REVIEW ARTICLE OPEN ACCESS

A review on: The influence of soil conditions on the seismic forces in RC buildings

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ABSTRACT
This study focuses on a review of the influence of soil conditions on the seismic forces in RC buildings. The aim of this study is to gain understanding the effect of the local site conditions on the seismic forces in building. The study helps in creating awareness about the importance of the local site conditions, such as proximity to the source of earthquakes (faults) and the local geological and topographical features in the earthquake resistant design of buildings. The current Indian code of practice for seismic analysis IS 1893:2002, specifies seismic zones to consider different levels of intensity of ground shaking, There are also maps of the principal tectonic features and lithological formations. This paper shows the soil condition effects studied by the various researchers.

Keywords – Local soil conditions, RC buildings, Standard codes, seismic analysis, parametric study

I. INTRODUCTION

This study investigates the effects of local site conditions on the base shear, overturning moments and the member forces of a moment resisting framed building. A model multi-story building is first analysed using IS 1893:2002. Next, the same building is analysed using the International Building Code (IBC: 2006) that provides a methodology for using data from seismic micro-zonation in the analysis of buildings for seismic forces.

II. A LIRERATURE REVIEW

Sekhar Chandra Dutta, et al. (2004) [1]
The present study attempts to assess the impact of soil–structure interaction on regulating the design force quantities under seismic loading both in elastic and inelastic range of vibration for low-rise buildings. The study may lead to the following broad conclusions:
1. The study shows that the effect of soil–structure interaction may play a significant role to increase the seismic base shear of low-rise building frames.
2. The study also shows that this effect may strongly be influenced by the frequency content of the earthquake ground motion. 3. Increase in seismic base shear due to soil flexibility generally decreases with increasing hardness of soil and increasing number of stories. Introduction of tie beam also lessens the possibility of increasing base shear due to soil–structure interaction.
4. The effect of soil–structure interaction on the change in base shear appreciably alters due to the change in column to beam stiffness ratio, irrespective of the type of ground motions, building frames and types of foundations. On the other hand, excitation frequency of the forcing function may moderately influence the seismic characteristics of the buildings.
5. Inelastic range demands of lateral load resisting structural elements may experience considerable increase due to the effect of soil–structure interaction
6. If the effect of soil flexibility is incorporated in the strength design, then the increased strength provided through the interaction effect in short period systems may help to reduce the inelastic range demands of the interactive systems considerably.

Muberra Eser Aydemir (2006) [2]
This paper addresses the behavior of multistorey structures considering soil structure interaction under earthquake excitation. For this purpose, sample 3, 6, 9 storey RC frames are designed based on Turkish Seismic Design Code and analyzed in time domain with incremental dynamic analysis. Strength reduction factors are investigated for generated sample plane frames for 64 different earthquake motions recorded on different site conditions such as rock, stiff soil, soft soil and very soft soil. According to the analysis result, strength reduction factors of sample buildings considering soil structure interaction are found to be almost always smaller than design strength reduction factors given in current seismic design codes, which cause an unsafe design and non-conservative design forces.

F. Mollaioli, S. Bruno (2008) [3]
Lateral displacements control of structures subjected to earthquake ground motion has now been recognized as a key factor in the assessment of system performance, leading to design approaches that use displacements rather than forces as the starting point for the seismic evaluation of structures. In fact performance-based approaches offer significant advantages in comparison with traditional force-based approaches, since the former are capable of focusing on nonlinear behaviour and consequent damage to the structure, in contrast to the latter. Lateral displacement demand, particularly in structures that exhibit nonlinear behavior, can be significantly affected by the features of strong ground motion, i.e., amplitude, frequency content and duration. Such characteristics are in turn profoundly influenced by the irregularity and changeability in earthquake ground motions, which should therefore be taken into account appropriately. The great number of strong motion records gathered throughout the last decades in the most widely varying soil-site conditions has made accounting for soil-site effects in the characterization of elastic and inelastic displacement demands feasible. The aim of this paper is to present the results of numerical investigations on the response of both single-degree-of-freedom (SDOF) and multiple-degree-of-freedom (MDOF) systems, through nonlinear time-history analyses performed on the basis of a wide data set of strong motion records. Constant ductility spectra of the ratios of the maximum inelastic displacement to the corresponding maximum elastic demand were derived for this purpose. In particular, the influences of earthquake magnitude, source-to-site distance, local soil-site conditions, ductility and hysteretic behavior were quantified. Finally, simplified expressions for the ratio of the maximum inelastic to the maximum elastic displacement were established, in order to allow the evaluation of inelastic displacements for new or rehabilitated structures for which the global displacement ductility can be estimated, directly from the knowledge of the corresponding elastic demands.

