# EFFECT OF DIAPHRAGM DISCONTINUITY IN THE SEISMIC RESPONSE OF MULTI-STOREYED BUILDING

*A THESIS*

*Submitted by*

**K. SURESH CHOWDARY (212CE2034)**

*In partial fulfillment of the requirements for the award of the degree of*

**MASTER OF TECHNOLOGY**

**Department of Civil Engineering**
**National Institute of Technology Rourkela**
**Orissa -769008, India**

**May 2014**

# EFFECT OF DIAPHRAGM DISCONTINUITY IN THE SEISMIC RESPONSE OF MULTI-STOREYED BUILDING

*A THESIS*

*Submitted by*

**K. SURESH CHOWDARY (212CE2034)**

*In partial fulfillment of the requirements for the award of the degree of*

**MASTER OF TECHNOLOGY**

**Department of Civil Engineering**
**National Institute of Technology Rourkela**
**Orissa -769008, India**

**May 2014**

NATIONAL INSTITUTE OF TECHNOLOGYROURKELA
Orissa– 769 008, India

## CERTIFICATE

This is to certify that the thesis entitled **"Effect of Diaphragm Discontinuity in the Seismic Response of Multi-Storeyed Building"** submitted by **Mr. Kilari Suresh Chowdary** in partial fulfillment of the requirements for the award of Master of Technology Degree in Civil Engineering with specialization in Structural Engineering at the National Institute of Technology Rourkela is an authentic work carried out by him under my supervision. To the best of my knowledge, the matter embodied in the thesis has not been submitted to any Other University/Institute for the award of any degree or diploma.

Place: NIT Rourkela
Date:

**Dr. Pradip Sarkar**
Department of Civil Engineering

# ACKNOWLEDGEMENT

To **Dr. Pradip Sarkar**, my guide, I express my sincere thanks for making this work possible. His valuable teachings will be engraved in my mind forever.

I would like to give special word of thanks to **N.Roy,** Head, Department of Civil Engineering and for their constant encouragement and help during my work.

I would like to thank my parents for making me believe in my dreams and for constantly supporting me to achieve them.

My deepest thank goes to my friends **MD. Zeeshan Ali** and **Sohrab Youldash** who shared with me the most significant moments of these years.

Finally, I would like to thank all friends and colleagues at the Department of Civil Engineering who have contributed in numerous ways to make this program an enjoyable one.

**K. SURESH CHOWDARY**

## ABSTRACT

**Keywords:** Seismic analysis, diaphragm discontinuity, nonlinear analysis, pushover analysis, time history analysis

Many buildings in the present scenario have irregular configurations both in elevation and plan. This in future may subject to devastating earthquakes. It is necessary to identify the performance of the structures to withstand against disaster for both new and existing buildings. Now a days openings in the floors is common for many reasons like stair cases, lighting architectural etc., these openings in diaphragms cause stresses at discontinues joints with building elements. Discontinuous diaphragms are designed without stress calculations and are thought-about to be adequate ignoring any gap effects. In this thesis an attempt is made to try to know the difference between a building with diaphragm discontinuity and a building without diaphragm discontinuity.

# CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

In multi-storeyed framed building, damages from earthquake generally initiates at locations of structural weaknesses present in the lateral load resisting frames. This behaviour of multi-storey framed buildings during strong earthquake motions depends on the distribution of mass, stiffness, strength in both the horizontal and vertical planes of buildings. In few cases, these weaknesses may be created by discontinuities in stiffness, strength or mass along the diaphragm. Such discontinuities between diaphragms are often associated with sudden variations in the frame geometry along the length of the building. Structural engineers have developed confidence in the design of buildings in which the distributions of mass, stiffness and strength are more or less uniform. There is a less confidence about the design of structures having irregular geometrical configurations (diaphragm discontinuities).

In the present thesis, the effect of diaphragm discontinuity on the seismic response of a selected multi storey building is studied.

### 1.1.1Diaphragm Discontinuity

According to IS-1893:2002: Diaphragms with abrupt discontinuities or variations in stiffness, which includes those having cut-out or open areas greater than 50 percent of the gross enclosed diaphragm area, or changes in effective diaphragm stiffness of more than 50 percent from one storey to the next.

In structural engineering, a diaphragm is a structural system used to transfer lateral loads to shear walls or frames primarily through in-plane shear stress. Lateral loads are usually wind and earthquake loads. Two primary types of diaphragm are rigid and flexible. Flexible diaphragms resist lateral forces depending on the area, irrespective of the flexibility of the members that they are transferring force to. Rigid diaphragms transfer load to frames or shear walls depending on their flexibility and their location in the structure. Flexibility of a diaphragm affects the distribution of lateral forces to the vertical components of the lateral force resisting elements in a structure.

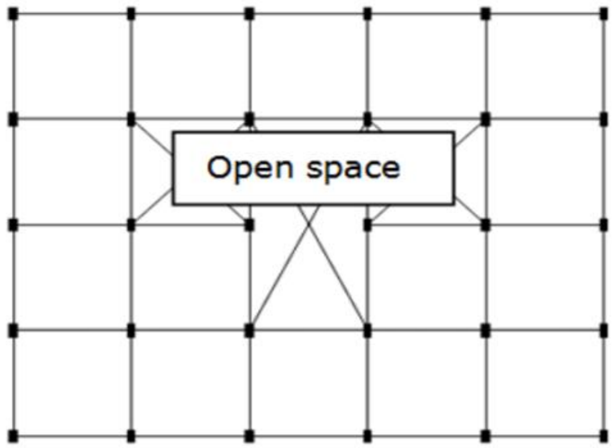


Fig. 1.1: Frame with diaphragm discontinuity

In the above figure is an example of a diaphragm discontinuity where an opening in the middle of the floor slab can be seen.

## 1.2OBJECTIVES

A detailed literature review is carried out to define the objectives of the thesis. The literature review is discussed in detail in Chapter 2 and briefly summarized as follows:

i) International Building Code (IBC) suggests that for buildings with diaphragm separation, the code prescribes a rise of twenty five percent within the design forces found for connections of diaphragms.

ii) American Concrete Institute Building Code, I 318-08 doesn't address the result of a gap on the floor.

iii) ASCE 7-05, Section 12.3.1.2, permits diaphragms of RCC slabs or concrete crammed metal decks with span-to-depth ratios of 3:1 or less.

iv) Nakashima et al. analyzed a multi storey RC building using non-linear analysis last that the inclusion of diaphragm flexibility failed to considerably modification the particular amount of the structure and therefore the most total base shear.

Based on the literature review, the salient objective of the present study have been identified as follows:

1. To investigate the seismic performance of a multi-story building with different diaphragms i.e., model-1 and model-2 through a detailed case study.
2. To evaluate the effect of diaphragm discontinuity on these two models.

## 1.3 SCOPE OF THE PRESENT STUDY

In the present study, a typical multi storey building is analyzed using commercial software SAP2000 for nonlinear static (pushover) and dynamic (time history) analysis. All the analyses has been carried out considering and ignoring the diaphragm discontinuity and the results so obtained have been compared. This study is done for RC framed multistory building with fixed support conditions. The results of this report is based on one case-study.

## 1.4METHODOLOGY

a) A thorough literature review to understand the seismic evaluation of building structures and application of pushover analysis and time history analysis.
b) Select an existing building with diaphragm discontinuity.
c) Design the building as per prevailing Indian Standard for dead load, live load, and earthquake load.
d) Analyze the building using linear/nonlinear static/dynamic analysis methods.
e) Analyze the results and arrive at conclusions.

## 1.5 ORGANIZATION OF THE THESIS

The thesis is organized as per detail given below:

Chapter 1: Introduces to the topic of thesis in brief.

Chapter 2: Discusses the literature review i.e. the work done by various researchers in the field of diaphragm discontinuity of building.

Chapter 3: Modelling of the building has been discussed in this chapter.

Chapter 4: In this chapter pushover analysis has been studied in detail. The theory and procedure of pushover analysis discussed in brief.

Chapter 5: In this chapter time history analysis has been discussed in detail. The theory related to time history analysis also discussed in brief.

Chapter 6: The results from push over analysis and time history analysis were studied. Comparison between the two models were done and conclusion was given followed by references.

## CHAPTER 2

## LITERATURE REVIEW

### 2.1 GENERAL

To provide a detailed review of the literature related to diaphragm discontinuity in its entirety would be difficult to address here. A brief review on diaphragm discontinuity of previous studies is presented here. This literature review focuses on recent contributions related to diaphragm and past efforts most closely related to the needs of the present work.

### 2.2 LITERATURE REVIEW

International Building Code-2006, needs the diaphragm with unexpected discontinuities or variations in stiffness, also those having cutout or open areas greater than 50 percent of the gross enclosed diaphragm area, or change in effective diaphragm stiffness of over 50 percent from one story to consequent, to be considered as irregular in plan. For structures with this diaphragm discontinuity, the code prescribes a rise of twenty five % within the design forces determined for connections of diaphragms to vertical components. The code doesn't attribute any criteria touching on the diaphragm style itself.

In the area of concrete design, American Concrete Institute Building Code ACI 318-08, addresses the impact of a gap on slabs in native terms. It restricts gap size in column strips and limits the allowable most openings size in middle strips. The interrupted reinforcement by a gap should be placed at one-half on both sides of the opening. ACI 318-08 doesn't address the general impact of a gap on the floor. This reinforcement replacement criterion has no restriction on the opening size as long because it is among the prescribed column and middle strips demand.

ASCE 7-05, the Guide to the planning of Diaphragms permits diaphragms of concrete slabs or concrete stuffed metal decks with span-to-depth ratio of 3:1 in structures that haven't any horizontal plan irregularities to be idealised as rigid, otherwise, the structural analysis shall expressly embody thought of the stiffness of the diaphragm while not explaining however.

