EFFECTS OF FLOOR DIAPHRAGM FLEXIBILITY IN REINFORCED CONCRETE STRUCTURES AND CODE PROVISION

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ABSTRACT

All the seismic codes generally accept that in most cases the floor diaphragms may be modeled as fully rigid without in-plane deformability for reinforced concrete structures. Even though a rigid floor diaphragm is a good assumption for seismic analysis of the most buildings, several building configurations may exhibit significant flexibility in floor diaphragms. In these configurations, some codes like (EC8, EBCS8, EAK-2000) set certain qualitative criteria related to the shape of the diaphragm, while some others (UBC-97, ASCE7-05, FEMA-274, IS1893:2000) set quantitative criteria relating the in-plane deformation of the diaphragm with the average drift of the associated storey.

In this thesis a review of the provisions of some modern seismic codes for the analytical modeling of the floor diaphragm action is made and a methodology using finite elements models, taking into consideration the in-plane flexibility, for monolithic floor is suggested. Using this method with comparative response-spectrum dynamic analyses, some reinforced concrete structures with different plan shapes like L-shape, U-shape, rectangular and rectangular with opening according to EC8 &UBC-97 are analyzed. Then, the mode period curve, story deformation curves and story shear with story curve and the results so obtained are compared to analyses the effect of in plane flexibility of diaphragm in multi -story building.

CHAPTER 1

1. INTRODUCTION

1.1BACKGROUND

The primary function of floor and roof systems is to support gravity loads and to transfer these loads to other structural members such as columns and walls. Furthermore, they play a central role in the distribution of wind and seismic forces to the vertical elements of the lateral load resisting system (such as frames and structural walls). The behavior of the floor/roof systems under the influence of gravity loads is well established and guidelines for use in structural design have been adopted.

In the earthquake resistant design of building structures, the building is designed and detailed to act as a single unit under the action of seismic forces. Design of a building as a single unit helps to increase the redundancy and the integrity of the building. The horizontal forces generated by earthquake excitations are transferred to the ground by the vertical systems of the building which are designed for lateral load resistance (e.g. frames, bracing, and walls). These vertical systems are generally tied together as a unit by means of the building floors and roof. In this sense, the floor/roof structural systems, used primarily to create enclosures and resist gravity (or out of plane) loads are also designed as horizontal diaphragms to resist and to transfer horizontal (or in-plane) loads to the appropriate vertical elements.

In the analysis of multistory buildings subjected to lateral loads, a common assumption is that the floor system undergoes no deformation in its own plan. Building structures are typically designed using the assumption that the floor systems serve as a rigid diaphragm between the vertical elements of the lateral load-resisting system. For the majority of buildings, floor diaphragms offer the most economical and rational method of resisting the lateral forces, since they are ordinarily included in the buildings to support the vertical workloads. It is thus, of the utmost importance, that they must be provided with sufficient in-plane stiffness and strength, together with efficient connections to the vertical structural elements.

For the rigid diaphragm model, diaphragm should have equal in plane displacements along its entire length under lateral seismic loads which will be further transferred to vertical resisting elements to their relative stiffness. Due to high flexural stresses along its boundaries, this flexibility of diaphragm increases the lateral load transfer to the frames that were not designed to carry these additional lateral loads based on rigid diaphragm models. However in certain type of structures the rigid floor assumption is found to create significant discrepancy on lateral force distribution. This discrepancy frequently occurs in frame -wall structure in which vertical elements compromises of shear walls and relative flexible frames. When there is a significant difference in story stiffness between two adjoining vertical elements, floor diaphragm connecting members would sustain high in plane shear which will cause in plane deformation of floor slab. Buildings having slender plan has same potential problems. In this bending deformation of slab becomes significant referred to as bowing action of slab. In either structure actual distribution to vertical elements could differ by great extent obtained on the basis of rigid diaphragm assumption.

So it's important to study the flexibility of diaphragm, the different factors with which it is associated and their effects in the building seismic performance. Some codes like (EC8, EBCS8, EAK-2000) set certain qualitative criteria related to the shape of the diaphragm, while some others (UBC-97, ASCE7-05, FEMA-274, IS1893:2000) set quantitative criteria relating the diaphragm as flexible or rigid .Flexibility ratio is nothing but ratios of deflection of flexible diaphragm to rigid diaphragm consideration. So a comparative study of variation in flexibility ratio with variation in aspect ratio and number of story is made.

In this thesis the flexibility of diaphragm in reinforce concrete structure has been discussed using finite element software. Then, the efficiency of codes provisions is investigated.

1.2 STATEMENT OF THE PROBLEM

In conventional Reinforced concrete buildings are typically analyzed and designed on the assumption that floor serve as rigid diaphragm spanning between vertical resisting elements. Such assumption is correct for most of the buildings, but several building configurations may exhibit significant flexibility in floor diaphragms.

Hence the statement of problem in this study is to find out the Floor Diaphragms Flexibility in Reinforced Concrete Structures by using different international building codes.

1.3 OBJECTIVE OF THE STUDY

With the development of high-speed personal computers nowadays, numerical methods have been widely used in solving engineering non-linear problems. Therefore, the main objectives of this study are: -

- To study the qualitative and quantitative criteria of diaphragm in different codes.
- To investigate the diaphragm flexibility in reinforced concrete structures.
- To compare the effects of flexible diaphragm with rigid diaphragm in reinforced concrete structures.
- To compare the quantitative criteria between codes UBC-97, ASCE7-05, FEMA-274 and IS1893:2000.

1.4 METHODOLOGY

a. Literature Review to study the back ground of seismic resistance of the diaphragm in multi story reinforced concrete frame structures.
b. Modeling different shape in plan of the diaphragm and three dimensional reinforced concrete frames. The Modeling is done by using commercial software(ETABS.V9.72)
c. Analyze the building using dynamic analysis methods.
d. Analyze the results and arrive at conclusions.
e. Code provision on floor diaphragm flexibility in reinforced concrete structures.
f. Then comparisons of the effects of codes per quantitative and quantitative criteria will be done.
g. Conclusion and recommendations.

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 flexibility of reinforced concrete buildings and code provision.

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

Chapter 4: In this chapter response spectrum analysis were performed with framed structures to investigate the effect of floor slabs flexibility on seismic response

Chapter 5: In this chapter the effects of rigid and flexible diaphragm based on different code provisions has been discussed in detail and Comparison between the two models was done.

Chapter 6: The results from dynamic analysis were studied and conclusion was given followed by references.

CHAPTER 2

2. LITERATURE REVIEW

2.1 GENERAL

To provide a detailed review of the literature related to diaphragm flexibility in its entirety would be difficult to address here. Although there has been a lot of work modeled as fully rigid diaphragms in reinforced concrete structures ranging from analysis assumptions to design recommendations - none provide in-depth understanding of the seismic response of reinforced concrete (RC) buildings contributions related to diaphragm and past efforts most closely related to the needs of the present work. A brief review on diaphragm flexibility and code provision of previous studies is presented here. This literature review focuses on flexibility of diaphragm in reinforced concrete structures and some code provisions will be addressed by area.

2.2 LITERATURE REVIEW

1. The Research done by MASMZOSH NAKASHIMA, TI HUNG and LE-WU LE [6] with a title of effects of diaphragm flexibility on seismic response of building structures, In the research the analysis was done by modeling reinforced concrete building with seven stories, six bays in width and one bay in depth, the ground acceleration was applied to the direction perpendicular to the longer horizontal direction of the structure. This structure has relatively slender plan section, whose aspect ratio is 1:6.the Newmark method (with β = ¼) was used in the direct integration, and the record of the N-S EL Centro Earthquake (1940) selected as in put ground motion with 0.33g of the maximum acceleration. Then the model was analyzed in three different cases (case 1 to 3): case1: linear elastic analysis with rigid slab assumption, case 2: linear elastic analysis and case 3: non linear analysis. Comparing the three numerical results, the inclusion of diaphragm flexibility change little the natural period of the structure and the maximum total base shear. Differences in base shear not more than 8 percent, the rigid slab assumption caused significant underestimate of the base shear resisted by the frames. The base shear in the middle frame was reduced to 23 percent if the rigid assumption was adopted; the floor slabs reached their maximum moment at the junction with the middle frame in the non linear analysis. In the model structure, the flexural behavior of the floor slab controlled the diaphragm action and non linear action of the structural components changed both the base shear distribution to the frame and

shear wall and the effective earthquake force distribution over the height of these components. The total earthquake force applied to each story was distributed approximately in the inverted triangular fashion along the height, but the distribution in each frame or shear wall was by no means inverted triangular. But the effect of opening in slab was not found in their study and appears to be absent in the literature.

2. A research journal with a title Diaphragm Flexibility in Buildings with Shear Walls, in 2004 was done by Dr. S. N. Tande & S.A.Devarshi [5]. In this paper they were considered the influence of factors (i.e. aspect ratio and number of stories) on flexibility of diaphragm had been discussed using finite element based software ETABS9.7.2.

For investigation they were considered three different types of buildings with 4, 7 and 10 storeys and each with variation in aspect ratio as 1:1, 1:2, 1:3 and 1:4. Then the analysis was done by using finite element software ETABS9.7.2.with the assumption of flexible as well as rigid floor. Based on which a comparative study was made. From the study they found that flexibility ratio decreases with increase in number of stories & flexibility ratio increases with increase in aspect ratio of building. Although these studies proved to be contributing to understanding the flexibility of diaphragms in buildings with shear walls, they didn't address the effects of diaphragm openings.

3. A research with a title Reinforced concrete floor slabs under in-plane monotonic and cyclic loading, in 1986 by Sheng-Jin Chen [14]. For partial fulfillment of Doctor of Philosophy in Civil Engineering Lehigh University Bethlehem, Pennsylvania,

In the study both experimental and analytical modeling was reported. The experimental studies, which include three different floor slab systems: flat plate, slab supported on beams, and waffle slab. The important parameters from the experimental studies were summarized and their effect on the in-plane characteristic of floor slabs were examined, And the analytical model was based on a modified Mohr-Coulomb yield-failure criterion with emphasis on the tension and tension-compression regions. The analytical model provided the capability of analyzing reinforced concrete panels under monotonic and cyclic loadings. Then he investigated results from three series of experimental studies of floor systems including flat plate floor slabs, floor slabs supported on beams and waffle slabs . A nonlinear finite element model was developed to simulate the in-plane behavior of reinforced concrete floor slabs. Then findings from the experimental Studies shrinkage and out-of-plane bending can induce cracking along the slab-wall junction, and significantly reduce the initial in-plane stiffness of the slab panel, in-plane strength of the slab panel is basically controlled by the in-plane flexural strength at the major crack. In all cases, the major crack forms near the cross section where many of the negative bending reinforcing bars for gravity load are terminated. The major crack runs parallel to the fixed edge for a distance before turning towards the fixed edge. After the formation of the major crack, the deflection characteristics of the floor slab panel are mainly controlled by the closing and opening of the crack. The final failure, typically occurring at a load below the ultimate, may be precipitated by the crushing of concrete and fracturing of reinforcing bars across the major crack, the presence of full service gravity load causes a decrease in the in-plane strength, about 10% under cyclic load and 20% under monotonic load. However, the displacement capacity is not seriously affected. The general behavior of the slabs is not altered by the gravity load, and the major crack still develops near the boundary between the column and middle strips. The complete formation of the major crack still governs the ultimate resistance and the bent-up (trussed) bars in a slab panel tend to straighten out after the opening of the major crack, and tend to accelerate the growth of the cracks. This is seen as a disadvantage. Therefore, it is suggested to avoid using bent-up bars in slabs where diaphragm action is important. Findings from Analytical Studies are Despite its simplicity, the proposed finite element model based on a modified Mohr-Coulomb criterion is capable of adequately estimating the stiffness, strength, and deformability of floor slabs under in-plane load and doubling the amount of longitudinal reinforcing bars in the column strips of the floor slab panel leads to an increase of the in-plane strength, by approximately 25%.

4. Journal of 15WCEE (LISBOA 2012) with title Structural Analyses with Flexibility Effect of the Floor slab by Kehila Fouad ,Zerzour Ali &Remki Mustapha [16]. They were considered two cases for analysis of flexibility effect of diaphragm those are frame buildings with the Dimensions 23.48m in length and 10.06m in width with 5, 10, and 15 stories were analyzed. These buildings contain 8 by 3 column lines; the height of story was 3.06m. For each structure, the slabs were modeled using different methods: the rigid diaphragm method and, the refined mesh method findings.

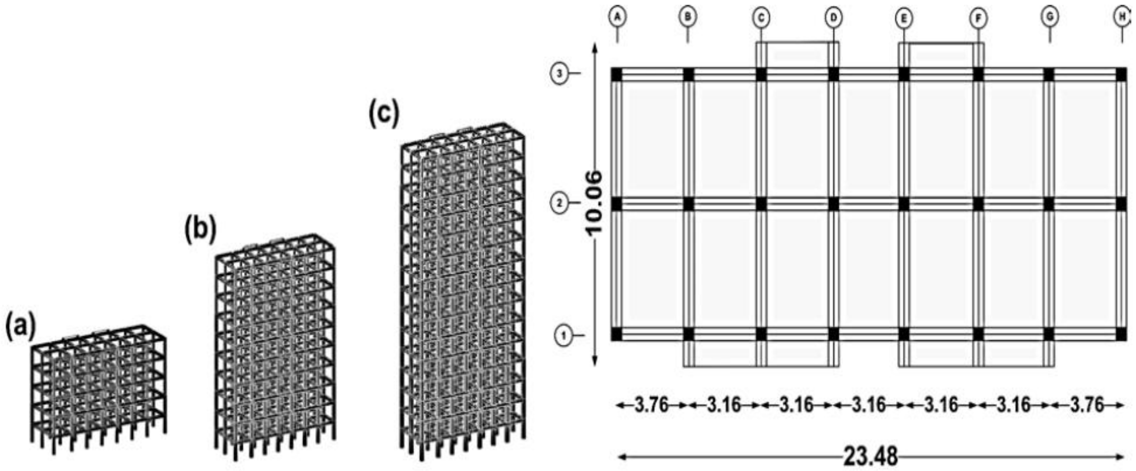

Figure 1.Plane view of frame building [16]

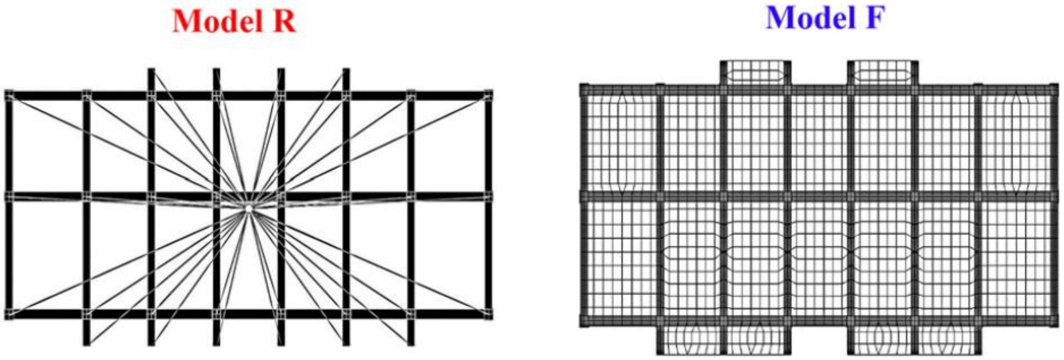

Figure 2.Rigid and flexible diaphragm of frame building [16]

And Analyses of shear walls buildings with the same plan, three different structures were analyzed: Shear wall buildings with 5, 10, and 15 stories, with a dimension of 23.48m in length and 10.06m in width. The thickness of the longitudinal shear wall is 16cm and transverse is 20cm.

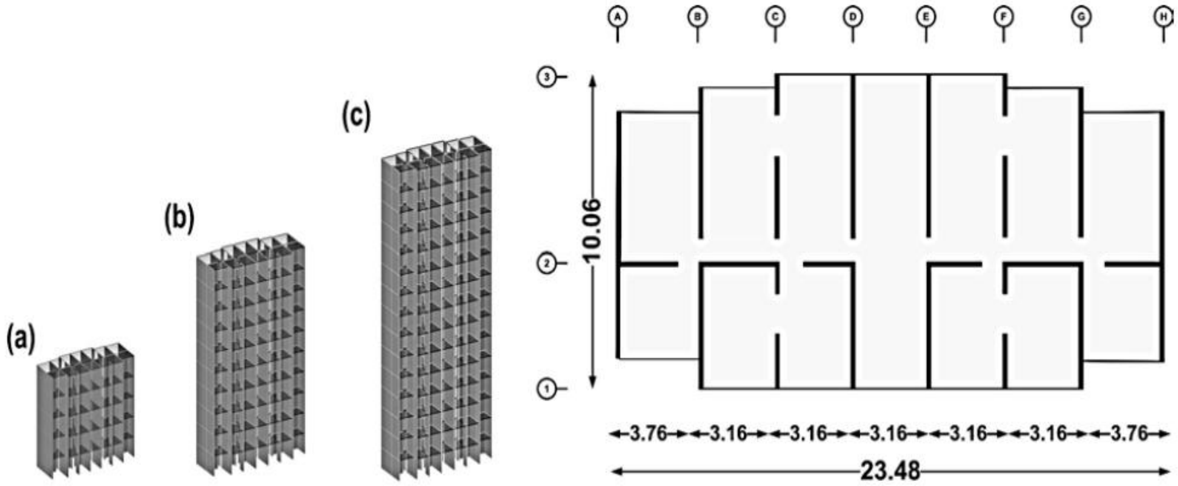

Figure 3.Plane view of shear wall building [16]

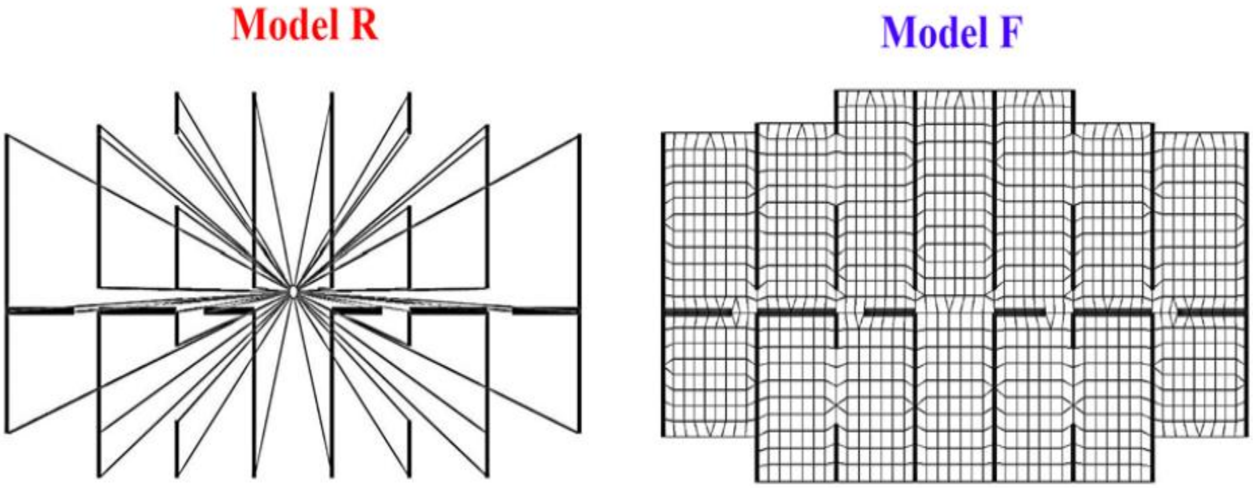

Figure4 .Rigid and flexible diaphragm of Shear wall building [16]

For each structure, the slabs were modeled using different methods: the rigid diaphragm method, the refined mesh method. A computer program ETABS was used for the analysis of those structures. Finally findings and conclusion for buildings with shear wall, the effect of the flexural stiffness of slabs is relatively significant, especially in taller buildings. If the flexural stiffness of the slabs was totally ignored, the lateral displacements may be overestimated and the seismic loads per the building code base shear may be significantly underestimated. It is recommended that the flexural stiffness of slabs is adequately included in the analysis of shear wall structures. Because of the non-uniform distribution of lateral stiffness and masses, the effects of flexible diaphragms in the typical building structure are complicated. The flexible diaphragms reduce the natural frequencies of the global structural modes.

