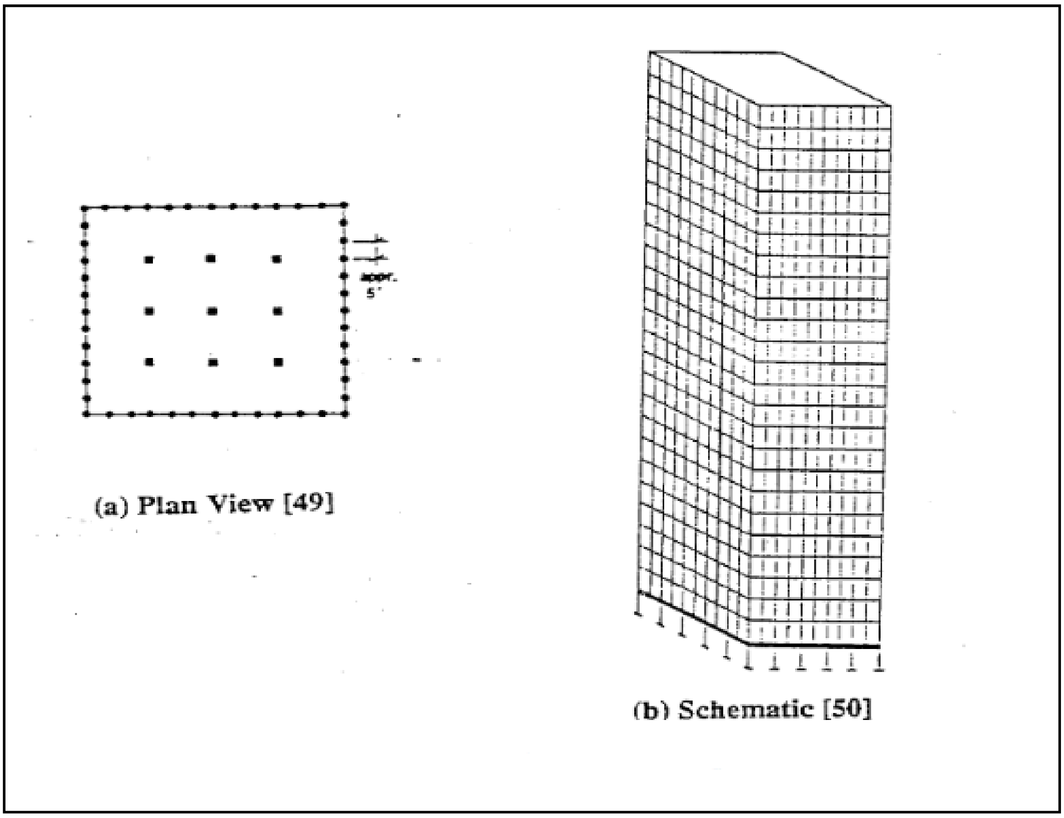


Figure 3.7 Frame tube system (a) plan view, (b) three dimension views

3.2.5 Tube-in-tube systems with interior columns

A tube-in-tube system or Hull-Core structures is a variation of the framed tube created by the shear walls, or as it is known from its name tube in tube and the outer tube consisting of the closely spaced column system as in Figure 3.8 and Figure 3.9. The tube in tube system has the advantage of both the shear wall type structures and the framed tube structures. The shear deflection of the columns of the framed tube is considerably reduced by the shear wall inner tube; thereby enhancing the structural characteristics of the exterior framed tube. The tube-in tube system is a refined and unique version of the shear wall-frame interaction type structures.

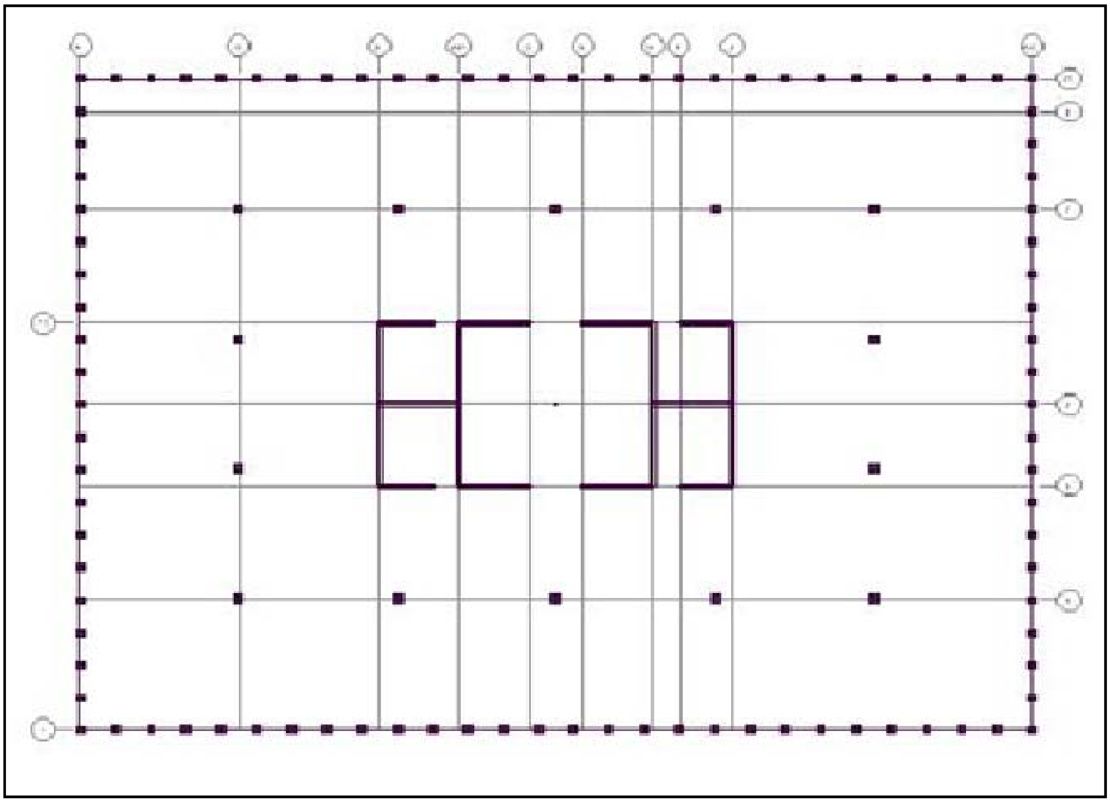


Figure 3.8 Internal sections in frame tube in tube system

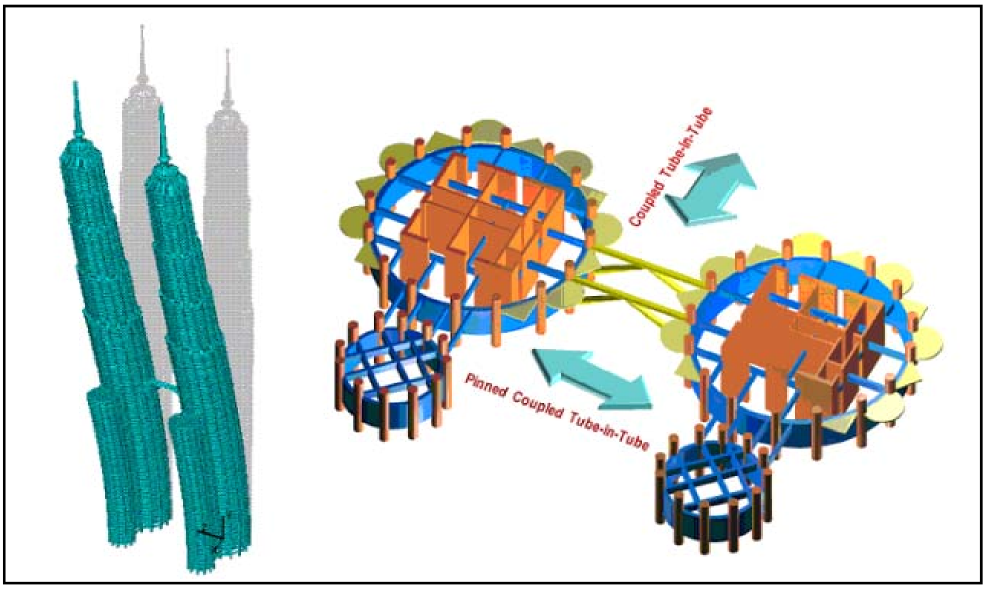


Figure 3.9 Inside section of frame tube in tube system showing joining between tubes

3.2.6 Bundled tubes and modular tubes

These structural systems consist of frame tubes, which are bundled together one with each other as in Figure 3.10 and Figure 3.11.

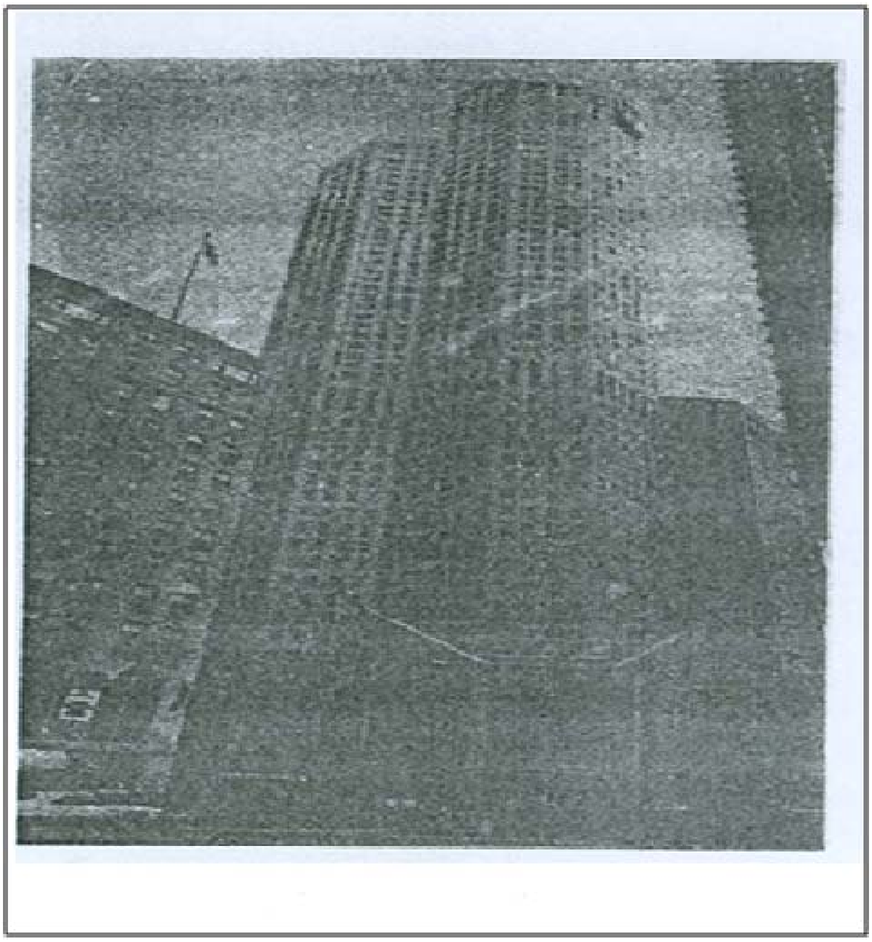


Figure 3.10 Bundle tube system building

As in the single-tube structure, the frames in the direction of lateral loading serve as "Webs" of the vertical cantilever, with the normal frames acting as "flanges". It is stated in [28], that the introduction of the internal webs greatly reduces the shear lag in the flanges.

Due to this, the columns of bundled-tube structures are more evenly stressed than in the single-tube structure and their contribution to the lateral stiffness are greater.