In the field of concrete beams with net openings, Nasser et. al. (1993), Mansur et. al. (1999) and Abdalla and Kennedy (1988) shed light-weight on however a gap in rectangular RC or prestressed beams affects stress distributions and capability of a concrete beam. Sadly, the theory provided was mark against accessible experimental results with no proof that it is extended to incorporate alternative configurations. Kato et. al. (1991), Taylor et. al. (1992) and Daisuke et. al. (1959), investigated the planning of RC shear walls with one gap. Again, the results were solely applicable to the pertinent cases.

Other studies were conducted within the area of concrete panels, notably within the area of buckling. Swartz and Rosebraugh (1974), Aghayere and Macgregor (1971), and Park and Kim (1992) addressed buckling of concrete plates beneath combined in-plane and transverse loads. Since concrete diaphragms is thought-about as concrete plates with beams as web stiffeners, this buckling approach doesn't address openings.

Button et. al. (1984) investigated the influence of floor diaphragm flexibility on 3 totally different buildings, massive arrange aspect ratio, three-winged (Y-shaped) and separate towered. Notwithstanding the insight given into however lateral force distribution differs from rigid to flexible diaphragms, openings weren't thought-about. Basu (2004), Jain (1984) and Tao (2008) had analyzed differing kinds of structures starting from formed, Y-shaped to long and slender buildings. Although these studies proved to be contributing to understanding the dynamics of such style of structures, they didn't address the effects of diaphragm openings.

Kunnath et. al. (1991) developed a modeling theme for the inelastic response of floor diaphragms, and Reinhorn et. al. (1992) and Panahshahi et. al. (1988) verified it, using shake table testing for single-story RC, 1:6 scaled model structures, gap effects weren't incorporated within the model and also the projected model’s ability to account for in-plane diaphragm deformations, confirmed the chance of building collapse, as a results of diaphragm yielding for low rise (one-, two-, and three-story) rectangular buildings with finish shear walls and building plan aspect ratio bigger than 3:1. Nakashima et. al. (1984) analyzed a seven story RC building exploitation linear and non-linear analysis final that the inclusion of diaphragm flexibility didn't considerably amendment the particular amount of the structure and also the most total base shear. Effects of diaphragm openings weren't a part of that analysis.

Anderson et. al. (2005) developed analytical models using commercial computer programs, SAP 2000 and ETABS to judge the seismic performance of low-rise buildings with concrete walls and versatile diaphragms. Again, openings weren't a part of the models devised. Barron and Hueste (2004) evaluated the impact of diaphragm flexibility on the structural response of 4 buildings having 2:1 and 3:1 set up plan ratios and were 3 and 5 stories tall, severally. The building diaphragms didn't yield and also the buildings in question didn't have diaphragm openings. Hueste and Bai (2004) analyzed a model five-story RC frame building designed for the mid-1980s code needs within the Central us. Recommending Associate in Nursing addition of shearwalls and RC columns jackets light-emitting diode to decrease within the likelihood of exceeding the life safety (LS) limit state. Unfortunately, retrofitting recommendations were specific to the current structure solely and no diaphragm opening effects were looked into.

Kunnath et al. (1987) developed associate analytical modeling theme to assess the damageability of RC buildings experiencing nonresilient behavior underneath earthquake loads. The results of the response analysis, expressed as damage indices, did not provide any respect to diaphragm openings. Jeong andElnashai (2004) projected a three-dimensional seismic assessment methodology for plan-irregular buildings. The analysis showed that plan-irregular structures suffer high levels of earthquake damage attributable to torsional effects. The analysis additionally verified that standard damage observation approaches may well be inaccurate and even unconservative. However, the assessment did not account for diaphragm openings.

Ju & lin (1999) and Moeini (2011) investigated the distinction between rigid floor and flexible floor analyses of buildings, using the finite element technique to analyze buildings with and while not shear walls. A slip formula was generated to estimate the error in column forces for buildings with plan regular arrangement of shear walls beneath the rigid floor assumption. Although 520 models were generated, none dealt with diaphragm openings. Kim and White (2004) proposed a linear static methodology applicable solely to buildings with flexible diaphragms. The procedure is predicated on the idea that diaphragm stiffness is tiny compared to the stiffness of the walls, which flexible diaphragms within a building structure tend to respond independently of one another. Though the proposed approach gave insight into the restrictions of current building codes, it did not deal with diaphragm opening effects.

Other related analysis addresses the consequence of presumptuous a rigid floor on lateral force distribution. Roper and Iding (1984) in brief examined the appropriateness of presumptuous that floor diaphragms are absolutely rigid in their plane. Two models were used, the primary was for a cruciform-shape building and also the second was for a rectangular building. Both models showed discrepancy between rigid and flexible floor diaphragm lateral force distribution. Specially, once shear walls exhibit an abrupt amendment in stiffness. Still, effects of openings on lateral force distribution weren't explored. Tokoro et al. (2004) replicated an existing instrumented 3 story building using ETABS and compared the model's diaphragm drift to the code allowable drift and judged the structure to be among the code's given drift limit; while not considering any diaphragm opening effects.

Saffarini and Qudaimat (1992) analytically investigated thirty-seven buildings, with diaphragm lateral deflection and inter-story shears as a comparison criterion between rigid and flexible diaphragms assumptions. The analysis showed wide distinction within the diaphragms' deflections and shears. The investigation in brief addressed gap effects as a part of different parameters being studied. it absolutely was terminated that a gap positively decreased the floor stiffness, and thence increased the inadequacy of the rigid floor assumption. Easterling and Porter (1992) conferred the results of an experimental analysis program during which thirty-two full-size composite (steel-deck and concrete floor slabs) diaphragms were loaded to failure. The most important analysis contribution was the event of a higher style approach for composite floor systems and stressing the importance of misshapen bars reinforcing to boost ductility and management cracking related to concrete failure around headed studs. The recommendations were solely pertinent to the cantilevered diaphragms tested and no gap effects were examined.

Lastly, within the area of precast concrete and parking structures, Rodriguez et. al. (2007) compared ASCE 7-05 seismic forces to generated shake table forces for a specific systems in question while not investigation openings. Lee and Kuchma (2008) and Wan et. al. (2005)

looked into precast concrete diaphragm structures accounting for the ramp cavity and diaphragm connections however ignoring block out-of-plane property and its effects.

The analysis assumes a plyboard diaphragm with openings behaves like a Vierendeel Truss. Chord components between shear webs of the Vierendeel Truss are assumed to own points of contraflexure at their mid-lengths. Diaphragm segments outside the openings are analyzed, then segments round the openings analyzed second presumptuous no openings are present. The procedure is carried-out once more with the openings thought-about. Finally net change in chord forces due to openings is achieved by superimposing each results. This methodology will satisfy equilibrium conditions, isn't altogether reliable. Kamiya and Itani (1998) investigated the APA technique by horizontally test-loading 3 plywood-sheathed floor diaphragms designed to a similar load. The tests conducted yielded diaphragm shear and deflection equations rather than the long APA technique for those 3 diaphragms; there was no indication on however their effort is extended to incorporate alternative configurations.
Philips et. al. (2006) studied however walls transverse to the loading direction in wood-framed buildings share lateral loads. The study shows that such interaction between transverse walls and plywood-sheathed diaphragms will go up as high as twenty five %. Gebremedhin and price (1999) examined however plyboard diaphragms distributed lateral loads to frames. Opening effects were checked out in a very manner solely to state that for walls with openings, the stiffness decrease isn't linear with the opening size. For a 25 percent loss in frame area, the wall stiffness decreased by 17 percent and for a 50 percent loss in frame space the stiffness of identical wall decreased by 64 percent.

Carney (1975) provided a bibliography on wood and laminate diaphragms analysis going back as far as the 1920’s and nearly none addressed diaphragm openings. Peralta et al. by experimentation investigated in-plane behavior of existing wood floor and roof diaphragms in un-reinforced masonry buildings consistent with elements and association details typical for pre-1950 construction. The end result was design curves defining the relationship between the applied lateral force and also the diaphragm mid-span displacement. Opening effects on diaphragm stiffness weren't addressed either.

Itani and Cheung (1984) introduced a finite element model to research the non-linear load-deflection behavior of incased wood diaphragms. The model is general and is in sensible agreement with experimental measurements. Nonetheless it is will not deal with openings and however to extend the developed model to account for them. Pudd and Fonseca (2005) developed a replacement progressive analytical model for sheathing-to-framing connections in wood shear walls and diaphragms. Though the new model is not like previous analytical models, being appropriate for each monotonic and cyclic analysis, it didn't account for the consequences of openings on neither shear walls nor diaphragms.

Degenkolb (1959) investigated pitched and curved timber diaphragms accenting that boundary stresses exist at any break within the protection plane and may be provided within the design of an economical diaphragm - no opening effects were thought-about. Bower printed laminate deflection formulas beneath lateral loading, stating that they'll be changed to apply to any diaphragm form or loading pattern while not giving examples.

Westphal and Panahshahi (2002) used three-dimensional finite element models to get in-plane deformations of wood roof diaphragms and story drift because of seismic load for buildings with plan ratio starting from 1.2 to 1.6. The results obtained show that the anticipated diaphragm deflections by the International building code (IBC) are conservative. However, effects of openings on this conclusion weren't investigated. As for the area of light gage steel deck (or metal decks), Nilson (1960) set the benchmark for all future experimental add metal diaphragms. Though the complete tests were intensive, with emphasis on shear strengths and diaphragm deflections, openings effects were never addressed. Bryan and El-Dakhakhni (1968) have any developed Nilson (1960) work to a additional general theory for crucial stiffness and strength of light gage metal deck. Still the theory developed failed to account for diaphragm openings. Easley (1975) centered on the buckling aspect of corrugated metal shear diaphragms. It had been concluded that for most applications, buckling happens once the quantity of fasteners is masses so localized failure at the fasteners doesn't occur. However, gap effects on diaphragm buckling weren't looked into.

