# Soil Structure Interaction Analysis on Raft Foundation

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## ABSTRACT

Soil Structure Interaction (SSI) is the response of the soil to the motion of the structure, or the structure's motion to the response of the soil. Heavy structures, particularly high-rise buildings built on soft soil, have a lot of soil-structure interaction. Inthis paper the major portion of work was carried out to know the parameters such as settlements, displacements, base shear, storey drift, bending moments, shear force and damages due to various forces when a buildings foundation is laid on raft foundation. soil structure interaction (SSI)analysis was done using various numerical, empirical, methods by using a combination of software such as ETabs and safe,ETabs and Plaxis 2d/3d, FLAC 3d ,Midas and SAP2000 . From those analysis it was found that SSI and Non-SSI interactionanalysis has shown a great difference in terms of Structural safety and stability. There was a great impact of subbase on the structure for different conditions of buildings such as high-rise structures, storage buildings, massive transportation structures, signal transmission towers and chimneys. Different structures with different utilities and different properties were studied and analyzed.

**Keywords:** Soil Structure interaction**,** Raft foundation, Displacements, Story drift, Base Shear, Bending moment, soil stiffness, settlements, SAP 2000.

## INTRODUCTION

Soil structure interaction is not considered generally while designing the building for various properties and parameter consider soil surface as a rigid base, but it plays a key role in making a building safe against displacements, drifts, shear forces and bending moments in different situations and soil structure parameters. Raft foundations are widely used to support buildings and structures on different soil types and different requirements of buildings. Soil has different loading patterns, pressures& different forces which can impact the structure and structure imposes different kinds of loads on to the sub base considering those factors soil structure interaction analysis is to be done. Most of the structural damages are due to failure of sub base/ the structures below sub base level which fail in transferring the super structure. Various studies have appeared in the literature to study the effect of SSI on dynamic response of structures such as nuclear power plants, high-rise structures storage structures, chimneys, towers, bridges etc.,.The main aspects run in background which makes SSI a main role in terms of building/structural safety, stability & durability are conditions of soil under the structure, soil strata, water tables, properties of building , different loading patterns according to the purpose of the structure . Raft foundation is a thick reinforced concrete slab which spreads over a large area of soil and provides support for several columns and load bearing walls. It is also called as mat foundation which are widely used foundation system. Raft foundation is a type of shallow foundation but in some cases it also needs support of deep foundation to resist and transfers loads at unstable sub base conditions. Numerical methods, adopting finite element or finite difference methods, are most used to study the complex and complicated interactive behaviors giving the researcher the ability to model complicated conditions of the ground with high degree of accuracy and efficiency. Therefore, the soil structure interaction analysis for Raft foundation is necessary to be conducted by using various software in different parameters.

## LITERATURE REVIEW

**Juan M. Mayoral, Miguel P. Romo, and Sergio Martinez:**They have studied the elastic expansions and settlements along with long term settlements due to consolidations to be used in the seismic – soil structure interaction analysis. Response of the system is evaluated in terms of ground displacements, structure distortions ground and structure accelerations.They have proposed as a foundation alternative of light to medium weight structures to be built in the low strength-highly compressible, fissured clays typically found at the Texcoco lake valley, in the Mexico City surrounding areas.

**John S. Horvath, Ph.D., P.E. (and) Regis J. Colasanti, P.E.:**In this paper they have developed three equations which can be directly used on practical models.The substitution of terms in that equations can be directly added from real time structures and subgrade.The new and novel MK-R hybrid subgrade model is the long-sought practical improvement to Winkler's hypothesis and was more effective for SSI analyses in routine practice.The accuracy of the MK-R model can be evaluated in two ways. The simpler and more fundamental way is to compare results for idealized problems involving one or more layers of linear-elastic material with relatively simple applied loads. The other type of evaluation involves case histories of actual structures where appropriate measurements have been made to allow comparison of measured values to those calculated using the MK-R model.

**M Roopa ,H. G. Naikar and Dr. D. S. Prakash :**In this paper they concentrated mailny on in-situ clayey sub grade conditions .They have used finite elements tools usch as ETABS 9.7.4 for modeling and SSI analysis using SAP2000 VER17and found thefollowing parameters such as:Story Drift Base shear and Natural Time Period of building under different soil conditions found that There Were significant variation after considering soil and structure interactions. When SSI is considered, there is a magnification of storey drift in themiddle storeys.The base shear for flexible base condition maximumcompared to fixed base condition is found to havealmost doubled when SSI effects are considered.

**Dr.D. Daniel Thangaraj and Dr.K. Ilamparuthi.** They have studied for interaction and non interaction analysis on a 3 x 5 bay 5 storeyed space frame .They have performed a study by Geometric and elastic properties of the frame and raft and soil , settlement of raft , contact pressure below the raft , axial forces and bending moments of beams and columns And also varied the factors (ksb) and (Ksr) Based on the interaction and the non-interaction analyses of the soil-raft-space frame system, The interaction analysis showed less total and differential settlements than the non-interaction analysis. Between the two parameters, krs and ksb, ksb has a significant influence on both the settlements indicating that the modulus of the soil plays major role in the performance of the raft.