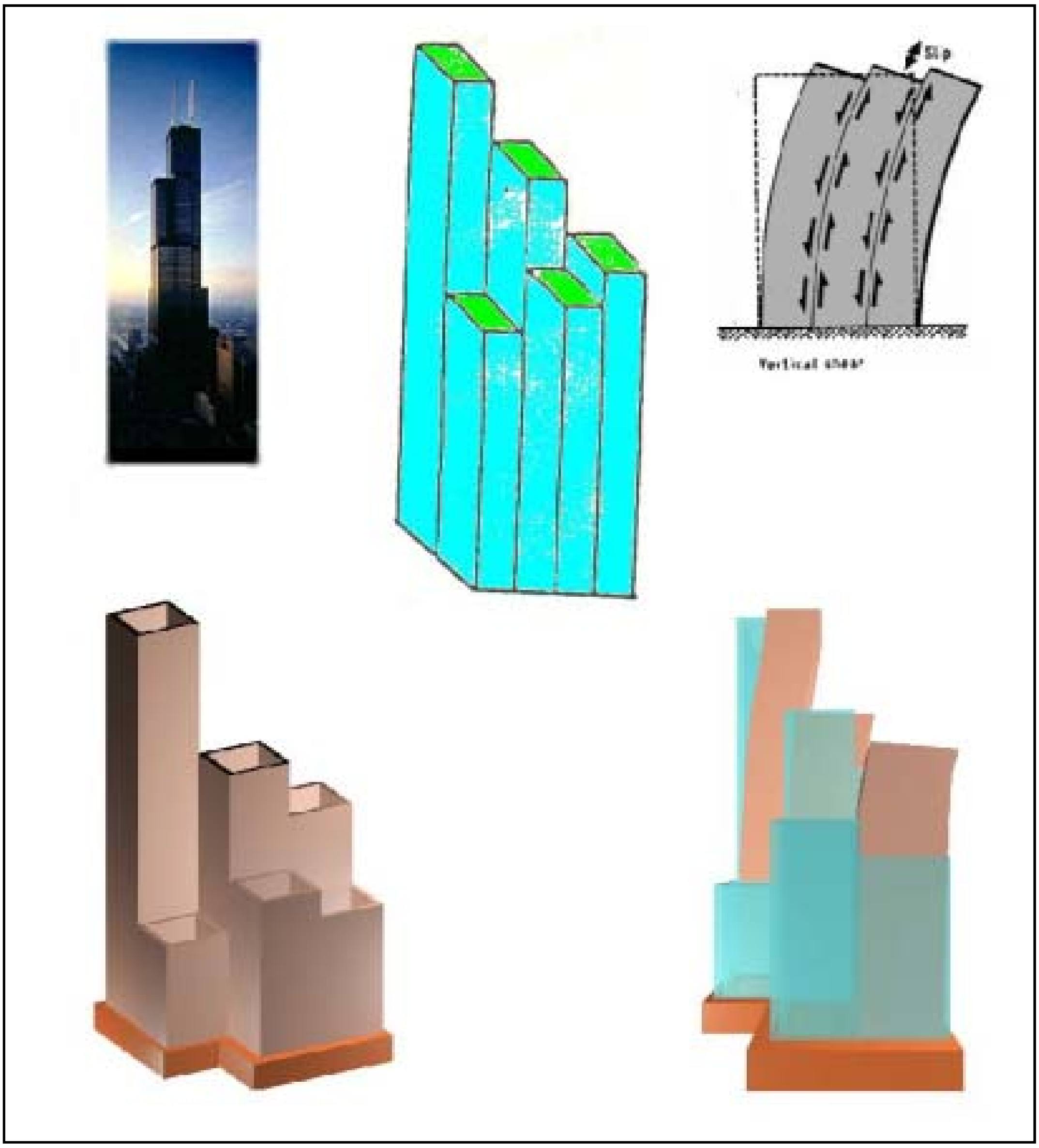


Figure 3.11 3D views of bundle tube system

CHAPTER 4

STAAD PRO AND P-Δ ANALYSIS

4.1 P-Δ Analysis by using computer programs

Computer programs can do P-Δ analysis but the result still depends on the input data used and formed by the engineer in addition to the model created. Also analysis procedure and type with output arrangement is important to get the correct results. Because of complexity of P-Δ calculations especially for large buildings or 3D (three dimensions) structures that its calculations needs time and sometimes it may be impossible doing it without any errors. If hand calculation methods are used it needs more iteration and sometimes it reaches 30 to 40 iteration or more, to get nearly exact or reasonable value.

All softwares use nearly same methods that are used for hand calculations but concentrate on iteration method or geometric stiffness that is nearly exact.

The differences between hand calculation and software performing analysis:

1. Limitations of hand computation methods :
   - a- Applicable for small problems or small structures
   - b- Difficult for even medium sized problems
   - c- Three dimension analysis almost impossible
   - d- Probability of errors raises with the size of structure
   - e- Time needing is high for performing analysis
2. Advantage for invention of computer:
   - a- Matrix methods of structural analysis
   - b- Development of numerical techniques
   - c- Finite element method

d- Programming languages develo*p*ed

e- Arranging input and output is easy with drawings

Several softwares can do P-Δ analysis using different methods like Staad Pro, SAP 2000 and Etab----etc.

4.2 Staad Pro and P-Δ Analysis

Staad Pro is the famous popular structural engineering software for 3D model generation, analysis and multi-material design. It is useful to analyze and design multi-story buildings. Multi story or high rise building subjected to lateral loads often experience secondary forces due to the movement of vertical loads point. This secondary effect is named as P-Δ effect, it plays an important role in the analysis of high-rise structure.

A unique procedure has been adopted to incorporate the P-Δ effect into the analysis. The procedure consists of the following steps:

1. The primary displacement is calculated based on the provided external loading.
2. Primary deflections are then combined with the originally applied external loading to create the secondary loadings. The load vector is then revised to include the secondary effects as mentioned. And then the lateral applied loading must be present concurrently with the vertical loading for proper consideration of the P-Δ effect.
3. A new stiffness analysis is carried out based on the new load vector to generate new deflections.

Element/ support reactions and member forces are calculated based on the new deflections.

Procedure yields very accurate results with all small displacement problems. Staad Pro allows the user to go through multiple iterations of the P-Δ procedure if necessary. The user is allowed to specify the number of iterations based on the requirements [29]. If the user wants to give a limit value to set the displacement convergence tolerance, (SET

DISP f) command can be applied before the joint coordinates. If the change in displacement from one iteration to the next is less than “f” then it is converged.

The P-Δ analysis is recommended by most of design codes like ACI 318 [30], LRFD [31], IS456-1978, etc. in lieu of the moment magnification method for the calculation of more realistic forces and moments.

4.3 Selection of model

Three methods are available in Staad Pro for modeling and assigning:

A: Using the command file

The Command File is a text file that contains data for the all the structure that have been modeled. This file consists of an English-language as normal text like commands, using a format native to Staad Pro. This command file may be created directly by user using the editor built into the program from a menu, or for that matter, any editor which saves data in text form, such as Notepad or WordPad available in Microsoft Windows also change in any property, material load value or type, repeating some process can be done here easily and quickly and especially when modifying of structure required in loads or property or the amount or length and any other.

B: Using the graphical model generation mode or graphical user interface (GUI). The graphical model generation mode and the command file are seamlessly integrated or updated. So, at any time, we may exit the graphical model generation mode and access the command file. We will find that it shows all data entered through the graphical model generation mode. Further, when we make changes to the command file and save it, the GUI immediately reflects the changes made to the structure through the command file. So they are same both in information or linked together.

C: Staad Pro can import AUTO CAD drawing saved as dxf file for the structure frame for two and three dimension this can be done directly by importing single clean line AUTO CAD drawing saved as dxf files and then needs some changes in Staad Pro before running the analysis, here importing is restricted only for structure with columns and beam members the other type like elements can be added in Staad Pro manually by creating elements, plates and surfaces and joined with beam, columns depending on the nodes of elements or surfaces.

4.4 Input parameter

The main parameters that are required by Staad Pro as input and entered directly by user in Staad Pro are [32]:

- **a-** Geometry: include coordinates of shape (beam, column, element, ------etc) and this can be defined directly in Staad Pro or with generating drawing directly or from importing dxf AUTO CAD files or using editor text file.
- **b-** Property: include dimension, thickness of beams, columns, elements, surfaces and can be input in all method explained in section 4.3.
- **c-** Material: material for member or element (concrete, steel, timber-----etc) and all specification and parameter for each is built in Staad Pro and can be changed by entering used material.
- **d-** Support: is defined as fixed, pinned, others such as (fixed but, inclined, spring, or releasing any point due to the structure requirement.
- **e-** Loading: all type of loading can be entered Dead Load (DL), Live Load (LL), Wind (WL), seismic, etc for static and dynamic (including response spectrum, time history).

Above information can be specified and assigned individually or as group.

4.5 Analyses

Staad Pro can perform different type analysis such as:

1. Normal analysis
2. P-Δ analysis
3. Direct analysis

4. Buckling analysis
5. Cable analysis
6. Imperfection analysis
7. Push over analysis

In this thesis first and second performances from above analysis list is used. For P-Δ analysis two different types can be performed.

1- P-Δ analysis with number of iterations entered by user (preferred 15-35 iteration) for static loads example.
2- P-Δ analysis using geometric stiffness (KG) with iterations (preferred 1-2 iteration) for dynamic loads examples

In the two types P-Δ and P-δ (or small delta for columns and other member) can be included here in the examples or test.These two types have been used in this thesis and it is seen that the results are nearly same.

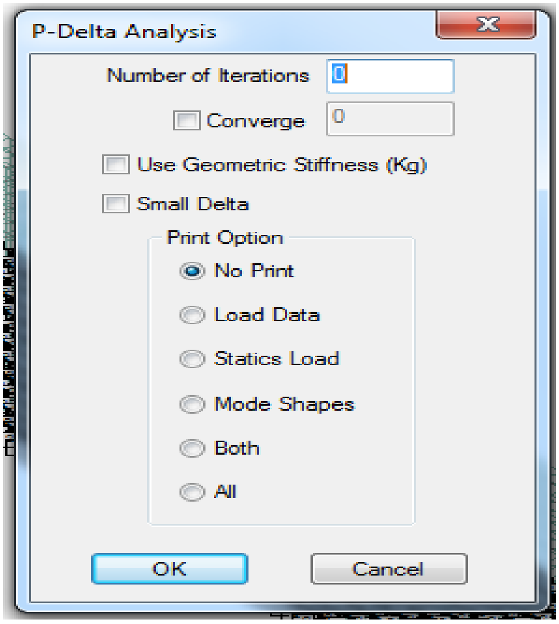


Figure 4.1 P-Δ analysis input window in Staad Pro

CHAPTER 5

EXAMPLES

5.1 Structural system used

Structural system models that have been used in this chapter are chosen from the classification shown in Figure 3.1 and rearranged as shown in Figure 5.1and they are as;

1- Rigid Frame

2- Frame with shear wall form

3- Frame with shear band and outrigger, with two branch and classified as bellow:

- **a-** Due to number of outriggers:
  - **1-** Frame with one outrigger in midpoint of height
  - **2-** Frame with two outrigger arranged through the height of frame with equal span nearly
  - **3-** Frame with three outrigger arranged through the height of frame with equal span nearly
  - **4-** Frame with four outrigger arranged through the height of frame with equal span nearly
- **b-** Due to location of outrigger:
  - **1-** outrigger at the top of multi story at 0 story from top
  - **2-** outrigger at 10 story starting from top
  - **3-** outrigger at 20 story starting from top
  - **4-** outrigger at 30 story starting from top
  - **5-** outrigger at 40 story starting from top
  - **6-** outrigger at 50 story starting from top

4- End Chanel frame tube

5- Exterior frame tube

6- Exterior diagonal tube

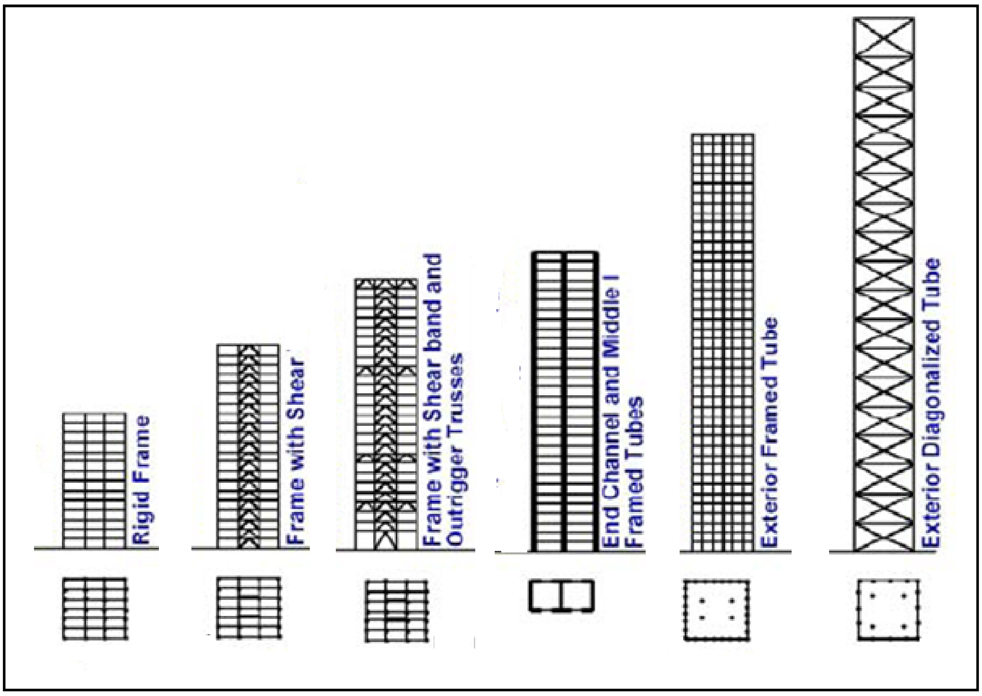


Figure 5.1 Structural system selected used in example tests

In this thesis, effects of outriggers, frame end channel, exterior frame tube and exterior diagonal bracing tube systems on the P-Δ behavior of multistory high rise buildings are studied. Also to show the relationship between P-Δ analysis and fundamental frequencies free vibration analyses are done for all examples. Dynamic analysis (Response spectrum and Time history) In all examples following boundary conditions, loadings and material properties are assumed.