5. JOURNAL OF STRUCTURAL ENGINEERING © ASCE / AUGUST 2004 /1175 with a title Seismic Analysis of Asymmetric Buildings with Flexible Floor Diaphragms by Dhiman Basu and Sudhir K. Jain [15] For the investigation they were considered A three-story building with floor diaphragms that are neither rigid nor completely flexible is analyzed to study its torsional response. The building consists of two end shear walls and seven interior frames, three of which include a small shear wall. The left shear wall was 10 m in length while right shear wall was 4 m in length; the length of each intermediate shear wall was 1.5 m. The thickness of all the shear walls was 150 mm. All columns are 400 mm X 340 mm, the longitudinal beams are 250 mm X 350 mm, and the transverse beams are 250 mm X 340 mm. The floor slabs were taken as 200 mm thick. The aspect ratio of the floor plan (50 m x 10 m) was chosen as 5, slightly more than that of typical buildings to show the effect of floor flexibility.

The first story height was taken as 4.5 m where as the height of the other two stories was 3.2 m. The modulus of elasticity and shear modulus of concrete were taken as 2.55×10^7 and 1.06×10^7 N/m^2, respectively. The gross moment of inertia is used in the analysis and the extra rigidity in the rigid end zones of the members is not modeled. The building was analyzed using the SAP2000 program. Beams and columns were modeled as line elements. Shear walls were modeled as shell elements by considering the membrane as well as the plate behavior while floor slabs were considered pure membrane elements. The design earthquake force on the building was calculated using Indian code provisions for seismic zone V. However, for many buildings that are long and narrow or have stiff end walls, floor diaphragm flexibility must be accounted for in the distribution of lateral load. Analysis results of a sample building clearly show the significance of considering the torsion provisions of design codes for asymmetric flexible diaphragm buildings. It was seen that treating the diaphragms of such buildings as rigid for torsional analysis may cause considerable error. The example also illustrates that the contribution of accidental torsion as well as the torsional amplification terms could be quite significant. However, the usual codal specification of accidental eccentricity as a fraction of the building dimension may be somewhat conservative for such buildings and this issue needs to be addressed in the future. Horizontal offset buildings constitute a class of structures that are particularly prone to in-plane floor deformation and torsion occurring simultaneously.

6. Journal of 15WCEE (LISBOA 2012) with a title Inelastic Seismic Response of Reinforced Concrete Buildings with Symmetric and Unsymmetrical Floor Diaphragm Openings by Mohamed T. Al Harash, Sc.D., P.E., S.E. – NCEES and Nader Panahshahi, Ph.D.[11]. For the investigation in the study they were considered five 3-stories, 12 m high (i.e., 4 m story height) reinforced concrete buildings. The structure's plan was twelve 6m bays in length (73m total) and three 6m bays in depth (18.3m total), with 0.2m thick shear walls placed symmetrically at the end frame. The columns were 0.36m x 0.36m and the girders were 0.36m x 0.61m. Floor diaphragm was a one-way 0.13m slab spanning across the frames with intermediate 0.36m x 0.36m supporting beams, i.e., 3m span. All elements were designed and detailed to meet ACI 318-08 and IBC 2009 prescribed forces. The lateral force resisting system in the N-S direction (short direction) consists of "Building Frame System" in which the shear walls will resist the entire seismic load, and intermediate moment resisting frames (IMRF) were used in the E-W direction (long direction). The equivalent lateral forces generated were based on a site class C, seismic design category (SDC) C and seismic use group I. Diaphragm openings were placed in the middle two-thirds of the building plan. From The investigation of the inelastic seismic response of 3-story reinforced concrete rectangular buildings with end shear walls and diaphragm plan aspect ratio of 4:1 with symmetric and unsymmetrical diaphragm openings placed within the middle two-thirds of the building floor plan, indicates that ignoring the inelastic diaphragm deformations can result in an incorrect assessment of the structure nonlinear seismic response (floor deformations and frame shear distributions), irrespective of the location of the openings relative to the building plan axes. Hence, the influence of floor openings should not be overlooked in such buildings.

7. A thesis by Sudhir Kumar Jani with a title of ANALYTICAL MODELS FOR THE DYNAMICS OF BUILDING, May 1983 [2]. For parietal fulfillment of the requirements for the degree of Doctor of philosophy at California institute of technology .he begin his findings by introducing evidences of floor flexibility in past earth quake. The damage of a two-story Administration building of Arvin High school due to July21, 1952 earth quake with magnitude of 7.7 in southern California (kern country) . The damage of the building is due to flexibility of diaphragm since the building is irregular geometry, During the Alaska earth quake with a

magnitude of 8.4 of March 27, 1964 a wing of the two –story west anchorage high school suffered several damage. The building was constructed from two wings joined at an angle(L and V shape in plan) very susceptible to damage induced by flexibility, because the fan- like deformations in the two wings of diaphragm lead to a stress singularity at the junction of the two wings. This building provides spectacular example of such damage. The damage of Fifth Avenue Chrysler center in anchorage (Alaska) was a one story rectangular building (about 48m long and 21m wide) that suffered extensively in the Alaska earth quake of March 27, 1964. This building provides another good example of significant in-plane floor flexibility in building. During imperial country earth quakes (magnitude 6.6) October 15, 1975, Imperial country service building, a six story reinforced concrete structure , was the only modern building to have sustain severe damage .note that in the upper stories of the building , the lateral load resistance was provided only by the end walls. Even though the aspect ratio (length=42m, width = 26m), a study of records obtained from roof reveals that there was significant floor-diaphragm deformation. This in –lane floor flexibility is not considered to have been responsible for the initiation of the damage in the building. However, the fact that it was significant, even in a building with a low aspect ratio, points out the importance of floor flexibility. Strong motion accelerograms obtained from the single story Mammoth thigh school gymnasium building, during the May, 1980, earth quakes provides another good example of significant floor flexibility in low aspect ratio buildings. This building, 44m length and 34m wide, has reinforced concrete exterior walls. [2]

Then using those damage records at different time and locations due to earth quake as in put he investigated the significance of in- plane flexibility on the dynamic behavior of buildings and develops new analytical method to analyze buildings with flexible floor diaphragm for one-story, two- story and multi storey reinforced concrete structures. By considering roofs us bending beam and end walls us shear beams, then the solution of this equation provides the natural frequency of the system. With this frequency known, the mode shapes and the participation factors for earth quake excitation can be obtained, thus enabling one to calculate the dynamic response of the building. [2]

8. A thesis by Kassahun Memru with a title Assessment of the effect of size of diaphragm discontinuity (opening) on the rigidity of diaphragm and distribution of lateral load to lateral load resisting elements [3]. For partial fulfillment of the requirements for the degree of masters of Science in civil engineering at Addis Ababa institute of technology.

For investigation a total 35 model structures were evaluated and discussed in detail to assess the effect of size of diaphragm discontinuity. From evaluation effects of diaphragm discontinuity on diaphragm rigidity and lateral load distribution to vertical element is mainly influenced by; vertical element stiffness, number of stories, aspect ratio of the slab dimension, shape and size of the diaphragm opening. Although these studies proved to be contributing to understanding the flexibility effects of diaphragm flexibility for opening more than 50% of the gross enclosed area of the diaphragms, he didn't address the effects of with different plan shapes like L-shape, U-shape, rectangular shape of diaphragms. Even it is difficult to address the flexibility of diaphragm to compute by using equivalent static analysis method according to Ethiopian Building Code Standard, EBCS-8.

2.3 CODE PROVISIONS

Following are summarized the floor-diaphragm modeling and design provisions of the codes considered .In this section a review of the provisions of some modern seismic codes for the analytical modeling of the floor diaphragm action is made. All the seismic codes generally accept that in most cases the floor diaphragms may be modeled as fully rigid without in plane deformability. Even though a rigid floor diaphragm is a good assumption for seismic analysis of the most buildings, several building configurations may exhibit significant flexibility in floor diaphragms.

In these configurations, some codes like (EBCS8, EC8, and EAK2000) set certain qualitative criteria related to the shape of the diaphragm, while some others (UBC-97, ASCE7-05, FEMA-273) set quantitative criteria relating the in-plane deformation of the diaphragm with the average drift of the associated storey.

2.3.1 ETHIOPIAN BUILDING CODE- 8, 1995 [EBCS 8, 1995]

In section 2.4.2.5 [7], Diaphragm and bracing in horizontal planes shall be able to transmit with sufficient over strength the effects of the design seismic action to the various lateral load resisting systems to which they are connected.

When the floor diaphragms of the building are sufficiently rigid in their plane, the masses and the moments of inertia of each floor may be lumped at the centre of gravity, thus reducing the degrees of freedom to three degrees of freedom per floor (two horizontal displacements and a rotation about the vertical axis).

In section 3.12 [7] diaphragm shall exhibit sufficient in-plane stiffness for the distribution of the horizontal forces to the vertical elements in accordance with the design assumption (e.g. rigid body motion of the diaphragm), particularly in the case of important the stiffness change of vertical element above and beneath the diaphragm.

The rigid body condition may be considered valid if the in-plane deviations of all points of the diaphragm from their rigid body position are less than (5%) of their respective absolute displacements under the seismic load combination.

The seismic design shall cover the verification of reinforced concrete (R.C.) diaphragms in the following cases of ductility class DC “H” and DC “M” structures:

- Irregular geometries or divided shapes in plan, recesses, re-entrances

- Irregular and large openings in the slabs
- Irregular distribution of masses and /or stiffness's (as, for example, in the case of set back or off-sets).
- Basements with walls located only in part of their perimeter, or only in part of the ground floor area.

In these cases, action effects in RC diaphragms may be estimated by modeling them as deep beams on yielding supports or plane trusses. The design values of the action effects should be derived taking into account section 2.4.2.5. [7]

In cases of core or wall structural systems of ductility class DC "H" and DC "M", it should be verified that the transfer of the horizontal forces from the diaphragms to the cores or walls has occurred. In this respect the following provisions apply:

- The design shear stress at the interface of the diaphragm and a core or wall should be limited to $1.5f_{ctd}$, to control cracking;
- An adequate strength to guard against shear sliding failure should be ensured, disregarding any contribution of the concrete (V_{cd}=0). Additional bars should be provided, contributing to the shear strength of the interface between diaphragms and cores or walls; anchorage of these bars should follow the provisions of 3.6.[7]

2.3.2. EURO CODE 8 [EC8, 2004]

There is a definition in section 4.2.1.5 [8]. In buildings, floors (including the roof) play a very important role in the overall seismic behavior of the structure. They act as horizontal diaphragms that collect and transmit the inertia forces to the vertical structural systems and ensure that those systems act together in resisting the horizontal seismic action. The action of floors as diaphragms is especially relevant in cases of complex and non-uniform layouts of the vertical structural systems, or where systems with different horizontal deformability characteristics are used together (e.g. in dual or mixed systems).

When the floor diaphragms of the building may be taken as being rigid in their planes, the masses and the moments of inertia of each floor may be lumped at the centre of gravity.

- The diaphragm is taken as being rigid, if, when it is modeled with its actual in-plane flexibility, its horizontal displacements nowhere exceed those resulting from the rigid diaphragm assumption by more than 10% of the corresponding absolute horizontal displacements in the seismic design situation.

In section 5.10 [8], the seismic design shall cover the verification of reinforced concrete (R.C.) diaphragms in the following cases of Ductility Class “DC H” structures:

- Irregular geometries or divided shapes in plan, recesses, re-entrances
- Irregular and large openings in the slabs
- Irregular distribution of masses and or stiffness
- Basements with walls located only in part of their perimeter, or only in part of the ground floor area.

In these cases, action effects in RC diaphragms may be estimated by modeling them as deep beams on yielding supports or plane trusses. The design values of the action effects should be derived taking into account section 4.4.2.5. [8].

In cases of core or wall structural systems of “DCH”, it should be verified that the transfer of the horizontal forces from the diaphragms to the cores or walls has occurred. In this respect the following provisions apply:

- The design shear stress at the interface of the diaphragm and a core or wall should be limited to $1.5f_{ctd}$, to control cracking;
- An adequate strength to guard against shear sliding failure should be ensured, assuming that the strut inclination is 45^o. Additional bars should be provided, contributing to the shear strength of the interface between diaphragms and cores or walls; anchorage of these bars should follow the provisions of 5.6.[8]

2.3.3. GREEK CODE FOR SEISMIC RESISTANT STRUCTURES [EAK2000]

In section 3.2.1 [10], for buildings subjected to horizontal seismic actions and under the condition that the diaphragm action of the slabs is ensured, it is sufficient to assume three degrees of freedom per floor (two translations and one rotation). For buildings where the diaphragm action is not ensured, the introduction of a sufficient number of additional degrees of freedom is required, with proper discretization, in order to represent the deformation of the plates within their plane.

For buildings subjected to horizontal seismic actions and under the condition that the diaphragm action of the slabs is ensured, it is sufficient to concentrate the mass of every floor and the respective mass moment of inertia about the vertical axis on the centre of gravity of the floor.

In section 3.5.1[10].The floors act as non-deformable diaphragms within their plane. This function, in the absence of a more accurate verification, is not considered as ensured for long rectangular buildings (or parts of buildings) with a ratio of their sides greater than 4, as well as for buildings with gaps exceeding 30% of the ground plan of the floor.

The increase or reduction $\Delta K_i = K_{i+1} - K_i$ of the stiffness K_i of a floor at any horizontal direction does not exceed the values $0.35K_i$ and $0.50K_i$ respectively. The stiffness of a floor on one direction shall be calculated as the sum of the stiffness's $E \cdot I/h$ of the floor vertical elements.

The variation $\Delta m_i = m_{i+1} - m_i$ of the mass mi of a floor does not exceed the value $0.35m_i$ when there is an increase and $0.50m_i$ when there is a reduction. From this criterion, the upper floor and any staircase end may be excluded.

2.3.4 Uniform Building Code [UBC97]

Flexible diaphragms, as defined in Section (1630.6).[17], Diaphragms shall be considered flexible for the purposes of distribution of story shear and torsional moment when the maximum lateral deformation of the diaphragm is more than two times the average story drift of the associated story. This may be determined by comparing the computed midpoint in-plane deflection of the diaphragm itself under lateral load with the story drift of adjoining vertical-resisting elements under equivalent tributary lateral load.

In other word diaphragm is rigid if $\beta < 2$

$$\beta = \frac{\Delta_{\text{Flexible Diaphragm}}}{\Delta_{\text{Average story drift}}} < 2$$

And it is flexible if $\beta \geq 2$

$$\beta = \frac{\Delta_{\text{Flexible Diaphragm}}}{\Delta_{\text{Average story drift}}} \geq 2$$

The deflection in the plane of the diaphragm shall not exceed the permissible deflection of the attached elements. Permissible deflection shall be that deflection that will permit the attached element to maintain its structural integrity under the individual loading and continue to support the prescribed loads. Floor and roof diaphragms shall be designed to resist the forces determined in accordance with the following formula:

$$Fpx = \frac{Ft + \sum_{i=x}^{n} \mathrm{Fi}}{\sum_{i=x}^{n} \mathrm{Wi}} Wp \qquad \text{(33-1) [17]}$$

The force F_{px} determined from Formula (33-1) need not exceed $1.0CaIW_{px}$, but shall not be less than $0.5CaIW_{px}$. [16].

2.3.5 AMERICAN SOCIETY OF CIVIL ENGINEERS [ASCE 7-05]

In section 1 2.3.1 .1[1] and Section 1 2.3.1 .3[1] defines the conditions under which a diaphragm can be considered as "flexible," the case where the diaphragm provides no stiffness. In the case of flexible diaphragms the loads are generally assumed to be distributed to the various frames based on tributary mass (seismic) or tributary exposure (wind).

Section 1 2.3.1 .2[1] defines the conditions under which a diaphragm can be considered as "rigid," the case where the diaphragm provides infinite stiffness; in the case of rigid diaphragms the loads can simply be applied as a single story force on the diaphragm at the center of mass plus or minus the required eccentricities (usually 5 percent) for seismic forces, or at the center of exposure for wind forces. The diaphragm provides the mechanism for distributing the loads to the frames, as a function of frame stiffness and location. The assumption of infinite rigidity is a valid and useful assumption when the diaphragm is much stiffer than the frames, as defined in Section 1 2.3.1 .2,[1] and the degree of error resulting from assuming that the finitely stiff diaphragm is infinitely stiff for analysis purposes is generally negligible.

Diaphragms that don't conform to either of these definitions are referred to as "semi-rigid." Section 1 2.3.1[1] requires that unless the diaphragm can be idealized as either flexible or rigid in accordance with the above-referenced sections, the structural analysis must explicitly include consideration of the stiffness of the diaphragm. That is, the diaphragm and its stiffness properties must explicitly be included in the structural analysis model. Again, the diaphragm provides the mechanism for distributing load to the frames, as a function of the relative stiffnesses of the diaphragm and frames and the locations of the frames. The loads must be applied at their true location, at the diaphragm mesh nodes for seismic forces (although with some modification to account for the Code-required 5 percent accidental torsion) and around the perimeter (exposed) nodes for wind forces. The loadings used for this calculation shall be those prescribed by Section 12.8 [1].

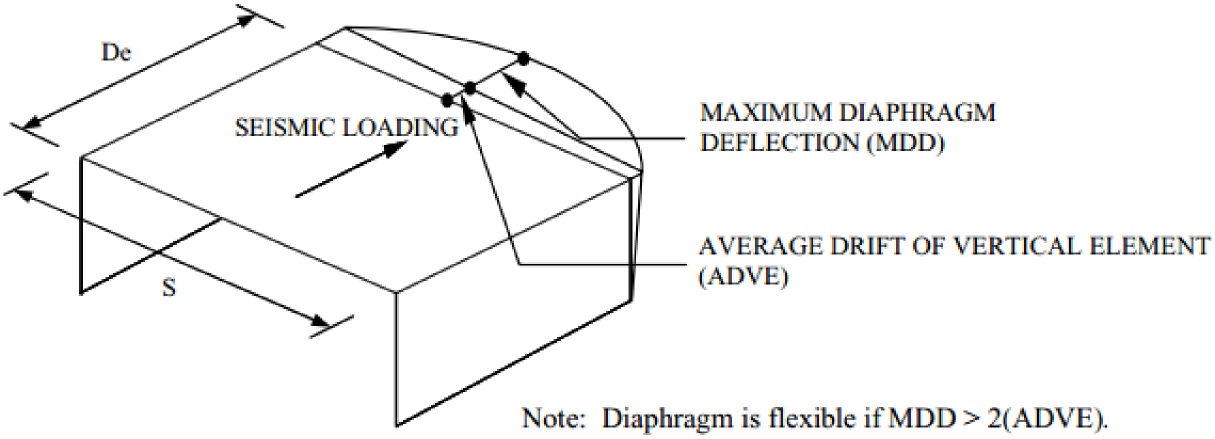

Figure 5.FLEXIBLE DIAPHRAGM FROM ASCE 7-05, [1]

Diaphragms shall be designed for both the shear and bending stresses resulting from design forces. At diaphragm discontinuities, such as openings and reentrant corners, the design shall assure that the dissipation or transfer of edge (chord) forces combined with other forces in the diaphragm is within shear and tension capacity of the diaphragm. Floor and roof diaphragms shall be designed to resist design seismic forces from the structural analysis, but shall not be less than that determined in accordance with Eq. 12.10-1 [1] as follows:

$$Fpx = \frac{\sum_{i=x}^{n} \mathrm{Fi}}{\sum_{i=x}^{n} \mathrm{Wi}} Wpx \qquad (12.10\text{-}1)\ [1]$$

Where

F_{px}=the diaphragm design force

F_i =the design force applied to Level i

w_i =the weight tributary to Level i

w_{px}=the weight tributary to the diaphragm at Level x

The force determined from Eq. 12.10-1[1] need not exceed $0.4S_{DS}Iw_{px}$, but shall not be less than $0.2S_{DS}Iw_{px}$. [1]. Where the diaphragm is required to transfer design seismic force from the vertical resisting elements above the diaphragm to other vertical resisting elements below the diaphragm due to offsets in the placement of the elements or to changes in relative lateral stiffness in the vertical elements, these forces shall be added to those determined from Eq. 12.10-1. The redundancy factor, applies to the design of diaphragms in structures assigned to Seismic Design Category D, E, or F. For inertial forces calculated in accordance with Eq. 12.10-1[1], the redundancy factor shall equal 1.0. For transfer forces, the redundancy factor, ρ, shall be the same as that used for the structure. For structures having horizontal or vertical structural irregularities of the types indicated in Section 12.3.3.4, the requirements of that section shall also apply [1].

