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Response of High-Rise Buildings, Against Earthquake Forces under Different Soil Conditions, And Wind Forces

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ABSTRACT: Past history and geological evidences show that rate of occurrence of natural hazards, such as cyclones, earth-quakes and tsunamis, has become increasing and frequently recurring phenomena all over the world. Severe cyclones and earthquakes cause extensive damage to buildings, structures, transmission lines, service reservoirs etc; leading to significant loss of life and property. Bitter experiences left during past mega earthquake events remind the coastal community on importance of understanding the behaviour of high-rise buildings when subjected to earthquake and wind forces. It is a known fact that when a similar structure rests on different soils it behave differently. Recent 2011 Japan and 2004 Indonesia earthquakes witnessed many failures of structures due to soil-structure interaction effects, particularly, when they are constructed on loose soils.

In the present investigation, a multi-storied building located in coastal region is chosen as an example for obtaining the response parameters like base shears and displacements when subjected to wind and earthquake loads. In the analysis, soil-structure interaction effects are also considered and the soil is represented by introducing two additional springs, one in horizontal direction and the other in rocking mode. A comparative study is made on the results obtained from the analysis to identify weather maximum response occurs at different storey levels due to either wind forces or earthquake forces. Accordingly, a useful guideline can be evaluated while designing high-rise buildings against lateral loads.

KEYWORDS: Earthquake, Wind, Soil-structure Interaction, Time Period, Base Shear, Displacement.

I. INTRODUCTION

The governing criteria for carrying out dynamic analyses for earthquake forces are different from wind loads. According to the provisions given in IS 1893(Part 1):2002, parameters like height of the structure, seismic zone, vertical and horizontal irregularities, soft and weak storey influences the dynamic analysis for earthquake load. The contribution of the higher mode effects are included in arriving at the distribution of lateral forces along the height of the building. However As per IS 875(Part 3):1987, when wind interacts with the building, both positive and negative pressures occur simultaneously, and the building must have sufficient strength to resist these pressures. The magnitude of the wind pressure is a function of basic wind speed, topography, building height, internal pressure, and building shape.

When a structure is subjected to an earthquake excitation, it interacts with the foundation and soil, and thus changes the motion of the ground. It means that the movement of the whole ground structure is influenced by type of soil as well as by the type of structure. Hence ,the behaviour of soil at the foundation level under the action of seismic forces is the most important factor to be considered in the analysis, particularly in loose soils.

The main objective of the study is to carry out seismic analysis on ten storied office building when similar building rest on different soils and the results are compared with those obtained when the building is assumed to be fixed at the base.

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Similarly wind load analysis following IS 875(part-3) is carried out when similar structure is located in different wind zones.

II. A LITERATURE REVIEW

K. Rama Raju, M.I. Shereef, Nagesh R Iyer, S. Gopalakrishnan et. al. (2013).

In this paper analysis of tall buildings subjected to wind load seismic loads. Studied the limit state method of analysis and design of a 3B+G+40-storey reinforced concrete high rise building under wind and seismic loads as per IS codes of practice is described. Safety of the structure is checked against allowable limits prescribed for base shear, roof displacements, inter-storey drifts, and accelerations prescribed in codes of practice and other relevant references in literature on effects of earthquake and wind loads on buildings.

Dr. K. R. C. Reddy, Sandip A. Tupat et. al. (2014)

Presented a comparative study of wind and earthquake loads to decide the design loads of a multi-storeyed building. In that multi-storeyed building is analyzed for earthquake loads in various zones based on IS 1893 and for wind loads IS 875 code is used. The wind loads are estimated based on the design wind speed of that zone with a variation of 20%. The wind loads so obtained on the building have been compared with that of earthquake loads. Finally, it is found the wind loads are more critical than the earthquake loads in most of the cases.