Boundary conditions: All analyzed buildings are assumed to be fully fixed at supports with full raft and there are no surrounding buildings and full free at top.

Material properties: Materials of the structure frames for all types are concrete for members (columns, beams and shear walls). Steel is used for interior shear trusses and bracing parts or members for outriggers. Both concrete and steel material properties are given in Table 5.1.

Table 5.1 Material properties of concrete and steel

	concrete	steel
Modulus of Elasticity E (kN/m^2)	2.17185×10^7	2.05×10^8
Poisson'sratio	0.17	0.3
Density (kN/m^3)	23.5616	76.8195
Alpha	1×10^{-5}	1.2×10^{-5}
Damp	0.05	0.0

Loadings: Buildings are analyzed under static and dynamic loadings but temperature affects were neglected. Static load case includes the following loads;

i.) Dead Load (DL) equal to 9.0 kN/m^2 includes self weight of all beams, columns and other bracing members. Slabs weight and equivalent partitions loads is included and has been applied to all floors because slab is not entered in the models, see Figure 5.3 (a).

ii.) Live Loads (LL) is taken as 2.5 kN/m^2 as floor load, see Figure 5.3 (b).

iii.) Wind Load (WL) has been applied to the frame in X-direction starting from intensity of 0.78 kN/m^2 at lower level and ending with 0.93 kN/m^2 at the top. See Figure 5.2.

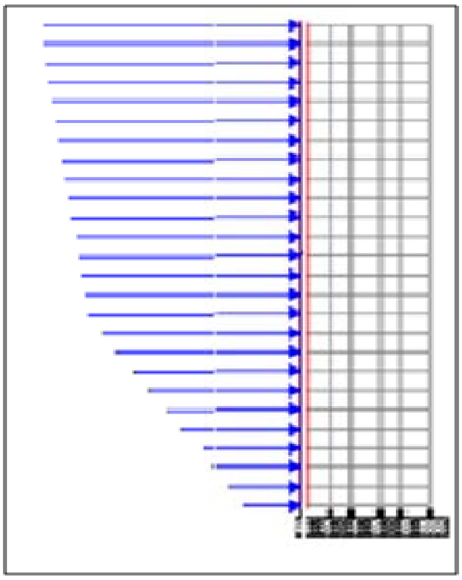
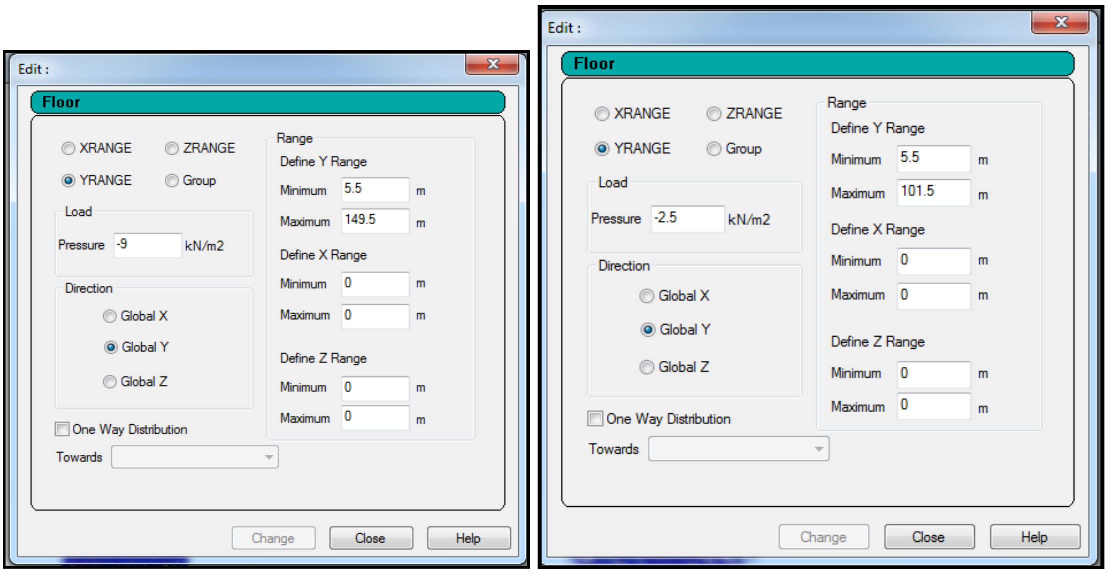


Figure 5.2 Wind load applied to the model

Combined load has been chosen as (1.2 DL+1.0 LL+1.6 WL) and used for all static analysis.

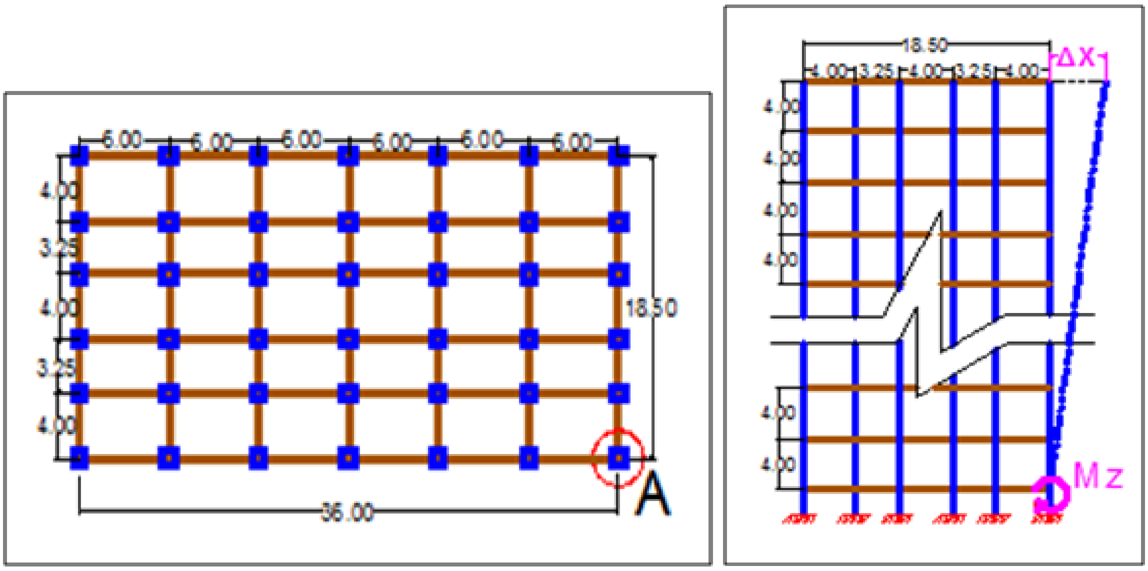


(a) (b)

Figure 5.3 (a) Dead load entered as floor load, (b) Live load entered as floor load

5.2 Rigid Frame buildings

In the first test four different numbers of stories shear frame buildings were tested. Plan views of (13, 25, 37 and 50 stories) building is shown in Figure 5.4 (a).Total base dimensions are 18.5**X**36.0 m. All concrete beams have cross section dimension of 30X50 cm. Columns are spaced and forms 5 by 6 bays with 4.0 m height (Figure 5.4 (b)) and column cross section dimensions are given in Table 5.2 and Table 5.3. Outrigger with shear band and shear truss member is steel with type and size (W36X300).



(a) (b)

Figure 5.4(a) Plan views of Rigid frame buildings (13, 25, 37 and 50 stories)
(b) Frame with point of Δx and Mz

Table 5.2 Column cross sections at each floor for rigid frame buildings

Number of story	**Column cross sections (cm)**					
corresponding stories	**1-3**	**4-7**	**8-13**	**14-18**	**19-25**	**25-37**
13 story	80×80	70×70	60×60	-	-	-
25 story	80×80	70×70	60×60	50×50	40×40	-
37 story	80×80	70×70	60×60	50×50	40×40	40×40

Table 5.3 Column cross sections for 50 story rigid frame building

corresponding stories	**1-10**	**11-20**	**21-30**	**31-40**	**41-50**
column cross section (cm)	100×100	90×90	80×80	70×70	60×60

Discussion of results:

Static analysis without and with P-Δ (with 35 iteration) and free vibration analysis are done. The displacement at top (Δx), base moment (Mz) and fundamental frequencies are given in Table 5.4, Table 5.5 and Figure 5.5 for 13 story building.

Table 5.4 Displacement Δx at point A in 13 stories building in Staad Pro

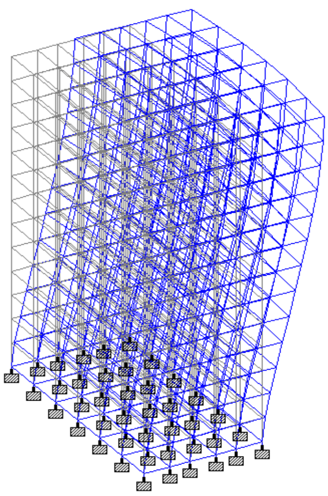
13 story without p-delta - Node Displacement

Node	L/C	X-Trans mm	Y-Trans mm	Z-Trans mm	Absolute mm	X-Rotan rad	Y-Rotan rad	Z-Rotan rad
2170	5	38.524	-6.279	-0.207	39.033	-0.000	-0.000	0.000
2170	4	24.126	-0.417	0.013	24.130	-0.000	-0.000	-0.000
2170	1	-0.008	-1.857	-0.027	1.857	-0.000	0.000	0.000
2170	3	-0.013	-0.636	-0.037	0.637	-0.000	-0.000	0.000
2170	2	-0.046	-2.290	-0.132	2.294	-0.000	-0.000	0.000

Table 5.5 Moment Mz at point A in 13 story building in Staad Pro

13 story without p-delta - Support Reaction

Node	L/C	Force-X kN	Force-Y kN	Force-Z kN	Moment-X kNm	Moment-Y kNm	Moment-Z kNm
4051	5	-48.055	2620.117	-13.102	-11.760	2.236	212.724
4051	4	-27.024	232.872	-0.064	-0.182	1.467	130.940
4051	2	-2.150	836.927	-6.527	-11.400	-0.076	3.754
4051	3	-0.597	232.480	-1.813	-3.167	-0.021	1.043
4051	1	-1.367	842.275	-2.795	4.482	-0.000	-1.939



13 story without p-delta - Frequencies & Mass Participations

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %
1	2.746	0.364	76.102	0.000	0.000
2	3.403	0.294	0.000	0.000	0.000
3	5.189	0.193	0.000	56.964	0.000
4	5.332	0.188	0.000	0.000	0.000
5	5.544	0.180	0.000	4.843	0.000
6	5.630	0.178	0.896	0.000	0.000

