JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY (JIT)

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

STRUCTURAL ENGINEERING STREAM

Comparative Study on the Behavior of Irregular Multi-storey Reinforced Concrete Building using Equivalent Static Method and Dynamic Response Spectrum Method

A Thesis Submitted to School of Graduate Studies Jimma University in Partial Fulfilment of the Requirements for the Degree of Masters of Science in Civil Engineering (Structural Engineering)

BY:

Bedasa Olani Gudeta

April, 2021

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DECLARATION

This Thesis is prepared by Bedasa Olani, entitled comparative study on the behavior of irregular multi-story reinforced concrete building using equivalent static method and dynamic response spectrum, and submitted in partial fulfillment of the requirements for the Degree of Master of Science in Structural Engineering complies with the regulations of the University and it is my original work, and has not been presented by any other person for an award of a degree in this or any other University.

SIGNATURE

Submitted by:

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	Signature	Date

Approved by:

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ABSTRACT

Irregularity of multistory buildings introduced in many modern structures due to their aesthetic value, utilities and functionalities. The irregularity of multistory buildings should take account to be recognized, they may result in unexpected damage and collapse. The present study conducts building models with different type and location of irregularity. The behaviour of structure using equivalent static and dynamic response spectrum analysis of seismic responses of building models have been compared with that of the regular building model. The different forms of behaviour of structure mass, stiffness, and setback structural irregularities have been introduced in the regular building model to generate irregular building models.

In the present study, three single and two multi-combination irregularity of multistory reinforced concrete building subjected to high seismic zone V are investigated using equivalent static and dynamic response spectrum analysis method by using ETABS (Extended Three-dimensional Analysis of Building System) software with respect to the regular structural model of storey 8 and 15 frame building. Load consideration was done based on Ethiopian Building Code ES EN 1998-1:2015. Structural response of base shear, story shear, storey drift and storey displacements were analyzed.

The result of base shear and shear force obtained using response spectrum analysis is greater than equivalent static analysis for analyzed regular and irregular structural model and for both story 8 and 15 rise building. Irregularity of base shear and shear force less with respect to regular building. Mass irregularity cases have shown greater base shear and storey shear for analyzed regularity and irregularity, due to the increase in the mass of the structure building at different story floor levels

Maximum result of story drift and story displacement is obtained by equivalent static analysis than response spectrum analysis from analyzed irregularity. Story drift and story displacement of irregular building is very maximum with compared to regular structure. Both Story drift and story displacement of irregular building increase as story height building increase. Combination irregularity have maximum story drift and story displacement than singular irregularity, especially the value of comb 2 irregularity extremely high. The sequence increases of story drift and story displacement of analyzed irregularity are R<SBI<MI<SI<Comb1<Comb2 building. For all studied cases, the sudden increase in the storey drift and storey displacements value is observed at the areas of discontinuity presents in the geometric configurations of the structural model of irregularity.

The difference of values of story drift and story displacement between static and response spectrum analysis in higher story and equivalent static analysis gives higher values than dynamic response spectrum analysis.

Building with stiffness and combination irregularity has more lateral story drift and reduction in base shear and story shear capacity compared to regular buildings. When compared to irregular configuration the story drift value is more in the regular structural model configuration. Story drift is increased as the height of the building increases from story 8 to story 15 rise building. Generally, the Stiffness, mass, setback and their combination irregularity causes twisting of buildings under lateral load due to the center of mass and center of stiffness of different storeys do not lie along the same vertical line, as is the case in buildings with regular overall geometry. By using response spectrum analysis methods we get more accurate responses than equivalent static analysis for irregular multi-storey for high rise building. So that in the modern high rise multi-storey building response spectrum analysis methods are the most better and save than equivalent static analysis according to our code of standard ES EN 1998-1:2015.

Keywords; Irregularity of multistory RC structure, Equivalent static method, &dynamic response spectrum method, Ethiopian Seismic current codes ES EN 1998-1:2015, ETABS 2016 Software

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ACRONYM

Symbols	Discerption
a_g	The design ground acceleration on type A ground
ag_R	Reference peak ground acceleration on type A ground
Comb 1 ES	Combination 1 irregular model by Equivalent static method
Comb 1 RS	Combination 1 irregular model by Response spectrum method
Comb 2 ES	Combination 2 irregular model by Equivalent static method
Comb 2 RS	Combination 2 irregular by Response spectrum method
EBCS	Ethiopia building standard code
EQ	Earthquake
ES EN	Ethiopian Standard based on European Norm
ETABS	Extended three dimensional Analysis of Building Systems
LFRS	Lateral-force –resisting system
MI ES	Mass irregular model by Equivalent static method
MI RS	Mass irregular by Response spectrum method
PGA	Peak ground acceleration
q_o	Behavior factor
R	Regular
RC	Reinforced Concrete
R ES	Regular model by Equivalent static method
R RS	Regular model by Response spectrum method
SBI	Setback irregularity
SI ES	Stiffness irregular model by Equivalent static method
SI RS	Stiffness irregular model by Response spectrum method
SBI ES	Setback irregular model by Equivalent static method
SBI RS	Setback irregular model by Response spectrum method
2D	Two dimensional
3D	Three dimensional

CHAPTER ONE

1. INTRODUCTION

1.1 Background of the Study

The component of the building, which resists the seismic forces, is known as the lateral force-resisting system (L.F.R.S). The L.F.R.S of the building may be of different types. The most common forms of these systems in a structure are special moment resisting frames, shear walls and frame-shear wall dual systems. The damage in a structure generally initiates at the location of the structural weak planes present in the building systems. These weaknesses trigger further structural deterioration which leads to structural collapse. These weaknesses often occur due to the presence of structural irregularities in stiffness, strength and mass in a building system. The structural irregularity can be broadly classified as plan and vertical irregularities. A structure can be classified as vertically irregular if it contains the irregular distribution of mass, strength and stiffness along with the building height [1].

In reality, many existing buildings contain irregularity, and some of them have been designed initially to be irregular to fulfil different functions e.g. basements for commercial purposes created by eliminating central columns. Also, reduction of the size of beams and columns in the upper story to fulfil functional requirements and for other commercial purposes like storing heavy mechanical appliances etc. This difference in usage of a specific floor with respect to the adjacent floors result in irregular distributions of mass, stiffness and strength along the building height. In addition, many other buildings are accidentally rendered irregular due to a variety of reasons like non-uniformity in construction practices and material used [7].

Ethiopian seismic code categorizes building structures into being regular or non-regular. The value of the behaviour factor q, which shall be decreased for buildings non-regular in elevation. Vertical irregularities may arise when the average story height, or when column dimensions in the story are drastically reduced, the seismic action effects in the vertical elements of the respective story's shall be increased. For non-regular in elevation buildings, the decreased values of the behavior factor are given by the reference values multiplied by 0.8. The recognition of many of these irregularities and conception for remedial measures for the avoidance or mitigation of their undesired effects rely on a sound understanding of structural behavior [1].

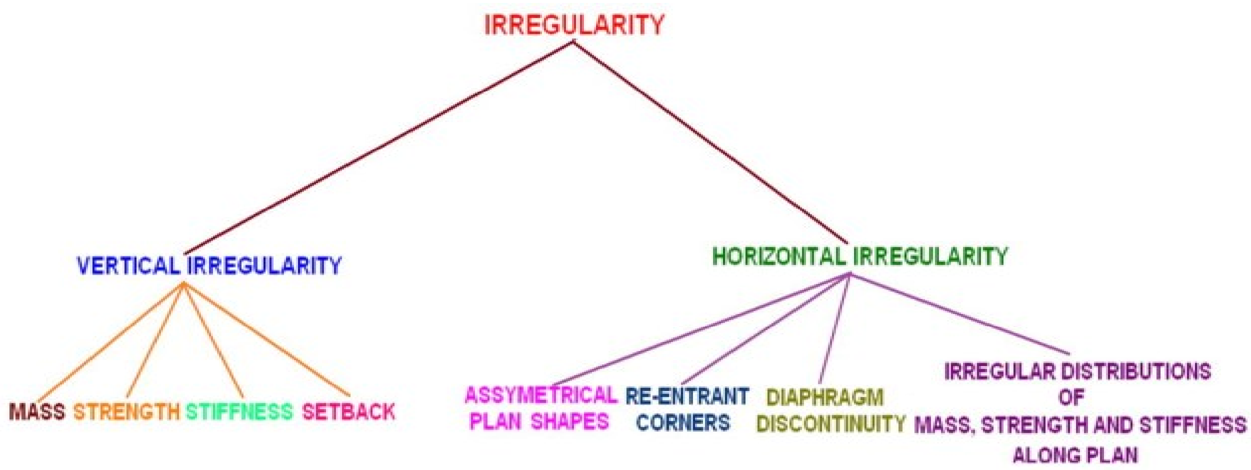


Figure 1.1 Classification of different types of structural irregularities [7].

There are four aspects of buildings that architects and design engineers work with to create the earthquake-resistant design of a building, namely seismic structural configuration, lateral stiffness, lateral strength, and ductility, in addition to other aspects like form, aesthetics, functionality, and comfort of the building. Seismic structural configuration entails three main aspects, namely (a) geometry, shape and size of the building, (b) location and size of structural elements, and (c) location and size of significant non-structural elements. Lateral stiffness refers to the initial stiffness of the building, even though the stiffness of the building reduces with increasing damage. Lateral strength refers to the maximum resistance that the building offers during its entire history of resistance to relative deformation. Ductility towards lateral deformation refers to the ratio of the maximum deformation and the idealized yield deformation [3].

In the modern world, where people are not ready to compromise with their needs, the incorporation of combinations of irregularity in structures is inevitable. As the structural response depends on the type, location, and degree of irregularity, these factors need to be taken care of while designing any structure. This would help in incorporating irregularities in structures without compromising their performance. The main purpose of seismic building codes ES EN 1998:2015 is to establish minimum requirements to ensure that, in an event of an earthquake: human lives are protected, the damage is limited, and structures important for civil protection remain operational. Note that the random nature of seismic events and the limited resource available to counter their effects makes the attainment of these goals partially possible and only measurable in probabilistic terms.

1.2. Statement of the Problem

Structural irregularities are one of the major causes of severe damage or collapse under seismic action. The main causes of structural irregularities are economic, functional, and aesthetics value. Architectural configuration determines the location, shape, and approximate size of structural and nonstructural elements of the building. Plan irregularities are characterized by uneven plan distribution of earthquake-resistant vertical structures and mass; it results in a dangerous torsional behavior consisting of large floor rotations. The main sources of plan irregularity-asymmetric building plans, irregular mass and stiffness distribution, irregular distribution of claddings. In a building vertical irregularities is due to sudden variations in mass, stiffness, and strength along with the building height, which result in the formation of soft/weak stories where an earlier collapse can develop because of concentration in member forces and ductility demands.

All buildings are vertical cantilevers projecting out from the earth's surface. Hence, when the earth shakes, these cantilevers experience whiplash effects, especially when the shaking is violent. Hence, special care is required to protect them from this jerky movement. Buildings intended to be earthquake-resistant have competing demands. Firstly, buildings become expensive, if designed not to sustain any damage during strong earthquake shaking. Secondly, they should be strong enough to not sustain any damage during weak earthquake shaking. Thirdly, they should be stiff enough to not swing too much, even during weak earthquakes. And, fourthly, they should not collapse during the expected strong earthquake shaking to be sustained by them even with significant structural damage [3].

This research will be forward the output of different parameter of single and multi-combination irregularity in vertical and plan multistory reinforced the concrete building at seismic zone V as per ES EN 1998-1:2015. I want to be determine the adequacy of the structural response of base shear, lateral displacement, story shear and story drift by analyzing irregularity of mass, stiffness, and geometry of single and multi-combination irregularity of the multistory reinforced concrete building in seismic zone V.

1.3 Research Questions

1. What is the effect of mass, stiffness, and setback irregularity on the performance of multistory RC building subjected to seismic action according to Ethiopian seismic codes ES EN 1998-1:2015?
2. What is the effect of single and combination irregularity on the structural response of deformation, base shear, story shear, and story drift subjected to ground motion?
3. Which method is better for determining the irregularity of the multi-story reinforced concrete building according to Ethiopian current seismic code?

1.4. Objectives of the Study

1.4.1. General Objectives

The main objective of this paper is comparative study of equivalent static method & response spectrum method on the behavior of single and combination irregularity of the multistory reinforced concrete structure according to Ethiopian seismic current code as per ES EN 1998-1:2015.

1.4.2. Specific Objectives

1. To analysis the effect of mass, stiffness, and setback irregularity by using equivalent static and dynamic response spectrum a method during the earthquake load.
2. To investigate the structural response of lateral maximum deformation, base shear, story shear and story drift of single and combination irregular multistory reinforced concrete building.
3. To identify better design approach method of determining irregularity of the multi-story reinforced concrete building according to Ethiopian seismic current code?

1.5. Significance of the Study

The high the intensity of earthquake effect lead to the damage the property and many people's loss of life. So the main importance of this research is to know the effect of structural irregularity under seismic load before construction and to understand the behavior of irregular multi-story RC buildings both in plan and vertical with different parametric study for designer and supervisors of a public building.

1.6. Scope and Limitation of the Study

The scope of this research is focused on linear analysis behavior of different irregular multi-story RC building based on equivalent static and dynamic response spectrum method at seismic zone V according to Ethiopia's current seismic code by using ETABS 2016 software. The scope of the study is limited to linear-elastic analysis of irregular multi-story RC building that resist lateral force by frame action. Seismic response parameters are limited to story displacement, story drift, base shear and base shear.

CHAPTER TWO

2. RELATED LITERATURE REVIEW

2.1 General

The behavior of a multi-story building during a strong earthquake, motion depends on structural configuration. Irregular configuration either in the plan or in elevation is recognized as one of the major causes of failure during earthquakes. Thus irregular structures, especially the ones located in seismic zones are a matter of concern. Structures generally possess a combination of irregularities and consideration of a single irregularity may not result in accurate prediction of seismic response. The choice of type, degree, and location of irregularities in the design of structures is important as it helps in improving the utility as well as aesthetics of structures.

The researcher studied analysis of G+10 the response spectrum of the irregular multi-story building of seismic zone V results were evaluated using different available commercial computer program ETAPS, SAP2000 and STAD PRO. The joint displacement in X, Y, and Z direction, axial force, fundamental time period of structure in different modes, and modal mass participation ratio in X and Z direction were analyzed. They conclude the dynamic analysis must be carried out for high-rise structures with vertical irregularities having a height of more than 40 m. As the modal mass participating factor is more than 75% in the higher mode, the considered structure is stiff for earthquake excitation. The joint displacement in X- direction is found more as compared to the Y and Z directions due to the fact that the earthquake motion was applied in the X-direction. This shows the uplift in the Y- Y-direction and displacement in Z-direction [2].

The researcher studied the Analysis of Irregular Structures under Earthquake Loads of the structural behavior of multi-story frames with single and combinations of irregularities is studied. The results indicate that irregularity considerably affects the structural response. In all the cases analyzed, change in response is observed for frames having single or multiple irregularities with respect to the regular configuration. Certain combinations of irregularities bring down the structural response. All the single irregularity cases analyzed have shown an increase in response when compared to the regular configuration under seismic loads. Among these cases, the configurations with vertical geometric irregularity have given maximum response. The combination of stiffness and vertical geometric irregularities has shown maximum displacement response whereas the combination of reentrant corner and vertical geometric irregularities has shown less displacement response [4].

The researcher presents a review of the comparison of static and dynamic analysis multistoried building. Design parameters such as Displacement, Bending moment, Base shear, Storey drift, Torsion, Axial Force was the focus of the study. They conclude the difference of values of displacement between static and dynamic analysis is insignificant for lower stories, but the difference is increased in higher stories and static analysis gives higher values than dynamic analysis. Building with re-entrant corners experienced more lateral drift and reduction in base shear capacity compared to regular buildings. When compared to irregular configuration the story drift value is more in the regular configuration. Story drift is increased as the height of the building increases. Building with severe irregularity produces more deformation than those with less irregularity, particularly in high seismic zones. And conjointly the story's overturning moment varies inversely with the height of the story. The irregular shape building undergoes more deformation and hence regular shape building must be preferred. The results of equivalent static analysis are approximately uneconomical because values of displacement are higher than dynamic analysis [5].

The authors studied Comparative Study of the Static and Dynamic Analysis of Multi-Story Irregular Building. The maximum displacement of stories and maximum displacement of the center of mass of multi-story irregular buildings with 20 stories have been modeled using software packages ETABS and SAP 2000 v.15 for seismic zone V in India. As a result of the comparison between the three mentioned analyses, it is observed that the displacements obtained by static analysis are higher than dynamic analysis including response spectrum and time history analysis. Time history analysis is an elegant tool to visualize the performance level of a building under a given earthquake. Seismic performance of structure can be obtained by selecting an adequate recorded ground motion for time history analysis. Static analysis is not sufficient for high-rise buildings and it’s necessary to provide the dynamic analysis (because of specific and nonlinear distribution of force). The difference of displacement values between static and dynamic analysis lower stories are insignificant but it increased in higher stories reached its peak in top story or roof. The displacement of each story at the center of mass is lower compare to those at the point of maximum displacement. The results of equivalent static analysis are approximately uneconomical because values of displacement higher than dynamic analysis [6].

The researcher studied the Comparison of static and dynamic behavior of a six story’s building has analyzed by using computerized solution available in all four seismic zones i.e. II, III, IV, and V. The Nodal forces and the seismic forces at various levels of the story has been tabulated for both the analysis and it is found that static shear force is nearly 3.01 times to the shear force obtained by dynamic analysis. It means the structure designed by static analysis will be much heavier and costly. Base shear in static analysis changes in the ratio of their zones factors, as the base shear is given by Z/2 x Sa/g x I/R, except Z all other parameter remains constant irrespective of seismic zone under which is designed. Therefore ratio of base shear in various earthquake zones are given by-ZI: ZII: ZIII: ZIV = 1:1.6:2.4:3.6. Similarly analyzing the building with same parameters in dynamic analysis, it is observed that parameters like base shear, nodal displacements and beam ends forces vary in the same ratio as described above, hence it is the very important conclusion derived in the analysis that, if we design one building in one of the seismic zones, and if the same building is likely to be constructed in another zone, then the different parameter can be worked out using this ratio, without going into detailed analysis, provided all other parameter remain unchanged [8].

2.2. Structural Irregularity

An aspect of seismic design of equal if not greater importance than structural analysis is the choice of building configuration. Lack of symmetry (in mass distribution and/or in stiffness, strength, and ductility) leads to torsional effects difficult to assess properly can be very destructive. Architects are responsible for the architectural configuration of buildings at the start. Configuration has to do with the size, shape and proportion of the 3D form of the building. Architectural configuration determines the location, shape and approximate size of structural and nonstructural elements of the building. Any architectural design should incorporate effective seismic design to minimize EQ hazards.

Plan and vertical irregularities-result in seismic over-demand onto specific structures/elements which can lead to their early collapse, while not allowing the entire building structure to exploit its full seismic capacity. Both plan and vertical irregularity do not allow uniform damage distribution and, therefore, strength and ductility resources of the entire structure cannot be fully exploited. Regularity of the structure (in elevation and in the plan) influences the required structural model (planar or spatial), the required method of analysis, and the value of the behavior factor q (ES EN 1998-1/4.2.3.1). For a structure regular in plan and in elevation, the simplest approach can be applied, i.e. a planar model can be used and a lateral force method can be performed [1]. For this research a structure irregular in plan and in elevation a spatial model and a Modal response spectrum analysis method is will be performed. Moreover, the Decreased value of the basic behavior factor q0 can be used as per ES EN 1998-1/Table 4.1.

Table 2.1: Consequences of structural regularity on seismic analysis and design [1].

Regularity		Allowed simplification		Behavior factor
Plan	Eleva-tion	Model	Linear elas-tic Analysis	Linear Analysis
Yes	Yes	planar	Lateral force	Reference value
Yes	No	planar	Modal	Decreased value
No	Yes	Spatial	Lateral force	Reference value
No	No	Spatial	Modal	Decreased value

CHAPTER THREE

3. RESEARCH METHODOLOGY

3.1 Study Area

National territories shall be subdivided into seismic zones depending on the local hazard. The hazard is described by the reference peak ground acceleration (PGA) on type A ground, ag_R. The Seismic hazard map of the Ethiopia current code is divided into 5 zones. For this research model ground types B and seismic zones V as per ES EN 1998-1:2015 is selected.

3.2 Study Period

This research study will be carried out within five months from start September, 2020 and it will end up On March, 2021. In order to finish this research at the right time, at the right budget and at the right resource the scope is already specified or determined.

3.3 Research Design

The data will be analyzed and interpreted in terms of quantitative data, because the aim of this study is to analysis behavior irregular multistory reinforced concrete under seismic zone of according to Ethiopian code. Both combination of vertical and horizontally irregular multistory will be analyzed which can be expressed numerically. Theoretical research will be engaged here in this research.

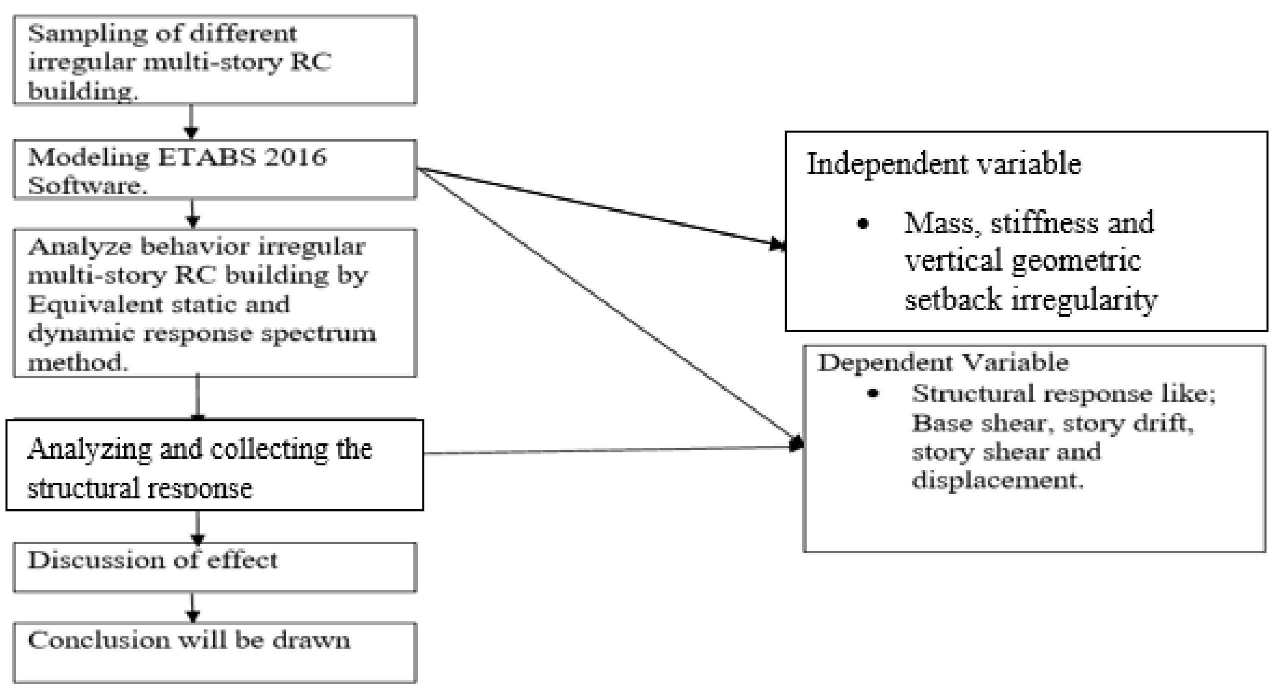


Figure 3.1: design procedure

3.4 Study Variables

Independent variables are plan and vertical irregularities of mass, stiffness and vertical geometric setback. Dependent variables are Structural response like base shear, story drift, story shear, and deformation capacity. Generally analyzing the performance of the irregular buildings is the dependent variable.

3.5. Structural model

The model of the building shall adequately represent the distribution of stiffness and mass in it so that all significant deformation shapes and inertia forces are properly accounted for under the seismic action considered. The model should also account for the contribution of joint regions to the deformability of the building, e.g. the end zones in beams or columns of frame type structures. Non-structural elements, which may influence the response of the primary seismic structure, should also be accounted for. In general, the structure may be considered to consist of a number of vertical and lateral load resisting systems, connected by horizontal diaphragms. 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 center of gravity. The masses shall be calculated from the gravity loads appearing in the combination of actions indicated in ES EN 1998-1/3.2.4. The combination coefficients ψEi are given in ES EN 1998-1/4.2.4 (2) P.

The program ETABS was used for analysis. The three-dimensional (spatial) structural model is used. The structural model fulfills all requirements of ES EN 1998-1/4.3.1-2. The basic characteristics of the structural model are, all elements are modeled as line elements. Effective widths of beams are calculated according to ES EN 1992. Two different widths for interior beams and another two for exterior beams are used. Rigid offset for the interconnecting beams and columns elements are not taken into account. All elements are fully fixed in the foundation. All frames are connected together by means of rigid diaphragms (in a horizontal plane) at each floor level. (ES-EN 1998-1/4.3.1 (3)). Masses and moments of inertia of each floor are lumped at centers of masses (ES-EN 1998-1/4.3.1 (4)). They were calculated from the vertical loads corresponding to the seismic design situation (EN 1998-1/4.3.1 (10). The cracked elements are considered (ES EN 1998-1/4.3.1 (6)).

The elastic flexural and shear stiffness properties are taken to be equal to one-half of the corresponding stiffness of the uncracked elements (EN 1998-1/4.3.1 (7)), i.e. the moment of inertia and shear area of the uncracked section were multiplied by factor 0.5. Also the torsional stiffness of the elements has been reduced. Torsional stiffness of the cracked section was set equal to 10% of the torsional stiffness of the uncracked section. Infills are not considered in the model. The accidental torsional effects are taken into account by means of torsional moments about the vertical axis according to ES EN 1998/4.3.3.3.3.

Footings with tie beams represent the foundation. Concrete C-30/37 is used. The corresponding modulus of elasticity amounts to E_{cm}= 33GPa (ES EN 1992/Table 3.1). Poisson's ratio was taken equal to v = 0.2 uncracked concrete according to ES EN 1992/3.1.3. Steel S500 Class C is used. The structure will be designed for ductility class DCM.

