International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES),(UGC APPROVED)
Impact Factor: 5.22 (SJIF-2017),e-ISSN:2455-2585
National Conference on
Sustainable Practices & Advances in Civil Engineering (SPACE 2019)
Volume 5, Special Issue 06, June-2019.

A REVIEW ON SOIL STRUCTURE INETRACTION

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Abstract— The process in which the response of the soil influences the motion of the structure and the motion of the structure influences the response of the soil is known as Soil structure interaction (SSI). SSI has been generally ignored while designing the structures. However in high rise structures the effects of SSI have to be considered. This paper presents the introduction of SSI, the Review of Literature and Case studies on dynamic analysis using different softwares. SAP2000 Software is the most commonly adopted software in this study area

Keywords— Soil Structure Interaction (SSI), base shear, storey drifts, response

I. INTRODUCTION

The Simulation of SSI is done by two methods.

a) Soil is Modeled as Spring Element: The flexibility of soil is usually modeled by inserting springs in between the foundation and soil medium. Translations of foundation in two mutually perpendicular principle horizontal directions and vertical direction, as well as rotations of the same about these three directions are considered to simulate the effect of soil flexibility.

b) Elastic continuum method: Soil is modelled using Solid Element (based on Finite Element Method). All the possible mechanical properties of soil such as elastic modulus, poison's ratio are assigned to the solid element. The interface between the soil and foundation is modelled using Gap elements available in the software packages.

Foundation is the interface between the superstructure and the ground. Its role is to transfer the building loads safely into the ground and to keep settlements within the permissible limit. It supports superstructure weight, resists horizontal forces from the adjacent ground and forces imposed on foundation due to wind and earthquake. The process in which the response of soil influences the motion of the structure and motion of the structure influences the response of soil is termed as soil-structure interaction (SSI). (Mohammed Zubair, 2016)

Methods available to solve SSI problems:

a. Numerical Methods: The numerical method are greatly being adopted because of the rapid advancements in computers. This method of calculations is considered as one of the most effective tools for the studies on SSI. Thus, some seismologists have used it, and a great deal of research outcomes based on it having sprung up from 1980 up to present.

b. Finite Element Method (FEM):

Finite element method is an efficient common computing method widely used in civil engineering. FEM can stimulate the mechanics of the soil and structure better than other methods. It can deal with the complicated geometry and applied load and nonlinear phenomenon. Till date, there are many general purpose programs developed by commercial corporations for research in the study of Soil structure interaction. They produced some notable discoveries in the field of SSI.

c. Experiment:

Experiments are an important mean for scientists and engineers to improve nature's law.

d. Prototype Observation:

Studies of recorded responses of understanding of structures by instrumentation constitute an integral part of seismic hazard-reduction programs. It leads to improved design and analysis procedures. By modelling a prototype structure and comparing the results with conventional design methods, safety of structure can be ensured.

