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A STUDY OF SOIL STRUCTURE INTERACTION FOR FRAMED STRUCTURES WITH PILE FOUNDATIONS

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Abstract - In this study,the purpose is to determine the response parameters by incorporating the effects of soil structure interaction on framed structures provided with deep (pile) foundations resting in different types of soil (medium and soft) by using some different methods of seismic design of structures and comparing the response parameters to study the SSI effect. As per ongoing practice, the structural design engineers generally do not consider the soil structure interaction and its detrimental or beneficial effect on a structure while designing the structure during an dynamic seismic loading in spite of the structures being supported on soil. The Soil-structure interaction is a mechanism which comprises both Structural and Soil Engineering.The soil parameters can affect the behaviour of the waves generated by earthquake which passes through the different soil or rock strata.

All the dead and live loads which are transferred to the some support (soil or rock) and hence this supporting medium (soil or rock) can vary the structural behavior in a small or large way.In case of soft and medium soil strata in which the pile foundations are laid,the soil-structure interaction has large effect. Hence during occurrence of earthquake, seismic forces are applied to the structures and the event of soil-structure interaction occurs among the structure,foundation and soil which changes the behavior of the ground motion and thus the behavior of structure. The relevant IS codes are followed for design of framed structures.

For the study of the response(SSI action),the framed structures supported by deep (pile) foundations have been adopted to be laid in two types of soils (medium and soft). The framed structures supported on fixed and flexible foundations were assumed to be subjected to seismic forces in seismic zones II,III,IV and V for the analysis . The structures were analyzed by various seismic design methods using software STAAD Pro. The response of framed structure in form of Base shear,Base moment and top Lateral deflection for all building frames are presented in this paper.

Keywords - Dynamic load, Soil-structure interaction, pile foundations with their specifications, Fixed base, Flexible base, Base shear,Base moment, top Lateral displacement, Static Design Method, SRSS Method,CQC Method,Capacity Spectrum Method and ABS Method.

I. INTRODUCTION

If sub-soil strata at shallow depth is loose/weak and/or superimposing loads are heavy, the open foundations are not feasible. In such a case deep foundations (pile/well foundations) are required to be adopted.The well foundations are generally adopted in bridges and the pile foundations are widely used in case of framed structures due to very heavy loads of super-structure and / or when the adequate bearing capacity of the soil is not available at reasonable depth. Such foundations are required to be designed for the lateral seismic load in addition to the gravity loads. The seismic response of pile foundations is greatly influenced by the behavior of the soil into which piles are embedded. However, seismic design codes either ignore the seismic behavior of the piles or greatly simplify the design procedure. This is considered to occur due to foundation flexibility which causes an increase in a structural time period resulting in reduction of seismic design forces. But the studies have shown that this is not always true, neglecting the behavior of foundation piles may sometimes prove detrimental..

In addition to it, many theoretical studies have shown that the design based on rigid foundation assumption is not always secure and hence the dynamic soil-pile-structure interaction need to be considered in the seismic design.

The soil – pile structure interaction involves: (a) kinematic interaction – The seismic shear wave propagating through the soil towards the pile head is modified by the presence of embedded pile due to soil-pile stiffness contrast. It also causes deformation in piles and motion and displacement of pile head. This can occur even in the absence of the superstructure . (b) Inertial interaction- The dynamic response of the superstructure induces additional deformation into the pile as well as the surrounding soil. Both the effects go on simultaneously. Thus the piles are subjected to kinematic forces caused by the deformation of soils by the incoming seismic dynamic waves and inertia forces induced near the pile head by structural excitation.

Various approaches have been considered for the dynamic response analysis of piles. One of such methods is the Beam on Nonlinear Winkler Foundation (BNWF) model, where the soil-pile interaction is approximated using parallel nonlinear soil-pile (p-y) springs (e.g. Matlock 1978).

II. OBJECTIVES OF THE STUDY

The study is conducted with an aim of this paper to find out the effect of SSI on the response parameters (Base Shear, Base Moment & Lateral Displacement) by considering the soil structure interaction and analysed by various seismic design methods and comparing them in case of framed structures with pile foundations resting in different types of soil (medium and soft).

III. LITERATURE REVIEW

The framed structures are normally analyzed with their bases considered to be either completely rigid or flexible. Various approaches have been developed for the dynamic response analysis of single piles, including the finite element method (Kuhlemeyer 1979; Angelides and Roesset 1980; Randolph 1981; Faruque and Desai 1982) and the boundary element method (Sanchez 1982; Sen et al. 1985), both of which treat the soil media as a continuum. The discretization of a three-dimensional continuum creates variuos degrees of freedom, making the method impractical for the design of anything but extremely expensive structures (e.g., atomic plants,long bridges or airports). The Beam on Nonlinear Winkler Foundation (BNWF) model is a simplified approach using nonlinear soil pile (p-y) springs that can consider the nonlinear soil-pile-structure interaction, and has been useful in engineering field (e.g. Abghari and Chai 1995). Trochanis et al. (1991) showed that the response of laterally loaded piles using a BNWF formulation matched well with static load test data and nonlinear three dimensional finite element analysis. Trochanis et al. (1991) used a degrading constitutive model developed by Wen (1976) to represent the p-y springs. Matlock et al. (1978) utilized the BNWF concept to seismic problems by calculating the ground motion time histories along the depth of the soil profile and then applying the ground motion time histories to the p-y springs as excitation to the system. Kagawa (1980) further utilized the BNWF analysis in seismic problems by considering viscous dashpots with the nonlinear p-y springs to model the effects of radiation damping.The dynamic BNWF model was applied by Wang et al. (1998). The computer codes PAR (PMB Engineering 1988), NONSPS (Kagawa 1983) and DRAIN-2D (Prakash and Powell 1993) were evaluated by Wang et al. (1998). Boulanger et al. (1998) extended the work of Wang implementing a new p-y element in the Finite Element program GeoFEAP (Bray et al. 1995). Many researchers (e.g. Brown et al.(1988), Crouse et al.(1984), Dunnavant and O'Niell (1989), and Ochaoa and O'Neill (1989) have also performed tests with cyclic loads applied at the pilehead.

