Dynamic Soil Structure Interaction of RC Multi Storey Buildings on Different Foundations - A Review

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Abstract— *This paper focuses on a review of the dynamic soil structure interaction of RC multi storey building under different foundation types. The aim of this study is to gain understanding about the effect of the foundation type on the seismic forces in the multi storey building. The study helps in creating awareness about the importance of the foundation, such as proximity to the source of earthquakes and the earthquake resistant design of buildings. In selecting the type of foundation best suited for high-rise buildings in high risk seismic zones, design engineers may consider that a shallow foundation, a pile foundation, or a pile-raft foundation can best carry the static and dynamic loads. However, different types of foundations behave differently during earthquakes, depending on the soil–structure interaction (SSI) where the properties of the in situ soil and type of foundation change the dynamic characteristics (natural frequency and damping) of the soil–foundation–structure system. This paper shows the different foundations and its behaviour under dynamic loading studied by the various researchers.*

Keywords— Soil Structure Interaction, RC Buildings, Seismic Behaviour, Shallow Foundation, Deep Foundation

I. INTRODUCTION

Several studies have been made on the effect of soil-structure interaction problems to obtain more realistic analysis. They have quantified the effect of interaction behaviour and established that there is redistribution of forces in the structure and soil mass. The interaction effects are found quite significant, particularly for the structures resting on highly compressible soils. The flexibility of soil mass causes the differential settlement and rotation of footings under the application of load. The relative stiffness of structure, foundation and soil influence the interaction behaviour of structure-foundation-soil system. During last few decades, due to rapid urbanization and lack of space for horizontal expansion, cities have grown vertically. High rise buildings are increasing at a rapid rate. For foundations of such high rise building, normally raft foundation, pile foundation or piled-raft foundation are used. Design of footing is a soil structure interaction problem and there are many factors affecting foundation design. It has been observed that in practice, it has been very much difficult for designer to consider the influence of all parameters, that are likely to affect design and generally simplified approach of conventional design is adopted in most of the cases.

II. LITERATURE REVIEW

A. Shallow Foundation

A shallow foundation is a type of foundation which transfers building loads to the earth very near the surface, rather than to a subsurface layer or a range of depths as does a deep foundation. Base-slab averaging results from adjustment of spatially variable ground motions that would be present within the envelope of the foundation, which are averaged within the foundation footprint due to the stiffness and strength of the foundation system. Base-slab averaging can be understood by recognizing that the motion that would have occurred in the absence of the structure is spatially variable. Placement of a foundation slab across these variations produces an averaging effect in which the foundation motion is less than the localized maxima that would have occurred in the free-field.

Martin (2002) made research on the soil-foundation-structure interaction with regards to seismic response. Geotechnical components of the foundation are known to have a significant effect on the building response to seismic shaking.[1] The nonlinearity of the soil and the interaction between the soil and foundation is shown to cause the building's stiffness and period to change to varying degrees. On the one hand, the nonlinearity of the soil may act as an energy dissipation mechanism, potentially reducing demands exerted on the structural components of the building. This associated nonlinearity, however, may result in permanent deformations (rotation or settlement) that cause damage to the building.

Charisis T.(2007) acknowledged the concept of “macro-element” which stands as a convenient alternative approach for fast but concise and accurate non-linear SSI analyses for shallow foundations provided it takes the different sources of non-linearity into account. It appears that the multi-mechanism plasticity formalism would allow the simultaneous treatment of the two basic mechanisms of non-linearity (soil yielding and uplift) encountered in the problem.[2] Initial results from the macro-element development process, which concern the definition of the ultimate surface of the “plasticity-type” model for the footing are already available from the determination of the seismic bearing capacity of the footing where it was concluded that the Euro code 8 equation for strip footings on homogeneous soils can be extended with minor modifications to the case of circular footings on soils with a vertical cohesion gradient.