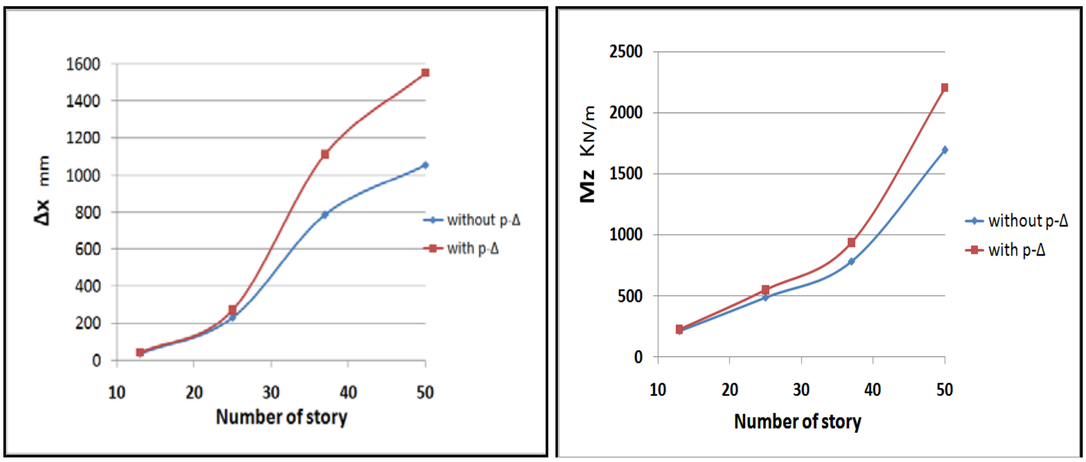
Figure 5.5 Free vibration results for 13 story building analysis in Staad Pro

And the result for all four type building is tabulated for obtained value from analysis results as shown in Table 5.6

Table 5.6 Displacement Δx, moment Mz and fundamental frequency results for the four types of multi story buildings

	STATIC				Free Vibration	
	Δx(mm)		Mz (KN/m)			
Number of story	without p-Δ	with p-Δ	without p-Δ	with p-Δ	frequency(Hz)	period(sec)
13	38.524	41.014	212.274	224.29	2.748	0.364
25	233.036	271.109	487.999	546.146	1.17	0.854
37	786.417	1112.018	781.976	934.937	0.644	1.553
50	1054.399	1552.025	1693.383	2205.23	0.558	1.792

Static analysis without and with P-Δ are done, the displacement at top floor (Δx) and base moment (Mz) for point A are given in Figure 5.6 (a,b) for four different story buildings. As expected, when the numbers of stories increase, displacements and moments increase for both with and without P-Δ analysis.



(a) (b)

Figure 5.6 Analysis results of rigid frame
(a) top displacements Δx (mm) and (b) base moments Mz (kN.m)

However; the rate of increase in displacements and base moments for analysis with

P-Δ is much higher than analysis without P-Δ. For example the difference in top displacement between without and with P-Δ for 13 story building is almost 6 % on the other hand for 50 story building this difference is 32 %. The results show that analysis with P-Δ for high-rise building must be done. So after this part, all examples are concentrated only on 50 story buildings.

Free vibration analysis is also done and fundamental frequencies are given in Figure 5.7. It is observed that there is a inverse relation between P-Δ effect and fundamental frequency. Such as if the fundamental frequency of building is low, the effect of P-Δ is higher.

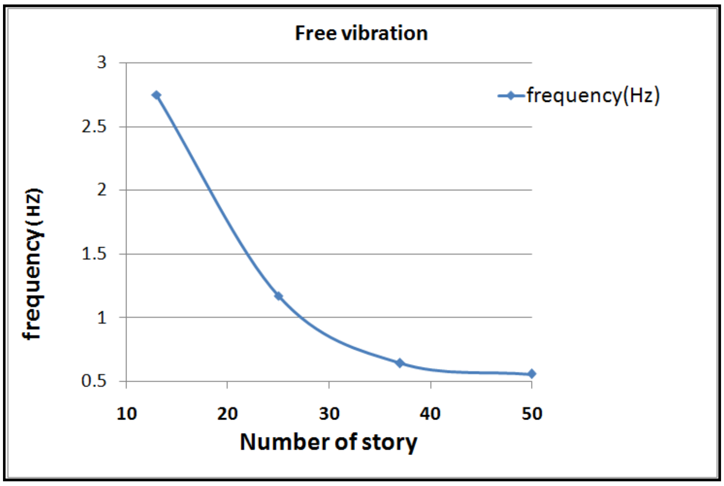
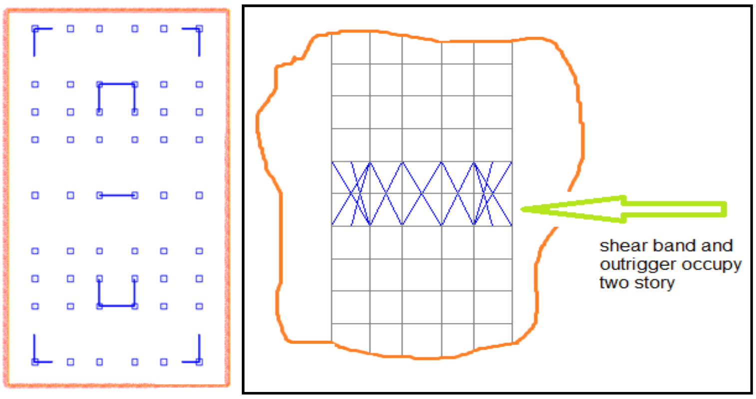


Figure 5.7 Fundamental frequencies (Hz) of rigid frame buildings

5.3 Frame with shear band and outriggers for static

Contribute to the development of engineering guidelines for protection against excessive P-Δ effects case studies for various structural systems are presented. The first example is concentrated on the performance of shear band and outriggers which given in the list of Khan [23]. The plan view and outrigger part of building of the structural system which is considered are given in Figure 5.8. The analysis is carried out for two cases. In the first case the effect of number of outriggers is observed whereas in the second case optimum location of a single outrigger is studied.



(a) (b)

Figure 5.8 Frame with shear band and outriggers (a) Normal shear wall in cross section (b) outrigger part of building in two floor

5.3.1 Effect of number of outriggers on P-Δ

The following models shown in Figure 5.9 are utilized to evaluate the effects of different number of outriggers on P-Δ analysis. The structures which have following number of outriggers are examined.

Type 0: without outrigger.

Type 1: with one outrigger at 25th floor.

Type 2: with two outriggers at 17th and 34th floor.

Type 3: with three outriggers at 17th, 34th and 50th floor.

Type 4: with four outriggers at 13th, 26th, 39th and 50th floor.

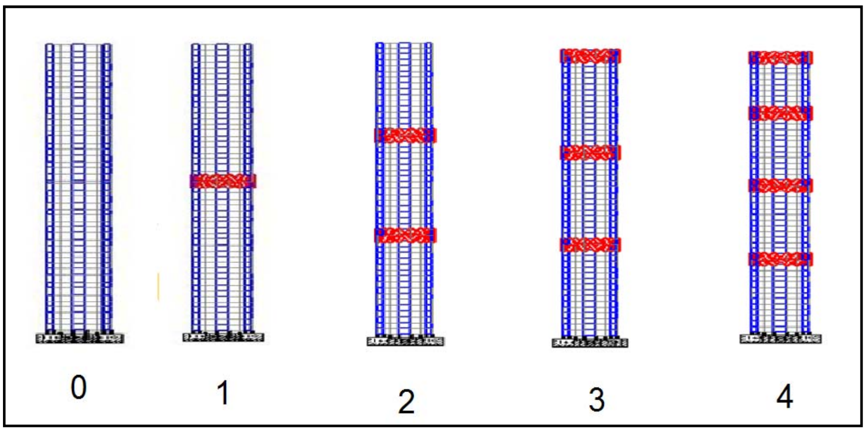
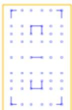
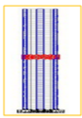
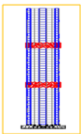
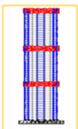
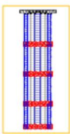


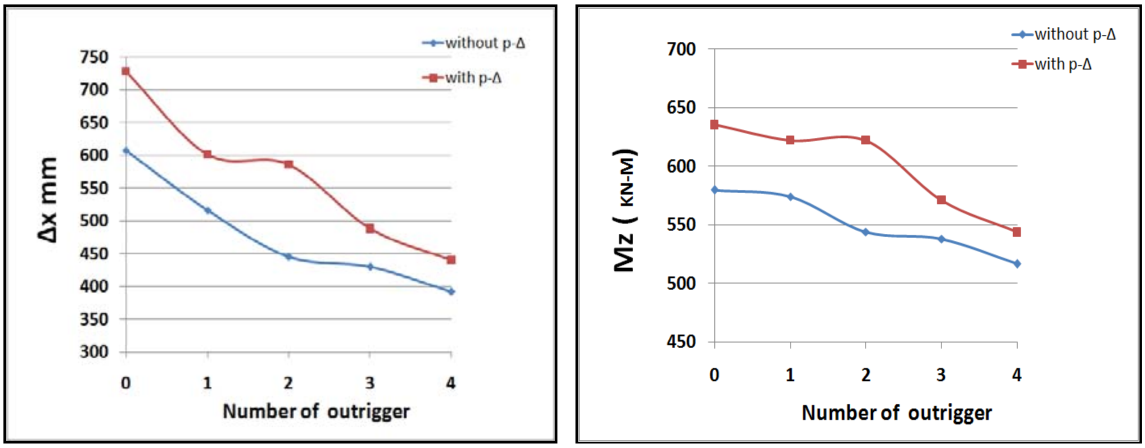
Figure 5.9 Number and location of outriggers

Discussion of results:

The use of outrigger has improved the serviceability of the structures. Static analysis without and with P-Δ are done. The displacement at top floor (Δx) and base moment (Mz) for point *A* are given in Table 5.7 and the curve relationship in Figure 5.10 for five types of outrigger configuration. In general trend, when the number of outrigger increases, displacements and base moments decrease.

Table 5.7 Δx and Mz and fundamental frequency results for shear frame with different number of outrigger

		ΔX		Mz		Free Vibration	
	Num of outrigger	without p-Δ	with p-Δ	without p-Δ	with p-Δ	frequency	time
	0	607.363	727.068	579.697	635.187	0.737	1.357
	1	515.975	601.062	574.083	621.96	0.801	1.248
	2	445.333	585.6	543.652	621.884	0.86	1.162
	3	429.504	487.722	537.727	570.705	0.871	1.148
	4	391.955	440.306	516.473	543.421	0.908	1.101



(a) (b)

Figure 5.10 Comparison of various outrigger configurations
(a) displacements Δx (mm) and (b) base moments Mz (kNm)

The results show appreciable decline in the both displacement and moments with the use of more outrigger systems. When the result of without and with P-Δ analysis are compared, an average18.72 % difference in displacement and 8.73 % difference in moments are observed. But in the type 2 the gap on displacement and base moment for without and with P-Δ analysis are larger than other types.

Table 5.8 Free vibration results for shear frame with one outrigger building

1.D.O.NORMAL - Frequencies & Mass Participations

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %
1	0.801	1.248	69.938	0.000	0.000
2	1.317	0.759	0.000	0.000	0.000
3	2.307	0.433	0.113	75.481	0.000
4	2.313	0.432	15.156	0.563	0.000
5	2.609	0.383	0.000	0.000	0.000
6	3.152	0.317	0.000	0.000	0.000

Free vibration analysis are also done and fundamental frequencies and corresponding model shapes are given in Figure 5.11 and Figure 5.12 for five types of outrigger configuration. It is clear that the rate of increase of the fundamental frequency curve decreases while the numbers of outriggers increases. When Figure 5.10 and Figure 5.11 are compared, it is observed that there is an inverse relation between P-Δ effect and fundamental frequencies. If the fundamental frequency of building is low, the effect of P-Δ is higher.