Davies (1976) developed a way to replace a metal deck diaphragm by a series of frame elements connected by springs. This methodology also can be extended to account for openings. a major disadvantage of this methodology is that results obtained are strictly linear. Atrek and Nilson (1980) established a non-linear analysis method for light gage steel decks. Results resembled closely out there experimental information, nevertheless openings weren't addressed and no insight was given on the way to extend this methodology to cover diaphragms apart from the tested ones

Luttrell (1996) suggested a technique to get shear stress distribution around an opening in metal deck diaphragms. The strategy developed would ratio the shear distribution around the gap by the proportion of diaphragm length lost parallel to the loading direction.

Hysteretic behavior has been observed and studied extensively in wooden shear walls. Fischer et. al. (2001) conducted a full-scale test structure laboratory experiment and used a nonlinear dynamic time history analysis program RUAUMOKO (Carr, 1998) and wood shearwalls program CASHEW (Folz and Filiatrault 2000) to create numerical models. Many hysteresis models have been developed to predict the seismic response of wood-frame structures. Some hysteretic models have produced relatively good results, but the data collected have usually been supported by displacement histories. Records from an instrumented site, such as California’s strong motion stations, only have acceleration time histories. Extraction of hysteresis parameters becomes more challenging in the absence of displacement time histories.

### 2.3 CONCLUSION

Here a question arises that what will the effect if the same building is designed with diaphragm discontinuity and without diaphragm discontinuity. It is studied in this project.

# CHAPTER 3

# MODELLING OF BUILDING

## 3.1 INTRODUCTION

In this project we are studying a multi storeyed building with diaphragm discontinuity and without diaphragm discontinuity as model-1 and model-2 respectively. The building is modeled and designed in STAAD-Pro from which reinforcing details were drawn. Further the building is modeled in SAP2000 with the above obtained reinforcing details in which pushover analysis and time history analysis are performed.

## 3.2 DETAILS OF SELECTEDBUILDING

For the study purpose, an existing building plan in Berhampur was taken which is meant for hospital. Even though this area is in seismic zone II, it is taken as zone V for study purpose. Building details are given below.

Table 3.1 Details of the building

| **Building Parameters** | **Details** |
|---|---|
| Plan size | 39.20m × 40.20m |
| Location | Berhampur, Odisha |
| Usage | Hospital Building |
| Building height | 17.50m (G+4) |
| Grade of Steel | Fe 415 |
| Grade of Concrete | M-20 |
| Seismic Zone* | V (PGA = 0.36g) |
| Column size | 300×500 |
| Beam sixe | 300×500 |
| Slab thickness | 120mm |
| Outside wall thickness | 230mm |
| Partition wall thickness | 230mm |
| Live load | 3kN/$m^2$ for slabs and 2kN/$m^2$ for roof |

## 3.3DESIGN OF THE BUILDING

Initially the building was modelled and designed in STAAD-Pro from which reinforcing details were drawn. Further the building is modeled in SAP2000 with the above obtained reinforcing details. The load combinations are shown below.

- COMB1 = 1.5 (DEAD + LIVE)
- COMB2 = 1.2 (DEAD + LIVE + EQ)
- COMB3 = 1.2 (DEAD + LIVE - EQ)
- COMB4 = 1.5 (DEAD + EQ)
- COMB5 = 1.5 (DEAD - EQ)
- COMB6 = 0.9 DEAD + 1.5 EQ
- COMB7 = 0.9 DEAD - 1.5 EQ

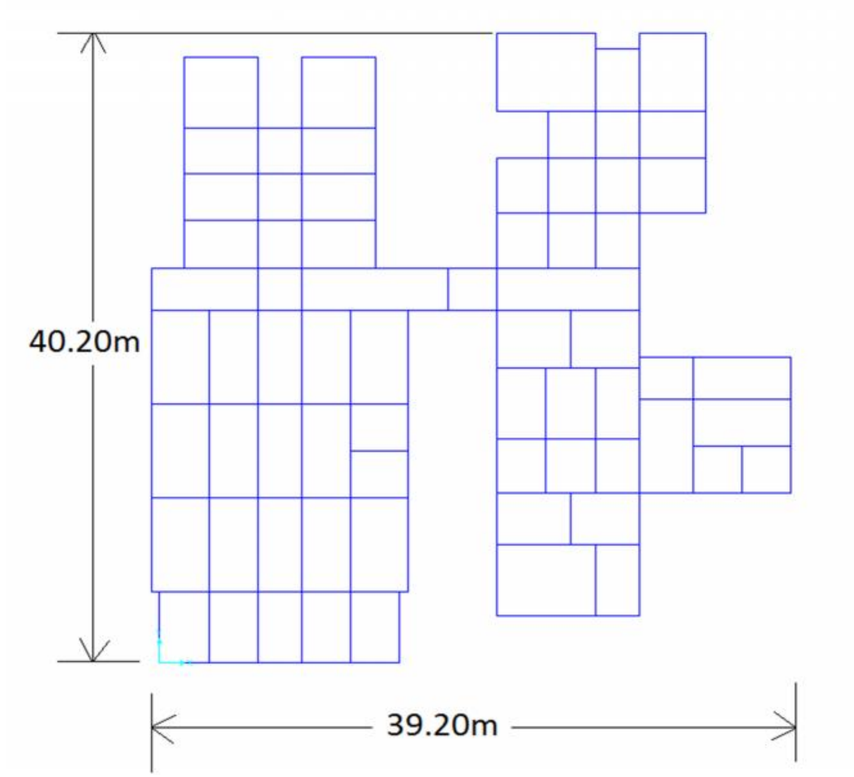


Fig 3.1 Plan of the building

The Fig. 3.1 shows the plan of the building that is studied in this thesis Fig. 3.2 shows the frame layout and Fig. 3.3 shows 3D model of the building. These figures were drawn using SAP2000.

