Seismic Analysis and Design of Residential Building on Sloping Ground using ETABS

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Abstract— In hilly areas, the buildings are built on sloping grounds. When the hilly areas come to under seismic zones, these buildings area highly vulnerable to earthquakes. The present study deals with analysis of multi-storied building (G+4) on sloped ground. The study comprising of analysis of multi-storied building (G+4) by considering gravity loads and seismic loads (response spectrum method used) and also includes slope stability analysis. The modelling has done by providing different elevations at foundation level and analysis of building has carried out by using finite element software such as ETABS. ETABS is a sophisticated and flexible to use, special purpose analysis such as gravity loads, earthquake analysis, P-δ analysis etc., and the programmers are integrated in the software in a well manner for the analysis of multi-storied building.

Keywords: Earthquake, Sloping Ground, Response Spectrum Method, Stability of Slopes, ETABS and GEOSTUDIO Software

I. Introduction

The building rest on hilly areas have to be constructed differently from flat ground. Multi storied building on sloping ground are infrequent over level grounds were as on hilly slopes these are quite common. Disaster due to Earthquake, Landslide, Instability of slopes as always been the greatest natural thrust upon the mankind. Generally the structures are constructed on level ground in some areas the ground itself is a slope in that condition it is very difficult to excavation, levelling and it is very expensive. Due to the scarcity of level ground engineers started construction on sloppy ground itself. Some of the hilly areas are more prone to the earthquake. In that areas generally construction works carried out by locally available materials such as bamboo, timber, brick, RCC and also they gave more important to the lightweight materials for the construction of houses. As the population density increases at hilly region requirement of structure also increases. The popularity and demand of multi-story building on hilly slope is also increases. Seismology is the study of vibrations of Earth, mainly caused by earthquakes. These are most commonly seen in North and North eastern part of India have a large scales of hilly region, which are categorized under seismic zone IV and V.

Most of the region in the hilly area which lies in the seismically active belt of Himalayan range. Sujit kumar et al2 (2014) has studied the, reinforced concrete (RC) frame buildings that have columns of different heights within one storey, suffered more damage in the shorter columns as compared to taller columns in the same storey. Buildings on the sloping ground are poor behaviour of shorter column is due to the fact that in an earthquake, a tall and a short column of cross section move horizontally. Short column stiffer as compared to long column and it attracts large horizontal forces/earthquake forces.

Stiffer of a column means resistance to deformation, the larger is the stiffness, large force required to deform it. Hence shorter columns should be properly designed, or otherwise use bracing system to resist horizontal forces (wind load, seismic action) and to transmit to the foundation. Hence analysis of both building and sloped ground are requirement for safe design, this can be done by two methods, finite element method and finite differential method, for the analysis of building finite element analysis software, ETABS is used for purpose analysis and design program developed specifically for building systems. ETABS features an intuitive and powerful graphical interface coupled with unmatched modelling, analytical, and design procedures, all integrated using a common database. Although quick and easy for simple structures, ETABS can also handle the largest and most complex building models, including a wide range of nonlinear behaviours, making it the tool of choice for structural engineers in the building industry. Even to this day, stability analyses are by far the most common type of numerical analysis in geotechnical engineering.

A. Objectives

1) The structure should withstand the moderate earthquakes, which may be expected to occur during the service life structure with damage within acceptable limits.
2) The building is modeled as a 3D space frame with six degrees of freedom at each node using the software ETABS.
3) Building (G+4) is analyzed using Static method on 0°, 15°, 30°,45° slope ground.
4) The static method is as per IS 1893 (Part 1):2002 for medium soil is used.
5) Comparison of results for (G+4) building is done for same slope and same soil condition.
6) Various static checks are applied on the results

B. Methodology

To study and evaluate the behaviour of reinforce concrete buildings resting on the sloping ground. Here, a static analysis of a RC-building with fixed base is done considering varying the slope of ground by using ETABS. In this analysis two different types of buildings are considered.

1) Step Back Building (Sloping Ground).

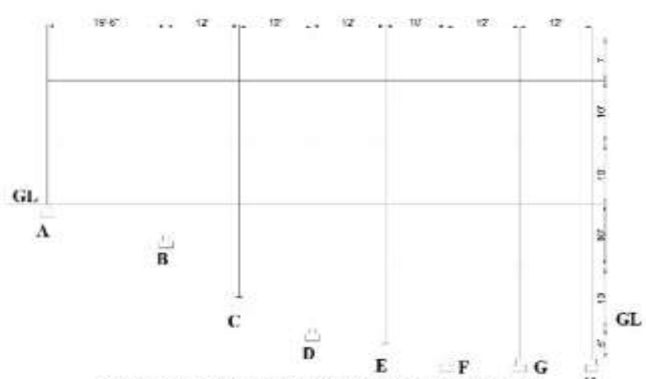

FIG: STEP BACK BUILDING ON SLOPING GROUND

2) Setback-Step Back Building (Sloping Ground).

