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Effect of Soil-Structure Interaction on Seismic Response of Buildings: An Overview

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***Abstract*—An earthquake is the recognizable trembling of the surface of the earth, which results in the sudden release of kinetic energy in the form of seismic waves. It could be violent enough to cause damages to structures and thus result in great human casualties along with the huge economic loss. The past earthquake studies shows that the interaction of soil and foundation plays a significant role in the response of structure. Also the response of structure during an earthquake is influenced by three linked systems i.e.: the structure, the foundation and the soil surrounding the foundation. Therefore, in the present scenario, seismic analysis of buildings is utmost important. In this review, we describe the past studies focusing on the effect of soil-structure interaction on different parametric structures.**

Keywords*—Seismic Response, Soil-Structure Interaction

I. INTRODUCTION

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. Eventually the designers came to notice the dynamic behavior of soil and structure as a single system considering soil-structure interaction. 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 [1]. 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. Over the past decades, the seismic excitation evidences could be considered as a function of the fault-rupture mechanism, local site effect, travel path effect and SSI effect [2]. In a nutshell the above first three factors can be summarized as a free-field motion. Though the foundation is not capable of following the deformation of free-field motion due to its stiffness, also the dynamic response of the structure itself would incite deformation of the supporting soil [3].

Under civil engineering, most of the system of structure is in direct contact with the ground surface. However the structure and ground surface are independent of each other and can be seen when earthquake or any other external forces acts on these system then ground does not displace, nor does the structure displace. Therefore, the soil-structure interaction (SSI) can be defined as the process by which the response of the soil affects the motion of the structure and that effect of motion of the structure further affects the response of the soil is termed as SSI. Fig. 1 represents the seismic soil-structure interaction of a building founded on soft soil subjected with the pile foundation.

The rest of the paper is systematized as follows: section 2 converges and discusses about the characteristics, approaches, types, factors prompting for SSI effects and about the problem which are left to solve. We outline our proposed scheme briefly in section 3, which is the methodology section. Finally, we summarize our review work, conclude the paper and target some future work in section 4 and 5 respectively.

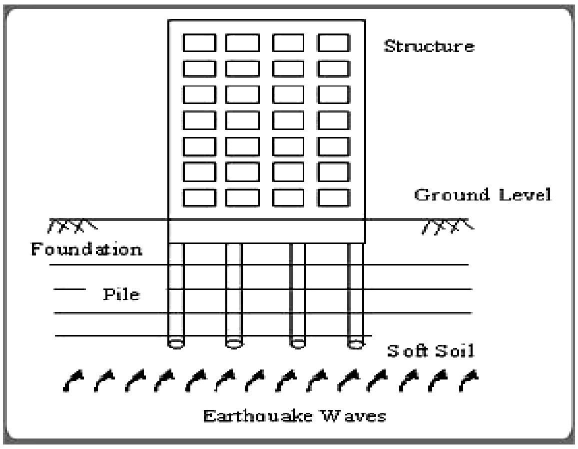

Fig. 1. Seismic soil-structure interaction [4]

II. PRELIMINARIES

In this portion, we describe the characteristics, approaches, types, degree of impact of soil-structure interaction in brief:

A. Characteristics of SSI

Characterization of the soil-structure interaction is followed by two significant effects as:

1. Flexibility of soil foundation immediately enhances the fundamental period of a fixed base structure.
2. Due to energy dissipation ability of soil through the radiation material type of damping, there is a change in the effective damping of a fixed base structure.

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B. *Approach to SSI difficulties*

There are two different approaches for the SSI effects:

1. Modification of given free-field motion and thus calculate response of the given structure to the modified foundation's motion.

2. Modification of structural dynamic properties and thus calculate response of the given structure to the recommended free-field motion.

C. *Types of SSI*

Basically, SSI is divided into two major types:

1. Kinematic interaction
2. Inertial interaction

Such response of SSI which is related with the structural stiffness is referred to as kinematic interaction where as Such response of SSI which is related with the structural mass is referred to as inertial interaction.
Actually the SSI system when directed to dynamic loading in an open system due to the flexibility of soil is called kinematic interaction and when energy radiates into the outer far-field region is called inertial interaction [5]. Despite the fact SSI has now became a leading affairs in dynamic analysis of bulky structures such as high-rise buildings, nuclear containment structures, tunnels, long span space truss, bridges, and tall industrial chimneys, so on [6-7].