V. M. Sorin, et al. (2009) [4]
A coupled spectrum seismic analysis of the ITER 'tokamak-building-basemat-soil' system has been performed. Soil structure interaction (SSI) is modeled as a set of springs and dampers. A new method is proposed to replace the detailed finite-element model of the building by an equivalent set of parallel oscillators having the same natural frequencies, modal effective masses and height as the building and creating the same shearing force and overturning moment. The response of the ITER tokamak is found versus different soil parameters. For some particular soil conditions, the natural frequency of the building is very close to that of the tokamak and critical resonance effects may take place.

C.C. Spyrakos, et al. (2009) [5]
The present study investigates the effects of soil structure interaction (SSI) on the response of base isolated multistory buildings founded on an elastic soil layer overlying rigid bedrock and subjected to a harmonic ground motion. Initially a four-degree-of-freedom system (4-DOF) is developed and the equations of motion are formulated in the frequency domain. Frequency independent expressions are used to determine the stiffness and damping coefficients for the rigid surface foundation on the soil stratum underlined by bedrock at shallow depth. Assuming the foundation mass to be negligible, an equivalent two-degree-of-freedom (2-DOF) system is derived. The first mode of motion of the equivalent 2-DOF system appears to be sufficient to describe the response of the overall system for all ranges of stiffness and inertia properties of the structure and its isolation. An extensive parametric study demonstrates that SSI effects are significant, primarily for squat, light structures, founded on soil-stratum of low stiffness. The methodology could serve as a means to perform a preliminary seismic design of base isolated building structures founded on homogenous soil-stratum over bedrock
A series of analytical expressions is derived in order to investigate the conditions under which SSI could play a significant role on the response of base-isolated buildings. A simple analytical model yet one which is capable of describing the most salient system characteristics are developed. More specifically, assuming a massless foundation system, the equations of motion are derived in the frequency domain for a 4-DOF structure-based isolation foundation system.
Considering an equivalent fixed-based 2-DOF system, on which an identical structural and base isolation response to the initial 4- OF is imposed, a series of parametric studies is performed.

Anand, N., et al. (2010) [6]
Shear wall is a wall composed of braced panels with hard concrete surrounding it to counter the effects of lateral loads acting on a structure. Although structures are supported on soil, most of the designers do not consider the soil structure interaction and its subsequent effect on structures during an earthquake. When a structure is subjected to an earthquake excitation, it interacts with the foundation and the soil, and thus changes the motion of the ground. This means that the movement of the whole ground-structure system is influenced by the type of soil as well as by the type of structure. Understanding of soil structure interaction will

enable the designer to design structures that will behave better during an earthquake. An attempt has been made during the present study to understand the behavior of RCC shear wall subjected to seismic forces in building frames for different soil conditions given in the response spectrum of the code IS 1893(Part I):2002. One to fifteen storey building space frames with and without shear wall were analysed and designed using the software ETABS and the results from the study are presented in this paper.

