Dynamic Analysis of RCC Building with Special Emphsis on Effect of Soil Structure Interaction

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Abstract - *During earthquakes seismic waves propagate from the bedrock through the soil layers and damage structures on the surface. In this present era of rapid growth and urbanization along with the scarcity of land area one is forced to build the structures even on the relatively soft soil which were considered unsuitable for constructing purpose in the past. However it is possible to construct the structure because of the advancement in various ground improvement techniques. Seismic behavior of structure that is built on soft soils is mainly influenced by the soil properties, and the structural response is considerably different from the fixed-base condition beholding to the interaction between the structures and the ground. Effect of the primitive soil on the seismic response of structures can be ignored when the ground has a stiff stratum, and subsequently the structure can be considered as a fixed-base condition. Analytic and numerical models for dynamic analysis typically ignored SSI effects of the coupled in nature structure-foundation-soil system. It has been recognized that SSI effects may have a significant impact for heavier structures and soft soil conditions. This paper presents an overview of literature related to the effect of soil structure interaction. The review includes literature based on software analysis and experimental results.*

Key Words*: *Soil Structure interaction, Winkler's approach, Piled Raft foundation, SAP2000

1. INTRODUCTION

Structures founded on the rock are considered as fixed base structures. When a structure is formed on solid rock is subjected to an earthquake, the extremely high stiffness of the rock constrain the rock motion to be very close to the free field movement and can be considered as a free field movement and fixed base structures. Dynamic analysis of SSI can be done using Direct Method and Substructure Method. The direct approach is one in which the soil and structure are modeled together in a single step accounting for both inertial and kinematic interaction. Substructure method is one in which the analysis is broken down in several steps that is the principal of superposition used to isolate the two primary causes of SSI (Wolf, 1985). If the structure is supported on soft soil deposit, the lack of the foundation to adapt to the deformations of the free field motion would cause the motion of the structure to deviate from the free field motion, additionally the dynamic response of the structure itself can induce deformation of the supporting soil. This process, in which the response of the soil influences the motion of the structure and the response of the structure influences the motion of the soil, is studied under the interaction effects and popularly known as soil structure interaction. These effects are more significant for stiff and heavy structures supported on relatively soft soils. For soft and light structures established on stiff soil these effects are generally small.

2. LITERATURE REVIEW

2.1 Software based analysis

Nguyen et al [1] investigated the soil structure interaction phenomena on a 15-story moment-resisting frame sitting on differently sized end-bearing and floating pile foundations. A three-dimensional (3D) numerical model is analyzed for the nonlinear behavior of the soil medium, the piles, and the structural elements. Results show that the kind and size of the pile parts influence the dynamic characteristics and unstable response of the building due to interaction between the soil, pile foundations, and the structure. A nonlinear time history dynamic analysis under the influence of the earthquake ground motions, including the 1994Northridge and 1940 El Centro earthquakes, was performed. SAP2000v14 software was used for the structural analysis and design of the cross sections of beams and columns.

Mathew et al [2] analyzed a nine storey RC building asymmetric in plan, located in seismic zone III using SAP2000. Pushover analysis has been performed to obtain effect of soil-structure interaction on buildings resting on different types of non-cohesive soil, viz., soft and rock. The properties assigned for these two soil classes are specified by ATC 40.Comparison was made between fixed base without considering soil structure interaction, flexible base by considering SSI in hard soil condition, and flexible base by considering SSI in soft soil condition. The stiffness of springs has been estimated using Richart and Lysmer model. The values of displacements for different types of soil have been compared.

Bagheri et al [3] investigated the effect of soil-pile structure interaction on seismic response of structures. Numerical simulations on two types of superstructures and six types of piled raft foundations were carried using finite element software SAP2000. Parametric study was conducted using time histories of various earthquakes. Two 15 and 30 storey buildings were selected with total heights of 45 and 90 m, respectively. In this research, the Mohr-Coulomb model was used to simulate the soil nonlinear behavior. The working mechanism of the composite piled raft foundation was carried considering a long pile arrangement with a short pile interval. 2D and 3D models were compared on the basis of lateral displacements.

Maheshwari and Rajib [4] developed a MATLAB to model three-dimensional soil-pile-structure systems. A 2 × 2 pile group in liquefiable soil was considered and a parametric study was conducted to investigate its seismic behavior. The effects of loading intensity and stiffness of the soil on the seismic behavior of the soil-pile system were investigated. Three conditions of soil behavior were considered such as linear elastic, soil without pore pressure generation capacity and soil without pore pressure generation capacity. Effects of stiffness, soil nonlinearity, amplitude of acceleration and pore pressure were studied.