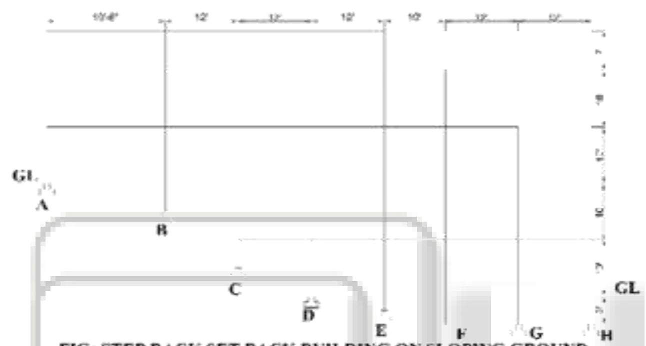

FIG: STEP BACK SET BACK BUILDING ON SLOPING GROUND

C. General

Following methodology is adopted to analyses of structure in sloping ground.

1) RC concrete structure is considered for the study having G+4 stories of height 15m each floors is considered as 3 m height.
2) The regular concrete moment resisting frame of plan irregularity is considered as base or reference model with varying slopes.
3) With reference to base model, all the structure with varying slope modelled using ETABS software.
4) In order to get consistent results, the floor height is kept constant for all slope variations.
5) Hence total models are 8 analysed for 2 and 4 Zones.
6) To understand the behaviour under lateral loads applied as per IS 1893: 2002 are used respectively.
7) Based on the results and responses from earthquake loads applied, conclusion are made.

1) Lateral Load Analysis of Structures in slope ground.

The design criteria for buildings in sloped ground are stability, serviceability, strength and comfort for human. But the factors control the slender buildings and design of buildings all the times are human comfort serviceability and serviceability against lateral loads. This work make an effort to analyse structural systems located on sloping grounds particularly variation of position of shear wall structures of different sloping grounds. For seismic analysis equivalent static method are carried out by using standard package ETABS. To check the variation of models for different parameters like storey displacement, storey drift, and storey shear, mode shape with respect to time period are presented for load cases. The effect of earth quake forces on building structures is to displace the each floor mutually to create inter story drifts. Due to axis deformations in the structure flexural mode will develop and girder or diagonal bracings deformation shear mode will exists. Lateral stiffness of the structure is due to the shear mode displacements in case of buildings with lesser height.

2) Design Lateral Force due to Earthquake as per IS 1893 (Part I):2002

Most of the civil engineering structures will suffer more during earthquake than disasters due to wind forces. Since earthquake forces are very complex in nature and we cannot expect earthquake to occur repeatedly, many times during short span of years. During earthquake, soil layers below sub structures will encounter different kinds of vibrations in three dimensional directions, where shock waves propagates are of P-wave, longitudinal wave and S-wave.

For the structural analysis purpose, only vibrations or movements along horizontal direction is considered, since this movement will affect the superstructure and dangerous hazard to civil structures. The vertical component of the earthquake is taken care by the structural components itself, since in general all the civil engineering structures, including load bearing structures are designed to carry gravity loads which is also a vertical component force of the structure. The seismic co-efficient method or equivalent static method is used to analyses buildings with lesser to medium in height and tall structures are analyzed using dynamic analysis only. The determination of earthquake force based on the code IS 1893(Part I):2002.

Mainly two types of design procedures,

1) Equivalent Static Analysis
2) Dynamic Response Spectrum Analysis

3) Equivalent Static load analysis of building Design seismic Base shear as per IS 1893 (Part I):2002

First step is find out design base shear, the design base shear of any building along principle direction is given below

$$V_b = (A_h) \times W$$

Where A_h= seismic design co-efficient of the structure in horizontal direction.

W= weight of the seismic building.

Horizontal co-efficient of the structure is given by

$$A_h = (Z\ I/2R) * Sa/g$$

In this equation,

Z = Zone factor depends on the region in which the structure is constructed.

I = Importance factors.

R = reduction factor. It explains the structure is brittle or ductile.

Sa/g = it is the average response acceleration co-efficient; it is varying for different type of soil.

T = Approximate fundamental natural period vibration.

$T_a = 0.075\ h^{0.75}$ for RC frame building

In these equations ‘h’ is total building height in meters.

Lateral force at each floor depends on

1) Mass of the floor
2) Stiffness distribution of the structure
3) Displacement of nodes at each mode shape

Base shear Distribution along the height building height is given by

$Q = Vb*(Wi\ hi / \sum_{i=1}^{n} Wi\ hi)$

Qi = Design lateral force at floor i,
Wi = Seismic weight of floor i,
hi = Height of floor i measured from base, and
n = Number of story's in the building is the number of levels at which the masses are located

A. Modeling

1) Bare frame for gravity load analysis.
2) Bare frame for seismic analysis (zone-2 and 5).

B. Building Modeling and Loading Data

1) Building Data

Type of structure - Concrete moment resisting frames.
Plan Configurations – Regular
Number of Stories - G+4
Height of each floor - 3 m
Height of building - 12 m
Building type- Residential

2) Material Properties

Grade of concrete FCK – M20
Grade of steel- FY -500
-FY-415

3) Material Property Design Data Section Properties

Column sections – C240X450mm.
Beam Sections – B230X500mm.
Slab Section – 150 mm thick.

