EFFECT OF SOIL STRUCTUE INTERACTION ON SEISMIC RESPONSE OF FRAMED STRUCTURE

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ABSTRACT :- Seismic response of structures is quite complex because of the randomness in loading and complexity in modelling. Framed structures are usually analysed assuming a fixed-base structure while ignoring the flexibility of soil and foundation. Seismic codes permit to compute seismic forces depending upon the nature of soil classified into three categories viz, soft, medium and rock. The interaction between the super-structure and sub-structure (SSI) is investigated by modeling the soil as elastic continuum. Soil property in terms of G (Shear modulus) and ν (Poisson's ratio) is taken to find the soil stiffness in all six directions. The value of G and ν are taken based on the classification given by IS 1893 and other international references. These values are then used to compute the stiffness in all the six degrees of freedom. The broad classification as given by international codes and their influence in estimating the seismic forces are investigated. The effects of soil- structure interaction on the seismic response of framed structures with 6 storeys have been considered with base supported as fixed base and ignoring the flexibility of soil. The same was repeated for different soil conditions. As per IS1893 and other international codes the structure is analysed in both static and Response Spectrum Analysis (RSA). The static and dynamic response results are compared. The modal analysis has been done to get deformation and natural mode of vibration with its own modal damping ratio. The effect of such soil structure interaction on the overall response during an earthquake is arrived at based on national classification of soil. Such a study is relevant in the context of designers moving from ductility based design to performance based design.

Keywords: soil structure interaction (SSI) static analysis, response spectrum analysis (RSA), fixed base, modal analysis, soil spring, elastic continuum, fixed base, seismic response.

INTRODUCTION

During an earthquake the dynamic response of a structure depends on the characteristics of ground motion, surrounding soil medium, its properties and the structure itself. The process by which the response of the soil influences the motion of the structure and the response of soil is termed as soil structure interaction (SSI). The seismic soil structure interaction of multi-story buildings becomes very important after the destruction structures in major earthquakes.

Usually in the seismic design of framed buildings, soil structure interaction is neglected and the dynamic response of the structure is evaluated under the assumption of a fixed or a hinged base response. The period of vibration of the structure is calculated based on this assumption and the seismic loads are evaluated. However, during actual seismic loading the soil undergoes deformations or settlements, which are imposed to the foundation, and also due to the actual soil parameters, the period of vibration of the structure increases. The increase in period of vibration makes a structure more flexible and causes reduction in the seismic loads acting on the structure.

STATIC METHOD:- This approach defines a series of forces acting on a building to represent the effect of earthquake ground motion, typically defined by a seismic design response spectrum. It assumes that the building responds in its fundamental mode. For this to be true, the building must be low-rise and must not twist significantly when the ground moves. The response is read from a design response spectrum, given the natural frequency of the building (either calculated or as per the empirical relation given in building code). The applicability of this method is extended to many building codes by applying factors to account for higher buildings with some higher modes, and for low levels of twisting. To account for effects due to "yielding" of the structure, many codes apply modification factors that reduce the design forces (e.g. force reduction factors).

RESPONSE SPECTRUM :-This approach permits the multiple modes of response of a building to be taken into account (in the frequency domain). This is required in many building codes for all except for very simple or very complex structures. The response of a structure can be defined as a combination of many special shapes (modes) that in a vibrating string correspond to the "harmonics". Dynamic analysis can be used to determine these modes for a structure. For each mode, a response is read from the design spectrum, based on the modal frequency and the modal mass, and they are then combined to provide an estimate of the total response of the structure.

OBJECTIVES

- Effect of soil stiffness on seismic load estimation in frames.
- Estimation of natural period of structures with different soil stiffness variation with shear wave velocity (Vs).
- The effect of such soil structure interaction on the overall response of structures during an earthquake is studied based on national and international classification of soil.

METHODOLOGY

STATIC LOAD METHOD :-In the preliminary design process, equivalent static seismic forces are used to determine the design internal forces of structural members using linear elastic analyses of structure and, in turn, determine the design member strength demands. Such static seismic forces are simply determined corresponding to the elastic design acceleration spectrum divided by a structural strength reduction factor, particularly called: the response modification factor R.