III. SOIL STRUCTURE INTERACTION

When a structure is subjected to an earthquake excitation, the seismic waves travel through different soil media change the motion of the ground. It means that the movement of the whole structure system is influenced by type of soil especially founded on relatively flexible soils. The interaction phenomenon is principally affected by the mechanical energy exchanged between the soil and the structure. The influence of soil structure interaction plays vital role in earthquake analysis of the structures. The method of estimating the basic parameters like, shear wave velocity, mass density, poisson's ratio, shear modulus and damping ratio, are suggested by whitmen and richart and the values of these parameters are given in table.1.

In the present study the following types of soils are considered for the analysis. TYPE-A : Clay/Soft Clay, TYPE-B: Sand/Red Soils, TYPE-C: Soft Rock/Murram,TYPE-D: Hard Rock, TYPE-E: Fixed Base Condition [No SSI].

Table.1.Properties of Soils

Type	Description of soil	Bearing Capacity of soil (KN/m ²)	Shear wave velocity V _s (m/sec)	Mass density ρ (KN – Sec ²) / m ⁴	Poisson's ratio (ν)	Shear modulus G=ρV _s ² (KN/m ³)	Damping ratio
A	Clay/Soft clay	100	60	1.70	0.45	6120	15%
B	Sand/red	200	150	1.85	0.40	41625	12.5%
C	Soft rock/murram	250	400	1.90	0.33	304000	10%
D	Hard rock	500	2700	2.60	0.30	18954000	6%
E (Fixed base)	Rock	-	-	-	-	-	5%

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IV. PRESENTATION OF MATHEMATICAL MODEL

SOIL MODEL

Soil Model is representing in terms of stiffness of soil, mass of the footing & damping ratios. Since the structures are usually designed for gravity loads, only horizontal and rocking springs are considered in the analysis. In the present analysis, rectangular type of footing is adopted for the building. These equivalent soil spring constants are worked out for different classification of soil based on work done by whitmen and richart [1967].

Equivalent stiffness values of soil springs are worked out as follows

$$k_x = 2(1 + \nu) G \beta_x (BL)^{1/2}$$

$$k_\psi = \frac{G \times \beta_\psi \times BL^2}{1 - \nu}$$

Where

k_x = Horizontal stiffness of soil in KN/m, k_ψ = Rocking stiffness of soil in KN-m, β_x & β_ψ are constants suggested Whitmen & Richart as Shown in fig.1., B is the width of the footing in the direction of horizontal excitation is the length of the footing in the direction of horizontal excitation.

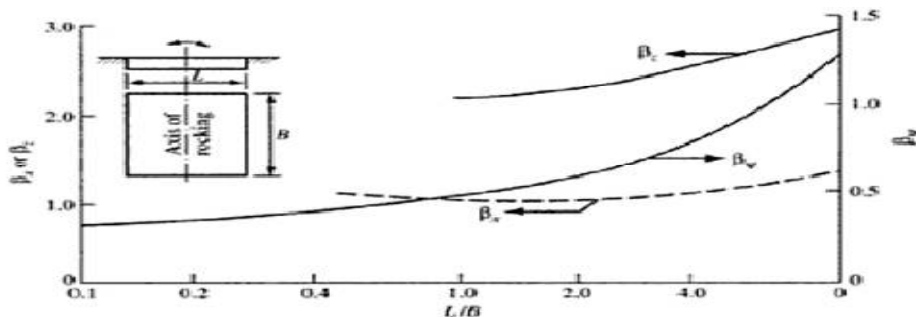


Fig.1. Constants for rectangular footings (Whitman and Richart) 1967.

Structure Model.

A ten stored office building 13.23 m x 24.23 m, size in plan as in fig.2, with 3m storey height of each floor, resting on different types of soil is chosen for the analysis.