C. Gravity and Lateral load consideration

1) Gravity load:
– Live load - 2kN/m2
– Wall load – 11.178 4.4.2 Earthquake inputs as per IS 1893 (Part I):2002

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Location of Building- Moderate intensity (Z-II, Z-V).
Soil type- Type II
Importance factors- 1.0 for all other structures.
- 1.5 important buildings.
Response reduction factors - 3.0

D. Load Combinations

Type	Design Load Combinations
Gravity analysis	1.5 (Dead Load + Live Load)
Equivalent Static Analysis	1.2 (Dead Load + Live Load + EQX)
	1.2 (Dead Load + Live Load - EQX)
	1.2 (Dead Load + Live Load + EQY)
	1.2 (Dead Load + Live Load - EQY)
	1.5 (Dead Load + EQX)
	1.5 (Dead Load - EQX)
	1.5 (Dead Load + EQY)
	1.5 (Dead Load - EQY)
	0.9 (Dead Load + EQX)
	0.9 (Dead Load - EQX)
	0.9 (Dead Load + EQY)
	0.9 (Dead Load - EQY)

Table 4.1: the list of design load combinations considered during the analysis as per 1893(Part-1):2002

II. SOFTWARE INTRODUCTION

The software used in this program is ETABS 2016. ETABS software is a special computer program developed specifically for different building systems. However, the need for special programs like ETABS, has never been more evident for structural engineers to put nonlinear static and dynamic analysis into practice and to use the greater computer power available today to create larger, more complex analytical models.

With ETABS, modeling and modifying a model, analysis, design and optimizing the design all these are done through a single interface which is completely integrated within Microsoft windows. These ETABS produces graphical displays of the results more easily.

Printed output and even we can save a file for selected elements or for all the elements are also easily available by using ETABS.

III. STEP BY STEP PROCEDURE FOR MODELING AND ANALYSIS

1) Grid Modeling
2) Initializing the units
3) Define Properties of Material
4) Define Section Properties of Material
5) Defining of frame Section
6) Assigning of material property
7) Assigning of Loads

GO TO ANALYSIS.
CHECK MODEL FOR ERRORS.
IF NO ERROR.
RUN THE MODEL.
EXTRACT THE RESULTS.

IV. MODELS CONSIDERED

The concrete bare frame structure is considered and the modeling is done using suitable parameters. The analysis is done for equivalent static method and the result comparison is being carried for varying Zones.

Model-1: Bare frame structure model compared for all zones

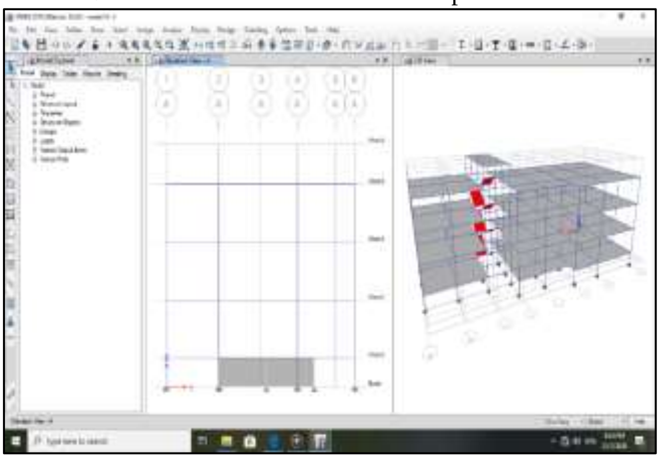


Fig.4.14 Plan and elevation view of bare framed structure

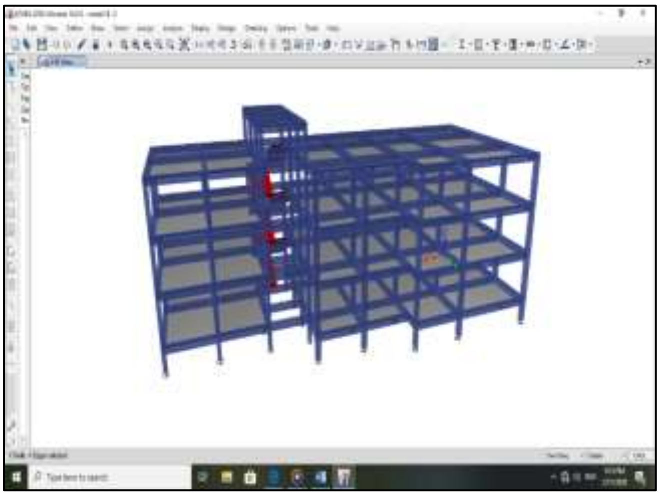


Fig.4.15 3D view of bare framed structure

V. RESULTS AND DISCUSSION

In this chapter the behavior of each model is captured and the results are tabulated. The variation of systematic parameters like story lateral displacement, story drift, natural time period and base shear has been studied for equivalent static method. The results of all the models are observed and comparing the results of each model.