Juirnarongrit and Ashord [5] used the p–y method for analysis of single piles and pile groups subjected to lateral spreading. The piles in the groups were modeled as an equivalent single pile with four times the flexural stiffness of a single pile for the four-pile group and nine times the flexural stiffness of a single pile for the nine-pile group. Winkler spring model was used to determine responses of the single piles by imposing the known free-field soil movement profile. For liquefied soils, zero spring stiffness was used and for non-liquefied soils, soil springs used were based on standard p–y springs. Curves were plotted of pile head displacement and maximum moment versus ground surface displacement for single pile considering linear and non-linear pile behavior. For piles in group, depth-displacement, depth-rotation and depth-moment curves were plotted.

Yang and Liang [6] derived solution to numerically solve the problem of laterally loaded piles in layered soils using beam on an elastic foundation model. Mathematica software was used to derive numerical solution. Stiffness of soil varied linearly along the length of pile. The soil profile consisted of two layers. Four different possible combinations of this profile were considered in this study. The numerical solution was validated against an existing solution for linearly varying soil stiffness in a single soil layer system and an existing solution for a two-layer soil system with constant soil stiffness. The results were compared with free and fixed head existing solutions.

Kim and Rosset [7] analyzed structures with a constant base and variable height. Response spectra for a single degree of freedom SDOF system simulating a building with a mat foundation on soft soil, with and without piles, were obtained considering the soil–structure system. The depth of the soil layer (H) was 30 m. horizontal and rocking stiffness were compared for linear and non-linear behavior of soil for mat foundation. Also, elastic and inelastic response spectra of SDOF system and that of soil were compared for mat foundation.

Haldar and Babu [8] examined pile failure mechanisms viz., bending, buckling, shear failure, and settlement failure. The finite difference program, FLAC was used to obtain the pile response. Response of a single end bearing pile in a liquefiable soil for different soil, pile, and earthquake parameters is analyzed using time history method. Concrete piles and steel tube piles with two different pile diameters were used. Shear strain-frequency, amplitude-frequency and depth-frequency curves were plotted.

Maheshwari et al [9] analyzed single piles and pile groups considering the effects of kinematic and inertial interaction. The harmonic seismic excitation is applied at the base of the bedrock for the single pile model, and the response was calculated at the pile head and at the top of the structure. The analysis was performed for excitation with different frequencies.

Ghandil and Behnamfar [10] studied the direct method of soil–structure interaction analysis. Dynamic non-linear time history analysis was implemented using earthquake records structural responses were compared for different assumptions of soil behavior including the elasto-plastic, Mohr–Coulomb, equivalent linear and the proposed modified equivalent linear method. Six 3D steel buildings with 5, 10, 15, 20, 25, and 30 stories were considered. Buildings were modeled in SAP2000 software. Maximum lateral displacements of stories with and without SSI were plotted fox all six buildings. Also, maximum storey shear with and without SSI were plotted.

Luo et al [11] compared an equivalent linear model developed from the ground response analysis and the modified Drucker–Prager model. Analysis was done on three types of soils viz., silty clay, sandy clay and rock. Time history method was used. Maximum lateral displacement curves were plotted for model with and without soil structure interaction. Maximum lateral deflections resting on model with equivalent linear soil and non-linear soil were plotted.

Ghandil and Behnamfar [12] analyzed short to tall buildings including 5, 10, 15 and 30 story structures. A number of consistent earthquakes were applied on two existing soft soils. Profile I consists of a single sand layer 25 m thick, on the bedrock. Profile II includes three layers of clay, totally 45 m thick, on the bedrock. Storey drifts and storey shears were plotted with storey height considering SSI and without SSI.

Sica et al [13] conducted parametric study of a vertical cylindrical pile embedded in a two-layer soil profile to vertically-propagating S waves. The analyses were performed using a mixed numerical-analytical beam-on-dynamic-Winkler-foundation (BDWF) model. The soil profile consisted of a soft surface soil layer lying on a stiffer stratum. Elastic bedrock conditions have been assumed at the bottom of the lower layer. Shear strain, stiffness and damping vs. depth curves and interface kinematic bending moment vs. frequency curves were studied.

Mucciacciaro and Sica [14] analyzed single pile embedded in a soil deposit made of two cohesive layers of huge stiffness contrast between the consecutive soil layers in order to represent the worst conditions in terms of kinematic pile bending at the soil layer interface. Analysis was carried using finite element code ABAQUS. Shear stress and bending moments were plotted with respect to depth of soil.