II. LITERATURE REVIEW

2.1 FOUNDATIONS OF THE STRUCTURE

The effect of SSI on structural behaviour of building supported on isolated footings is studied by using ETABS. 14 models of 5 and 8 stories supported on square and rectangular footings were considered on hard, medium, soft soils. Based on Comparison of time period for point spring element and fixed support, it was observed the magnitude of time period for Soft Soil Condition is higher in comparison to Fixed Support, Medium and Hard Soil types. The Story responses such as Displacements, Base Shears and Overturning moments are always higher for Soft Soil. Thus Soft Soil condition is more critical in all cases (**Lavanya et al. 2018). ** Due to flexibility of soil the differential settlements, rotation of footing and stiffness of the frame results in redistribution of forces/stresses in the frame members. Model analysis by FEM in ANSYS11.0 and 2D analysis for 10 storey 3 bay x 3 bay for raft footing was performed. Soil is modelled as linear elastic having modulus of elasticity 200 x 10^6 N/m^2, poisons ratio 0.2 and unit weight as 20 kN/m3, and safe bearing capacity as 200 kN/m^2. The extent of soil is taken as 100 m x 100 m x 50 from the above analysis it is concluded, that it is essential to do Interaction analysis for actual response of Flexible base. The basic objective of checking response of soil mass for different shapes of raft is fulfilled with positive results. With optimization of shapes of footing, economical results can be achieved (**Gaurav D Dhadse 2017)**. The study of Analytical Method of Mega Foundations for High-Rise Building was studied to predict the behaviour of sub- structures. The model done in YSMAT (Yonsei-MAT) and YSPR (Yonsei Piled Raft) can be effectively used for the preliminary design of a raft or a piled raft foundation for high-rise buildings. This analytical method is intermediate in theoretical accuracy between general three-dimensional Finite Element Analysis and the linear elastic numerical method. The proposed method is shown to be capable of predicting the behavior of a large raft and piled raft. Nonlinear load-transfer curve and flat-shell element can overcome the limitations of existing numerical methods by considering the realistic nonlinear behavior of soil and membrane action of flexible raft (**Sangseom et al. 2017**).The effect of soil structure interaction on G+5 storied building with raft foundation with incremental static analysis for various load combinations was studied and the parameters like displacement, shear force and bending moment were determined. Then a same 5 storey RC frame is analyzed by numerical analysis using Finite Element Method (FEM) with raft foundation by assigning the soil properties to substructure to determine the parameters displacement, shear force and bending moment. The value of sub grade modulus reaction Ks has been assumed as 12000 kN/m^3. According to the results, the parameters varies from conventional to numerical analysis. Displacements of the structure increases, shear forces of structure decreases and bending moment of the structure decreases at some points and increases at some points when conventional method of analysis is compared to numerical method of analysis (**Vijay Baskar et al 2016)**.The SSI of Multistoried Framed Structure with different support conditions have been studied the displacements for different types of support conditions like Fixed Support, Pinned Support and Fixed butt Support (**Sai Kumar et al 2016)** were determined. The effect of foundation size on the seismic performance of buildings considering the soil-foundation-structure interaction was studed. 15 storey model using ABAQUS was used to numerically simulated for soil-foundation-structure system by conducting a fully coupled nonlinear time history analysis. The mid-rise moment resisting building frame with shallow foundations on soft soil had a natural period in the long period region of the acceleration response spectrum curve, and because of this natural period lengthening, there was a significant reduction in the base shears when the size of the foundation was reduced. Minimum size of footing is to be maintained as per design requirements (**Nguyen et al. 2016).**

2.2 SEISMIC AND WIND LOADS ON STRUCTURE

A multi-storied building of 10 storey 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. And soil-structure interaction effects were studied. 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 force (**Nagarjuna et al. 2018)**

The finite element soil structure interaction analysis of 10 STOREY building structure having piled-raft foundation with soil model and without soil model (in ANSYS V 17.0) is conducted. Dead load and Live load are given as per IS 875 (Part I) and (Part II), 1987, respectively. The complete interaction among the soil field depth, settlement of building and stress developed in building have been evaluated. It has been observed that total deformation (vertical) of building is more in flexible base model than in fixed base model, which means that in actual case settlement occurs and it depends on type of soil beneath. In the model where soil is considered, stress distribution pattern has varied. Average stress developed in model with soil is greater than other model .This study indicates that building should be modelled along with the soil on which it is resting considering all properties of soil for the analysis and design purpose (**Nimisha et al. 2017).**

Lakshmi et al. (2016) investigated on the methods of improving soil stiffness by reducing the effects of soil structure interaction. Shallow foundations resting on soft soils having shear wave velocity 125 to 150 m/sec are considered. Isolated Circular and Square footings are analyzed considering SSI. Using HYPERMESH software FEM model is created. Modal Analysis and Linear static analysis is carried out using NASTRAN software to study the frequency and deformations with SSI. Natural frequency and deformations are determined with SSI effects. With effect of SSI, natural frequency of structure is very less and deformations are more. The improvements in soil properties can be observed by constructing brick work/concrete below footing.