Juan M. Mayoral, et al. (2010) [7]
A numerical study on the influence that cracks and discontinuities (closed cracks) can have on the seismic response of a hypothetical soil–structure system is presented and discussed. A 2-D finite-difference model of the soil was developed, considering a bilinear failure surface using a Mohr–Coulomb model. The cracks are simulated with interface elements. The soil stiffness is used to characterize the contact force that is generated when the crack closes. For the cases studied herein, it was considered that the crack does not propagate during the dynamic event. Both cases open and closed cracks are considered. The nonlinear behaviour was accounted for approximately using equivalent linear properties calibrated against several 1-D wave propagation analyses of selected soil columns with variable depth to account for changes in depth to bed rock. Free field boundaries were used at the edges of the 2-D finite-difference model to allow for energy dissipation of the reflected waves. The effect of cracking on the seismic response was evaluated by comparing the results of site response analysis with and without crack, for several lengths and orientations. The changes in the response obtained for a single crack and a family of cracks were also evaluated. Finally, the impact that a crack may have on the structural response of nearby structures was investigated by solving the seismic-soil–structure interaction of two structures, one flexible and one rigid to bracket the response. From the results of this investigation, insight was gained regarding the effect that discontinuities may have both on the seismic response of soil deposits and on nearby soil–structure systems.

Gheorghe Asachi, et al. (2011) [8]
Seismic risk assessment of structures is one of the key elements in estimating and reducing losses that may appear after earthquakes. Building vulnerability quantifies the damages a structure can handle under a known seismic load. Usually, structures are considered to be fixed at the base in the design process, but researchers have highlighted the importance of considering the actual soil conditions in the analysis. In this paper, a nonlinear static analysis (pushover) is performed in SAP 2000, for a reinforced concrete 2-D frame resting on different types of soils. Comparisons between capacity curves, vulnerability curves and between the failure mechanisms have been performed. From these comparisons, it was possible to extract some observations concerning the soil condition influence upon building vulnerability and seismic risk for a RC frame.

Kraus, et al. (2011) [9]
It is often the case that soil beneath the structure is ignored in numerical analyses. In most cases there are two reasons for neglecting the soil in analyses: complexity in modeling of the soil and, as mostly believed, beneficial effects of the soil on structures. The paper discusses three different approaches on numerical modeling of fixity of structures with the soil beneath: conventionally fixed structure, structure on Winkler springs and structure on half-space. Linear elastic analysis was carried out on three-, seven- and ten-story three-bay reinforced concrete frames using time history analysis. All of the structures were founded on soft soil as defined according to Euro codes. Ground motions used were selected from the European Strong-Motion Database. Also, the paper gives outline of recommendations on including soil-structure interaction in structural models according to
European and American seismic regulations and highlights detrimental effects of soil structure interaction on low-rise buildings.

M. Eser, et al. (2011) [10]
In this study, strength reduction factors for SDOF systems of period range of 0.1-3.0 s. with elasto-plastic behavior are obtained for 20 earthquake motions recorded on soft soils considering soil structure interaction. Soil structure interacting systems are modeled with effective period, effective damping and effective ductility values differing from fixed-base case. For inelastic time history analyses, Newmark method for step by step time integration was adapted in an in-house computer program. Results are compared with those calculated for fixed-base case. It is concluded that soil structure interaction reduces strength reduction factors for soft soils, therefore, using the fixed-base strength reduction factors for interacting systems lead to non-conservative design forces.
In this study, strength reduction factors are investigated for SDOF systems of period range of 0.1-3.0 s. with elasto-plastic behavior considering soil structure interaction for 20 different earthquake motions recorded on soft soils. Soil structure interacting systems are modeled with effective period, effective damping and effective ductility values differing from fixed-base case. A new

equation is proposed for strength reduction factor of interacting system as a function of structural period of system (T), ductility ratio (μ) and period lengthening ratio (T'/T). The fitness of the regressed function of the strength reduction factor is shown in figures. The following conclusions can be drawn from the results of this study.

H. Matinmanesh, et al. (2011) [11]
During earthquakes seismic waves propagate from the bedrock through the soil layers and damage structures on the surface. The understanding of local site effects on strong ground motion is of particular importance for the mitigation of earthquake disasters as well as future earthquake resistant design. The analysis performed by considering three actual ground motion records representing seismic motions with low, intermediate and high frequency content earthquakes. Through these analyses, influence of different sub soils (dense and loose sand), buildings height, in addition to the frequency content of the earthquake have been investigated on amplification, acceleration response and stress propagation on the soil-foundation interface. Results illustrate that both sandy soils amplify seismic waves on the soil-structure interface because of the soil-structure interaction effect.