B. Raft Foundation

Kuladeepu (2015) studied the dynamic behaviour of building frames over raft footing under seismic forces uniting soil structure interaction is considered. The analysis is carried out using FEM software SAP2000 *Ver14. For the interaction analysis of space frame, foundation and soil are considered as parts of a single compatible unit and soil is idealized using the soil models for analysis.[3] The soil system below a raft footing is replaced by providing a true soil model (continuum model). In continuum model, soil is considered as homogeneous, isotropic, elastic of half space for which dynamic shear modulus and Poisson’s ratio are the inputs. The study leads to the following broad conclusions: The fundamental natural period of a specific structure considering interaction is more than that of non-interaction investigation furthermore it increments as the shear modulus of the soil declines. With expansion in number of stories, fundamental natural period is increased. Base shear values for interaction case is more than that of non-interaction case, as the shear modulus of the soil abatements base shear increments. With expansion in number of stories, base shear is increased. For the increment in shear modulus and number of stories the maximum lateral displacement of the structural element discovered to be expanded. The estimations of maximum lateral displacement resulting from a fixed base analysis are impressively improved when interaction analysis of the system is considered.

Patil (2016) studied the effect of soil flexibility on the performance of the building frames resting on raft foundation. The soil flexibility is incorporated in the analysis by using Winkler approach (Spring Model). SAP-2000 software is used to model fixed base and flexible base. The effect of SSI on various dynamic properties i.e. natural time period and base shear are discussed. The comparison is made between the non-interaction (non-SSI) and soil structure interaction (SSI) analyses with fixed base and flexible base conditions.[4] The Base shear of the structure increases due to SSI effect. For soft soil, the effect is more as compared to hard soil. The percentage variations are lesser for low rise building and increases with increase in storey height. The increase in soil flexibility and storey height, the base shear increases in higher rate. Increase in soil flexibility, natural time period is also increased. Natural time period is a primary parameter which regulates the seismic lateral response of the building frames. The effect is more prominent for soft soil as compared to hard soil. Thus evaluation of this parameter without considering SSI effect may cause major error in seismic design.

Roopa (2015) showed that the variation of storey drift is parabolic with middle storeys showing maximum drift irrespective of the consideration of SSI effect. But when SSI is considered there is a magnification of storey drift in the middle storeys. The base shear for flexible base condition is higher when compared to fixed base condition.[5] The response of the tall building founded on clayey soil has shown significant increase compared to conventional approach of assuming fixed base and founded on soft soil. Significant increase in response of tall building when SSI is considered is because of flexibility induced to the base by the softness of clayey soil.

C. Pile Raft Foundation

Piled-raft foundations for important high-rise buildings have proved to be a valuable alternative to conventional pile foundations or mat foundations. The concept of using piled raft foundation is that the combined foundation is able to support the applied axial loading with an appropriate factor of safety and that the settlement of the combined foundation at working load is tolerable. Piled raft foundation behaviour is evaluated with many researches and the effect of pile length; pile distance, pile arrangement and cap thickness are determined under vertical or horizontal static and dynamic loading.

Shukla, Desai and Solanki C.H(2015) performed an iterative dynamic analysis using SAP2000 program to carry out three dimensional time history analysis of non-linear soil-foundation-building models under a great earthquake ground motions. The interaction between the soil and the structure is represented by Winkler spring model. The obtained results confirmed that the dynamic characteristics of soil structure system should be recommended for conservative nonlinear seismic response of the high building since it mitigates the earthquake hazards. For medium duration earthquake the ϕ soil behaves in desired manner. The settlement and displacement of raft gets reduced in considerable extent and for short duration earthquake these results are even more effective considering all the three specified sub soil types. This exhibits excellent behaviour of medium dense sand as subsoil.[6] The frequency of occurrence of longer duration earthquake with high PGA is relatively very less but for medium to low duration earthquake it is very frequent. In that way performance of dense sand or medium dense sand as a sub soil results in reduced settlement and displacement to a considerable extent as compared to c and c-ϕ soil.