Mao-guang Yue et al. (2015) studied the influences of soil-structure interaction on seismic response of structure. One real project was considered as an example of the 25 stories taken as model (using the Chinese seismic code), the influences of soil-structure interaction can be considered when the fundamental period of structure is within the scope of 1.2~5 times of the characteristic period of site. The story drift is calculated according to the reduced story shear force. Extensive studies are still needed to ascertain a rational reduction factor.

Guangling et al. (2008) conducted a comparative study on seismic analysis of wind turbine system including soil structure interaction. Based on the integrated model, the seismic analysis is carried out. According to the analysis results, the SSI effect significantly influences the global dynamic performance of the system and should never be neglected.

Masoud et al. (2003) investigated the effects of increased wind loads due to climate change on 50 storey building has been modeled in ANSYS and PLAXIS SOFTWARES. The effect of increased wind loads on vertical contact stresses was studied. The effect of increased wind loads on vertical displacements and Lateral deflection of building center line was studied. The greatest effect of the increased wind load was almost doubling the lateral deflections (sway) of the building.

2.3 HEIGHT OF THE STRUCTURE

Manekar et al. (2017) studied the SSI for the G+9 storey building and mode created in ETABS software. They compared the storey shear for the fixed base with soft, medium, hard soils and concluded that Storey shear is maximum in fixed soil type model when to compare to hard, medium and soft. Storey shear is maximum in soft soil type model when compare to hard, medium when fixed.

Kun-Sung Liu. (2016) investigated the dynamic characteristics of a 51-story high-rise building by the transfer function (TF) method. He assessed the SSI effects. From the spectral ratio of the accelerations (47F/ basement), it is noted that the peaks of the 47th floor Fourier amplitude spectra (FAS) and the spectral ratio seem to coincide with each other, suggesting that there is no significant SSI effect in both the longitudinal and transverse directions.

Rahul et al. (2016) Investigated the interaction between the super structure and sub structure by modelling the soil to capture the overall response of the system. A Structural model of G+42 storeys was developed in ETABS and Soil model with pile raft foundation is developed in MIDAS GTX NX by considering wind and seismic, loading parameters and material and geometric properties. He investigated that the use of flexible base in the analysis leads to reduction in the structural response and damage consequences in joints and infill’s.

2.4 CASE STUDIES ON SAP2000 MODEL FOR DIFFERENT TYPES OF SOILS AND SUPPORT CONDITIONS.

Pijus et al. (2017) studied the behavior of RCC building with Fixed and Flexible support subjected to seismic forces for different types of soil conditions give in the response spectrum of the code IS 1893 (Part1) : 2002. The study has been carried out on G+15 storey building supported on dense, stiff and soft soils. They investigated the seismic performance by using nonlinear static pushover analysis in SAP 2000.

Spring stiffness equations based on FEMA 273, FEMA 356, GAZETAS 1992, and WOLF 1985 were considered. In structure idealization of building data, the soil parameters like mass density of soil, shear wave velocity, poisons ratio and shear modulus are taken from IBC CODE 2006. Geometrical and material properties of frame, footing and soil mass are taken from IS 456-2000 code. Modelling of the structure is done in SAP2000 of G+15 stories for open ground storey (OGC) and for infiled building.