In other word diaphragm is rigid if λ < 0.5

$$\lambda = \frac{\Delta_{\text{Max Diaphragm deflection}}}{\Delta_{\text{Average story drift}}} < 0.5$$

And it is flexible if λ ≥ 2

$$\lambda = \frac{\Delta_{\text{Max Diaphragm deflection}}}{\Delta_{\text{Average story drift}}} \geq 2$$

And it is stiff if 0.5 < λ ≤ 2

$$0.5 < \lambda = \frac{\Delta_{\text{Max Diaphragm deflection}}}{\Delta_{\text{Average story drift}}} \leq 2$$

2.3.6. FEDERAL EMERGENCY MANAGEMENT AGENCY (FEMA274)

In section C3.2.4 of [9], Floor diaphragms are a key element of the seismic load path in a building. Diaphragms transfer seismically induced inertia forces at floor and roof levels to vertical elements of the seismic framing system, and distribute forces among vertical elements where relative stiffnesses and strengths of vertical elements differ from location to location. Floor diaphragms shall be classified as flexible, stiff, or rigid. Diaphragms shall be considered flexible when the maximum lateral deformation of the diaphragm along its length is more than twice the average inters story drift of the story immediately below the diaphragm. For diaphragms supported by basement walls, the average inter story drift of the story above the diaphragm may be used in lieu of the basement story. Diaphragms shall be considered rigid when the maximum lateral deformation of the diaphragm is less than half the average inters story drift of the associated story. Diaphragms that are neither flexible nor rigid shall be classified as stiff.

In other word diaphragm is rigid if λ < 0.5

$$\lambda = \frac{\Delta_{\text{Flexible Diaphragm}}}{\Delta_{\text{Average story drift}}} < 0.5$$

And it is flexible if λ ≥ 2

$$\lambda = \frac{\Delta_{\text{Flexible Diaphragm}}}{\Delta_{\text{Average story drift}}} \geq 2$$

And it is stiff if 0.5 < λ ≤ 2

$$0.5 < \frac{\Delta_{\text{Flexible Diaphragm}}}{\Delta_{\text{Average story drift}}} \leq 2$$

The inter story drift and diaphragm deformations shall be estimated using the seismic lateral forces (Equation 3-6) [9]. The in-plane deflection of the floor diaphragm shall be calculated for an in-plane distribution of lateral force consistent with the distribution of mass, as well as all in-plane lateral forces associated with offsets in the vertical seismic framing at that floor.

Mathematical models of buildings with stiff or flexible diaphragms should be developed considering the effects of diaphragm flexibility. For buildings with flexible diaphragms at each floor level, the vertical lines of seismic framing may be designed independently, with seismic masses assigned on the basis of tributary area.

Floor diaphragms shall be designed to resist the effects of the inertia forces developed at the level under consideration (equal to F_{px} in Equation 3-9)[9], and the horizontal forces resulting from offsets in, or changes in stiffness of, the vertical seismic framing elements above and below the diaphragm. Forces resulting from offsets in, or changes in stiffness of, the vertical seismic framing elements shall be taken to be equal to the elastic forces (Equation 3-6)[9] without reduction, unless smaller forces can be justified by rational analysis.

$$F_{px} = \frac{1}{C_1 C_2 C_3} \sum_{i=x}^{n} F_i \; \frac{w_x}{\sum_{i=x}^{n} w_i} \qquad \text{(3-9) [9]}$$

Where:

F_{px}= Total diaphragm force at level x

F_i = Lateral load applied at floor level i given by Equation 3-7[9]

w_i = Portion of the total building weight W located on or assigned to floor level i

w_x = Portion of the total building weight W located on or assigned to floor level x

Coefficients C1, C2, and C_3 are described in Section 3.3.1.3A. [9]

The lateral seismic load on each flexible diaphragm shall be distributed along the span of that diaphragm, considering its displaced shape.

2.3.7. INDIAN STANDARD [IS 1893 (Part 1): 2002]

In section 4.8 [12], Diaphragm is a horizontal or nearly horizontal system, which transmits lateral forces to the vertical resisting elements, for example, reinforced concrete floors and horizontal bracing systems.

In section 7.7.2.2[12], In case of building whose floor diaphragms cannot be treated as infinitely rigid in their own plane, the lateral shear at each floor shall be distributed to the vertical elements resisting the lateral forces, considering the in-plane flexibility of the diaphragms.

- A floor diaphragm shall be considered to be flexible, if it deforms such that the maximum lateral displacement measured from the chord of the deformed shape at any point of the diaphragm is more than 1.5 times the average displacement of the entire diaphragm.
- Reinforced concrete monolithic slab-beam floors or those consisting of prefabricated/precast elements with topping reinforced screed can be taken a rigid diaphragm.
- In other word diaphragm is rigid if $\beta \leq 1.5$
- $\beta = \frac{\Delta_{\text{Flexible Diaphragm}}}{\Delta_{\text{Average story drift}}} \leq 1.5$
- And it is flexible if $\beta \geq 2$
- $\beta = \frac{\Delta_{\text{Flexible Diaphragm}}}{\Delta_{\text{Average story drift}}} > 1.5$

CHAPTER 3

MODELING

3.0. MODELS OF BUILDING ANALYSES

For building analyses under the rigid-floor assumption, master and slaved nodes are used. Each rigid floor contains a master node with three degrees of freedom at the mass center of the floor to control the two in plane translations and one out-of-plane rotation of all the slaved nodes in this rigid floor. The slaved nodes include three additional degrees of freedom-two in-plane rotations and one out-of-plane translation. Thus, the total number of degrees of freedom is equal to three times the total number of slaved nodes and master nodes in the mesh for a three-dimensional (3D) building analysis. For building analyses under the flexible-floor assumption, each node contains six degrees of freedom three translations and three rotations.

In the proposed methodology, the floor diaphragms were initially modeled as semi-rigid. The semi-rigid diaphragm designation causes the stiffness of the diaphragm to be determined based on the properties assigned to the slab. The computational results for the four Building’s mode shape suggest that the diaphragm is flexible; therefore the diaphragm in the, modeling with both rigid and semi-rigid diaphragm assignments for comparison purposes. Thus, to compare the results of the rigid-and flexible-floor analyses, dynamic analysis is probably a better choice since the earthquake loading can be applied to the building base without any differentiation between the rigid and flexible-floor analyses. Forced dynamic analyses include time-history and response-spectrum analyses. For time-history analysis, it is not easy to compare the complex analysis results between the rigid- and flexible-floor analyses. For example, the two results may differ due to a significant time shift, so comparing them at a certain time will cause error. The response-spectrum analysis does not have this problem, since only the maximum responses are calculated in this method. Thus this method with the response spectrum of the UBC-97 (Fig. 3.1) and EUROCODE 8 (Fig. 3.2) are used to perform the two types of building analyses.

For the analytical modeling and dynamic analyses of the structure considered, the commercial computer analysis software ETABS (CSI 2005, V9.72) was used. The results for the modal shapes are displayed and used for investigation of diaphragm flexibility based on each code requirements.

3.1 Response spectrum method

In the response spectrum method, the peak response of a structure during an earthquake is obtained directly from the earthquake response (or design) spectrum. This procedure gives an approximate peak response, but this is quite accurate for structural design applications. In this approach, the multiple modes of response of a building of an earthquake are taken into account. For each mode, a response is read from the design spectrum, based on the modal frequency and the modal mass. The responses of different modes are combined to provide an estimate of total response of the structure using modal combination methods such as complete quadratic combinations (CQC), square root of sum of squares (SRSS), or absolute sum (ABS) method.

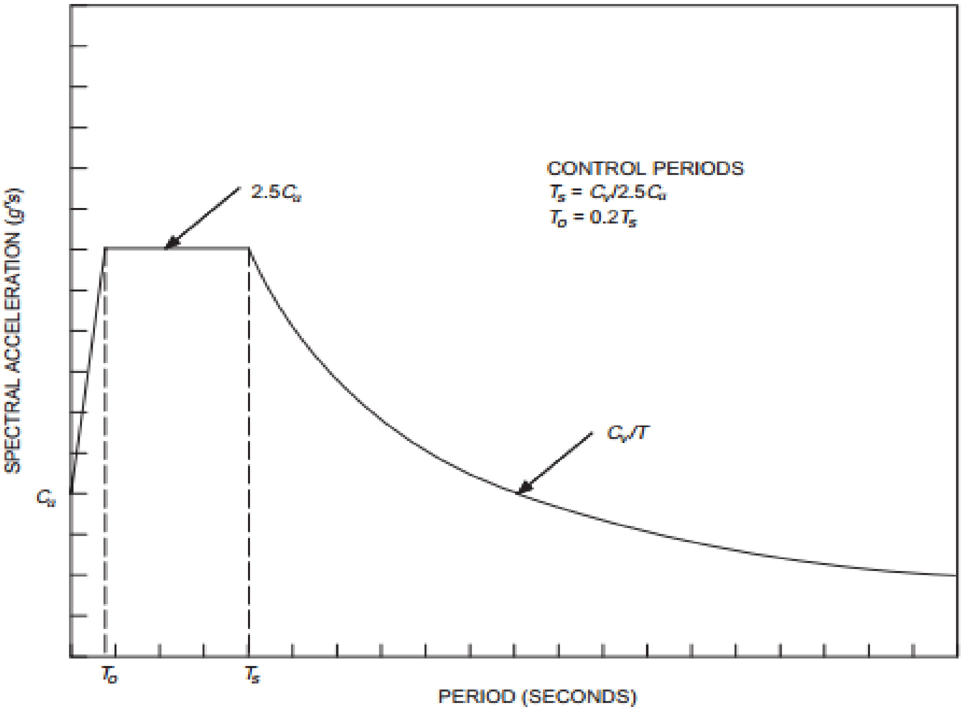

Figure 6.Response spectrum curve of UBC-97. [16]

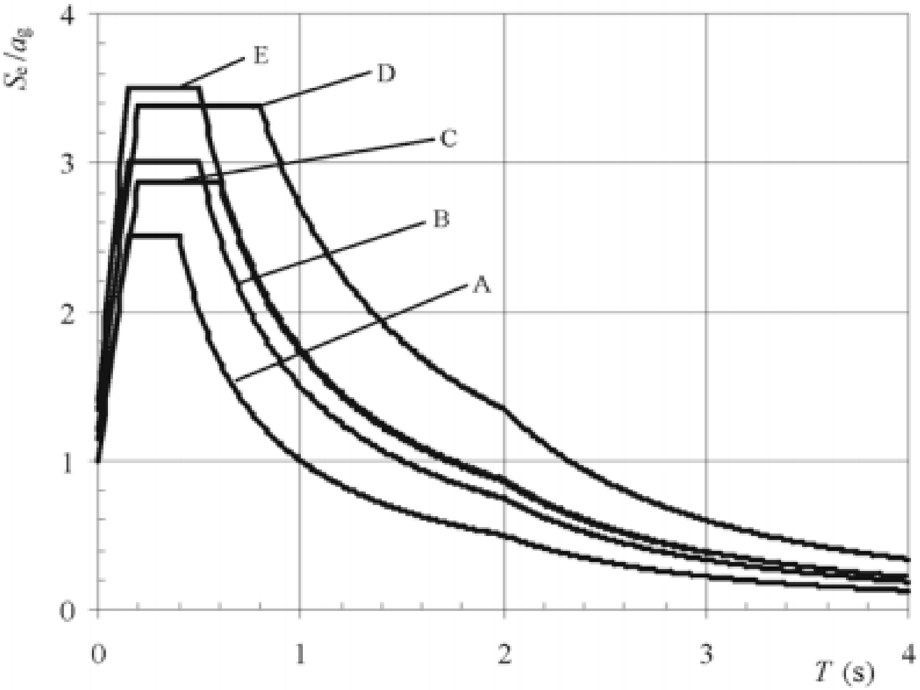

Figure 7 .Recommended Type 1 elastic response spectra for ground types

A to E (5% damping) EUROCODE 8[8]

3.2 CHARACTERISTICS OF BUILDINGS

For the investigation of flexibility of diaphragm, some reinforcement concrete buildings with L shaped, U-shaped, rectangular plan shape and rectangular with openings are considered. These buildings are analyzed with shear wall and without shear walls. L-shaped building consists of two long rectangular interconnected parts, with aspects ratio ≈ 1:4.5 for each of them. 6- Story U-shaped building consists of three long rectangular interconnected parts, with aspects ratio ≈ 1:3.75 and 1:5.2. The floor plan in rectangular building has a rectangular shape with aspect ratio 1:4.33 and the floor plan in rectangular building with an opening has a rectangular shape with aspect ratio 1:2.

The stiffness of the diaphragm depends on the material, thickness, shape and the dimensions of the diaphragms, while the stiffness of the vertical elements depends on the material, cross-section properties of these elements and the storey's height. As much as the in-plane stiffness of the diaphragm becomes smaller in relation to the lateral stiffness of the walls and columns, so much the influence of the in-plane flexibility to the stress of the walls and columns becomes greater. If cracked sections of the vertical elements (columns, walls) have been considered (due to code provisions), then cracked sections for the diaphragms (reduced thickness) must be considered also.

3.2.1. Material Properties

Properties of Concrete

Characteristic strength: 25 N/mm^2

Modulus of elasticity: 2.9 x 10^{10} N/m^2

Mass density: 2400 kg/m^2

Poisson’s ratio: 0.0

Yield stress: 300 x 10^6 N/m^2

3.2.2. Response spectrum input data

INPUT DATA FOR UBC 97

SEISMIC ZONE	4	
Z factor	0.4	TABLE 16-I
Soil Profile Description	Rock	
Soil Profile Type	SB	TABLE 16-J
N_a For Zone 4 only	1	TABLE 16-S
N_v For Zone 4 only	1	TABLE 16-T
C_a	0.4	TABLE 16-Q
C_v	0.4	TABLE 16-R
R	5.5	TABLE 16-N

INPUT DATA FOR EURO CODE 8

Response Curve	Type 1		
Seismic Zone	4		
Soil Profile Description	Rock	TABLE 3-1	
Soil Profile Type	A	TABLE 3-1	
Soil coefficients S,TB, TC, TD	According Table 3.2 for Response Curve Type 1		
S =	1.20	TB =	0.15
TC =	0.50	TD =	2.00
q The behavior factor	2.0	Table 4-4	
β The lower bound factor	0.2		
Damping correction factor η	5%		
I (Importance Factor)	1.00	TABLE 4-3	

3.2.3. Cross Section Property

Table 1 Cross section property

Shape of buildings	Beam section (cm)	Column section (cm)	Slab thickness (cm)	Shear wall thickness (cm)	Number of stories	Story height (m)
Rectangular	50X80	80X80	15	15	5	4
U-shape	50X80	80X80	15	30	6	4
	40X80					
L-shape	40X80	50X50	12	15	4	4
RVs opening	50X80	80X80	15	15	5	4

3.3. Computational Model

3.3.1 Rectangular Building Computational Model

A screen shot of the rectangular building computer model is shown in Figure P below.

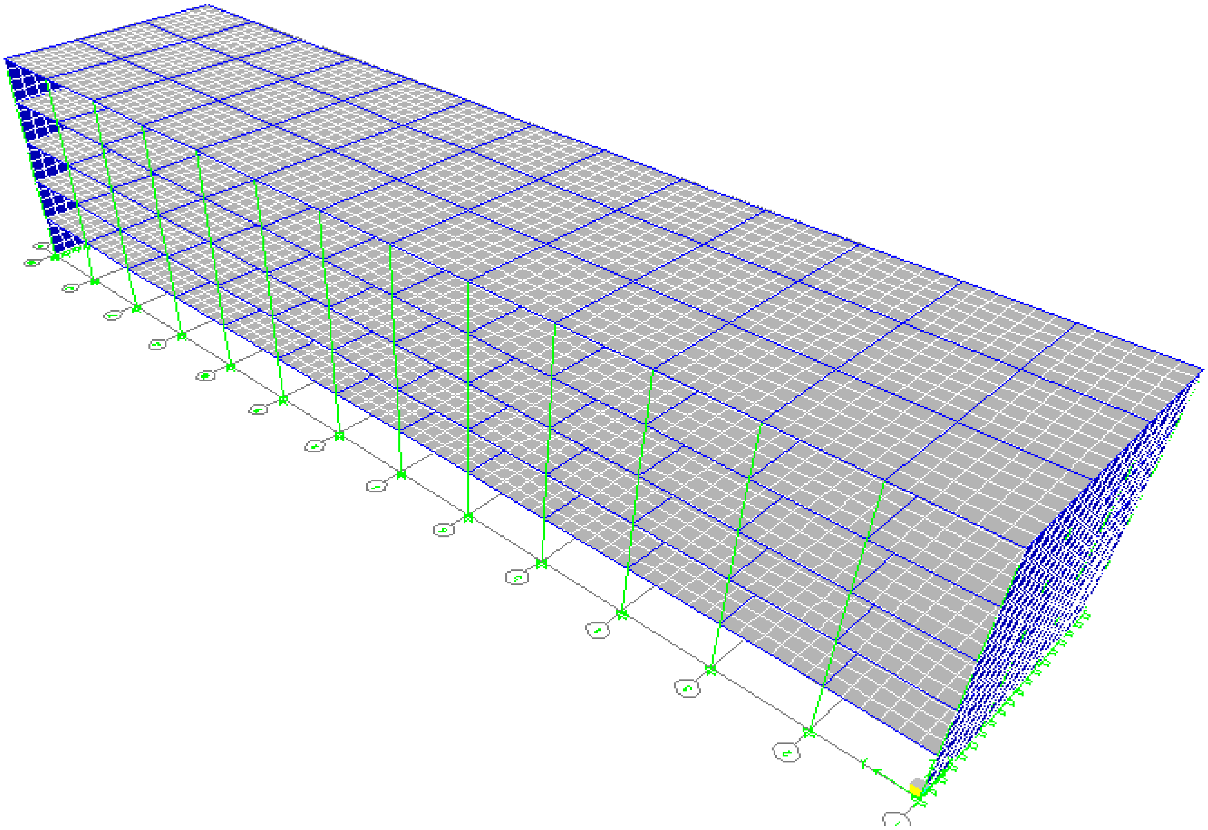

Figure 8. Rectangular building Computer Generated 3D Model.