1. All soil types amplify bedrock motions in the soil-structure interface but with different degrees. The amount of amplification is affected by many factors including the soil type and properties, earthquake frequency content and the properties of the overlying building.
2. Those combinations of soil condition, structural models and seismic excitations that lead to lower effective damping, will amplify the bedrock motion most significantly
3. soil-structure models including dense sand has shorter period in comparison with loose sand and high rise buildings have longer period in comparison with low-rise buildings. The combination of these two can assess the amount of amplification of each earthquake.
4. Shorter period soil-structure systems (5 storey building over dense sand) demonstrated the highest amplification for Hav earthquake and lowest maximum acceleration (on the soil-structure interface) on Lav earthquake.
5. Longer period soil-structure system presented the highest amplification in Lav earthquake and lowest in Hav earthquake.
6. Maximum principle stress on the soil-foundation interface in all models occurred beneath the columns while the lowest stress was in the middle of foundation.

H. Shakib, et al. (2011) [12]
Generally in the analysis of structures, the base of structures is assumed to be fixed. Whereas, the soil under the structures foundation modify earthquake loading and also change the structural properties. Therefore, considering the fixed base in the structure analysis is not realistic. On the other hand, recent studies have pointed out that for an important class of widely used structural elements such as reinforced concrete flexural walls; stiffness is a strength dependent parameter. This implies that the lateral stiffness distribution in an asymmetric wall-type system cannot be evaluated prior to the assignment of elements' strength. Consequently, both stiffness and strength eccentricity are important parameters affecting the seismic response of asymmetric wall-type systems. In this study, for different position of stiffness and strength eccentricity, torsional response of asymmetric wall-type system is evaluated. In this evolution the effect of foundation flexibility, is assumed.
In general flexibility condition increases the lateral displacement and decrease the rotational response. In balance condition, the effect of flexibility is not noticeable so that for any type soil (soft, stiff, very stiff) the lateral and rotational responses are almost similar compared to fix condition.

Boominathan, et al. (2012) [13]
Peninsular India has been considered as a stable continental region for years. It is primarily the damages caused during the 2001 Bhuj earthquake (Mw 7.6) demanded the immediate study of the peninsular region. Earthquakes of Koyna (1967; Mw 7.6), Latur (1993; Mw 6.1) and Jabalpur (1997; Mw 5.8) also occurred in the stable Indian shield. A review of the historical as well as recent earthquake activity in peninsular India indicated that different parts of the peninsular region are characterized by a low to moderate level of seismic activity. But it is only in recent decades that the occurrence of some large and damaging earthquakes has caused concern, which led to the study of peninsular seismicity in greater detail (Chandra, 1977). With the revised seismic zoning map pegged Chennai at a higher activity zone (Zone III), there is a need to prepare seismic hazard map and site specific design response spectra which will enable urban planners to design earthquake resistant structures and strengthen existing unstable structures. In this paper, an attempt has been made to carry out seismic hazard assessment for Chennai city considering the site effects.
This chapter presents hypothetically supports, facts concerning the effort done by different persons method recognized, innovative approach in addition to the in study field of the effect of soil conditions on the seismic forces in RC buildings.

S.D. Fotopoulou, et al. (2012) [14]
The present study aims at the assessment of seismic vulnerability of RC buildings taking into account the soil – structure –interaction (SSI) and the aging effects due to corrosion of the RC structural members. Two dimensional non-linear dynamic analyses were performed to assess the expected performance of initial (t=0 years) and 50 years old RC frame structures. The time-dependent probabilistic fragility functions are derived for adequately predefined damage states at different time periods in terms of peak ground acceleration at the base of the studied structure typologies. As it was expected, the fragility of the structures increases over time due to corrosion. Moreover, the consideration of soil deformability and SSI effects is found to yield to a significant increase on the seismic vulnerability. Hence the combination of these two effects may modify detrimentally the vulnerability of RC structures compared to the usually assumed case of fixed base structure with no aging affects.