Various analysis of interaction have been given in many thesis. Till recently the only research by Buragohain et al. was related to the interaction analysis of frames on piles.The research material given by Buragohain et al. was conducted using the stiffness matrix method and was on the basis of the simplified assumptions meaningless realistic approach. This was the drawback in the interaction analysis of a framed structure resting on pile foundation presented by Buragohain et al(1977). Some researchers later presented the mechanism for the interaction analysis of building frame on the rational approach and realistic assumptions. The most research analysis used sub-structure approach, some of them used direct approach where the structure and foundation were considered to be a single compatible unit. The sub-structure approach is preferred in such interaction analysis owing to simplicity in the method, less memory requirement on part of the computational resources and not much variation in the results obtained using substructure method and direct approach.Reddy and Rao (2011) conducted an experimental work on a model building frame supported by a pile group and compared the results analytically using finite element analysis.

Recently a lot of research is available in the literature on axially loaded as well as laterally loaded single pile and pile groups. The approaches available for the analysis of axially loaded pile foundations include the elastic continuum method and load transfer method , while those for analyzing the laterally loaded pile foundations include the elastic continuum approach and modulus of subgrade reaction approach. Now the finite element method has become popular for analyzing the interaction of pile foundations in the context of both linear and non-linear analysis.

IV. METHODOLOGY

The response of a structure subjected to seismicity is complex and it depends upon various parameters namely characteristics of ground motion, allowable deformation limits of the structure, strength of structural material, soil structure interaction and many others. Till now most of studies have been carried out considering base of the structure as a fixed, but this is not the realistic approach. Therefore soil structure interaction effect is incorporated to study the seismic behaviour of various structures.

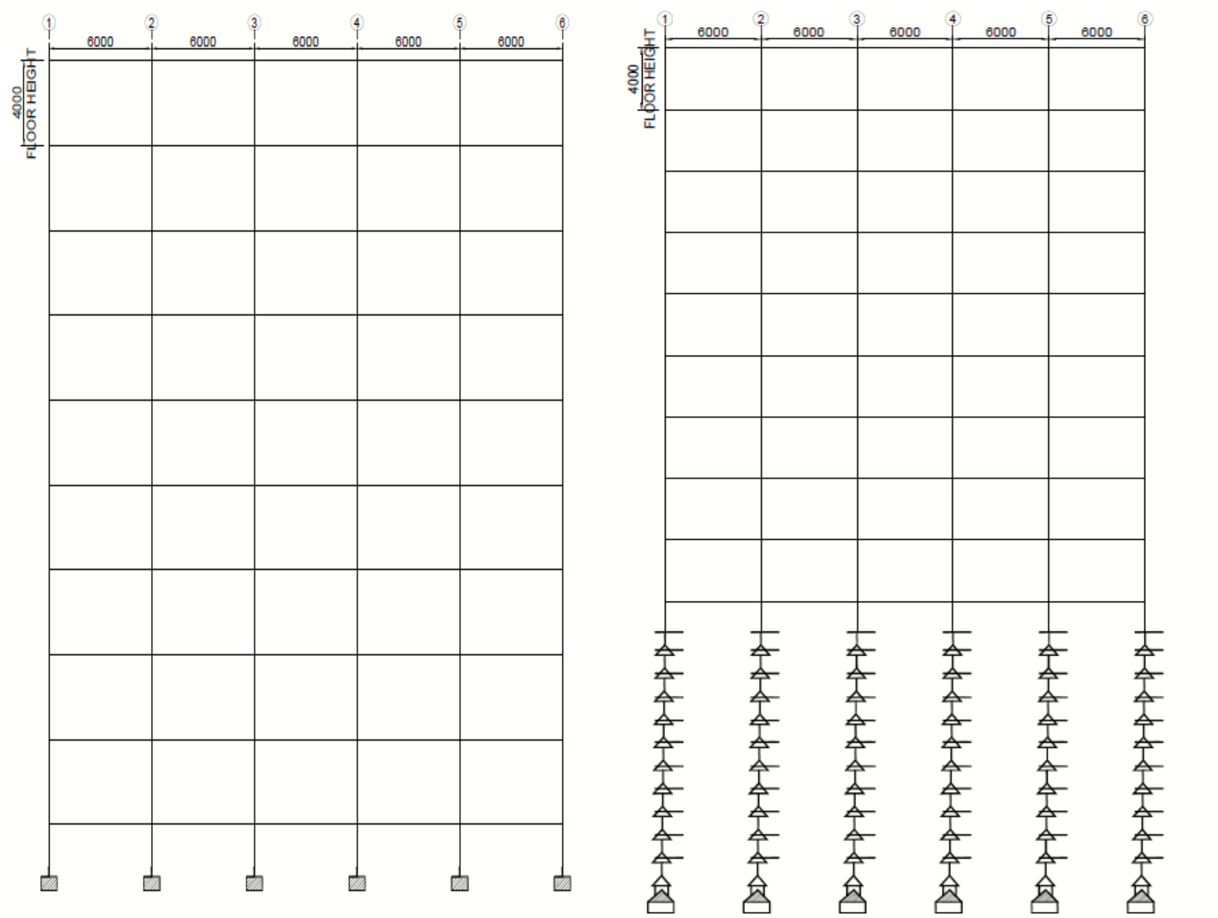
The advancement in knowledge about the earthquakes, their characteristics, structure's seismic behavior and response; other factors such as concept of response spectra, period of vibration of the structures, ductility etc has led to periodic development of seismic design methodologies. In the present work some of available methodologies have been considered to include the effect of soil-structure interaction following the same response spectra.

i. Static Method(SM)
ii. Square Root of the Sum of Squares Method(SRSSM)
iii. Complete Quadratic Combination Method(CQCM)
iv. Capacity Spectrum Method(CSM)
v. Absolute Sum Method(ABSM)

The framed structures under different seismic zones (Zone-II,III,IV and V) supported on Raft (shallow) foundations with fixed and flexible base subjected to seismic forces were analyzed under different soil condition (medium and hard). The framed structure was analyzed using Response spectrum method using software STAAD Pro and the response results were found for framed structures resting on pile (deep) foundations with fixed and flexible base.