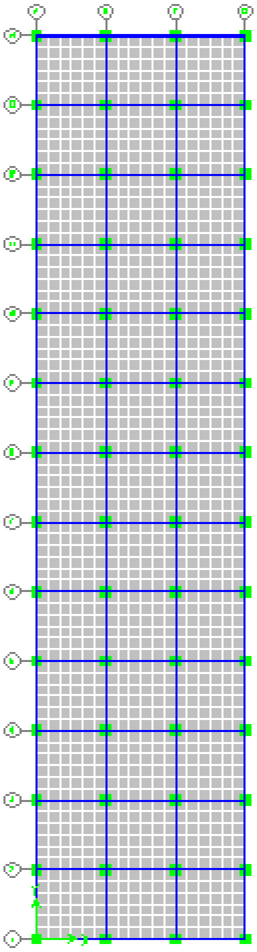

Figure 9. Rectangular building Computer Generated Floor Plan.

Consider two five-storey buildings with 13 bays of 6m each along the Y-direction, and 3bays each of the same 6m long the x-direction. Thus, the two buildings have plan aspect ratios of 4.33. These two buildings are designed for gravity loads and lateral load of the building using response spectrum method and have 150mm thick reinforced concrete structural walls at the two ends while regular 800×800 columns and 500x800beams are present at every 6m grid and 150mm thick slab. The reinforced concrete shear walls with a modulus of elasticity of 29 GPA and Poisson’s ratio of 0. This assumption for the modulus of elasticity is based each code provision and an assumed concrete strength of 25MPA.

3.3.2 U Shape Building Computational Model

A screen shot of the U shape building computer model is shown in Figure P below

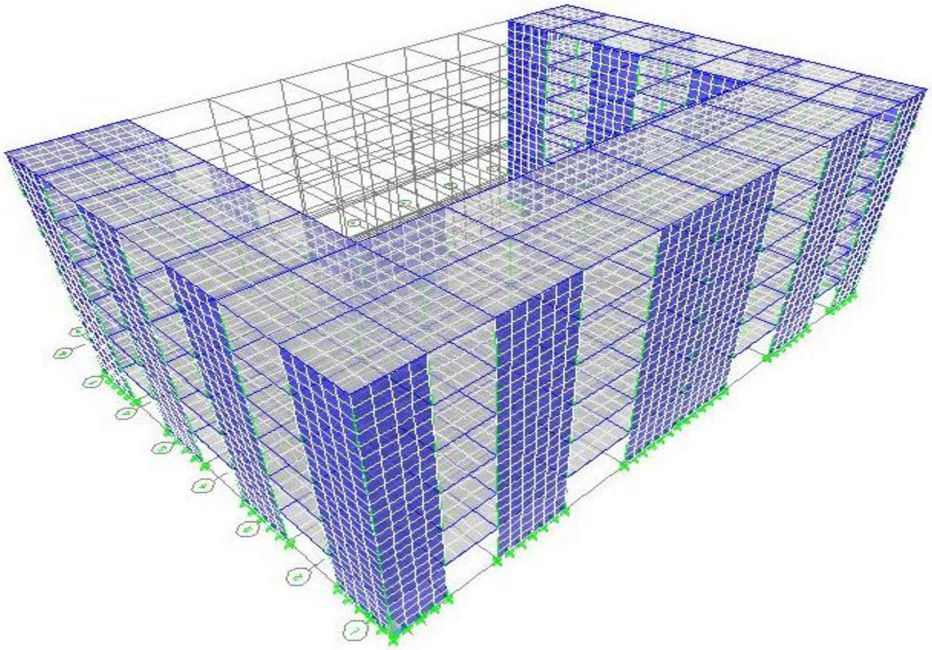

Figure 10 U shape building Computer Generated 3D Model

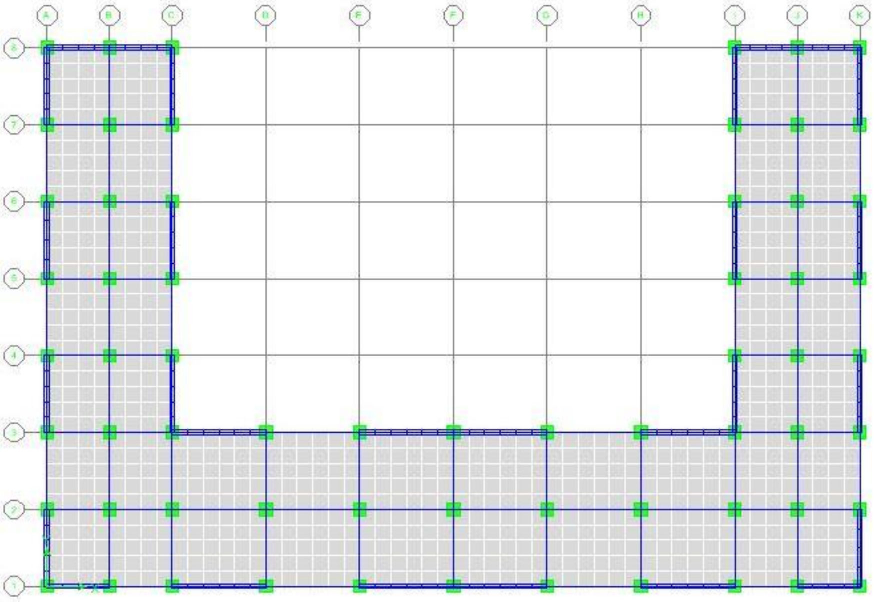

Figure 11. U shape building Computer Generated Floor plane.

Consider two U shape six-storey buildings with 7 bays, 2bays of 5m each along the Y-direction, and 10 bays,2 bays each of 6m and 4m long the x-direction respectively. Thus, These two buildings are designed for gravity loads and lateral load of the building using response spectrum method and have 300mm thick reinforced concrete structural walls at the two ends while regular 800×800 columns and 500x800beams and 400X 800 are present at every 6m,5m and 4m grid respectively and 150mm thick slab. The reinforced concrete shear walls with a modulus of elasticity of 29 GPA and Poisson’s ratio of 0. This assumption for the modulus of elasticity is based each code provision and an assumed concrete strength of 25MPA.

3.3.3 L Shape Building Computational Model

A screen shot of the U shape building computer model is shown in Figure 3.7 below

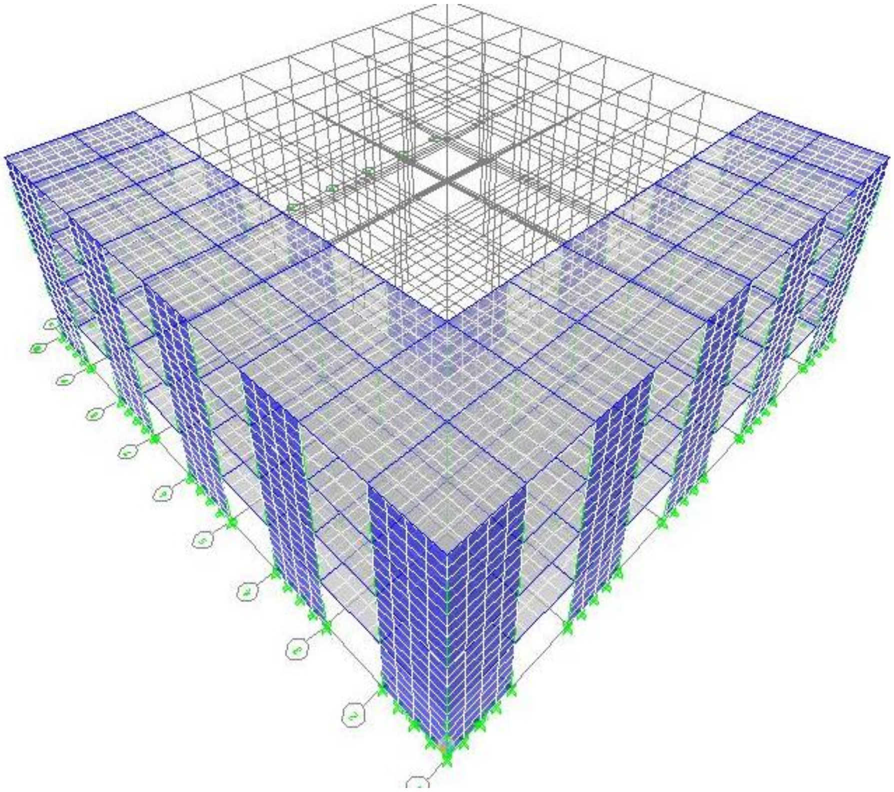

Figure 12. L shape building Computer Generated Floor Plan.

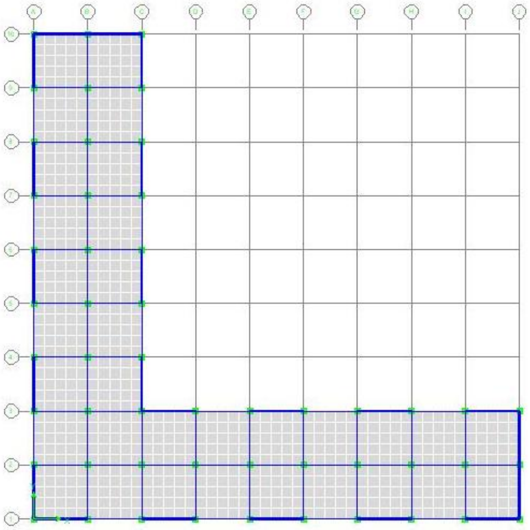

Figure 13. L shape building Computer Generated Model

Consider two L shape four-storey buildings with 9 bays, 2bays of 5m each along the Y-direction, and 9 bays, 2 bays each of 5m long the x-direction. Thus, these two buildings are designed for gravity loads and lateral load of the building using response spectrum method and have 150mm thick reinforced concrete structural walls at the two ends while regular 500×500 columns and 400X 800 are present at every 5m grid and 120mm thick slab. The reinforced concrete shear walls with a modulus of elasticity of 29 GPA and Poisson’s ratio of 0. This assumption for the modulus of elasticity is based each code provision and an assumed concrete strength of 25MPA.

3.3.4 Rectangular Building with Opening Computational Model

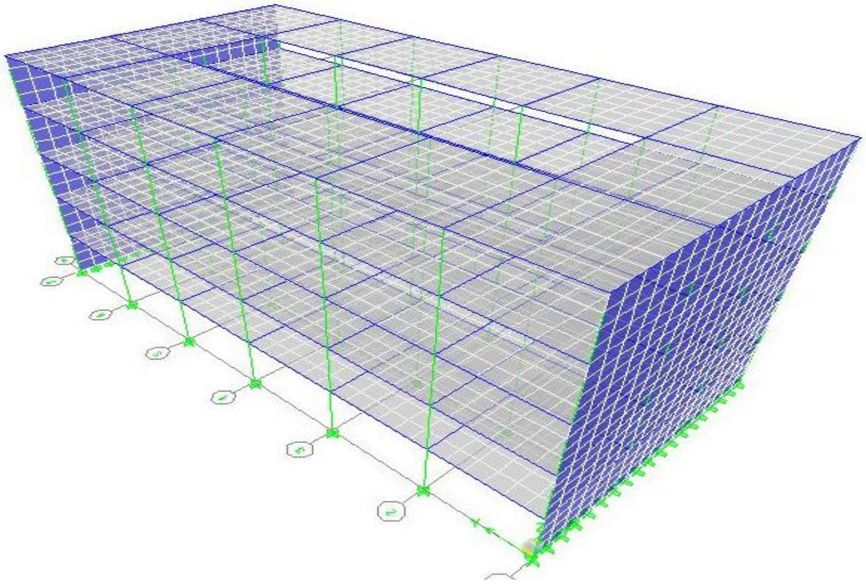

Figure 14. Rectangular building with opening Computer Generated 3D Model

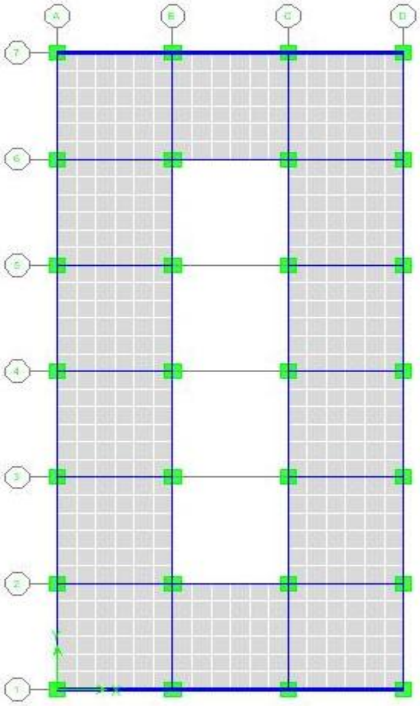

Figure 15. Rectangular building with opening Computer Generated Floor Plan

Consider two five-storey buildings with 6 bays and 1bays of 6m each along the Y-direction, and 3bays and 1 bays each of the same 6m long the x-direction. Thus, the two buildings have plan aspect ratios of2. An internal opening of 25 %.These two buildings are designed for gravity loads and lateral load of the building using response spectrum method and have 150mm thick reinforced concrete structural walls at the two ends while regular 800×800 columns and 500x800beams are present at every 6m grid and 150mm thick slab. The reinforced concrete shear walls with a modulus of elasticity of 29 GPA and Poisson’s ratio of 0. This assumption for the modulus of elasticity is based each code provision and an assumed concrete strength of 25MPA.

CHAPTER 4

INVESTIGATION OF FLOOR DIAPHRGAM FLEXIBLITY AND CODE PROVISION

4.1 Introductions

The buildings with and without shear walls, and with rigid and flexible diaphragm assumption are analyzed using Finite Element Analysis (ETABS V9.72) with a number of response-spectrum analyses based on input data and model in chapter three. However, in this chapter codes provisions are investigated by use the results of building analyses. In order to set the conditions under which the in-plane deformability must be taken into consideration, some codes (EC8&EBCS8) set certain qualitative criteria related to the shape of the diaphragm, while some others (UBC97& ASCE 7-05) set quantitative criteria relating the in plane deformation of the diaphragm with the average drift of the associated storey, as mentioned above in chapter two.

4.2 Dominated Building Mode Shape.

4.2.1. Rectangular Building Mode Shape

The screen shout of dominated mode shape for diaphragm flexibility in rectangular building shapes from ETABS output.

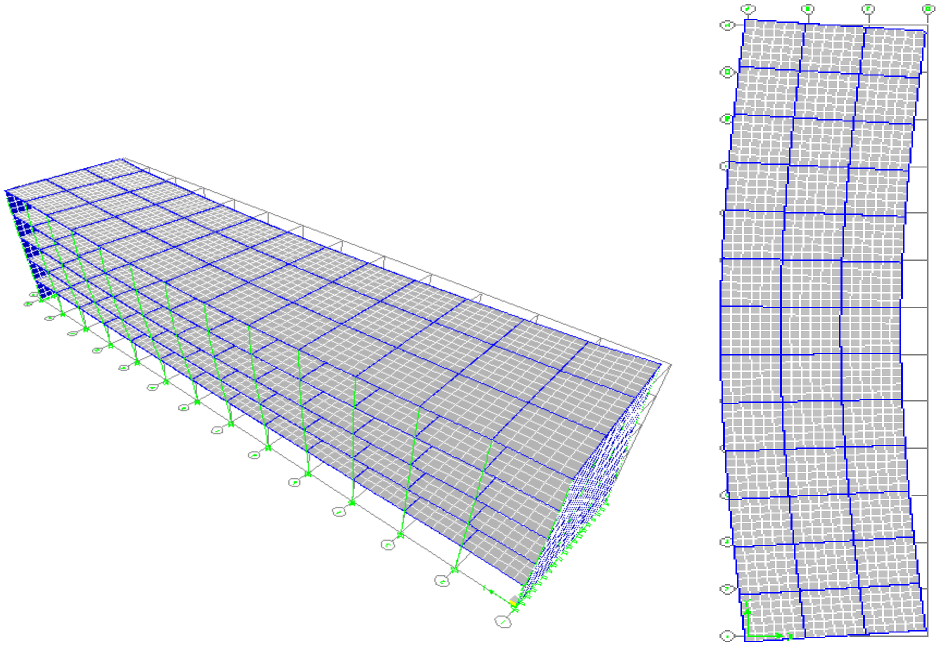

Figure16 .Rectangular building Computer Generated Dominant Mode Shapes

4.2.2. U Shape Building Mode Shapes

The screen shout of dominated mode shape for diaphragm flexibility in U shape buildings from ETABS outputs.

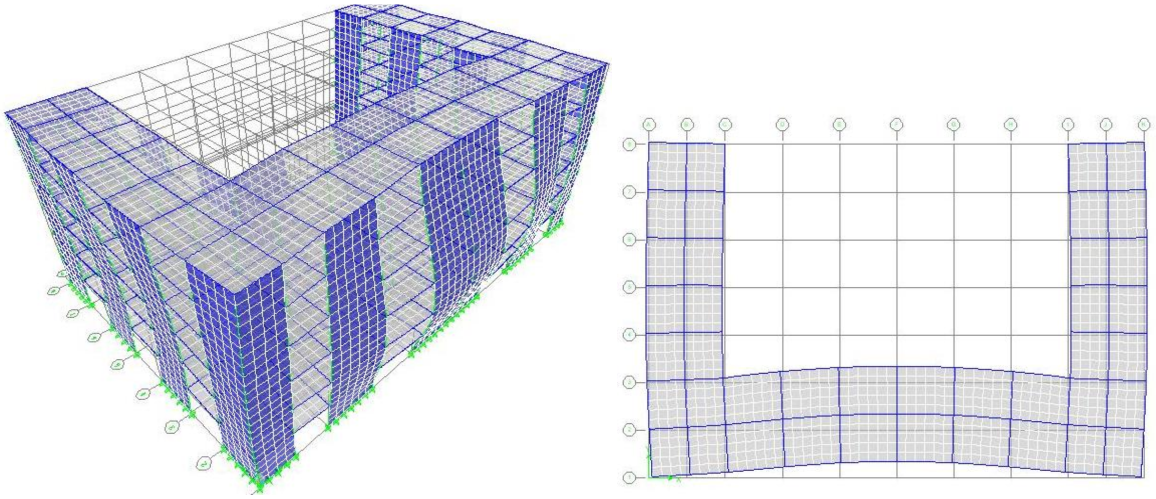

Figure 17 .U Shape building Computer Generated Dominant Mode Shapes

4.2.3. L Shape Building Mode Shapes

The screen shout of dominated mode shape for diaphragm flexibility in L shape buildings from ETABS outputs.

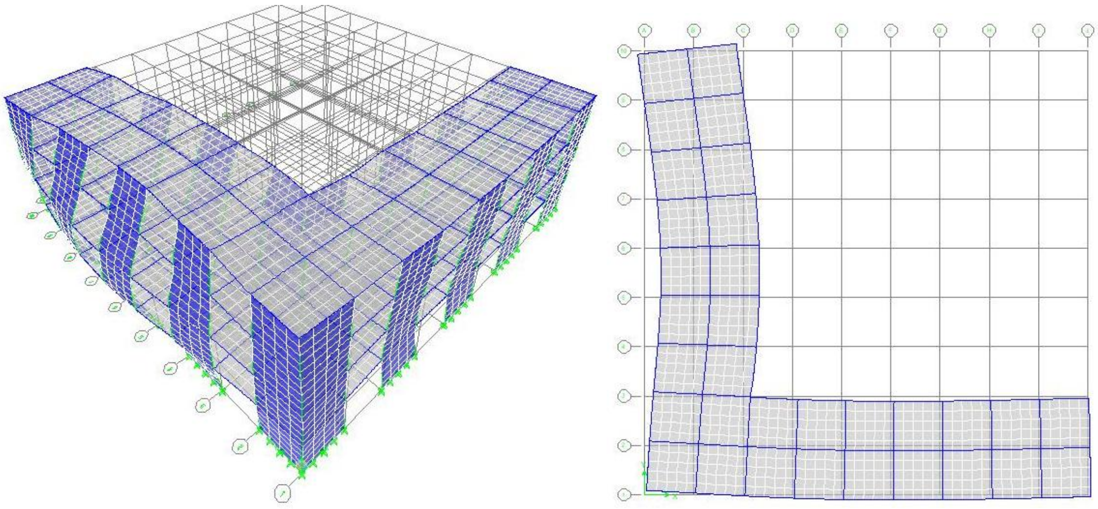

Figure 18.L Shape building Computer Generated Floor Plan of dominant mode shape.