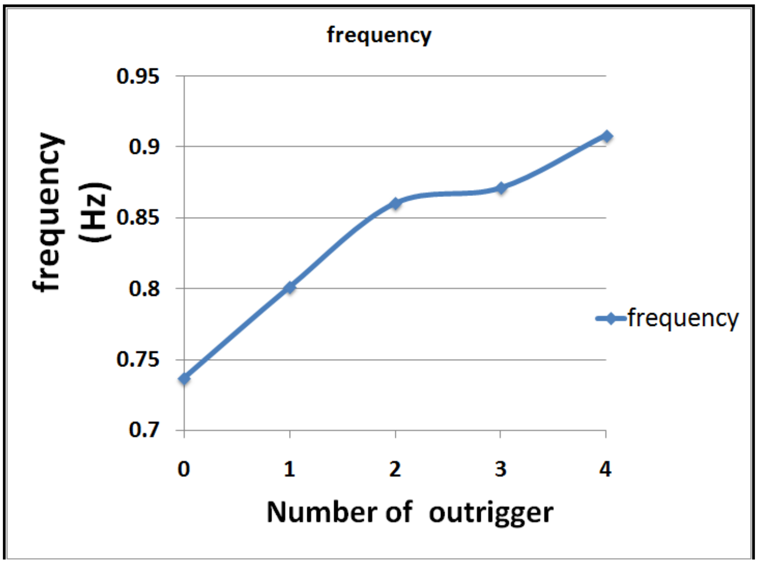


Figure 5.11 For different number of outriggers fundamental frequencies (Hz)

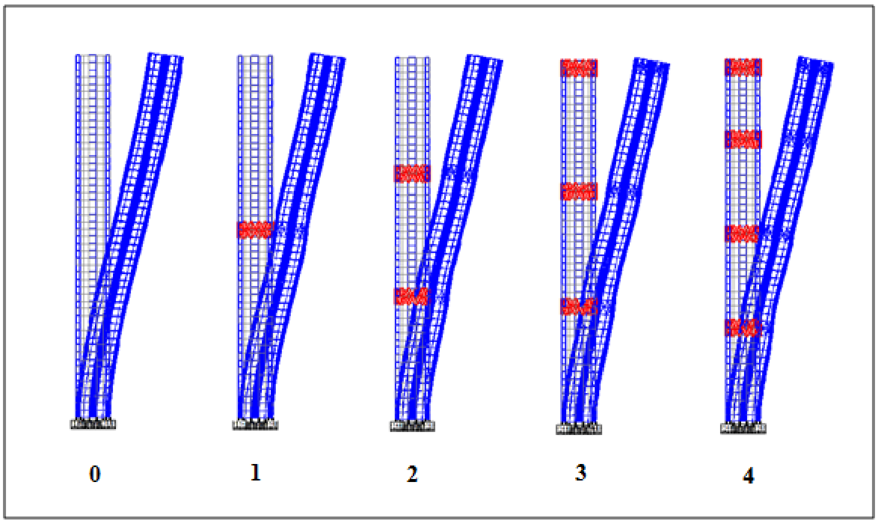


Figure 5.12 Mode shapes for outrigger numbers

5.3.2 Optimum location of single outrigger for static and free vibration analysis

The rigorous three dimensional analyses of structures with outriggers provided very approving results in the form of effective deflection and base moment control (reduction in these values) in somewhat slender and tall structures. For that reason, it is decided to obtain best location for single outrigger is studied by changing the location of it, see Figure 5.13. The analyses are repeated by placing single outrigger to 0 (base), 10th, 20th, 30th, 40th and 50th (top) floor.

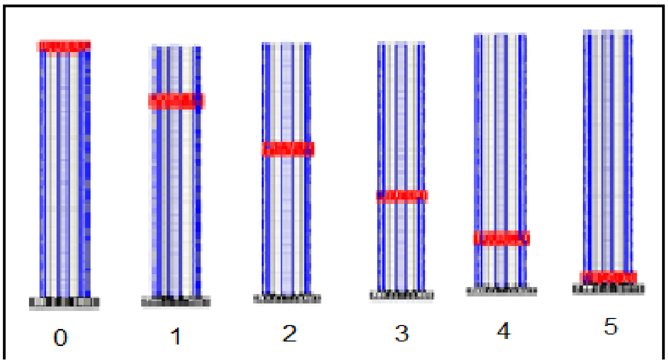


Figure 5.13 Single outrigger frame system due to its location

Table 5.9 Free vibration results for shear frame with single outrigger at 50 floors from bottom in Staad Pro

1.D.O.NORMAL - Frequencies & Mass Participations

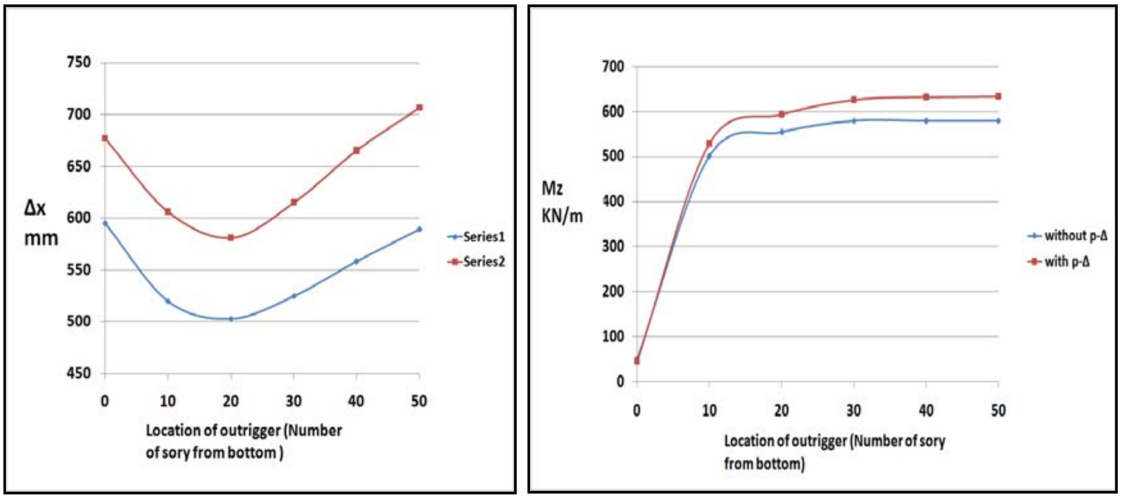
Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %
1	0.801	1.248	69.938	0.000	0.000
2	1.317	0.759	0.000	0.000	0.000
3	2.307	0.433	0.113	75.481	0.000
4	2.313	0.432	15.156	0.563	0.000
5	2.609	0.383	0.000	0.000	0.000
6	3.152	0.317	0.000	0.000	0.000

Discussion of results:

Static analysis without and with P-Δ are carried out by changing the location of single outrigger. The displacement at top floor Δx and base moment Mz for point *A* are given in Table 5.10 and plotted as a curve relationship in Figure 5.14. In the view of minimize the displacement, Figure 14 (a) shows the best location for single outrigger option is at level 20, i.e. 0.4 times the height of the structure. The difference at the base moments are very small for results obtained without and with P-Δ analyses. When the outrigger placed to base floor, the base moment at point A is reduced sharply see Figure 14 (b).

Table 5.10 Δx and Mz and fundamental frequency value in single outrigger frame with six different location of outrigger

		STATIC				Free Vibration	
		Δx(mm)		Mz (KN/m)			
	Location of outrigger (Nunmber of story from bottom)	without p-Δ	with p-Δ	without p-Δ	with p-Δ	frequency (Hz)	period (sec)
Out Rigger	50	589.467	706.762	579.813	634.211	0.742	1.348
	40	558.207	665.096	579.362	632.182	0.76	1.316
	30	524.941	615.209	579.903	626.656	0.791	1.264
	20	503.226	581.165	554.463	594.281	0.815	1.226
	10	520.01	606.332	500.384	529.19	0.798	1.253
	0	594.812	676.799	50.3	44.384	0.761	1.314



(a) (b)

Figure 5.14 Single outrigger frames (a) displacements Δx (mm) and (b) base moments Mz (kN.m)

Free vibration analysis was applied to see the fundamental frequencies and searching for the best location of outriggers. The fundamental frequencies and corresponding model shapes are given in Figures 15 and 16 for various location of a single outrigger respectively. Free vibration and static analysis shows that the best location for single outrigger option is at level 20.

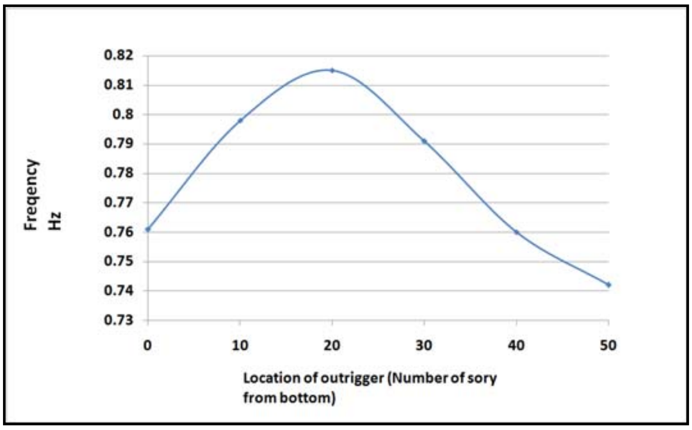


Figure 5.15 Frequency (Hz) for different outrigger locations

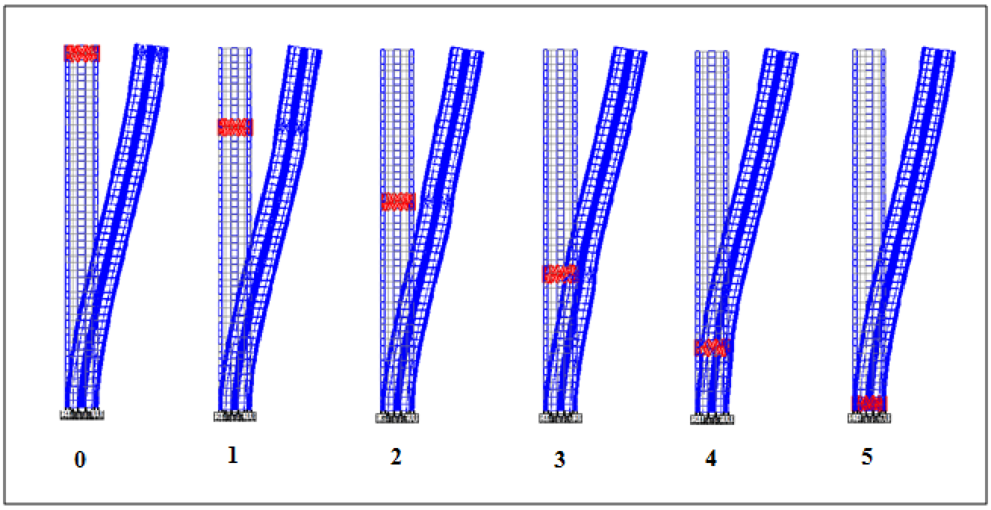
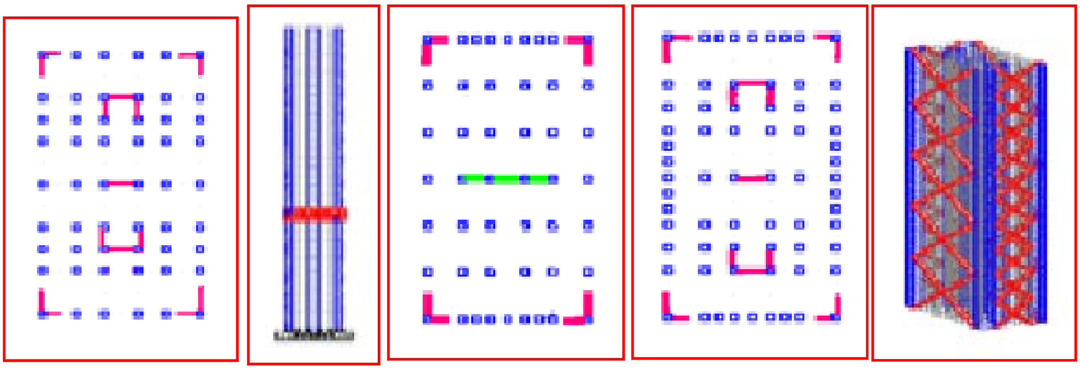


Figure 5.16 Mode shapes for optimum location of outriggers

5.4 P-Δ performance of various structural systems

The outrigger system is not only proficient in controlling the overall lateral displacement and base moments but also very capable of reducing them. However, the introduction of other type of structural systems may be results in further deflection and moment reductions. The other structural systems defined by Khan [23] and shown in Figure 5.17 are investigated;

1. Frame with shear wall
2. Frame with shear band and single outrigger at 20th story
3. End channel frame tube
4. Exterior frame tube
5. Exterior diagonal tube



1 2 3 4 5

Figure 5.17 Plan views of all structural systems

Discussion of results:

The displacement at top floor Δx and base moment Mz for point *A* are given in Table 5.12 and plotted as a curve relationship in Figure 5.18 for five different structural systems. Comparing the results for the five structural systems, it is seen that the P-Δ effect mainly depends on the type of building systems selected. The displacement at top floor Δx of exterior frame tube and exterior diagonal tube type of systems are extremely smaller than other type of structures. However, the base moment Mz of end chanel frame tube and exterior diagonal tube type of systems are smaller than others. Overall results show that best performance against P-Δ effect is obtained using exterior diagonal tube type of structure. This conclusion is also verified by free vibration analysis result which is shown in Figure 5.19.