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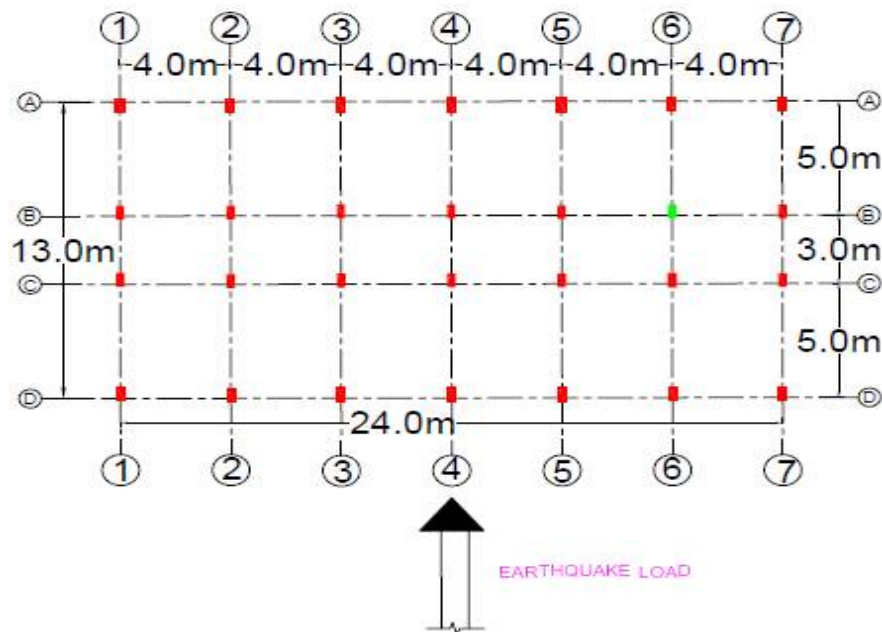


Fig-3. PLAN OF AN OFFICE BUILDING

Preliminary Data

PARAMETER	DIMENSIONS
Height of The Building	30m
Height of The Each Storey	3m
No. of Storeys	10
Column Size	0.3m x 0.6m
Beam Size	
Longitudinal Beam Size	0.23m x 0.35m
Transverse Beam Size	0.23m x 0.5m
Slab Thickness	0.12m
Parapet Wall Height	1m
External Wall Thickness	0.23m
Internal Wall Thickness	0.15m
IS 1893 Part 1 (2002) & IS 875-1987(Part-3) Codes are used	
Proposed Software	MATLAB R2018a & STAAD PRO

Property of Materials & Gravity Loads

PROPERTY OF MATERIAL	LOADS
Grade of Concrete	M25
Grade of Steel	Fe 415
Unit Weight of Concrete	25 KN/m ³
Unit Weight Of Brick	19 KN/m ³

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Live Load (Roof Level)	4KN/m ²
Live Load (Terrace)	1.5 KN/m ²
Floor Finish Load	1 KN/m ²
Terrace Finish Load	1.5 KN/m ²

Mathematical Model:

The masses are lumped at each storey level and equivalent stiffness values of all columns & infill walls in each storey are represented as spring at each storey level as shown in fig.3.

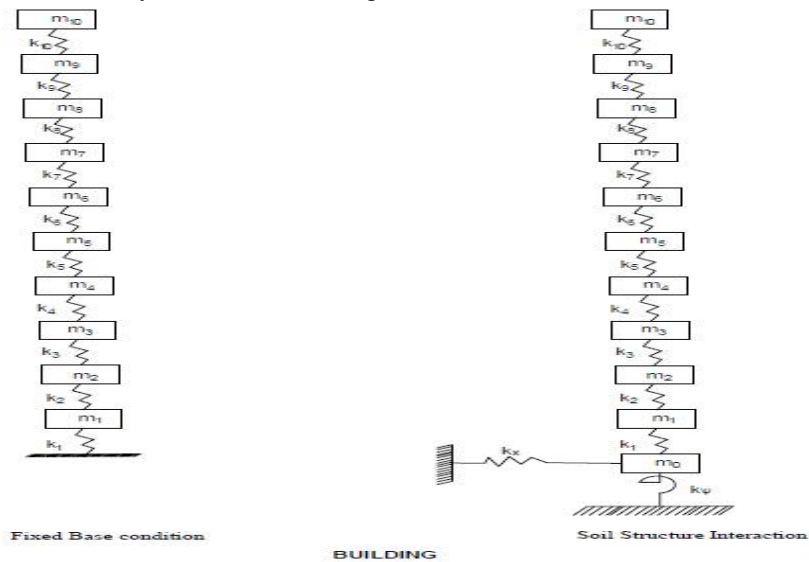


Fig.4. Building Model

The stiffness of each storey is evaluated considering the effect of stiffness of columns as well as infill walls. Each column stiffness value is taken as $k_c = \frac{12E_c I_c}{L^3}$. The infill wall is treated as an equivalent diagonal strut i.e., the system is modelled as a braced frame and infill walls as web element in the buildings, the periphery walls are considered with 230 mm thick and Interior walls are of 115 mm thick.