4.2.4. Rectangular With Opening Building Mode Shapes

The screen shouts of dominated mode shape for diaphragm flexibility in rectangular buildings with opening from ETABS outputs.

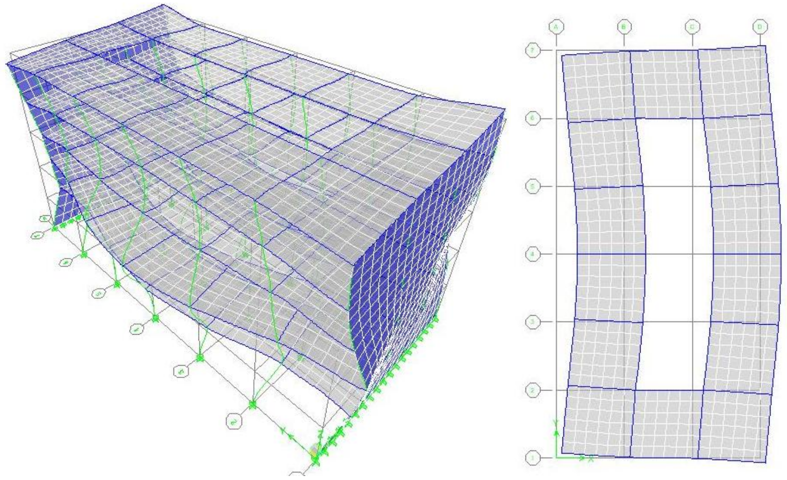

Figure 19 .Rectangular with Opening building Computer Generated dominant mode shapes.

4.3. UBC-97 QUANTITATIVE CRITERIA

The provisions of this code for about the diaphragm shall be considered flexible when the maximum lateral deformation of the diaphragm is more than twice the average drift of the associated storey ($\beta \geq 2$) and diaphragms shall be considered flexible when ($\beta < 2$). The values of β are shown in tables 4.1 to 4.8 and in accordance with that in buildings with shear walls, only the rectangular building is flexible and other Rectangular with opening, L-shaped and U-shaped buildings are rigid. All of the buildings without shear walls are rigid.

In other word diaphragm is rigid if $\beta < 2$

$$\beta = \frac{\Delta_{\text{Flexible Diaphragm}}}{\Delta_{\text{Average story drift}}} < 2$$

And it is flexible if $\beta \geq 2$

$$\beta = \frac{\Delta_{\text{Flexible Diaphragm}}}{\Delta_{\text{Average story drift}}} \geq 2$$

Table 2.the value of UBC 97 ratio (β) for rectangular building with shear wall

Floor	Diaphragm orientation	Maximum diaphragm Deformation $\Delta_{max(m)}$	Corresponding average associated story drift (δ_0)(m)	UBC 97 Code Ratio (β) Δ_{max}/δ_0
5th F	X	0.017443	0.007071	2.46
4th F	X	0.016514	0.011329	1.46
3rd F	X	0.013843	0.014714	0.94
2nd F	X	0.009357	0.016557	0.57
1st F	X	0.003614	0.011786	0.31

Table 3.the value of UBC 97 ratio (β) for rectangular building without shear wall

Floor	Diaphragm orientation	Maximum diaphragm Deformation $\Delta_{max(m)}$	Corresponding average associated story drift (δ_0)(m)	UBC 97 Code Ratio (β) Δ_{max}/δ_0
5th F	X	0.00	0.155243	0.00
4th F	X	0.00	0.138500	0.00
3rd F	X	0.00	0.110443	0.00
2nd F	X	0.00	0.072486	0.00
1st F	X	0.00	0.029157	0.00

Table 4.the value of UBC 97 ratio (β) for U-shape building with shear wall

Floor	Diaphragm orientation	Maximum diaphragm Deformation $\Delta_{max(m)}$	Corresponding average associated story drift (δ_0)(m)	UBC 97 Code Ratio (β) Δ_{max}/δ_0
6th F	Y	0.0645	0.0601	1.1
5th F	Y	0.0552	0.0503	1.1
4th F	Y	0.0427	0.0385	1.1
3rd F	Y	0.0298	0.0264	1.1
2nd F	Y	0.0178	0.0152	1.2
1st F	Y	0.0070	0.0057	1.2

Table 5.the value of UBC 97 ratio (β) for U-shape building without shear wall

Floor	Diaphragm orientation	Maximum diaphragm Deformation $\Delta_{max(m)}$	Corresponding average associated story drift (δ_0)(m)	UBC 97 Code Ratio (β) Δ_{max}/δ_0
6th F	Y	0.00	0.0099	0
5th F	Y	0.00	0.01736	0
4th F	Y	0.00	0.0241	0
3rd F	Y	0.00	0.02966	0
2nd F	Y	0.00	0.03248	0
1st F	Y	0.00	0.02228	0

Table 6.the value of UBC 97 ratio (β) for L-shape building without shear wall

Floor	Diaphragm orientation	Maximum diaphragm Deformation $\Delta_{max(m)}$	Corresponding average associated story drift (δ_0)(m)	UBC 97 Code Ratio (β) Δ_{max}/δ_0
4th F	X	0.00609	0.00617	0.99
3rd F	X	0.00496	0.00731	0.68
2nd F	X	0.00327	0.00686	0.48
1st F	X	0.00173	0.00537	0.32

Table 7.the value of UBC 97 ratio (β) for L-shape building without shear wall

Floor	Diaphragm orientation	Maximum diaphragm Deformation $\Delta_{max(m)}$	Corresponding average associated story drift (δ_0)(m)	UBC 97 Code Ratio (β) Δ_{max}/δ_0
4th F	X	0.0	0.01698	0
3rd F	X	0.0	0.03060	0
2nd F	X	0.0	0.04155	0
1st F	X	0.0	0.04193	0

Table 8.Summary of Diaphragm verification, UBC 97

Building type		Max of β	Associated story
Buildings with shear walls	Rectangular	2.46	Flexible
	L-shaped	0.55	Rigid
	U-shaped	1.1	Rigid
	Rectangular Vs opening	0.6	Rigid
Buildings without shear walls	Rectangular	0	Rigid
	L-shaped	0	Rigid
	U-shaped	0	Rigid
	Rectangular Vs opening	0	Rigid

4.4.ASCE7 QUANTITATIVE CRITERIA

Floor diaphragms shall be classified as either “flexible”, “stiff”, or “rigid”. “Flexible” when the maximum lateral deformation of the diaphragm along its length is more than twice the average inter-storey drift of the storey immediately below ($\lambda \geq 2$), “rigid” when this lateral deformation of the diaphragm is less than half the average inter-storey drift of the associated storey ($\lambda < 0.5$) and “stiff” when the diaphragm it is neither flexible nor rigid ($0.5\ \lambda \leq \lambda < 2$).In accordance with table 4.8 in buildings with shear walls, the Rectangular shaped building is flexible, the L-shaped, U-shaped and rectangular with opening buildings are semi-rigid (stiff). All of the buildings without shear walls are rigid.

Table 9.Summary of Diaphragm verification, ASCE7

Building type		Max of λ	Associated story
Buildings with shear walls	Rectangular	2.46	Flexible
	L-shaped	0.55	Stiff
	U-shaped	1.1	Stiff
	Rectangular Vs opening	0.6	Stiff
Buildings without shear walls	Rectangular	0	Rigid
	L-shaped	0	Rigid
	U-shaped	0	Rigid
	Rectangular Vs opening	0	Rigid

4.5.EUROCODE 8 [EC8] QUALITATIVE CRITERIA

Since all of the four buildings in model have irregular geometries or divided shapes in plan. Recesses, re-entrances, are classified in Class “H” structures. The diaphragm is considered rigid, if, when it is modeled with its actual in-plane flexibility, its horizontal displacements nowhere exceed those resulting from the rigid diaphragm assumption by more than 10% of the corresponding absolute horizontal displacements in the seismic design situation, and accordance with this observation in table 4.9 to 4.17, all of the buildings with shear walls are flexible and all of the buildings without shear walls are rigid.

Table 10.The maximum horizontal drift ratio of EURO CODE 8 for rectangular building with shear wall

Floor	Diaphragm orientation	Max displacement of Rigid diaphragm (m)	Max displacement of flexible diaphragm (m)	Ration	% Of Drift
5th F	X	0.0209	0.0395	1.89	89
4th F	X	0.0175	0.0355	2.03	102
3rd F	X	0.0133	0.0285	2.14	114
2nd F	X	0.0085	0.0188	2.21	121
1st F	X	0.0038	0.0077	2.03	103

Table 11.The maximum horizontal drift ratio of EURO CODE 8 for rectangular building without shear wall

Floor	Diaphragm orientation	Max displacement of Rigid diaphragm (m)	Max displacement of flexible diaphragm (m)	Ration	% Of Drift
5th F	X	0.08805	0.08732	1.0	0
4th F	X	0.08000	0.07805	1.0	0
3rd F	X	0.06366	0.06265	1.0	0
2nd F	X	0.04217	0.04146	1.0	0
1st F	X	0.01805	0.01707	1.0	0

Table 12.The maximum horizontal drift ratio of (EURO CODE 8) for U-Shape building with shear wall

Floor	Diaphragm orientation	Max displacement of Rigid diaphragm (m)	Max displacement of flexible diaphragm (m)	Ration	% Of Drift
6th F	Y	0.0262	0.0318	1.21	21
5th F	Y	0.0213	0.0272	1.28	28
4th F	Y	0.0161	0.0210	1.30	30
3rd F	Y	0.0108	0.0147	1.36	36
2nd F	Y	0.0060	0.0088	1.47	47
1st F	Y	0.0021	0.0034	1.62	62

Table 13.The maximum horizontal drift ratio of (EURO CODE 8) for U-Shape building without shear wall

Floor	Diaphragm orientation	Max displacement of Rigid diaphragm (m)	Max displacement of flexible diaphragm (m)	Ration	% Of Drift
6th F	Y	0.0615	0.0618	1.005	0.5
5th F	Y	0.057	0.0572	1.004	0.4
4th F	Y	0.0491	0.0492	1.002	0.2
3rd F	Y	0.0381	0.0383	1.005	0.5
2nd F	Y	0.0247	0.0248	1.004	0.4
1st F	Y	0.010	0.010	1.00	0

Table 14.The maximum horizontal drift ratio of (EURO CODE 8) for L-Shape building with shear wall

Floor	Diaphragm orientation	Max displacement of Rigid diaphragm (m)	Max displacement of flexible diaphragm (m)	Ration	% Of Drift
4th F	X	0.0088	0.0153	1.74	74
3rd F	X	0.0066	0.0118	1.79	79
2nd F	X	0.0041	0.0075	1.83	83
1st F	X	0.0017	0.0034	2	100

Table 15.The maximum horizontal drift ratio of (EURO CODE 8) for L-Shape building without shear wall

Floor	Diaphragm orientation	Max displacement of Rigid diaphragm (m)	Max displacement of flexible diaphragm (m)	Ration	% Of Drift
4th F	Y	0.0638	0.0638	1.0	0
3rd F	Y	0.0555	0.0555	1.0	0
2nd F	Y	0.0406	0.0406	1.0	0
1st F	Y	0.0204	0.0204	1.0	0

Table 16.The maximum horizontal drift ratio of (EURO CODE 8) for Rectangular with opening building with shear wall

Floor	Diaphragm orientation	Max displacement of Rigid diaphragm (m)	Max displacement of flexible diaphragm (m)	Ration	% Of Drift
5th F	X	0.017	0.019	1.12	12
4th F	X	0.015	0.017	1.13	13
3rd F	X	0.011	0.013	1.18	18
2nd F	X	0.0072	0.0082	1.14	14
1st F	X	0.0032	0.0033	1.031	3.1

Table 17.The maximum horizontal drift ratio of (EURO CODE 8) for Rectangular with opening building without shear wall

Floor	Diaphragm orientation	Max displacement of Rigid diaphragm (m)	Max displacement of flexible diaphragm (m)	Ration	% Of Drift
5th F	X	0.016	0.017	1.063	6.3
4th F	X	0.0028	0.0029	1.04	4
3rd F	X	0.0114	0.0116	1.02	2
2nd F	X	0.0165	0.0167	1.01	1
1st F	X	0.009	0.0091	1.01	1

Table 18.Summary of Diaphragm verification, EURO CODE 8 (EC8)

Building type		% of Max Displacements	Associated story
Buildings with shear walls	Rectangular	89	Flexible
	L-shaped	74	Flexible
	U-shaped	21	Flexible
	Rectangular Vs opening	12	Flexible
Buildings without shear walls	Rectangular	0	Rigid
	L-shaped	0.5	Rigid
	U-shaped	0	Rigid
	Rectangular Vs opening	0	Rigid

4.6. ETHIOPIAN BUILDING CODE- 8, QUALITATIVE CRITERIA

Since all of the four buildings in model have irregular geometries or divided shapes in plan. Recesses, re-entrances, are classified in Class "H" structures. The diaphragm is considered rigid, if, when it is modeled with its actual in-plane flexibility, its horizontal displacements nowhere exceed those resulting from the rigid diaphragm assumption by more than 5% of the corresponding absolute horizontal displacements in the seismic design situation, and accordance with this observation in table 4.18, all of the buildings with shear walls are flexible and all of the buildings without shear walls are rigid.

Table 19.Summary of Diaphragm verification, EBCS 8 (1995)

Building type		% of Max Displacements	Associated story
Buildings with shear walls	Rectangular	89	Flexible
	L-shaped	74	Flexible
	U-shaped	21	Flexible
	Rectangular Vs opening	12	Flexible
Buildings without shear walls	Rectangular	0	Rigid
	L-shaped	0.5	Rigid
	U-shaped	0	Rigid
	Rectangular Vs opening	0	Rigid

CHAPTER 5

EFFECTS OF FLOOR DIAPHRGAM FLEXIBLITY IN REINFORCED CONCRETE STRUCTURES ON SEISMIC RESPONSE

5.1 Introductions

Plan types were analyzed with Rectangular, U- shape, L-shape and Rectangular with opening structures. In order to emphasize the differences, the gross section of the slab was used for slab stiffness in this comparison. Response spectrum analysis was performed with the shear wall structures to investigate the effect of diaphragm flexibility on seismic response by excluding the frame structures for all four types of structures because we are all ready investigated the diaphragm rigidity in chapter four for frame structures. In these analyses, two models were used for each plan type (Rigid and flexible diaphragms).

5.2. Natural periods of vibration

5.2.1 Euro code 8

Natural periods of vibration for the example structures are shown in figure 5.1 to 5.4. And table 5.1 to 5.4. For Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening building respectively. They showed that in all cases, the natural period is longer when the flexibility of the diaphragm is considered. The flexibilities of diaphragm effects are more noticeable in shear wall structures.

Table 20.Natural periods of Rectangular Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

period		
Spec	Mode	Period
RSX	1	0.94798
RSX	2	0.48254
RSX	3	0.30057
RSX	4	0.25808
RSX	5	0.16744
RSX	6	0.15743
RSX	7	0.10771
RSX	8	0.08462

(a)

Rigid

Period		
Spec	Mode	Period
RSX	1	0.94791
RSX	2	0.35342
RSX	3	0.30041
RSX	4	0.16718
RSX	5	0.11217
RSX	6	0.10731
RSX	7	0.06334
RSX	8	0.04582

(b)

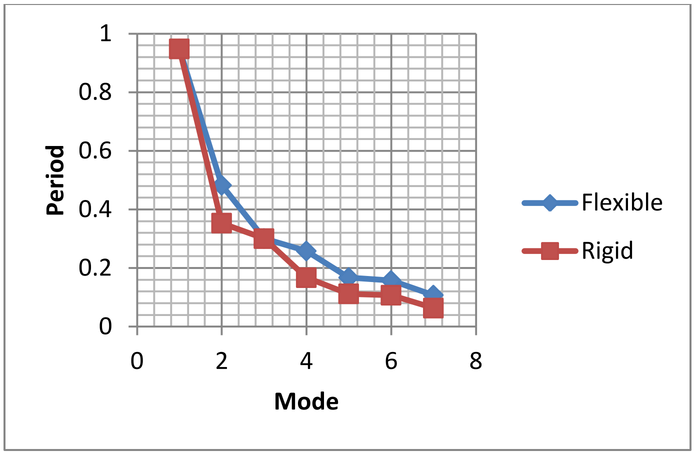

Fig 5.1 Natural periods of Rectangular Building Flexible Diaphragm Vs rigid diaphragm

Table 21.Natural periods of U-Shape of Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

PERIOD

Spec	Mode	Period
RSX	1	0.39751
RSX	2	0.33523
RSX	3	0.29518
RSX	4	0.24241
RSX	5	0.19568
RSX	6	0.15399
RSX	7	0.11729
RSX	8	0.08013

(a)

Rigid

PERIOD

Spec	Mode	Period
RSX	1	0.38346
RSX	2	0.30875
RSX	3	0.2826
RSX	4	0.09724
RSX	5	0.08576
RSX	6	0.04853
RSX	7	0.04493
RSX	8	0.03206

(b)

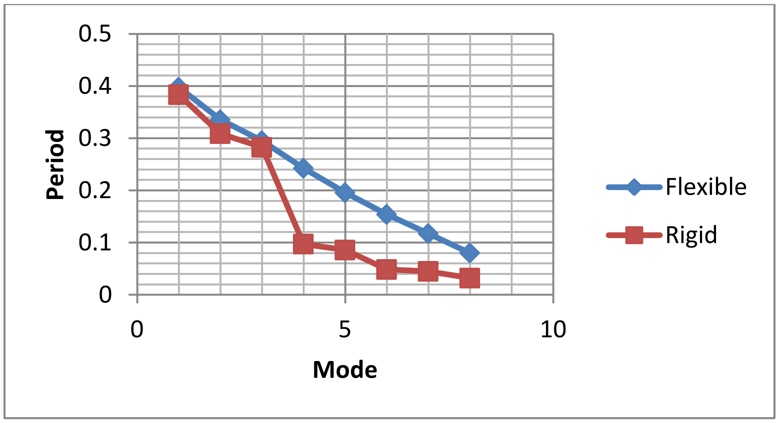

Fig 5.2 Natural periods of U-Shape of Building Flexible Diaphragm Vs rigid diaphragm

Table 22.Natural periods of Vibration in L-Shape of Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

PERIOD

Spec	Mode	Period
RSX	1	0.26803
RSX	2	0.26798
RSX	3	0.1895
RSX	4	0.14212
RSX	5	0.13067
RSX	6	0.08384
RSX	7	0.06606

(a)

Rigid

PERIOD

Spec	Mode	Period
RSX	1	0.24098
RSX	2	0.2314
RSX	3	0.16367
RSX	4	0.06922
RSX	5	0.06712
RSX	6	0.03676
RSX	7	0.03664

(b)