RESPONSE ACCELRATION COEFFICIENT (Sa/g):-The curves shown below are for rock and soil sites as given by Fig3.1 and appropriate natural periods and 5 percent damping of the structure. These curves represent the free field ground motion.

Dynamic analysis of structures :-Most civil structures are exposed to dynamic loading during their lifetime. This dynamic load can for instance be caused by storms, earthquakes or ocean waves. The structural response to such a load can be described by the equation of motion. For explanatory purposes a Single Degree of Freedom system (SDOF) will be considered (Chopra, 2006). A SDOF system is shown schematically in Figure 3.3. This system may be considered as an idealization of a one storey structure. The system consists of a frame which provides the stiffness k to the system, but is considered to have no mass. The mass m of the system is concentrated at the roof level and a viscous damper c which dissipates vibrational energy is added to the system. The height h denotes the distance from the base to the center of the mass. The relative displacement of the system is denoted with u, total displacement with u_t , the ground displacement is represented with u_g, the elastic deformation of the frame with u_{ed} and θg denotes the ground rotation.

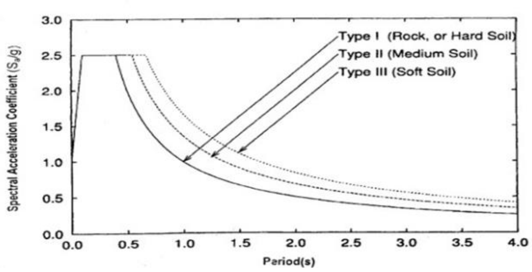

Figure:1 Response spectra for rock and soil sites for 5 percent damping

MODAL RESPONSE SPECTRUM (RS) METHOD:- As per building codes response spectra used for design tend to be smooth curves, whereas response spectra obtained from ground motion recordings are generally very rugged with sharp spikes and valleys. The effects of these differences are discussed along with recommendations on how to graphically smooth out the curves. In general, response spectra are used to analyse structures that respond within elastic-linear limits. Response spectrum analysis includes sufficient modes of vibration to capture participation of at least 90% of the structure's mass in each of two orthogonal directions. Response spectrum techniques allow engineers to visually imagine how buildings will perform during major damaging earthquakes.

MODELLING OF SOIL

The dynamic stiffness of a soil is simulated in the program using translational and rotational elastic springs. Many researchers have proposed ways to calculate spring constants that could simulate the dynamic behavior of soil.

The column is normally considered as fixed in analysis of frame to get the lateral response. The soil below the individual footing of each column is modelled as spring in all six degree of freedom as shown in figure 3.3. The expression given in Table 3.3 [Smitha gopinath] is used for computing the six components of stiffness values. These values of spring are used under every footing for computation response.

The values of the stiffnesses of the springs are dependent on the mechanical characteristics of the soil material, the dimensions of the foundation, and its embedment depth. The mechanical characteristics of the foundation soil medium are represented by the effective shear modulus G, the mass density ρ, and Poisson's ratio ν.