$$\text{Stiffness of infill wall } K_w = \frac{AE_m}{L_d} \cos^2 \theta$$

Where

E_m = Elastic modulus of masonry wall, E_f = Elastic modulus of frame material, A = Cross-sectional area of diagonal strut = $w \times t$, w = Width of strut, t = Thickness of wall

$$w = \frac{1}{2}(\sqrt{(\alpha_h^2 + \alpha_l^2)}), \alpha_h = \frac{\pi}{2} \left[\frac{E_f \times I_c \times h}{2 \times E_m \times t \times X \sin 2\theta} \right]^{\frac{1}{4}}, \alpha_l = \pi \left[\frac{E_f \times I_b \times l}{E_m \times t \times X \sin 2\theta} \right]^{\frac{1}{4}}, \theta = \tan^{-1} \frac{h}{l}$$

Method of Analysis

The analysis of the proposed building is carried out by two methods; one is earthquake analysis considering soil-structure interaction in seismic zones III, IV & V and the other is wind load analysis in wind speed zones III, IV & V. The mathematical model with masses and springs as explained above are used.

The equilibrium equation is $m\ddot{x} + kx = 0$ and can be represented in matrix form

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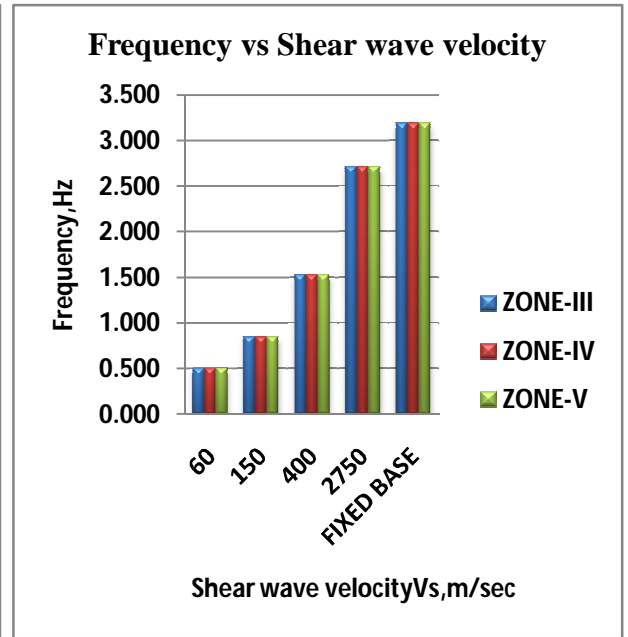
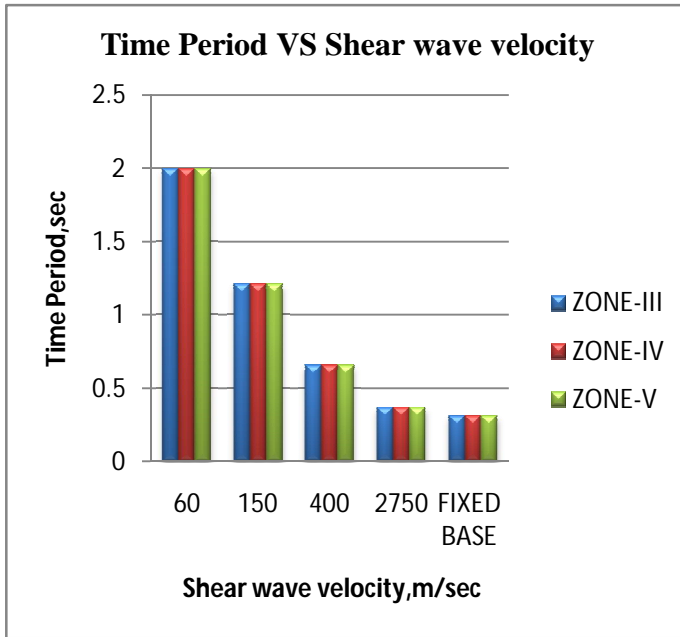


Fig.5. Time Period VS Shear wave velocity

Fig.6. Frequency vs. Shear wave velocity

Earthquake analysis.