3.6 Detail description of the structural model

3.6.1 Regular structural model for 8 and 15 story

The regularity of this structural model designed to fulfill the requirement of criteria for structural regularity described in ES EN 1998-1/4.2.3. For the purpose of seismically designed the Structural model analysis is obey the rule of regularity of both floor plan and elevation as explained in ES EN 1998-1/ 4.2.3.2 and 4.2.3.3. Lateral stiffness and mass distribution of the building structure are approximately symmetrical in plan with respect to two orthogonal axes and vertically lateral stiffness and the mass of the individual story are constant from the base to the top of a particular building. Uniformity in plan is characterized by an even distribution of the structural elements which allows short and direct transmission of the inertia forces created in the distributed masses of the building. Story 8 and 15 building structures have similar floor plan shape and have different structural element dimension. The structural model plan layout and 3D ETABS are shown in figure 3.2 and 3.3. The detail dimension of the structural model beam, column, and slab are shown in table 3.1.

Table 3.1: - dimension of regular structural model for 8 and 15 storey

No. of story	Floor plan	Slab	beam	column	Typical story height	Total story Height
8 story	24x30m	0.18m	0.4x0.45m	0.40x0.60m	3m	24m
15 story	24x30m	0.18m	0.4x0.5m	0.5x0.8m	3m	45m

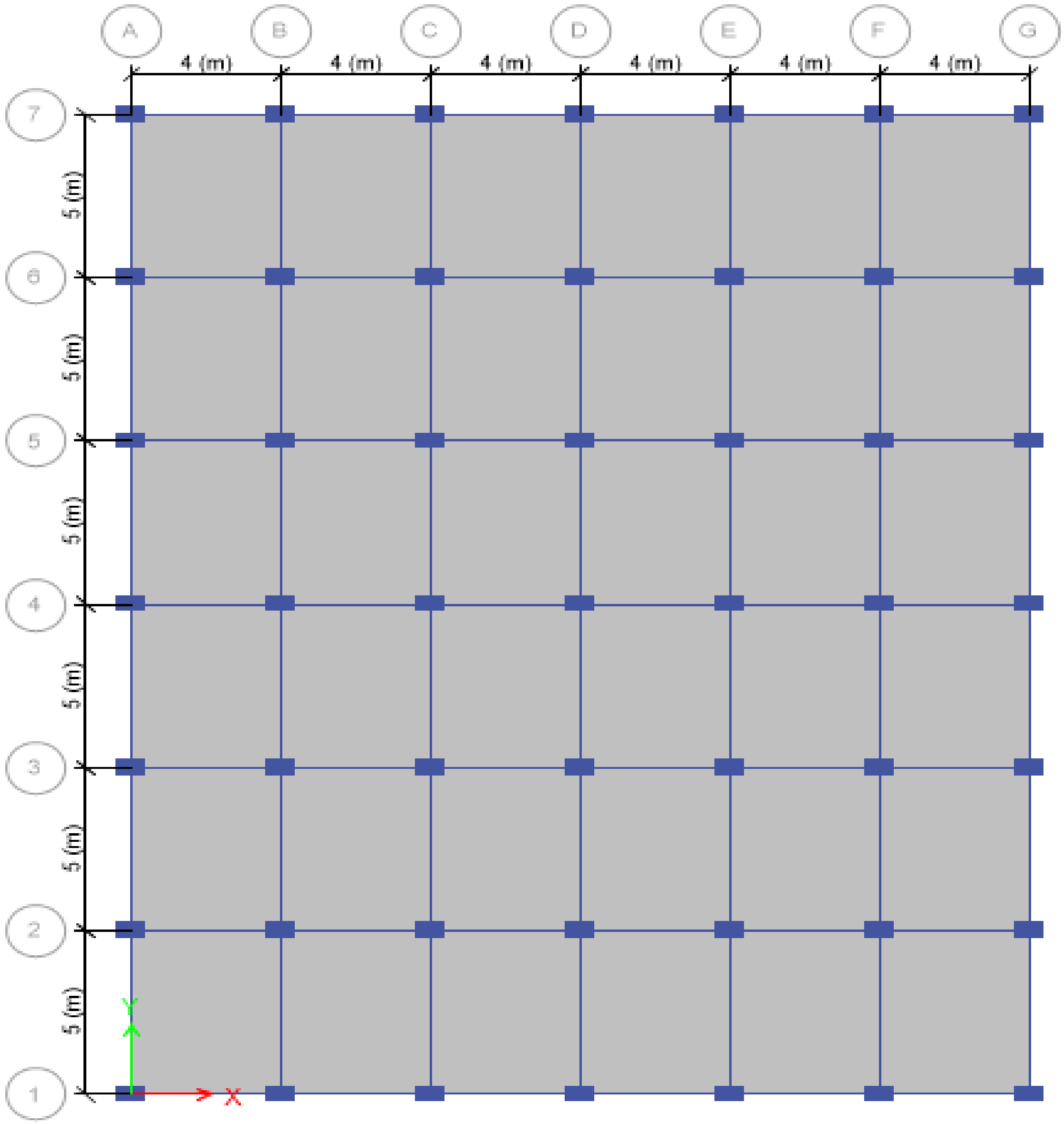
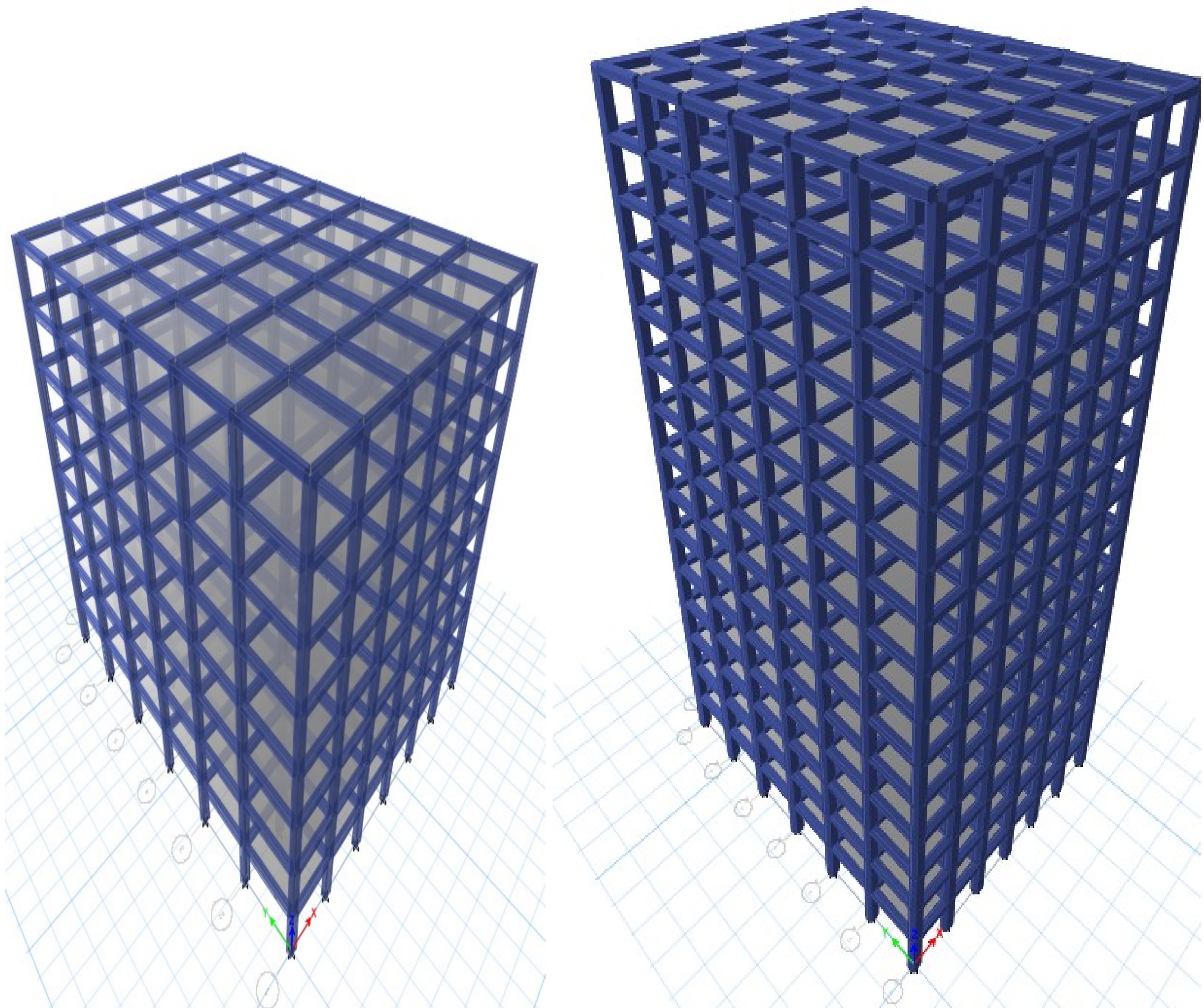


Figure 3.2:-floor plan of regular structural model storey 8 and 15 building



a) b)

Figure 3.3:-3D ETABS regular structural model of building a) story 8 and b) story 15

3.6.2 Mass irregularity (MI) of the structural model for story 8 and 15 building

Mass irregularity arises in this structural model is due to the uneven distribution of mass in the inner part of the structural building. The investigated building is a mass irregular multi-story reinforced concrete frame structure. Ethiopian seismic standard code describe mass regularity in the plan as mass distribution of the building structure shall be approximately symmetrical in plan with respect to two orthogonal axes (ES EN 1998:-2015/4.2.3.2. (2P) and 4.2.3.3. (2P)) and vertically, the mass of individual stories shall remain constant or reduce gradually, without abrupt changes, from the base to the top of a particular building. For this specific use of investigated structural model is design for office building or category B building as defined in ES EN

1991-1-1:2015/ 6.3.1.1 1(P). Different imposed load and super dead load is applied on the story 8 building 1, at 1st, 3rd, 4th, 5th, 6th and 7th floor levels used for office service imposed load 3 KN/m². 2, at 2nd and 6th floor levels used for areas of storage E1 for that office (areas susceptible to accumulation of goods, including access areas or areas for storage use including storage of books and other documents) as defined in the ES EN 1991-1-1:2015/6.3.2.1 1(P) imposed load is 7.5KN/m². 3, at the 8th or top roof levels used for support 10m³ elevated water tank at the one corner side of the building. For all the three case different magnitude of imposed load and super dead load is applied according to ES EN 1991-1-1:2015. This case opposes the regularity of building restricts by the standard code of ES EN 1998-1/4.2.3.2. (2P). in this process irregularity of masses are develop in the internal part of the structure. The same for story 15 building for story 5th and 12th used for storage service of that office imposed load is 7.5, all story of building except from story 5th and 12th applied imposed load is 3 KN/m² and elevated water tank 10m³ on the top of roof floor levels. The other detail dimension of structural models like a beam, column, typical story height, and floor plan dimension is the same as the regular structural model described above shown in table 3.1 for both story 8 and 15 building.

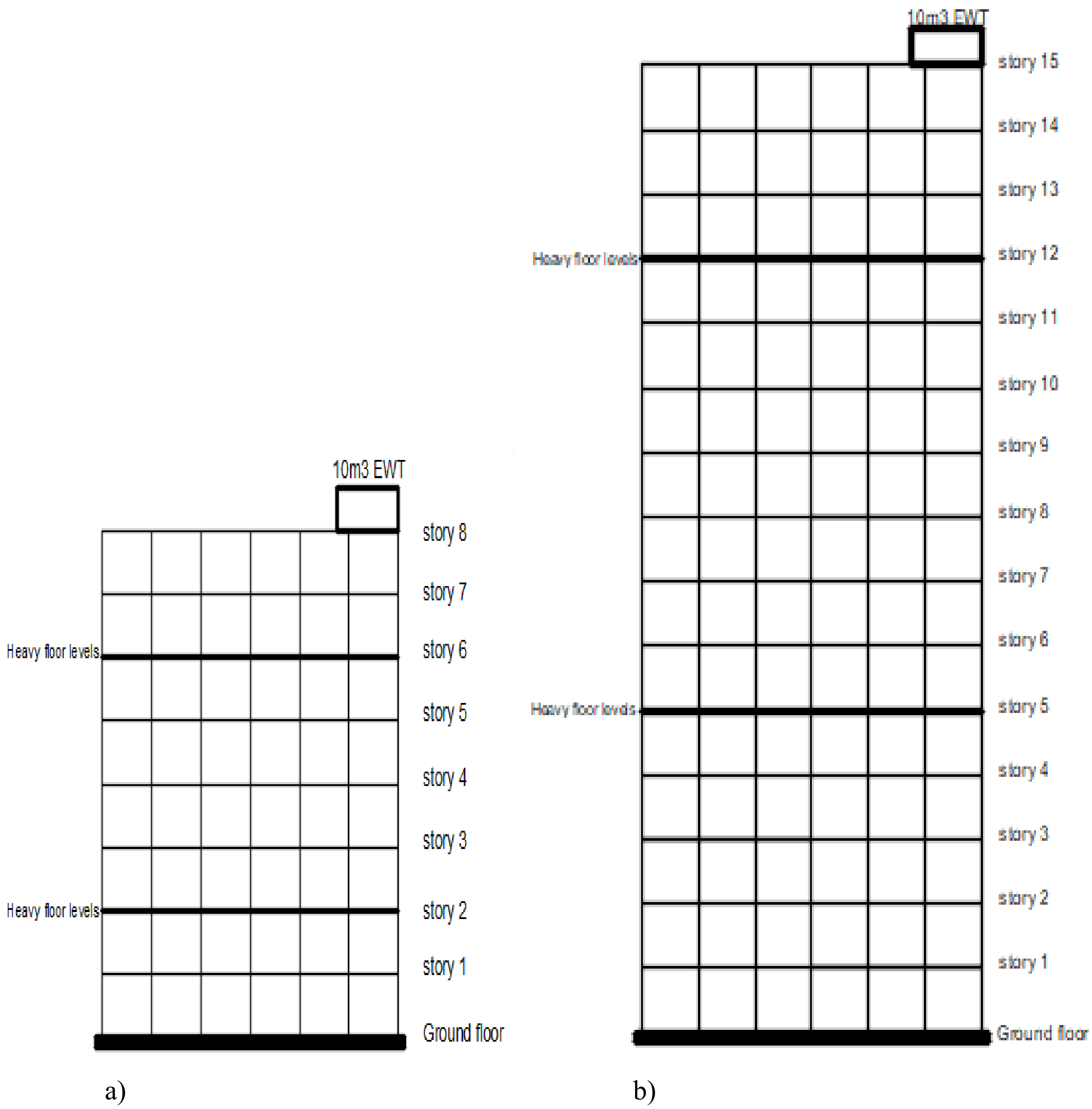


Figure 3.4:-2D view of mass irregular structural model; a) storey 8 and b) storey 15

3.6.3 Stiffness irregularity of structural model of story 8 and 15 building

ES EN 1998-1/ 4.2.3 define the Criteria for structural regularity that the lateral stiffness of the building structure shall be approximately symmetrical in plan with respect to two orthogonal axes. The lateral stiffness of the individual stories shall remain constant or reduce gradually, without abrupt changes, from the base to the top of a particular building. But, for the investigated frame structural model Sizes of lateral load resisting elements are varied along with the height of buildings and use varied typical story height. The structural model along plan is regular. Irregularity occurs in elevation where sizes of lateral load resisting elements are varied along with the height of buildings and using different typical story height. Irregularity in stiffness along elevation use varies typical story height at 1st, 5th, and 8th is 4m and 3m for the other story for story 8 building. Also for story 15 building at 1st, 7th, and 15th typical story height are 4m and for other stories is 3m. The structural model of the floor plan and slab dimensions are similar to the regular model and the other dimensions of beam, column, and total story height are shown in table 3.2. The selected structural model due to the use of different sizes of the column and different typical story height makes the model stiffness irregular. The stiffness irregularity structural model plan layout and 2D ETABS is shown in Figures 3.6 and 3.7.

Table 3.2: - Description of stiffness irregular structural model for 8 and 15 storey

No.		8 story	15 story
		Plan irregularity	Plan irregularity
1.	Dimension of column	400x600mm from 1st -5th story and 300x400mm from story 6 up to 8	500x800mm from 1st -8th story and 400x450mm story 9 up to 15
2.	Beam	350x450mm from story 1st -5th, and 250x300mm from story 6th up to 8	400x500mm from story 1 up to 9, and 300x400mm from story 10 up to 15
4.	Total story Height	27m	48m

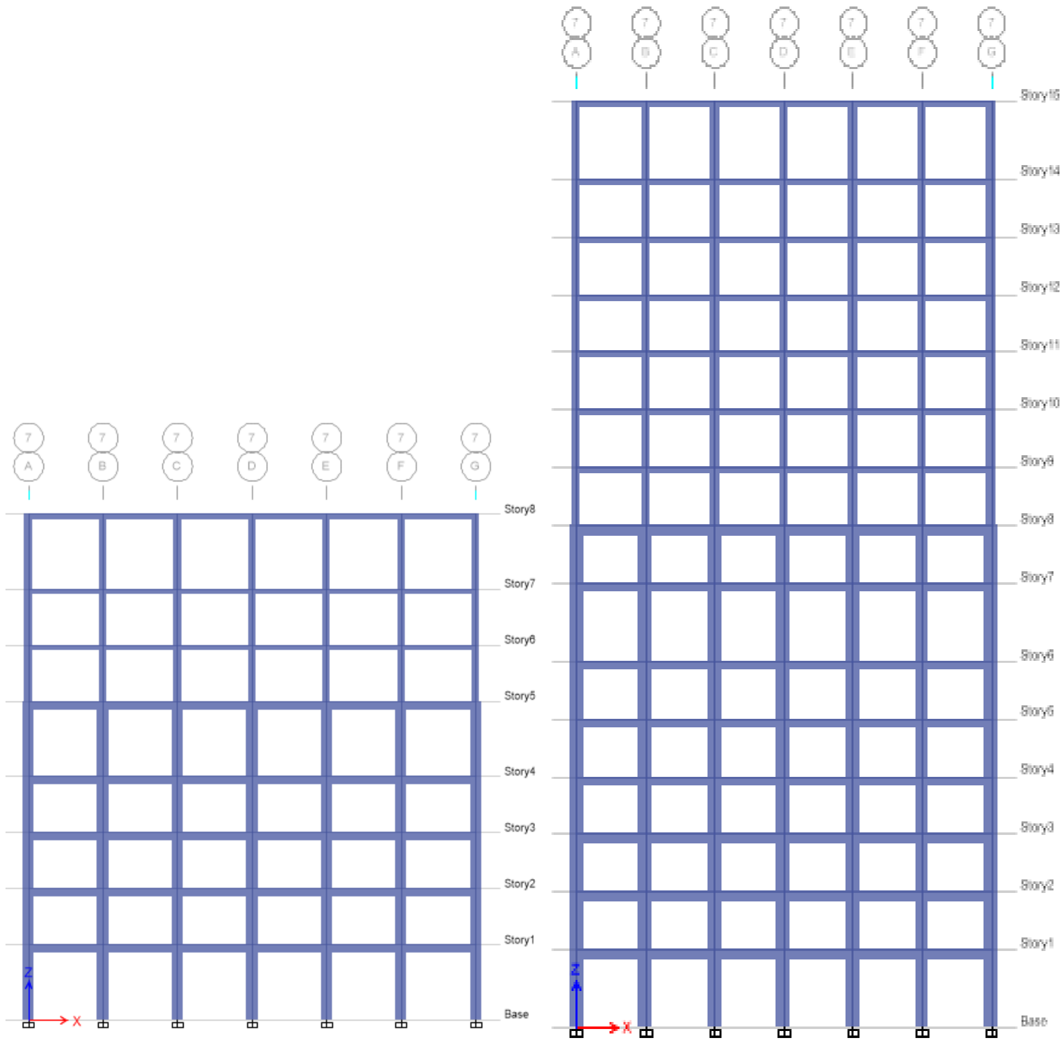
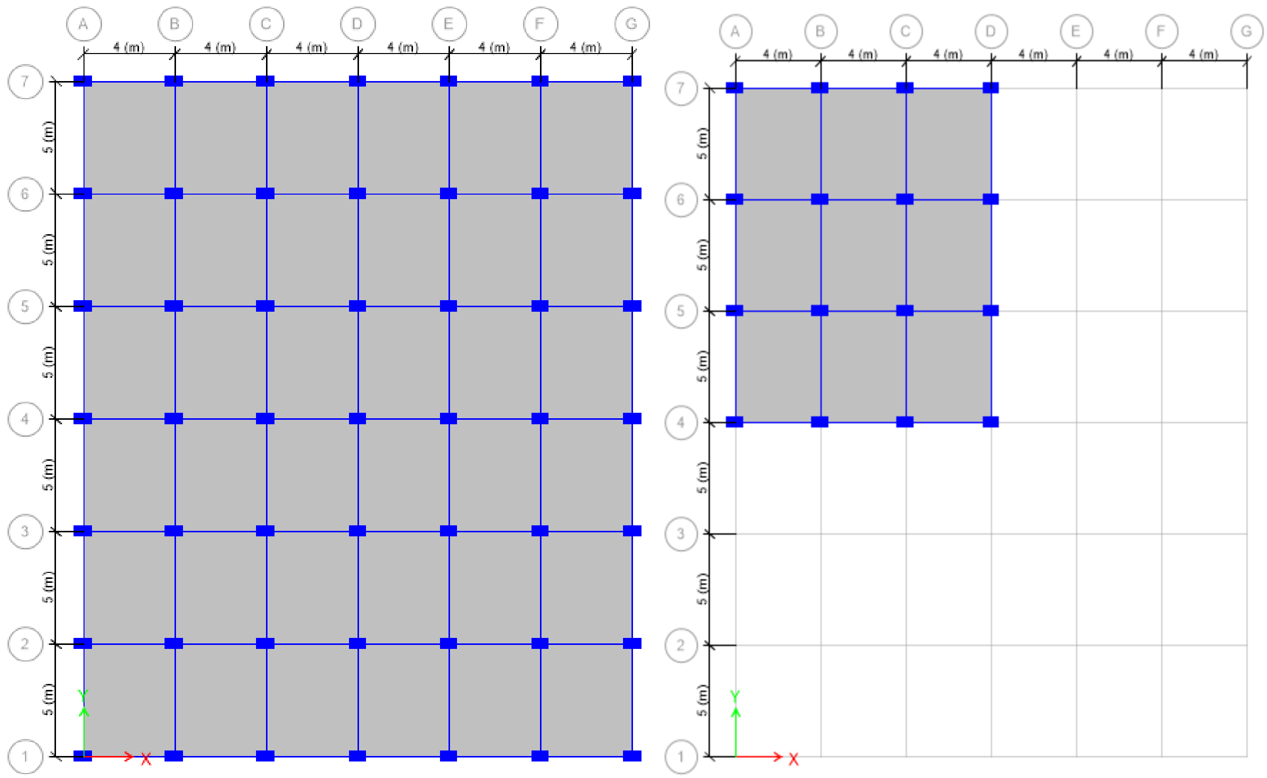


Figure 3.5:-2D view of stiffness irregular structural model; a) story 8 and b) story 15

3.6.4 Setback vertical geometric irregular structural model for 8 and 15 story

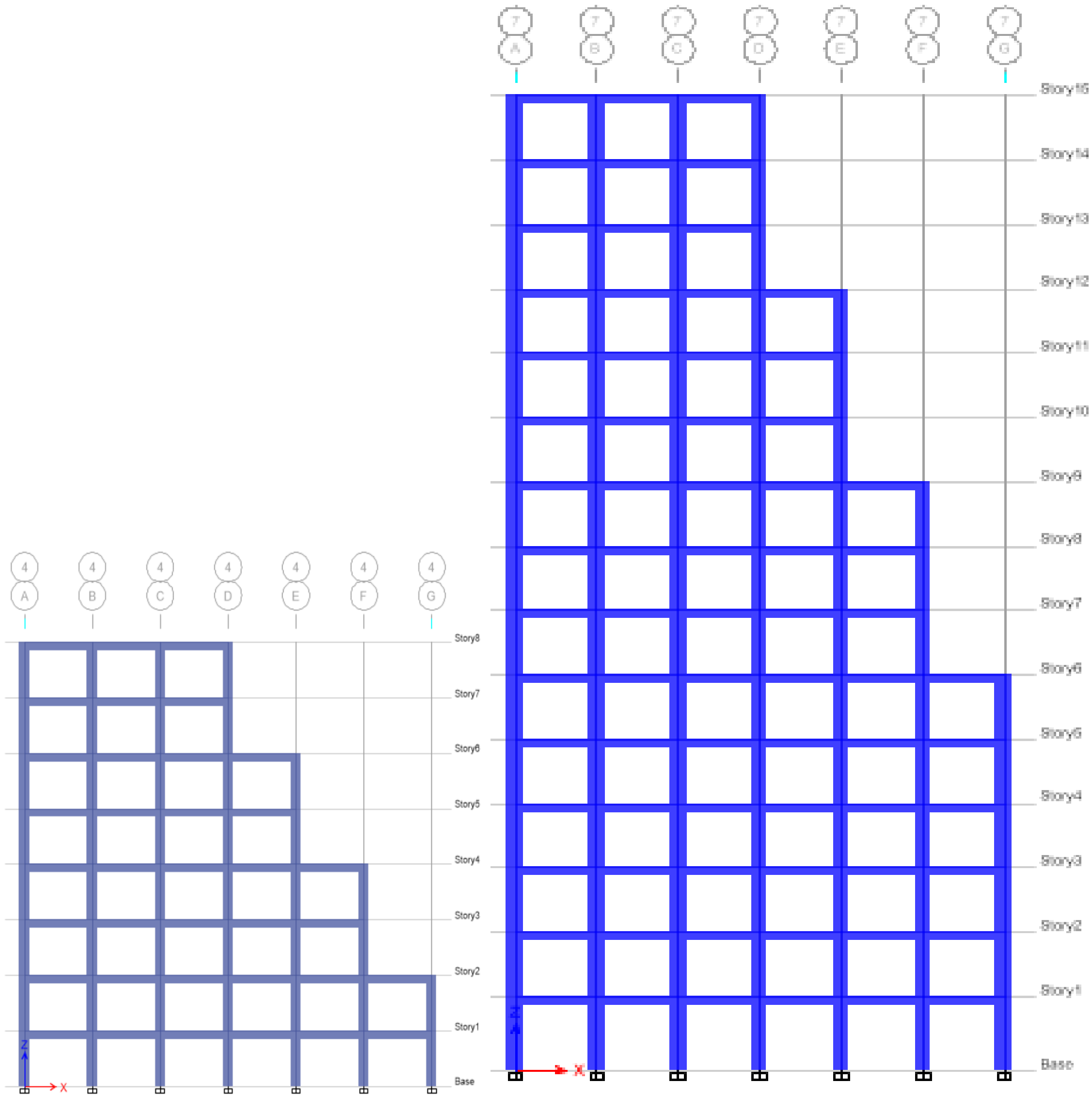
The investigated building is vertical geometric setback irregularity of multi-story reinforced concrete frame structure. The structural model plan layout and 3D ETABS are shown in figure 3.10 and 3.11. Stepped buildings have frames of different heights. Thus, both mass and stiffness distribution changes along with the height; the center of mass and center of the stiffness of different stories do not lie along the same vertical line, as is the case in buildings with regular overall geometry. ES EN 1998-1/ 4.2.3 defined the Criteria for structural regularity that if the setbacks do not preserve symmetry, in each face the sum of the setbacks at all story shall be not greater than 30 % of the plan dimension at the ground floor above the foundation or above the top of a rigid basement, and the individual setbacks shall be not greater than 10 % of the previous plan dimension. For this investigated research the setback irregularity reject the criteria of ES EN 1998-1/ 4.2.3.3(5) criteria d). Percentage of setback irregularity all story is 50 % and the individual setbacks is 25%. Except for its geometric shapes, the detail total descriptions of setback frame irregularity beam, column, slab and typical story height are similar with regular dimension as explained above section in table 3.1



a) Ground floor plan b) Top floor plan

Figure 3.6:- floor plan of Setback irregular structural model story 8 and story 15:- a) ground and top floor plan

a)



a) b)

Figure 3.7:- 2D view of Setback irregular structural model; a) story 8 and b) story 15

3.6.5 Mass and stiffness irregular structural model for 8 and 15 story (Comb 1)

For this investigated building structural model irregularity of mass and stiffness described above section 3.6.2 and 3.6.3 cometh up combined into one gave multi-irregularity of multi-story reinforced concrete frame structure. The structural model plan layout and 2D view of combination 1 irregular shown in Figures 3.8 and 3.9. The property and detail description of the structural model discussed above sections from 3.6.2

and 3.6.3 applied also in this structural model. Storey building 8 and 15 have similar floor plan shape, but their detail dimensions of structural elements are different.