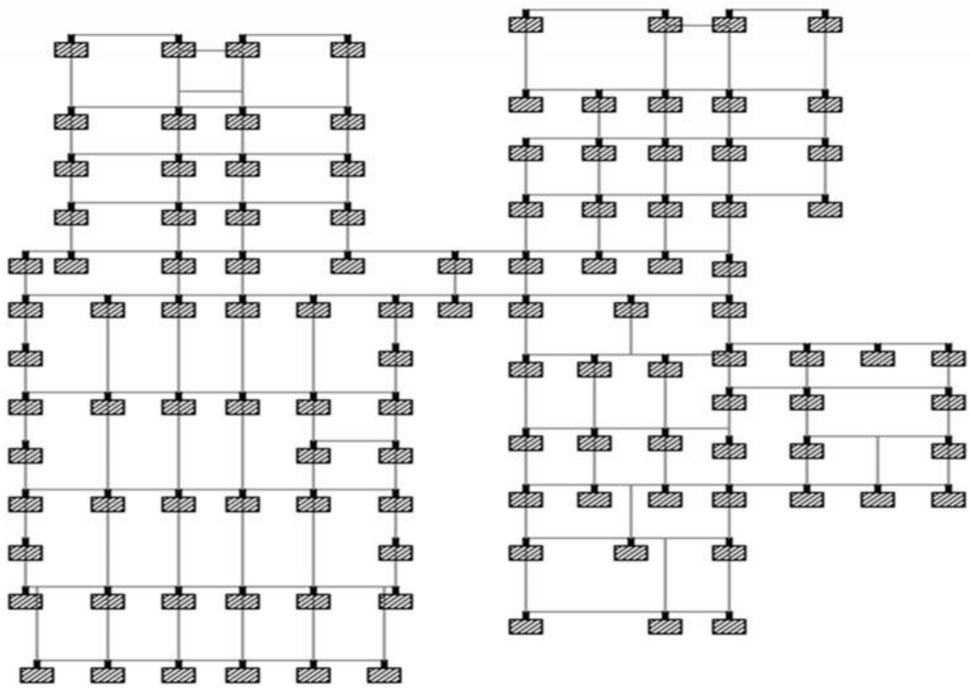

Fig 3.2 Typical frame layout

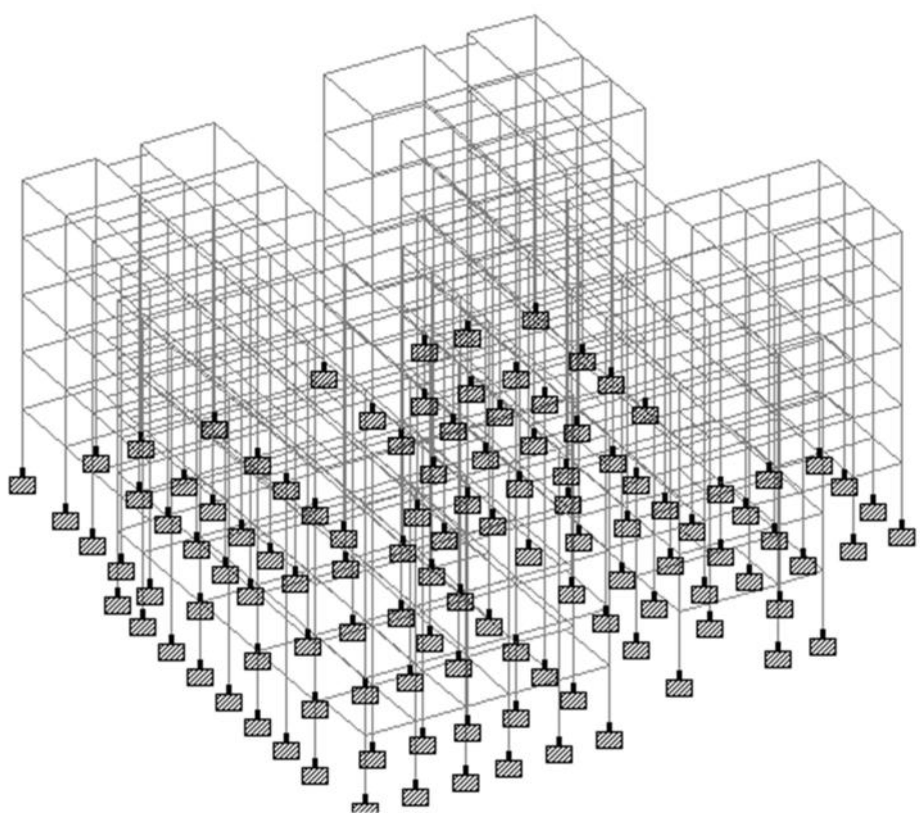

Fig 3.3 Computer model of the building

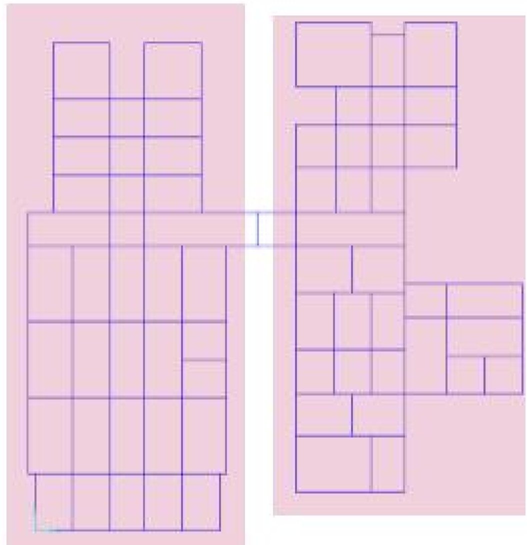

Fig 3.4 Model – 1 (with discontinuous diaphragm)

In model-1 (Fig. 3.4) the building is divided into two diaphragms. Loads are assigned separately to each diaphragm and the building is analyzed. The pushover curves and hysteresis loops are shown for this building in the last chapter.

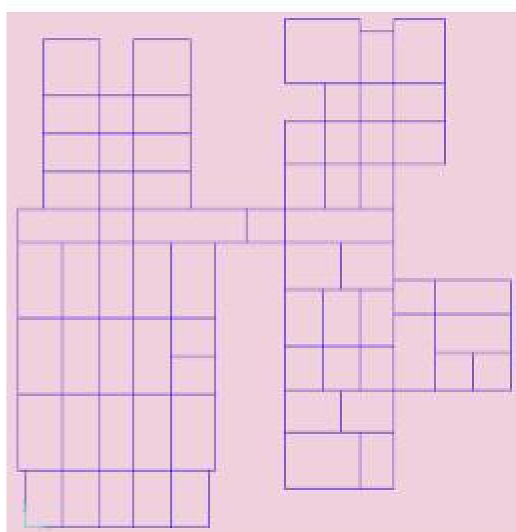

Fig 3.5 Model – 2 (with continuous diaphragm)

In model-2 (Fig. 3.5) the building is taken as a whole i.e., single diaphragm. Loads are assigned to the complete building as a single diaphragm and the building is analyzed. The pushover curves and hysteresis loops are shown for this building in the last chapter.

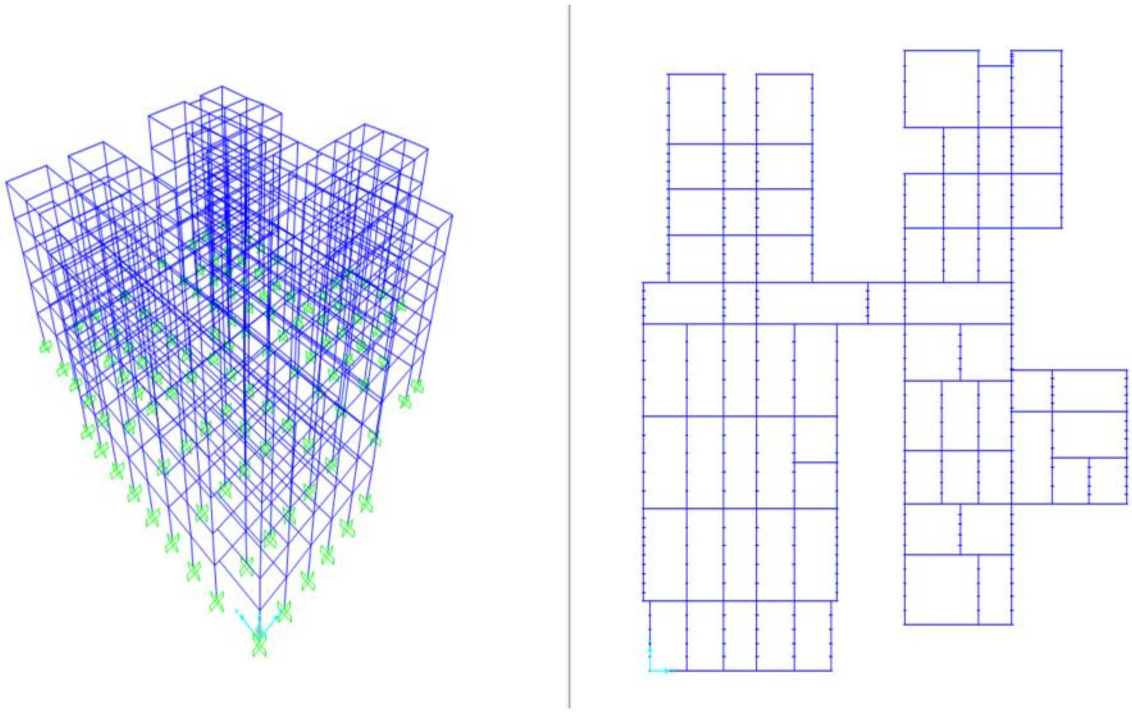

Fig 3.6 Building Model in SAP-2000

## CHAPTER 4

## PUSHOVER ANALYSIS

### 4.1 INTRODUCTION

The pushover analysis of a structure is a static non-linear analysis under permanent vertical loads and gradually increasing lateral loads. A plot of total base shear versus top displacement in a structure is obtained by this analysis that would indicate a premature failure or weakness. All the beams and columns which reach yield or have experienced crushing and even fracture are identified. A plot of total base shear versus inter - story drift is also obtained. A pushover analysis is performed by subjecting a structure to a monotonically increasing pattern of lateral loads, that shows the inertial forces which would be experienced by the structure when subjected to ground motion. Under incrementally increasing loads many structural elements may yield sequentially. Therefore, at each event, the structure experiences a decrease in stiffness. Using a nonlinear static pushover analysis, a representative non-linear force displacement relationship can be obtained.

Nonlinear static analysis , or pushover analysis , has been advanced over the past twenty years and has now become the most preferred analysis technique for design and seismic performance estimation purposes as this technique is comparatively simple and considers post-elastic performance. However, this technique includes certain approximations and simplifications due to which some extent of variation is always probable to exist in the seismic demand prediction of pushover analysis.

Though, pushover analysis is known to capture vital structural response characteristics when the structure is under seismic action, however the reliability and the accuracy of pushover analysis in estimating global and local seismic demands for all of the structures have been a topic of discussion and enhanced in pushover procedures have been suggested to overcome certain limitations of traditional pushover techniques. However, the improved techniques are mostly computationally hard and theoretically complex therefore use of such techniques are impractical in engineering profession and codes. As traditional pushover analysis is used widely for the design and seismic performance estimation purposes, therefore its weaknesses, limitations and predictions accuracy in routine application must be identified by studying all the factors that the pushover prediction. That is, the applicability of pushover analysis for predicting seismic demands must be investigated for low-rise, mid-rise and high-rise structures by recognizing certain issues like modeling nonlinear member performance, computational scheme of the technique, efficiency of invariant lateral load patterns in demonstrating higher mode effects, variations in the estimations of different lateral load patterns used in traditional pushover analysis and precise estimation of target displacement where seismic demand prediction of pushover technique is executed .

**4.2 Limitations**

Although pushover analysis has certain advantages in comparison to elastic analysis techniques, underlying various assumptions, the accuracy of pushover predictions and the restrictions of current pushover procedures must be recognized. The estimation of target displacement, selection of the lateral load patterns and identification of failure mechanisms due to higher modes of vibration are vital issues that have an effect on the accuracy of pushover result. Target displacement is global displacement likely in a design earth quake.

In pushover analysis, target displacement for a multi degree of freedom system is generally estimated similar to the displacement demand for corresponding equivalent single degree of freedom system. The fundamental properties of an equivalent SDOF system are gotten from a shape vector that represents the deflected shape of MDOF system. Most researchers recommend using the normalized displacement profile at target displacement level as a shape vector, but since this displacement is not known beforehand, an iteration is needed. Therefore, by most of the approaches, a fixed shape vector, elastic first mode, is utilized for simplicity without regarding higher modes. The target displacement is found by the roof displacement at mass center of the structure.

The accurate estimation of the target displacement associated with particular performance objective, has an effect on accuracy of the seismic demand predictions of pushover analysis. Furthermore, hysteretic characteristics of MDOF must be incorporated into the equivalent SDOF model, in case displacement demand is affected from stiffness degradation or pinching, strength deterioration, P-Δ effects. Foundation uplift, torsional effects as well as semi-rigid diaphragms may also affect target displacement.

However, in pushover analysis, usually an invariant lateral load pattern is utilized that the distribution of the inertia forces is assumed to be not changing during earthquake and deformed configuration of the structure under the action of invariant lateral load pattern is likely to be similar to that which is experienced in the design earthquake. As response of the structure, therefore the capacity curve is highly sensitive to the lateral load distribution selected choice of lateral load pattern is more critical as compared to the accurate estimation of the target displacement.