Table1.equivalent spring stiffness with designation types **(**Pijus et al. 2017)

Equivalent spring stiffness based on	Designation
FEMA 273	TYPE 1
FEMA 356	TYPE 2
GAZETAS 1992	TYPE 3
WOLF 1985	TYPE 4

Table 2.Percentage increase of hinges failure for fully infilled buildings: (Pijus et al. 2017)

Base condition	Dense soil	Stiff soil	Soft soil
TYPE 1	21.47	35.52	-15.34
TYPE 2	21.47	-6.75	-9.82
TYPE 3	18.40	-6.13	-14.72
TYPE 4	22.70	-1.84	-1.23

Table3. Lateral displacements for fully infilled buildings: (Pijus et al. 2017)

Base condition	Lateral displacement (mm)		
	Dense soil	Stiff soil	Soft soil
TYPE 1	91	92	96
TYPE 2	91	92	96
TYPE 3	91	93	98
TYPE 4	91	91	93

From the comparative study they concluded that base condition equation for type 1 gives better results for stiff soil by 15.34% and for type 2 (soft soil) 6.75% and for type3 (dense soil) 18.4% for hinge failures. In OGS buildings, lateral deflection and base shear are same for type 1 and 4 buildings and for infilled buildings the lateral deflection and base shear are maximum for soft soil base condition.

Nirav et al. (2016) studied the effect of SSI of irregular 15 storey RC framed structure with and without SSI for three types of soil i.e. dense, medium and hard soils. The modelling has been done in SAP 2000. Soil is modeled as spring model and stiffness is calculated by using gerorge gazetas equation. They studied the effect of SSI in terms of structural parameters like natural time period, base shear, roof displacement. In this paper the main objective is to study the SSI when structure is hit by earth quake for long duration. And how the response modified when soil effects are taken.

For interaction analysis – "Winkler or spring model and elastic continuum approach or FEM" are considered.

The analysis is carried out in two different cases: fixed base with and without considering SSI. The seismic analysis for static and dynamic analysis are carried out for seismic Zone V

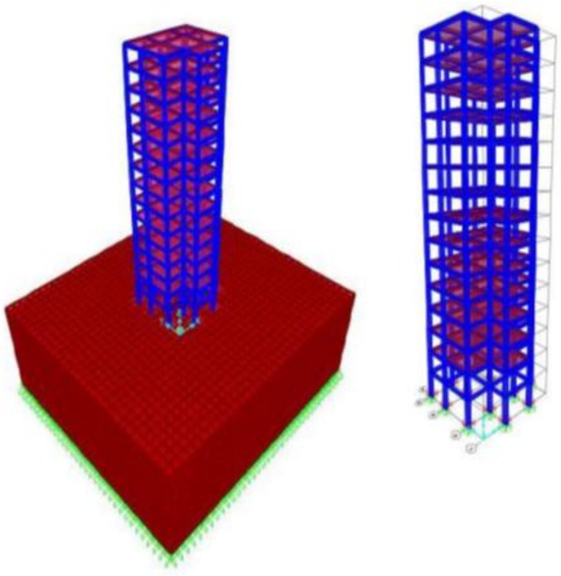

Fig.1 Shows model with fixed base with SSI and fixed base without considering SSI. (Nirav et al. 2016)

Table 4. Showing the designation, modulus of elasticity, and shear modulus and poisons ratio for different types of soils.

Soil type	designation	Modulus of elasticity (kN/m^2)	Shear modulus	Poisons ratio
Hard soil	E-65000	65000	26000	0.25
Medium soil	E-35000	35000	13461.53	0.3
Soft soil	E-15000	15000	5357.14	0.4

Concluded that from the results that as the building height increases the base shear and displacement increases. In case of soft soils, the SSI analysis has been recommended as height of the building increases. Percentage of displacement increases with increase of soil flexibility when compared to spring and fixed base models in FEM.

Zubair et al. (2016) studied the response of the building frame with raft foundation undersoil flexibility due to seismic loads. The 3D frame is analyzed by using software SAP 2000 V14. The soil and the structure are considered as a single continum model. Studied that the parameters influencing the structure such as number of storeys, different seismic zones. It is

Evaluated as Interaction analysis (IA) and Non Interaction Analysis (NIA).The responses studied in this analysis are fundamental time period, base shear, joint displacement, axial force shear force and bending moment for base columns and bending moment for beam (B1).