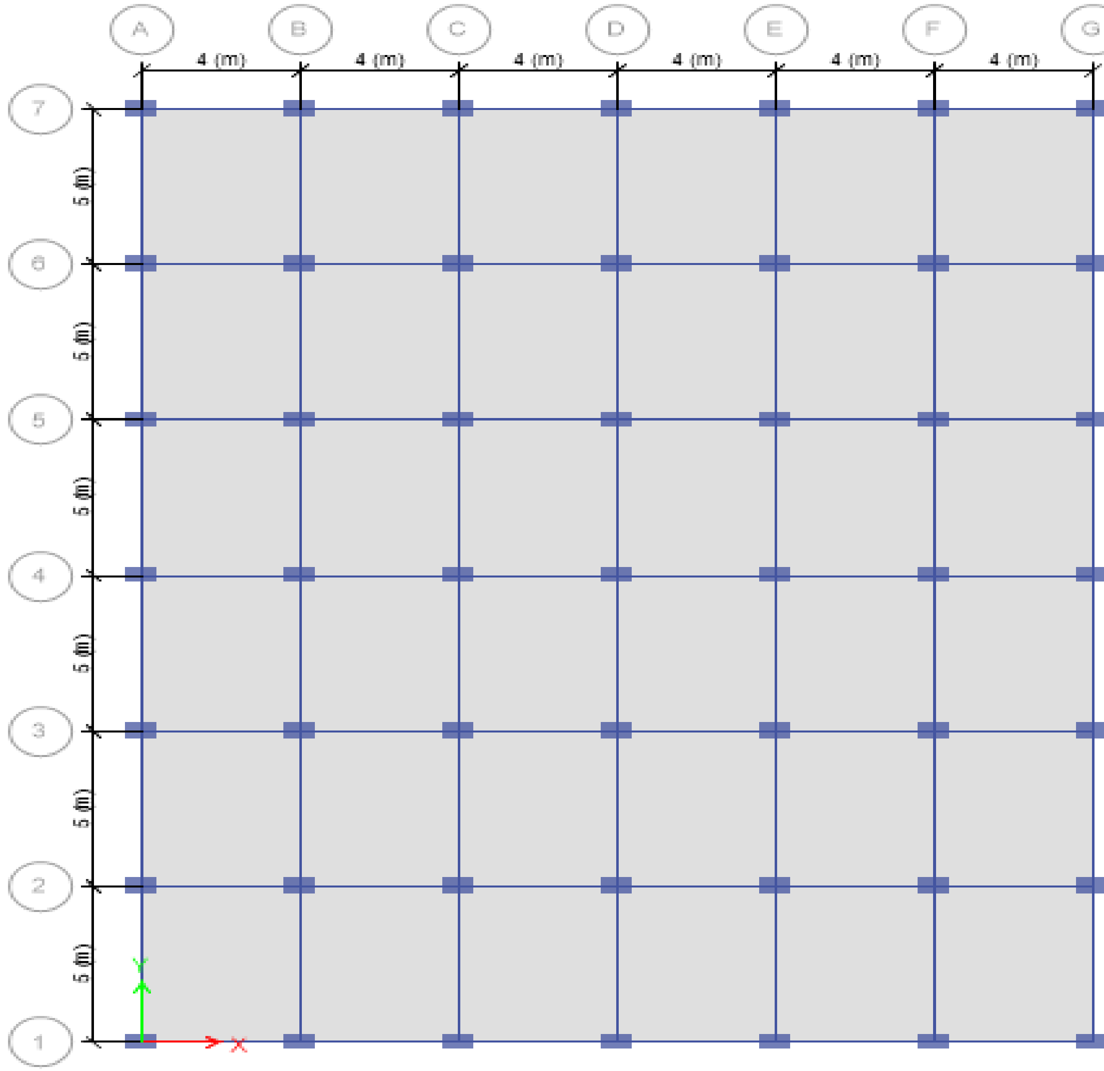


Figure 3.8:- floor plan of comb1 irregular structural model of storey 8 and 15:-a) ground and b) top floor plan

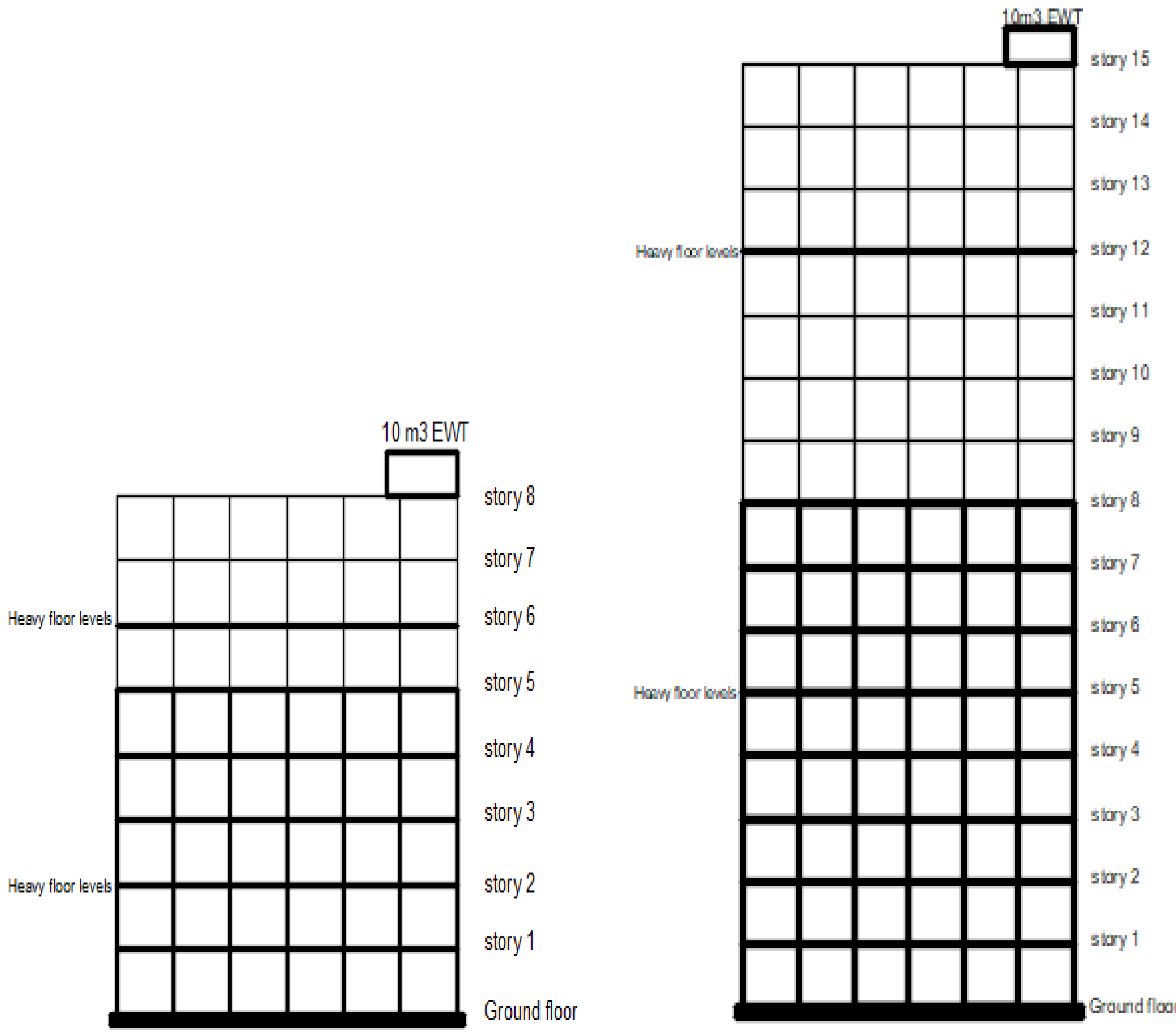


Figure 3.9:- 2D view of comb1 irregular structural model; a) story 8 and b) story 15

3.6.6 Mass, stiffness and setback irregular the structural model for 8 and 15 stories (Comb 2)

In this structural model analysis all irregularity described above section 3.6.2, 3.6.3 and 3.6.4 irregularity of mass, stiffness, and setback included. A three-dimensional spatial structural model is used. The structural model plan layout and 3D ETABS are shown in Figures 3.18 and 3.19. The detail dimension of structural model combinations irregularity of mass, stiffness and setback are similar with the described above individual topics 3.6.2, 3.6.3 and 3.6.4. But, the total story height is 27m and 48m for story 8 and 15 buildings respectively.

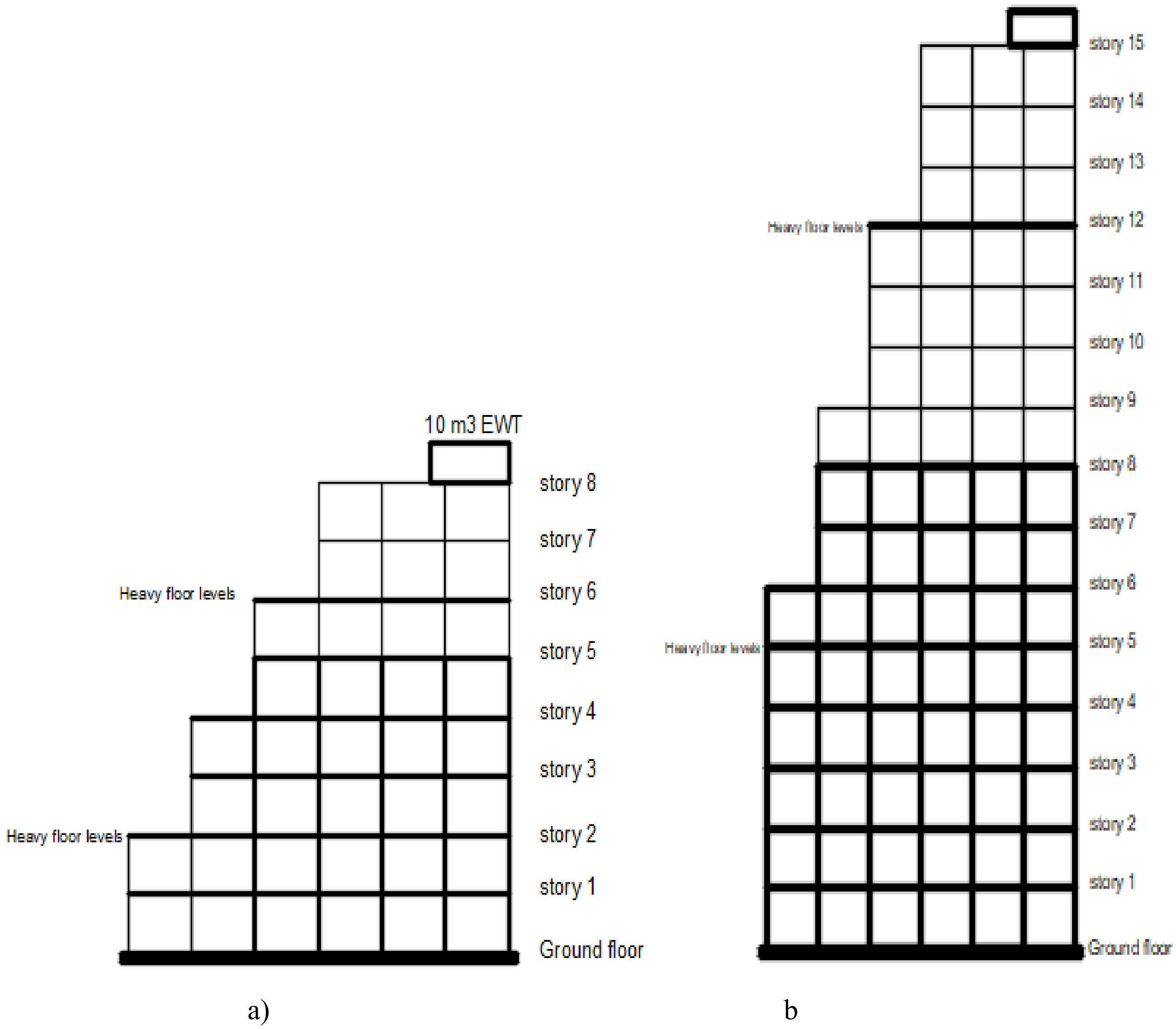
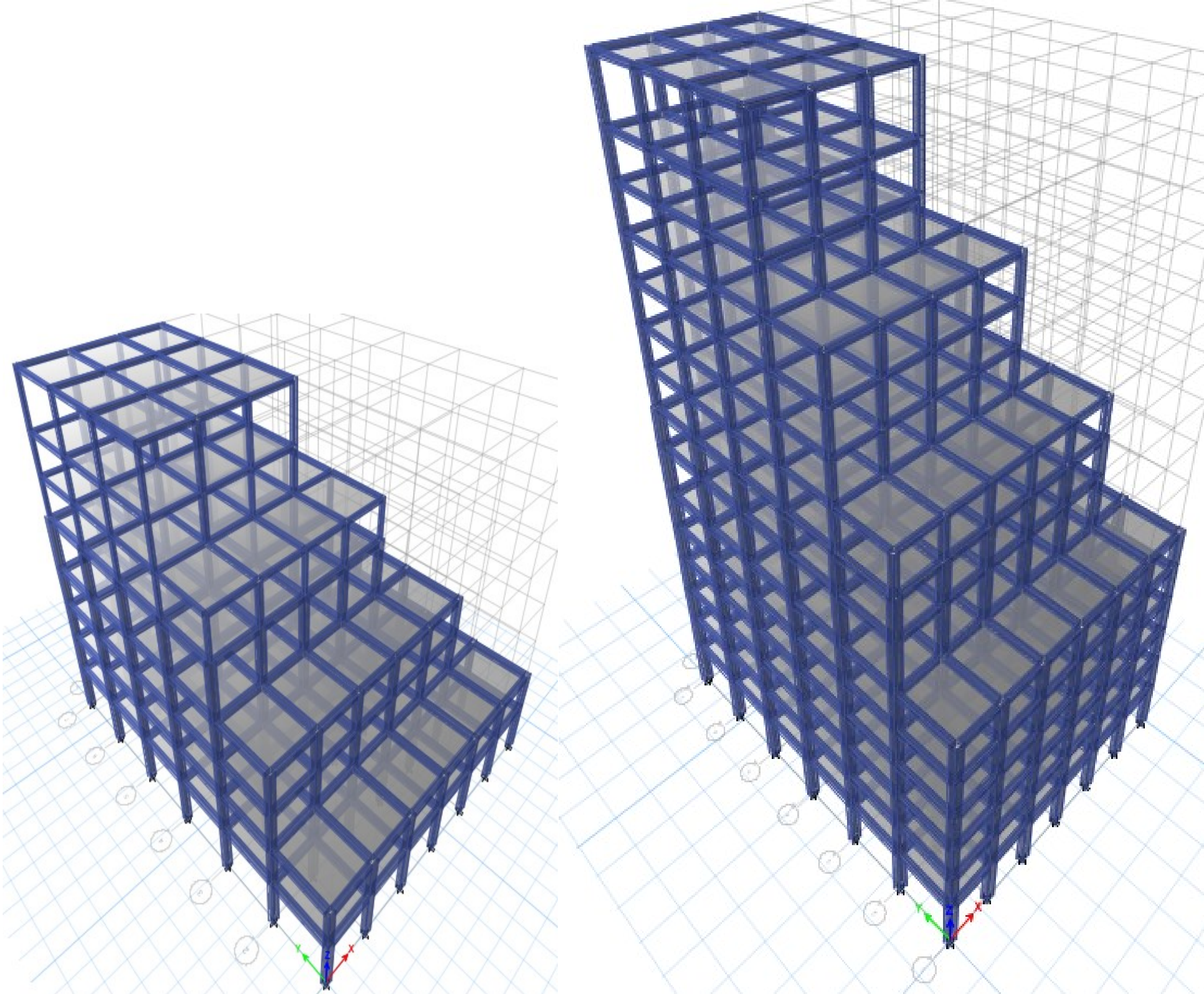


Figure 3.10: - 2D view of comb 2 irregular structural model for a) storey 8 and b) storey 15



a) b

Figure 3.11: - 3D view of comb 2 irregular structural model for a) storey 8 and b) storey 15

3.7 Purpose of ES EN 1998:2015

Earthquake is the most disastrous and unpredictable natural phenomenon which causes huge destruction to human lives as well as infrastructure. Seismic forces generated during an earthquake lead to severe damage to structural elements and sometimes structural failure. The purpose of ES EN 1998:2015 is to ensure that, in an event of an earthquake: human lives are protected, the damage is limited, and Structures important for civil protection remain operational. Note that the random nature of seismic events and the limited resource available to counter their effects makes the attainment of these goals partially possible and only measurable in probabilistic terms.

3.8 Fundamental Requirements ES EN 1998:2015

Structures in the seismic region shall be designed & constructed to meet requirements no collapse requirement and damage limitation requirement with adequate reliability.

1. No collapse requirement

The structure shall be designed and constructed to withstand the design seismic action without local or global collapse, thus retaining its structural integrity and a residual load-bearing capacity after the seismic event. The no collapse requirement is related to the protection of life under a rare event, through the prevention of the global or local collapse of the structure that, after the event, should retain its integrity and a sufficient residual load-bearing capacity. After the event, the structure may present substantial damages, including permanent drifts, to the point, that it may be economically unrecoverable, but it should be able to protect human life in the evacuation process or during aftershocks. The design ground acceleration 475 years return period (10% probability in 50 years)

2. Damage limitation requirement

The structure shall be designed and constructed to withstand a seismic action having a larger probability of occurrence than the design seismic action, without the occurrence of damage and the associated limitations of use, the costs of which would be disproportionately high in comparison with the costs of the structure itself. The second requirement is related to the reduction of economic losses in frequent earthquakes, both in what concerns structural and non-structural damages. Under such kind of events, the structure should not have permanent deformations and its elements should retain its original strength and stiffness and hence should not need structural repair. In view of the minimization of non-structural damage the structure should have adequate stiffness to limit, under such frequent events, its deformation to levels that do not cause important damage on such elements. Some damage to nonstructural elements is acceptable but they should not impose significant limitations of use and should be repairable economically. The design ground acceleration 95 years return period (10% probability in 10 years).

3.9 Importance Class and Importance Factors

ES EN 1998-1 classifies buildings into 4 importance classes (I, II, III, IV) depending on the consequences of collapse for human life, their importance for public safety and civil protection in the immediate post-earthquake period and the social and economic consequences of collapse.

Table 3.3 Importance classes and recommended values for importance factors for buildings

Importance Class	Building	Importance Factor
I	Buildings of minor importance for public safety, e.g. agricultural buildings, etc.	0.8
II	Ordinary buildings, not belonging to other categories	1
III	Buildings whose seismic resistance is of importance in view of the consequences associated with a collapse, e.g. schools, assembly halls, cultural institutions, etc.	1.2
IV	Buildings whose integrity during earthquakes is of vital importance for civil protection, e.g. hospitals, fire stations, power plants, etc.	1.4

Importance class II is the reference case and is assigned to (ordinary) buildings for which the reference seismic action is derived as indicated above. Accordingly, the important factor for this class of buildings is γ_I =1. For this research structural model, the Importance class II corresponds to consider. Besides these aspects influencing the important class of each building, the importance factor may also have to take into consideration the specific case of buildings housing dangerous installations or materials.

3.10 Seismic actions

National territories shall be subdivided into seismic zones depending on the local hazard. The hazard is described by the reference peak ground acceleration (PGA) on type A ground, a_{gR}. The reference peak ground acceleration, chosen for each seismic zone, corresponds to the reference return period *T*NCR of the seismic action for the non-collapse requirement (or equivalently the reference probability of exceedance in 50 years, *P*NCR). An important factor *γ*I equal to 1.0 is assigned to this reference return period. For return periods other than the reference the design ground acceleration on type A ground a_g is equal to a_{gR} times the importance factor γ_I =(a_g=γ_I*a_{gR})

The selection of the categories of structures, ground types, and seismic zones for which the provisions of low seismicity apply is found in the National Annex. It is recommended to consider as low seismicity cases either those in which the design ground acceleration on type A ground, a_g, is not greater than 0.08 g (0.78m/s2), or those where the product $a_g *S$ is not greater than 0.1 g (0.98 m/s2). The selection of whether the value of a_g or that of the product $a_g{*}S$ will be used to define the threshold for low seismicity cases is found in the National Annex.

The Seismic hazard map of Ethiopia is divided into 5 zones, where the ratio of the design bedrock acceleration to the acceleration of gravity g = αo for the respective zones is indicated in Table D1 of ES EN 1998-5:2015.

Table 3.4: Bedrock Acceleration Ratio αo

Zone	**5**	**4**	**3**	**2**	**1**	**0**
α**o=** a_g/g	0.20	0.15	0.10	0.07	0.04	0

The seismic action to be considered for design purposes should be based on the estimation of the ground motion expected at each location in the future, i.e. it should be based on the hazard assessment. Seismic hazard is normally represented by hazard curves that depict the exceedance probability of a certain seismologic parameter (for instance the peak ground acceleration, velocity or displacement) for a given period of exposure, at a certain location (normally assuming a rock ground condition). It is widely recognized that peak values of the ground motion parameters (namely the peak ground acceleration) are not good descriptors of the severity of an earthquake and of its possible consequences on constructions. The seismic hazard described ES EN 1998-1 only by the value of the reference peak ground acceleration on-ground type A, (a_{gR}). The purpose of ES EN 1998, national territories shall be subdivided into seismic zones, depending on the local hazard. By definition, the hazard within each zone is assumed to be constant. The reference peak ground acceleration (a_{gR}) for each seismic zone corresponds to the reference return period T_{NCR}, chosen by the National Authorities for the seismic action for the non-collapse requirement (it is recalled that, as indicated above, the recommended value is T_{NCR} = 475 years).

The seismic action considered for this investigation is represented by the elastic response spectrum, Type 1 (M_s> 5.5, ES EN 1998 1/3.2.2.2(2) P) for soil B (EN 1998-1/Table 3.1). The reference peak ground acceleration amounts to a_{gR} = 0.2g for seismic zone five. The values of the periods (TB, TC, TD) and of the soil factor (S), which describe the shape of the elastic response spectrum, amount to TB = 0.15s, TC = 0.5 s, TD = 2 s and S = 1.2 (ES EN 1998-1/Table 3.2). The building is classified as importance class II (ES EN 1998-

1/Table 4.3) and the corresponding importance factor amounts to γ_I= 1.0 (ES-EN 1998-1/4.2.5 (5) P). Therefore the peak ground acceleration is equal to the reference peak ground acceleration a_g=γ_I*a_{gR}= 0.2g. Using the equation in ES EN 1998-1/3.2.2.2 the elastic response spectrum was defined for 5% damping.

