A Parametric Study for Analysis of Space Frame with Isolated Footings Supported on Winkler's Spring Base with Reference to Idealized Fixed/Hinged Base

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Abstract— A G+3 storied reinforced concrete Space frame having 3 bays of 5m each in X direction and 3 bays of 4 m each in Y direction located in seismic zones IV and V has been analyzed with the fixed, hinged and flexible foundation. The building with the flexible foundation has been analyzed incorporating soil-structure interaction (SSI) effects. For flexible foundation frame is supported by isolated footing on Winkler's spring bed. Winkler's spring base is applied in software by assigning nodal springs having value equal to soil stiffness at the base of discretized plate. Soil-structure interaction (SSI) effects as per FEMA 356 are also done. The space frame is subjected to various combinations of gravity and earthquake loads. The space frame is analyzed keeping its base fixed and hinged and based on the result of analysis, it is designed as per IS: 456 (2000) and IS: 1893 (2002). The parameter varied for the study is the modulus of subgrade reaction of the soil. A comparison of the displacements of the frame and the time period of the whole structure is done.

Key words: Isolated Footings, Winklers spring base, fixed/hinged base

I. INTRODUCTION

Some recent earthquakes (Kobe, 1995) highlighted that seismic behavior of a structure is highly influenced not only by the super structural response but also on the response of the foundation and ground. Hence, the seismic analysis of a structure strongly recommends the usage of a whole structural system considering the superstructure, foundation and ground giving rise to an area called Soil Structure Interaction (SSI). SSI is the phenomenon where the response of the soil influences the motion of the structure and vice versa. In conventional structural design, SSI guidelines given by FEMA 356 and FEMA 440 as well as isolated footings are modelled standard procedure for considering SSI in the seismic analysis, hence the on Winkler's spring Effects are not considered. Neglecting SSI effect for a relatively flexible structure founded on hard soil is reasonable. But, for a relatively stiff structure founded on either soft or medium soil neglecting SSI has a great impact on structural response and design. IS 1893(Part I):2002 suggests that SSI may not be considered in the seismic analysis of structure supported on rock or rock like material. But, the code does not provide a bed to consider to incorporate the SSI effect in the seismic analysis of RC building. The seismic analysis of RC building is done by creating a 3D model in Staad Pro V8i Select series 5 using seismic coefficient method

II. PROBLEM

In this paper, a three story RC building, having regular plan geometry is considered for analysis. This building is analysed for two different seismic zones: IV and V as per IS 1893:2002 and foundation with and without SSI, have been considered for analyses. The plan of the building is shown in Figure 1.

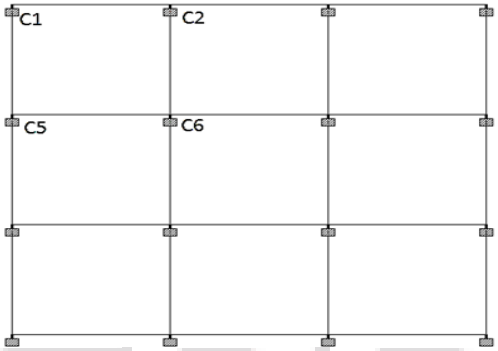

Fig. 1: Plan of Building

A. Loading Parameters:

Dead Load (IS: 875 part1 – 1987) (SLAB thickness = 125 mm)	
Floor Load	3 kN/m²
Floor finish Load	1 kN/m²
Total Dead Load	4 kN/m²
Live Load (IS 875 – Part 2 1964)	
Floor Live Load	3 kN/m²
Wall load	
External Wall	12 kN/m
Internal Wall	7.21 kN/m

Seismic load (IS: 1893 - 2002)	
Zone factor Z	0.24 0.36
Importance Factor I	1
Response reduction factor R	5
Soil Type	Type II
Spectral Acceleration Coefficient for medium soil (Sa/g)	2.50

Table 1: Seismic Parameters

B. Element Specification:

	Zone IV	Zone V
Slab	125 mm (All)	125 mm (All)
Beam	300 mm x 450 mm (All)	300 mm x 600 mm (All)
Column	400 mm x 400 mm (All)	400 mm x 400 mm (All)

Table 2: Element properties

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C. Load Combination for Design:

Space frame has been analysed for the following load combinations:

1) 1.5(D.L+L.L)
2) 1.2(D.L+L.L+EQX)
3) 1.2(D.L+L.L-EQX)
4) 1.5(D.L+EQX)
5) 1.5(D.L-EQX)
6) 1.2(D.L+L.L+EQZ)
7) 1.2(D.L+L.L-EQZ)
8) 1.5(D.L+EQZ)
9) 1.5(D.L-EQZ)

After selecting the space frame and the software to be used for the present task, the space frame is analysed keeping its base fixed, hinged as well as spring, it has been also analysed by calculating soil stiffness by equivalent method given in FEMA- 356

D. Selection of Soil Subgrade Modulus:

Space frame will be analysed for carry out effect of soil structure interaction for the following subgrade modulus. Where the unit of Soil subgrade modulus is kN/m3 and SBC kN/m2

The equivalent SBC from the soil subgrade modulus can be calculated as

$$Ks = P/\delta$$

Where δ = Allowable settlement (here 40 mm is taken)

E. Elevation with Fixed Base:

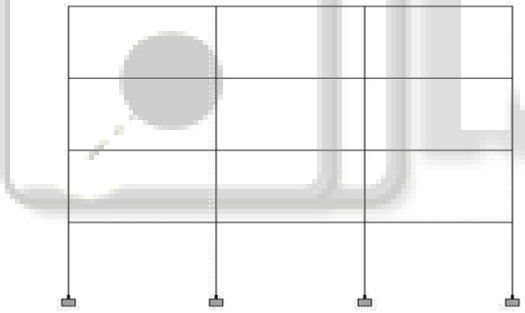

Fig. 2: Elevation with Fixed Base

F. Elevation with Winkler's Base:

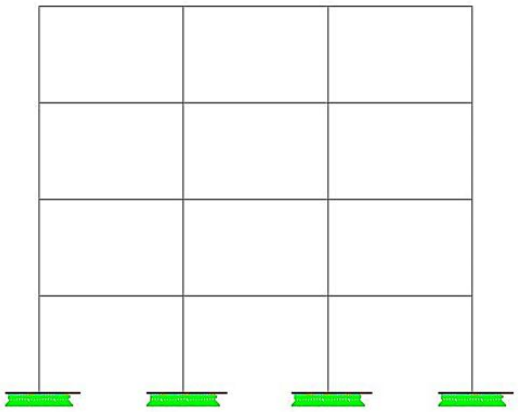

Fig. 3: Elevation with Winkler's Base

G. Elevation with Hinged Base:

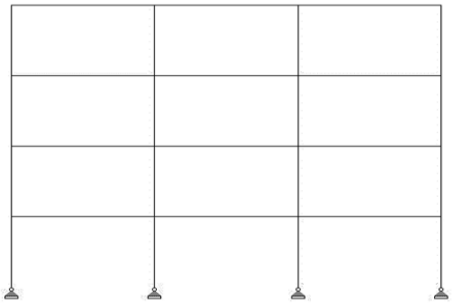

Fig. 4: Elevation with Hinged Base

H. Elevation with FEMA -356 spring Base:

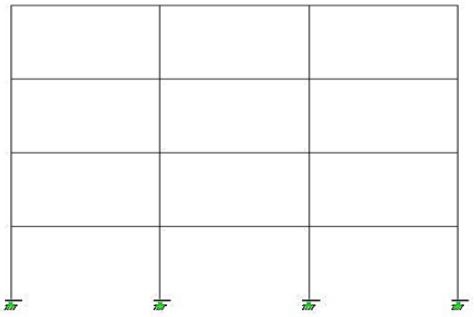

Fig. 5: Elevation with FEMA -356 spring Base

Fig 2 Elevation of Building

Ks = 5000 SBC = 200	Ks = 10000 SBC = 400	Ks = 12000 SBC = 480	Ks = 15500 SBC = 620	Ks = 31000 SBC = 1240	Ks = 39000 SBC = 1560

Table 3: Selected Subgrade Modulus

I. Flexible Foundation Effect by Winkler's Spring Bed:

While considering SSI effect as of winkler's spring model first of all from support reactions foundation is proportioned and designed for the appropriate load combinations as per discussed. Then after the foundation is modelled in the software as 3D plate element beneath the column and subgrade is modelled as springs. Finite Element Analysis (FEA) is used for analyzing this problem of plate resting on springs. FEA is computer based numerical technique for calculating the strength and behavior of engineering structures, where in a structure is broken down into many small simple blocks or elements and each elements is analyzed individually. While modelling foundation thickness of the plate beneath the column has given larger than compare to the foundation.it has given almost to the floor height as for making it as rigid element. All the other plates have the thickness equal to the thickness of foundation. Meshing is applied in the foundation considering aspect ratio lies between 1-2 and below each meshed element vertical spring is modelled at each discretized node having value equal to soil subgrade modulus.