Matinmanesh and Asheghabadi [15] carried the soil-structure interaction analysis using Abaqus V.6.8 program. Two buildings with 5 and 20 storey, one-bay moment resistant frames representing low and high rise buildings were used to investigate the effect of structure height on response of the soil-structure system. Analysis was performed using low, intermediate and high magnitude earthquakes. Influence of different sub-soils (dense and loose sand), buildings height on earthquake response were investigated. Maximum acceleration and maximum principal stresses were plotted.

Abbasa et al [16] studied the influence of vertical and lateral loads on pile group. The analysis was done using finite element method and p-y analysis. Effect of load combinations on pile group was performed on three pile group configurations. Lateral displacements of single pile and that of group of piles was compared and it was concluded that group interaction effect led to reduced lateral resistance for the pile in the group compared to that for the single pile.

Mohti and Khodair [17] investigated pile-soil interaction due to application of axial and lateral loads to piles in sand. 3-D finite element models were created using Abaqus/Cae and SAP2000. The steel H-piles were used to support the abutment of integral bridges. Various types of soft soils were studied such as loose, medium, and dense sand. Nonlinear soil springs were assigned at different depth locations along the pile length. Bending moments and lateral displacements along the depth of the pile were obtained from FE analyses.

Badry and Satyam [18] analyzed asymmetric L-shaped 11 storey building resting on pile foundation with soil structure interaction effect. Applicability of equivalent pier method was studied. The parametric study was carried out for different input of earthquakes and soil types. Four different trial configurations for equivalent piers were considered. Lateral displacements at different depths were plotted with respect to time. It was found that, the EPM model which makes the SSI model computationally more efficient shows the same variation in responses as observed in the general pile layout model.

Chore and Sawant [19] carried numerical modeling of space frame-pile foundation system using finite element models. Parametric study was done using sub-structure approach. The soil used for analysis was cohesionless soil. Two different pile groups comprising two and three piles each in a group with series and parallel arrangement of piles were considered. Displacements and bending moments were compared with that of fixed base model. Also the effect of L/D ratio on displacements was found.

Jegatheeswaran and Muthukkumaran [20] studied the behavior of pile foundation due to combined vertical and horizontal loads in homogenous layer of sandy soil. Also, analysis of pile foundation on sloped ground was done by varying slope angles. Behavior of pile due to lateral soil movement was studied. Influence of lateral load as well as combined load on displacement at pile head at both horizontal and sloped grounds was plotted. Also, settlement of a pile on both horizontal and sloped grounds was plotted.

Jesmani et al [21] performed three dimensional finite element analyses to study the buckling behavior of fully and partially embedded concrete piles. Loose, medium and dense sandy soil was used for analysis and only axial load was applied. Static vertical load was applied and increased till buckling of pile occurs. Results of the numerical model have been verified by previous experimental results. Critical buckling load vs. normalize length of pile was plotted for fully and partially embedded piles for three types of sandy soil considered.

Khodair and Mohti [22] analyzed pile- soil interaction numerically under axial and lateral loads using Abaqus/Cae and SAP2000. Two three dimensional, finite element (FE) models of steel piles for bridge embedded in clay were analyzed. The soil profile consisted of three layers; two layers of stiff clay without free water and one layer of weak rock. The effect of varying the number of soil springs (7, 9, 12) on the induced bending moment and lateral displacement along the depth of the pile was examined from the FD solutions and FE. The results from SAP2000 were compared to those from FD solution by LPILE due to the effect of an induced displacement of 2 cm at the top of the pile.

Lee and Moon [23] developed a computer program incorporating an approximate hybrid analysis method for the practical design of piled raft foundations. In the presented method of analysis, the interactions between pile-soil, raft-soil, pile-soil-pile and raft-soil-pile were considered, and the effect of nonlinear behavior of piles and the interactions between piled raft components and soil were investigated by comparing with 3-dimensional

FEM program analysis results. It was found that the piles in a piled raft foundation reduce the total settlement as well as increases the total bearing capacity, it is very important to estimate accurately the nonlinear behavior of piles after yielding for the economic design of piled raft foundation.

Fayun et al [24] solved the equations of axially loaded piles subjected to lateral soil movement based on the flexural differential equations of elastic piles and Winkler's spring model of pile-soil interaction. Finite difference method was used to solve the flexural differential equations. Shielding effect between piles was analyzed using Mindlin's method. A parametric study was conducted to examine the influence of pile spacing, number, location and the magnitude of axial load.

