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Seismic response of RC-multistoryed building resting on pile foundation considering interaction effects – a review

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ABSTRACT

Current seismic design exercise assumes the base of the building to be fixed and does not take into account about the flexibility of base soil. This assumption is most effective when the structure is founded on hard stratum or when the relative stiffness of the foundation soil is excessive in comparison to the superstructure. Whereas, in fact due to the capacity of the soil is to deform evidently, supporting soil medium modifies the response of the structure in the course of earthquake to a few notable quantities. This aims to look at the impact of soil structure interaction during seismic activity, on RC multistory building especially observed on pile foundation. Two strategies of analysis are used for seismic evaluation in buildings such as Response Spectrum (RS) and Time History evaluation and a brief review of interaction effects is presented in this paper.

Keywords- Soil structure interaction, Pile foundation, Poor subsoil, Seismic response, Response spectrum, time history analysis.

INTRODUCTION

The system in which the reaction of the soil impacts the motion of the structure and the motion of the structure have an impact on the response of soil is termed as Soil structure interaction (SSI). In this situation neither structural displacements nor the ground displacements are independent from one another. Due to shortage and very excessive prices of land the best possible answer is to construct multi-storied homes in areas having poor subsoil situations. [2]. Damages to the structures throughout earthquakes substantially depends on traits of soil and also relies upon on the strong ground motion.

When a structure is subjected to external forces including earthquakes, it interacts with surrounding soil and results in the amendment of reaction of building. During earthquake, the interaction acts on three systems specifically building, foundation, soil and it has a tendency to modify the whole system. Soil structure interaction is the phenomena in which the reaction of soil and motion of structure influence each other. The impact of SSI, however, becomes mandatory for heavy structures resting on relatively gentle soils. The multi-storey building (G+15) is taken into consideration to find the interaction effects, [6] as a Residential building.

KINEMATIC AND INERTIAL EFFECTS

Structure on soil revels two forms of interaction impact known as kinematic and inertial effects. The SSI effect which is associated with the stiffness of the structure is termed as Kinematic interaction. This exist because of alternate in wave propagation media as a result of change in density and elasticity of the media. It changes the wave propagation velocity and ends in mirrored image and refraction of incoming seismic wave [12].

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Kinematic outcomes of SSI constitute the change in response of structure while response is acquired using free-field motions, those are the ground motions that aren't motivated by the presence of structure. [3] Yesane concluded that, Kinematic interaction doesn't rely upon the mass of structure and is stricken by the geometry and configuration of structure, the foundation embedment, the composition of incident free-field waves, and the angle of incidence of these waves.

Inertial outcomes are result from the combined dynamic behavior of the three systems. Soil media, owing to its elastic and inertial properties, increases the degrees of freedom of structure and makes it feasible to deplete the strength of incoming seismic waves by the radiation of waves away from the structure and hysteretic deformation of supporting soil media [5]. Inertial effect depends on the relative flexibility of helping soil media to the structure, which implies isn't always extensive for every shape of the regular structure founded on Stiff soils or rock, rather shaking has a tendency to be stronger at sites with softer surface layers, where seismic wave movement is very slow.

SOIL–STRUCTURE INTERACTION UNDER SEISMIC LOADING

Structures are typically assumed to be fixed at their bases in the process of analysis and layout beneath dynamic loading. But the consideration of real support, flexibility reduces the overall stiffness of the structure and increases the duration of the system [2]. Considerable change in spectral acceleration with natural period is determined from the response spectrum curve. Thus, the change in natural period may additionally modify the seismic response of any structure drastically. In addition to this, soil medium imparts damping due to its inherent traits. The issues of increasing the natural period and involvement of excessive damping in soil because of soil–structure interaction in building structures are also discussed by the some of the researches, this was briefly mentioned in [3]. Moreover, the relationship among the periods of vibration of structure and that of supporting soil is profoundly crucial concerning the seismic response of the structure. The demolition of a part of a factory in 1970 earthquake at Gediz, Turkey; destruction of buildings at Carcas earthquake (1967) raised the importance of this problem. These show that the soil–structure interaction must be accounted for the analysis of dynamic conduct of structures, in practice. Hence, soil–structure interaction beneath dynamic masses is a critical aspect to predict the overall structural response. The dynamic equation of motion of the soil and structure system can be written as:

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\}=[M]\{m\}\ddot{u}g+\{Fv\} \quad \text{-----(1)}$$

Where, {u}, {ů} and {ü} are the nodal displacements, velocities and accelerations with respect to the underlying soil foundation, respectively. [M], [C] and [K] are the mass matrix, damping matrix and stiffness matrix of the structure, respectively. It is more suitably to use the incremental form of Eq. (1) when plasticity is covered, after the matrix [K] should be the tangential matrix. If only the horizontal acceleration is considered, then

{m}= [1,0,1,0, ...,1,0] ^T.

Fv is the force vector corresponding to the viscous boundaries.

The mentioned technique above, wherein the complete soil structure system is modelled in a single step, is called Direct Method. The use of direct method requires a computer program that could deal with the behavior of both soil and structure with equal rigor. The techniques to clear up the soil structure interaction problem can be grouped as direct approach, substructure approach [23], studied the outcomes of soil-structure – interaction in computation of lateral natural period and seismic base shear of building frames.

RESPONSE SPECTRUM METHOD

The response spectrum represents an interaction between the ground acceleration and the structural system, by way of an envelope of numerous ground motion records. For the purpose of the seismic evaluation the design spectrum given in fig 2 of IS1893 (part1)-2002 is used. This

spectrum is based on strong motion of informative records of eight Indian earthquakes. Following procedure proposed by [1], is generally used for the spectrum analysis.