R. M. Jenifer Priyanka, et al. (2012) [15]
Though the structures are supported on soil, most of the designers do not consider the soil structure interaction and its subsequent effect on structure during an earthquake. Different soil properties can affect seismic waves as they pass through a soil layer. When a structure is subjected to an earthquake excitation, it interacts the foundation and soil, and thus changes the motion of the ground. It means that the movement of the whole ground structure system is influenced by type of soil as well as by the type of structure. Tall buildings are supposed to be of engineered construction in sense that they might have been analyzed and designed to meet the provision of relevant codes of practice and building bye-laws. IS 1893: 2002 "Criteria for Earthquake Resistant Design of Structures" gives response spectrum for different types of soil such as hard, medium and soft. An attempt has been made in this paper to study the effect of Soil-structure interaction on multi storeyed buildings with various foundation systems. Also to study the response of buildings subjected to seismic forces with Rigid and Flexible foundations. Multi storeyed buildings with fixed and flexible support subjected to seismic forces were analyzed under different soil conditions like hard, medium and soft. The buildings were analyzed by Response spectrum method using software STAAD Pro. The response of building frames such as Lateral deflection, Storey drift, Base shear, axial force and Column moment values for all building frames were presented in this paper

B. R. Jayalekshmi, et al. (2013) [16]
Conventional analyses of structures are generally carried out by assuming the base of structures to be fixed. However, the soil below foundation alters the earthquake loading and varies the lateral forces acting on structure. Therefore, it is unrealistic to analyse the structure by considering it to be fixed at base. Multi-storey reinforced concrete framed buildings of different heights with and without shear wall supported on raft foundation incorporating the effect of soil flexibility are considered in present study to investigate the differences in spectral acceleration coefficient, base shear, and storey shear obtained following the seismic provisions of Indian standard code and European code. Study shows that the value of base shear obtained for symmetric plan building is lowest in buildings with shear wall at all the four corners.

Abbas Moustafa, et al (2014) [17]
This paper deals with damage assessment of adjacent colliding buildings under strong ground motion. In previous studies, the structure input-response pair is used to examine pounding effects on adjacent buildings under seismic loads. In this paper, pounding of adjacent buildings is assessed using input energy, dissipated energy and damage indices. Damage indices (DI) are computed by comparing the structure's responses demanded by earthquakes and the associated structural capacities. Damage indices provide quantitative estimates of structural damage level, and thus, a decision on necessary repair can be taken. Adjacent buildings with fixed-base and isolated-base are considered. The nonlinear viscoelastic model is used for capturing the induced pounding forces. Influences of the separation distance between buildings, buildings properties, such as, base-condition (fixed or isolated), and yield strength on damage of adjacent buildings are investigated. The set of input ground motions includes short, moderate and long-duration accelerograms measured at near-fault and far-fault regions with different soil types. Earthquake records with different characteristics are considered to study damage of adjacent buildings under seismic loads. Numerical illustrations on damage of fixed-base and isolated-base adjacent buildings with elastic–plastic force–deformation relation are provided.

Nilang Pansuriya, et al (2015) [18]
This Paper consist the review on the performance of the analysis of RCC building. Performance Based Seismic Engineering is the modern approach to earthquake resistant design. It is an attempt to predict the buildings with predictable seismic

performance. In one sense, it is limit-states design extended to cover complex range of issues faced by earthquake engineers. This paper is an attempt to understand the basic fundamentals and procedures of Performance Based Analysis of R.C.C. buildings. The analysis was performed on new as well as existing R.C.C. buildings and the performance of buildings in future earthquake was obtained.

III. CONCLUSION

The primary goals of this investigation were: (i) to characterize the inelastic displacement and drift demand, respectively for SDOF and MDOF systems exposed to earthquake ground motions; (ii) to quantify the influence of both aspects intrinsic of structures, such as stiffness, ductility and hysteretic behaviour, and factors pertaining to the exterior context, such as earthquake magnitude, source-to-site distance, and local soil-site conditions; and (iii) to evaluate inelastic displacement and drift ratios so that the assessment of the inelastic displacement and drift demands can be accomplished from maximum elastic displacements and drifts. In order to characterize the inelastic behavior of the MDOF systems representative of real multi-storey frame structures, an equivalent discrete shear-type model has been adopted. The results of a statistical study of inelastic displacement and drift ratios computed for the SDOF and MDOF systems subjected to a large number of strong motion records and enduring prescribed levels of inelastic deformation have been presented.