D. *Degree of impact of SSI*

The degree of impact of SSI on the response of structure depends on the factors as follows:

1. Soil stiffness
2. Structure's dynamic characteristics i.e. damping factor and natural period
3. Mass and stiffness of structure

E. *Approaches of SSI*

The following are the two different approaches that have been adopted in the past to examine the problems of SSI and assimilate the effect of soil conformity in the dynamic analysis:

- Direct approach
- Sub-structure approach

1. *Direct Approach:*

In this approach, the soil and structure are assembled together in a single step computing for inertial and kinematic interaction. Inertial interaction acts in structure due to its own strokes giving rise to base shear and moment, which in turn stimulates displacements of the foundation relative to free-field motion. Whereas, the kinematic interaction acts due to existence of stiff foundation elements in or on the soil including foundation motion to vary from free-field motion.

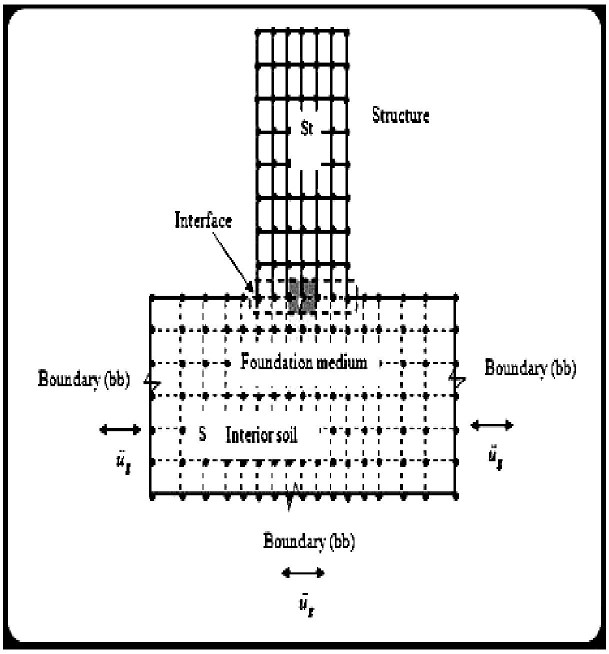

Fig. 2. FE model of SSI system for direct method of analysis [8]

In fig. 2, st is denoted as nodes of the structure, s are the nodes along interior foundation soil, and $\ddot{u}_g$ is the free-field ground acceleration.

2. *Sub-structure Approach:*

In this sub-structure approach, the analysis run-down into several steps i.e. the principal of superposition is used to dissociate the two primary causes of SSI i.e. impotence of foundation to adapt the free-field deformation and the reaction of dynamic response of foundation-structure system on the adjustability of supporting soil. Fig. 3 depicts the seismic SSI with sub-structure method in which the structure and the foundation medium are depicted as two independent analytical models.

In comparison with the direct approach, sub-structure approach is much more complex in assembling the SSI system. By the sub-structure method one can perform a dynamic SSI analysis in just three steps as follows:

1. Computation of foundation input motion by determining the kinematic interaction.

2. Computation of frequency dependent impedance functions by defining the damping and stiffness characteristics of the foundation-soil interacting system. The geometric and material properties of foundation and soil deposits should be accounted in this step and is commonly measured using equivalent linear elastic properties for soil which is appropriate for the in-situ dynamic shear strain. In turn this step produces the so-called soil springs.

3. Determination of response of the substantial structure guided by frequency dependent soil springs and headed at the base of these springs to the motion of the foundation input.

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NOTE: if the structural foundations were absolutely rigid/stiff, then the solution by sub-structure method would apparently be equivalent to the solution by direct approach. Practically the foundation input motion is pretended to be the same for free-field motion that is the kinematic interaction effects are ignored in SSI analysis for most of the ordinary constructions. But the kinematic interaction should be considered if the foundation on which the structure to be constructed are very large, rigid and massive.

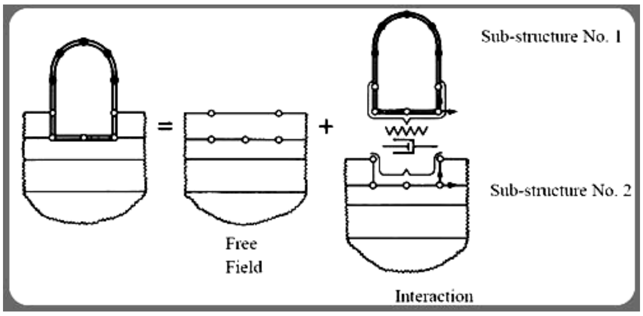

Fig. 3. Seismic SSI with substructure method [9]

F. Factors prompting for SSI effects

Different parameters are responsible in effecting the soil and eventually the SSI gets affected. Some of these parametric factors are introduced below in brief:

1. Impedance contrast:

Seismic waves travels slower in soft rocks and sediments while faster in hard rocks. The waves of higher amplitude carry the same amount of energy as it passes from hard to soft rocks. Thus, trembling tends to be stronger at locations with soft layer surfaces, where seismic waves move much slowly. Impedance contrast may be defined as the product of density and velocity of the material [10].