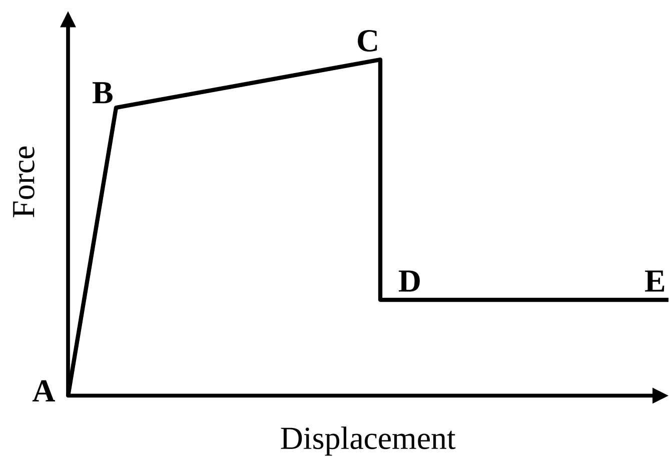


Fig 4.1 Force-Deformation for pushover hinge

In order to obtain performance points as well as the location of hinges in different stages, we can use the pushover curve. In this curve, the range AB the elastic range, B to IO the range of instant occupancy, IO to LS the range of life safety and LS to CP the range of collapse prevention.

When a hinge touches point C on its force-displacement curve then that hinge must start to drop load. The manner in which the load is released from a hinge that has reached point C is that the pushover force or the base shear is reduced till the force in that hinge is steady with the force at pint D.

As the force is released, all the elements unload and also displacement is decreased. After the yielded hinge touches the point D force level, the magnitude of pushover force is again amplified and the displacement starts to increase again.

If all the hinges are within the given CP limit then the structure is supposed to be safe. Though, the hinge after IO range may also be required to be retrofitted depending on the significance of the structure.

a) Immediate Occupancy – Achieves elastic behavior by limiting structural damage (e.g., yielding of steel, significant cracking of concrete, and nonstructural damage.)
b) Life Safety - Limit damage of structural and nonstructural components to minimize the risk of injury or casualties and to keep essential circulation routes accessible.
c) Collapse Prevention – Ensure a small risk of partial or complete building collapse by limiting structural deformations and forces to the onset of strength and stiffness degradation.

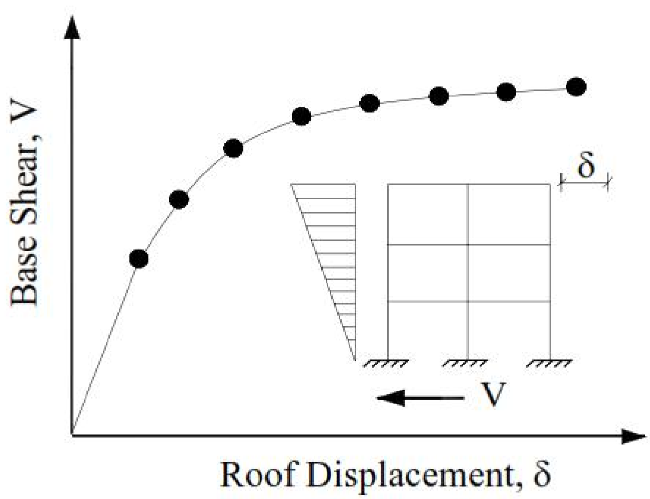


Fig 4.2 Global capacity (Pushover) curve

## CHAPTER 5

## TIME HISTORY ANALYSIS

### 5.1 INTRODUCTION

Time-history analysis is a step-by-step analysis of the dynamical response (in time domain) of a structure subjected to a specified ground motion. This section explains the nonlinear parameters, input ground motion, time integration and damping used in the present study. The dynamic input has been given as a ground acceleration time-history that was applied uniformly in any respect points of the base of the structure. Computer software SAP2000 was used for carrying out nonlinear time-history analysis.

‘Hilber-Hughes-Taylor alpha’ (HHT) method was used for performing direct-integration time-history analysis. The HHT method is an implicit method and is popular due to its intrinsic stability. The HHT method uses a single parameter (alpha) whose value is bounded by 0 and -1/3.

### 5.2 NATURAL RECORD OF EARTHQUAKE GROUND MOTION

Natural ground acceleration time histories have been used for the dynamic analysis of the structural models. All these acceleration data were imported from SAP2000 and were scaled to have peak ground accelerations 0.36g.

In the current project ground motion is taken from Century city- Lacc north at 0 degrees. 3000 points of acceleration data equally spaced at 0.02 sec was taken. So, total duration is 3000×0.02= 20 sec.

### 5.3 HYSTERESIS LOOP

Hysteresis is the dependence of the output of a system on its current input, and also on its history of past inputs. The dependence arises because the history affects the value of an internal state. To predict its future outputs, either its history or its internal state must be known. If a given input alternately increases and decreases, a typical mark of hysteresis a loop as in the figure 5.1 is forms.

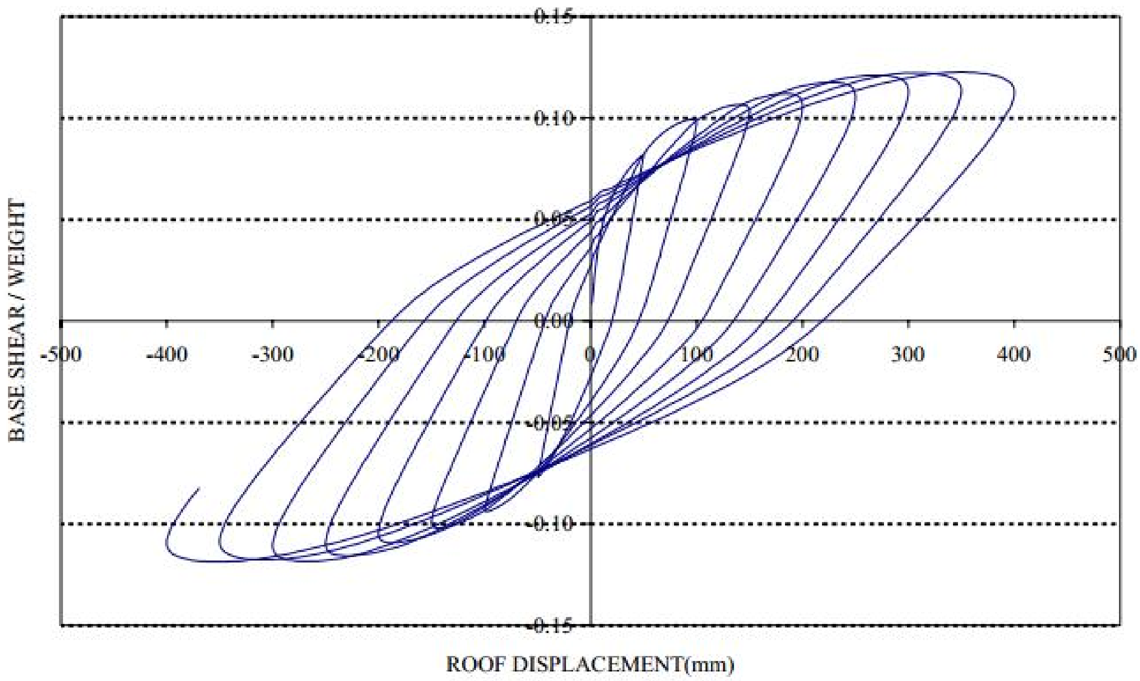


Fig. 5.1 Hysteresis loop

Such loops may occur because of a dynamic lag between input and output. This effect disappears as the input changes more slowly. This effect meets the description of hysteresis given above, but is often referred to as rate-dependent hysteresis to distinguish it from hysteresis with a more durable memory effect.

In structural engineering, hysteresis refers to the path-dependence of the structure's restoring force versus deformation. The physical reasoning behind this behavior is the softening of connection joints. The hysteresis loops of a structure offer vital information about the forces that act upon it and the resulting deformations. It is imperative to accurately map hysteresis curves since they play a pivotal role in creating a better nonlinear model. Fortunately, many of the commercial products that provide nonlinear analyses have the option to input a hysteresis model. The hysteretic behavior of a structure plays a crucial role in many current approaches to seismic performance-based analysis and design. As a result, many experiments have been conducted to record hysteretic data for shear walls and other subassemblies. Extraction of hysteretic characteristics of frame building components can lead to an understanding of the structure's degradation and nonlinear response range. The process involves the construction of a hysteresis curve by plotting time history pairs of restoring force across the component (on the vertical axis), and relative displacement across the component (on the horizontal axis).

# RESULTS AND DISCUSSIONS

## 6.1. MODAL PROPERTIES

Table 6.1: Mass participation ratio for first 12 modes of the Buildings

| Mode | Model-1 | | | Model-2 | | |
|---|---|---|---|---|---|---|
| | Period | UX | UY | Period | UX | UY |
| 1 | 1.18 | 0.00 | 0.86 | 0.52 | 0.00 | 0.86 |
| 2 | 1.03 | 0.00 | 0.00 | 0.46 | 0.00 | 0.00 |
| 3 | 0.88 | 0.84 | 0.00 | 0.39 | 0.84 | 0.00 |
| 4 | 0.76 | 0.00 | 0.00 | 0.34 | 0.00 | 0.10 |
| 5 | 0.70 | 0.00 | 0.00 | 0.31 | 0.00 | 0.00 |
| 6 | 0.39 | 0.00 | 0.10 | 0.17 | 0.10 | 0.00 |
| 7 | 0.38 | 0.00 | 0.00 | 0.10 | 0.00 | 0.03 |
| 8 | 0.29 | 0.00 | 0.00 | 0.09 | 0.00 | 0.00 |
| 9 | 0.28 | 0.10 | 0.00 | 0.08 | 0.00 | 0.01 |
| 10 | 0.28 | 0.01 | 0.00 | 0.07 | 0.04 | 0.00 |
| 11 | 0.24 | 0.00 | 0.03 | 0.07 | 0.00 | 0.00 |
| 12 | 0.24 | 0.00 | 0.00 | 0.06 | 0.00 | 0.00 |

According to IS-1893:2002 the number of modes to be used in the analysis should be such that the total sum of modal masses of all modes considered is at least 90 percent of the total seismic mass. Here the minimum modal mass is 95 percent.