- Select the design spectrum
- Determine the mode shapes and period of vibration to be blanketed within the evaluation.
- Read the extent of response from the spectrum for the period of each of the modes considered.
- Calculate the participation of each mode corresponding to the single degree of freedom response obtained from the curve.
- Add the consequences of modes to obtained combined maximum response.
- Convert the combined maximum reaction into shears and moments for use in design of the structures.
- Analyze the building for the resulting moments and the shear in the same way as of the static loads.

The code suggests that the number of modes to be used in the evaluation should be such that the total masses of all loads considered is at least 90% of the overall seismic mass. If the natural frequencies fluctuate from each other by 10% then the modes are considered as closely spaced. The peak response portions are combined using Complete Quadratic Combination (CQC) method. If the modes aren't closely spaced, then Square Root of Sum of Squares (SRSS) technique is employed. If there were few intently spaced modes, then it indicates the use of Sum of Absolute Values (ABSSUM) technique and rest of the mode could be combined using CQC technique.

TIME HISTORY ANALYSIS

It is a step by step analysis of a dynamic response of a structure to a distinctive loading that may vary with time. The widespread equation is given [9],

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\} = F\{t\}$$

$$[M]\{\ddot{u}\}+[C]\{\dot{u}\}+[K]\{u\} = -M[\ddot{u}g\{1\}]$$

Every mode is perpendicular to one other that is mode shapes are orthogonal to other mode shapes. In time history evaluation the entire reaction is obtained. Participation factor (P) indicates the quantity of mass present in that mode. In MDOF (say up to 15 floors), it will have massive variety of mode shapes, consequently in doing time history analysis where mass participation is more than 95% that many modes may be considered.

DETAILS OF THE SOIL

The present study especially focuses on the clayey soil. The critical parameters for the clayey soil are indexed. According to the laboratory test, the spring values for clayey soil as per [2] and [10] have been calculated. The clayey soil spring values are implemented to the pile raft foundation to facilitate Soil Structure Interaction. This mode of applying soil springs to the pile raft foundation is also known as Winkler approach [19], investigated the effects of soil structure interaction on the response of base isolated multistory buildings founded on an elastic soil layer overlying rigid bedrock and subjected to a harmonic ground motion.

The modulus of subgrade reaction is a conceptual relationship between soil pressure and deflection that is extensively used in the structural analysis of foundation members. It is used for continuous footing, mats and various types of piling. Subgrade reaction modulus (k_s) may be considered as an appropriate interface between the geotechnical and structural engineers. One of the famous models in determining the modulus of subgrade reaction is Winkler model [3]. Modulus of subgrade reaction of clayey soil may be decided by using different field tests and lab tests inclusive of plate load test, California Bearing Ratio tests. An attempt is made on these studies to determine the modulus of subgrade reaction values which are the basic parameter in the soil structure interaction analysis, soil idealization is stated [12]. Rigid and flexible plates with unique thickness are used for the experimental program and are considered as flexible and rigid foundation. For gentle soils, the foundation motion differs from that in the free field due to the coupling of the soil and structure at some point during the earthquake. This interaction results from the scattering of waves from the

foundation and the radiation of energy from the structure due to structural vibrations [20].

PILE FOUNDATION

The pile foundations are adopted to transfer the load from the structure to soil while the structure is embedded in a weak soil stratum. Piles are often used to ensure structural safety. In other cases [22], analyzed multi-storey buildings with raft foundations resting on smooth, medium and stiff soil. The end result showed that the natural period decreases with the increasing plan dimension due to the extended stiffness of the base.

Martin (2002) made research on the soil-foundation-structure interaction with seismic response. Geotechnical components of the foundation are known to have a great effect on the building response to earthquake shaking Pile foundations are subjected to sizeable quantity of lateral forces in addition to the vertical forces [7] and [9]. The lateral forces are because of the wind wave, earthquake, dredging, and impact loads. Depth of pile should never be much less than 12m. In case of horizontal and earthquake loads 0.8% of reinforcement should be adopted [15]. The soil – pile interaction is a crucial aspect which affects the stiffness and damping of foundation. The liquefaction of a layer of saturated fine sand can reduce the horizontal stiffness drastically, and further damage is feasible. The soil-pile-structure interaction should be considered in a seismic evaluation. The theoretical prediction for a structure fixed on a rigid base without the interaction does not constitute the actual seismic response, since the stiffness is overestimated and the damping is underestimated. The problem of soil-pile-structure interaction is complicated in seismic surroundings. As in line with [16], In this sense, designers should prefer symmetric foundations to uneven foundations. It is noted that the inelastic analysis of soil-foundation device was also performed for a confined number of load cases and it was shown that, at least for small deformations expected here, the response can be very well approximated with elastic soil behavior, [17].

CONCLUSIONS

The evaluation of the present-day practice is carried out in seismic response of structure considering interaction effect and its analysis leads to the broad conclusions.

1. To accurately estimate the response of structure, the effect of soil structure interaction is needed to be considered beneath the affect seismic loading.
2. The forces in building, foundation, soil are substantially altered because of the effect of soil structure interaction.
3. Soil-structure interaction may cause increase in seismic base shear, time period, response of low-rise building frames resting on isolated footings, and pile foundations in soft soils.
4. The displacement for flexible base condition is more to fixed base conditions when SSI effects are taken into account.
5. Finally, it can be concluded that while designing the buildings, the effect of SSI should be taken into consideration particularly when building is resting on pile foundation.

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