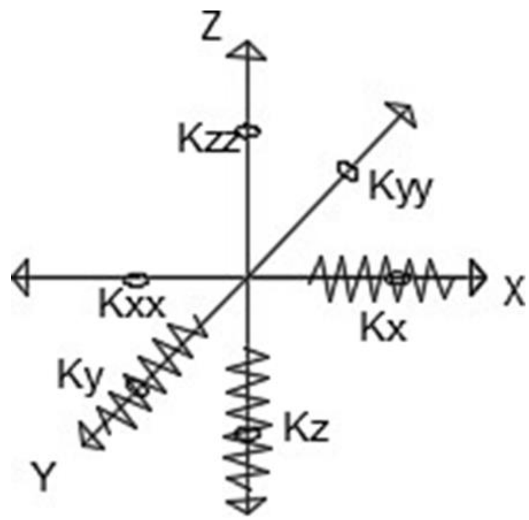

Figure 2: Model of soil spring below each footing

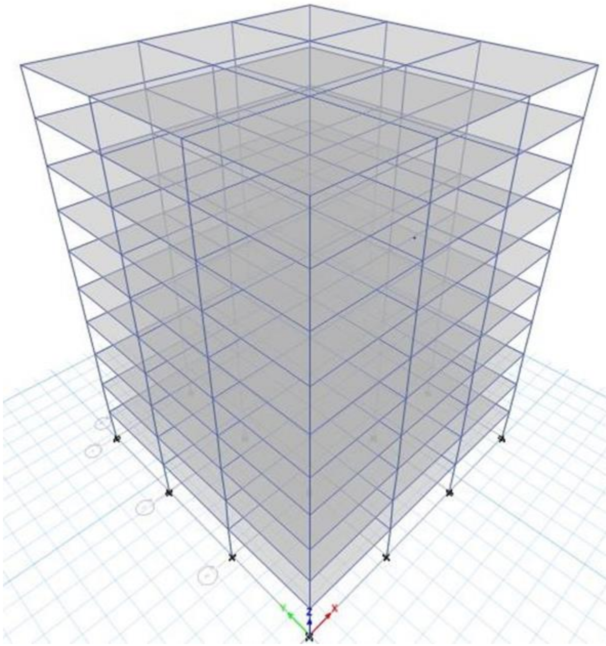

Figure:3 3D view of the G+9 storey framed structure fixed base

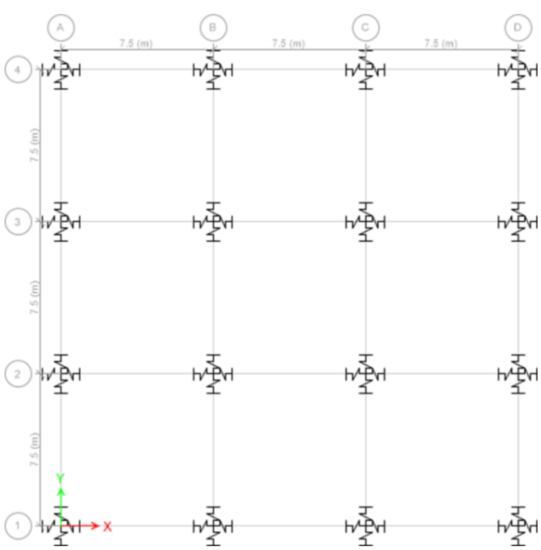

Figure 4 : with flexible base of the structure

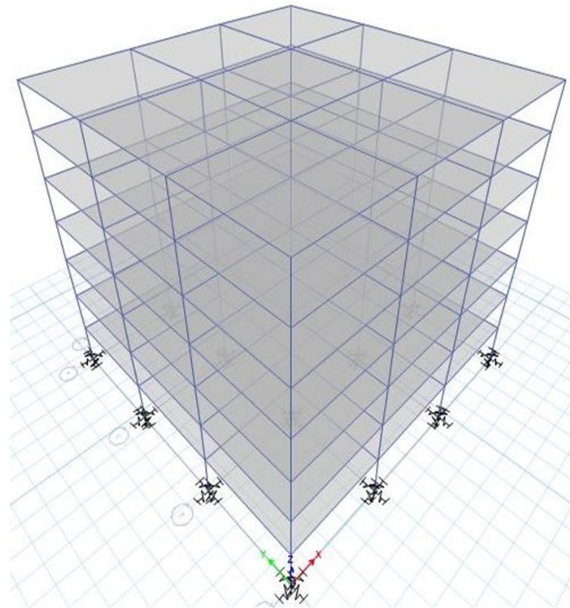

Figure 5: 3d view of the six storey framed structure with flexible base

Table 1: Details of different cases considered for analysis

Building name	No.of stories	Type of soil	Zone
B6-1	6	Hard	III, IV, V
B6-2	6	Medium	III, IV, V
B6-3	6	Soft	III, IV, V
B9-1	9	Hard	III, IV, V
B9-2	9	Medium	III, IV, V
B9-3	9	Soft	III, IV, V