Model-1 is having maximum time period of 1.18 s and model-2 is having maximum time period of 0.52 s. So, model-1 is more flexible than model-2.

Modal Analysis results show that there are some unusual modes (Fig. 6.1a) when diaphragm discontinuity modeled. However, the mass participation for those modes is found to be negligible. Therefore, these modes will not change the response of the building significantly.

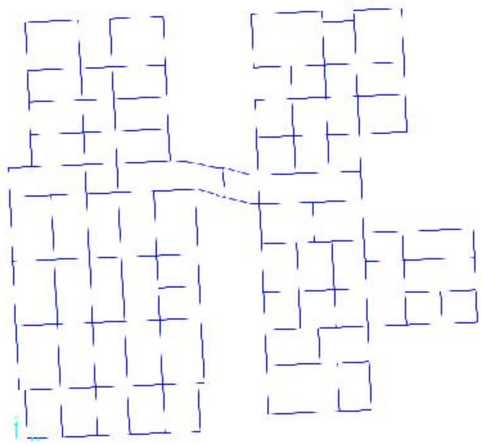

Fig. 6.1(a) Mode - 4

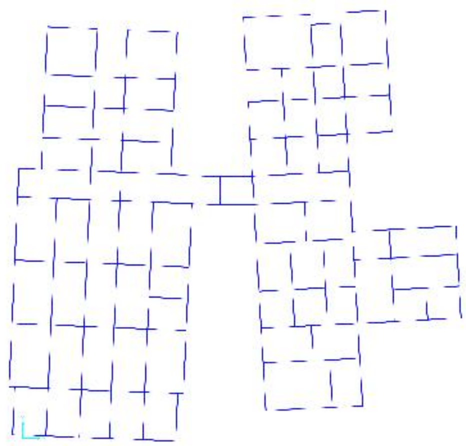

Fig. 6.1(b) Mode - 5

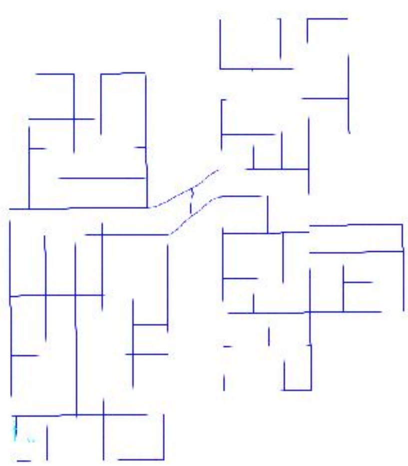

Fig. 6.1(c) Mode - 7

Fig. 6.1(a), (b), (c) Unusual modes found in Model -1

## 6.2 PUHOVER ANALYSIS RESULTS

From the above graph we have seen that the push over curve of both the models are allmost coinsiding in X direction. In Y direction also the push over curve of both the models are allmost coinsiding. Pushover Curves obtained from this study show that there is no significant difference in the response of the building for modelling discontinuous diaphragm.