Table 3.5: Values of the parameters recommended Type 1 elastic response spectra

Ground type	S	TB(s)	TC(s)	TD(s)
A	1.0	0.15	0.4	2.0
B	1.2	0.15	0.5	2.0
C	1.15	0.20	0.6	2.0
D	1.35	0.20	0.8	2.0
E	1.4	0.15	0.5	2.0

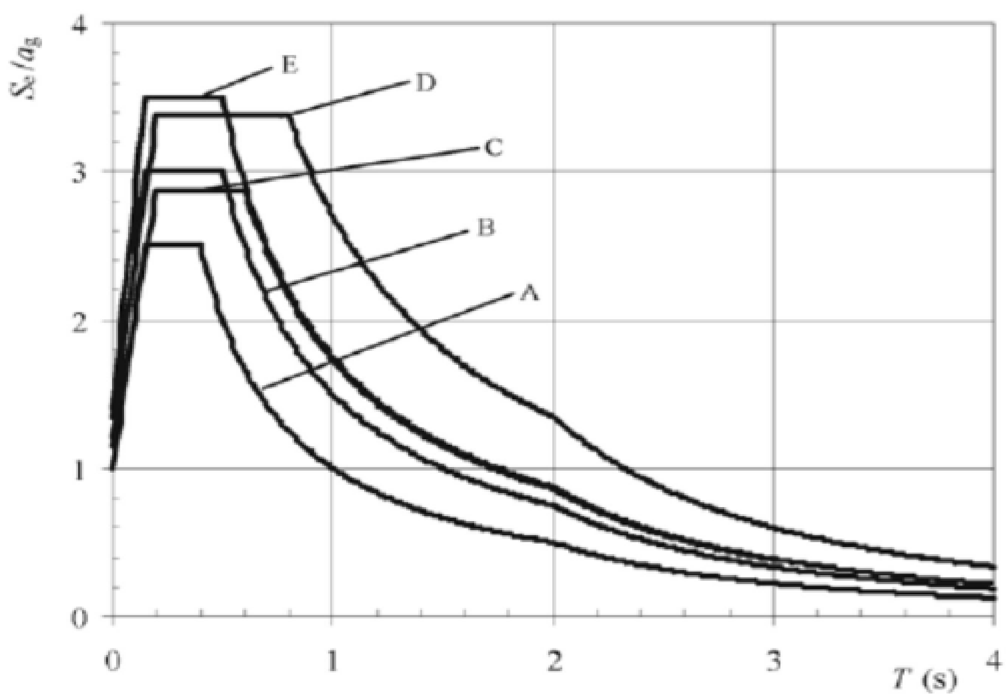


Figure: 3.12- Recommended Type 1 elastic response spectra for ground types A to E (5% damping) ES EN 1998-1/3.2.2.2 (2P).

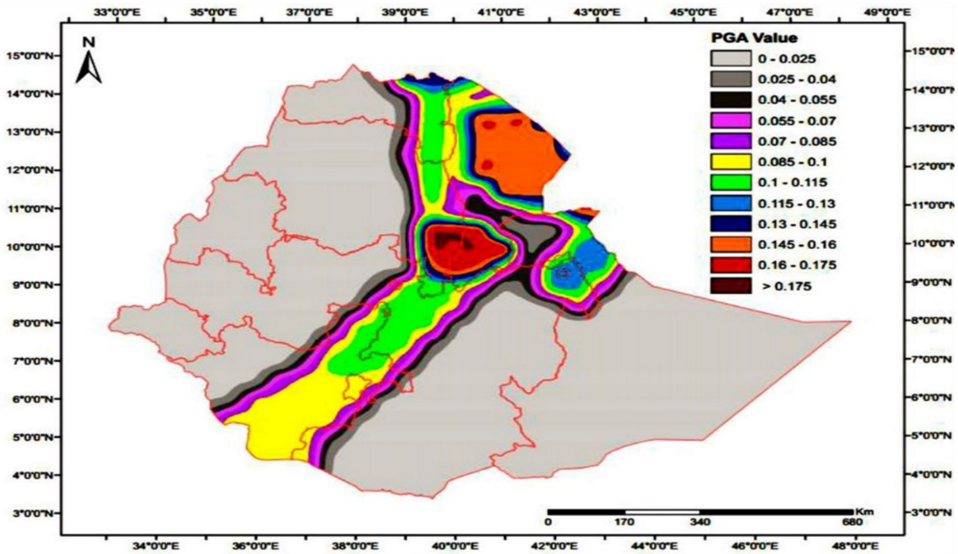


Figure 3.13:- Ethiopia's Seismic hazard map in terms of peak ground acceleration [1].

3.11 Vertical actions

In a seismic design situation, the vertical actions (permanent loads "G" and variable-live loads "Q") have to be taken into account. The permanent loads "G" are represented by the self-weight of the structure and additional permanent load. In the case of an investigated building (which represents an office building – category B (ES EN 1991/Table 6.1)), the variable-live load in terms of uniformly distributed load amounts to 3kN/m2 (EN 1991/Table 6.2) and permanent super dead load 3kN/m2 is assumed. The variable-live loads are, in a seismic design situation, reduced with a factor of Ψ_{2i} = 0.3 (ES EN 1990/Table A.1.1).

Based on the unit weight of the concrete and on the geometry of the structure, the self-weight of the beams and plates in terms of uniform surface loads was defined. The self-weight of the vertical elements (columns and walls) was automatically generated in the program ETABS.

The uniform surface loads corresponding to permanent loads "G" and to variable-live loads "Q" were distributed to the elements with regard to their influence areas. The uniform live load was calculated as a product of the influence area of the beams and the uniform surface load, divided by the length of the beam. The concentrated load represents the product of the influence area and the uniform surface load.

3.12 Load combination on the structural model

The design value E_d of the effects of actions in the seismic design situation shall be determined in accordance with ES EN1990:2015, 6.4.3.4. The inertial effects of the design seismic action shall be evaluated by taking into account the presence of the masses associated with all gravity loads appearing in the following combination of section 3.12.1 and 3.12.2 actions.

Table 3.6: - Equivalent static load case

No.	Load cases	Direction and eccentricity	eccentricity
1	EQ X1	X-direction + eccentricity	5%
2	EQ X2	X-direction - eccentricity	5%
3	EQ Y1	Y-direction + eccentricity	5%
4	EQ Y2	Y-direction - eccentricity	5%

Table 3.7:-dynamic response spectrum load case

No.	Load cases	Direction and eccentricity	Modal damping	Diaphragm eccentricity
1	EQ Spect X	X-direction + eccentricity	5%	5%
2	EQ Spect Y	Y-direction + eccentricity	5%	5%

For the determination of the design value of the action effects (e.g. internal forces) the load combination of gravity and seismic loads has to be taken into account due to the seismic design situation (ES EN 1990/6.4.3.4)

$$1.0\,\mathbf{G}+\psi 2i.\mathbf{Q} \pm \mathbf{E}_{XY} \quad 3.1$$

Where G represents permanent gravity loads (self-weight and additional dead loads), Q is live load (variable, imposed load), which is reduced with factor $\Psi_{2i} = 0.3$ (EN 1990/Table A.1.1, office building), and E_{XY} is the combined seismic action for both directions obtained by modal response spectrum analysis with included torsional effects (± *Ma).*

3.12.1 Load combination of Seismic case for equivalent lateral force

- Comb 1 G+ 0.3Q + EQX1 + 0.3EQY1
- Comb 2 G+ 0.3Q + EQX1 - 0.3EQY1
- Comb 3 G + 0.3Q - EQX1 + 0.3EQY1
- Comb 4 G + 0.3Q – EQX1 - 0.3EQY1
- Comb 5 G + 0.3Q + EQY1 + 0.3EQX1
- Comb 6 G + 0.3Q + EQY1 - 0.3EQX1
- Comb 7 G + 0.3Q – EQY1 + 0.3EQX1
- Comb 8 G + 0.3Q – EQY1 - 0.3EQX1

- Comb 9 G+ 0.3Q + EQX2 + 0.3EQY2
- Comb 10 G+ 0.3Q + EQX2 - 0.3EQY2
- Comb 11 G + 0.3Q – EQX2 + 0.3EQY2
- Comb 12 G + 0.3Q – EQX2 - 0.3EQY2
- Comb 13 G + 0.3Q + EQY2 + 0.3EQX2
- Comb 14 G + 0.3Q + EQY2 - 0.3EQX2
- Comb 15 G + 0.3Q – EQY2 + 0.3EQX2
- Comb 16 G + 0.3Q – EQY2 - 0.3EQX2

3.12.2 Load combination of Seismic case for Response spectrum

- Comb 17 G+ 0.3Q + EQ Spect X + 0.3EQ Spect Y
- Comb 18 G+ 0.3Q + EQ Spect X - 0.3EQ Spect Y
- Comb 19 G + 0.3Q - EQ Spect X + 0.3EQ Spect Y
- Comb 20 G + 0.3Q - EQ Spect X - 0.3EQ Spect Y
- Comb 21 G+ 0.3Q + EQ Spect Y + 0.3EQ Spect X
- Comb 22 G+ 0.3Q + EQ Spect Y - 0.3EQ Spect X
- Comb 23 G+ 0.3Q - EQ Spect Y + 0.3EQ Spect X
- Comb 24 G+ 0.3Q - EQ Spect Y - 0.3EQ Spect X

3.13 Structural systems and Behaviour factors

The behaviour factor *q* described in the ES EN 1998-1/ 3.2.2.5 (3) is an approximation of the ratio of the seismic forces that the structure would experience if its response was completely elastic with 5% viscous damping, to the seismic forces that may be used in the design, with a conventional elastic analysis model, still ensuring a satisfactory response of the structure. The values of the behaviour factor q, which also account for the influence of the viscous damping being different from 5%, are given for various materials and structural systems according to the relevant ductility classes in the various Parts of ES EN 1998. The value of the behaviour factor q maybe different in different horizontal directions of the structure, although the ductility classification shall be the same in all directions.

Determination of the behaviour factor q, which depends on the type of the structural system, regularity in elevation and plan, and ductility class, is described in ES EN 1998-1/5.2.2.2 (2) P table 5.1, (5) P. The design spectrum for elastic analysis was defined using expressions in ES EN 1998-1/3.2.2.5 (4) P. The upper limit value of the behaviour factor q, introduced in 3.2.2.5(3) to account for energy dissipation capacity shall be derived for each design direction as follows:

$$q = q_0 k_w \geq 1.5 \quad 3.2$$

For buildings that are regular in elevation in accordance with ES EN 1998-1/4.2.3.3, the basic values of q_0 for the various structural types are given in Table 5.1.

Table 3.8: Basic value of the behaviour factor, qo, for systems regular in elevation

Structural type	DCM	DCH
Frame system, dual system, coupled wall system	$3.0\alpha_u/\alpha_1$	$4.5\alpha u/\alpha 1$
Uncoupled wall system	3.0	$4.0\alpha u/\alpha 1$
Torsional flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

For buildings which multistory, multi-bay frames or frame-equivalent dual structures is $\alpha u/\alpha 1=1.3$ and the factor k_w is 1 for frame and frame-equivalent dual systems. For the structural systems conducted in this research for regular in both plan and elevation, the amounts of behavior factor are q=3*1.3*1=3.9. For non-regular in elevation buildings the decreased values of the behavior factor are given by the reference values multiplied by 0.8 is defined in the ES EN 1998-1/4.2.3.1(7) and Table 4.1). For the structural model systems conducted in this research for which is not regular in both plan and elevation behavior factor is q=3.12.

3.14 Data Analysis and Presentation

3.14.1 Data Analysis

Analysis was executed by ETABS 2016 vs 16.2.1. Equivalent static analysis and response spectrum analysis is adopted as a seismic analysis method. Complete Quadratic Combination (CQC) was used as modal combination technique because it accounts for modal damping and the most realist approach. Dead and live load assigned mass source with appropriate coefficient

3.14.2 Data Presentation

Result of this thesis is presented using tables, graphs and charts in terms of: Base shear, Shear force, Story drift and Story displacement.

CHAPTER FOUR

4. RESULT AND DISCUSION

4.1. Result and discussions of regular and irregular structural model building

4.1.1 Comparisons result of base shear

Base shear is maximum lateral force that will occur due to seismic ground motion at the base of structure. This base shear has been distributed to different floors of the building, as the height of the building increases more load acts on the top stories of the building. Base shear result obtained from ETABS is arranged for comparison based on the formula below according to ES EN 1998-1/ 4.3.3.2.2

$$F_b = S_d(T_1)*m*\lambda \tag{4.1}$$

Where:

F_b is seismic base shear force

S_d (T_1) is the ordinate of the design spectrum (see 3.2.2.5) at period T

T_1 is the fundamental period of vibration of the building for lateral motion in the direction considered

m is the total mass of the building, above the foundation or above the top of a rigid basement,

λ is the correction factor, the value of which is equal to: λ= 0.85

The result of base shear obtained from the equivalent static analysis and response spectrum analysis method of analyzed regular and irregular structural model of the multi-story building are plotted as shown in the figure 4.1 and 4.2.

Regular structural model has greater base shear than irregular building for both story 8 and 15 building. Base shear of combination irregularity is less than Singe irregularity. The result of base shear obtained by the response spectrum analysis is larger than the result that obtained by equivalent static analysis method for all cases of analyzed regular and irregular structural model and for both story 8 and 15 rise building. Generally, due to the occurrence irregularity of mass, stiffness and vertical geometric setback in structural frame system, total mass of building is reduced and base shear result irregular building is also reduce. Base shear along the long direction of plan (Y-direction) has greater base shear along the short direction of plan (X-direction) building by response spectrum analysis and equivalent static analysis except for story 15 building equivalent static analysis has equal base shear in X and Y-direction. Base shear of equivalent static analysis in the X and Y-direction is the same, but for the response spectrum maximum base shear is obtained in the X-direction along short direction of plan building.

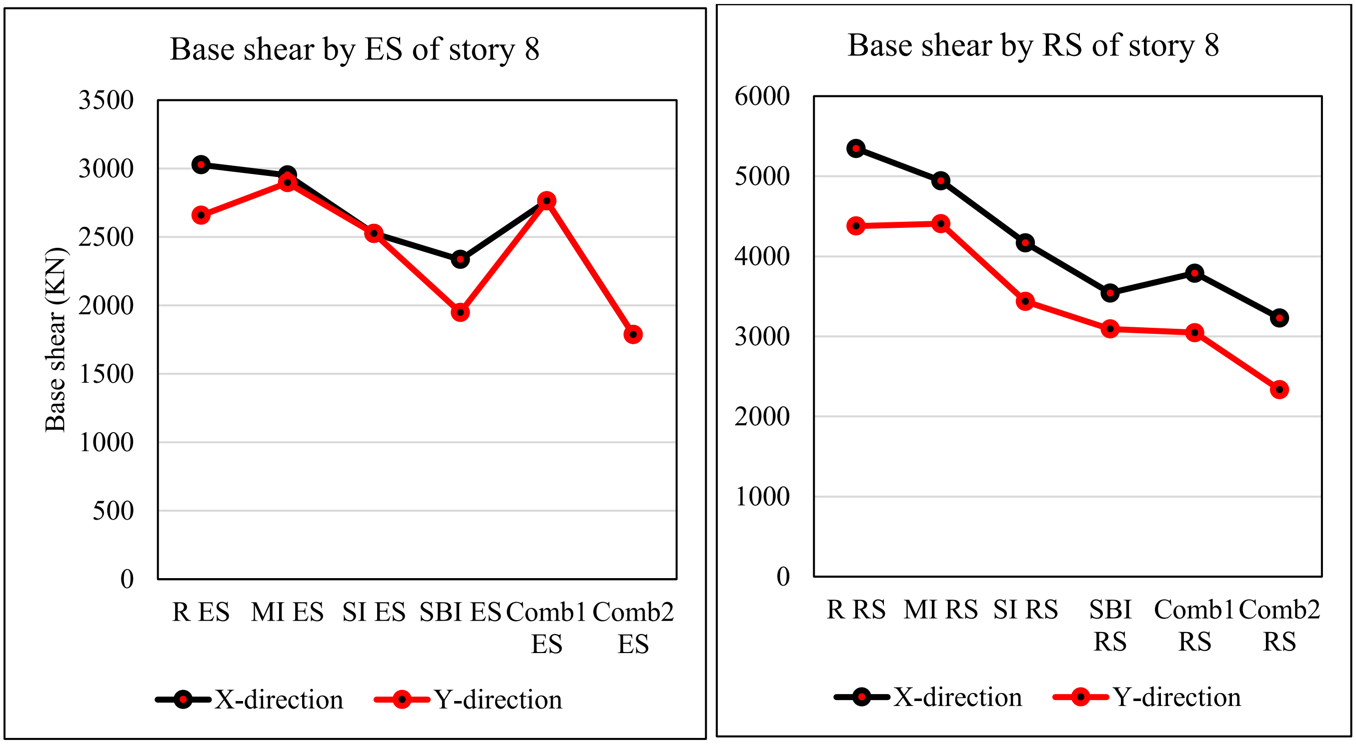


Figure 4.1: - Response of base shear for storey 8

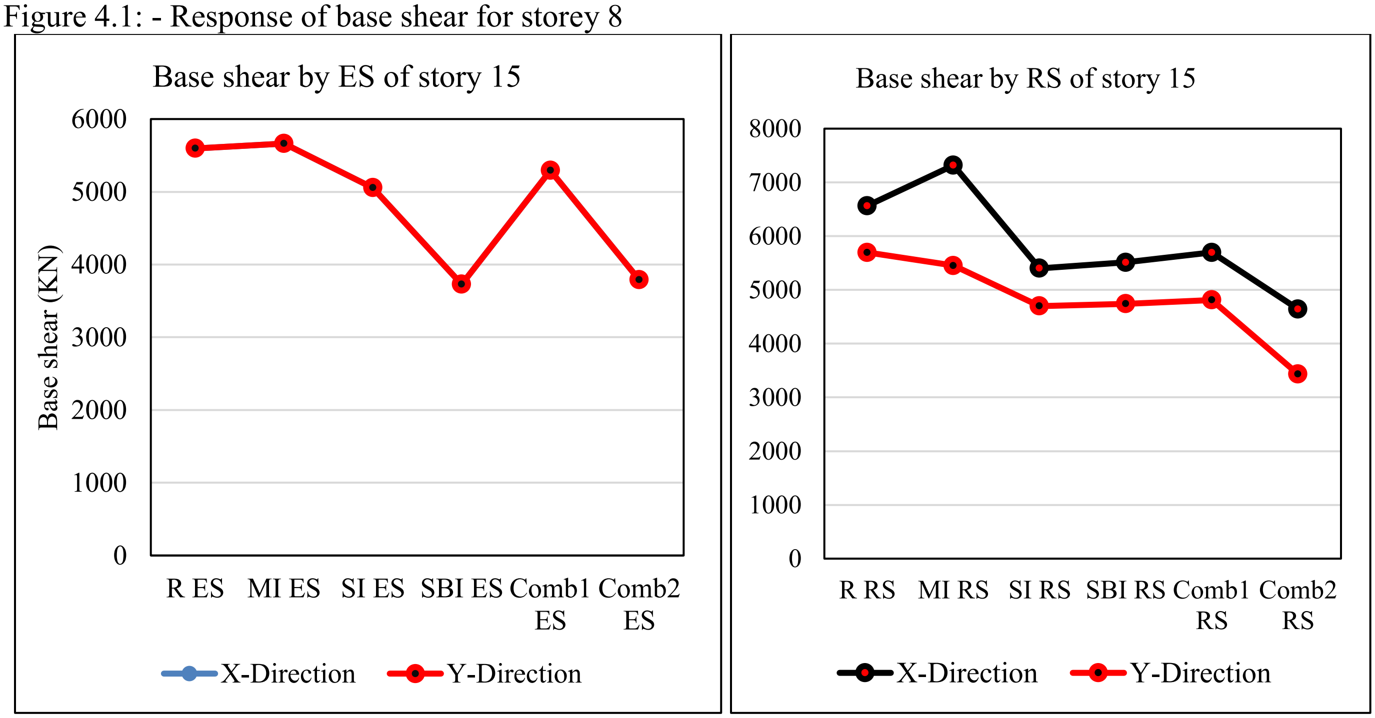


Figure 4.2: - Response of base shear for storey 15

4.2.2. Comparisons result of story shear force

Story shear is the graph showing how much lateral horizontal load like wind or seismic, is acting per story. The results of story shear obtained from the different behaviour of irregular multi-story building frames having single and combination of irregularities are plotted in the following figure 4.3 and 4.4 compared with respect to regular structural model of story 8 and story 15 building. The response of store shear obtained by response spectrum analysis greater than the result in equivalent static analysis in all studied irregularity cases. When the mass of the structure increase, base shear and story shear also increase. They have direct relationships. For vertical setback irregularity, maximum reduction result in story shear is observed at each setback irregularity occurred by the equivalent static analysis method. From all investigated structural model irregularity, except MI, the result of storey shears are reduced due to the uneven distributions of mass, stiffness, strength and geometric configuration in the internal body of structure in both methods of analysis. Reduction in storey shear of the irregular structure shows the capability of lateral resisting force is low under severe seismic earthquake.

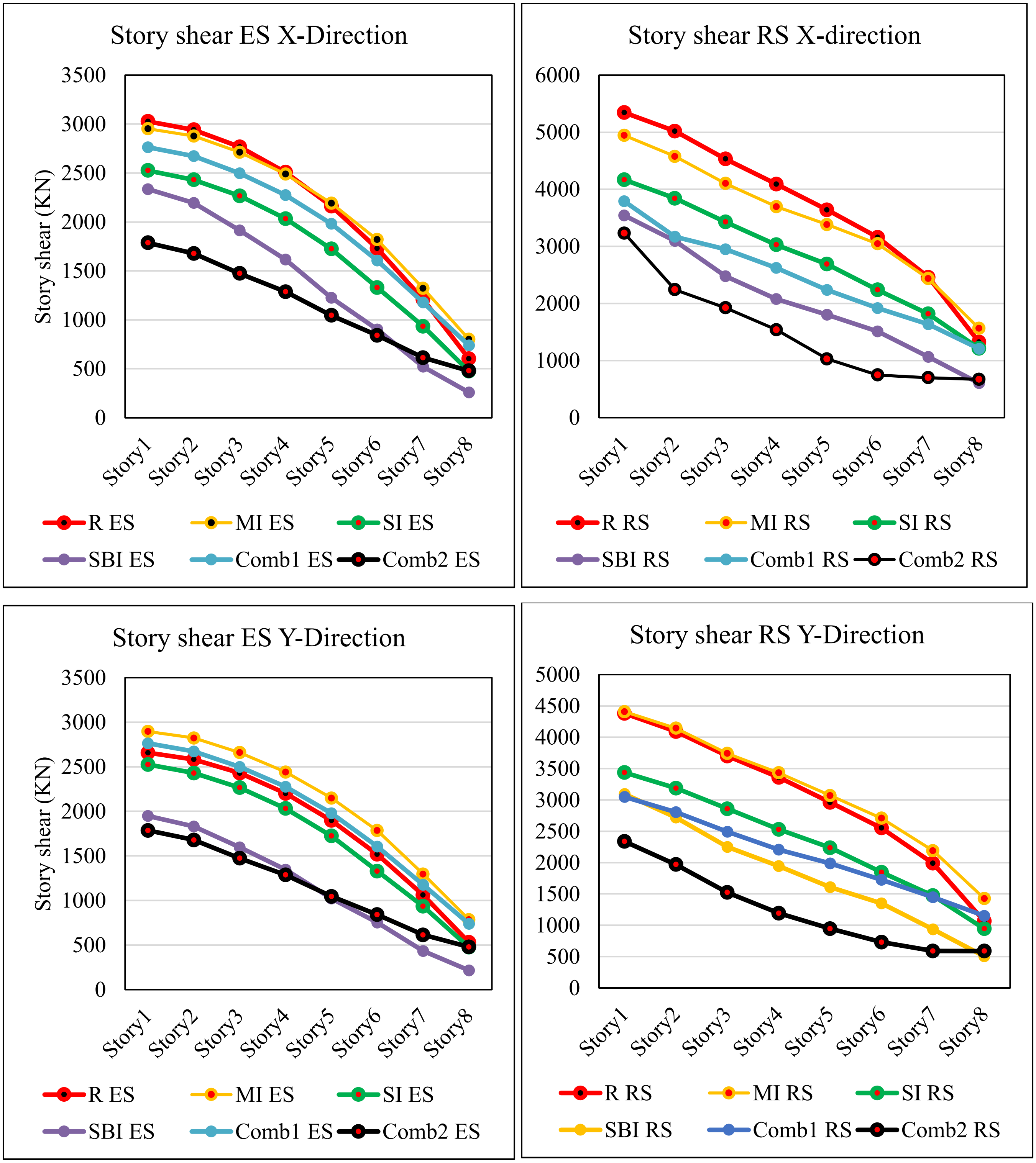


Figure 4.3: - Response of story shear for story 8 building in X and Y-direction

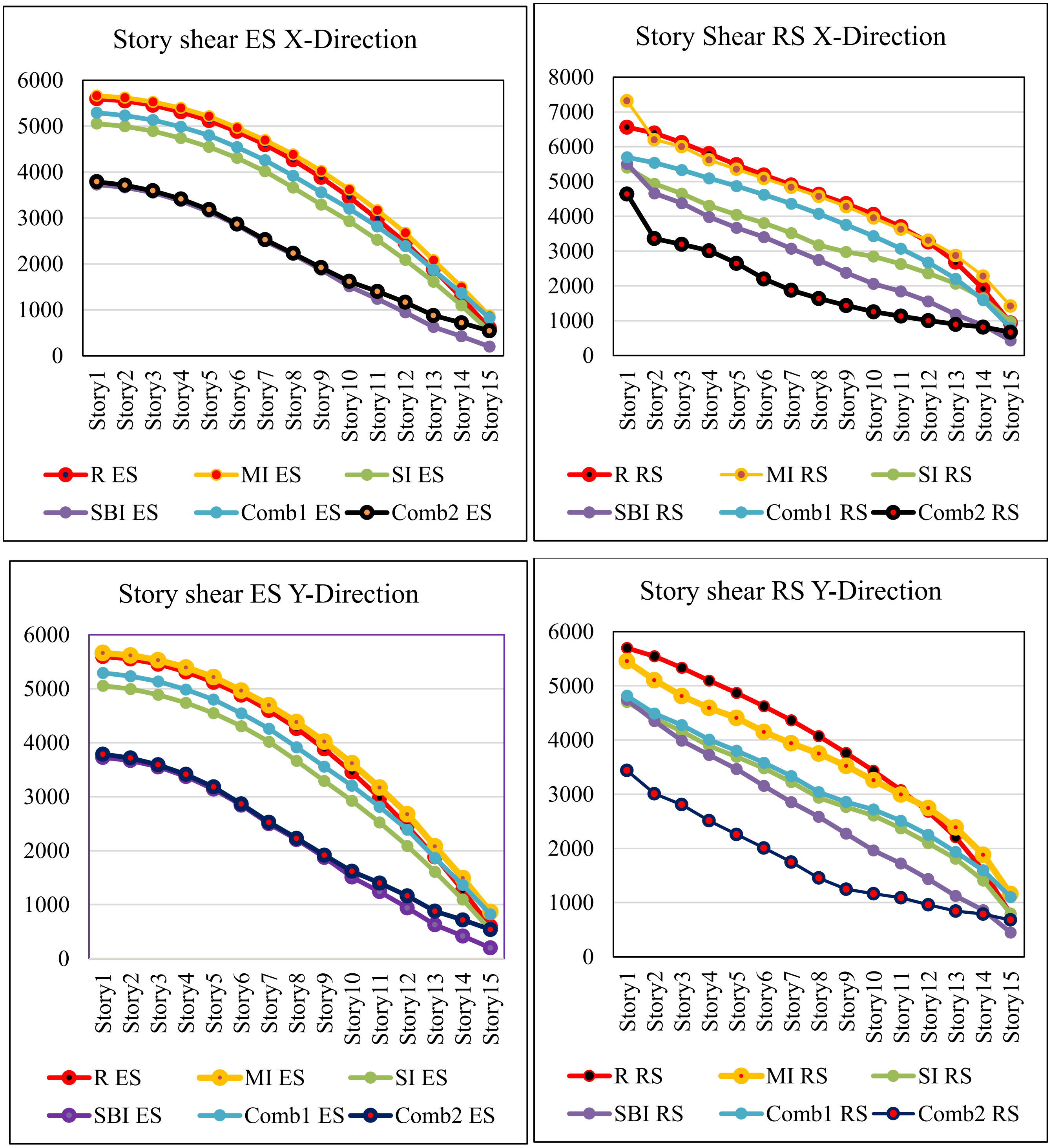


Figure 4.4: - Response of story shear for story 15 building in X and Y-direction

4.1.3 Comparisons result of storey drift

Story drift *dr* is evaluated as the difference of the average lateral displacements ds at the top and bottom of the story (ES EN 1998-1/4.4.2.2 (2)).

$$\text{Story drift ratio} = \left(\frac{d_{top-}d_{bottom}}{h}\right) \qquad 4.2$$

Where:

dtop is lateral displacement at top of the story

dbottom is lateral displacement at bottom of the story

h: is height of the story

The response of storey drift analysis obtained from different the behaviour of irregularity of multi-storey building having single and combination of irregularities are presented in the diagram by using equivalent static analysis (ES) and response spectrum analysis (RS) analysis method compared with that of a regular frame for both storey 8 and 15 building. The response of store drift obtained by response spectrum analysis greater than the result in equivalent static analysis for story 8 building irregularity cases. But for story 15 building maximum result of story drift obtained in the equivalent static analysis is greater than response spectrum analysis. Combination irregularity has maximum story drift than singular irregularity, especially the value of comb 2 irregularity extremely high. The sequence of increased story drift from singular to combination irregularity of analysed irregularity are R<SBI<MI<SI<Comb1<Comb2 building.