Free vibration Staad Pro window results are shown in Table 5.11 for frame tube structural system and first mode is shown in red rounded line.

Table 5.11 Free vibration results for exterior frame tube structural system in Staad Pro

Tube & Shear.F.V NOR - Frequencies & Mass Participations

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %
1	1.085	0.922	59.245	0.000	0.000
2	2.249	0.445	0.000	75.848	0.000
3	2.382	0.420	0.000	0.000	0.000
4	2.434	0.411	0.000	0.034	0.000
5	3.185	0.314	22.608	0.000	0.000
6	4.441	0.225	0.000	0.532	0.000

Table 5.12 All structural systems models showing Δx, Mz, free vibration for static loads

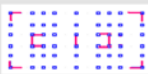
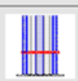
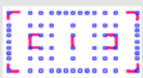
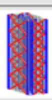
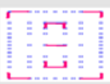
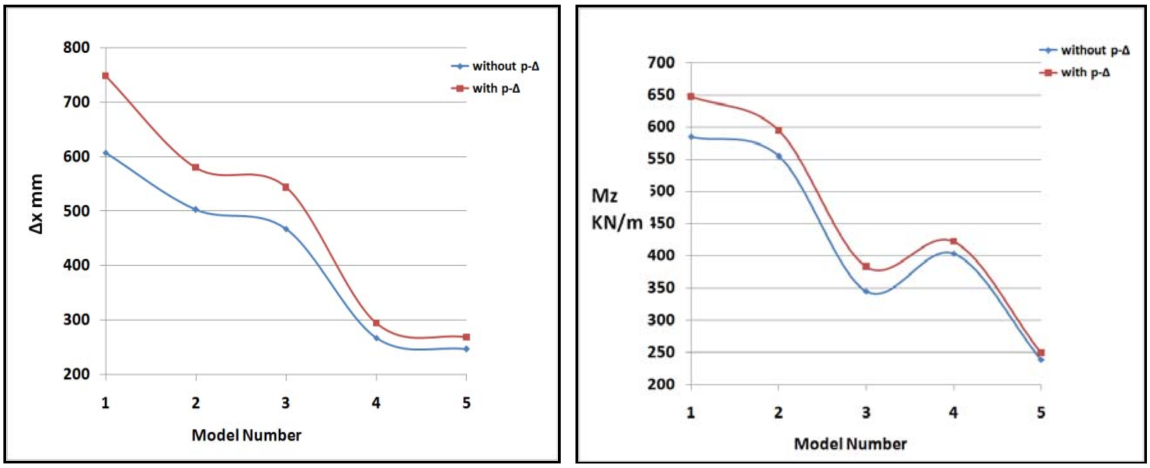
			STATIC				Free Vibration	
			Δx(mm)		Mz (KN/m)			
model numbe	type of system	model view	without p-Δ	with p-Δ	without p-Δ	with p-Δ	frequency(Hz)	period(sec)
1	Shear Only		607.446	748.23	584.782	647.41	0.735	1.36
2	out rigger @30 story from top		503.226	580.165	554.465	594.281	0.815	1.226
3	Frame End Channel		467.784	543.714	345.02	382.992	0.828	1.208
4	Exterior Frame Tube		267.687	294.772	403.6	422.135	1.085	0.922
5	Exterior Diagonal Bracing Tube	 	246.896	269.069	238.378	248.691	1.124	0.889

Table 5.13 Free vibration results for exterior frame tube structural system in Staad Pro

Tube & Shear.F.V NOR - Frequencies & Mass Participations

Mode	Frequency Hz	Period seconds	Participation X %	Participation Y %	Participation Z %
1	1.085	0.922	59.245	0.000	0.000
2	2.249	0.445	0.000	75.848	0.000
3	2.382	0.420	0.000	0.000	0.000
4	2.434	0.411	0.000	0.034	0.000
5	3.185	0.314	22.608	0.000	0.000
6	4.441	0.225	0.000	0.532	0.000



(a) (b)

Figure 5.18 Various structural systems (a) displacements Δx (mm) and

(b) base moments Mz (kNm)

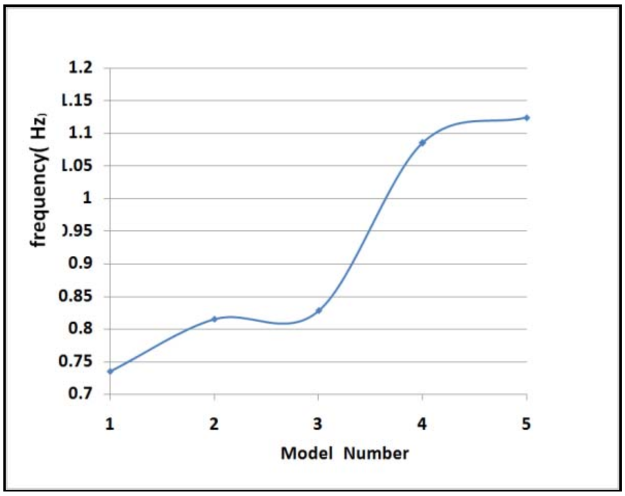


Figure 5.19 Various structural systems fundamental frequencies (Hz)

5.5 Dynamic analysis of 50 story buildings

From a design perspective it is helpful to understand the behavior characteristics of the structure from a dynamic analysis to evaluate the influence of P-Δ effects on the dynamic response. The different seismic behaviors in the same structural system may be produced according to the assumptions within the system as well as response spectrum and time history employed, due to the fact that the structural responses of structures are dominantly affected by applied force. Nevertheless, previous studies [19] have used the linear model or the stiffness degradation model constructed on the basis of the load-displacement relationship without the additional consideration of the axial force. The implications of this are that reliable dynamic responses of the structures may not be obtained. Therefore in this study, to observe the P-Δ effect in structures subjected to earthquake loading, nonlinear dynamic analysis were carried out. Dynamic analysis (with and without P-Δ) were done by using two different method such as Response Spectrum and Time History method which are available in Staad Pro program.

5.5.1 Response Spectrum Analysis

The parameters that have been chosen and allowed for response spectrum method by Staad Pro are:

Code IS-1893

Combination method = SRSS

Direction X

Damping =0.05

Subsoil classification = medium soil type

Depending upon time period, type of soil, damping, average response acceleration coefficient (Sa/g) will be calculated internally in software, see Figure 5.20.

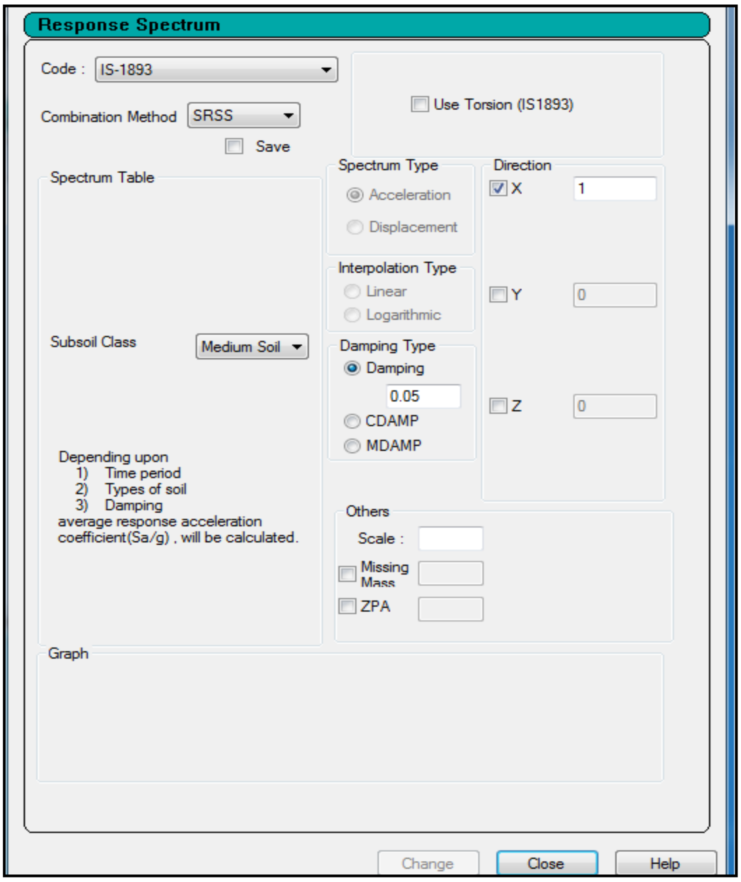


Figure 5.20 Response spectrum data input in Staad Pro

All other required DL (self weight and floor weight (slab + partition)) in direction X & Y is included with Response spectrum load. Load cases and Combinations are listed below:

1- Load 1:Factored gravity loads (DL+LL)
2- Load2: Response spectrum load
3- Combination 1: Load 1+Load 2

4- Combination 2: Load1-Load2

5.5.2 Time History Analysis

The parameters that have been chosen and allowed for time history by Staad Pro are:

Function type = Harmonic function

Loading type = acceleration

Function shape = Sine

Frequency = 10 cycle /sec

Amplitude = 100

Cycle = 100

All other required DL (self weight and floor weight (slab+ partition)) in direction X & Y is included with Time History load.

Load cases and Combination is as following:

1. Load 1:Factored Gravity Loads (DL+LL)
2. Load2: Time History load.
3. Combination 1 = Load 1+Load 2
4. Combination 2 = Load1-Load2

The load type as shown in Figure 5.21 can be entered in three types acceleration, force and moment.

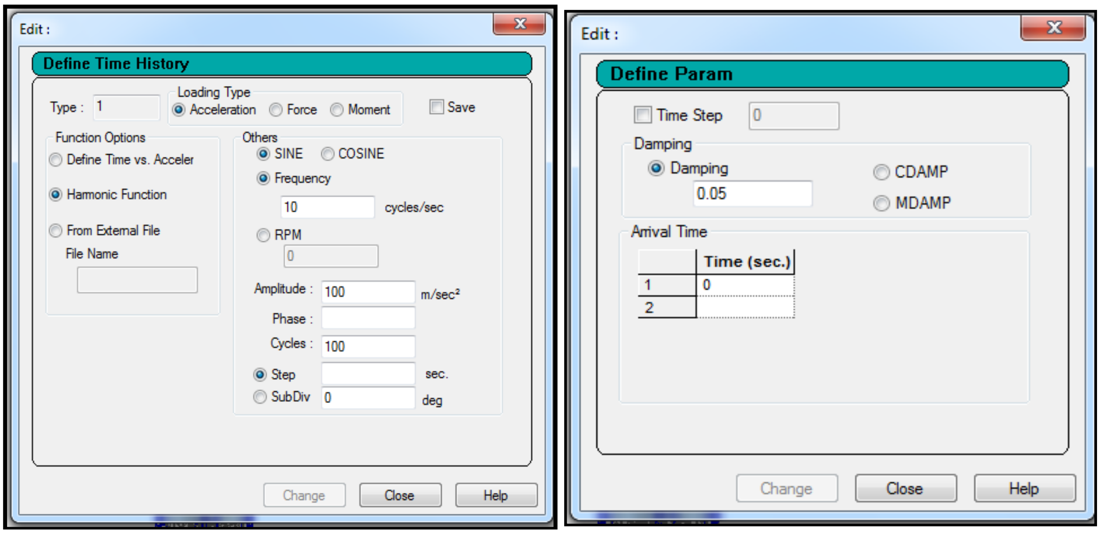


Figure 5.21 Time History defining in Staad Pro

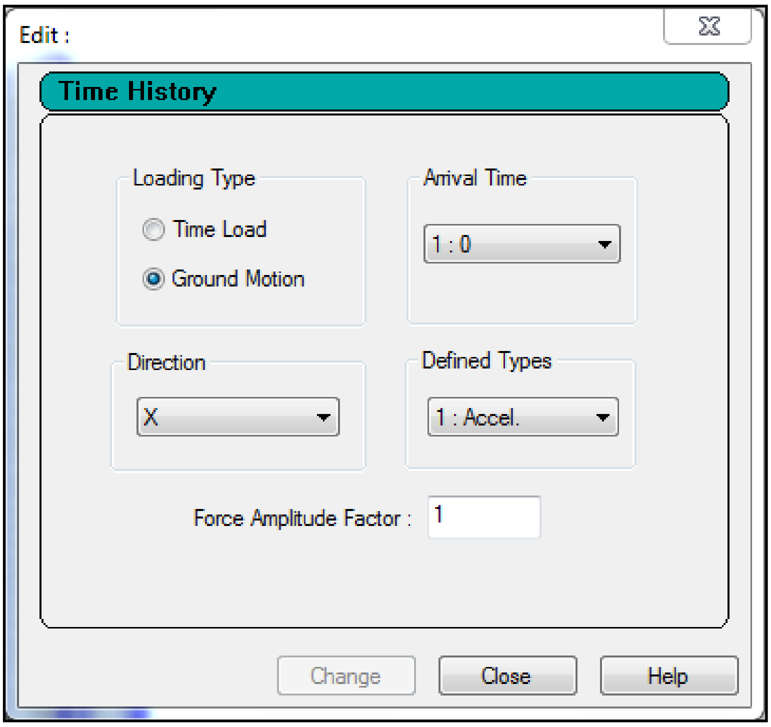


Figure 5.22 Time history load as ground motion acceleration in Staad Pro

After applying all the loads as mentioned above, Response spectrum and Time history types of analyses are done without and with P-Δ