Chaudhari (2013) studied pile soil structure interaction by finite element software ANSYS 11. The soil structure interaction has been found to be significantly affects the performance of structure. Due to the material discontinuity at the interface of the two different surfaces, the structure has to be modelled using the interface element.[7] The maximum moments of soft clay are much larger than that of silty sand and stiff clay in all the cases. The maximum settlements are less affected by soil types. Moment carrying capacity of soil pile structure system is a function of a) Soil type b) Pile diameter c) Pile configuration d) Quantity of concrete. It is also observed that the optimum configuration of pile is soil dependent. The best configuration varies from soil-to-soil.

D. Pile Foundation

The pile foundations are adopted to transfer the load from the structure to soil when the structure is embedded in a weak soil stratum. In an axially loaded pile, the load is transferred to the soil through the side friction at the soil–pile interface and base resistance offered by the soil bed. Pile foundations are subjected to significant amount of lateral forces in addition to the vertical forces. The lateral forces are due to the wind, wave, earthquake, dredging, and impact loads.

Yingcai Han (2013) described an approximate and practical method for the seismic analysis. Two commercial software packages are used for considering the nonlinear soil-pile structure interaction. Stiffness and damping of the pile foundation are generated from a computer program DYNAN, and then input into a finite element model by SAP2000 program. The nonlinear behavior of the soil-pile system can be simulated using the model of boundary zone. The validity of the model has been verified by dynamic experiments on full-scale pile foundations for both linear and nonlinear vibrations.[8] The soil – pile interaction is an important factor which affects the stiffness and damping of foundation. The liquefaction of a layer of saturated fine sand can reduce the horizontal stiffness significantly, and further damage is possible. The soil-pile-structure interaction should be considered in a seismic analysis. The theoretical prediction for a structure fixed on a rigid base without the interaction does not represent the real seismic response, since the stiffness is overestimated and the damping is underestimated. The problem of soil-pile-structure interaction is complex in a seismic environment. The approximate and practical method described in this study is workable with the help of two computer programs (DYNAN 2.0 and SAP2000).

Pulikanti Sushma(2010) carried out a numerical study by considering the complexities in soil-pile structure interaction of group of pile supported structures. Initially a two dimensional study is considered for understanding the seismic response of high rise structure supported on piles. For this purpose different case studies are taken by considering structure soil structure interaction (SSSI).[9] The seismic behavior of high rise structures supported on pile foundation is different from that of rigid base structure. It has been observed from the responses of different cases that the group effect of neighbouring pile supported structures are playing a major role in dynamic analysis. So a reasonable seismic analysis for high rise buildings supported on pile foundations is needed to produce a safe and economic design.

Renu Raghuveeran,(2015) attempted to show the response of a structure in earthquake analysis by considering the effect of soil structure interaction. From modal analysis, the natural period is found to be increasing with increase in soil flexibility and with number of storeys.[10]The percentage variation in natural period increases with soil flexibility while it is found to be decreasing with increase in number of storeys. From transient analysis it was observed that roof displacement increases with increase in soil flexibility and number of storeys. While the percentage increase in lateral deflection decreases with increase in number of storeys. Soil settlement also increases with increase in soil flexibility and number of storeys.

III. Conclusion

The review of the current practice as applied in soil-structure interaction analysis leads to the following broad conclusions.

1) The forces in superstructure, foundation and soil mass are significantly altered due to the effect soil-structure interaction. For accurate estimation of the design force quantities, the interaction effect is needed to be considered.
2) Soil-structure interaction may cause considerable increase in seismic base shear of low-rise building frames resting on isolated footings.
3) The finite element method has proved to be a very useful method for studying the effect of soil-structure interaction
4) To accurately estimate the response of structure, the effect of soil structure interaction is needed to be considered under the influence of both static and dynamic loading.
5) Load redistribution significantly modifies the total and differential settlements. Settlements are found to be more in the non-linear analysis.
6) The buildings designed without the consideration of SSI effects will be less safe during the time of earthquakes.

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