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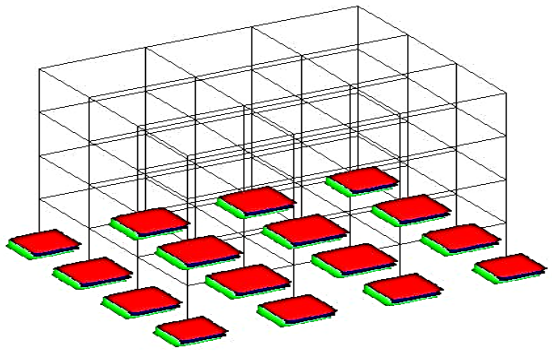


Fig. 6: Building with Winkler's spring base

J. Flexible Foundation Effect as per FEMA:

In RC building with shallow foundation, the flexible foundation effect is incorporated with the help of six soil springs, whose stiffnesses are calculated by Eq. 1.These soil springs represent the stiffness of soil in three translational directions and three rotational directions. Kx, Ky, Kzare translational soil stiffnesses in N/min x,y and z directions respectively. Kxx, Kyy, Kzzare rotational spring stiffnesses in N-m/rad about x,y and z directions repectively.

$$Ki = kisur \times \beta i \qquad (1)$$

where,i = x, y, z, xx, yy and zz;

Ki, sur is stiffness of foundation at surface and βi is correction factor for embedment, which can be calculated from the formulas given in Tables

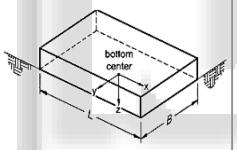
Degree of Freedom	Stiffness of Foundation at Surface	Note
Translation along x-axis	$K_{x,sur} = \frac{GB}{2-\nu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 1.2\right]$	
Translation along y-axis	$K_{y,sur} = \frac{GB}{2-\nu}\left[3.4\left(\frac{L}{B}\right)^{0.65} + 0.4\frac{L}{B} + 0.8\right]$	
Translation along z-axis	$K_{z,sur} = \frac{GB}{1-\nu}\left[1.55\left(\frac{L}{B}\right)^{0.75} + 0.8\right]$	
Rocking about x-axis	$K_{xx,sur} = \frac{GB^3}{1-\nu}\left[0.4\left(\frac{L}{B}\right) + 0.1\right]$	
Rocking about y-axis	$K_{yy,sur} = \frac{GB^3}{1-\nu}\left[0.47\left(\frac{L}{B}\right)^{2.4} + 0.034\right]$	Orient axes such that $L \geq B$
Torsion about z-axis	$K_{zz,sur} = GB^3\left[0.53\left(\frac{L}{B}\right)^{2.45} + 0.51\right]$	

Table 4: Spring constraints at ground surface for rigid footing

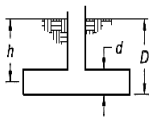
Degree of Freedom	Correction Factor for Embedment	Note
Translation along x-axis	$\beta_x = \left(1 + 0.21\sqrt{\frac{D}{B}}\right)\cdot\left[1 + 1.6\left(\frac{hd(B+L)}{BL^2}\right)^{0.4}\right]$	
Translation along y-axis	$\beta_y = \beta_x$	
Translation along z-axis	$\beta_z = \left[1 + \frac{1}{21}\frac{D}{B}\left(2 + 2.6\sqrt{\frac{B}{L}}\right)\right]\cdot\left[1 + 0.32\left(\frac{d(B+L)}{BL}\right)^{2/3}\right]$	d = height of effective sidewall contact (may be less than total foundation height)
Rocking about x-axis	$\beta_{xx} = 1 + 2.5\frac{d}{B}\left[1 + \frac{2d/B}{(d/D)^{0.2}}\sqrt{\frac{B}{L}}\right]$	h = depth to centroid of effective sidewall contact
Rocking about y-axis	$\beta_{yy} = 1 + 1.4\left(\frac{d}{L}\right)^{0.6}\left[1.5 + 3.7\left(\frac{d}{L}\right)^{1.9}\left(\frac{d}{D}\right)^{-0.6}\right]$	For each degree of freedom, calculate $K_{emb} = \beta K_{sur}$
Torsion about z-axis	$\beta_{zz} = 1 + 2.6\left(1 + \frac{B}{L}\right)\left(\frac{d}{B}\right)^{0.9}$	