A. *Storey Displacement*

It is total displacement of the storey with respect to ground and there is maximum permissible limit prescribed in IS codes for buildings. The lateral displacements obtained for equivalent static method (EQS) for G+4 (including stair case head room) storey building models of different Zones, along both X and Y directions are listed in the tables below.

STOREY DISPLACEMENT						
Story	Elevation m	Location	X-Dir mm	Y-Dir mm	X-Dir mm	Y-Dir mm
Story5	12.6	Top	0.024	0.027	0.039	0.027
Story4	10.5	Top	0.038	0.094	0.038	0.094
Story3	7.5	Top	0.03	0.076	0.031	0.076
Story2	4.5	Top	0.017	0.044	0.018	0.044
Story1	1.5	Top	0.002	0.006	0.003	0.006
Base	0	Top	0	0	0	0

Table 5.1: Storey Displacement for bare frame structures

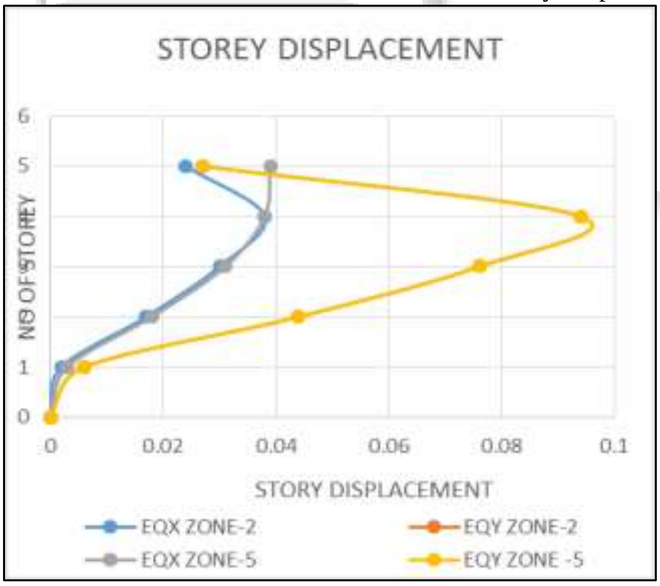


Fig. 5.1: storey vs. displacement for bare frame structures without seismic

B. *Storey Drift*

It is defined as ratio of displacement of two consecutive floors to height of that floor. It is very important term used for research purpose in earthquake engineering. Storey drift obtained for G+4 storey all building models along both X and Y directions are listed for both Equivalent static in the below tables

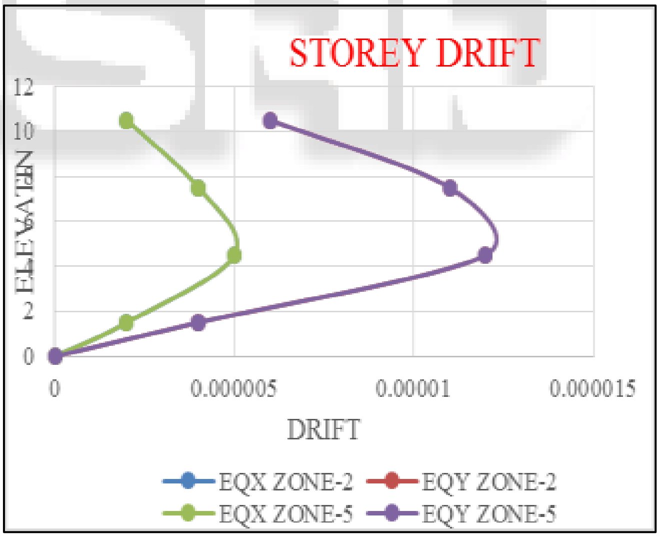


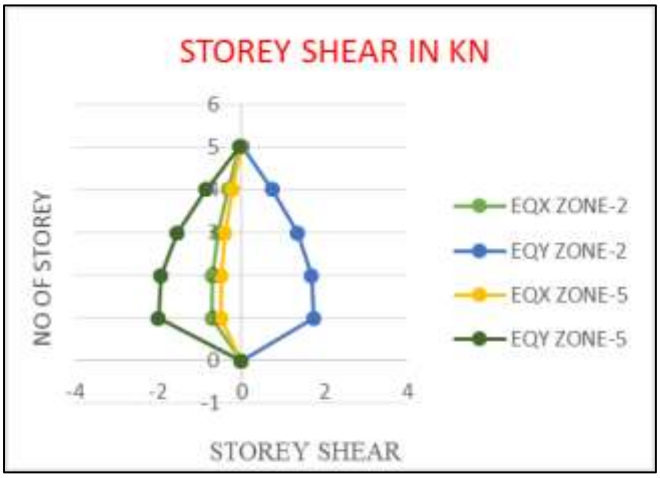
Fig. 5.2: Elevation vs. drift for bare frame structures with seismic

Story	Elevation	X-Dir	Y-Dir	X-Dir	Y-Dir
	m	Zone-2	Zone-2	Zone-5	Zone-5
Story5	12.6	3.687E-07	4.747E-07	0.000001	4.44E-07
Story4	10.5	0.000002	0.000006	0.000002	0.000006
Story3	7.5	0.000004	0.000011	0.000004	0.000011
Story2	4.5	0.000005	0.000012	0.000005	0.000012

Story1	1.5	0.000002	0.000004	0.000002	0.000004
Base	0	0	0	0	0

Table 5.2: Storey Drift for Bare frame structures

C. STOREY SHEAR



It is the lateral force acting on a storey due to the forces such as seismic and wind force. It is calculated for each storey, changes from minimum at the top to maximum at the bottom of the building.