Methodology: Three types of models of (5, 10, 15 stories) were modelled in SAP2000. Seismic zones 3, 4, 5 and Live Load 4Kn/m^2 were adopted. Raft of 800mm taken as constant in all cases.3 layers of Soils of shear modulus 30000 kN/m^2, 20000 kN/m^2 and 10000 kN/m^2 for soil layers from top to bottom were adopted.

Dynamic analysis of structure-soil frame work (continum model) by the strategy for Reaction spectrum exhibited in IS1893:2002 is done by using SAP2000 ver 14 software. The parameters considered, are different soil property (shear modulus) between the raft foundation and the soil underneath. For the non-interaction case (fixed base condition) and interaction case, the parameters like Fundamental Time Period, Base Shear, Maximum Lateral, Displacement, Axial force in the base columns, Bending moment in beam (B1) are studied.

Concluded based on results that the authors (Zubair et al. 2016) fundamental time period of 5, 10, 15stories considering non interaction case is less than that for interaction case and does not vary with seismic zones. Base shear, axial forces and Maximum lateral displacement values increases with the increase in number of storeys and with higher seismic zones. Bending Moment is higher in Interaction case than in non-interaction case.

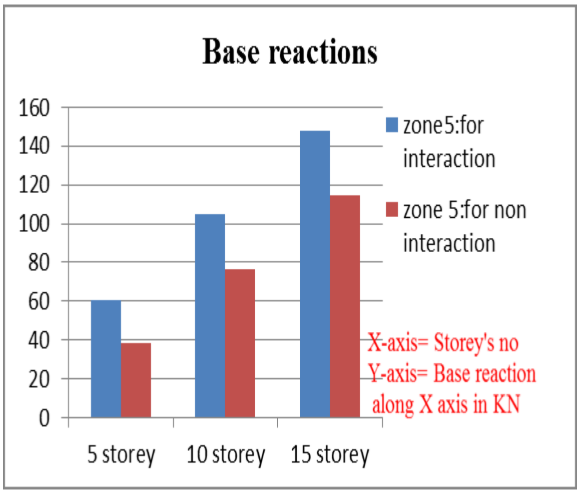

Fig. Base reactions for fixed base condition and SSI condition Zubair et al (2016)

Rahim et al. (2011) studied the contribution of SSI to seismic response of buildings by doing iterative dynamic analysis by using SAP2000, 3D time history analysis of nonlinear soil foundation building models under earthquake ground motions. Structural response was compared for flexible and fixed base conditions. Three types of building models of plan 12mx12m with three, six and twelve storyes were considered. Storey height taken as 3m,

Beam 25 cm x 70 cm of 4m spacing,

Slab thickness of 14cm,

Column 65 cm x 65 cm has taken. SAP2000 has ability to solve multi-support SSI problems.

The authors considered the building models under

Fixed Base condition,

Isolated square footing with ties in the 2.5m and 4m from ground level (GL),

Mat foundation thickness of 1m at 2.5m and 4m from GL.

Input loading: A time history analysis was carried out El Centro Earthquake and 10 models are excited by 3 orthogonal components of seismic motion, which has maximum acceleration of 0.25g

The authors studied,

The time history displacements in X, Y and Z directions for different types of base conditions. Time history for Base Shear in X and Y directions for 3, 6 and 12 storey buildings with different types of base conditions, Time history of axial force in Z direction for 3,6,12 storey buildings and Time history of moments in X and Y directions for 3,6,12 stories for different types of base conditions. It was concluded that if the effect of SSI is considered, it can reduce the column base shear up to 70% and 30% for high and short building respectively relative to the original fixed base condition. It was observed that, when SSI is considered, the column base moment reduces up to 70% when compared to that of fixed base condition. It was compared different models with and without SSI and it is confirmed that the dynamic characteristics of soil structure system should be recommended for conservative nonlinear seismic response of high building since it mitigates earthquake hazards.