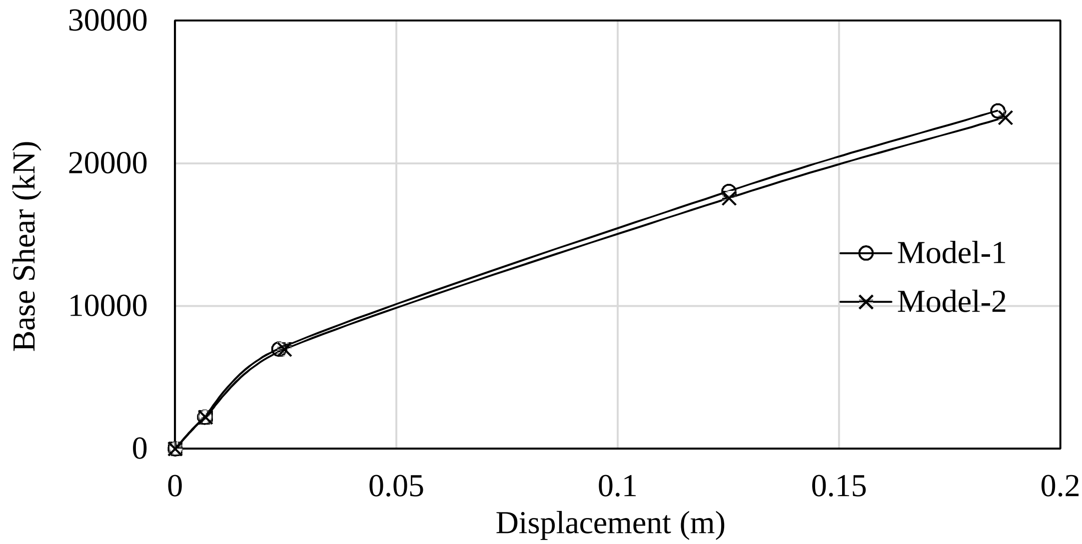


Fig. 6.2(a), Push curve - X

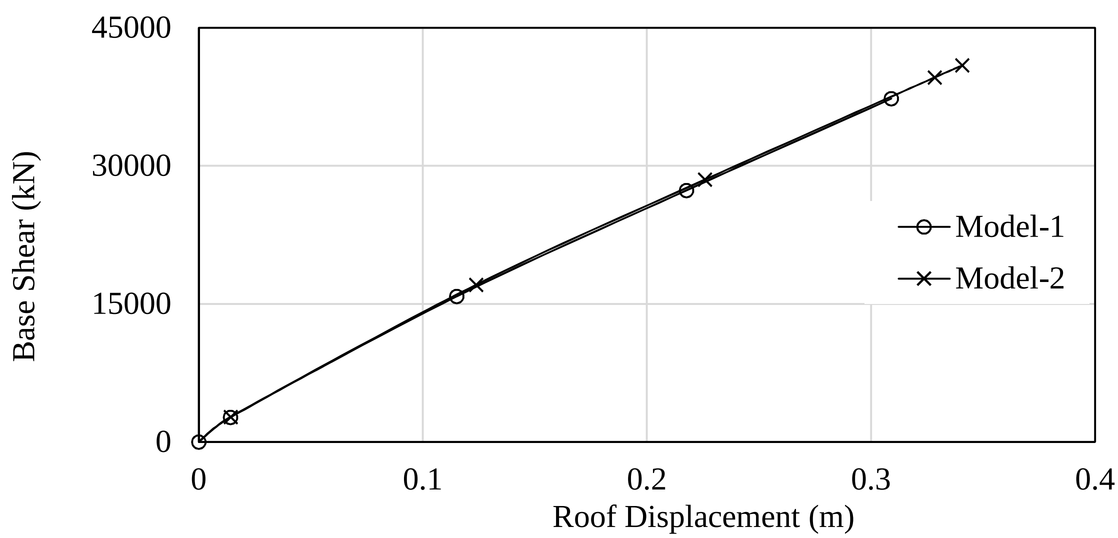


Fig. 6.2(b), Push curve – Y

## 6.3 TIME HISTORY ANALYSIS RESULTS

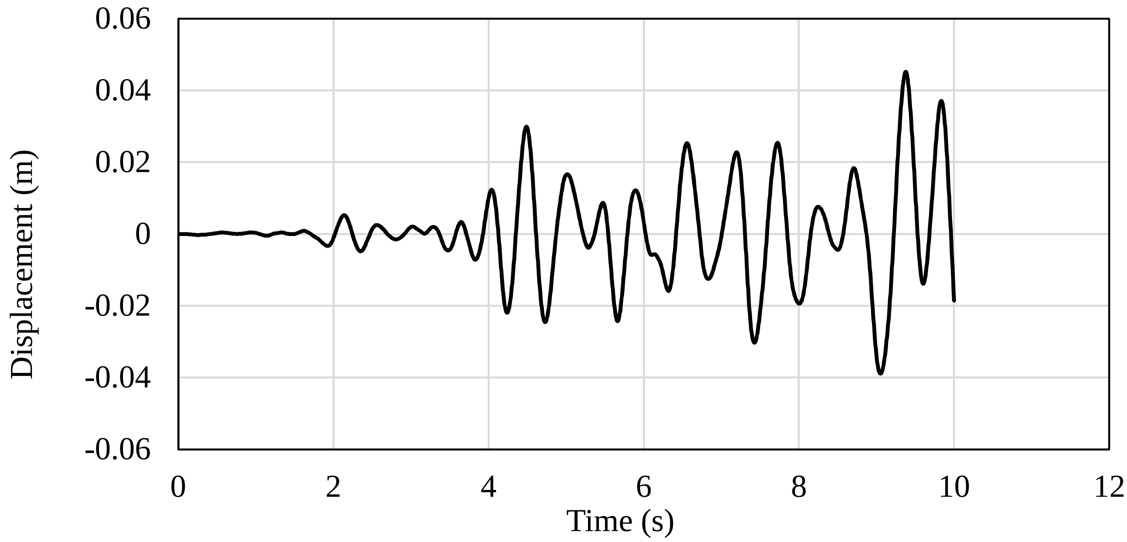


Fig 6.3 (a)Time history graph

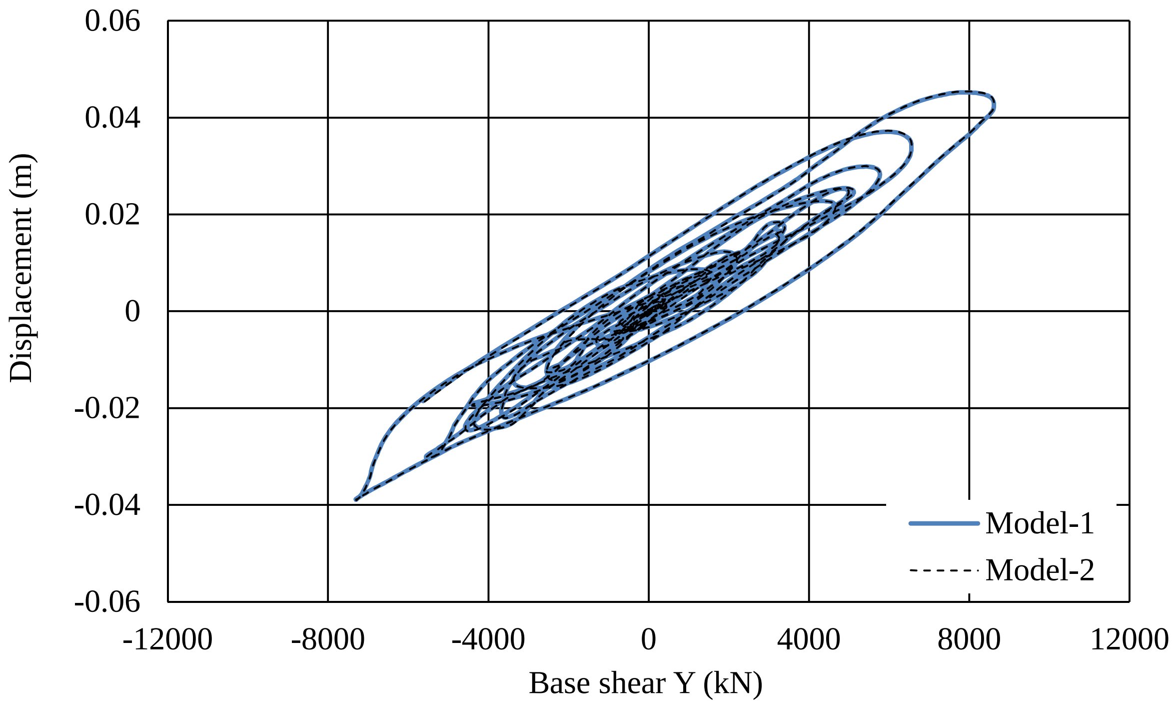


Fig 6.3 (b)Hysteresis curve of the building (Uni directional motion)

From Figs. 6.3b abd 6.3c we have seen that the hysteresis curve of both the models are allmost coinciding for uni direction and bi-direction loading.

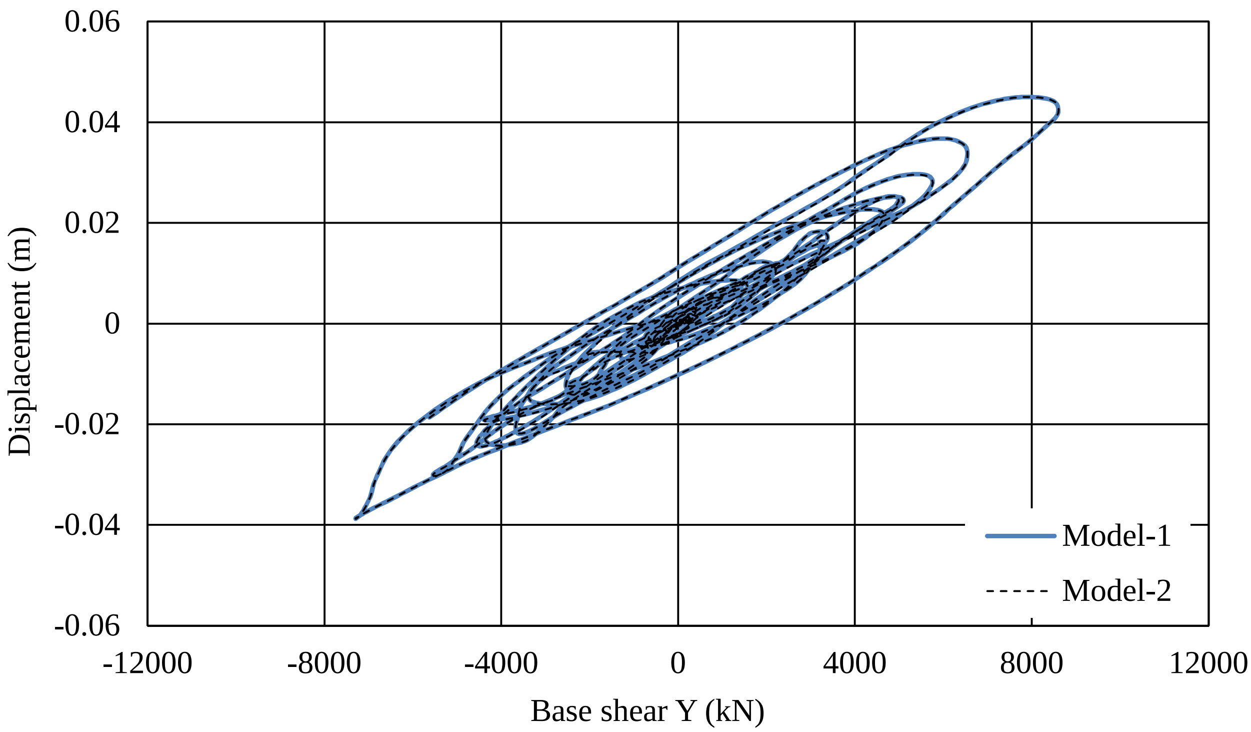


Fig 6.3 (c)Hysteresis curve of the building (Bi directional motion)

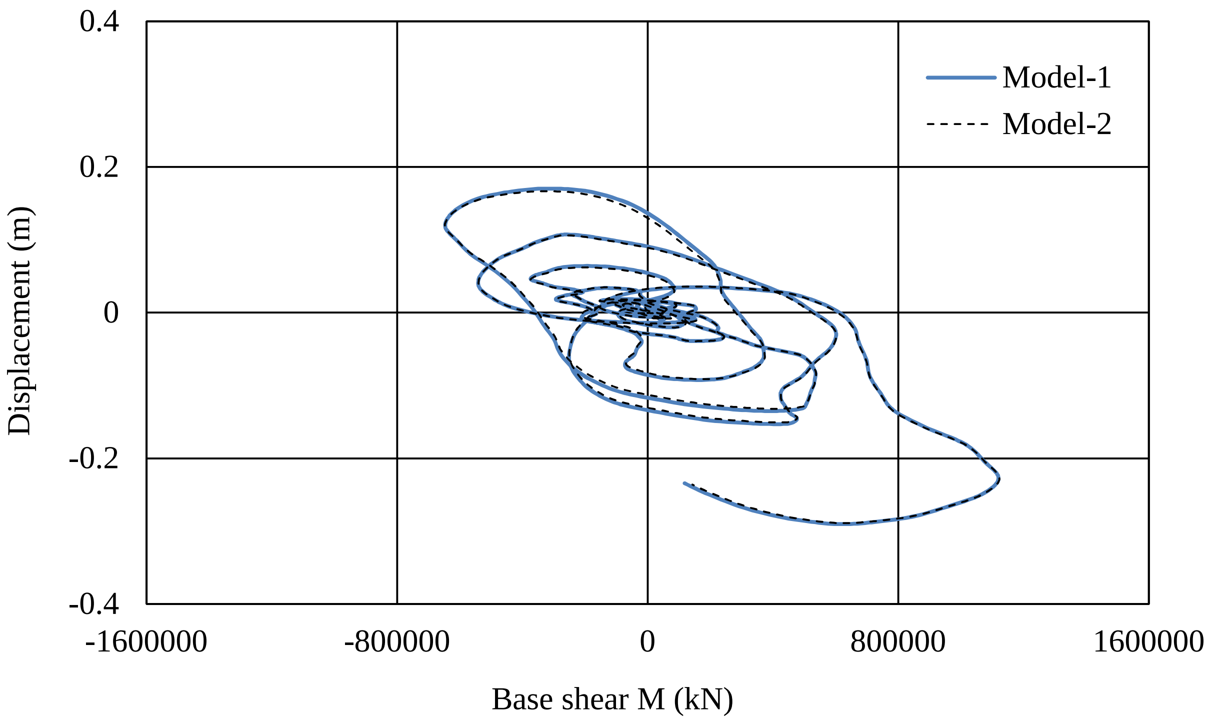


Fig 6.3 (d)Hysteresis curve of the building (Torsion)

In torsion also the hysteresis curve of both the models are coinsiding.Base shear vs. roof displacement hysteresis relation obtained from the non-linear time history analysis for both the models studied here are found to be identical.

**6.4 CONCLUSION**

a) Discontinuous diaphragm makes the building flexible. Fundamental period of building with diaphragm discontinuity is found to be higher than a similar building with continuous diaphragm.
b) The empirical equation given in design codes (such as IS 1893:2002) are good for building with continuous diaphragm. The use of this equation for a building with discontinuous diaphragm can be very conservative.
c) Modal Analysis results show that there are some unusual modes when diaphragm discontinuity modelled. However, the mass participation for those modes are found to be negligible. Therefore, these modes will not change the response of the building significantly.
d) Pushover Curves obtained from this study show that there is no significant difference in the response of the building for modelling discontinuous diaphragm.
e) Base shear vs. roof displacement hysteresis relation obtained from the non-linear time history analysis for both the models studied here are found to be identical.
f) This study indicates that modelling discontinuous diaphragm may not change the seismic behavior of framed building significantly.