OVERTURNING MOMENTS						
Story	Elevation	Location	X-Dir	Y-Dir	X-Dir	Y-Dir
	m		kN-m	kN-m	kN-m	kN-m
Story5	12.6	Top	0	0	0	0
Story4	10.5	Top	0.0921	-0.0319	-0.0668	-0.0927
Story3	7.5	Top	2.6388	-0.6818	-2.2979	-1.06
Story2	4.5	Top	7.241	-1.8391	-6.3364	-2.7304
Story1	1.5	Top	13.0264	-3.2789	-11.4141	-4.8031
Base	0	Top	16.0028	-4.0161	-14.0249	-5.8668

Table 5.3: Storey shear for bare frame structures with zone comparison.

D. Storey Overturning Moments

Story	Elevation	X-Dir	Y-Dir	X-Dir	Y-Dir
	m	kN	kN	kN	kN
Zone		zone-2		zone-5	
Story5	12.6	-0.0442	0.0318	-0.0152	-0.0438
		-0.0442	0.0318	-0.0152	-0.0438
Story4	10.5	-0.3224	0.7437	-0.2177	-0.8464
		-0.3224	0.7437	-0.2156	-0.8514
Story3	7.5	-0.5568	1.3462	-0.3865	-1.5323
		-0.5568	1.3462	-0.385	-1.5359
Story2	4.5	-0.6909	1.6925	-0.4803	-1.9277
		-0.6909	1.6925	-0.4796	-1.9293
Story1	1.5	-0.7091	1.7405	-0.4914	-1.9842
		-0.7091	1.7405	-0.4914	-1.9842
Base	0	0	0	0	0
		0	0	0	0

Table 5.3: Storey overturning moments with zone comparison.

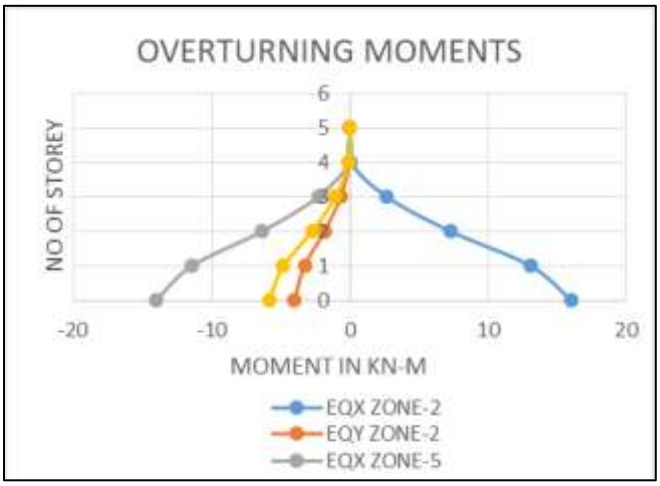


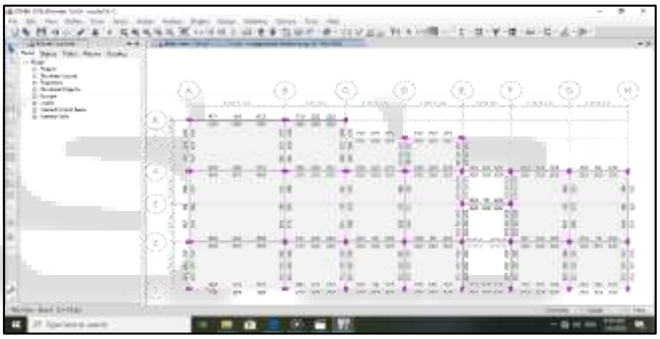
Fig. 5.4: storey vs overturning moments with seismic.