Seismic coefficient method is used for obtaining the response of the chosen structure to earthquake loads using IS 1893(part-1):2002 code. The importance factor and response reduction factors are taken as I=1 and R = 3 respectively.

The base shears and maximum displacements at base of the structure are presented in Table-5 below.

Table 5 Base shear and Displacements in Different Seismic Zones

Type of Soil	Seismic Zone-III		Seismic Zone-IV		Seismic Zone-V	
	Base shear (KN)	Displacements (mm)	Base shear (KN)	Displacements (mm)	Base shear (KN)	Displacements (mm)
A	163.46	16.62	245.19	24.93	367.78	37.40
B	188.80	10.17	283.19	15.26	424.79	22.89
C	244.27	4.76	366.42	7.14	549.63	10.71
D	248.62	1.56	373.20	2.34	559.82	3.51
E (Fixed)	255.86	1.43	383.60	2.14	575.21	3.22

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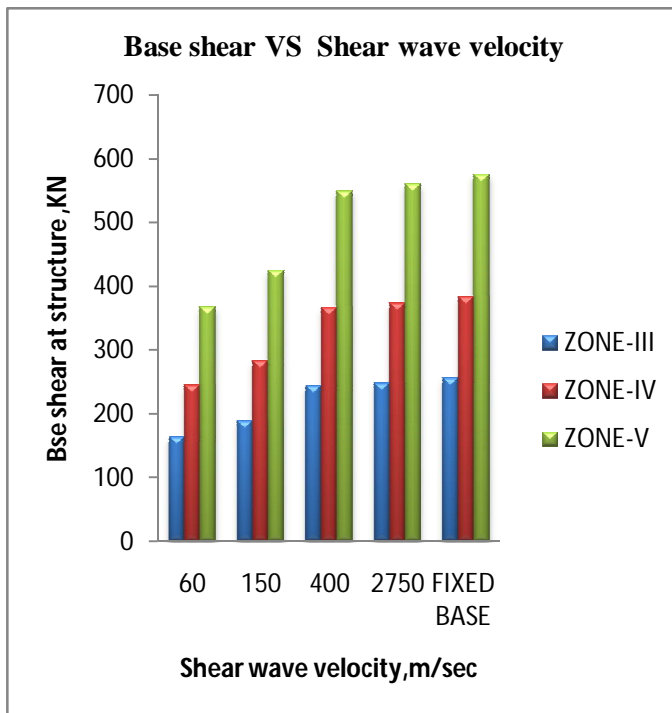