**Peter T. Brown and Si K. R. Yu :**The influence of interaction between a framed structure and the foundation-soil system beneath it, on the distribution of load between the columns and the differential settlements, has been described in this paper .This paper compares the results of these two forms of loading and the way in which they are related .They have taken a 3-bay x 3-bay four-story steel-framed office building with precast concrete floor and roof slabs, was designed to rest on a rigid base they have analyzed in two cases :All loads applied after completion of the frame and Considering the structure–foundation soil system after completion of each story . They have used FOCALS program for calculation and Interaction analysis of both plane and space frames shows that the effective stiffness for interaction purposes, of a building that is loaded progressively during construction, is about half the stiffness of the completed building.

**Ashutosh Kumar, Milind Patil and Deepankar Choudhury:**They have made a case study on a raw material storage building in vietnam for CPRF (Combined Piled-Raft Foundation) abilities. They have usedplaxis 3D for simulations and analysis .The present study deals with the analytical and numerical analysis of a CPRF design for a raw materials storage building in Vietnam adopted as a possible foundation solution because an unpiled raft did not satisfy the serviceability requirement in the foundation design. The vertical load shared by the raft varied from 23% to 31%. The study investigated the use of closed-form design and computer-based numerical techniques with reasonable accuracy. A similar design procedure can be adopted for the analysis and design of the CPRF for structures that are subjected to vertical loading conditions .

**Shehata E. Abdel Raheem, Mohamed M. Ahmed ,Tarek M. A. Alazrak**They have used 3 methods for finding the parameters underneath the soil conditions.The three methods are : Time History analysis **(TH)** ,Equivalent Static Load **(ESL) and** Response spectrum **(RS)** . They have used ETABS and Sap2000 software for simulations and analysis for evaluation of 6 and 12 story model :Story Drift ratio with SSI and NSSI(Non Soil structure interaction) Story lateral displacements with SSI and NSSI and Story shear force response with

SSI and NSSI .They have used Egyptian code of practice (ECP-201) as codal provisions and found that ,considering SSI effects in the seismic design of mid-rise moment-resisting building frames, particularly when resting on soft soil deposit, is essential. If SSI is not taken into account in analysis and design properly the accuracy in assessing the structural safety, facing earthquakes, could not be reliable .

**B. R. Jayalekshmi, S. V. Jisha, R. Shivashankar, and S. Soorya Narayana :**In this paper they have numerically analyzed soil-structure-interaction (SSI) of tall reinforced concrete chimneys with piled raft foundation subjected to El Centro ground motion (1940) using finite element method. Seismic analysis in time domain was performed on the basis of direct method of SSI on the three-dimensional SSI system. The chimney, foundation, and soil were assumed to be linearly elastic in the analysis. The stress resultants and settlement of raft of piled raft foundation were evaluated under different soil properties and different geometrical features of raft and chimney. Soil properties were selected based on the shear wave velocity corresponding to sand in the loose to dense range. Chimneys with different elevations of 100 m, 200 m, and 400 m were taken with a ratio of height to base diameter of chimney of 17. Raft of different thickness was considered to evaluate the effect of stiffness of foundation. The dynamic SSI effect is more prominent in 100 m and 200 m chimney as compared to 400 m chimney.

**B. R. Jayalekshmi , S. V. Jisha and R. Shivashankar :**In this paper they have studied for 100 and 400 m high R/C chimneys having piled annular raft and annular raft foundations considering the flexibility of soil subjected to a cross-wind load .They have used ANSYS a finite element method for analysis following Wind codes for chimneys : IS: 4998 (Part 1)-1992 , CICIND-(2005) , ACI 307-2008 ect. and found that The settlement of raft is reduced by 62%due to the addition of piles in the annular raft foundation of higher elevation chimney resting on loose sand, tangential and radial moments increases with decrease in stiffness of raft **,** Considerable increase in the radial moment in raft due to interaction with loose sand and medium sand as compared to the conventional method and Location of maximum tangential moment in raft is shifted from inner edge to chimney wind shield location due to increase in stiffness of foundation and supporting soil .

**Kuladeepu M N , G Narayana, B K Narendra :**In this paper they have used FEM software SAP2000 *Ver14 for SSI effect on dynamic behavior of 3D building frames with raft footing .Influence of number of parameters such as number of storey's, soil types and height ratio for seismic zone-V was considered . Building responses are considered for bare frame with and without accounting for soil flexibility. The responses in terms of natural period and seismic base shear, lateral displacement (story drift), with and without soil flexibility was compared to evaluate the contribution of soil flexibility on building frames. 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 increased. For the increment in shear modulus and number of stories the maximum lateral displacement of the structural element was expanded. The estimations of maximum lateral displacement resulting from a fixed base analysis are impressively improved when interaction analysis of the system was considered.