V. **ANALYTICAL MODELING**

The Elevation of the modelled multi-storeyed building with pile foundation is shown in Fig.1. A three dimensional geometric model of the framed superstructure-pile foundation-soil system is considered for analyzing its response adopting the bases of column first as fixed and then the pile foundations are considered to get the effect by adopting the bases of column as flexible.The effect of soil-structure interaction on the response of the frame is then calculated by the interaction analysis.The Discretization of structural elements of the superstructure (beam, column and slab), of pile foundation (pile and pile cap) and of soil constituents is carried out as continuum elements for analysis purpose. The base shear,base moment and lateral displacement in three directions in X, Y and Z are compared in this paper.



(a)Fixed base *(b) Flexible base*

Fig.1: Elevation of the modelled multi-storeyed building with Pile foundation

IV. ANALYSIS PARAMETERS

- Size of the building : 30m x 36m
- Type of structure : RCC framed structure (X- bays=5, Z-bays=6)
- Type of foundation: Circular Pile of 600 mm stem diameter 10.0 m length
- Height of the building : 40m
- Number of storey: 10 with height of each storey as 4m
- Imposed load : 4 kN/m^2
- Grade of concrete: M-25
- Grade of steel: Fe-500
- Beam sizes: 0.5mx0.3m
- Column Sizes: 0.5mx0.5m
- Slab thickness: 175mm
- Brick wall thickness: 230mm
- Unit weight of RCC: 25kN/m^3
- Unit weight of Masonry: 20kN/m^3
- Seismic zone: Zone-II to Zone-V as per IS:1893(Part-1)
- Method of seismic analysis: Response spectra as per IS:1893(Part-1)
- Damping: 5% ,
- Type of soil : Medium and Soft
- Soil spring constant: 17-1104 t/m for soft soil
  58-2581 t/m for medium soil

VII. RESULTS AND DISCUSSION

Computed values of base shear, base moment and lateral displacement for both the types(fixed and flexible based) of building frames (situated in different seismic zones,I,II,III & IV) using the above mentioned five analytical methods are plotted and shown in Fig.2 to Fig.6 for base shear; Fig.7 to Fig.11 for base moments and Fig.12 to Fig.16 for lateral displacements.