2. Resonance:

When the magnitude of excitation frequency (frequency of seismic waves) matches with the system's fundamental natural frequency then this phenomenon is termed as resonance. In the past, attempts have been presented that the response of structure against earthquake is aberrant for fixed-base analysis than the SSI analysis in frequency field. [11].

3. Damping in soil:

In the dynamic analysis, when the seismic waves move along the soil mass then those wave energy gets dissipated due to dispersion of the waves into the limitless domain. Hence in this phenomenon the loss of wave energy took place is referred as radiation damping. The seismic wave energy can also be utilized in the deformation of the soil mass which ultimately changes the property of the soil material and is termed as material damping [12]. Energy is absorbed mainly due to the inelastic property of medium where the particle of a medium does not respond perfect elastic behavior with their nearby resident and thus a part of the wave energy get lost rather than being transmitted through medium, subsequently after every cycle.

4. Trapping of Waves:

Impedance contrast within different layers of soil mass is a crucial phenomenon that causes the seismic waves trapping in the soil mass.

5. Lateral discontinuities:

Lateral discontinuities could be elucidated as the rigid material lie besides a softer one and in reverse. In the Bhatwari-Sonar village (1999), the damage provoked by the lateral discontinuities was observed where Chamoli earthquake due to the layer of fragments deposited beneath the stiff soil [13].

Many previous research works have been implemented on SSI analysis established on the different types of deep and shallow foundation framework. It has been examined that plenty of research gap is left with the efforts built on the interaction analysis of building established on piles [14].

III. METHODOLOGY

Finite Element Method-All the tangible phenomena (essentially the elastic behavior of one-dimensional, two-dimensional and three-dimensional bodies, including plates, torsion, groundwater flow, beams and columns, etc.) confronted in engineering mechanics are designed by differential equations, and mostly the problem encountered is too difficult to be resolved by classical analytical technique [15]. The finite element method (FEM) is a mathematical approach by means of which generic differential equations could be solved in an approximate way [15]. FE technique has been widely practiced in the analysis of complicated loading conditions where soil is modeled as a continuum [16].

A salient feature of this vigorous method involves the capacity to employ any combination of torsion, lateral, and axial loads; the ability to perform the structure and soil behavior nonlinearly; and to model the soil-pile-structure interaction accessibly [16]. Most of the finite element software (like ABAQUS, NASTRAN, ANSYS, etc.) is competent tool yet its complexity is high and is meant for professional engineers in order to interpret the results properly.

ABAQUS software is a software suite for computer-aided engineering as well as for finite element analysis. There were three separate stages for every complete FEA:

1. First stage involves modeling or pre-processing for creating an input file which is an engineer's design.

2. Second stage includes FEA or pro-processing for an output visual file.

3. Third stage involves post-processing or generating image, animation report, etc. form the output file and it's a visual rendering stage.

ABAQUS/CAE is efficient of performing all the above processing stages successfully.

Modeling of soil continuing medium

It is very well-known that the Earth's crust is vast on the geometrical rim as compared to the structural rim in engineering practices, and consequently can be regarded as an infinite medium referring to the mathematical analysis side. This poses a challenging problem for the prevailing finite element method on account of the modeling domain should be finite in the prevailing finite element analysis.

However, in our future work soil is modeled with finite boundary by providing the plan dimension of near field finite element soil should be considered 5 times the structure length [17]. Also the column height or say normal height of every storey for a residential building is taken equal to 3metre [18].

IV. CONCLUSION

The adoption of finite element method has acquired a sudden access to study the complex reciprocated behavior of structures. It is possible to prepare the models of much complex estates with high degree of authenticity including non-homogeneous material estate, non-linear stress-strain behavior, and geometrical change and so on. Hence numerical analysis is a proficient tool in the analysis of structures which can predict the possible deflection and settlements related to seismic loads in the act of designing the structure safely.

V. FUTURE SCOPE OF STUDY

1. By considering different layers of soil, we can carry out the present study.
2. In what condition does the SSI effect show its advantages or disadvantages?
3. In what way does the computer program and the analytical model that are being developed for the soil-structure interaction analysis be legally approved and made accessible for the actual practice.

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