Acknowledgements

I have a great pleasure to express my deep sense of gratitude and sincere regards to my guide Dr. M. N. Bajad , for his guidance and friendly discussion which helped me immensely in selecting this topic. His generous encouragement throughout my dissertation work helped me in completing this project work.

I would like to thank our Head of Civil Engineering Department Dr. S. S.Shastri for allowing me to do this project. He has immensely helped in providing all opportunities and facilities for the project work.

I am thankful to all the faculty members of Civil Engineering and library staff for helping me in this work.

Finally, I would like to thank all those who directly or indirectly helped me during my work.

REFERENCES

Journal Papers:

[1] X. Qi, J.P. Moehle, Displacements design approach for reinforced concrete structures subjected to earthquake, Report No. UCB/EERC-91/02 *Earthquake Engineering Research Center, University of California at Berkley, 1991.*

[2] M.J.N. Priestley, Displacement-based seismic assessment of reinforced concrete buildings, *Journal of Earthquake Engineering 1 (1) (1997)* 157–192.

[3] M.J.N. Priestley, G.M. Calvi, Concepts and procedures for direct displacement-based design and assessment, in: P. Fajfar, H. Krawinkler (Eds.*), Seismic Design Methodologies for the Next Generation of Codes, Balkema, Rotterdam, 1997*, pp. 171–181.

[4] A. Whittaker, M. Constantinou, P. Tsopelas, Displacement estimates for performance-based seismic design, ASCE *Journal of Structural Engineering 124 (8) (1998)* 905–912.

[5] E. Miranda, Approximate seismic lateral deformation demands in multistory buildings, *ASCE Journal of Structural Engineering 125 (4) (1999)* 417–425.

[6] A. Gupta, H. Krawinkler, Estimation of seismic drift demands for frame structures, *Earthquake Engineering and Structural Dynamics 29 (2000)* 1287–1305.

[7] E. Miranda, Estimation of inelastic deformation demands of SDOF systems, *ASCE Journal of Structural Engineering 127 (9) (2001)* 1005–1012.

[8] A.K. Chopra, R.K. Goel, Direct displacement-based design: Use of inelastic vs. elastic design spectra, *Earthquake Spectra 17 (1) (2001).*

[9]] B. Borzi, G.M. Calvi, A.S. Elnashai, E. Faccioli, J.J. Bommer, Inelastic spectra for displacement-based seismic design, *Soil Dynamics and Earthquake Engineering 21 (2001)* 47–61.

[10] E. Miranda, C.J. Reyes, Approximate lateral drift demands in multistory buildings with nonuniform stiffness, *ASCE Journal of Structural Engineering 128 (7) (2002)* 840–849.

[11] E. Miranda, J. Ruiz-Garcia, Evaluation of approximate methods to estimate maximum inelastic displacement demands, *Earthquake Engineering and Structural Dynamics 31 (2002)* 539–560.

[12] L. Decanini, L. Liberatore, F. Mollaioli, Characterization of displacement demand for elastic and inelastic SDOF systems, Soil *Dynamics and Earthquake Engineering 23 (2003)* 455–471.

[13] H. Krawinkler, R. Medina, B. Alavi, Seismic drift and ductility demands and their dependence on ground motions, *Engineering Structures 25 (2003)* 637–653.

[14] A.S. Veletsos, N.M. Newmark, Effect of inelastic behavior on the response of simple systems to earthquake motions, in: *Proceedings of the 2nd World Conference on Earthquake Engineering, Japan, vol. 2, 1960*, pp. 895–912.

[15] A.S. Veletsos, N.M. Newmark, C.V. Chelapati, Deformation spectra for elastic and elastoplastic systems subjected to ground shock and earthquake motions. in: *Proceedings of the 3rd World Conference on Earthquake Engineering, New Zealand, vol. 2, 1965*, pp. 663–682.