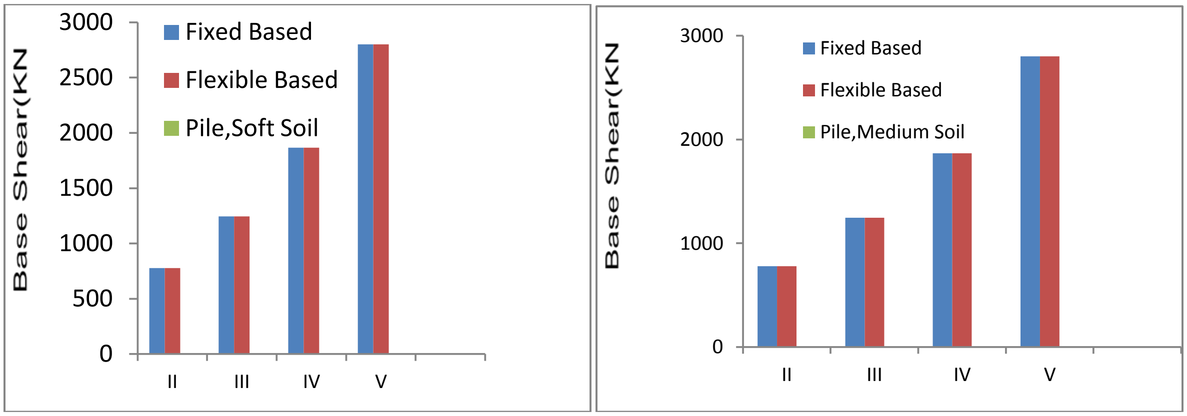


Fig.2: Effect of Soil Structure Interaction in case of Base Shear using SM

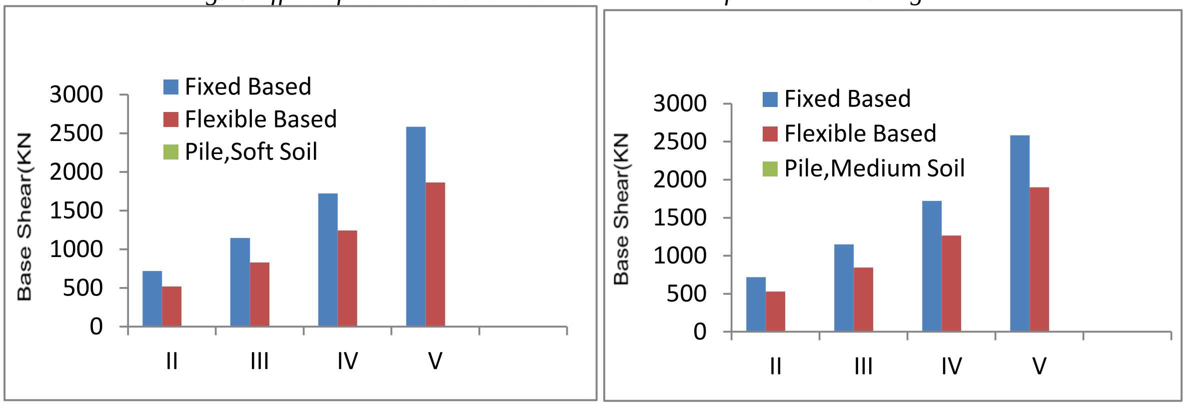


Fig.3: Effect of Soil Structure Interaction in case of Base Shear using SRSSM

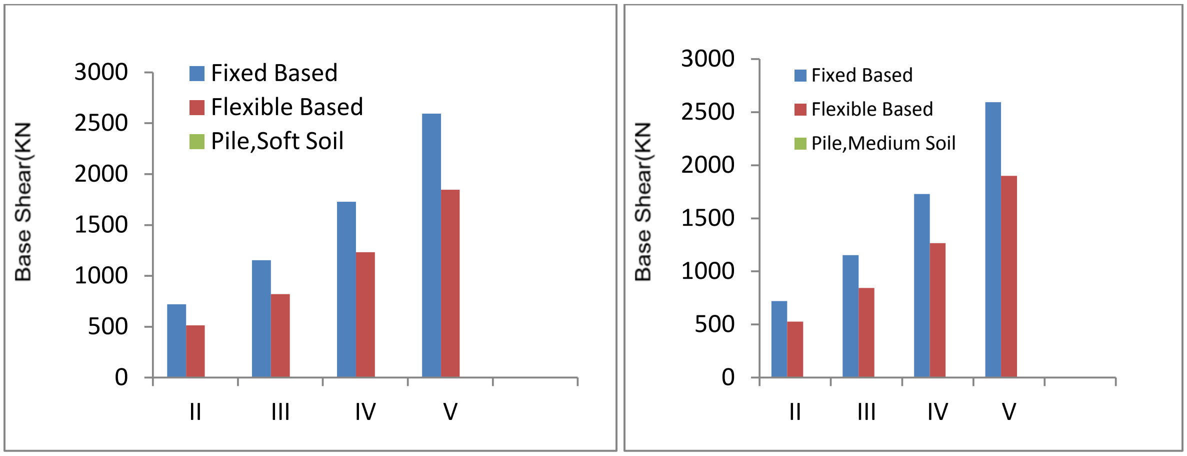


Fig.4: Effect of Soil Structure Interaction in case of Base Shear using CQCM

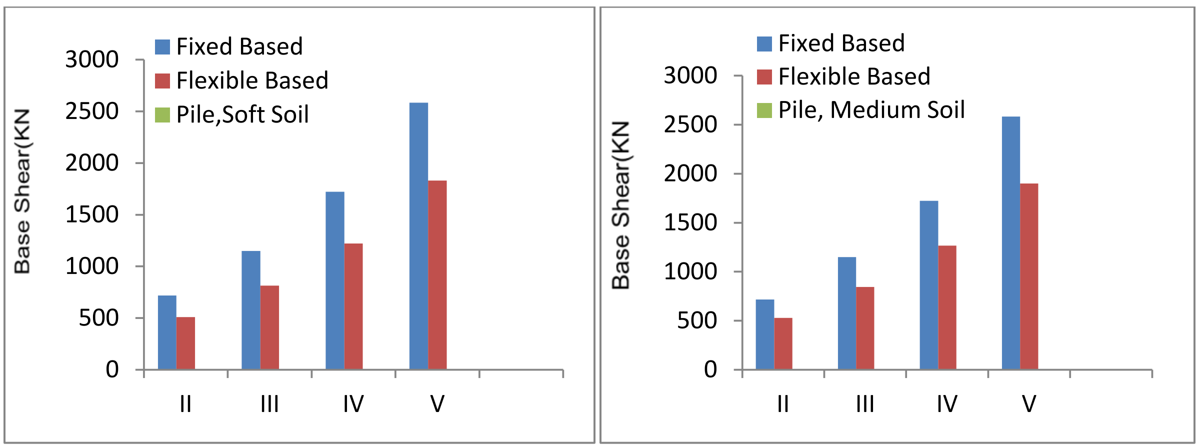


Fig.5: Effect of Soil Structure Interaction in case of Base Shear using CSM