**Gaurav D. Dhadse**

In this paper the response of flexible base with different shapes of Raft footing is discussed . They have assumed that the footing is embedded in the cohesive soil mass .The effect of different shapes of raft footing on flexible base is evaluated through Interaction Analysis. Using the below mentioned and shown data of properties and dimensions of building and soil parameters they have made analysis and found displacement and stresses for different shapes of raft .They have used ansys for analysing all the models and found that at geometric discontinuities, the stress concentration is more so all the shapes are modelled considering this concept.

**Jonathan P. Stewart, Raymond B. Seed, and Gregory L. Fenves :**Two sets of analyses for soil structure interaction are described in this paper: (1) Simplified design procedures that can be used to predict period lengthening ratios and foundation damping factors for structures with surface (MV) or embedded (MV or MB) foundations; and (2) system identification procedures for evaluating fixed- and flexible-base modal vibration parameters from earthquake strong motion data. The greatest uncertainty in use of the MV and MB procedures for a given free-field motion is associated with the impedance function. Careful consideration must be given to evaluation of the shear-wave velocity profile, the modeling of embedded foundations (the MB procedure may not be appropriate if basement walls are not continuous around the foundation perimeter), oblong foundations, or flexible foundations supporting a central core of stiff shear walls. Parametric system identification procedures provide a reliable basis for evaluating modal vibration parameters in structures for different base fixity conditions.

**Jonathan P. Stewart, Raymond B. Seed, and Gregory L. Fenves II :**

In this paper effects of aspect ratio, Effects of Foundation Type, Effect of Structure type, Effects of Foundation Shape, Effect of foundation flexibility were Studied and found that type of structural lateral force resisting system as well as foundation type and shape, were found to have a relatively small influence on SSI.A key finding of this research is that these inertial interaction effects can generally be reliably predicted by the MV ( ModifiedVeletsos) analysis procedure.

**H. *G.* POULOS :**This paper presents a method of analysis of piled-raft foundations in which the raft is modelled as a thin plate and the piles as interacting springs of appropriate stiffness. The analysis is based on elastic theory, but allows for the important non-linear features of the system: the development of limiting pressures below the raft, and of the ultimate load capacity of the piles. It allows consideration of the foundation response to applied loads and moments, and also to free-field vertical soil movements. The analysis is implemented via the computer program GARP, and is very convenient to use for developing parametric solutions or investigating the influence of parameter variations on foundation response.

**Sahar A. Ismail**, **Fouad K. Kaddah and Wassim E. Raphael :**In this paper the behaviour of 15 storey seismic midrise concrete frame structure rested on raft foundation and founded on silty sandy soil under the effects of raft and column sizes while considering SSI effects was investigated. The results showed that the size of raft as well as column stiffness can affect the performance of the structure. Larger foundations can attract more energy than smaller foundations. However, the increase in raft size and the decrease in column size cause a decrease in the amount of distortion component with an increase in the amount of rocking component. Nevertheless, raft size slightly affects shear force values and response spectrum curves while the increase in column size decreases average level shear force values. These results were related to the use of silty sandy soil as well as the relation between the structure-foundation-soil different natural frequencies, earthquake wave attenuation and PGA along with column stiffness and raft size.

## CONCLUSIONS:

1. When SSI is considered, there is a magnification of storey drift in the middle storeys. The base shear for flexible base condition compared to fixed base condition is found to havealmost doubled.
2. Interaction analysis of both plane and space frames shows that the effective stiffness for interaction purposes, of a building that is loaded progressively during construction, is about half the stiffness of the completed building.
3. Considering SSI effects in the seismic design of mid-rise moment-resisting building frames, particularly when resting on soft soil deposit, is essential.
4. The settlement of raft is reduced by 62%due to the addition of piles in the annular raft foundation of higher elevation chimney resting on loose sand.
5. The underlying grid walls with sort length in Raft Foundation influence the dynamic response andis very helpful to uniform long term settlements.
6. Significant increase in response of tall building when SSIis considered is because of flexibility of the baseby the softness of clayey soil .
7. If SSI is not taken into account in analysis and design properly; the accuracy in assessing the structural safety, facing earthquakes, could not be reliable.

### 4.Future scope

1. Though research in soil structure interaction analysis is been happening from many years and decades there is improvement over time.

2. They used to implement multiple softwares and combination of softwares to perform SSI and in recent years softwares have updated and now SSI can be peformed in only one software with ease .
3. The scarcity of place for construction gives way for multi storeyed structures and for multi/high rise structures it is important to check in terms of SSI to get good stability and safety .
4. As the whole loads are distributed at foundation level, massive structures definitely need to go for Raft foundation and SSI on Raft foundation is necessary .

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