Table 5: Correction factor for spring constraints due to embedment effect for rigid footing

To compute the soil-spring stiffness, the effective shear modulus, Poisson's ratio and dimensions of Foundation are required. The foundations are designed as per codal provisions by obtaining the design forces from Staad, to find effective shear modulus, G, simple approach from N value is adopted.

We have the value of SBC from that SBC we can derive the value of N. we can find out the SBC value from the Bearing capacity equations, there are two methods for finding out Bearing Capacity. 1. From Shear criteria 2.From Settlement Criteria. For different values of Ø we can find out different values of SBC and from IS:6403-1981 we have graph of Ø vs N so we can find out the N value for corresponding SBC.

There is a relation between E vs N where E = modulus of elasticity

E = 500 (N + 15) kPa (Foundation Analysis & Design By J.E.Bowles,table 5-6)

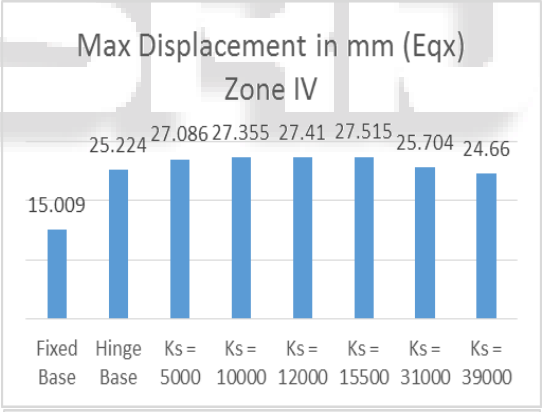
And we also know the relation between E vs G where G = Shear Modulus

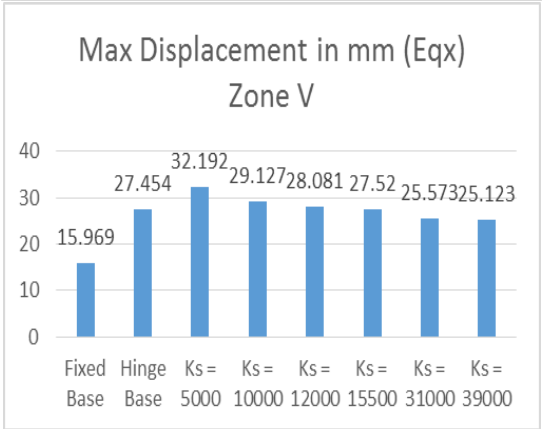
G = E/(2(1+μ)) where **μ** = poisons ratio (For sand **μ** = 0.3)

Col.No	SBC = 200 kN/m²	SBC = 400 kN/m²	SBC = 480 kN/m²	SBC = 620 kN/m²	SBC = 1240 kN/m²	SBC = 1560 kN/m²
1	1.8 m X 1.8 m	1.6 m X 1.6 m	1.6 m X 1.6 m	1.4 m X 1.4 m	1.4 m X 1.4 m	1.4 m X 1.4 m
2	2.0 m X 2.0 m	1.6 m X 1.6 m	1.4 m X 1.4 m	1.4 m X 1.4 m	1.0 m X 1.0 m	1.0 m X 1.0 m
5	2.0 m X 2.0 m	1.6 m X 1.6 m	1.4 m X 1.4 m	1.2 m X 1.2 m	1.0 m X 1.0 m	1.0 m X 1.0 m
6	2.2 m X 2.2 m	1.8 m X 1.8 m	1.8 m X 1.8 m	1.4 m X 1.4 m	1.0 m X 1.0 m	1.0 m X 1.0 m

Table 6: Foundation Sizes for different SBC values (for 3 bays X 3 bays, G+3)