Larger story drift is starts to increase for the case of SI, Comb1 and Comb 2 irregularity at the 5^{th}-8^{th} and storey 8^{th} -15^{th} storey floor level, where at abruptly change of lateral stiffness and maximum irregularity occurred for both storey 8 and 15 building respectively. Combination irregularity more affected and low performance under severe seismic earthquake load as shown from result plotted on the below figure 4.3 and -4.4.

Geometric configuration setback irregularity have less response in storey drift are observed with compared to the regular structural model in both methods of analysis. The result of story drift in the Y-direction along long direction of plan building is greater than the story drift obtained in the X-direction short direction plan of building, this means X direction may be stiffer than Y direction.

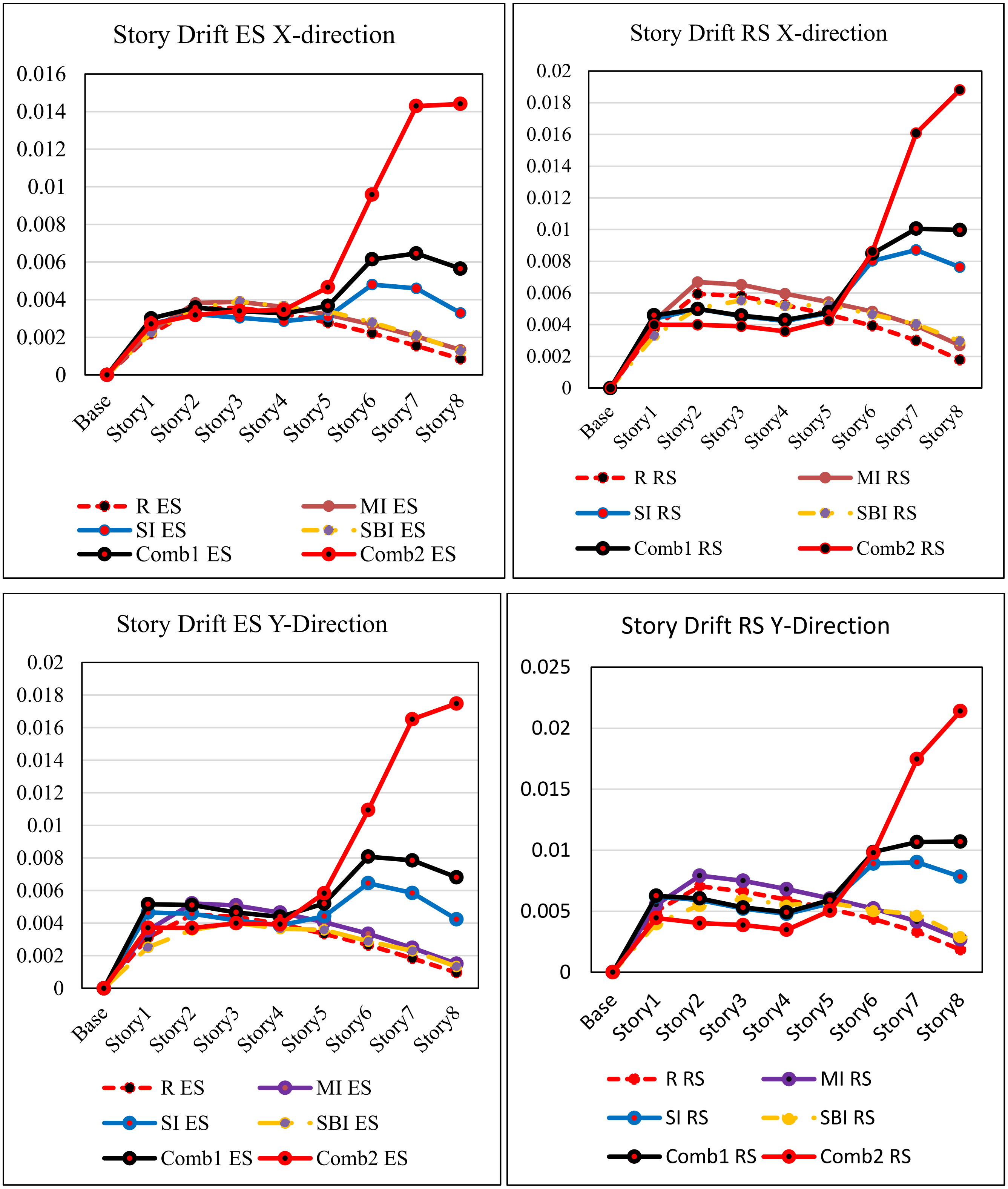


Figure 4.5: - Response of story drift for story 8 building in X-direction and Y-direction

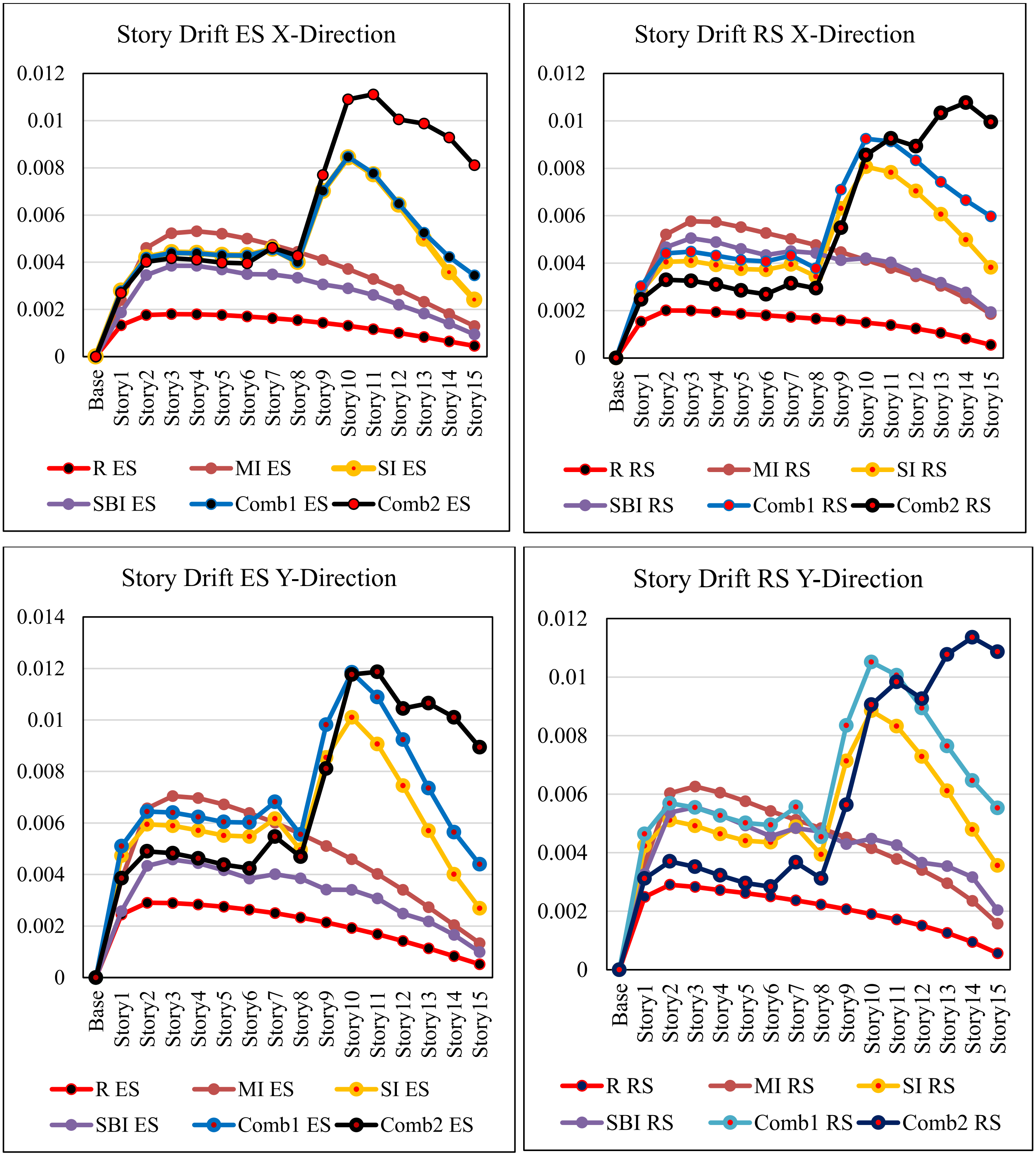


Figure 4.6: - Response of story drift for story 15 building in X and Y-direction

4.1.4. Comparisons result of maximum story displacement

The response of story displacement is obtained from the analysis of different behaviour of irregular multi-story building frames having single and combination irregularities are presented by diagram with compared regular structural model frame building. Figure 4.7 and figure 4.8 represents the structural response of story displacement of analyzed model by using equivalent static analysis and response spectrum analysis method for both story 8 and 15 building respectively. The response of story displacement obtained by story 8 building by response spectrum analysis greater than the result obtained by using equivalent static analysis in all studied except Comb 2 irregularity cases. But for high rise building story 15 model the story displacement of equivalent static analysis is greater than the displacement of response spectrum analysis method. Irregular building has greater story displacement than regular building.

Combination irregularity has greater story displacement than singular irregularity, especially Comb 2 irregularity has extreme story displacement. The sequence of increasing of story displacement of analyzed irregularity are the displacement of R<SBI<MI<SI<Comb1<Comb2 building for both method of analysis and for both story 8 and 15 building. Story displacement is maximum along X-direction of short direction of plan building of story 8 and 15 building. Maximum story displacement is obtained at the irregularity occurred in the internal body structure where stiffness and mass of lateral resisting force system reduced from story 5^{th} -8^{th} and 8^{th}-15^{th} for story 8 and 15 building respectively. SBI has less story displacement compared to regular structural model one. Story displacement story 8 building is less than story 15 building.

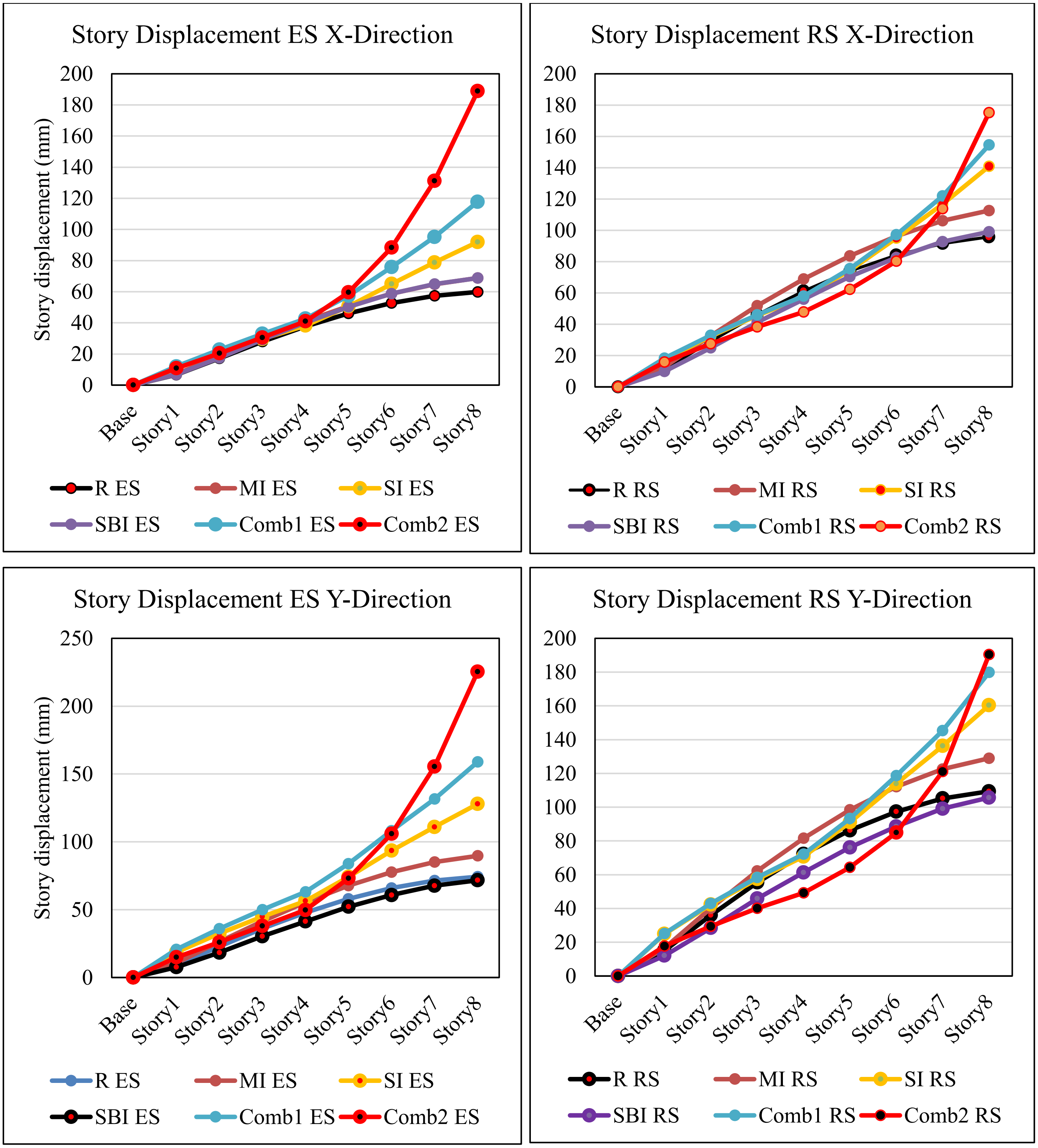


Figure 4.7: - Response of storey displacement for story 8 X and Y-direction

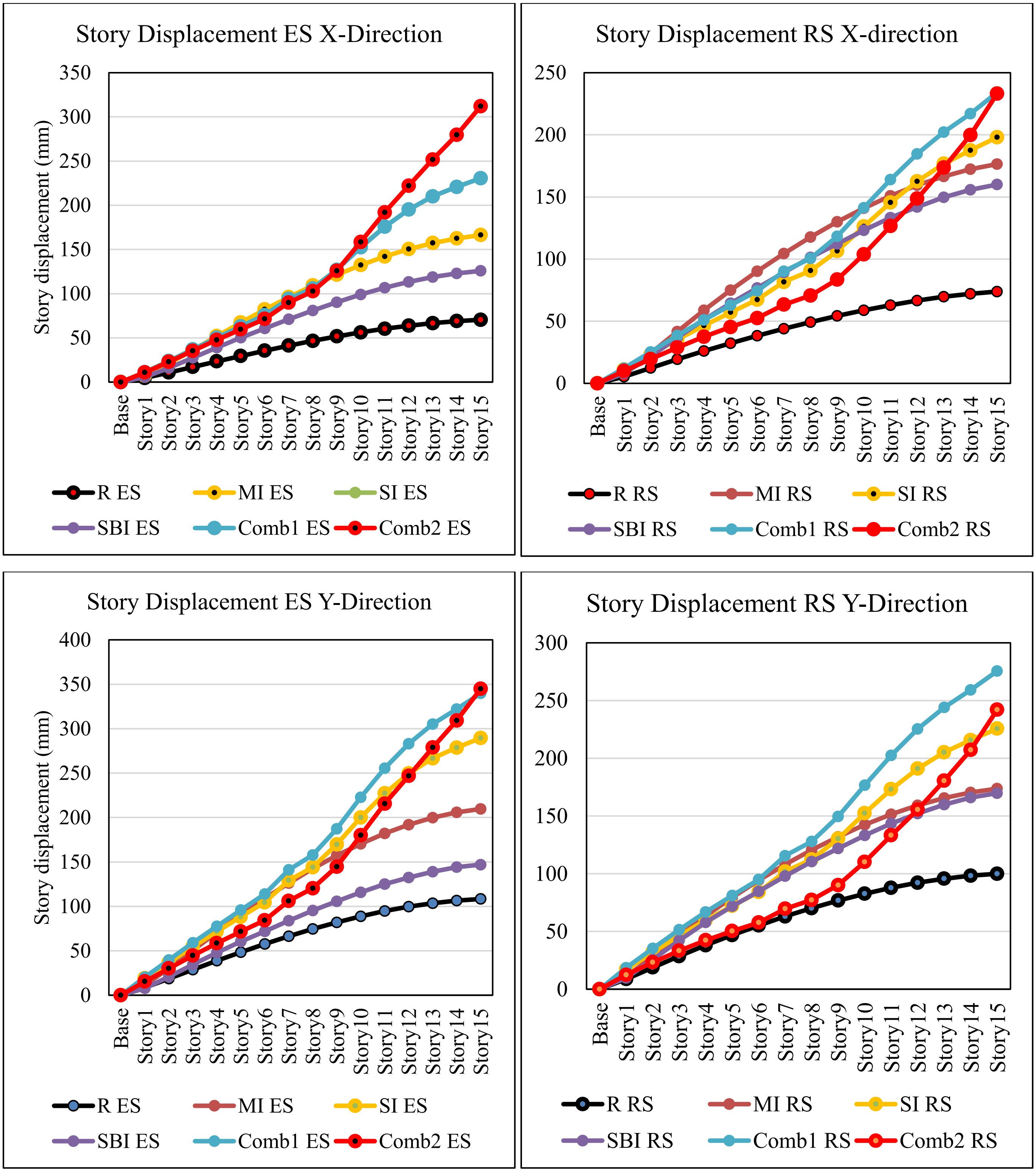


Figure 4.8: - Response of storey displacement for storey 15 in X and Y-direction

4.2. Result mode of vibration periods and effective modal mass participation

For analyzed different behaviour of the irregular structural model, the results of fundamental natural periods are compared to the regular structural model. The natural periods of the building of storey 8 are less than the natural periods of building storey 15. Setback irregularity has minimum vibration time periods with compared to the vibration periods of regular structural model for both storey 8 and 15 building. Vibration periods of analyzed irregular structural buildings are increased from SBI<R<MI<SI<Comb1< Comb2 building. Time periods of irregular multi-storey buildings increase with the increase storey height of the building. Buildings tend to oscillate in the directions in which they are most flexible and have larger translational natural periods. Modal periods of buildings mainly depend upon building properties mass, stiffness, strength, storey height, and number of storeys and location of irregularity. Fundamental natural period of building calculated according to formula of ES EN 1998-1:2015 is almost similar with analysis software output. The response of time period investigated regular and irregular structural model are summarized in table 4.1 and 4.2 for story 8 and 15 building respectively.

Table 4.1:- Mode of vibration of regular and irregular of structrular model story 8 building

mode vibration periods (Tn)	Regular	Mass irregular	Stiffness irregular	Setback irregular	Comb 1irregular	Comb 2 irregular
T1	2.118	2.278	2.517	1.592	2.817	2.893
T2	1.704	1.886	2.018	1.328	2.364	2.414
T3	1.653	1.712	1.946	0.899	2.029	1.411
T4	0.686	0.728	1.093	0.645	1.197	1.246
T5	0.545	0.58	0.879	0.512	0.993	1.045
T6	0.394	0.469	0.727	0.407	0.872	0.857
T7	0.305	0.413	0.633	0.332	0.676	0.706
T8	0.227	0.3	0.497	0.252	0.459	0.483
T9	0.169	0.251	0.365	0.226	0.375	0.388
T10	0.151	0.232	0.279	0.171	0.332	0.366
T11	0.142	0.183	0.168	0.14	0.265	0.271
T12	0.08	0.11	0.095	0.089	0.127	0.133

Table 4.2:- Mode of vibration of regular and irregular of structrular model story 15 building

mode vibration periods (Tn)	Regular	Mass irregular	Stiffness irregular	Setback irregular	Comb 1irregular	Comb 2 irregular
T1	3.308	3.693	3.767	2.505	4.01	3.446
T2	2.765	3.156	3.197	2.147	3.482	2.957
T3	2.651	2.867	3.033	1.496	3.169	1.877
T4	1.072	1.191	1.52	1.01	1.599	1.602
T5	0.886	1.005	1.285	0.854	1.375	1.419
T6	0.806	0.926	1.237	0.767	1.282	1.225
T7	0.622	0.674	0.852	0.601	0.912	0.974
T8	0.499	0.555	0.717	0.482	0.782	0.815
T9	0.414	0.451	0.605	0.418	0.639	0.765
T10	0.304	0.395	0.493	0.342	0.541	0.641
T11	0.223	0.35	0.335	0.257	0.353	0.413
T12	0.199	0.25	0.277	0.204	0.344	0.356
T13	0.175	0.229	0.218	0.187	0.289	0.334
T14	0.156	0.212	0.179	0.15	0.224	0.211
T15	0.086	0.15	0.098	0.1	0.142	0.129

The basic modal properties of the regular and irregular building are summarized in Table 4.3. The effective masses indicate that the first mode is predominantly translational in the X direction, the second mode is translational in the Y direction and the third mode is predominantly torsional. In the modal response spectrum analysis 12 and 15 modes of vibration were taken for story 8 and 15 building structural model respectively in order to get sufficient to satisfy the requirements in ES EN 1998-1/4.3.3.3 (3) the sum of the effective modal masses amounts to at least 90% of the total mass. Most of them are satisfy the requirements of ES EN 1998-1/4.3.3.3 (3) at 12 modes. Irregular building has higher natural periods than regular building and also increase with story height of building. ES EN 1998-1 codes require 90% of modal mass participation to capture the overall response of the system. But for comb 1 and 2 analyzed irregular structure does not fulfill this criteria at all.