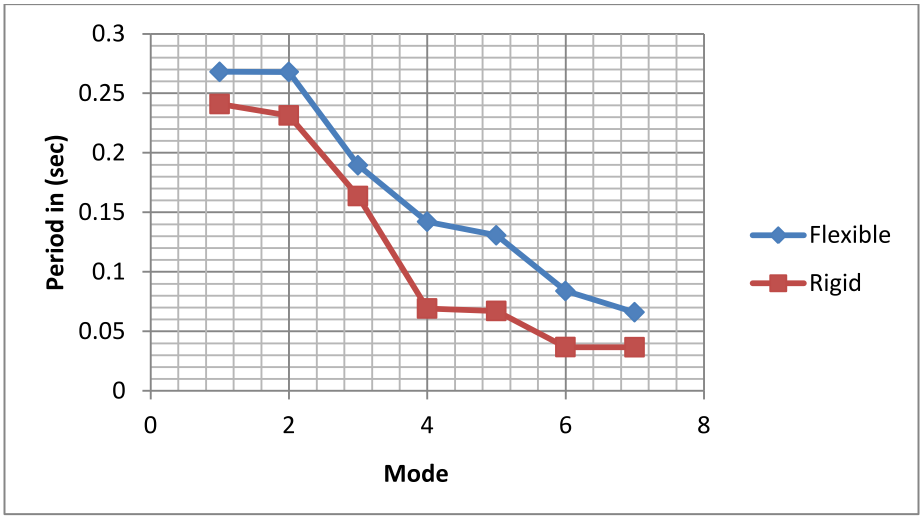

Fig 5.3 Natural periods of Vibration in L-Shape of Building Flexible Diaphragm Vs rigid diaphragm

Table 23.4 Natural periods of Vibration in rectangular Building with opening (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

period

Spec	Mode	Period
RSX	1	0.90179
RSX	2	0.28466
RSX	3	0.2461
RSX	4	0.15753
RSX	5	0.12359
RSX	6	0.10048
RSX	7	0.09146
RSX	8	0.04977

(a)

Rigid

Period

Spec	Mode	Period
RSX	1	0.90414
RSX	2	0.28529
RSX	3	0.23975
RSX	4	0.15778
RSX	5	0.10052
RSX	6	0.07627
RSX	7	0.0432
RSX	8	0.03168

(b)

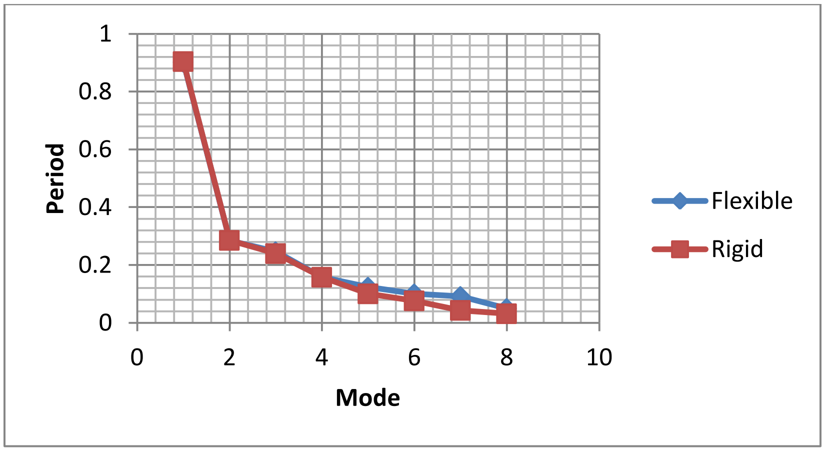

Fig 5.4 Natural periods of Vibration in Rectangular Building with opening Flexible Diaphragm Vs rigid diaphragm

5.2.2 UBC97

Natural periods of vibration for the example structures are shown in figure 5.5 to 5.7. And table 5.5 to 5.7. For Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening building respectively. They showed that in all cases, the natural period is longer when the flexibility of the diaphragm is considered. The flexibilities of diaphragm effects are more noticeable in shear wall structures.

Table 24.Natural periods of Rectangular Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

period

Spec	Mode	Period
RSX	1	0.96048
RSX	2	0.48916
RSX	3	0.30451
RSX	4	0.26161
RSX	5	0.16962
RSX	6	0.15935
RSX	7	0.1091
RSX	8	0.0859

(a)

Rigid

Period

Spec	Mode	Period
RSX	1	0.96041
RSX	2	0.35811
RSX	3	0.30435
RSX	4	0.16935
RSX	5	0.11363
RSX	6	0.10868
RSX	7	0.06416
RSX	8	0.0464

(b)

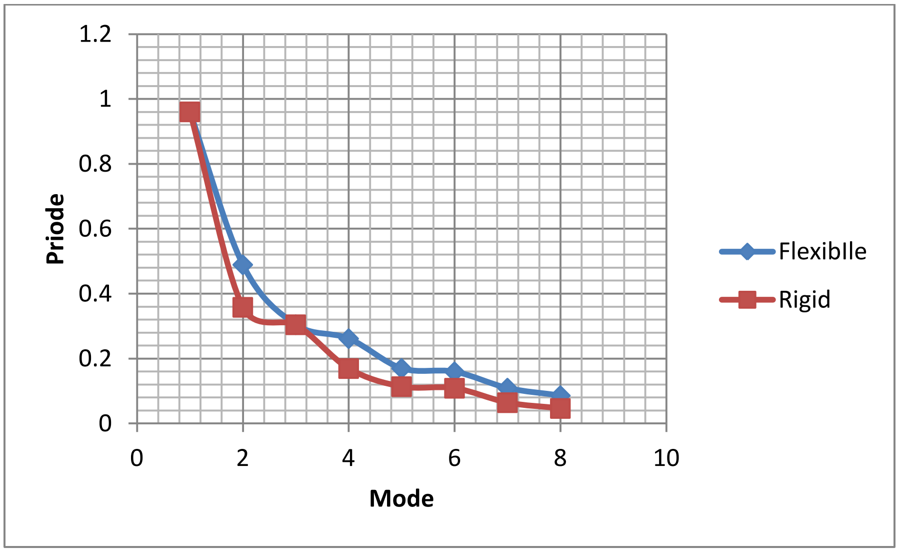

Fig 5.5 Natural periods of Rectangular Building Flexible Diaphragm Vs rigid diaphragm

Table 25.Natural periods of U-Shape of Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible
Period

Spec	Mode	Period
RSX	1	0.40112
RSX	2	0.33815
RSX	3	0.29776
RSX	4	0.24421
RSX	5	0.19711
RSX	6	0.15545
RSX	7	0.11829
RSX	8	0.08082

(a)

Rigid
Period

Spec	Mode	Period
RSX	1	0.38688
RSX	2	0.31141
RSX	3	0.28495
RSX	4	0.09809
RSX	5	0.08648
RSX	6	0.04895
RSX	7	0.04525
RSX	8	0.03235

(b)

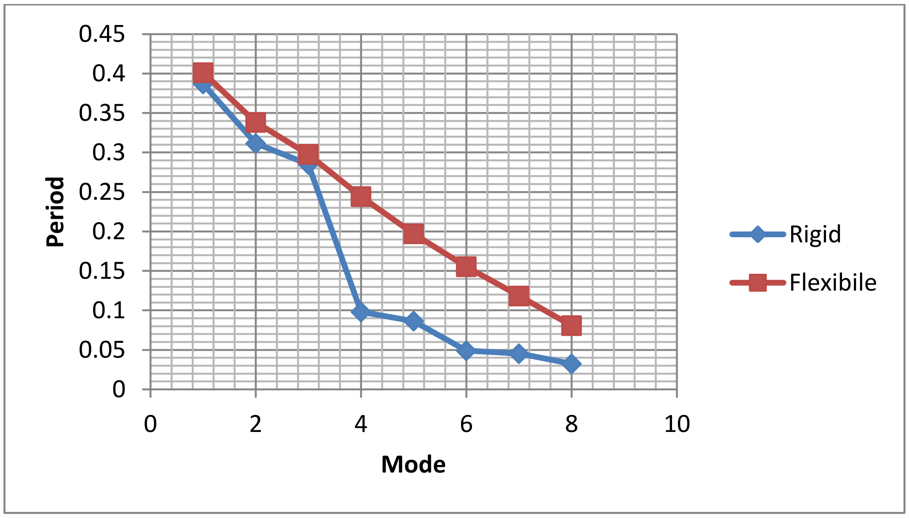

Fig 5.6 Natural periods of U-Shape of Building Flexible Diaphragm Vs rigid diaphragm

Table 26.Natural periods of Vibration in L-Shape of Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

Period

Spec	Mode	Period
RSX	1	0.27207
RSX	2	0.27204
RSX	3	0.19222
RSX	4	0.14403
RSX	5	0.13258
RSX	6	0.08494
RSX	7	0.06702

(a)

Rigid

Period

Spec	Mode	Period
RSX	1	0.24454
RSX	2	0.23483
RSX	3	0.16582
RSX	4	0.0702
RSX	5	0.06806
RSX	6	0.03725
RSX	7	0.03715

(b)

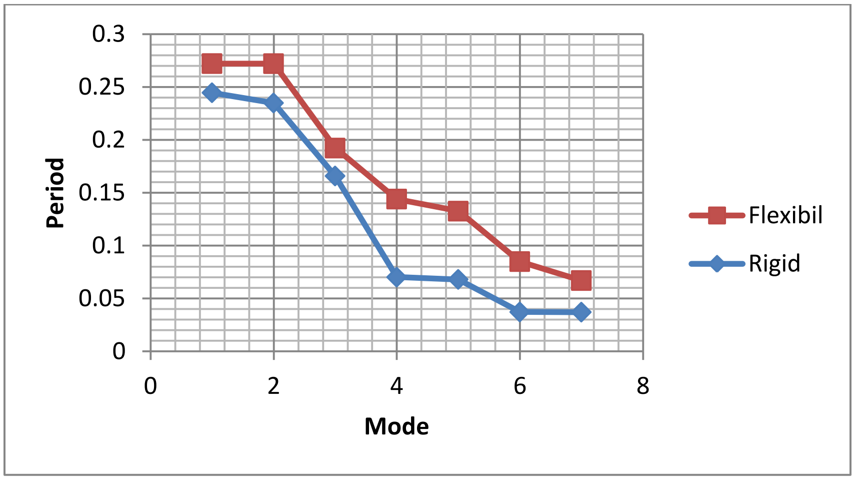

Fig 5.7 Natural periods of Vibration in L-Shape of Building Flexible Diaphragm Vs rigid diaphragm

5.3. Lateral displacements

5.3.1 Euro code8

Lateral displacements for response spectrum analysis are plotted in figure in figure 5.8 to 5.11. And table 5.8 to 5.11. For Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening building respectively. In all cases, the lateral displacements are more when the flexibility of diaphragm is considered in the analysis than rigid diaphragms analysis for all structures with shear wall however in the framed structures; the lateral displacement is the same for both flexible diaphragm and rigid diaphragm effects.

Table 27.Displacements of Rectangular Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

Displacement

Story	Diaphragm	Load	UX	UY
5	D5	RSX	39.731	0
4	D4	RSX	35.718	0
3	D3	RSX	28.659	0
2	D2	RSX	18.954	0
1	D1	RSX	7.7512	0

Story	Diaphragm	Load	UX	UY
5	D5	RSY	0	60.734
4	D4	RSY	0	54.598
3	D3	RSY	0	43.767
2	D2	RSY	0	28.944
1	D1	RSY	0	11.912

(a)

Rigid

Displacement

Story	Diaphragm	Load	UX	UY
5	D5	RSX	20.901	0
4	D4	RSX	17.541	0
3	D3	RSX	13.271	0
2	D2	RSX	8.5322	0
1	D1	RSX	3.8011	0

Story	Diaphragm	Load	UX	UY
5	D5	RSY	0	60.72
4	D4	RSY	0	54.59
3	D3	RSY	0	43.76
2	D2	RSY	0	28.94
1	D1	RSY	0	11.89

(b)

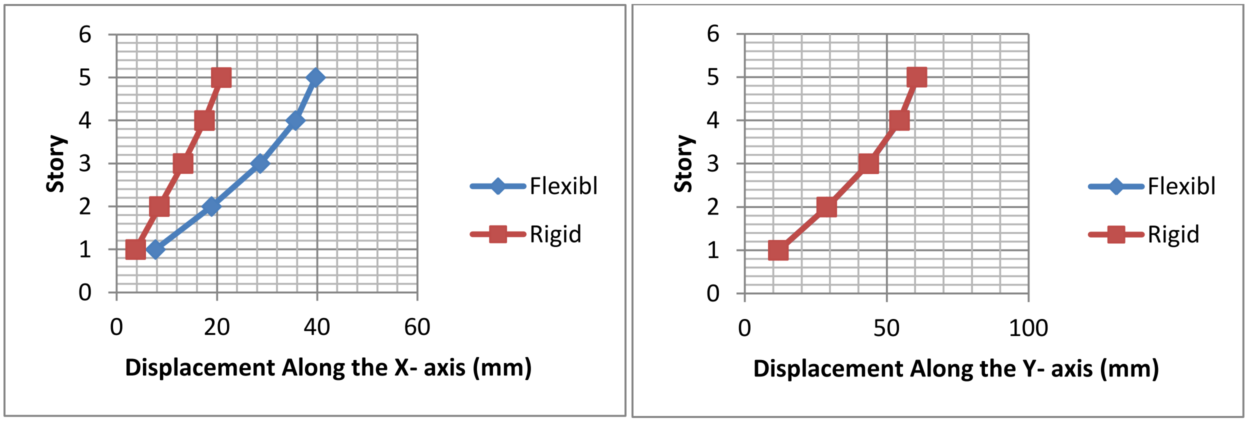

Fig 5.8 Displacements of Rectangular Building Flexible Diaphragm Vs rigid diaphragm

Table 28.Displacements of U-shape Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible
Displacement

Story	Diaphragm	Load	UX	UY
6	D6	RSX	17.604	0.0044
5	D5	RSX	14.703	0.0039
4	D4	RSX	11.154	0.0032
3	D3	RSX	7.6191	0.0024
2	D2	RSX	4.3866	0.0015
1	D1	RSX	1.7372	0.0006

Story	Diaphragm	Load	UX	UY
6	D6	RSY	1.644	31.7524
5	D5	RSY	1.8102	27.1859
4	D4	RSY	1.4718	21.0407
3	D3	RSY	1.5205	14.6566
2	D2	RSY	1.3809	8.7518
1	D1	RSY	0.9263	3.4387

(a)

Rigid
Displacement

Story	Diaphragm	Load	UX	UY
6	D6	RSX	16.361	0
5	D5	RSX	13.573	0
4	D4	RSX	10.454	0
3	D3	RSX	7.241	0
2	D2	RSX	4.1937	0
1	D1	RSX	1.6366	0

Story	Diaphragm	Load	UX	UY
6	D6	RSY	0.042	26.2114
5	D5	RSY	0.0473	21.3202
4	D4	RSY	0.0395	16.0783
3	D3	RSY	0.03	10.8182
2	D2	RSY	0.0194	5.9812
1	D1	RSY	0.0085	2.1372

(b)

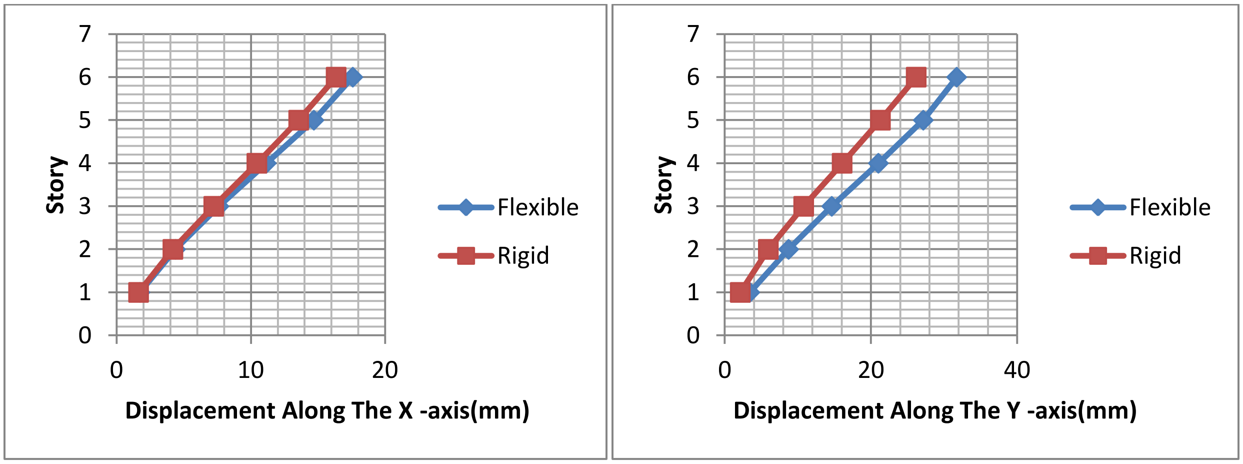

Fig 5.9 Displacements of U-Shape Building Flexible Diaphragm Vs rigid diaphragm

Table 29.Displacements of L-shape Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

Displacement

Story	Diaphragm	Load	UX	UY
4	D4	RSX	13.836	2.584
3	D3	RSX	10.493	2.74
2	D2	RSX	6.4542	2.285
1	D1	RSX	2.7551	1.733

Story	Diaphragm	Load	UX	UY
4	D4	RSY	0.339	13.81
3	D3	RSY	0.5088	10.65
2	D2	RSY	0.5546	6.552
1	D1	RSY	0.4939	2.821

(a)

Rigid

Displacement

Story	Diaphragm	Load	UX	UY
4	D4	RSX	9.1076	2.5949
3	D3	RSX	6.7144	1.9012
2	D2	RSX	4.0791	1.1449
1	D1	RSX	1.639	0.4578

Story	Diaphragm	Load	UX	UY
4	D4	RSY	2.5949	9.1076
3	D3	RSY	1.9012	6.7144
2	D2	RSY	1.1449	4.0791
1	D1	RSY	0.4578	1.639

(b)

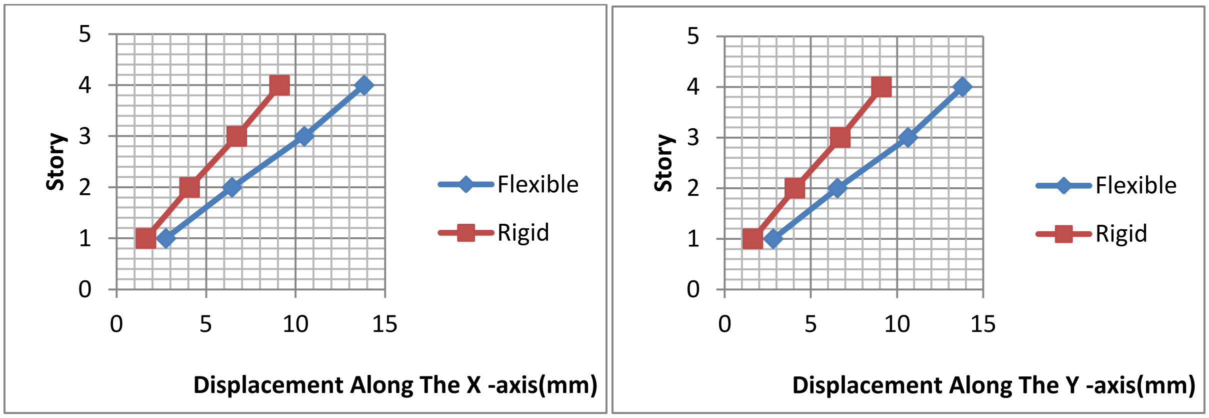

Fig 5.10 Displacements of L-Shape Building Flexible Diaphragm Vs rigid diaphragm

Table 30.Displacements of Rectangular with opening Building (a) Flexible diaphragm,(b) rigid diaphragm

Flexible

Displacement

Story	Diaphragm	Load	UX	UY
5	D5	RSX	11.385	0.8869
4	D4	RSX	9.8375	0.9405
3	D3	RSX	7.5317	0.81
2	D2	RSX	4.9013	0.7262
1	D1	RSX	2.0743	0.4793