1. **Jain, S. K.,** and **Jennings, P. C., (1984).** “Continuous Models for Frame and Shear-Wall Buildings with Flexible Floors,” 8 th World Conference on EQ. Eng., San Francisco, CA, Vol. 4, pp. 743-750.

2. **Aghayere, A. O.** and **MacGregor, J. G., (1990).** “Analysis of Concrete Plates Under Combined In-plane and Transverse Loads,” ACI Struct. J. 87 (5), pp. 539-547.

3. **Abdalla, H.** and **Kennedy, J. B., (1995).** “Design of Prestressed Concrete Beams with Openings,” J. Struct. Engrg. ASCE 121 (5), pp. 890-898.

4. **Aktan, A. E.** and **Nelsonl, G. E., (1988).** “Problems in Predicting Seismic Responses of RC Buildings,” J. Struct. Engrg. ASCE 114 (9), pp. 2036-2056.

5. **Philips, T. L., Itani, R. Y.** and **McLean, D. I., (1993).** “Lateral Load Sharing by Diaphragms in Wood-Framed Building,” J. Struct. Engrg. ASCE 119 (5), pp. 1556-1571.

6. **Park, H.** and **Kim, E. H., (1999).** “RC Flat Plates Under Combined In-plane and Out-ofplane Loads,” J. Struct. Engrg. ASCE 125 (10), pp. 1136-1142.

7. **Panahshahi, N., Kunnath, S. K.,** and **Reinhorn, A. M., (1988)** “Modelling of RC Building Structures with Flexible Floor Diaphragms (IDARC2),” Technical Report NCEER-880035, State University of New York at Buffalo, Buffalo, NY.

8. **Luttrell, L., (1991).** “Steel Deck Institute Diaphragm Design Manual - 2 Ed.,” FoxRiver Grove, IL.

9. **Degenkolb, H. J., (1959)**. “Design of Pitched and Curved Timber Diaphragms,” J. Struct. Engrg. ASCE 85 (ST1), pp. 65-75.

10. ACI Committee 442, (1971). “Response of Buildings to Lateral Forces,” ACI Struct. J. 68 (11), pp. 81-106.

11. **Saffarini, H. S.** and **Qudaimat, M. M., (1992).** “In-plane Floor Deformations in RC Structures,” J. Struct. Engrg., ASCE 118 (11), pp. 3089-3102.

12. AISC Steel Design Guide No. 2, (2003). “Steel and Composite Beams with Web Openings,” Chicago, IL.

13. Computers and Structures, Inc. “SAP 2000, Version 7”, Berkeley, CA.

14. **Bower, W. H., (1974).** “Lateral Analysis of Plywood Diaphragms,” J. Struct. Engrg. ASCE 100 (ST4), pp. 759-772.

15. **Bryan, E. R.** and **El-Dakhakhni, W. M. (1968)**. “Shear Flexibility and Strength of Corrugated Decks,” J. Struct. Engrg. ASCE 94 (ST11), pp. 2549-2580.

16. **Mansur, M. A., Tan, K. H., Lee, Y. F.** and **Lee, S. L., (1991).** "Piecewise Linear Behavior of RC Beams with Openings," J. Struct. Engrg. ASCE 117 (6), pp. 1607-1621.

17. **Westphal, M. J.** and **Panahshahi, N., (2002)**. "Deflections of Wood Roof Diaphragms inModerate Seismic Risk Regions," The Seventh U.S. National Conference on EQ. Eng.,Boston, MA, paper No. SC-1 82.

18. **Roper, S. C.** and **Iding, R. H., (1984).** "Appropriateness of the Rigid Floor Assumption for Buildings with Irregular Features," 8th World Conference on EQ. Eng., San Francisco, CA, Vol. 4, pp. 751-758.

19. **Peralta, D. F., Bracci, J. M.** and **Hueste, M. B. (2004).** "Seismic Behavior of Wood Diaphragms in Pre-1950's Unreinforced Masonry Buildings," ASCE Struct. J. 130 (12), pp. 2040-2050.

20. **Degenkolb, H. J., (1959).** "Design of Pitched and Curved Timber Diaphragms," J. Struct. Engrg. ASCE 85 (ST1), pp. 65-75.

21. **Barron, J. M.** and **Hueste, M. D., (2004).** "Diaphragm Effects in Rectangular Reinforced Concrete Buildings," ACI Struct. J. 101-S60, pp. 615-623.

22. **Jain, S. K., (1984).** "Seismic Response of Buildings with Flexible Floors," J. Engrg. Mech. ASCE 110 (1), pp. 125-129.

23. **Nakashima, M., Huang, T.** and **Lu, L. W., (1984).** "Effect of Diaphragm Flexibility on Seismic Response of Building Structures," 8th World Conference on EQ. Eng., San Francisco, CA, Vol. 4, pp. 735-742. Nakashima, M., Huang, T. and Lu, L. W., (1984). "Effect of Diaphragm Flexibility on Seismic Response of Building Structures," 8th World Conference on EQ. Eng., San Francisco, CA, Vol. 4, pp. 735-742.

24. **Kim, S. C.** and **White, D. W., (2004).** "Linear Static Analysis of Low-rise Buildings with Flexible Diaphragms Using the Structural Separation Method," Engineering Structures, V26, Issue 1, pp. 83-93.

25. **Kunnath, S. K., Reinhorn, A. M.** and **Park, Y. J., (1990).** "Analytical Modeling of Inelastic Seismic Response of RC Structures," J. Struct. Engrg. ASCE 116 (4), pp. 9961017.

26. **Panahshahi, N., Reinhorn, A. M., Kunnath, S. K., Lu, L. W., Huang, T.** and **Yu, K. (1991).** "Seismic Response of a 1:6 Reinforced Concrete Scale-Model Structure with Flexible Floor Diaphragm," ACI Struct. J. 88-S34, pp.315-324.

27. **Luttrell, L., (1996).** "Designing Roof and Floor Diaphragms", Modern Steel Construction, Chicago, IL.

28. **Daisuke, K., Toshimi K., Shunsuke O.** and **Hiroyuki A., (1995)**. "Earthquake-Resistant Design of Shearwalls with One Opening," ACI Struct. J. 92 (4), pp. 1-6.

29. **Hueste, M. B.** and **Bai, J. W., (2004)**. “Impact of Retrofit on the Seismic Fragility of a Reinforced Concrete Structure,” 13th World Conference on EQ. Eng., Vancouver, B.C.,Canada, Paper No. 1163.

30. **Yanev, P. I., Gillengerten, J. D.** and **Hamburger, R. O., (1991).** “The Performance of Steel Buildings in Past Earthquakes,” American Iron and Steel Institute, pp.37-39.

31. **Nasser, K. W., Acavalos, A.** and **Daniel, H. R., (1964).** “Behavior and Design of Large Openings in Reinforced Concrete Beams,” ACI Struct. J. 64 (3), pp. 25-33.

32. International Code Council (ICC), (2006). “International Building Code 2006,” Whittier, CA.

33. **Kunnath, S. K., Panahshahi, N.,** and **Reinhorn, A. M., (1991)**. “Seismic Response of RCBuildings with Inelastic Floor Diaphragms,” J. Struct. Engrg., ASCE 117 (4), pp. 12181237.

34. **Tissell, J. R.** and **Elliott, J. R., (1993).** “Plywood Diaphragms,” Research Report 138, APA – The Engineered Wood Associates, Tacoma, WA.

35. **Itani, R. Y.** and **Cheung, C. K., (1984).** “Nonlinear Analysis of Sheathed Wood Diaphragms,” J. Struct. Engrg. ASCE 110 (9), pp. 2137-2147.

36. Computers and Structures, Inc. “ETABS, Version 7”, Berkeley, CA.

37. **Jain, S. K.** and **Jennings, P. C., (1985).** “Analytical Models for Low-Rise Buildings with Flexible Floor Diaphragms,” EQ. Eng. and Struct. Dyn., Vol. 13, pp. 225-241.

38. **Tokoro, K. T., Anderson, J. C.** and **Bertero, V. V., (2004).** “Uncertainties in Determining Diaphragm Flexibility,” 13th World Conference on EQ. Eng., Vancouver, B.C., Canada, Paper No. 565.

39. **Faherty, K. F.** and **Williamson, T. G. (1997).** “Wood Engineering and Construction Handbook- 3rd Ed.,” McGraw-Hill Handbooks, New York, NY.

40. **Easley, J. T., (1975).** “Buckling Formulas for Corrugated Metal Shear Diaphragms,” J. Struct. Engrg. ASCE 101 (ST7), pp. 2549-2580.

41. **Nilson, A. H. (1960).** “Diaphragm Action in Light Gage Steel Construction,” Report presented as Philadelphia Regional Technical Meeting of American Iron and Steel Institute, pp.1-30.

42. The 14th World Conference on Earthquake Engineering October 12-17, 2008, Beijing, China.

43. http://books.google.co.in/books?id=xAG2Sbh0EFIC&pg=PA62&lpg=PA62&dq=diaphragm+discontinuity+seismic&source=bl&ots=9j5dHX_C49&sig=o75tQRNgxOmXGAKL

WZLJfKfg0ko&hl=en&sa=X&ei=C31NUp7iB4aFrAf41oHQDw&ved=0CGYQ6AEwCQ#v=onepage&q=diaphragm%20discontinuity%20seismic&f=false<Oct. 1, 2013>

44. http://article.sapub.org/pdf/10.5923.j.arch.20120203.01.pdf<Oct. 25, 2013>

45. IS-1893:2002. Criteria for Earthquake Resistant Design of Structures: Part 1 General Provisions and Buildings, Bureau of Indian Standards, New Delhi

46. http://www.youtube.com/watch?v=F-jZlLQvr4Y<Nov. 28, 2013>