Table 4.3:-Percentage result of effective modal mass participation factor for story 8 and 15

		story 8			story 15		
	static	dynamic response spectrum			dynamic response spectrum		
		Sum UX	Sum UY	Sum UZ	Sum UX	Sum UY	Sum UZ
R	100	99.53	99.71	94.86	98.87	99.36	95.59
MI	100	98.14	99.66	87.96	98.87	99.28	91.25
SI	100	99.42	99.67	93.58	98.64	98.89	99.49
SBI	100	99.64	99.97	90.7	97.8	99.31	91.23
Comb 1	100	98.32	99.62	82.5	98.96	99.47	89.85
Comb 2	100	97.41	99.33	80.49	97.65	99.32	88.64

4.3. Mode shape and Determination of fundamental periods of vibration *T*1 according to formula of ES EN 1998-1

The Regular buildings have three basic modes of oscillation, namely, pure translational along X-direction, pure translational along Y-direction and pure rotation about Z-axis, but, irregular buildings has mode shapes that are a mixture of these pure mode shapes. The three fundamental periods of vibration of the building considering the cracked elements sections amount are summarized in the following section 4.3.1 and 4.3.2 for building storey 8 and 15 respectively. Each of these mode shapes is independent, implying, it cannot be obtained by combining any or all of the other mode shapes. The overall response of a building is the sum of the responses of all of its modes. The contributions of different modes of oscillation vary; usually, contributions of some modes dominate. Generally, Low strengthening buildings have a high natural fundamental period. But, high strengthening or regular buildings have smaller natural period. Determination of the fundamental period of vibration T_1 of the building, expressions based on methods of structural dynamics (for example the Rayleigh method) may be used according to ES EN 1998-1/ 4.3.3.2.2 (2P).

$$T_1=2\pi\sqrt{\frac{\sum_{i=1}^{n}(m_i * s_i^2)}{\sum_{i=1}^{n}(f_i * s_i)}} \qquad 4.3$$

Where n-number of story

mi- story massess above rigid basement

Si- displacements of masses

Fi- horizontal story force

4.3.1 Determination of fundamental periods of vibration $T1$ for story 8 structural model

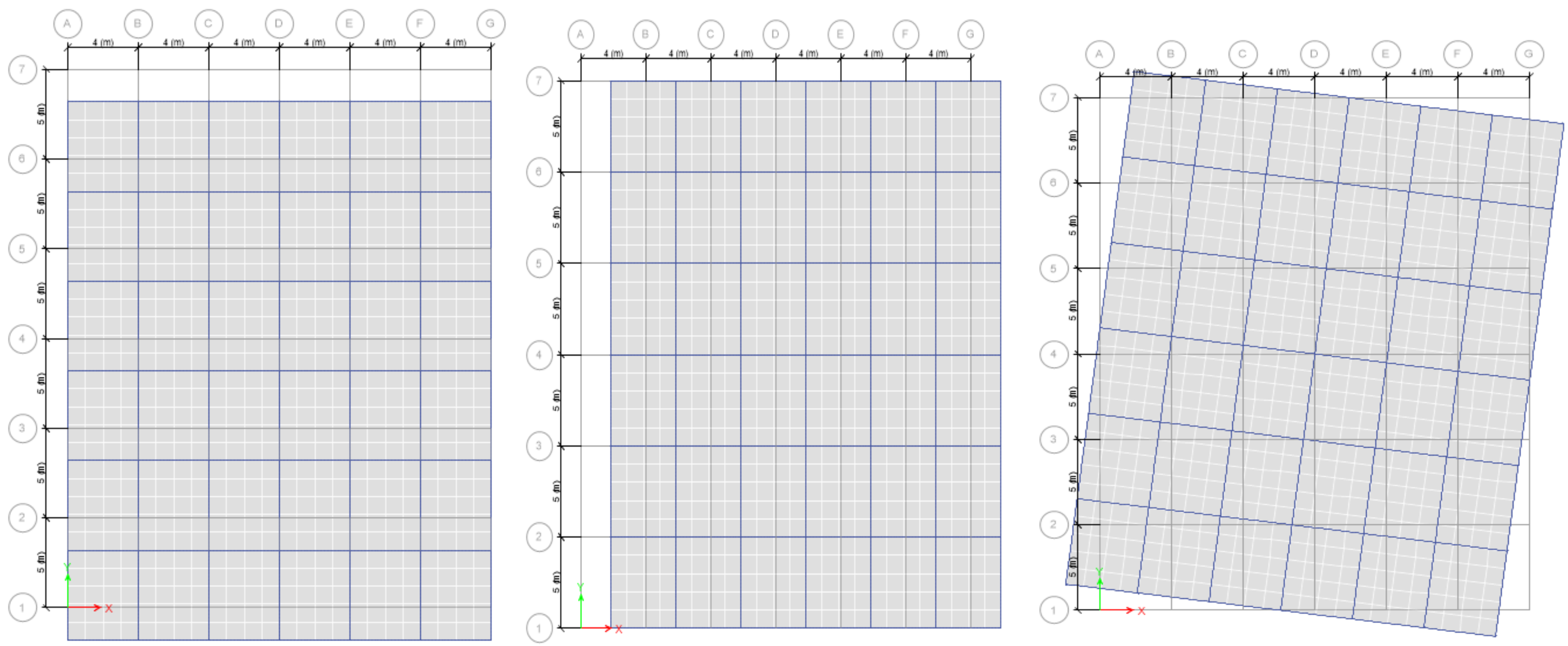
1. Determination of mode shape and fundamental vibration periods of T1 for regular structural model of story 8 building

Table 4.4 quantity of mass, story force and displacement for regular structural model of story 8 building

	Masses (ton)		Story force (KN)		Displacement (mm)					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	$M_x*S_{ix}^2$	$M_y*S_{iy}^2$	$f_{ix}*S_{ix}$	$f_{iy}*S_{iy}$
1	749.80	749.80	597.88	529.63	0.05	0.07	2.04	3.71	27.62	37.24
2	860.84	860.84	600.62	532.06	0.05	0.07	2.14	3.92	26.50	35.93
3	860.84	860.84	514.82	456.05	0.05	0.06	1.80	3.34	20.84	28.41
4	860.84	860.84	429.02	380.04	0.04	0.05	1.37	2.58	15.16	20.82
5	860.84	860.84	343.21	304.04	0.03	0.05	0.92	1.76	9.91	13.76
6	860.84	860.84	257.41	228.03	0.02	0.03	0.50	1.00	5.50	7.78
7	860.84	860.84	171.61	152.02	0.01	0.02	0.19	0.41	2.26	3.30
8	860.84	860.84	85.80	76.01	0.01	0.01	0.03	0.07	0.43	0.67
						∑=	8.98	16.79	108.22	147.90

Fundamental periods of vibration T1 of regular structural model story 8 according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=1.8055s and T1y=2.116s. From the result analysis of ETABS software is mode 1 periods 2.118s and mode 2 periods 1.704s. The fundamental periods of vibration T1 result obtained from the formula of ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software have not much difference.

The first three mode shape of vibration periods of regular structural model of story 8 building



Mode 1 periods T=2.118s — 1st mode of vibration pure in Y-direction

Mode 2 periods T=1.704s — 2nd mode of vibration pure in X-direction

Mode 3 periods T=1.653s — 3rd mode of vibration torsional

Figure 4.9 mode shape of regular structrular model of story 8 builing

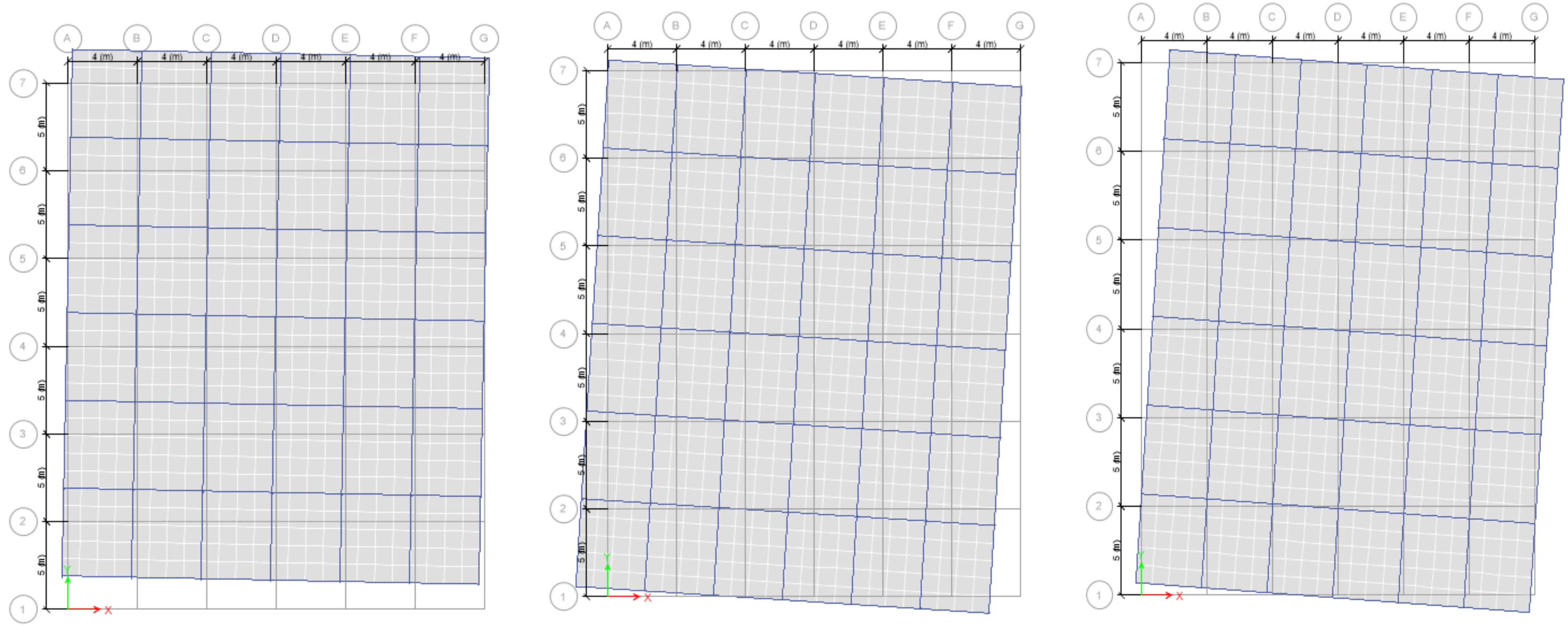
2. Determination of fundamental periods of vibration T1 for mass irregular structural model

Table 4.4 quantity of mass, story force and displacement of mass irregularity of story 8 building

	Masses (ton)		Story force (KN)		Displacement (mm)					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	$Mx*six^2$	$My*siy^2$	fix*six	fiy*siy
1	1157.6838	1157.6838	800.4743	785.1118	0.0564	0.0818	3.6831	7.7528	44.2834	64.2488
2	860.8444	860.8444	520.8230	510.8275	0.0499	0.0757	2.1410	4.9305	25.4755	38.6594
3	959.9608	959.9608	497.8198	488.2658	0.0454	0.0693	1.9826	4.6135	22.1897	33.8490
4	860.8444	860.8444	372.0164	364.8768	0.0394	0.0605	1.3374	3.1559	14.3820	22.0926
5	860.8444	860.8444	297.6131	291.9014	0.0321	0.0498	0.8850	2.1333	9.3592	14.5311
6	860.8444	860.8444	223.2098	218.9261	0.0237	0.0374	0.4819	1.2030	5.1800	8.1841
7	959.9608	959.9608	165.9399	162.7553	0.0146	0.0237	0.2033	0.5411	2.3686	3.8641
8	860.8444	860.8444	74.4033	72.9754	0.0055	0.0097	0.0264	0.0807	0.4043	0.7067
						∑=	10.7408	24.4108	123.6427	186.1359

Fundamental periods of vibration T1 according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=1.850 and T1y=2.274. From the result analysis of ETABS software is mode 1 periods 2.274s and mode 2 periods 1.886s. The fundamental periods of vibration T1 result obtained from the formula of ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software have almost similar result.

The first three mode shape of vibration periods of mass irregular structural model of story 8 building



Mode 1 periods T1=2.274s
1st mode of vibration is not pure Y-direction

Mode 2 periods T1=1.886s
2nd mode of vibration is not pure X-direction

Mode 3 periods T1=1.712s
3rd mode of vibration torsional

Figure 4.10 mode shape of mass irregular structrular model of story 8 builing

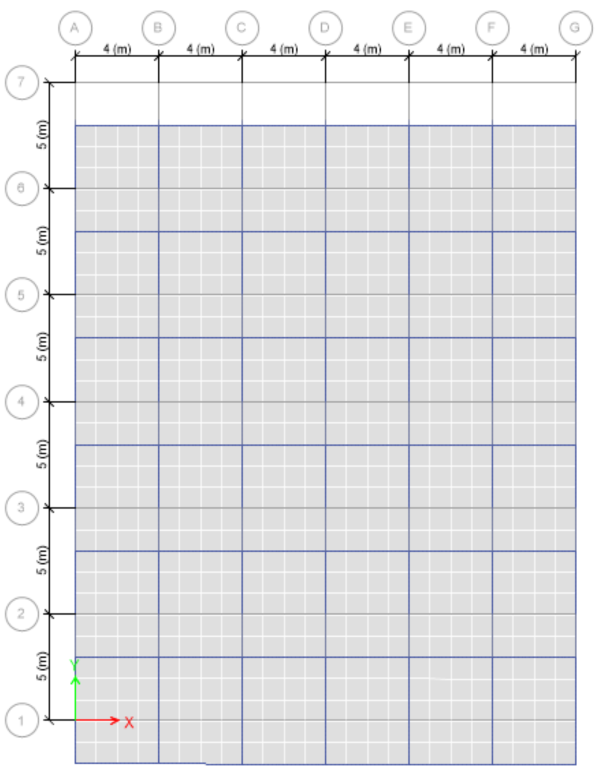
3. Determination of fundamental periods of vibration T1 for stiffness irregular structural model

Table 4.5 quantity of mass, story force and displacement of stiffness irregularity of story 8 building

	Masses (ton)		Story force (KN)		Displacement (mm)					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	$Mix*six^2$	$Miy*siy^2$	fix*six	fiy*siy
1	647.2776	647.2776	474.5947	474.5947	0.079228	0.11962	4.0630107	9.2618592	37.6011889	56.771018
2	735.83995	735.83995	459.5997	459.5997	0.067802	0.10395	3.3827381	7.951194	31.1617789	47.7753888
3	728.34504	728.34504	395.5813	395.5813	0.055923	0.087654	2.2778131	5.5960379	22.122093	34.6742833
4	853.3495	853.3495	393.953	393.953	0.043526	0.069593	1.6166814	4.1329301	17.1471983	27.4163711
5	875.83424	875.83424	309.196	309.196	0.032873	0.053028	0.9464564	2.4628185	10.1642001	16.3960455
6	860.84441	860.84441	233.7724	233.7724	0.02547	0.0422	0.5584478	1.5330262	5.95418303	9.86519528
7	860.84441	860.84441	163.6407	163.6407	0.017614	0.030504	0.2670796	0.8010106	2.88236729	4.99169591
8	875.83424	875.83424	95.1372	95.1372	0.009293	0.017607	0.0756369	0.2715143	0.88411	1.67508068
						∑=	13.187864	32.010391	127.917119	199.565079

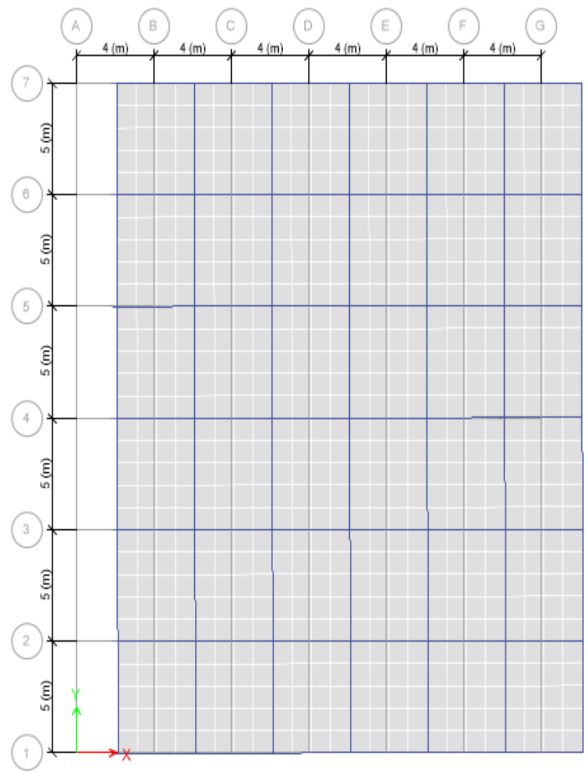
Fundamental periods of vibration T1 of stiffness irregularity according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=2.064 and T1y=2.515. From the result analysis of ETABS software is mode 1 periods 2.515s and mode 2 periods 2.064s. The fundamental periods of vibration T1 result obtained from the formula of ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software have almost similar result.

The first three mode shape of vibration periods of stiffness irregular structural model of story 8 building



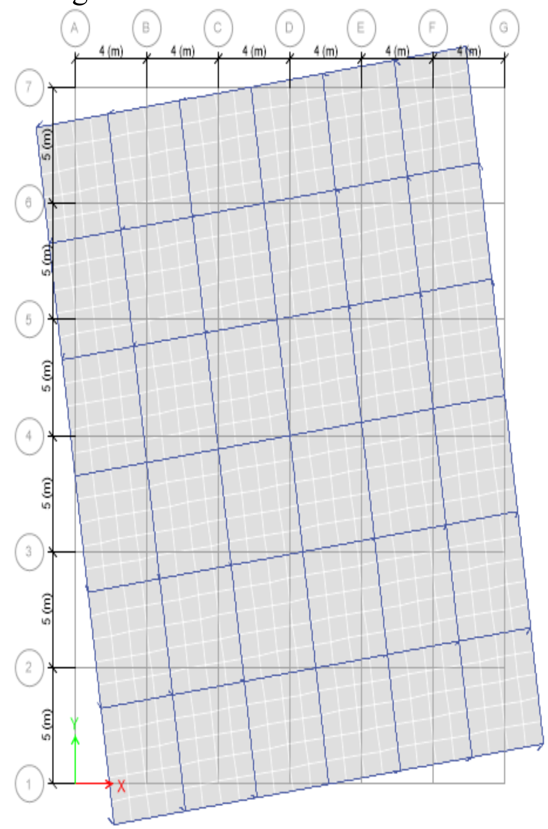
Mode 1 periods T1=2.515s

1st mode of vibration is negative pure Y-direction



Mode 2 periods T1=2.064s

2nd mode of vibration is pure X-direction



Mode 3 periods T1=1.946s

3rd mode of vibration torsional

Figure 4.11 mode shape of stiffness irregular structrular model of story 8 building

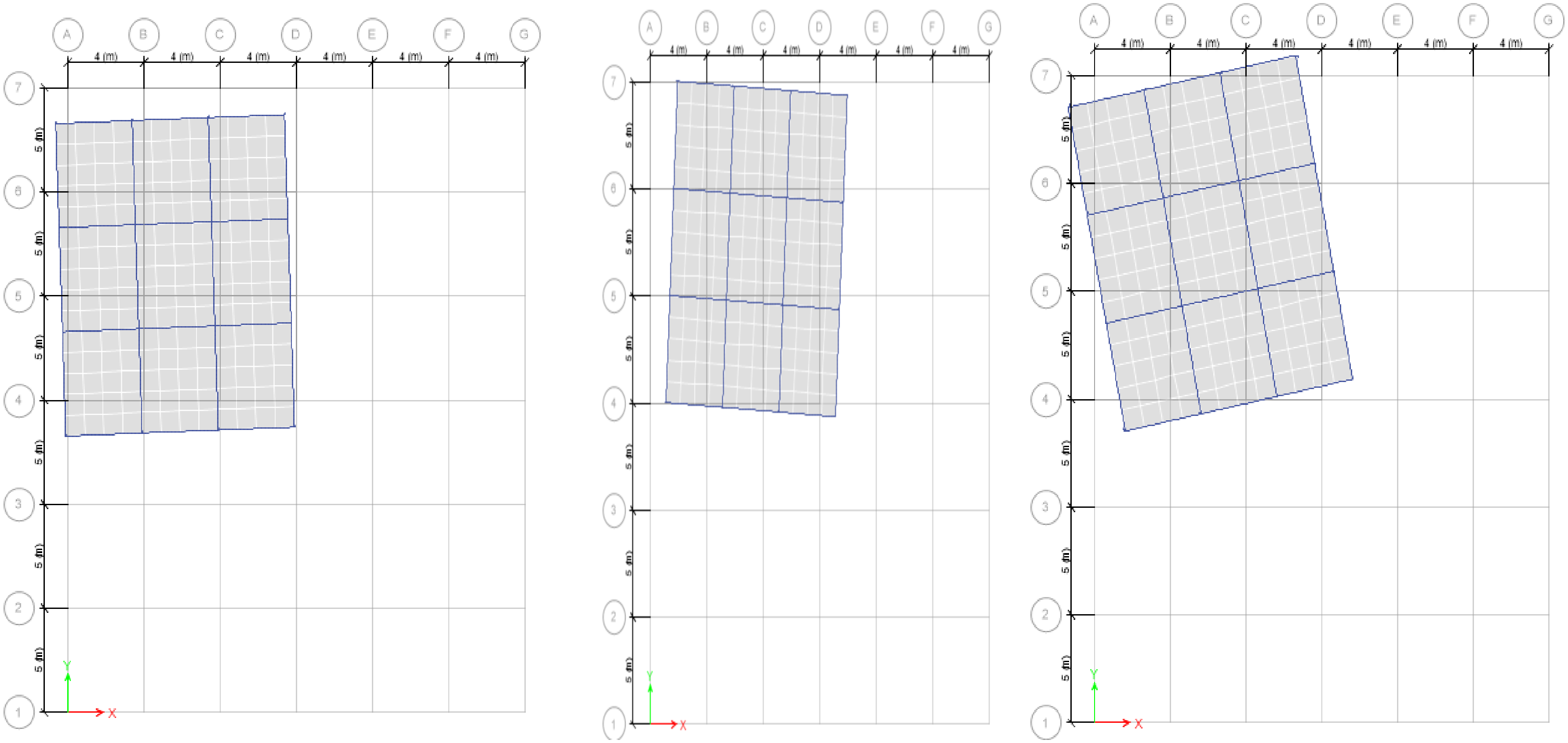
4. Determination of fundamental periods of vibration T1 for setback irregular structural model

Table 4.6 quantity of mass, story force and displacement of setback irregularity of story 8 building

	Masses (ton)		Story force (KN)		Displacement (mm)					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	**Mix*six²**	**Miy*siy²**	**fix*six**	**fiy*siy**
1	196.39734	196.39734	258.5735	215.6635	0.052639	0.065198	0.5441904	0.8348417	11.352311	14.0608289
2	227.60065	227.60065	262.1983	218.6868	0.049307	0.061446	0.5533382	0.8593315	10.78279	13.4374291
3	385.14681	385.14681	380.3084	317.1967	0.042461	0.053207	0.6943952	1.0903448	13.4684891	16.8770848
4	393.40651	393.40651	323.7203	269.9993	0.036114	0.045564	0.513089	0.8167426	9.75075472	12.3022481
5	594.39257	594.39257	391.2837	326.3506	0.027217	0.03485	0.4403053	0.7219032	8.88228428	11.3733184
6	604.48776	604.48776	298.4469	248.92	0.019689	0.025625	0.2343337	0.3969312	4.90098588	6.378575
7	848.91373	848.91373	279.4164	233.0476	0.011032	0.014938	0.1033171	0.1894299	2.57098112	3.48126505
7	860.84441	860.84441	141.6717	118.1614	0.004284	0.006244	0.0157988	0.0335622	0.50620344	0.73779978
						∑=	3.0987677	4.9430871	62.2147995	78.6485491

Fundamental periods of vibration T1 of setback irregularity according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=1.40 and T1y=1.574. From the result analysis of ETABS software is mode 1 periods 1.592s and mode 2 periods 1.328s. The fundamental periods of vibration T1 result obtained from the formula of ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software have almost similar result.

The first three mode shape of vibration periods of setback irregular structural model of story 8 building



Mode 1 periods T1=1.592s — 1st mode of vibration is not pure Y-direction

Mode 2 periods T1=1.328s — 2nd mode of vibration is not pure X-direction

Mode 3 periods T1=0.899s — 3rd mode of vibration torsional

Figure 4.12 mode shape of setback irregular structrular model of story 8 builing

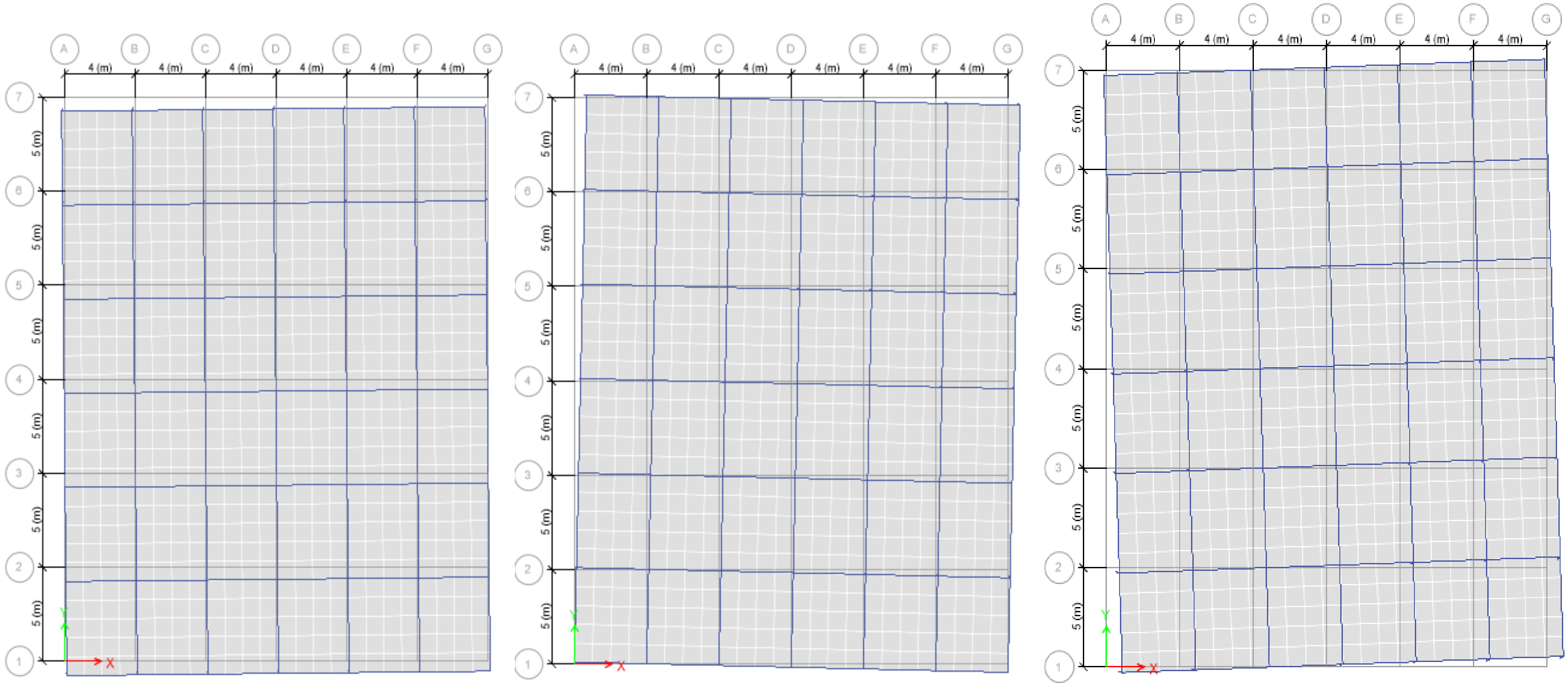
5. Determination of fundamental periods of vibration T1 for Comb 1 irregular structural model

Table 4.7 quantity of mass, story force and displacement of comb 1 irregularity of story 8 building

	Masses (ton)		Story force (KN)		Displacement (mm)					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	**Mix*six²**	**Miy*siy²**	**fix*six**	**fiy*siy**
1	588.07033	588.07033	737.8855	737.8855	0.108246	0.15263	6.8905356	13.699638	79.8731538	112.623464
2	205.30711	205.30711	438.3454	438.3454	0.086018	0.125634	1.5190871	3.2405473	37.7055946	55.071086
3	394.94564	394.94564	428.6304	428.6304	0.066945	0.102301	1.7700014	4.1333015	28.6946621	43.8493186
4	414.39227	414.39227	375.7345	375.7345	0.051058	0.079766	1.0802872	2.6366184	19.1842521	29.9708381
5	646.0004	646.0004	294.8971	294.8971	0.037019	0.059379	0.8852831	2.2777106	10.9167957	17.5106949
6	634.98747	634.98747	222.9615	222.9615	0.02857	0.047068	0.5183053	1.4067491	6.37001006	10.4943519
7	959.96082	959.96082	174.0431	174.0431	0.019214	0.033639	0.3543962	1.0862747	3.34406412	5.85463584
7	875.83424	875.83424	90.7376	90.7376	0.010126	0.0194	0.0898044	0.329629	0.91880894	1.76030944
						∑=	13.1077	28.810468	187.007342	277.134699

Fundamental periods of vibration T1 comb 1 irregularity according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=1.66 and T1y=2.025. From the result analysis of ETABS software is mode 1 periods 2.817s and mode 2 periods 2.364s. The fundamental periods of vibration T1 result obtained from the formula of ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software have great diffirence result.