E. Effect in Structure Due To Seismic Variation

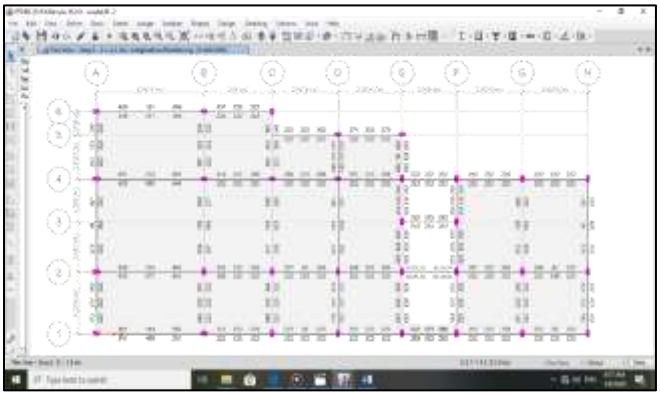
1) Reinforcement variation in beams:

1) Zone-II

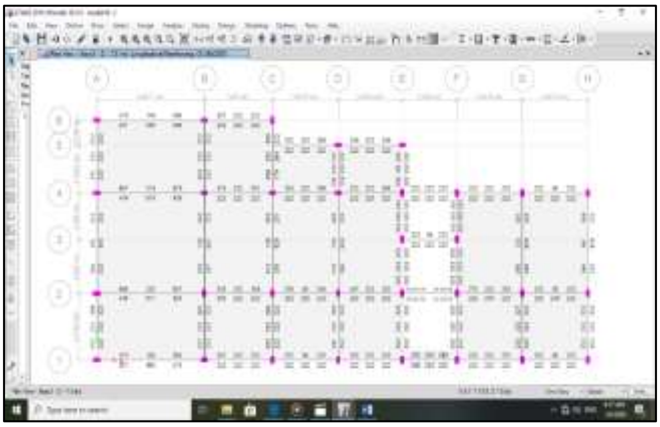
STORE-1



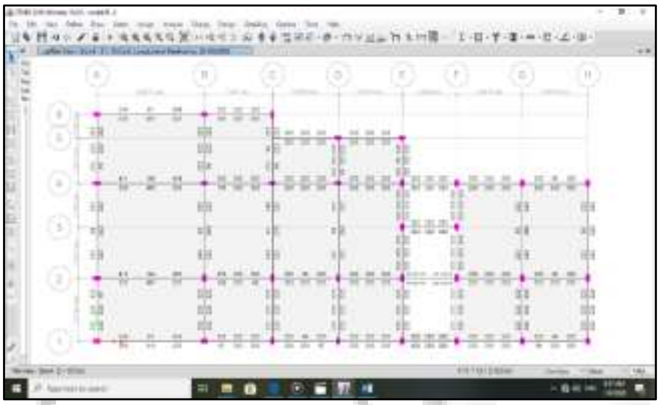
STOREY-2



STOREY-3

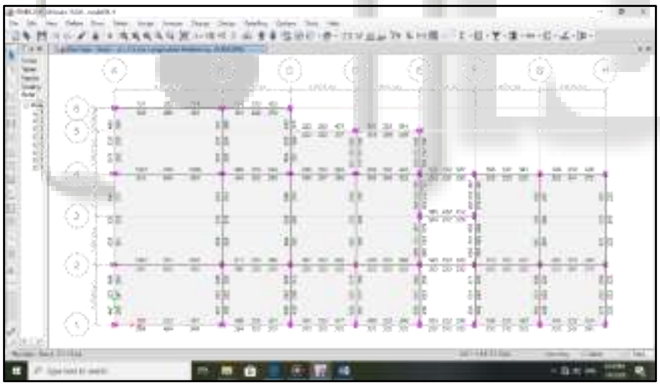


STOREY-4

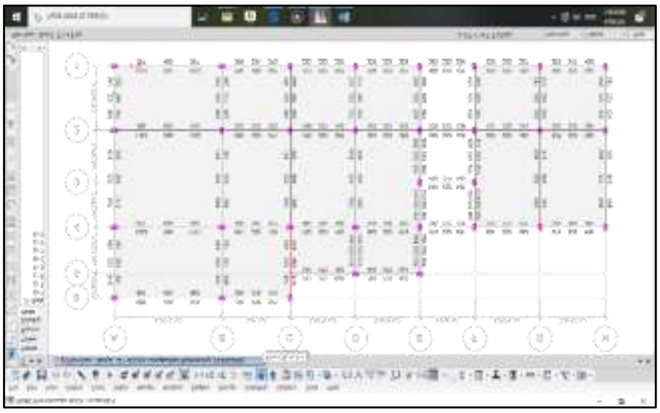


1) Zone-V