Story	Diaphragm	Load	UX	UY
5	D5	RSY	0	58.631
4	D4	RSY	0	52.683
3	D3	RSY	0	42.181
2	D2	RSY	0	27.792
1	D1	RSY	0	11.345

(a)

Rigid

Displacement

Story	Diaphragm	Load	UX	UY
5	D5	RSX	9.6788	0
4	D4	RSX	8.1008	0
3	D3	RSX	6.1189	0
2	D2	RSX	3.9311	0
1	D1	RSX	1.7689	0

Story	Diaphragm	Load	UX	UY
5	D5	RSY	0	58.581
4	D4	RSY	0	52.625
3	D3	RSY	0	42.107
2	D2	RSY	0	27.684
1	D1	RSY	0	11.219

(b)

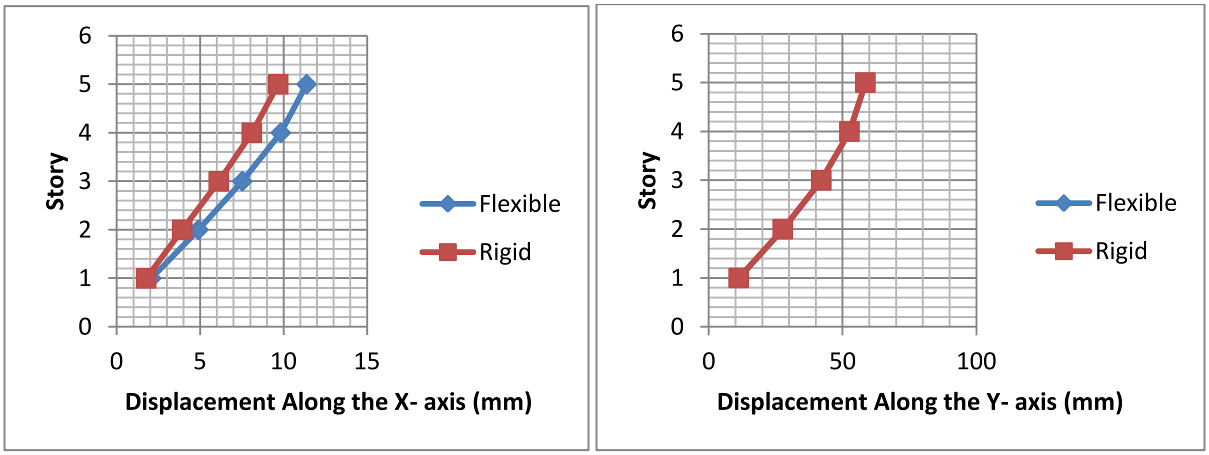

Fig 5.11 Displacements of Rectangular with opening Building Flexible Diaphragm Vs rigid diaphragm

5.3.2 UBC 97

Lateral displacements for response spectrum analysis are plotted in figure in figure 5.8 to 5.11. And table 5.8 to 5.11. For Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening building respectively. In all cases, the lateral displacements are more when the flexibility of diaphragm is considered in the analysis than rigid diaphragms analysis for all structures with shear wall however in the framed structures; the lateral displacement is the same for both flexible diaphragm and rigid diaphragm effects.

Table 31.Displacements of Rectangular Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

STORY DISPLACEMENT

Story	Diaphragm	Load	UX(mm)	UY
5	D5	RSX	79.3616	0
4	D4	RSX	71.292	0
3	D3	RSX	57.2028	0
2	D2	RSX	37.8804	0
1	D1	RSX	15.5243	0

Story	Diaphragm	Load	UX	UY(mm)
5	D5	RSY	0	123.62
4	D4	RSY	0	111.11
3	D3	RSY	0	89.064
2	D2	RSY	0	58.908
1	D1	RSY	0	24.252

(a)

Rigid

STORY DISPLACEMENT

Story	Diaphragm	Load	UX	UY
5	D5	RSX	42.9117	0
4	D4	RSX	36.0035	0
3	D3	RSX	27.2412	0
2	D2	RSX	17.5272	0
1	D1	RSX	7.8199	0

Story	Diaphragm	Load	UX	UY
5	D5	RSY	0	123.608
4	D4	RSY	0	111.091
3	D3	RSY	0	89.0507
2	D2	RSY	0	58.8923
1	D1	RSY	0	24.1987

(b)

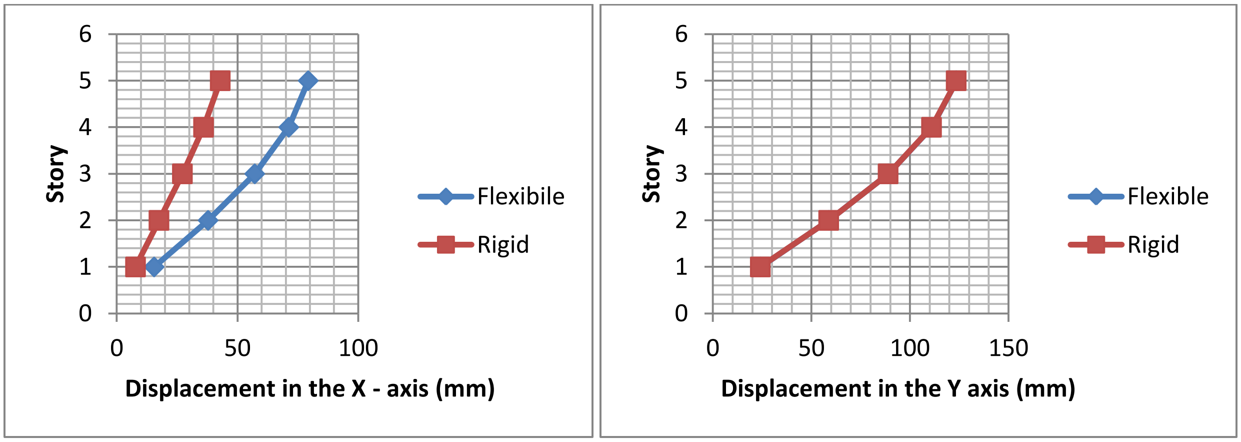

Fig 5.12 Displacements of Rectangular Building Flexible Diaphragm Vs rigid diaphragm

Table 32.Displacements of U-shape Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

Displacement

Story	Diaphragm	Load	UX	UY
6	D6	RSX	35.829	0.0089
5	D5	RSX	29.908	0.0079
4	D4	RSX	22.693	0.0065
3	D3	RSX	15.544	0.0048
2	D2	RSX	9.0205	0.003
1	D1	RSX	3.6278	0.0013

Story	Diaphragm	Load	UX	UY
6	D6	RSY	3.2588	64.537
5	D5	RSY	3.5803	55.229
4	D4	RSY	3.0001	42.736
3	D3	RSY	3.1902	29.771
2	D2	RSY	2.7689	17.777
1	D1	RSY	2.0287	7.0088

(a)

Rigid

Displacement

Story	Diaphragm	Load	UX	UY
6	D6	RSX	33.33	0
5	D5	RSX	27.642	0
4	D4	RSX	21.29	0
3	D3	RSX	14.757	0
2	D2	RSX	8.5609	0
1	D1	RSX	3.3504	0

Story	Diaphragm	Load	UX	UY
6	D6	RSY	0.0866	53.3395
5	D5	RSY	0.0975	43.3775
4	D4	RSY	0.0817	32.7122
3	D3	RSY	0.0623	22.0198
2	D2	RSY	0.0404	12.1881
1	D1	RSY	0.0178	4.3647

(b)

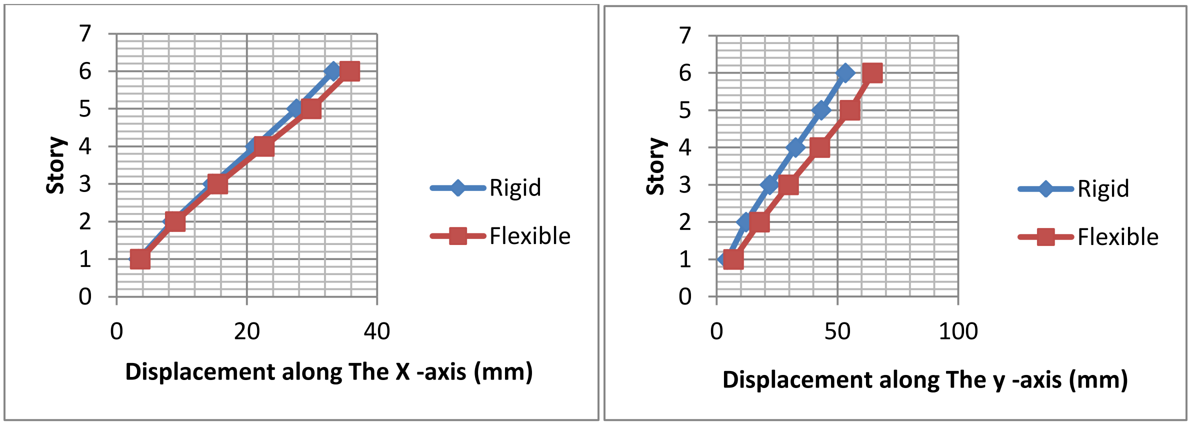

Fig 5.13 Displacements of U-Shape Building Flexible Diaphragm Vs rigid diaphragm

Table 33.Displacements of L-shape Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

Displacement

Story	Diaphragm	Load	UX	UY
4	D4	RSX	28.3473	0.7987
3	D3	RSX	21.5703	5.5399
2	D2	RSX	13.3004	4.7311
1	D1	RSX	5.7098	3.7267

Story	Diaphragm	Load	UX	UY
4	D4	RSY	5.0635	28.504
3	D3	RSY	1.0334	21.844
2	D2	RSY	1.1629	13.564
1	D1	RSY	1.0796	5.9891

(a)

Rigid

Displacement

Story	Diaphragm	Load	UX	UY
4	D4	RSX	18.7515	5.3372
3	D3	RSX	13.819	3.9085
2	D2	RSX	8.3992	2.3534
1	D1	RSX	3.3827	0.9428

Story	Diaphragm	Load	UX	UY
4	D4	RSY	5.3372	18.752
3	D3	RSY	3.9085	13.819
2	D2	RSY	2.3534	8.3992
1	D1	RSY	0.9428	3.3827

(b)

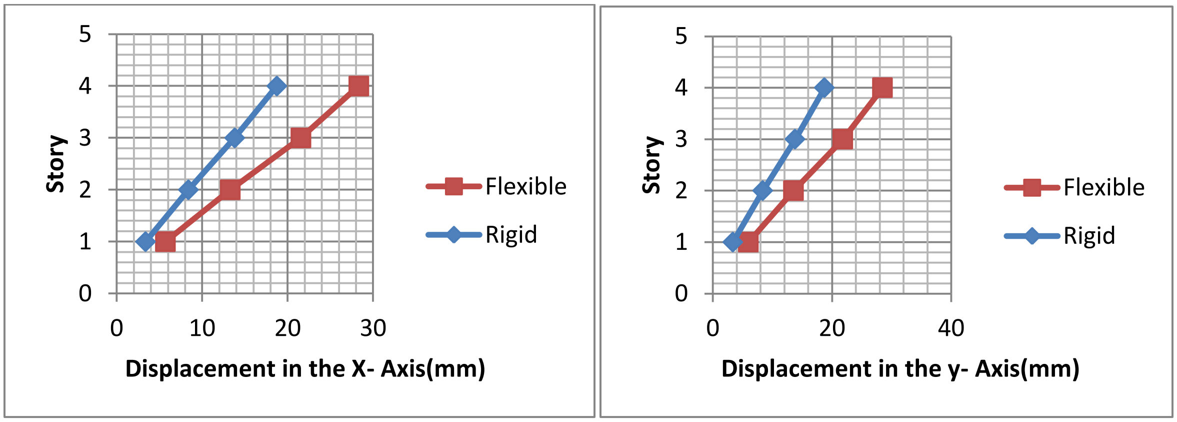

Fig 5.14 Displacements of L-Shape Building Flexible Diaphragm Vs rigid diaphragm

5.4. Story Shear

5.4.1. EURO CODE 8

Story Shear for response spectrum analysis are plotted in figure in figure 5.15 to 5.18. And table 5.15to 5.18. For Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening building respectively.

In all cases, the story shears are reduced when the flexibility of diaphragm is considered in the analysis. In the framed structures, the effects of the diaphragms flexibility with rigid diaphragms are similar for all Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening buildings. The effects are more significant, however, in Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening buildings with shear wall structures.

Table 34.Story Shear of Rectangular Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

Story Shear

Story	Load	VX	VY
5	RSX	16281.4	0
4	RSX	31167.3	0
3	RSX	42531.7	0
2	RSX	50612.5	0
1	RSX	54753.9	0

Story	Load	VX	VY
5	RSY	0	10462.7
4	RSY	0	17860.2
3	RSY	0	23056
2	RSY	0	27274.2
1	RSY	0	30113.4

(a)

Rigid

Story Shear

Story	Load	VX	VY
5	RSX	20630.7	0
4	RSX	39155.8	0
3	RSX	52841.3	0
2	RSX	62135.1	0
1	RSX	66834.5	0

Story	Load	VX	VY
5	RSY	0	10463.1
4	RSY	0	17861.1
3	RSY	0	23057.3
2	RSY	0	27275.5
1	RSY	0	30114.4

(b)

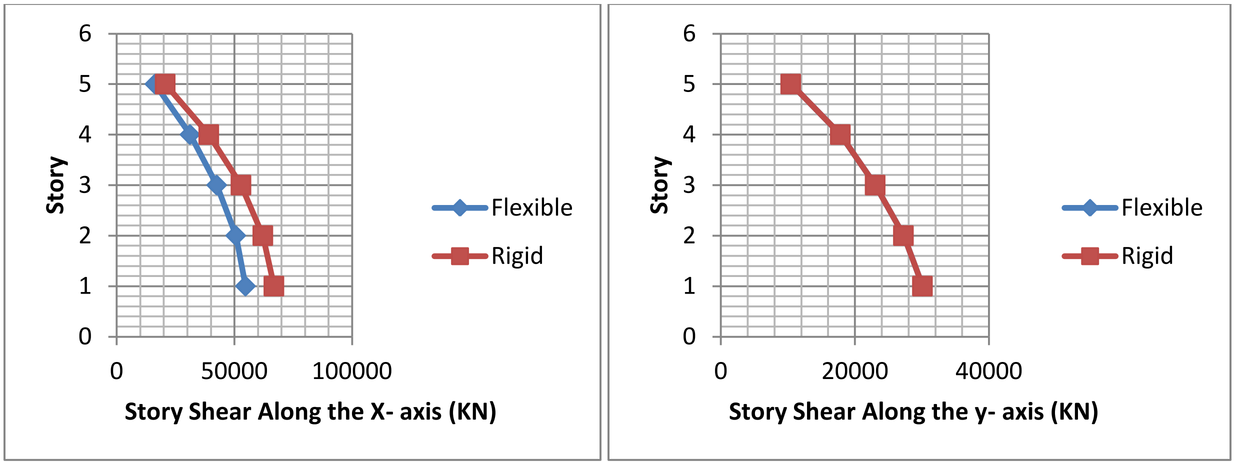

Fig 5.15 Story Shear of Rectangular Building Flexible Diaphragm Vs rigid diaphragm

Table 35.Story Shear of U-shape Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

story shear

Story	Load	VX	VY
6	RSX	16135.9	2.94
5	RSX	33165.3	5.99
4	RSX	45846.4	8.19
3	RSX	54815.6	9.51
2	RSX	60677.2	10.37
1	RSX	63705.8	13.09

Story	Load	VX	VY
6	RSY	3.07	18707.7
5	RSY	6.02	38577.1
4	RSY	8.12	53422
3	RSY	9.58	63638.9
2	RSY	10.49	69893.8
1	RSY	12.41	73424.1

(a)

Rigid

story shear

Story	Load	VX	VY
6	RSX	19126.2	0
5	RSX	38870.2	0
4	RSX	53445	0
3	RSX	63901.1	0
2	RSX	70768.3	0
1	RSX	73877.8	0

Story	Load	VX	VY
6	RSY	0	20076.1
5	RSY	0	39895.6
4	RSY	0	54312.4
3	RSY	0	64541.3
2	RSY	0	71045.3
1	RSY	0	73965.2

(b)

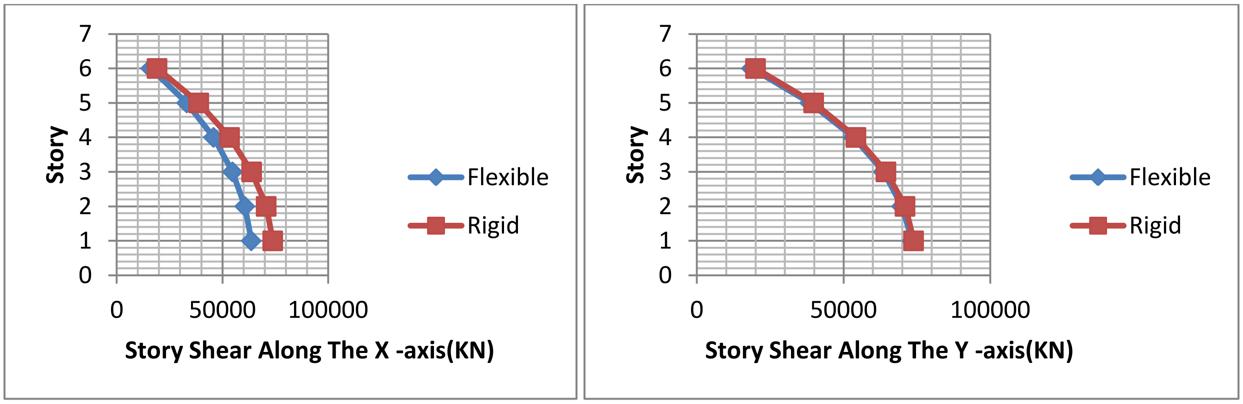

Fig 5.16 Story Shear of U-Shape Building Flexible Diaphragm Vs rigid diaphragm

Table 36.Story Shear of L-shape Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

Story Shear

Story	Load	VX	VY
4	RSX	9459.09	805.6
3	RSX	17756.1	1243.98
2	RSX	22875.4	1410.39
1	RSX	25303.8	2670.53

Story	Load	VX	VY
4	RSY	797.77	9469.04
3	RSY	1224.09	17771.1
2	RSY	1339.66	22860.7
1	RSY	2580.71	25543.8

(a)

Rigid

Story Shear

Story	Load	VX	VY
4	RSX	10031.8	2734.65
3	RSX	18377.7	5066.76
2	RSX	23584.8	6502.08
1	RSX	25995.1	7130.58

Story	Load	VX	VY
4	RSY	2734.39	10034.4
3	RSY	5067.11	18376.9
2	RSY	6502.02	23584
1	RSY	7130.58	25995.2

(b)

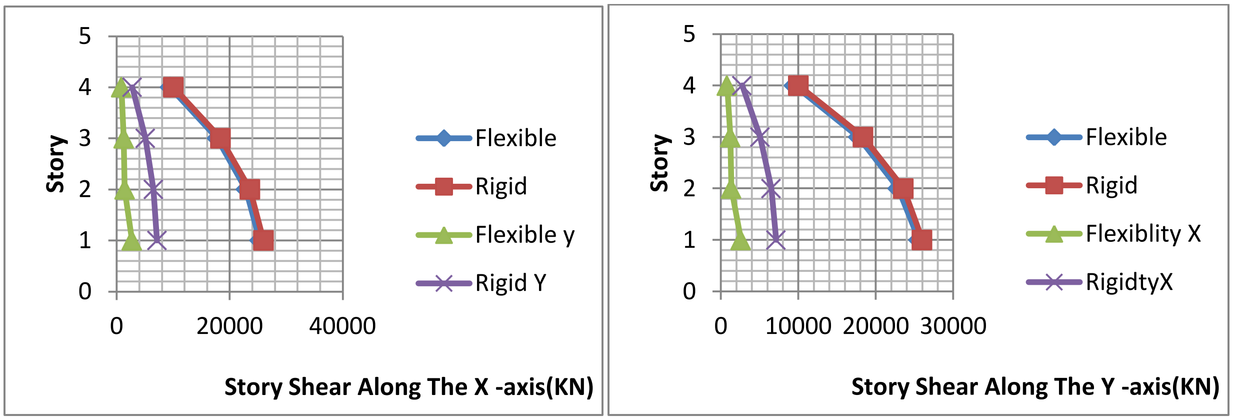

Fig 5.17 Story Shear of L-Shape Building Flexible Diaphragm Vs rigid diaphragm

Table 37.Story Shear of Rectangular with opening Building (a) Flexible diaphragm,