The first three mode shape of vibration periods of comb 1 irregular structural model of story 8 building



Mode 1 periods T=2.817s — 1st mode of vibration is not pure Y-direction

Mode 2 periods T=2.364s — 2nd mode of vibration is not pure X-direction

Mode 3 periods T=2.029s — 3rd mode of vibration torsional

Figure 4.13 mode shape of comb 1 irregular structrular model of story 8 building

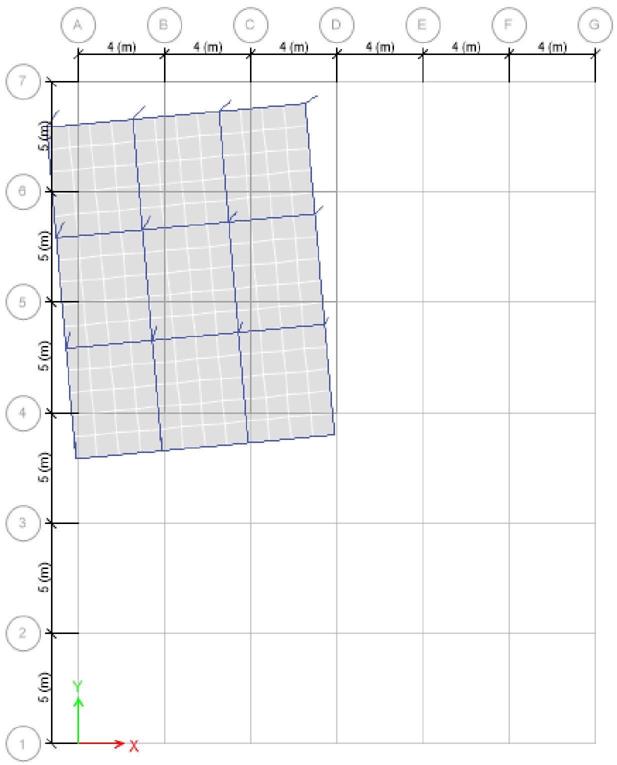
6. Determination of fundamental periods of vibration T1 for Comb 2 irregular structural model

Table 4.8 quantity of mass, story force and displacement of comb 2 irregularity of story 8 building

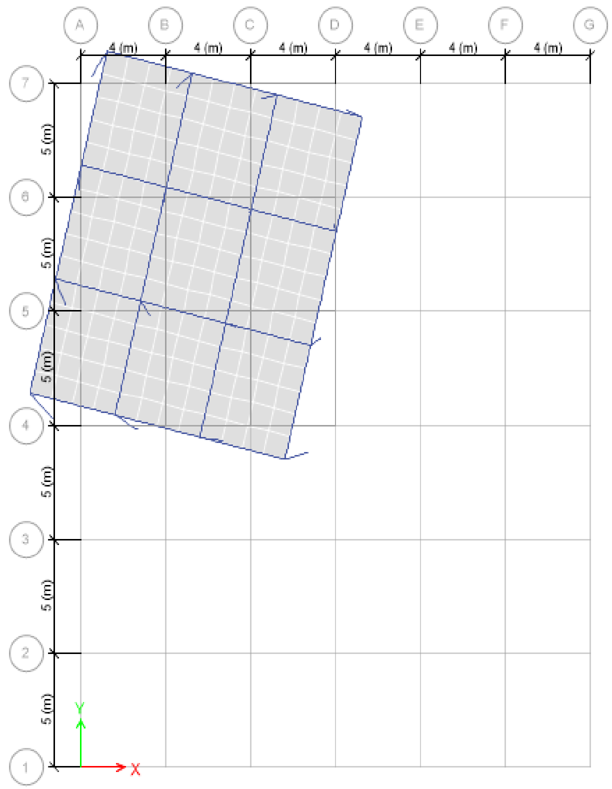
	Masses (ton)		Story force (KN)		Displacement (mm)					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	**Mix*six²**	**Miy*siy²**	**fix*six**	**fiy*siy**
1	572.71723	572.71723	846.8504	477.8418	0.302957	0.199443	52.565673	22.781265	144.765518	95.3022021
2	187.31549	187.31549	235.9414	133.1318	0.19062	0.132706	6.8062927	3.2987911	25.3775837	17.6673887
3	365.0329	365.0329	399.8202	225.6016	0.114541	0.08855	4.7891005	2.8622604	25.8406329	19.9770217
4	387.00141	387.00141	360.2999	203.302	0.072683	0.061033	2.0444582	1.4415907	14.7765993	12.408131
5	602.04044	602.04044	428.6193	241.8517	0.046439	0.04021	1.2983488	0.9734055	11.2313511	9.72485686
6	604.48776	604.48776	331.0474	186.796	0.034969	0.030892	0.7391863	0.5768721	6.53206932	5.77050203
7	948.03014	948.03014	363.4318	205.0691	0.021231	0.020505	0.4273297	0.398604	4.35382206	4.2049419
7	875.83424	875.83424	191.8601	108.2585	0.011262	0.011925	0.1110844	0.1245486	1.21920723	1.29098261
						∑=	68.781474	32.457338	234.096784	166.346027

Fundamental periods of vibration T1 according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=2.41 and T1y=2.784. From the result analysis of ETABS software is mode 1 periods 2.893s and mode 2 periods 2.414s. The fundamental periods of vibration T1 result obtained from the formula ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software is almost similar.

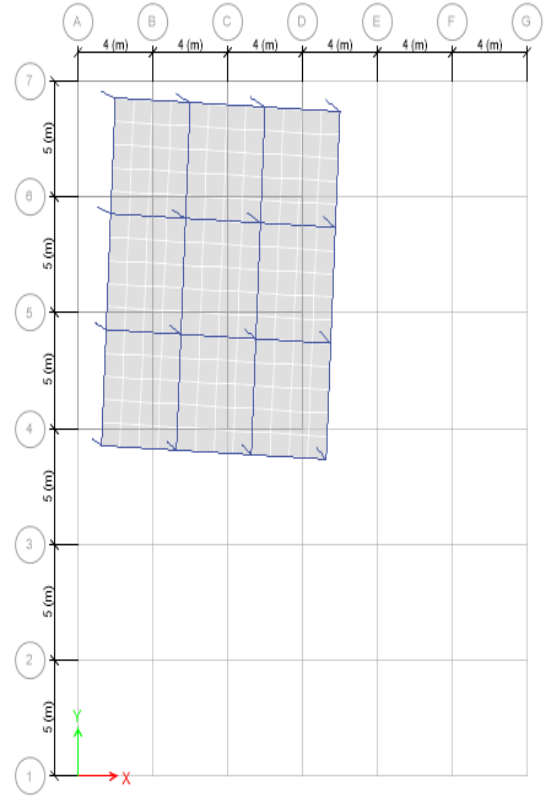
The first three mode shape of vibration periods of comb 2 irregular structural model of story 8 building



Mode 1 periods T1=2.893s
1st mode of vibration is not pure Y-direction



Mode 2 periods T1=2.414s
2nd mode of vibration is not pure X-direction



Mode 3 periods T1=1.411s
3rd mode of vibration torsional

Figure 4.14 mode shape of comb 2 structrular model of story 8 builing

4.3.2 Mode shape and fundamental periods of vibration *T*1 for story 15 structural model

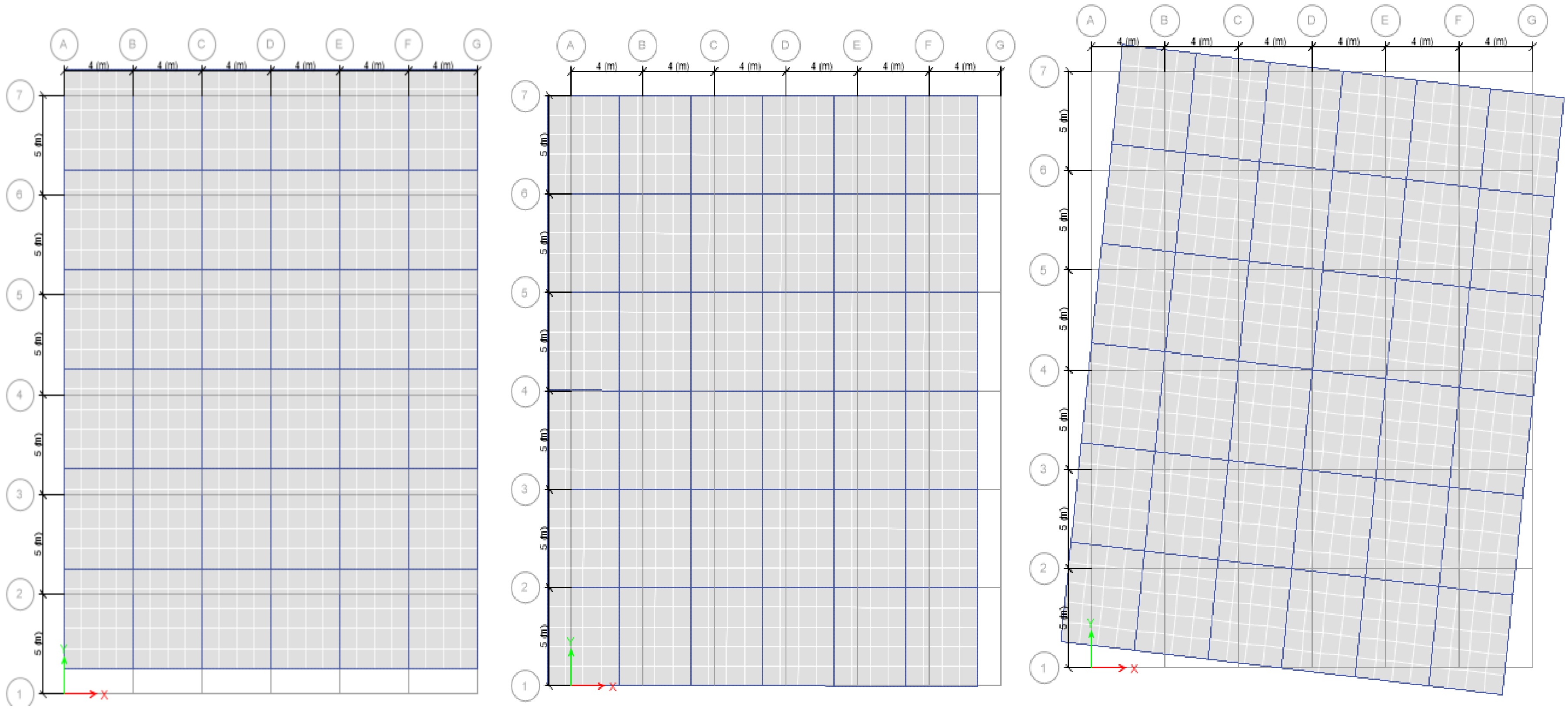
1. Determination of fundamental periods of vibration T1 for regular structural model

Table 4.8 quantity of mass, story force and displacement of story 15 regular structural model

	masses (ton)		story force (KN)		Displacement (m)					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	Mix*six²	Miy*siy²	fix*six	fiy*siy
1	790.484	790.484	586.6336	586.6336	0.125493	0.176233	12.44893	24.55091	73.61841	103.3842
2	931.5107	931.5107	645.2062	645.2062	0.123214	0.173753	14.14191	28.12241	79.49844	112.1065
3	931.5107	931.5107	599.12	599.12	0.119799	0.169537	13.36886	26.77422	71.77398	101.573
4	931.5107	931.5107	553.0339	553.0339	0.115121	0.163489	12.34517	24.89803	63.66582	90.41496
5	931.5107	931.5107	506.9477	506.9477	0.109205	0.155681	11.10895	22.57663	55.36122	78.92212
6	931.5107	931.5107	460.8616	460.8616	0.102121	0.14622	9.714445	19.91597	47.06365	67.38718
7	931.5107	931.5107	414.7754	414.7754	0.093959	0.135221	8.22365	17.03241	38.97188	56.08634
8	931.5107	931.5107	368.6892	368.6892	0.084815	0.122808	6.700901	14.04886	31.27037	45.27798
9	931.5107	931.5107	322.6031	322.6031	0.074789	0.109106	5.210307	11.08881	24.12716	35.19793
10	931.5107	931.5107	276.5169	276.5169	0.063989	0.094247	3.814157	8.274141	17.69404	26.06089
11	931.5107	931.5107	230.4308	230.4308	0.052532	0.078368	2.570607	5.720914	12.10499	18.0584
12	931.5107	931.5107	184.3446	184.3446	0.040565	0.061621	1.532819	3.537084	7.477939	11.3595
13	931.5107	931.5107	138.2585	138.2585	0.028315	0.044205	0.746829	1.820248	3.914789	6.111717
14	931.5107	931.5107	92.1723	92.1723	0.016253	0.02652	0.246068	0.655141	1.498076	2.444409
15	931.5107	931.5107	46.0862	46.0862	0.005617	0.009903	0.02939	0.091353	0.258866	0.456392
						∑=	102.203	209.1071	528.2996	754.8416

Fundamental periods of vibration T1 according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=2.7618 and T1y=3.305. From the result analysis of ETABS software is mode 1 periods 3.308s and mode 2 periods 2.765s. The fundamental periods of vibration T1 result obtained from the formula ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software is almost similar

The first three mode shape of vibration periods of regular structural model of story 15 building



Mode 1 periods T1=3.308s
1st mode of vibration is pure Y-direction

Mode 2 periods T1=2.765s
2nd mode of vibration is pure X-direction

Mode 3 periods T1=2.651s
3rd mode of vibration torsional

Figure 4.15 mode shape of regular structrular model of story 15 building

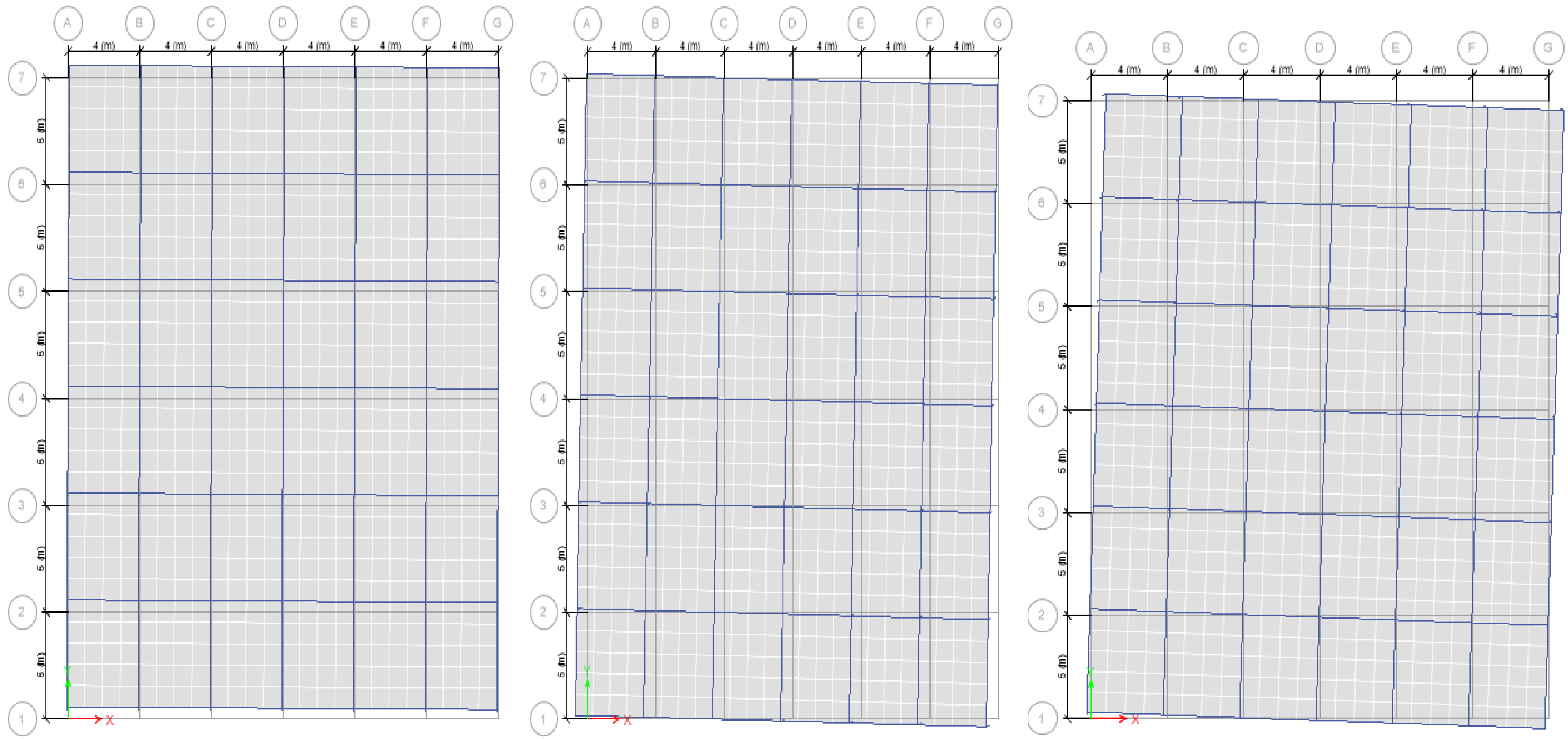
2. Determination of fundamental periods of vibration T1 for Mass irregular structural model

Table 4.9:- Quantity of mass, story force and displacement story 15 mass irregular structural model

	masses (ton)		**story force (KN)**		**Displacement (mm)**					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	**Mix*six²**	**Miy*siy²**	**fix*six**	**fiy*siy**
1	1565.468	1565.468	1107.248	1107.248	0.150315	0.212569	35.37113	70.73659	166.4359	235.3665
2	931.5107	931.5107	614.9291	614.9291	0.147877	0.209226	20.36991	40.77737	90.93387	128.6592
3	931.5107	931.5107	571.0056	571.0056	0.1432	0.203366	19.10178	38.52517	81.768	116.1231
4	1544.564	1544.564	873.9697	873.9697	0.137093	0.195466	29.0293	59.0131	119.8151	170.8314
5	931.5107	931.5107	483.1586	483.1586	0.129423	0.185232	15.6031	31.96097	62.53184	89.49643
6	931.5107	931.5107	439.2351	439.2351	0.120456	0.17316	13.51589	27.93078	52.9085	76.05795
7	931.5107	931.5107	395.3116	395.3116	0.11039	0.159534	11.35135	23.70797	43.63845	63.06564
8	931.5107	931.5107	351.3881	351.3881	0.099352	0.144505	9.194775	19.45152	34.91111	50.77734
9	931.5107	931.5107	307.4646	307.4646	0.087447	0.128198	7.123242	15.30912	26.88686	39.41635
10	931.5107	931.5107	263.5411	263.5411	0.074767	0.110725	5.207242	11.42035	19.70418	29.18059
11	1544.564	1544.564	364.154	364.154	0.061375	0.092125	5.818204	13.10874	22.34995	33.54769
12	931.5107	931.5107	175.694	175.694	0.04733	0.07234	2.086704	4.874666	8.315597	12.7097
13	931.5107	931.5107	131.7705	131.7705	0.032967	0.051778	1.012387	2.497344	4.344078	6.822813
14	931.5107	931.5107	87.847	87.847	0.018877	0.030981	0.331936	0.894085	1.658288	2.721588
15	931.5107	931.5107	43.9235	43.9235	0.006504	0.011529	0.039405	0.123814	0.285678	0.506394
						∑=	175.1563	360.3316	736.4874	1055.283

Fundamental periods of vibration T1 of mass irregularity according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=3.0625 and T1y=3.669. From the result analysis of ETABS software is mode 1 periods 3.693s and mode 2 periods 3.156s. The fundamental periods of vibration T1 result obtained from the formula ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software is almost similar result.

The first three mode shape of vibration periods of mass irregular structural model of story 15 building



Mode 1 periods T1=3.693s
1st mode of vibration is not pure Y-direction

Mode 2 periods T1=3.156s
2nd mode of vibration is not pure X-direction

Mode 3 periods T1=2.867s
3rd mode of vibration torsional

Figure 4.16 mode shape of mass irregular structrular model of story 15 building

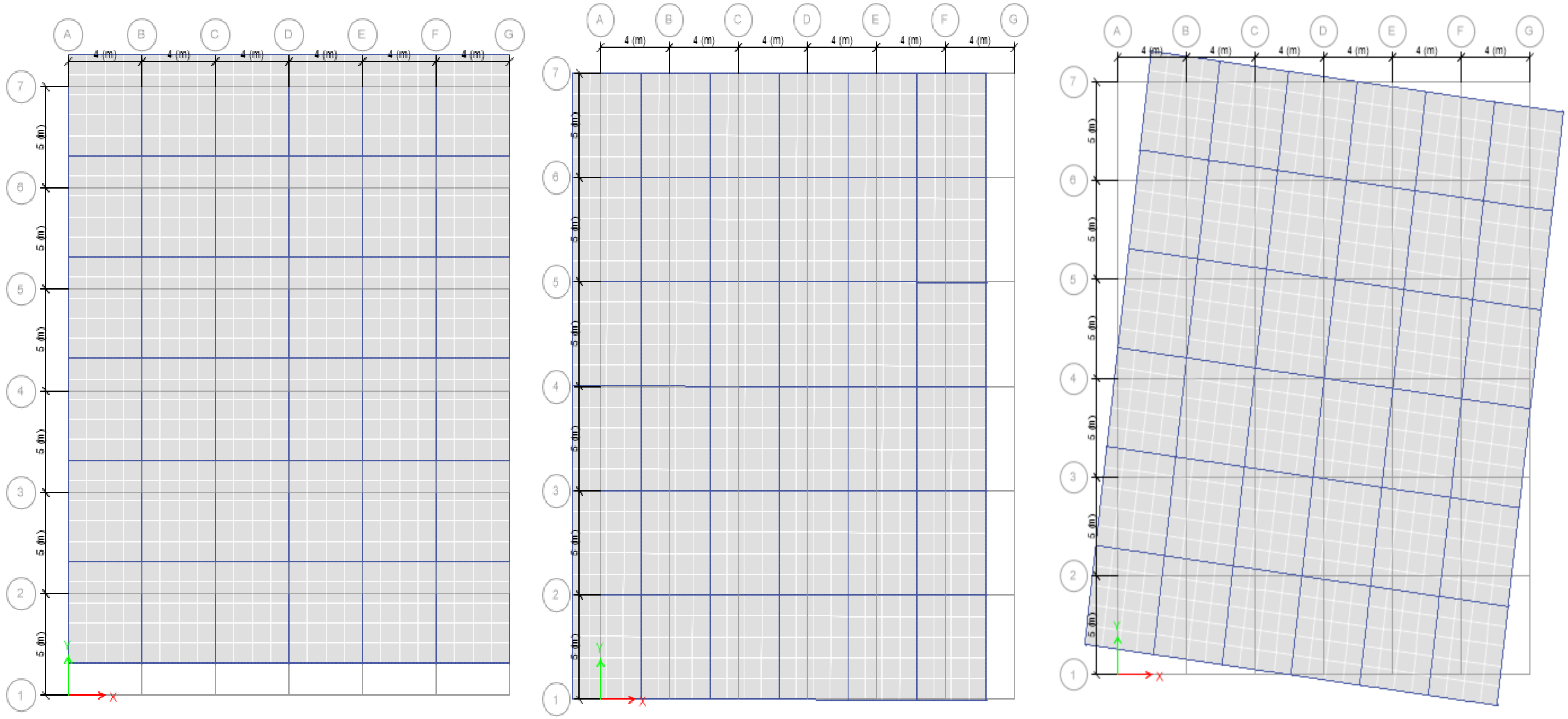
3. Determination of fundamental periods of vibration T1 for Stiffness irregular structural model