III. ANALYSIS RESULTS





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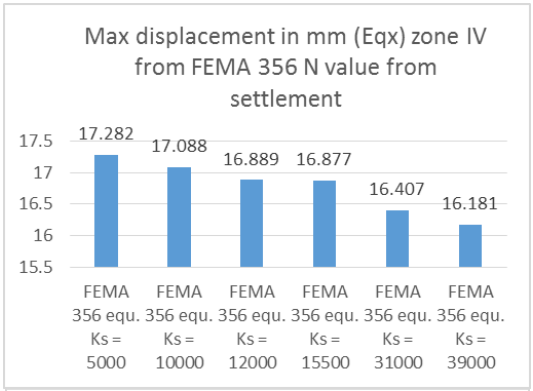

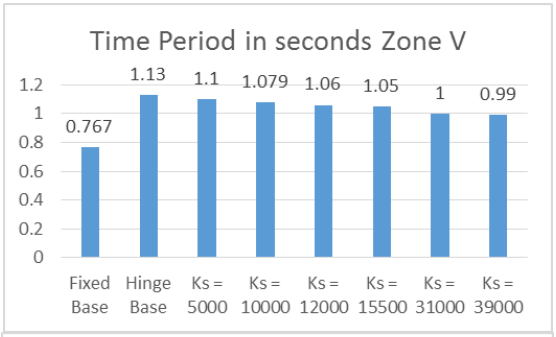

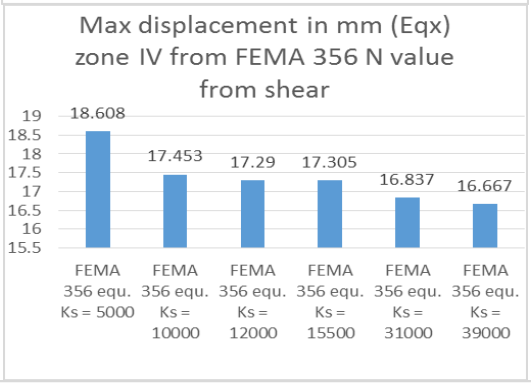

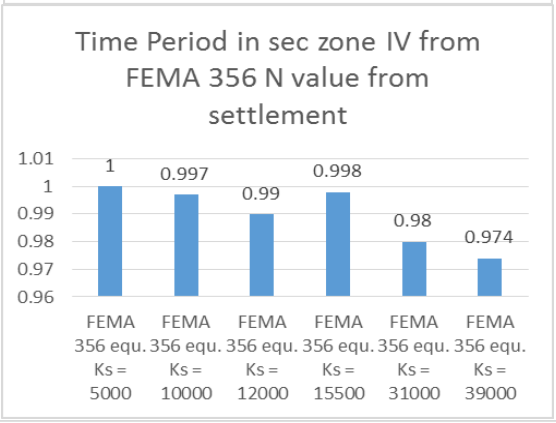

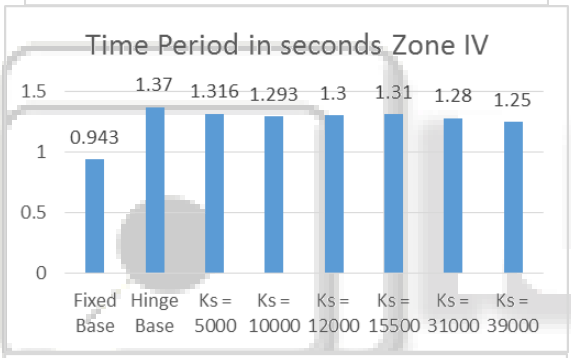

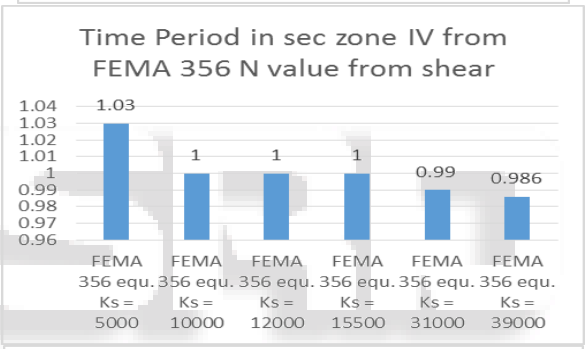

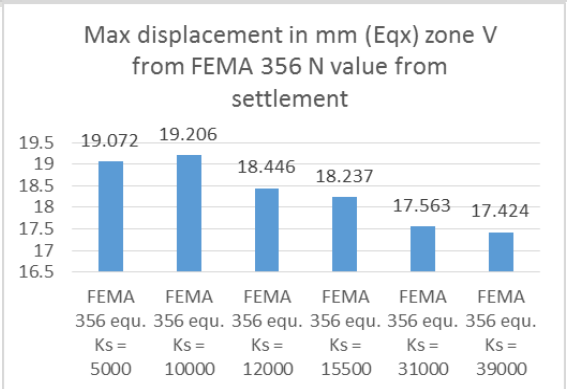

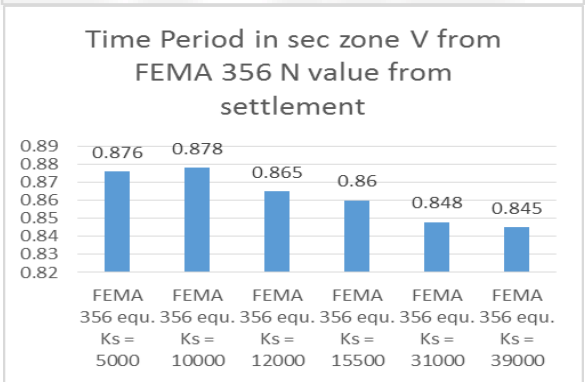

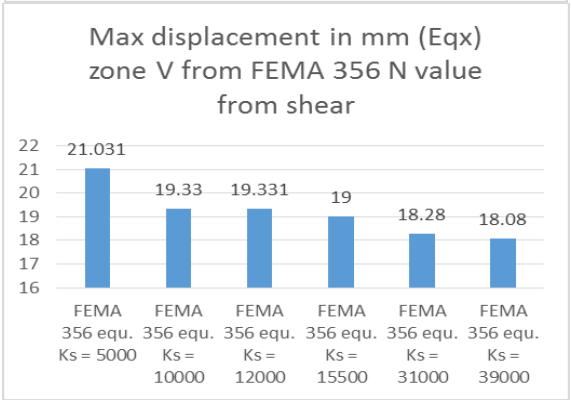

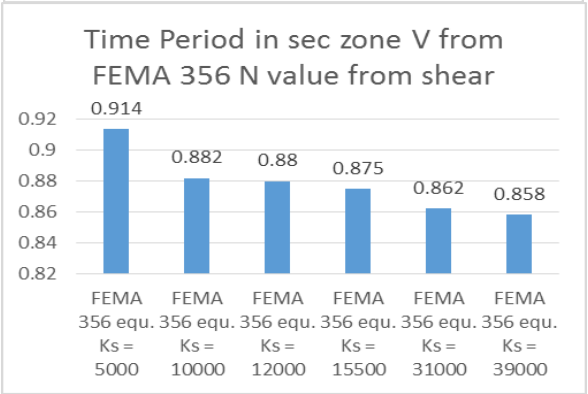

Fig. 7: Analysis Results

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IV. CONCLUSION

1) For this particular frame maximum displacement caused by Eqx load case is computed least for the fixed base condition while increasing the value of subgrade modulus the displacement is decreasing for the building on winkler's spring base as well as building on flexible foundation with the help of FEMA-356
2) The value of nodal displacement is maximum for the value of ks = 5000 kN/m3 for the building on flexible foundation frame is supported by isolated footing on Winkler's spring bed for zone IV as well as for zone V
3) The value of nodal displacement for ks = 39000 kN/m3 for the building on flexible foundation frame is supported by isolated footing is less than that of building on hinged base for zone IV
4) The value of nodal displacement for ks = 31000 kN/m3 and ks = 39000 kN/m3 for the building on flexible foundation frame is supported by isolated footing is less than that of building on hinged base for zone V
5) While displacement for the building on flexible foundation frame with the help of FEMA 356 for all subgrade modulus lies between building on fixed base and building on hinged base.
6) Time period of the whole structure is minimum for the building on fixed base and maximum for the building on the hinged base
7) While time period of the whole structure for all the soil subgrade modulus on winkler's spring base as well as for SSI effect as per FEMA- 356 lies between both the extremes for zone IV as well as for zone V
8) The value of time period decreases as per increase of the soil subgrade modulus value for SSI effects as per both the methods.
9) SSI effect as per FEMA-356 gives more stiff results than SSI effects for foundation frame is supported by isolated footing on Winkler's spring bed for this particular case.

V. ACKNOWLEDGEMENT

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