Jinyuan et al [25] studied the finite element analyses of negative skin friction on a single pile under various conditions. Finite element program, ABAQUS was used to develop 2-D axisymmetric model. Parametric analysis was performed to investigate the influence of negative skin friction along the pile length of various influencing factors, including the consolidation time, the properties of pile/soil interface, the lateral earth pressure coefficient, pile-soil limiting displacement, the intensity of surcharge, and soil stiffness. A simple design procedure was proposed for estimating the pile load caused by negative skin friction based on the field measurements from literature and this investigation.

2.2 Experimental studies

Kim et al [26] analyzed effect of negative skin friction on single piles by one-dimensional consolidation model test. Computer program pile negative skin friction (PileNSF) was developed to calculate bearing capacity of pile embedded in a consolidating ground due to surcharge loading. Laboratory model test was performed to investigate the development of negative skin friction on single piles, as well as to validate the computer program (PileNSF). The values of soil settlement, excess pore water pressure, and axial force on pile were found and compared between the two methods adopted. Various models of piles with stratified soils were analyzed in PileNSF considering negative skin friction. Effects of consolidation, axial load, pile diameter, bearing layer were found with respect to depth of embedment.

Hokmabadi et al [27] considered 5-storey, 10-storey and 15-storey model structures and conducted shake table tests on these structures. Also a 3 dimensional numerical model was designed to compare the results with shake table tests. Influence of Northridge, Kobe, El Centro, and Hachinohe earthquakes was studied on each model by considering effect of soil structure interaction and without considering effect of soil structure interaction. Lateral deflections, bending moments and inter storey drifts were compared at each storey levels.

Suleiman et al [28] experimentally investigated the soil-structure interaction of piles used to stabilize failing slopes by applying lateral load to piles. Displacement and tilt gauges at the pile head and strain gauges, a flexible shape acceleration array, and thin tactile pressure sheets along the pile length were used. The soil used in the experiment was classified as well-graded sand. The lateral load was applied on the top soil and the displacements measured at three locations- at top soil box, the displacement of the pile at the soil surface and the displacement of the pile at the sliding surface. Applied load versus lateral displacement graphs were plotted.

Lin et al [29] conducted the experiment to investigate the soil-structure interaction of single short, stiff laterally loaded hollow steel pipe pile. Sensors clinged to the pile were used to develop the compressive soil-pile interaction pressures and also the lateral displacement along the pile length. Using these measures, force-displacement curve and depth strain curve were plotted. The results of this test were compared with results of tests conducted by different methods and data in literature.

Ashour et al [30] evaluated behavior of a long flexible pile group in uniform and layered soil. Strain wedge model was developed to analyze pile group under lateral loading. Load test was carried on pile group and single pile in layered clay, sand, layered sand and clay soil, in loose and medium dense sand. The lateral response of individual pile and pile group were assessed by plotting load-deflection curve.

Hussien et al [31] conducted shake table tests to examine the dynamic responses of single and grouped end bearing piles in dense sand. The model was prepared in a strong container. Distributions of normalized steady state bending moments of piles in a group for free head piles, group piles supporting SDOF structure and group piles supporting 2DOF structure were plotted w.r.t. depth.

Ghayoomi et al [32] studied the behavior of pile foundation supported single degree of freedom structures in dry and unsaturated fine sands. Centrifuge tests were carried to study the behavior of structure. Two types of sands of different degree of saturation were considered. The time history of Northridge earthquake was used as input motion. Seismic responses in terms of acceleration, lateral displacement, and frequency content were plotted. The lateral deformation profiles of the systems both in far field and piles showed lower deformations for unsaturated soil-pile systems due to higher stiffness of unsaturated sand.

3. CONCLUSIONS

The review of soil- structure interaction leads to following conclusions:

1. The effect of interaction should be considered for accurate calculation of design forces.

2. Soil-structure interaction may cause increase in seismic base shear, time period of building frames. This effect is seen mostly in soft soils than hard soils having higher stiffness.

3. The soil mass is considered as homogenous, isotropic and behaving in linear and nonlinear manner in the interaction analysis.

4. Roof displacement, storey displacement is also observed to be increasing due to incorporation of SSI.

5. Compared to Winkler's approach (Spring Model) the Natural Period, Roof Displacement, Base Shear, Beam Moment and Column Moment are observed to be increasing more in case of Elastic continuum approach (FEM model).

6. At least Winkler's method should be employed to consider SSI instead of fixed base condition for practical purpose.

7. Parametric studies consisting of pile spacing, number, and location and magnitude of axial load are conducted to investigate the influence of soil-structure interaction.

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