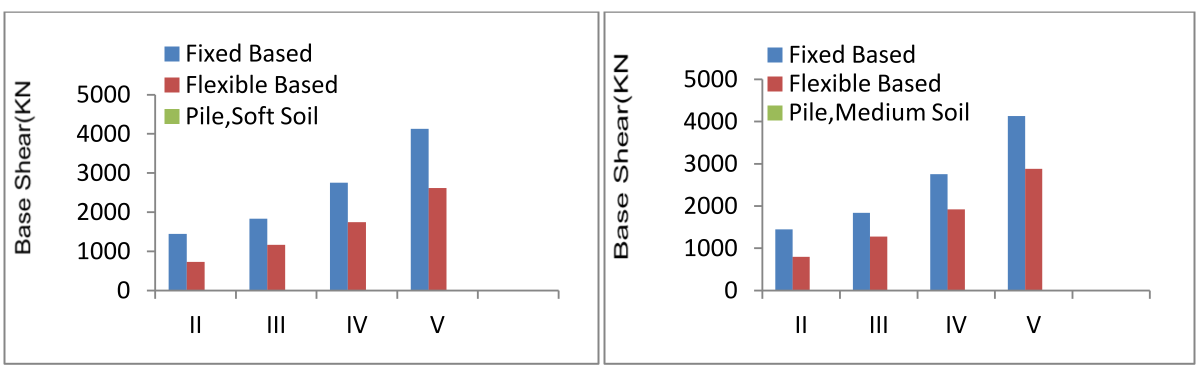


Fig.6: Effect of Soil Structure Interaction in case of Base Shear using ABSM

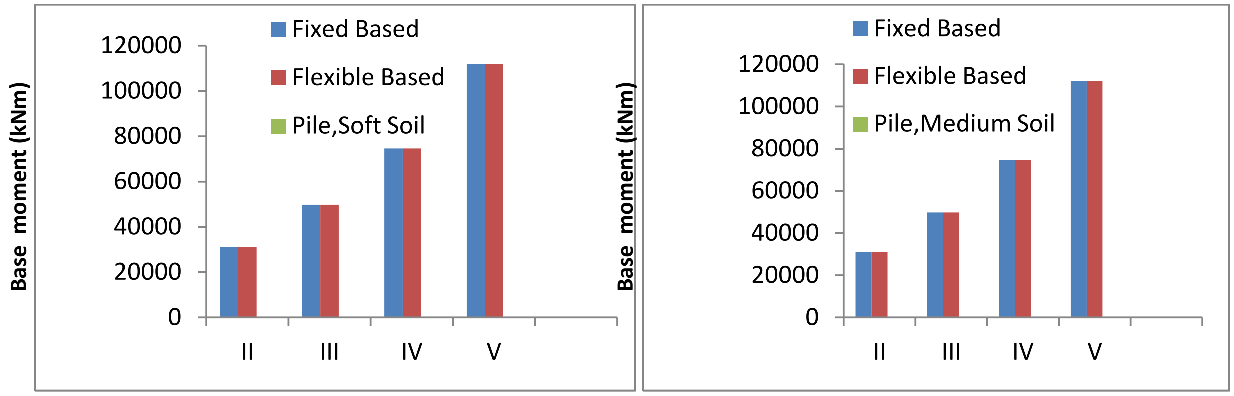


Fig.7: Effect of Soil Structure Interaction in case of Base Moment using SM

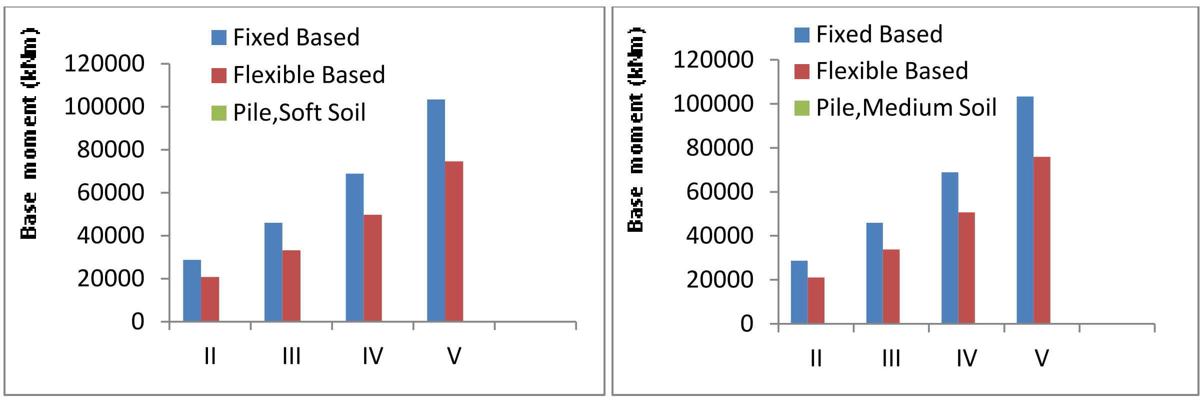


Fig.8: Effect of Soil Structure Interaction in case of Base Moment using SRSSM

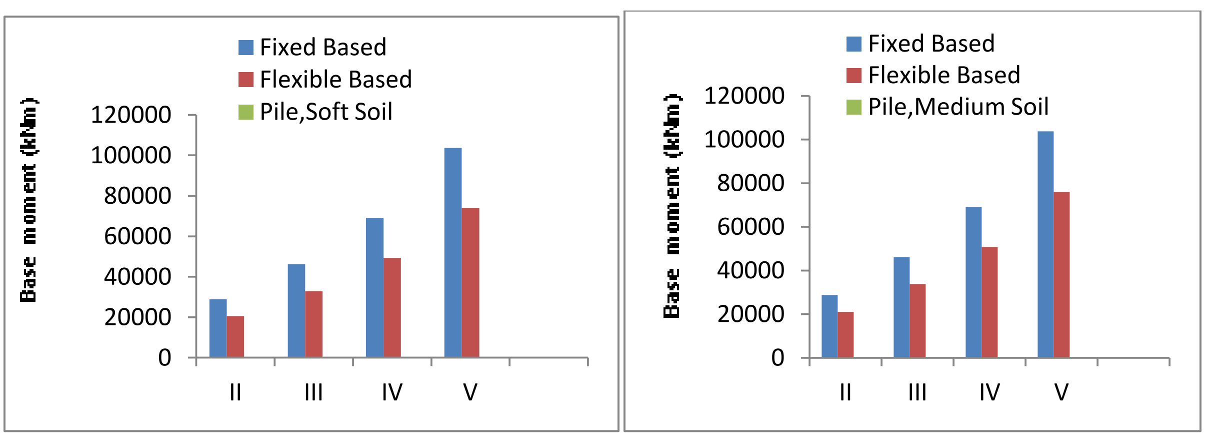


Fig.9: Effect of Soil Structure Interaction in case of Base Moment using CQCM