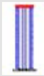
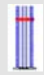
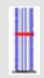
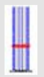
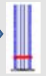
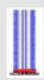
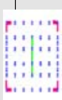
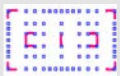
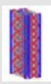
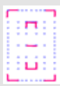
Discussion of results:

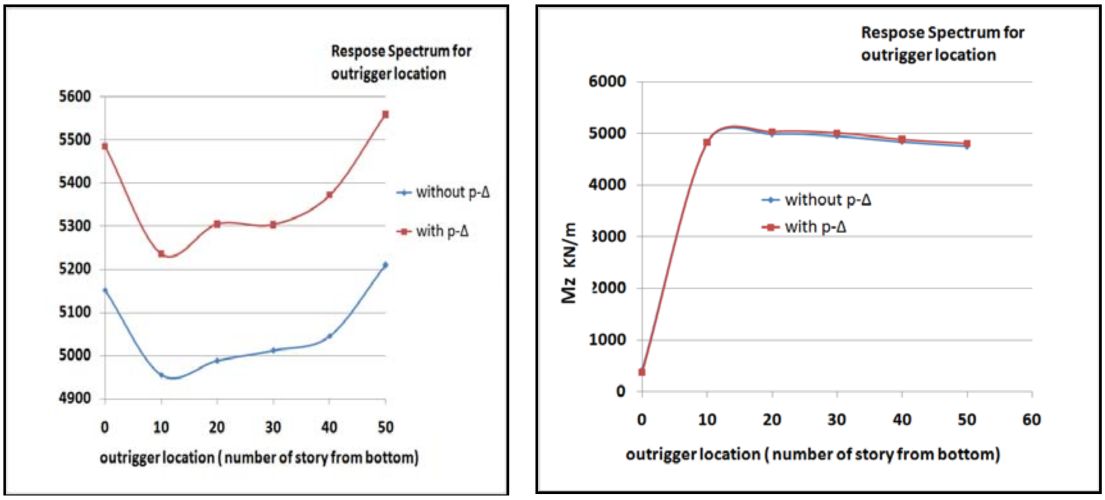
In order to review the seismic P–Δ effect in various structural systems, nonlinear dynamic analyses were conducted. To summarise all analysis, displacements Δx and base moments Mz for without and with P-Δ analysis are tabulated in Table 5.14. Response spectrum results are shown in Figure 5.23 and Figure 5.24. And Time History results are shown in Figure 5.25 and Figure 5.26.

Generally similar to static analysis modifying the structural systems will decreases P-Δ effects. Comparing the dynamic analysis results of both analysis type of the all structural system, it is seen that the P-Δ effect mainly depends on the type of building systems selected. The displacement at top floor Δx of exterior frame tube and exterior diagonal tube type of systems are extremely smaller than other type of structures. However, the base moment Mz of end channel frame tube and exterior diagonal tube type of systems are smaller than others.

From Figure 5.23 (a) optimum location for single outrigger structural system in Response Spectrum analysis is the system with outrigger at 10 stories from bottom. As location of outrigger will move down from top value of Δx will be lowered to the limit when outrigger at 10 stories from bottom that it is the optimum limit and then with changing outrigger location Δx will rise again. The gap between normal analyses without P-Δ and analyses with P-Δ is wide and nearly constant through all location and it means amount of P-Δ is constant. From Table 5.14 and Figure 5.24 for various structural systems in Response Spectrum analysis as the models go to high advanced structural system type, Δx value will be lowered and best model is exterior diagonal bracing system (model 5) from the five models that has been entered to the tests and also the gap between normal analysis without and with P-Δ (P-Δ amount) is shown in Figure 5.24 between two types of analysis and it will move to be narrow with changing in the models to more advanced system.

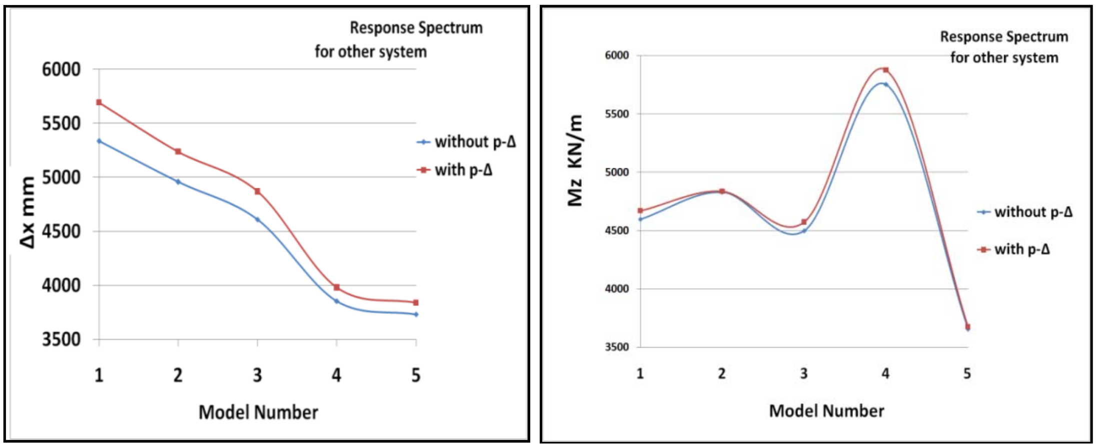
Table 5.14 Dynamic analysis of various structural systems displacements Δx (mm) and base moments Mz (kNm)

model number	structural system		Dynamic							
			Response Spectrum				Time History			
			Δx (mm)		Mz(KN/m)		Δx (mm)		Mz(KN/m)	
			without p-Δ	with p-Δ	without p-Δ	with p-Δ	without p-Δ	with p-Δ	without p-Δ	with p-Δ
1	Shear Only		5331.243	5688.828	4598.105	4670.334	4009.67	4245	3146.185	3291.4
	Out Rigger	 50 story (top)	5209.964	5558.786	4751.375	4807.199	3859	4065.848	3762.459	3864.304
	Out Rigger	 40 story	5045.144	5372.737	4839.032	4888.662	3726.392	3928	3551.504	3691.489
	Out Rigger	 30 story	5011.835	5303.701	4954.598	5013.806	3791.76	3973	3973	3873.597
	Out Rigger	 20 story	4988.533	5305.185	4989.652	5037.722	3795.642	3986.28	3551.752	3536.509
2	Out Rigger	 10 story	4955.22	5236.152	4829.079	4835.193	3711.425	3887.483	3225.355	3304.315
	Out Rigger	 0 story (base)	5151.551	5484.716	418.258	377.907	3870.746	4088.08	274.442	250.156
3	Frame End Channel		4608.897	4864.898	4497.769	4572.453	3473.873	3635.821	3620.805	3773.03
4	Exterior Frame Tube		3854.716	3978.601	5750.971	5874.718	2906.3	2976.914	4815.47	4874.08
5	Exterior Diagonal Bracing Tube	 	3729.95	3837.04	3655.049	3675.148	2784.97	2850.814	3135.92	3175



(a) (b)

Figure 5.23 Response Spectrum analysis for single outrigger locations (a) displacements Δx (mm) and (b) base moments Mz (kN.m)

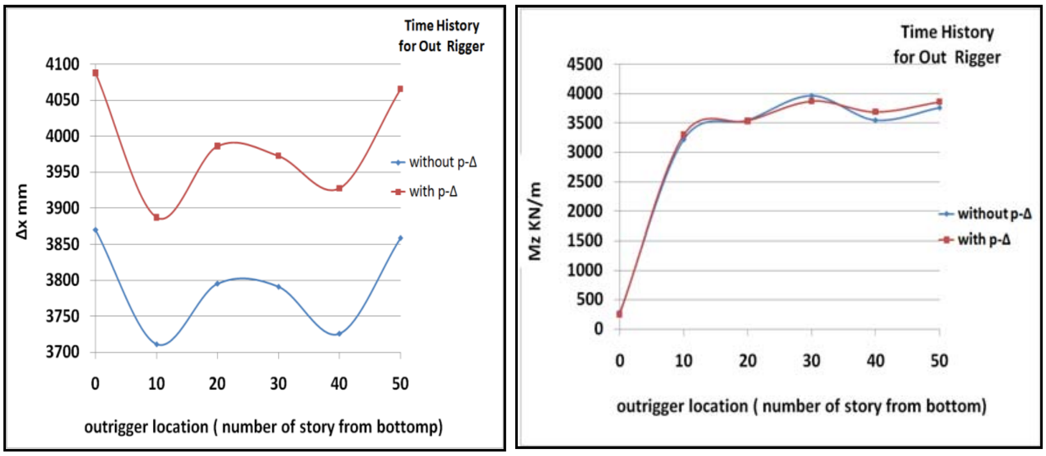


(a) (b)

Figure 5.24 Response Spectrum analyses of various structures

(a) displacements Δx (mm), (b) base moments Mz (kN.m)

Now for Time History results from Table 5.14 and Figure 5.25 and for optimum location for single outrigger structural system is the system with outrigger at 10 stories. As location of outrigger will move down from top, value of Δx will be lowered to the limit when outrigger at 40 stories from top that it is the optimum limit and then with changing outrigger location Δx will rise again. The gap between without and with P-Δ analysis is wide and nearly constant through all location and it means amount of P-Δ is constant, again similar to the result in Response Spectrum analyses.

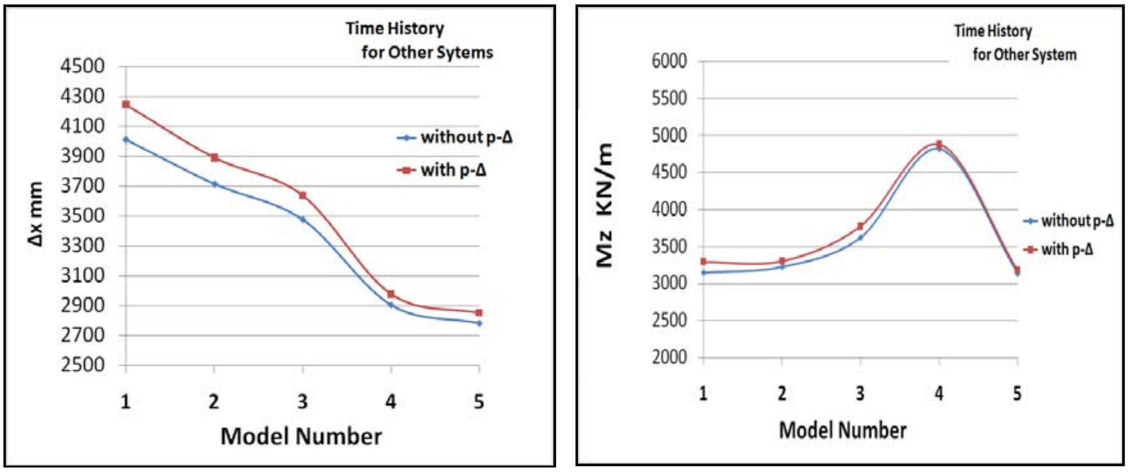


(a) (b)

Figure 5.25 Time History analyses for single outrigger locations

(a) displacements Δx (mm), (b) base moments Mz (kN.m)

From Table 5.14 and Figure 5.26 for various structural systems in Time History as the models go to high advanced structural system type, Δx value will be lowered and best model is exterior diagonal bracing system (model 5) from the five models that has been entered to the tests and also the gap between without and with P-Δ analysis is shown in Figure 5.26 (a) between two types of analysis is clear and it will move to be narrow with changed the models to more advanced system again similar to the result in Response Spectrum analyses.