Flexible

Story Shear

Story	**Load**	**VX**	**VY**
5	RSX	8263.24	0
4	RSX	16374.4	0
3	RSX	22366.7	0
2	RSX	26310.7	0
1	RSX	28198	0

Story	Load	VX	VY
5	RSY	0	4579.47
4	RSY	0	8040.35
3	RSY	0	10505.3
2	RSY	0	12453.8
1	RSY	0	13705.4

(a)

Rigid

Story Shear

Story	Load	VX	VY
5	RSX	8584.13	0
4	RSX	16722.8	0
3	RSX	22757.2	0
2	RSX	26799.3	0
1	RSX	28813.7	0

Story	Load	VX	VY
5	RSY	0	4570.54
4	RSY	0	8018.41
3	RSY	0	10471.5
2	RSY	0	12413.4
1	RSY	0	13664.3

(b)

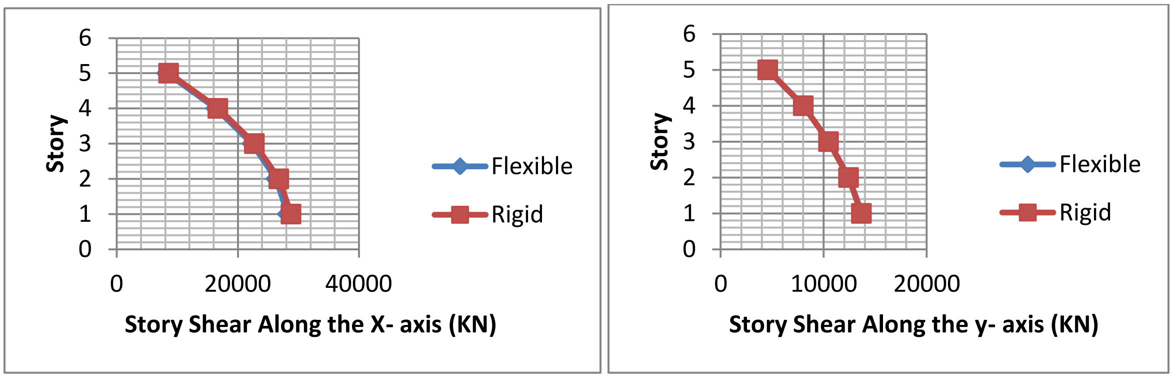

Fig 5.18 Story Shear of rectangular with opening Building Flexible Diaphragm Vs rigid diaphragm

5.4.2. UBC 97

Story Shear for response spectrum analysis's are plotted in figure 5.15 to 5.18. And table 5.15to 5.18. For Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening building respectively.

In all cases, the story shears are reduced when the flexibility of diaphragm is considered in the analysis. In the framed structures, the effects of the diaphragms flexibility with rigid diaphragms are similar for all Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening buildings. The effects are more significant, however, in Rectangular shape of building, U-Shape of building, L shape of Building and Rectangular with opening buildings with shear wall structures.

Table 38.Story Shear of Rectangular Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

story shear

Story	Load	VX	VY
5	RSX	32764.4	0
4	RSX	62339.4	0
3	RSX	84870	0
2	RSX	100995	0
1	RSX	109602	0

Story	Load	VX	VY
5	RSY	0	21425.2
4	RSY	0	36421.5
3	RSY	0	46946.9
2	RSY	0	55559.1
1	RSY	0	61354.7

(a)

Rigid

story shear

Story	Load	VX	VY
5	RSX	43017.9	0
4	RSX	80790	0
3	RSX	108525	0
2	RSX	127640	0
1	RSX	137647	0

Story	Load	VX	VY
5	RSY	0	21426.6
4	RSY	0	36424.2
3	RSY	0	46950.9
2	RSY	0	55563.7
1	RSY	0	61358.4

(b)

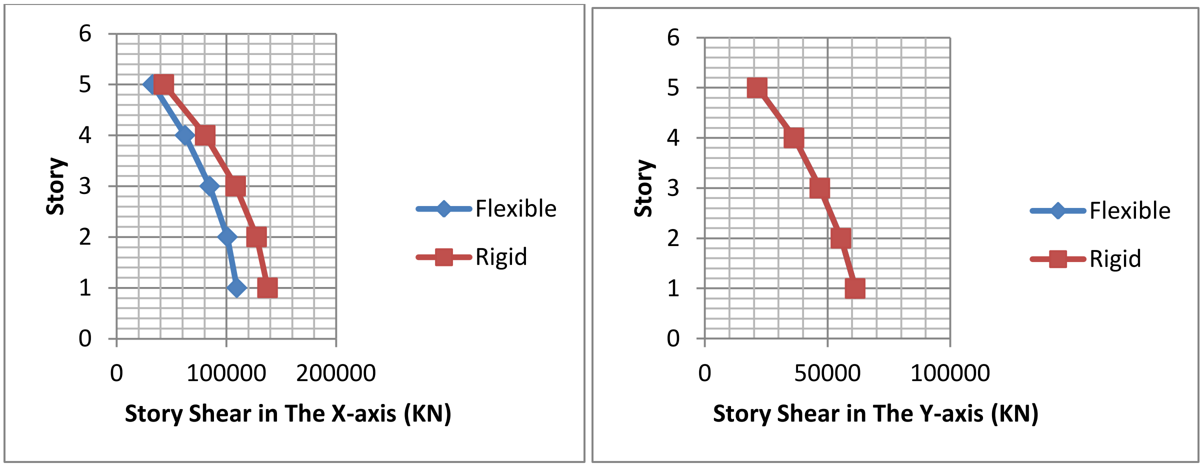

Fig 5.19 Story Shear of Rectangular Building Flexible Diaphragm Vs rigid diaphragm

Table 39.Story Shear of U-shape Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

STORY SHEAR

Story	Load	VX	VY
6	RSX	33256.1	6.08
5	RSX	67867.3	12.31
4	RSX	93423.3	16.76
3	RSX	111589	19.34
2	RSX	123786	21.2
1	RSX	130822	28.93

Story	Load	VX	VY
6	RSY	6.36	38174.7
5	RSY	12.42	78482.2
4	RSY	16.69	108559
3	RSY	19.57	129194
2	RSY	21.37	141966
1	RSY	27.04	150994

(a)

Rigid

STORY SHEAR

Story	Load	VX	VY
6	RSX	40127.1	0
5	RSX	80220.6	0
4	RSX	109092	0
3	RSX	130192	0
2	RSX	145034	0
1	RSX	152066	0

Story	Load	VX	VY
6	RSY	0	42003.6
5	RSY	0	82043.6
4	RSY	0	110642
3	RSY	0	131419
2	RSY	0	145384
1	RSY	0	152057

(b)

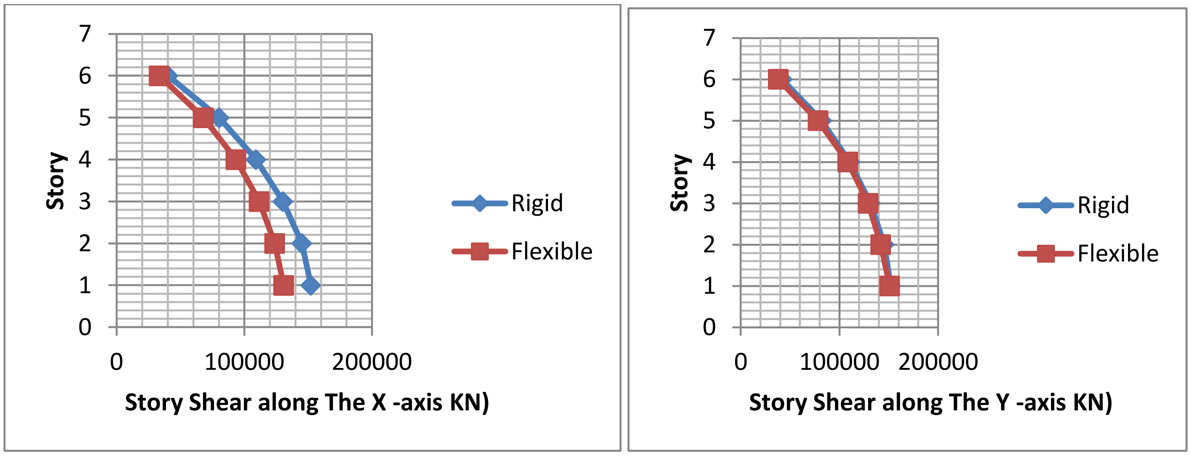

Fig 5.20 Story Shear of U-Shape Building Flexible Diaphragm Vs rigid diaphragm

Table 40.Story Shear of L-shape Building (a) Flexible diaphragm, (b) Rigid Diaphragm

Flexible

STORY SHEAR

Story	Load	VX	VY
4	RSX	19565.8	1824.8
3	RSX	36571	2686.9
2	RSX	47063.6	2917.35
1	RSX	52363.2	6417.53

Story	Load	VX	VY
4	RSY	1786.16	19631.5
3	RSY	2650.34	36634.1
2	RSY	2761.49	47029.3
1	RSY	6114.02	53184.2

(a)

Rigid

STORY SHEAR

Story	Load	VX	VY
4	RSX	21034.3	5693.91
3	RSX	37926.1	10431.2
2	RSX	48571.6	13364.6
1	RSX	53848.4	14707.8

Story	Load	VX	VY
4	RSY	5693.18	21042.2
3	RSY	10432.1	37922.9
2	RSY	13364.5	48569.4
1	RSY	14707.8	53848.7

(b)

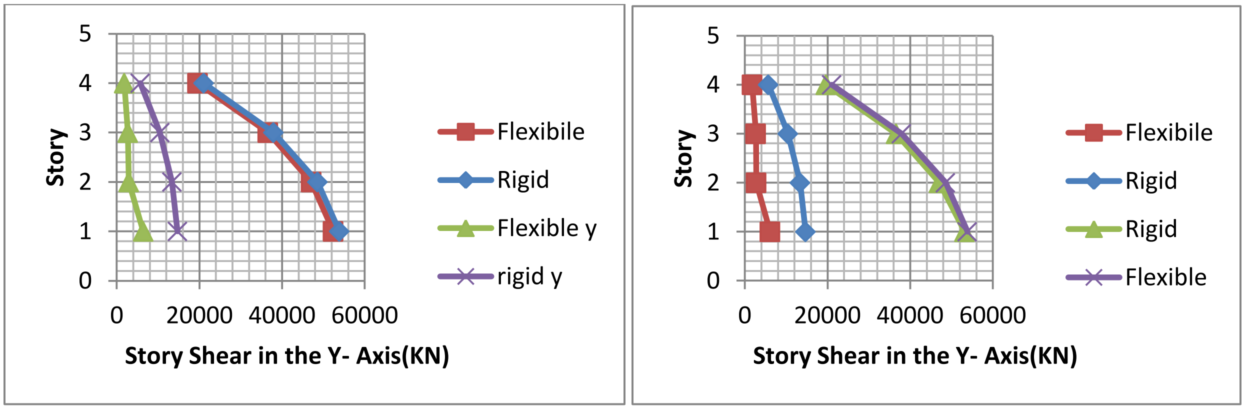

Fig 5.21 Story Shear of L-Shape Building Flexible Diaphragm Vs rigid diaphragm

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introductions

In seismic analysis of buildings, the floor diaphragm in reinforced concrete structures is usually assumed to be rigid in its own plane in all modern codes. However, for many buildings that are long and narrow or have stiff end walls, floor diaphragm flexibility must be accounted for in the distribution of lateral load. In this research the proposed frame structure and frame with shear wall with different floor diaphragm shapes have been successfully modeled using nonlinear finite element software called ETABS V9.72. Effects of diaphragm flexibility will occur if the frame structure with shear walls was modeled for all qualitative and quantitative codes approach.

6.2 Conclusions

Based on the limited studies, the following conclusions are highlighted: -

1. For the buildings without shear walls, this study indicates that the rigid-diaphragm model is as accurate as the flexible model even for non regular diaphragm systems. This is observed since the effects of flexible and rigid diaphragm are the same in all four shapes of diaphragm for both qualitative and quantitative criteria of floor diaphragms flexibility in L-shape, U – shape and Rectangular shapes of diaphragms.
2. The diaphragm flexibility effect increases with increase in aspect ratio of building we can say that flexibility of diaphragm increases with increase in aspect ratio, especially in rectangular with stiff end shear wall buildings for both qualitative (Euro code 8) and quantitative (UBC-97) criteria of diaphragms in this specific research.
3. For buildings with shear walls, the effect of the diaphragm flexibility in reinforced concrete structures for all codes considered in these studies is relatively significant. If the flexibility of diaphragm is totally ignored, the lateral displacements and the natural periods of vibration may be underestimated, whereas the seismic loads per the building code base shear may be significantly overestimated.

If flexibility of diaphragm considered in analysis of reinforced concrete structures with shear wall,

I. The natural periods of vibration and horizontal displacement of concrete structure to different shapes of diaphragms with shear walls underestimated by an average of.

Shape of diaphragms	Period (%)	Displacement (%)	
		X	Y
Rectangular shapes	42	107	0.06
U- shape	102	6.43	37.04
L -shape	64.45	58.63	60.75

Table 41. based on qualitative criteria of diaphragms (Euro code 8)

Shape of diaphragms	Period (%)	Displacement (%)	
		X	Y
Rectangular shapes	42.8	101.52	0.06
U shape	102.8	6.88	36.77
L shape	56.43	58.60	62.16

Table 42. Based on quantitative criteria of diaphragms (UBC-97)

II. The seismic loads per the building code base shear of concrete structure to different shapes of diaphragms with shear walls overestimated by an average of

Shape of diaphragms	Story shear (%)	
	X	Y
Rectangular shapes	24.3	0.004
U shape	16.91	2.7
L shape	3.85	3.5

Table 43. based on qualitative criteria of diaphragms (Euro code 8)

Shape of diaphragms	Story shear (%)	
	X	Y
Rectangular shapes	28.15	0.007
U shape	17.62	3.55
L shape	4.31	3.81

Table 44. Based on quantitative criteria of diaphragms (UBC-97)

4. The results from qualitative criteria in this specific study indicate that, the behavior of diaphragm in L&U –shape is rigid but the effects of the diaphragm is different for both rigid and flexible diaphragms. There for the quantitative criteria in building codes have not enough accuracy and they need to reform.

6.3 Recommendation

1. The quantitative and qualitative criteria of diaphragms in reinforced concrete structure must be use with together. The quantitative criteria for classification of a floor diaphragm as “flexible”, “stiff” or “rigid” (UBC-97, ASCE-07, FEMA- 273, IS1893:2000) are rather ambiguous and nonobjective, because the determination of the in plane deformations of the diaphragm depends on the forces acting on it, while these forces depend on the deformations to be determined.
2. The shape of the floors in plan must guarantee the “rigid floor” diaphragm action in point of stiffness and strength. For this reason, long shapes in plan (length to width ratio ≥ 3) must be avoided, as well as plan shapes composed of long parts (U,L, etc.) or with large re-entrances, especially when the opening area is large than 50%. When this is not possible, the effects of the in-plane floor flexibility to the distribution of the lateral forces at the vertical resisting elements must be taken into consideration and the strength capacity at the weak areas of the diaphragm must be checked.

6.4 Future Research Work

Several recommendations are proposed for future studies of the effects of diaphragm flexibility in reinforced concrete structures.

1. The present Study can easily be extended to include detailing of flexible diaphragm interconnection to Frame and walls in reinforced concrete structures and code provision.
2. The Effects of Diaphragm Components in Resisting Lateral Stability of Precast Concrete Frames.
3. Flexibility effects of diaphragms in tall reinforced concrete structures.

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Appendix

STORY DRIFT DETERMINATION [1]

The design story drift (Δ) shall be computed as the difference of the deflections at the centers of mass at the top and bottom of the story under consideration. See Fig. 12.8-2[1]. Where allowable stress design is used, Δ shall be computed using the strength level seismic forces specified in Section 12.8[1] without reduction for allowable stress design.

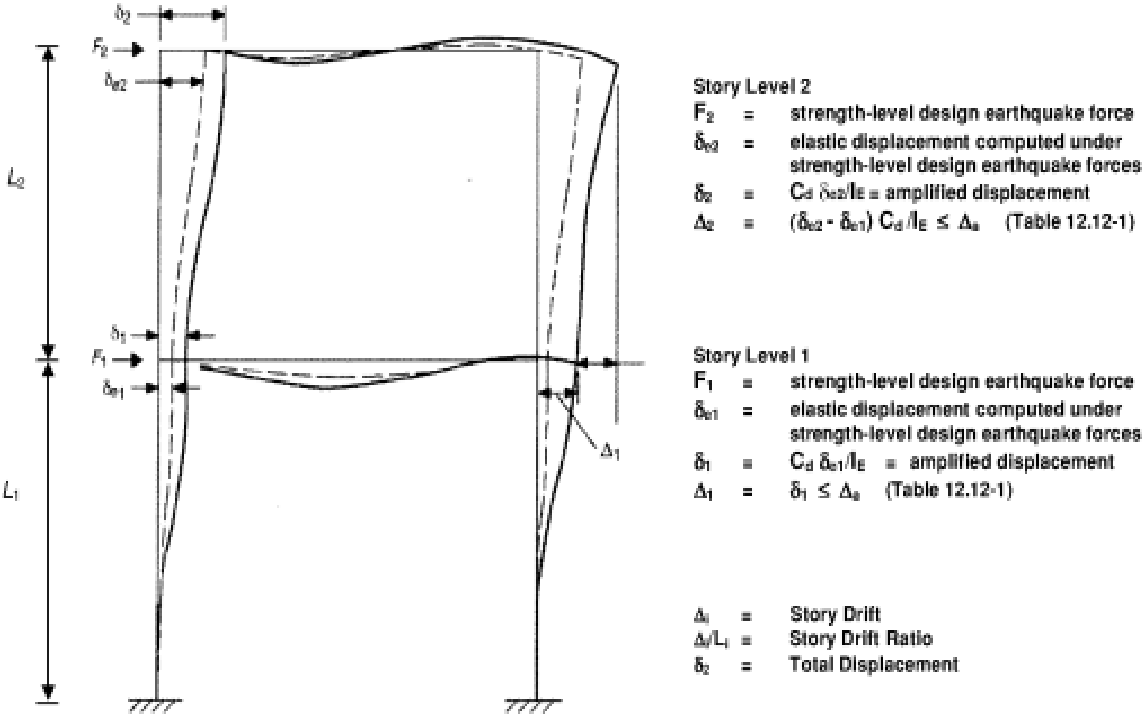

FIGURE 12.8-2 STORY DRIFT DETERMINATION

Appendix 1.STORY DRIFT DETERMINATION [1]

DECLARATION

I, the undersigned, declare that this thesis is my work and all sources of materials used for the thesis has been duly acknowledged.

Name: Sintayehu Abera

Signature _______________

Place Addis Ababa University
Institute of Technology
Date of submission December, 2015