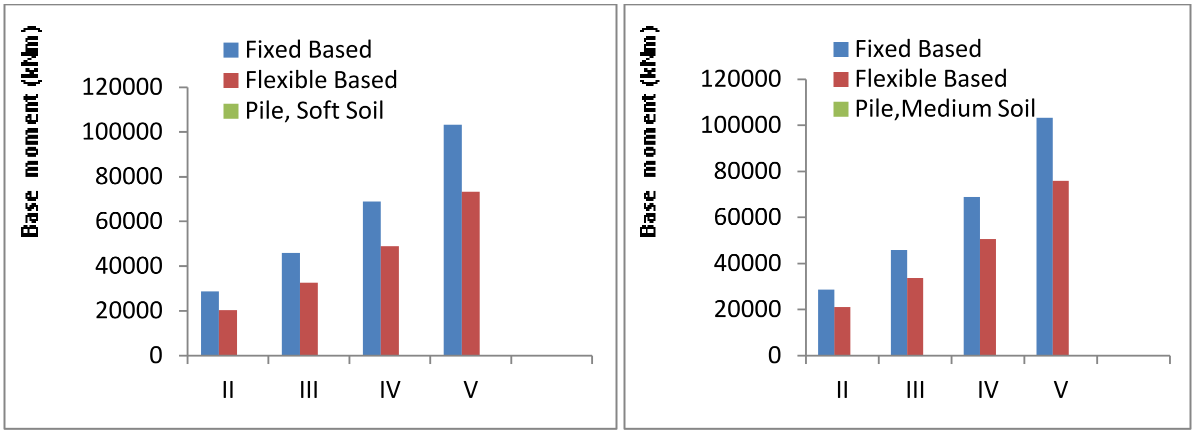


Fig.10: Effect of Soil Structure Interaction in case of Base Moment using CSM

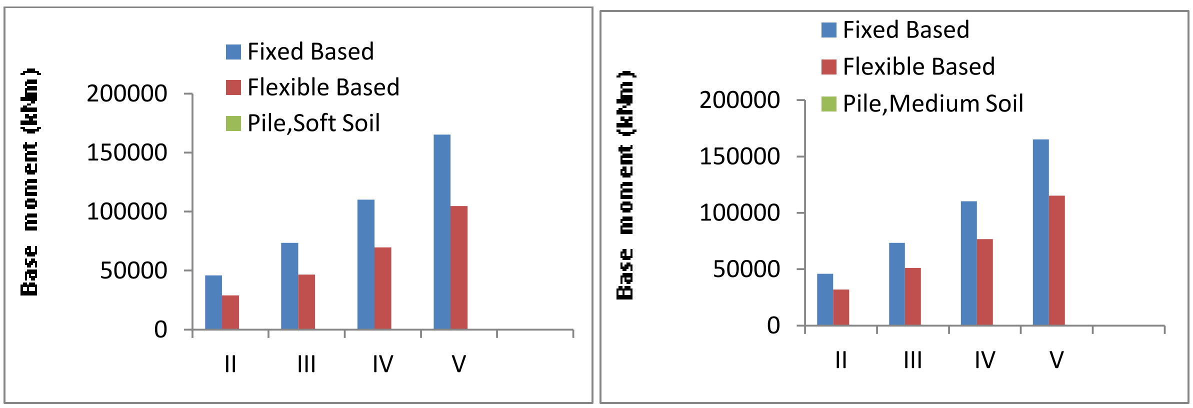


Fig.11: Effect of Soil Structure Interaction in case of Base Moment using ABSM

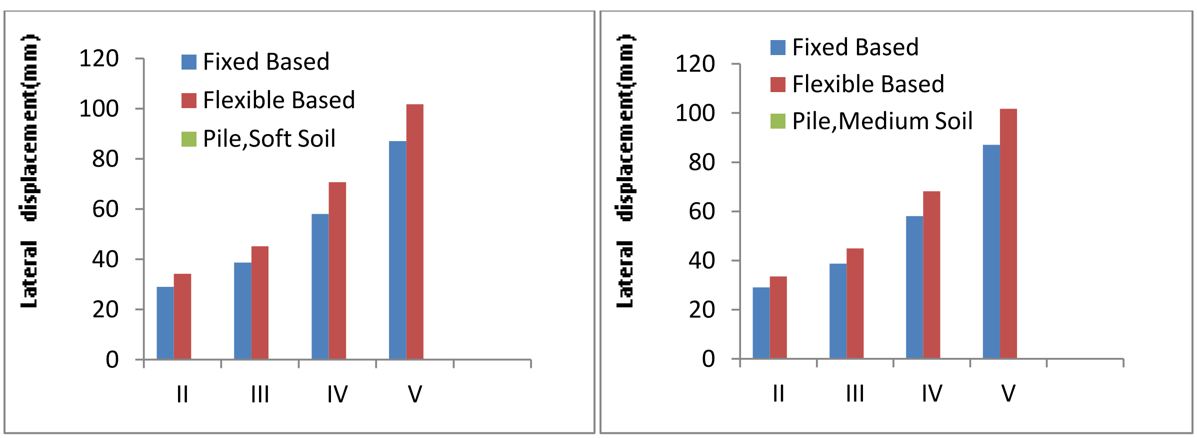


Fig.12: Effect of Soil Structure Interaction in case of Lateral displacement using SM

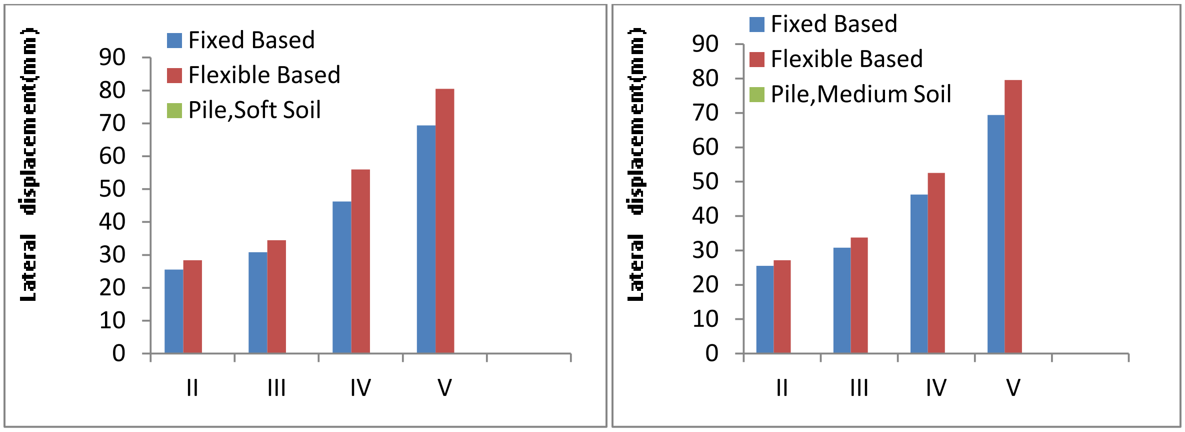


Fig.13: Effect of Soil Structure Interaction in case of lateral displacement using SRSSM