Fig.7. Base shear VS Shear wave velocity

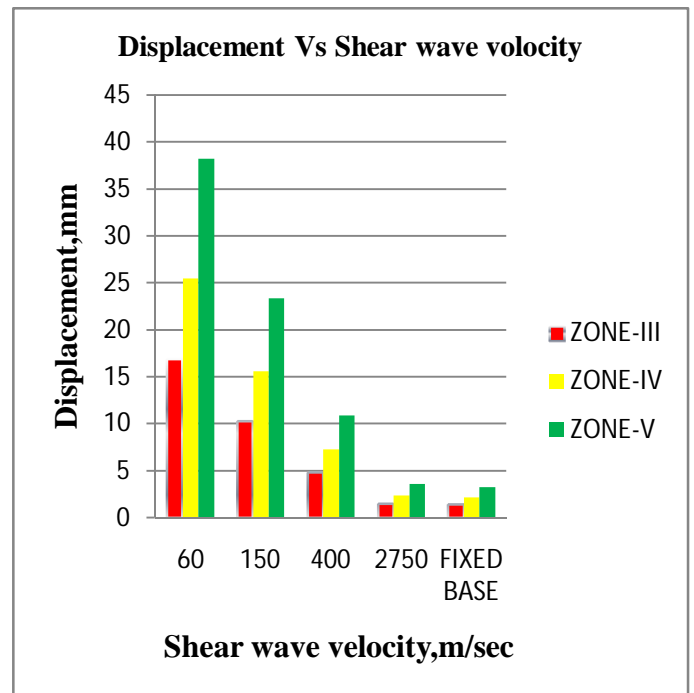


Fig.8. Displacement Vs Shear wave velocity

Wind load analysis:

Wind load analysis is carried out by using staad pro software when the structure is located in wind speed zone-III, IV & V with basic wind speed 44m/sec, 47 m/sec & 50 m/sec respectively as given in IS 875(Part 3):1987.

b) Design wind speed (V_z)

The basic wind speed (V_b) at any site is calculated according to IS 875 and the design wind velocity at any height (V_z) for a chosen structure, is obtained from the equation,

$$V_z = V_b * k_1 * k_2 * k_3$$

Where, V_z = Design wind speed at any height z in m/sec., k_1 = Probability factor (risk coefficient),

k_2 = Terrain, height and structure size factor, k_3 = Topography factor.

c) Design wind pressure (P_z)

The design wind pressure at any height above mean ground level is obtained from the equation.

$$P_z = 0.6 * V_z^2$$

Where, P_z = wind pressure in N/m^2 , V_z = Design wind speed in m/sec at height z.

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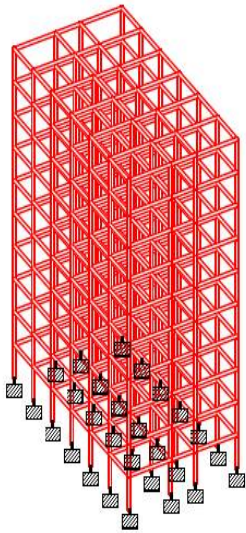


Fig.9.1.3D.Model

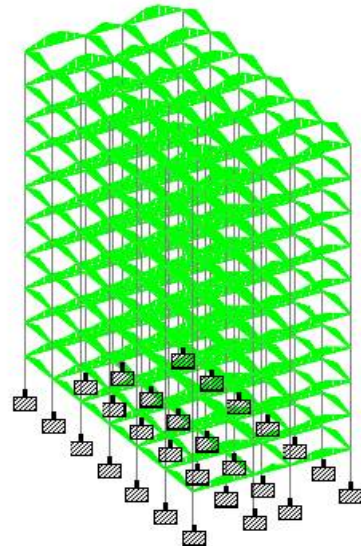


Fig.9.2.Load combination 1.5(DL+LL)

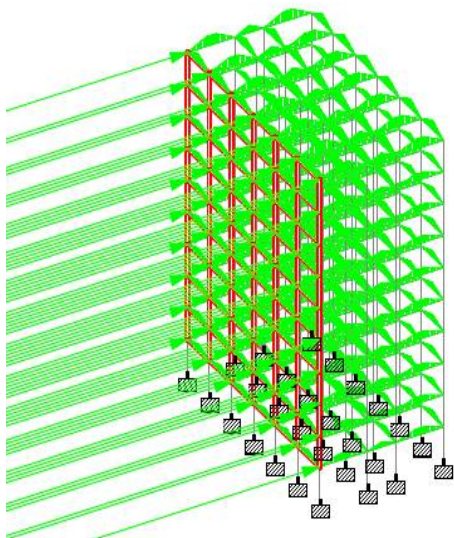


Fig.9.3.Load combination 1.5(DL+WL)