As per present industry practice buildings are designed under Fixed Base condition. But in practice foundations rest on soil medium and undergo deformations whereas fixed support ignores these deformations. For that purpose

Martin et al. (2017) has done a comparative study on building frames with and without soil structure interaction subjected to seismic forces. The authors considered a G+10 symmetrical building model with isolated footing. Dynamic analysis of building frame as per IS 1893 (part1)-2002 using SAP2000 was performed. SBC of soil is considered as 250kN/m^2.

The authors compared the results and showed the variations in area of column reinforcements with and with SSI. They also compared the results of varying modulus of elasticity of soil for variation in time period, storey displacement, storey drift, and base shear, column bending moment, column shear force and column axial forces. It is observed that there is significant increase in the Response of building from fixed support model to SSI model. Area of column reinforcement is much demanded by SSI model. Finally it was concluded the conventional method of analysing a structure neglecting SSI is not adequate to ensure the resistance against lateral forces when subjected to seismic excitation on relatively flexible soil.

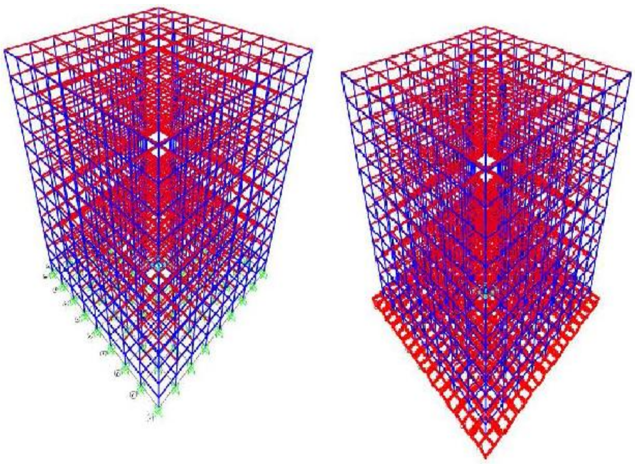

Fig:6 Building Models with fixed base and with SSI case (Martin et al (2017)).

III CONCLUSIONS

1. The Story Responses such as Displacements, Base Shears and Overturning moments was always higher for Soft Soil
2 Nonlinear load-transfer curve and flat-shell element can overcome the limitations of existing numerical methods by considering the realistic nonlinear behavior of soil and membrane action of flexible raft
3. The parameters like displacements, shear force and bending moment varies from conventional analysis to numerical analysis.
4. A comparative study can be done 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.
5. It has been observed that total deformation (vertical) of building is more in flexible base model than in fixed base model, which means that in actual case settlement occurs and it depends on type of soil beneath.
6. With effect of SSI, natural frequency of structure is very less and deformations are more. Structures soil properties can be improved by constructing brick work/concrete below footing.
7. The greatest effect of the increased wind load was an almost doubling of lateral deflections (sway) of the building.
8. Storey shear is maximum in fixed soil type model as compare to hard, medium and soft. Storey shear is maximum in soft soil type model as compare to hard, medium and fixed.
9. The use of flexible base in the analysis lead to reduction in the structural response and damage consequences in joints and infill's.
10. The lateral deflection and base shear are maximum for soft soil base condition.
11. As the building height increases the base shear and displacement increases. In case of soft soil, the SSI has been recommended.

12. Base shear, axial forces and Maximum lateral displacement values increases with the ascent of storeys and with higher seismic zones.
13. Bending Moment is higher in Interaction case than in non-interaction case. Extensive studies are still needed to ascertain a rational reduction factor.
14. The effect of SSI can reduce up to 70% and 30% for high and short building respectively of column base shear, there is reduction of column base moment up to 70% compared to that of fixed base and reduction becomes more when the height of the building increases.
15. On comparing the different models with and without SSI it is confirmed that the dynamic characteristics of soil structure system should be recommended for conservative nonlinear seismic response of high building since it mitigates earth quake hazards.
16. The conventional method of analyzing a structure neglecting SSI is not adequate to assure the resistance against lateral forces when subjected to seismic excitation on relatively flexible soil.

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