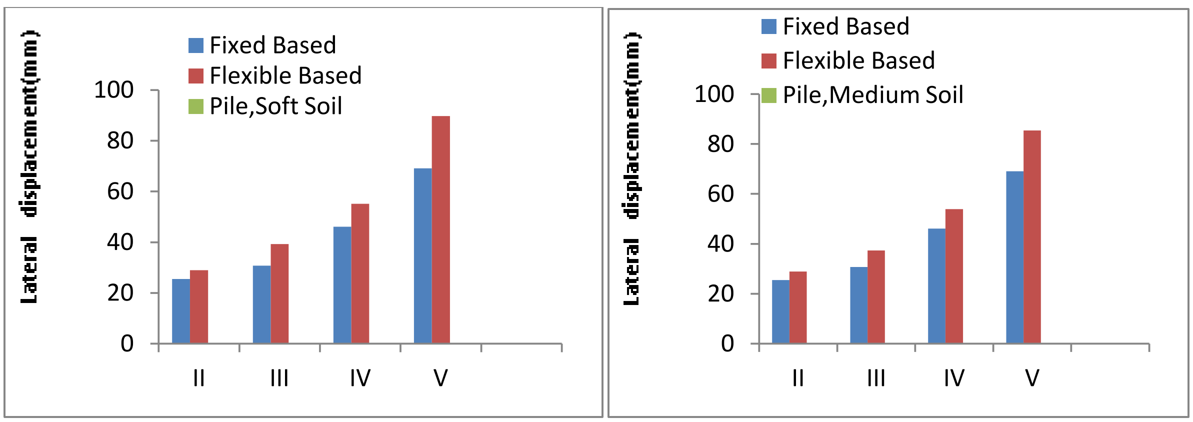


Fig.14: Effect of Soil Structure Interaction in case of lateral displacement using CQCM

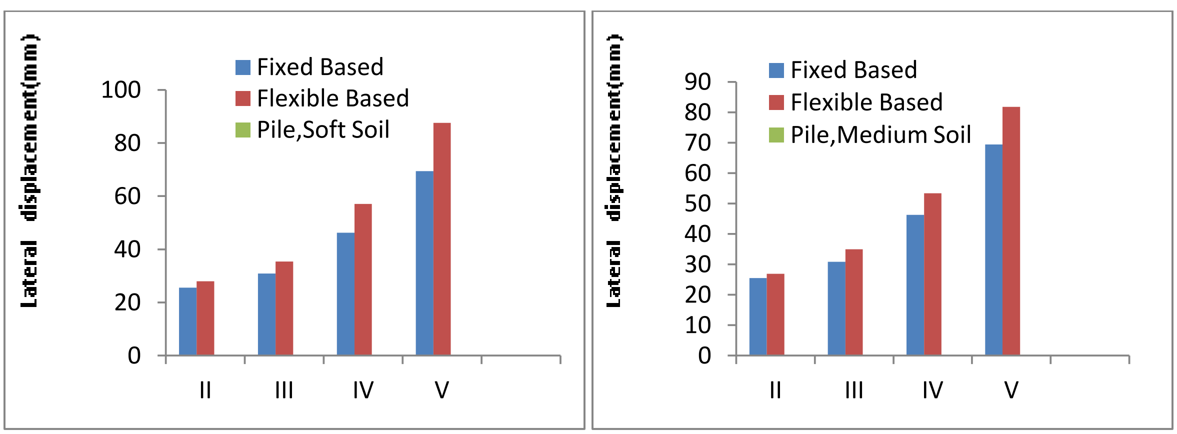


Fig.15: Effect of Soil Structure Interaction in case of lateral displacement using CSM

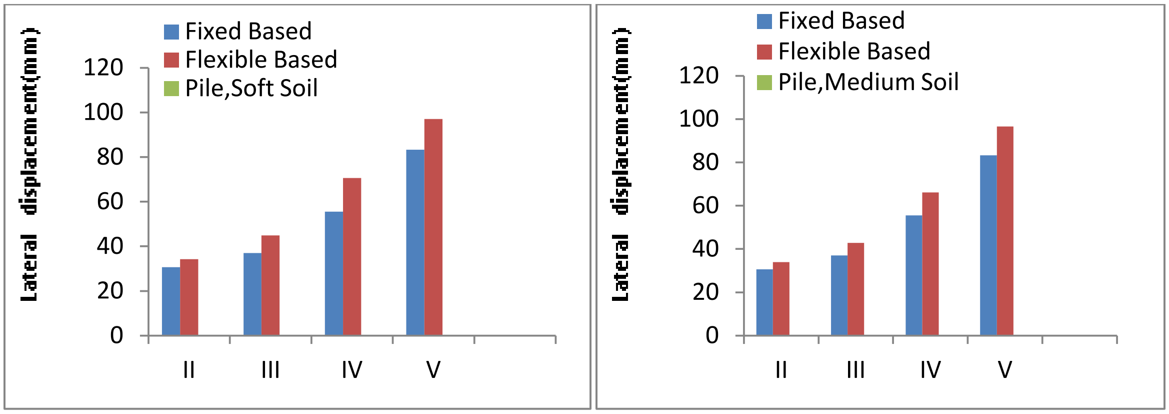


Fig.16: Effect of Soil Structure Interaction in case of lateral displacement using ABSM

It can be seen from the Fig.2 to Fig.16 that the values of Base Shear, Base Moment and Lateral Displacement (at the top of frame) for framed structures with pile foundation are found to be varying in variable soil conditions and seismicity, Lateral deflection being higher for foundations founded on soft soil as compared to medium soil while Base shear and base moment being higher for foundations founded on medium soil as compared to soft soil. These response parameters are higher for framed structures located in zone-V as compared to zone-IV and higher in zone-IV as compared to zone-III and so on.These response parameters are higher for structures with flexible base as compared to fixed base.
From the above parametric study results carried out on a framed structure with pile foundation, it is observed that the top displacement is very less when the framed structure bases are assumed to be fixed and increases when the effect of soil-structure interaction(flexible based) is taken into consideration. Hence if the mechanism of soil-structure interaction is considered,it is found to increase the top lateral displacement much when compared with the displacement obtained in view of the fixed base condition.