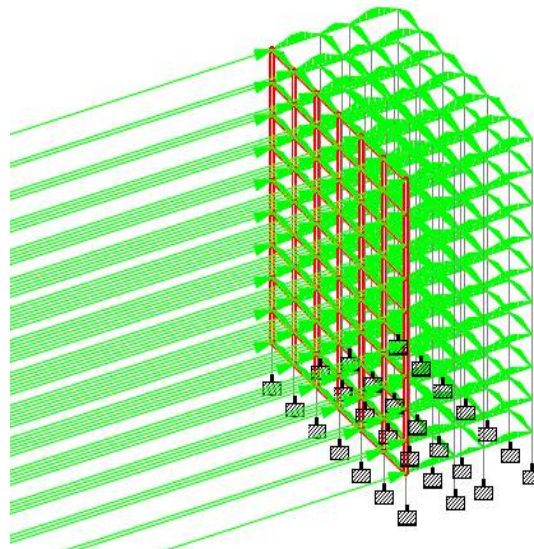


Fig.9.4.Load combination 1.2(DL+LL+WL)

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Table 6 Results for Wind Load Analysis with Different Wind Zones

Type of Wind zone	Basic wind Speed zone (m/sec)	Load combination	Displacements (mm)	Base shear (KN)
III	44	1.5(DL+LL)	4.79	408.50
		1.5(DL+WL)	14.58	
		1.2(DL+LL+WL)	12.12	
IV	47	1.5(DL+LL)	4.79	497.76
		1.5(DL+WL)	16.58	
		1.2(DL+LL+WL)	13.67	
V	50	1.5(DL+LL)	4.79	585.48
		1.5(DL+WL)	18.74	
		1.2(DL+LL+WL)	15.35	