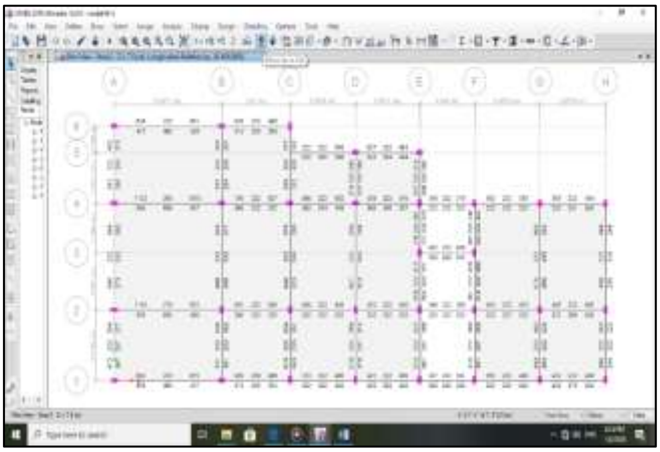
STOREY-1



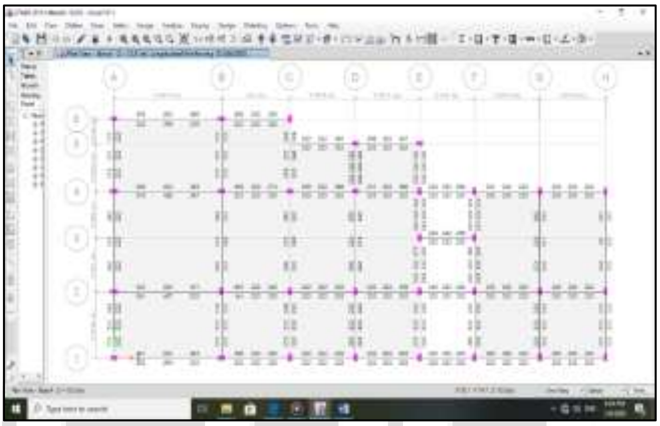
STOREY-2



STOREY-3

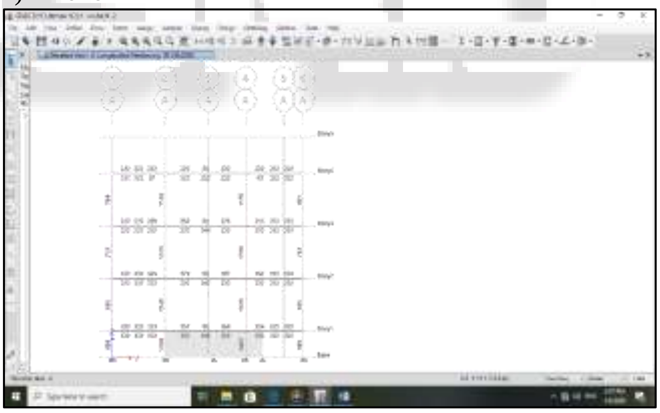


STOREY-4

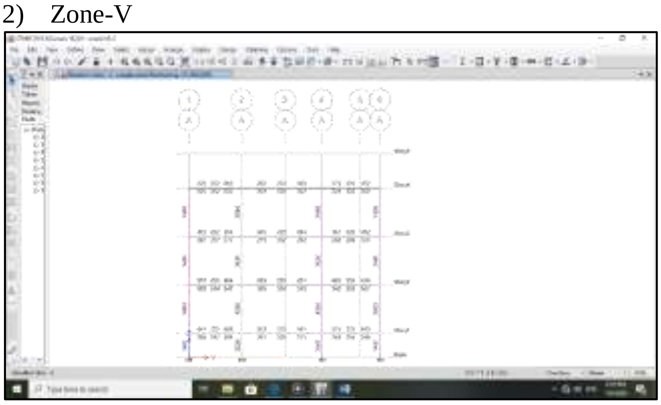


2) Reinforcement variation in Columns:

1) Zone-II

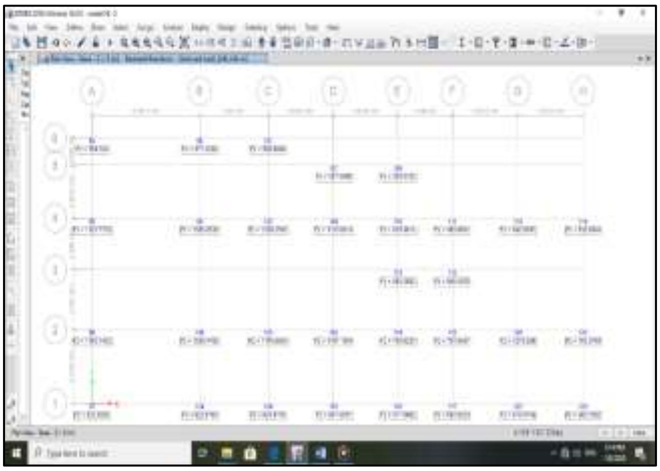


2) Zone-V

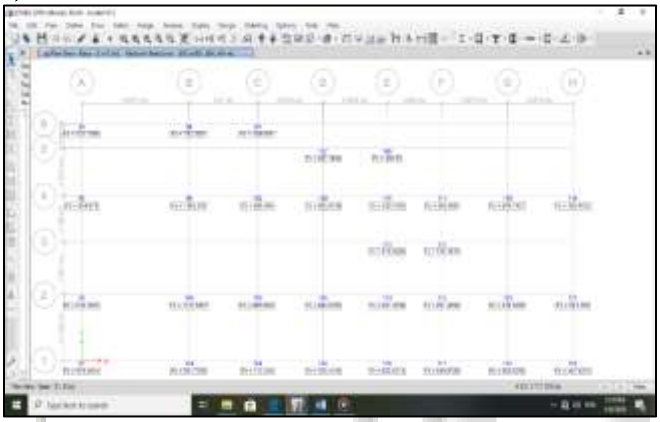


3) Variation in Column reaction:

1) Zone-II

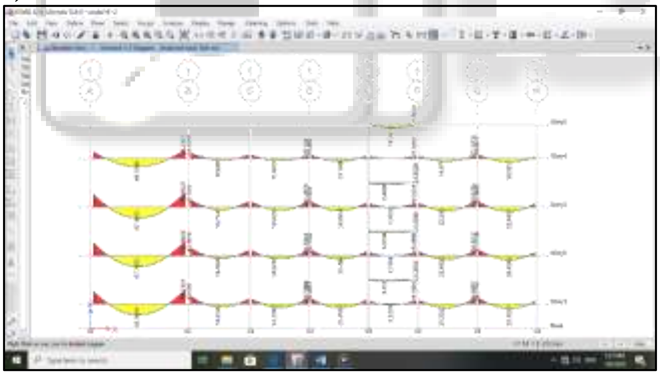


2) Zone-V

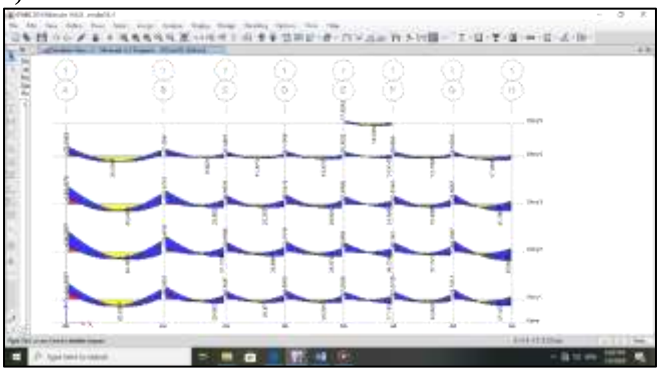


4) Bending moment reaction:

1) Zone-II

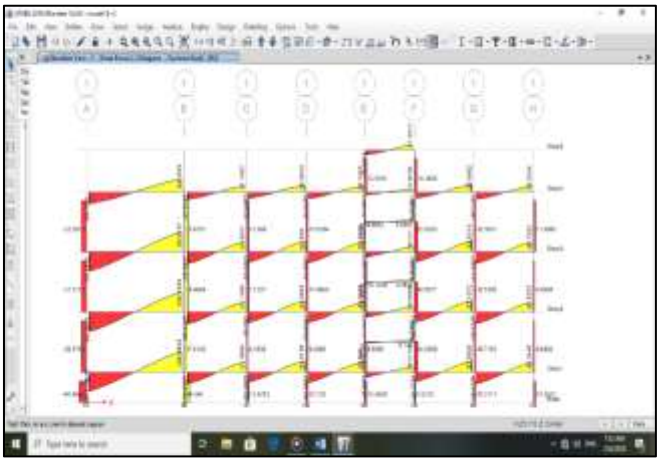


2) Zone-V

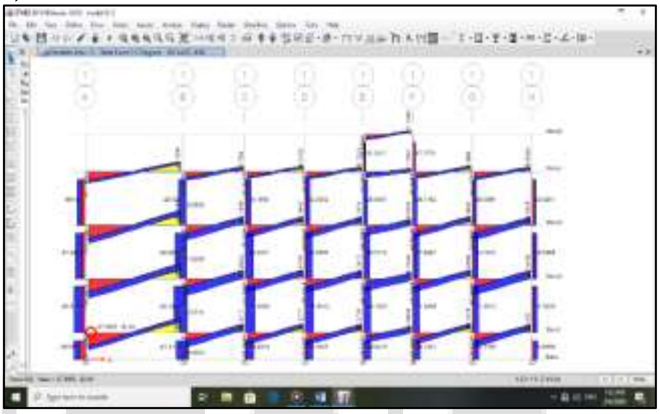


5) Shear force reaction

1) Zone-II



2) Zone-V



VI. Conclusions

A. General

The present work is focused on the study of behavior of structure with varying zone are studied and displacement, drift, storey shear, time period and base shear are the parameters considered for analysis and study the variation in the beam details, column details, base reaction for all zones in the structure.

B. Conclusions

1) From the above study we can observed that the displacement increases when we considered seismic action for the structure.
2) Compare to zone-II, Zone –V have maximum value for all considered parameters.
3) Storey shear is reduced for shear wall structure compared to bare frame structure.
4) Time period got for models is within limitations.
5) From the study we can say that the building have effect from the seismic factors.
6) While designing the structures we need to consider the seismic factor for the analysis.
7) From the study of reinforcement details of different storey of different zone we can say that seismic effect the area of reinforcement in each story at each zone

C. Scope for Future Work

Within the limited scope of the present work, the broad conclusions drawn from this work have been reported.

However, further study can be undertaken in the following areas:
1) By considering different material property analysis can be done.
2) By varying the story height and increasing story number the analysis can be done for different zones.
3) Varying the column and beam dimensions for same models can be analyzed.
4) Consideration of soil surface interaction for the model.
5) Irregular structures are considered for analysis.

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