VIII. CONCLUSIONS

For assessing the effect of soil-structure interaction, a ten storeyed framed structure was selected for which pile foundations in soils with both fixed and flexible bases were considered. The various methods of seismic design were adopted for analyzing various response parameters i.e. Base Shear,Base Moment and Lateral Displacement at top of framed structure.These parameters were analysed for different conditions (soft and medium) of soil strata.The seismic zones II to V were considered in which framed structures were assumed to be located.The values of response parameters were analysed adopting above mentioned conditions and obtained results were compared.From the comparision of the response parameters obtained on the basis of analysis for pile foundations in soils with both fixed and flexible bases,following conclusions were drawn:

- The values of Base Shear, Base Moment and Lateral displacement for pile foundations for framed structures are found to be varying in variable soil conditions and seismicity.
- The increase in the value of Lateral displacement being more for foundations founded on soft soil (the variation found in the range of 9.5-29.74%) as compared to medium soil(the variation found in the range of 5.56-23.61%) while the decrease in the value of base shear and base moment being more for foundations founded on soft soil(the variation found in the range of 27.85-36.68%.%) as compared to medium soil(the variation found in the range of 26.48-30.31%) for both cases, fixed and flexible bases.
- These response parameters are higher for framed structures located in zone-V as compared to zone-IV and higher in zone-IV as compared to zone-III and so on for both cases, fixed and flexible bases.These response parameters are higher for structures with flexible base(the effect of SSI taken into consideration) as compared to fixed base. On the basis of above analysis and comparisions, it is concluded that the response parameters vary substantially, sometimes which may be detrimental to the structure, if flexibility of soil is considered,hence the effect of soil-structure interaction by incorporating stiffness of soil should be taken into consideration for designing the framed structures for considering the earthquake excitation forces.

REFERENCES

[1] Abghari A. and Chai, J. (1995). *"Modeling of soil-pile-superstructure interaction in the design of bridge foundations," Performance of Deep Foundations under Seismic Loading,* John Turner, Ed., Geotechnical Special Publication No. 51, ASCE, New York, N.Y., pp. 45-59.
[2] Angelides, D.C. and Roesset, J.M. (1980). *"Nonlinear dynamic stiffness of piles,"*Research Report R80-13, Dept. of Civil Engineering, MIT, Cambridge,Massachusetts.

[3] Boulanger, R.W., Kutter, B.L., and Wilson, D.W. (1998). *"The response of piles during earthquakes: dynamic soil-pile-superstructure interaction,"* Report No.UCD/CGM-98/01, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis.

[4] Bray, J.D., Espinoza, R.D., Soga, K., and Taylor, R.L. (1995). "GeoFEAP*: "Geotechnical Finite Element Analysis Program. Version 1.2,"* Report No. UCBGT/95-05,Department of Civil and Environmental Engineering, University of California,Berkeley.

[5] Buragohain, D.N., Raghavan, N. and Chandrasekaran, V.S. (1977), *"Interaction of Frames with Pile Foundation".* Proc.Int. Symp. Soil-Structure Interaction, Roorkee, 109-115.

[6] Crouse, C.B, Liang, G.C and Martin G.R, (1984). *"Experimental study of soil-structure interaction at an accelerograph station",* Bulletin of the Seismological Society of America; 74, 1995-2013.

[7] Dunnavant, T.W. and O'Neill, M.W. (1989). *"Experimental p-y model for submerged,stiff clay,"* Journal of Geotechnical Engineering, ASCE, Vol. 115, No. 1, pp. 95-114.El Sharnouby,

[8] Faruque, M.O. and Desai, C.S. (1982). *"3-D material and geometric nonlinear analysis of piles",* Proceedings of the Second International Conference on Numerical Methods in Offshore Pilling, University of Texas at Austin, Texas, pp. 553-575.

[9] Kagawa, T., Minowa, C., Mizuno, H., and Abe, A. (1994). *"Shaking-table tests on piles in liquefying sand",* Proceedings, Fifth US National Conference on Earthquake Engineering, Chicago, Illinois, Vol. IV, pp. 107-113.

[10] Kuhlemeyer, R.L. (1979). *"Vertical vibration of piles"*, Journal of Geotechnical Engineering, ASCE, Vol. 105 No. GT2, pp. 273-288.

[11] Lee, I.K. and Brown, P.T. (1972),*"Structures and Foundation Interaction Analysis".* Journal of Structural Engineering,11, 2413-2431.

[12] Matlock, H. (1970), "*Correlations for Design of Laterally Loaded Piles in Soft Clay*". Proceedings of the 2nd Offshore Technology Conference, Houston, 22-24 April 1970,577-594.

[13] Ochoa, M, and O'Neill, M. (1989). *"Lateral pile interaction factors in submerged sand,"* Journal of Geotechnical Engineering, Vol. 115, No. 3, pp. 359-378.

[14] Prakash, V., Powell, G.H., and Campbell, S., (1993). "*DRAIN-2DX base program description and user guide,"* Version 1.10, Report No., UCB/SEMM-93/17,University of California, Berkeley.

[15] Randolph (1981). *"Response of flexible piles to lateral loading,"* Geotechnique, Vol. 31,No. 2, pp. 247-259.

[16] Reddy, R.C. and Rao, G.T.D. (2011), *"Experimental Study of a Modelled Building Frame Supported by a Pile Group Embedded in Cohesionless Soils*". Interaction and Multiscale Mechanics, 4, 321-336.

[17] Sanchez, S.I. (1982). *"Static and dynamic stiffnesses of single pile",* Research Report GR82-31, Deptartment of Civil Engineering, The University of Texas at Austin,Austin, Texas.

[18] Sen, R., Davis, T.G. and Barnerjee, P.K. (1985).*"Dynamic analysis of piles and pile groups embedded in homogeneous soils,"*International Journal Earthquake Engineering and Structural Dynamics,Vol.13, pp.53-65.

[19] Trochanis, A.M., Bielak, J., and Christiano, P. (1991). *"Simplified model for analysis of one or two piles,"* Journal of Geotechnical Engineering, ASCE, Vol. 117, No. 3,pp. 448-466.

[20] Wang, S., Kutter, B.L., Chacko, M.J., Wilson, D.W., Boulanger, R.W., and Abghari, A.(1998). *"Nonlinear seismic soil-pile structure interaction."* Earthquake Spectra,EERI, Vol. 14, No. 2, pp. 377-396.

[21] Wen, Y.-K. (1976). *"Method for random vibration of hysteretic systems,"* Journal of the Engineering Mechanics Division, ASCE, Vol. 102, No. EM2, pp. 249-263.