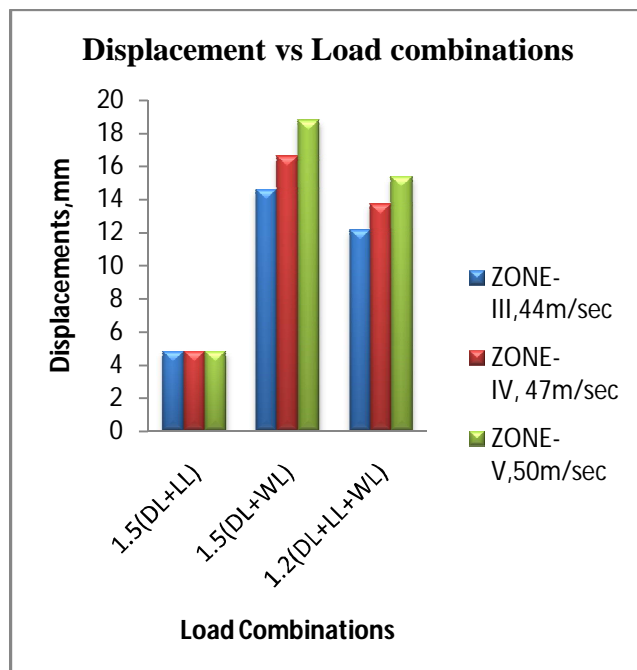


Fig.10. Displacement Vs Load combinations

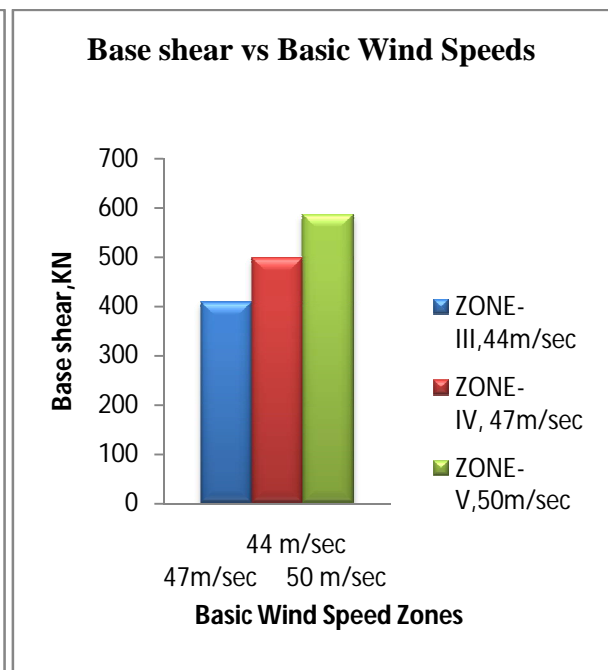


Fig.11. Base shear Vs Load combinations

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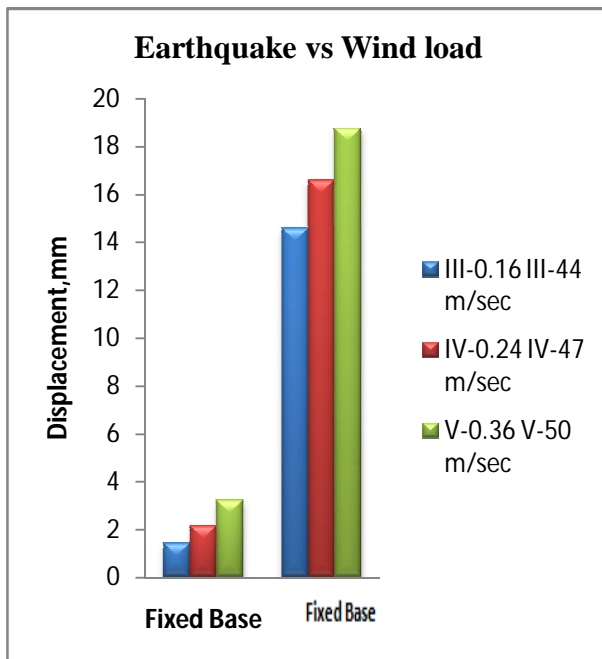


Fig.12.Earthquake Displacement vs Wind load Displacement

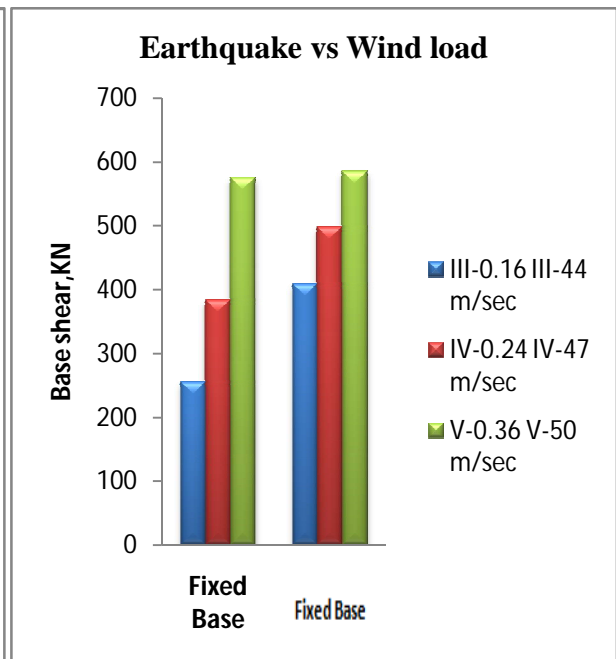


Fig.13.Earthquake Base shear vs Wind load Base shear

V. CONCLUSION

- Shear wave velocity influences significantly the change in shear modulus of soil from static to dynamic state and is found that the shear modulus increases exponentially with the increase of soil stiffness
- Time periods of the structure invariably decrease with the increase in soil stiffness.
- The displacements of structure increases with the decrease of soil stiffness; particularly in loose soils. This increase mainly attributes due to rotational springs constant of soil.
- When soil-structure interaction is considered, it is observed that base shear decreases with decrease of soil stiffness and this is mainly because loose soils absorb more shear wave energy compared to stiffness of soil or rock.
- When buildings rest on loose soils, the displacements due to earthquake forces are observed more compared to wind forces. However when buildings rest on stiff soils, the displacements due to wind are found high compared to earthquake forces.
- Base shears due to wind with higher velocities are observed more compared to the earthquake forces, However when these structures rest on stiff soils or rock and located in higher seismic zones, the base shears are found more compared to those obtained due to wind forces.

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