(a) (b)

Figure 5.26 Time History analyses of various structures

(a) displacements Δx (mm), (b) base moments Mz (kN.m)

In table 5.15 summarizes all analysis which have done with all results.

Table 5.15 All result for third and fourth example tests

		STATIC				Dynamic											
		without P-Δ		with P-Δ		Free Vibration		Response Spectrum				Time History					
								without P-Δ		with P-Δ		without P-Δ		with P-Δ			
		Δx(mm)	Mz	Δx	Mz	frequency (Hz)	period (sec)	Δx	Mz	Δx	Mz	Δx	Mz	Δx	Mz		
Shear Only		607.446	584.782	784.23	647.41	0.735	1.36	5331.24	4598.11	5688.83	4670.334	4009.67	3146.185	4245	3291.4		
Out Rigger	50 story (top)	592.808	533.385	710.105	592.763	0.742	1.348	5209.96	4751.38	5558.79	4807.199	3859	3762.459	4065.85	3864.3		
Out Rigger	40 story	558.846	532.386	665.736	590.193	0.76	1.316	5045.14	4839.03	5372.74	4888.662	3726.392	3551.504	3928	3691.49		
Out Rigger	30 story	525.767	529.747	616.035	584.423	0.791	1.264	5011.84	4954.6	5303.7	5013.806	3791.76	3973	3973	3873.6		
Out Rigger	20 story	504.126	507.182	581.065	551.59	0.815	1.226	4988.53	4989.65	5305.19	5037.722	3795.642	3551.752	3986.28	3536.51		
Out Rigger	10 story	520.941	435.515	607.254	486.127	0.798	1.253	4955.22	4829.08	5236.15	4835.193	3711.425	3225.355	3887.48	3304.32		
Out Rigger	0 story (base)	570.754	48.882	677.742	45.857	0.761	1.314	5151.55	418.258	5484.72	377.907	3870.746	274.442	4088.08	250.156		
Frame End Channel		467.784	345.02	543.714	382.992	0.828	1.208	4608.45	4497.77	4864.9	4572.453	3473.873	3620.805	3635.82	3773.03		
Exterior Frame Tube		267.687	403.6	294.772	422.135	1.085	0.922	3854.72	5750.97	3978.6	5874.718	2906.3	4815.47	2976.91	4874.08		
Exterior Diagonal Bracing Tube		246.896	238.378	269.069	248.691	1.124	0.889	3729.95	3655.75	3837.04	3675.148	2784.97	3135.92	2850.81	3175		

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

Tall building has been growth and developed with increasing in population and high demand of land. The problem was solved by increasing number of stories from 10 to 20 and last now to be more than 200 to 300 and may be more in near future with tower system.

The problem is not easy for structural engineer because now many points that were before not important to be include in calculations for the reason that their effects are very small or negligible or some simple modification or amplification can solve that with easy calculations. But now with increasing in number of stories the value of these effects cannot be neglected or simplified or changing to equivalent linear calculations.

One of these new points is P-Δ effect that was before in small structure neglected and in medium structures some amplification or factors can be added that is accepted by some codes and structural references for limit conditions. But now after passing these limits and especially in large structures designer has to use advanced real calculations with details using computer structural softwares to obtain P-Δ first, and second to solve the problem for high value that is not accepted by codes and is important part.

Solving problem of high displacement and P-Δ effects are done in this thesis by choosing different structural systems., it needs several tests with a lot of experience in design to choose the best type with low cost and more efficiency.

First checked was done in different number of stories (13, 25, 37, and 50) structure to observe P-Δ effects, from the results it is clear that highest difference is in 50 stories, and as number of stories increases, P-Δ effects increases. The analysis with P-Δ can be ignored for 13 story frame and lower because of the difference (between analysis without and with P-Δ) is not reasonable. And this is not condition because slender of structure members, amount or type of loads make influence and cross section area of the whole building due to the height of structure need to be calculated or checked before giving decision. So 50 stories building has been chosen for all remain examples to be studied. Same discussion is applicable for base moment almost.

The relationship for numbers of stories and fundamental frequency, indicates that increasing in number of stories will reduce the frequency and thus the stiffness will be lower and this cause the displacement to be high.

One modification has been added to the structure to decrease P-Δ effect that is adding outriggers (in some selected floors) with internal shear trusses or bracing with different numbers of outriggers. When the lateral load acts on this type of building, the bending of the core rotates the stiff outrigger arms, which is connected to the core and induces tension and compression in the columns.

There are some factors affecting the efficiency of outrigger system comparing with others, such as stiffness of member, location of the outrigger, the geometry of building, the core shear wall dimension and shape, and floor to-floor height of the building.

Selecting optimum location of single outrigger system are important, four type of outrigger system has been chosen due to outrigger location starting from top to the base by 10 story intervals analysis are repeated. The aim of this part is to find best location of outrigger, and due to the results at 20 stories starting from bottom is best. This is also clear for free vibration, maximum frequency is for frame with outrigger at 20 floors from bottom and it gives same results for optimum location.

Some important selected systems have been used in the test including outrigger system. Here first in outrigger system and for the best location of outrigger for dynamic has been included and best location for outrigger is at 10 story starting from bottom for dynamic case. The location is differs here from static affect that is at 20 story because more affection of static will start from top (as example from wind affect) but in dynamic in our test loads are coming from seismic ground motion it means from bottom near foundation.

Two types of dynamic loads have been chosen, response spectrum and time history that is found in Staad Pro. As a general same point has been found that with modifying bracing system for any frame or multistory structure will reduce p-Δ value like static but nearly smooth curve will appear and not like outrigger systems that differs in locations that shows non smooth curve with concave down giving two different optimum points for dynamic results.

6.2 Future works

Future work is proposed to expand and develop of this study:

Analysis can be extended to include multi story from 51 to 100 to 200 or for large tower that require changing in system of structure and testing new types of structures.

P-Δ effect can be extend to include P-δ and torsional P- Δ and studying and testing with detail affect of size and distribution of shear and bracing members on their effects. And this may affect by acting wind or seismic loads in inclined direction or unsymmetrical of shape or loading cause torsional affect.

LIST OF REFERENCES

[1] Black,E.F. (2011). "Use of stability coefficients for evaluating the P–Δ effect in regular steel momentresisting frames", *Engineering Structures,* **33**, 1205-1216,.

[2] Dobson, A.J. (2002). "*An Introduction to Generalized Linear Models*", Second Edition, Taylor & Francis Group.

[3] Chen, S.J. and Wang, W.C. (1999). "Moment amplification factor forP-δ Effect of steel beam-column",*Journal of Structural Engineering*, **125**(2), 219-223,.

[4] Shakya, A.M. (2011). "*P-Delta Effects on Steel Moment Frames with Reduced Beam Section Connection*", M.Sc. Thesis, Southern Illinois University Carbondale, Department of Civil and Environmental Engineering,.

[5] Montgomery C.J.(1981) "Influence of P-delta effects on seismic design",*Canadian Journal of Civil Engineering***8**, 31-43,.

[6] Gupta A andKrawinkler H. (2000). Dynamic P-delta effects for flexible inelastic steelstructures. "*Journal of Structural Engineering*", **126(1)**:145-54,.

[7] Tremblay R, Coté B and Léger P. (1999) ."An evaluation of P-Δ amplification factors in multi-storey steel moment resisting frames". *Canadian Journal of Civil Engineering*, **26**:535-48.

[8] NBCC. (2005). National Building Code of Canada.12th ed. Canadian commission on building and fire codes. Ottawa (ON, Canada): National Research Council of Canada (NRCC),

[9] Paulay T, Priestley MJN. (1992). *Seismic design of reinforced concrete and masonry buildings*. New York (NY): John Wiley & Sons, Inc.

[10] NEHRP. (2000). (National Earthquake Hazards Reduction Program). NEHRP Recommended provisions for seismic regulations for new buildings and other structures.Washington (DC): Building Seismic Safety Council. FEMA 368 and 369,.

[11]Dobson, R. and Arnott, K. “A brief overview of 2ndorder (or P-Delta) Analysis”, Technical Director for FastrakKennyArnott – Product Manager for S-Frame, CSC (UK)

[12] Angela M., (2001) “*Comparison of P-Δ analyses of plane frames using commercial structural analysis programs and current AISC design specifications*”, Blacksburg, VA 24061.

[13] Brown, D. **(**2002) “Multi-storey Frame Design”, *New Steel Construction*,**10(6),**(2002).

[14] Rathbone A.J. “Second-order effects who needs them?”,*Structural Engineer*, **80(21),**.

[15] DavidsonB.J., FenwickR.C. and ChungB.T., **(**1992). “P-Δ effects in multi-story structural design”,*Earthquake Engineering*,Tenth World Conference at Balkema Rotterdam **17,**.

[16] Bhowmick, A.K., Driver, R.G. and Grondin, G.Y. (2009). “Seismic analysis of steel plate shear walls considering strain rate and P-delta effects”,*Journal of Constructional Steel Research*, **65,**1149-1159,.

[17] Applied Technology Council, (1978). “*Tentative Provisions for the Development of Seismic Regulation for Buildings*, ATC Publication ATC 3-06,.

[18] Wilson E.L. (1997). “*Three dimensional dynamic analysis of structures: with emphasis on earthquake engineering*”, *Computers and Structures Inc*.,.

[19]Andrews, A.L. (1977). “Slenderness effects in earthquake engineering frames”, *Bull NZNatSoc Earthq Eng*, **10**, 154–158.

[20] Paulay, T. (1978). “A consideration of P–delta effects in ductile reinforced concrete frames”,*Bull NZ Nat SocEarthqEng*, **11**, 151–160.

[21] Rutenberg, A. (1987). “Simplified P-Delta Analysis for Asymmetric Structures”, Struct. Div. ASCE, P1993-2013.

[22] Dobson R. Technical Director for S-Frame TM and 3D+TM, CSC (UK) Ltd.”*An Overview of P-Delta Analysis*”.

[23] Khan; F.R. (1974). “New structural systems for tall buildings and their scale effects on cities”, *Proceedings of Symposium held at Vanderbilt University,*

Nashville, Tennessee, November 14-15, 99-129,.

[24] Gunel M. H.and Ilgin H.E. (2006), A proposal for the classification of structural systems of tall buildings. Faculty of Architecture, Middle East Technical University, Ankara, Turkey.

[25] Iyenger. Hal, (1995). “Composite and Steel High Rise Systems. Habitat and The HighRise, Tradition & Innovation”. In Proceedings of the Fifth World Congress.Amsterdam.

[26] Kian,P. J. and Siahaan, F.T. (2001).”*The use of outrigger and belt truss system for high-rise concrete-buildings* “, DimensiTeknikSipil, **3(1),**36-37,.

[27] Madison R Paulino, (2010). “*PrelIminary DesignofTall Buildings”*, Submitted to the Faculty Of the Worcester Polytchnic Institute (sec 1.2.4.1 to 1.2.4.2).

[28] Stafford, B. and Couls, A. (1991). “*Tall building structure / analysis &design*”,.

[29]Er.T. and Ranga R.,P-Δ& Buckling –in Staad Pro

[30]ACI Committee 318. (1999). “Building code requirements for reinforced concrete(ACI 31899)”, Detroit: American Concrete Institute,

[31]LRFD–AISC, (1999). “Manual of steel construction. Load and resistance factor design. Metric conversion of the second edition”, **I, II**.

[32] Staad Pro V8i. (2008), Technical Reference,sec1.2,input generation,.