Table 4.10:- Quantity of mass, story force and displacement story 15 stiffness irregular structural model

	masses (ton)		**story force (KN)**		**Displacement (mm)**					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	**Mix*six²**	**Miy*siy²**	**fix*six**	**fiy*siy**
1	691.676	691.676	532.4884	532.4884	0.200021	0.269616	27.67285	50.27986	106.5089	143.5674
2	795.2282	795.2282	561.1909	561.1909	0.191539	0.259683	29.17469	53.62642	107.4899	145.7317
3	782.7367	782.7367	514.7137	514.7137	0.182195	0.248557	25.98296	48.35793	93.77826	127.9357
4	782.7367	782.7367	477.0517	477.0517	0.169189	0.232732	22.40577	42.39629	80.7119	111.0252
5	782.7367	782.7367	439.3898	439.3898	0.152438	0.212047	18.18872	35.19492	66.9797	93.17129
6	782.7367	782.7367	401.7278	401.7278	0.132341	0.186861	13.70896	27.33084	53.16506	75.06726
7	782.7367	782.7367	364.0658	364.0658	0.11036	0.158759	9.533208	19.72842	40.1783	57.79872
8	894.0362	894.0362	372.8161	372.8161	0.092064	0.134924	7.577654	16.27547	34.32294	50.30184
9	956.4938	956.4938	352.8387	352.8387	0.081608	0.121067	6.37012	14.01954	28.79446	42.71712
10	956.4938	956.4938	291.4754	291.4754	0.065756	0.097968	4.135737	9.180168	19.16626	28.55526
11	931.5107	931.5107	239.0419	239.0419	0.054564	0.082638	2.773322	6.361323	13.04308	19.75394
12	931.5107	931.5107	194.2215	194.2215	0.043348	0.067205	1.750354	4.207179	8.419114	13.05266
13	931.5107	931.5107	149.4012	149.4012	0.031912	0.051193	0.948628	2.441232	4.767691	7.648296
14	931.5107	931.5107	104.5808	104.5808	0.020429	0.034666	0.38876	1.119426	2.136481	3.625398
15	956.4938	956.4938	61.3632	61.3632	0.009518	0.017931	0.086651	0.307533	0.584055	1.100304
						∑=	170.6984	330.8266	660.0461	921.0521

Fundamental periods of vibration T1 of stiffness irregularity according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=3.1936s and T1y=3.7637. From the result analysis of ETABS software is mode 1 periods 3.767s and mode 2 periods 3.197s. The fundamental periods of vibration T1 result obtained from the formula ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software is almost similar

The first three mode shape of vibration periods of stiffness irregular structural model of story 15 building



Mode 1 periods T1=3.767s
1st mode of vibration is not pure Y-direction

Mode 2 periods T1=3.197s
2nd mode of vibration is not pure X-direction

Mode 3 periods T1=3.033s
3rd mode of vibration torsional

Figure 4.17 mode shape of stiffness irregular structrular model of story 15 building

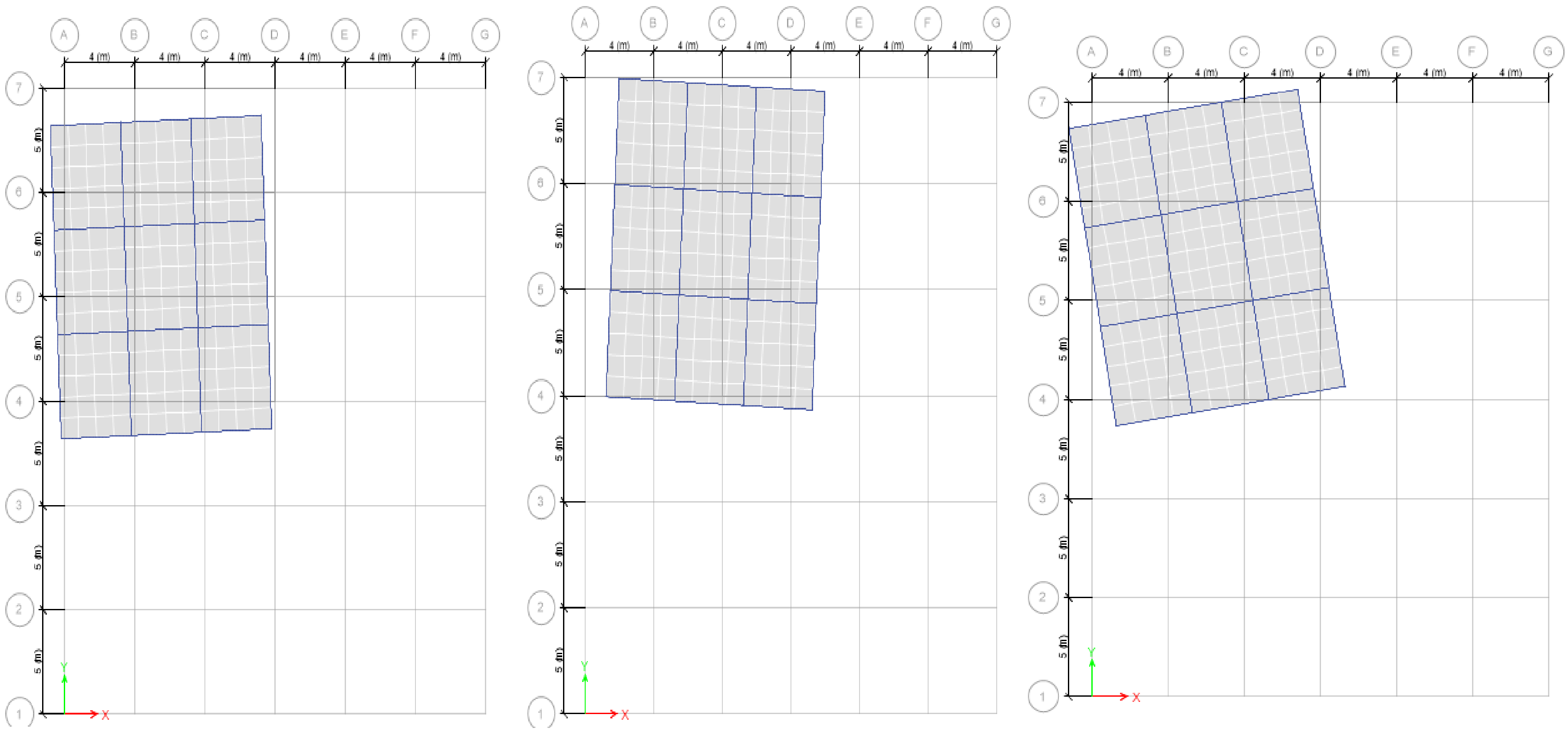
4. **Determination of fundamental periods of vibration T1 for setback irregular structural model**

Table 4.11:- Quantity of mass, story force and displacement story 15 setback irregular structural model

	masses (ton)		**story force (KN)**		**Displacement (m)**					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	**Mix*six²**	**Miy*siy²**	**fix*six**	**fiy*siy**
1	209.2458	209.2458	198.5679	198.5679	0.104857	0.133486	2.300655	3.728448	20.82123	26.50603
2	250.2384	250.2384	221.6373	221.6373	0.102299	0.130713	2.618766	4.275545	22.67327	28.97088
3	250.2384	250.2384	205.8061	205.8061	0.098587	0.126092	2.432166	3.978588	20.28981	25.9505
4	415.3304	415.3304	315.3087	315.3087	0.087794	0.116183	3.201278	5.606333	27.68221	36.63351
5	429.0966	429.0966	298.613	298.613	0.082405	0.10949	2.913816	5.144035	24.6072	32.69514
6	429.0966	429.0966	271.4664	271.4664	0.076384	0.101433	2.503571	4.414826	20.73569	27.53565
7	639.3621	639.3621	364.0411	364.0411	0.064895	0.089428	2.692584	5.113213	23.62445	32.55547
8	656.1874	656.1874	332.1077	332.1077	0.058238	0.080764	2.225568	4.280195	19.34129	26.82235
9	656.1874	656.1874	290.5942	290.5942	0.051173	0.07111	1.718342	3.318098	14.87058	20.66415
10	911.6263	911.6263	346.0422	346.0422	0.040581	0.05897	1.501282	3.170145	14.04274	20.40611
11	931.5107	931.5107	294.6585	294.6585	0.033573	0.04962	1.049949	2.293514	9.89257	14.62095
12	931.5107	931.5107	235.7268	235.7268	0.026263	0.039533	0.642505	1.455819	6.190893	9.318988
13	931.5107	931.5107	176.7951	176.7951	0.018547	0.028685	0.320432	0.766474	3.279019	5.071367
14	931.5107	931.5107	117.8634	117.8634	0.010756	0.017382	0.107768	0.281441	1.267739	2.048702
15	931.5107	931.5107	58.9317	58.9317	0.003755	0.006556	0.013134	0.040037	0.221289	0.386356
						∑=	26.24182	47.86671	229.54	310.1862

Fundamental periods of vibration T1of setback irregularity according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=2.123s and T1y=2.4669s. From the result analysis of ETABS software is mode 1 periods 2.4669s and mode 2 periods 2.123s. The fundamental periods of vibration T1 result obtained from the formula ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software is almost similar.

The first three mode shape of vibration periods of regular structural model of story 15 building



Mode 1 periods T1=2.4669s
1st mode of vibration is not pure Y-direction

Mode 2 periods T1=2.123s
2nd mode of vibration is not pure X-direction

Mode 3 periods T1=1.496s
3rd mode of vibration torsional

Figure 4.18 mode shape of setback irregularity structrular model of story 15 building

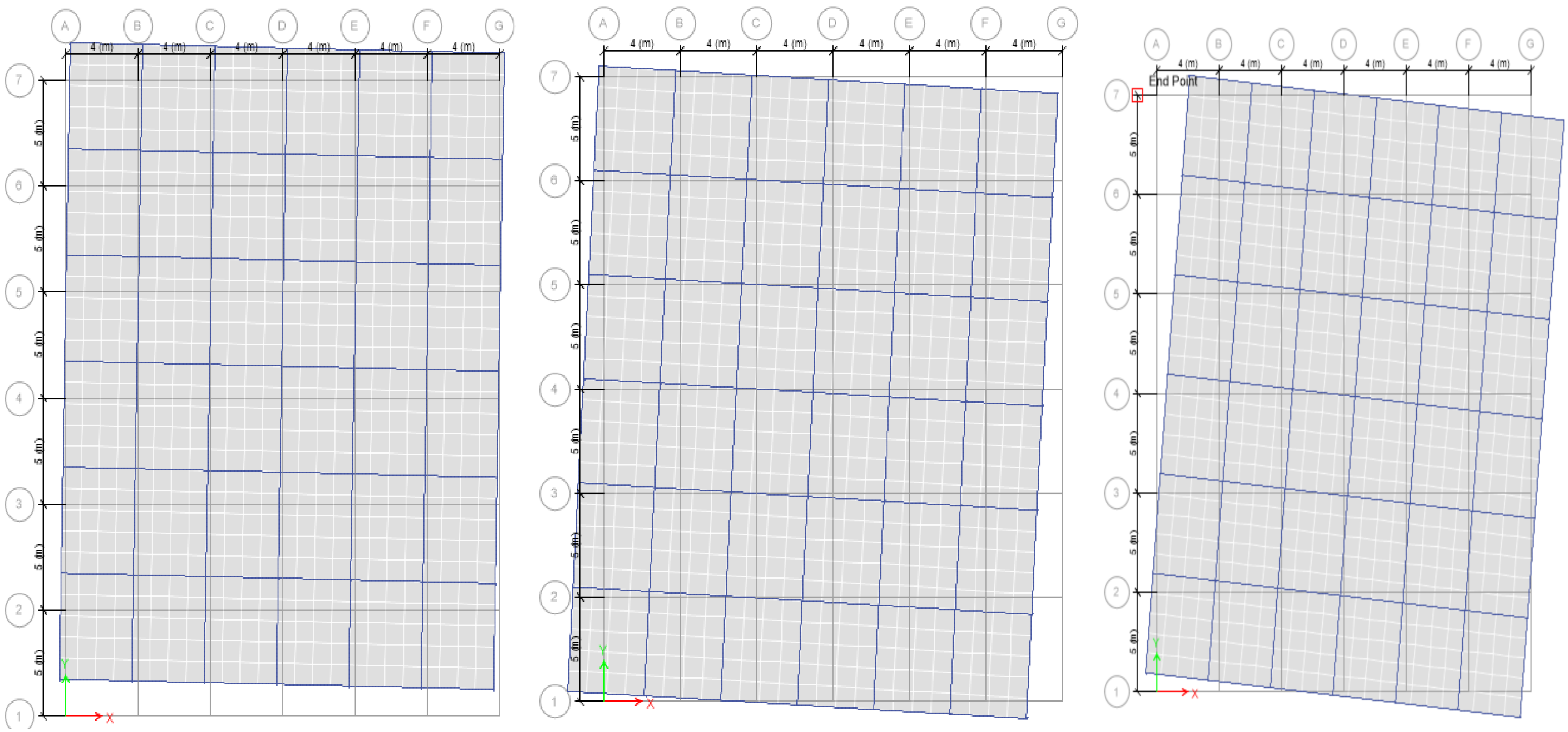
5. Determination of fundamental periods of vibration T1 for Comb 1 irregular structural model

Table 4.12:- Quantity of mass, story force and displacement story 15 comb 1 irregular structural model

	masses (ton)		**story force (KN)**		**Displacement (mm)**					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	**Mix*six²**	**Miy*siy²**	**fix*six**	**fiy*siy**
1	1099.563	1099.563	821.3526	821.3526	0.238484	0.310116	62.5372	105.7471	195.8795	254.7146
2	795.2282	795.2282	544.5189	544.5189	0.211501	0.286283	35.57268	65.17528	115.1663	155.8865
3	782.7367	782.7367	499.4224	499.4224	0.199774	0.272232	31.23875	58.00882	99.77161	135.9588
4	881.8531	881.8531	521.4928	521.4928	0.184379	0.253462	29.97914	56.65288	96.15232	132.1786
5	782.7367	782.7367	426.3362	426.3362	0.165035	0.229505	21.31905	41.22873	70.36039	97.84629
6	782.7367	782.7367	389.7931	389.7931	0.142306	0.200946	15.8512	31.60636	55.4699	78.32736
7	782.7367	782.7367	353.25	353.25	0.117862	0.169624	10.87335	22.52114	41.63475	59.91968
8	894.0362	894.0362	361.7403	361.7403	0.097811	0.143444	8.553237	18.39585	35.38218	51.88948
9	956.4938	956.4938	342.3564	342.3564	0.086537	0.128486	7.162849	15.79042	29.6265	43.988
10	956.4938	956.4938	282.8162	282.8162	0.069579	0.103761	4.630613	10.29794	19.67807	29.34529
11	1030.627	1030.627	256.6197	256.6197	0.057667	0.087438	3.427333	7.879561	14.79849	22.43831
12	931.5107	931.5107	188.4515	188.4515	0.045758	0.071034	1.950392	4.700244	8.623164	13.38646
13	931.5107	931.5107	144.9627	144.9627	0.033646	0.054056	1.05452	2.721922	4.877415	7.836104
14	931.5107	931.5107	101.4739	101.4739	0.021515	0.036573	0.431192	1.245974	2.183211	3.711205
15	956.4938	956.4938	59.5402	59.5402	0.010013	0.018904	0.095898	0.341814	0.596176	1.125548
						∑=	234.6774	442.314	790.1999	1088.552

Fundamental periods of vibration T1 according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=3.422s and T1y=4.003s. From the result analysis of ETABS software is mode 1 periods 4.01s and mode 2 periods 3.482s. The fundamental periods of vibration T1 result obtained from the formula ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software is almost similar

The first three mode shape of vibration periods of comb 1 irregular structural model of story 15 building



Mode 1 periods T1=4.01s
1st mode of vibration is not pure Y-direction

Mode 2 periods T1=3.482s
2nd mode of vibration is not pure X-direction

Mode 3 periods T1=3.169s
3rd mode of vibration torsional

Figure 4.19 mode shape of comb 1 structrular model of story 15 building

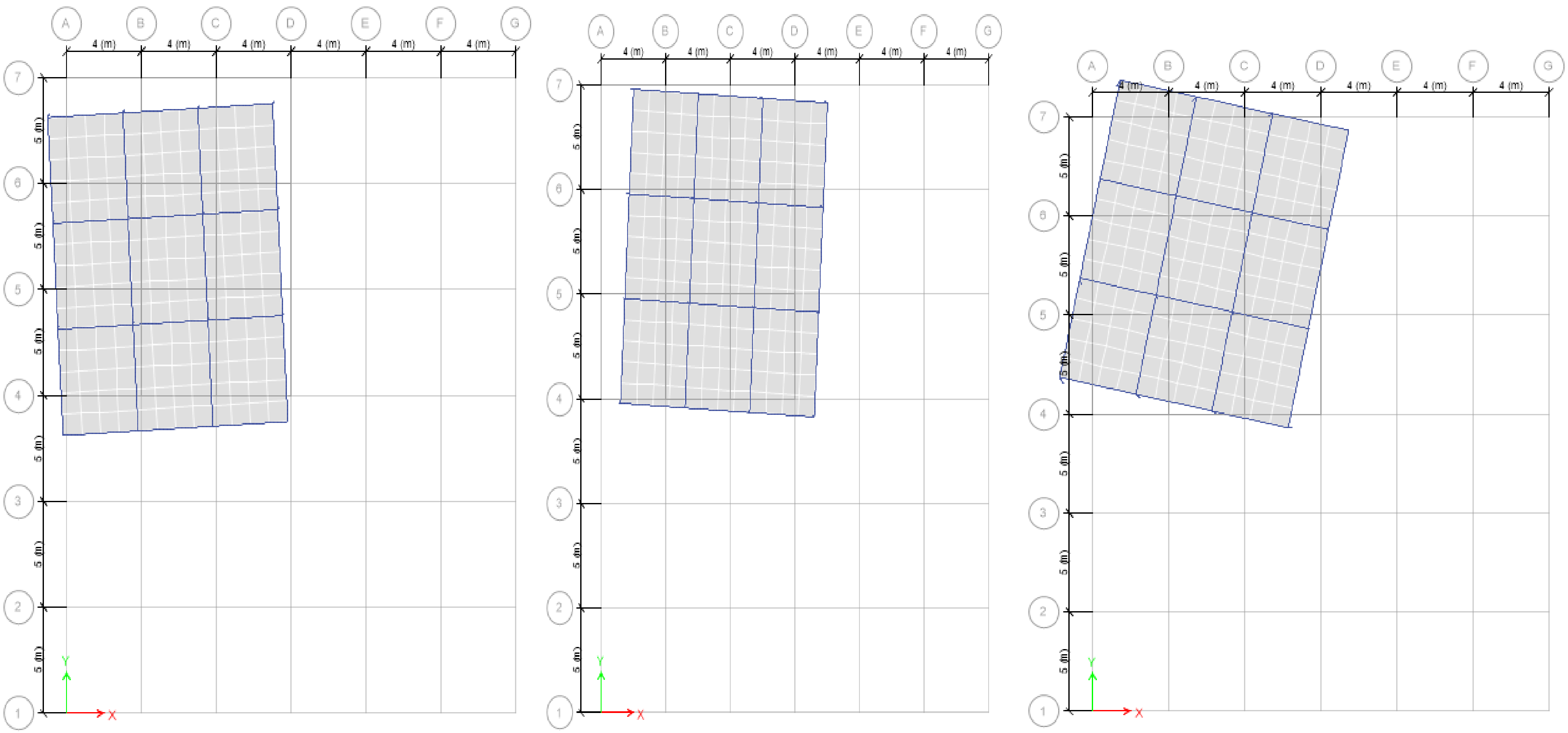
6. Determination of fundamental periods of vibration T1 for Comb 2 irregular structural model

Table 4.13:- Quantity of mass, story force and displacement story 15 comb 2 irregular structural model

	masses (ton)		**story force (KN)**		**Displacement (mm)**					
No. Story	X-direct	Y-direct	X-direct	Y-direct	X-direct	Y-direct	**Mix*six²**	**Miy*siy²**	**fix*six**	**fiy*siy**
1	302.3612	302.3612	289.5913	289.5913	0.202714	0.247694	12.42492	18.55056	58.70421	71.73003
2	208.7512	208.7512	183.2736	183.2736	0.182592	0.226812	6.959731	10.73893	33.46429	41.56865
3	204.6723	204.6723	167.4408	167.4408	0.168998	0.210395	5.845508	9.060037	28.29716	35.22871
4	392.8712	392.8712	297.8874	297.8874	0.141722	0.183866	7.890866	13.28168	42.2172	54.77136
5	355.7025	355.7025	248.4124	248.4124	0.125375	0.164042	5.591249	9.571875	31.1447	40.75007
6	355.7025	355.7025	227.1199	227.1199	0.106337	0.140238	4.022126	6.995493	24.15125	31.85084
7	539.978	539.978	312.4585	312.4585	0.080376	0.111523	3.48842	6.715911	25.11416	34.84631
8	628.655	628.655	326.14	326.14	0.067111	0.094615	2.831391	5.627719	21.88758	30.85774
9	674.5423	674.5423	309.5675	309.5675	0.059322	0.084289	2.373781	4.792377	18.36416	26.09314
10	929.9812	929.9812	352.5706	352.5706	0.044387	0.065409	1.832254	3.978773	15.64955	23.06129
11	1030.627	1030.627	329.0333	329.0333	0.037134	0.055889	1.421167	3.219247	12.21832	18.38934
12	931.5107	931.5107	241.6293	241.6293	0.029892	0.046017	0.832334	1.972534	7.222783	11.11906
13	931.5107	931.5107	185.8687	185.8687	0.022253	0.035395	0.46128	1.167002	4.136136	6.578823
14	931.5107	931.5107	130.1081	130.1081	0.014382	0.024149	0.192675	0.543233	1.871215	3.141981
15	956.4938	956.4938	76.3415	76.3415	0.006761	0.012564	0.043722	0.150986	0.516145	0.959155
						∑=	56.21142	96.36636	324.9589	430.9465

Fundamental periods of vibration T1 according to ES EN 1998-1/ 4.3.3.2.2 (2P) by using Rayleigh method formula T1x=3.422s and T1y=4.003s. From the result analysis of ETABS software is mode 1 periods 3.041s and mode 2 periods 2.633s. The fundamental periods of vibration T1 result obtained from the formula ES EN 1998-1/ 4.3.3.2.2 (2P) and ETABS software have different result

The first three mode shape of vibration periods of regular structural model of story 15 building



Mode 1 periods T1=3.041s
1st mode of vibration is not pure Y-direction

Mode 2 periods T1=2.633s
2nd mode of vibration is not pure X-direction

Mode 3 periods T1=1.77s
3rd mode of vibration torsional

Figure 4.20 mode shape of comb 2 structrular model of story 15 building

CHAPTRER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The study has undertaken comparisons behaviour of irregular multi-storey reinforced concrete building using equivalent static analysis and response spectrum analysis by ETABS 2016 software program. By using different cases of the irregular structural model, three single irregularity and two multi-combinations irregularity with respect to regular structural models was done to fulfil the objective of this research for storey 8 and storey 15. Structural models design was done based on the code of ES EN 1998-1:2015 subjected to a high seismic earthquake. The graphed results indicated the behaviour of irregular multi-storey reinforced concrete building for each independent variables of mass, stiffness and setback irregularity.

The contribution of this thesis work can be summarized as follows:

- The result of base shear and shear force obtained using response spectrum analysis is greater than equivalent static analysis for analyzed regular and irregular structural model and for both story 8 and 15 rise building. Generally, due to the occurrence irregularity of mass, stiffness and vertical geometric setback in structural frame system total mass and base shear of building is reduced. Irregularity of base shear and shear force less with respect to regular building. Mass irregularity cases have shown greater base shear and storey shear for analyzed regularity and irregularity, due to the increase in the mass of the structure building. When multi-combinations irregularity cometh up under seismic earthquake in single multi-storey building the response of base shear and storey shear force is reduced
- Maximum result of story drift and story displacement is obtained by equivalent static analysis than response spectrum analysis from analyzed irregularity. Story drift and story displacement of irregular building is very maximum with compared to regular structure. Both Story drift and story displacement of irregular building increase as story height building increase. Combination irregularity have maximum story drift and story displacement than singular irregularity, especially the value of comb 2 irregularity extremely high. The sequence increases of story drift and story displacement of analyzed irregularity are R<SBI<MI<SI<Comb1<Comb2 building. For all studied cases, the sudden increase in the storey drift and storey displacements value is observed at the areas of discontinuity presents in the geometric configurations of the structural model of irregularity.

- By using response spectrum analysis methods we get more accurate responses than equivalent static analysis for irregular multi-storey for high rise building. So that in the modern high rise multi-storey building response spectrum analysis methods are the most better and save than equivalent static analysis.
- Maximum time periods are observed in the case of mass irregularity, stiffness irregularity, comb1 irregularity and comb2 irregularity in both storey 8 and 15 building. In case of setback (SBI), maximum percentage reduction in time periods observed for both storey 8 and 15 building.
- Time periods of irregular multi-storey buildings increase with the increase storey height of the building. Modal periods of buildings mainly depend upon building properties mass, stiffness, strength, storey height, and number of storeys and location of irregularity. Regular structural building has three basic modes of oscillation, namely, pure translational along X-direction, pure translational along Y-direction and pure rotation about Z-axis, but, irregular buildings has mode shapes that are a mixture of these pure mode shapes.

As a similar to the study of Kakpure and Bagheri the difference of values of story drift and story displacement between static and response spectrum analysis is in higher stories and equivalent static analysis gives higher values than dynamic response spectrum analysis. Building with stiffness and combination irregularity has more lateral story drift and reduction in base shear and story shear capacity compared to regular buildings. When compared to irregular configuration the story drift value is more in the regular structural model configuration. Story drift is increased as the height of the building increases from story 8 to story 15 rise building. Generally, the Stiffness, mass, setback and their combination irregularity causes twisting of buildings under lateral load due to the center of mass and center of stiffness of different storeys do not lie along the same vertical line, as is the case in buildings with regular overall geometry.

5.2. Recommendation

Irregularity has significant effects on seismic performance of a building and major causes of damage and collapse of building. So special care should be take account at designing and construction level of irregular building. Building with stiffness and combination severe irregularity produces more lateral story drift and displacement than those with less or singular irregularity, particularly in high seismic zones V. so that regular building shape must be preferred than irregular building. Irregularity of mass (heavy mass of water tank) in placed at the top roof levels building at the one side corner of the building is causes of twisting the building under earthquake load shaking, So that elevated water tanks with large mass of water are placed at centers of roof levels of building is more preferred.

Recommendation for future studies are;

- Future study shall make a further study on the seismic effect of nonlinear-elastic analysis according to Ethiopian standard current code.
- This research is limited to irregularity of mass, stiffness, vertical setback and combinations of them, future research is recommended to cover other buildings with different irregularities.
- Future study shall make a further study on the seismic effect by changing different method of analysis according to Ethiopian standard current code.

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