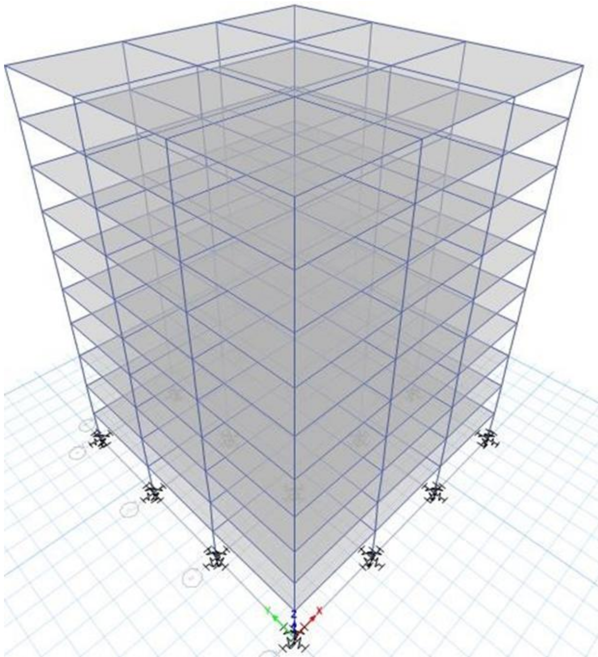

Figure 6: 3D view of the G+9 storey framed structure with flexible base

RESULTS AND DISCUSSIONS

ROOF DISPLACEMENTS :-The first set of analysis was carried out by considering all column footings as fixed. The analysis cases include dead load, live load and the seismic load as per IS 1893. The results of the lateral roof displacements of the building with 6 and 9 storeys as obtained from the analysis is given in Table 5.1 and 5.2. The maximum lateral roof displacement permitted as per the provision given in IS 1893 is 0.004 times the height of the building. According to this clause the permitted lateral roof displacement of the three buildings considered are 84mm and 120mm respectively. As per this condition the G+6 and G+9 storey building experiences permissible roof displacement in zone III and IV. But in case of zone V the response crosses the allowable limit in the case of soft soil supported structure in six storey building and in the case of medium and soft soil supported structure in case and nine storey building.

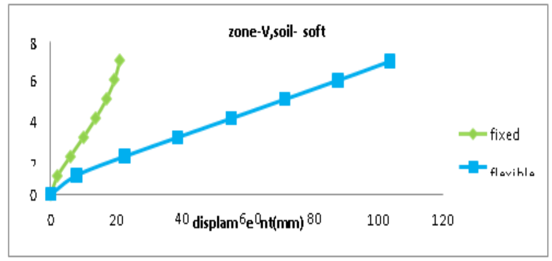

Figure :7 Displacement of 6 storey building with fixed and flexible support

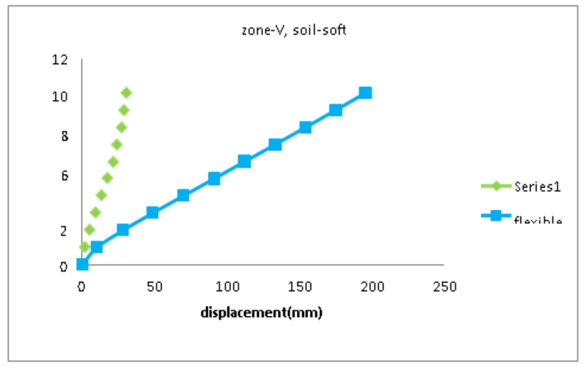

Figure: 8 Displacement of 9 storey building with fixed and flexible support

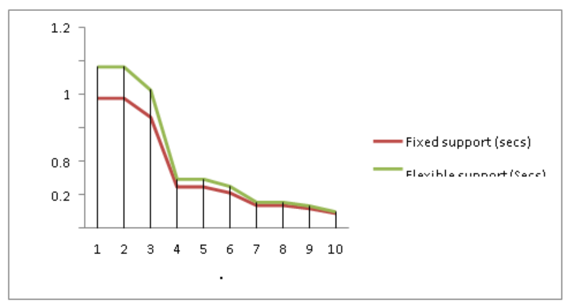

Figure: 9 Time period for fixed base and the flexible base

CONCLUSIONS

Different building frames were investigated with different types of soils and zones. Analytical research on behaviours of the building frames was done by static analysis and response spectrum analysis. From the static analysis and response spectrum analysis of buildings with different shapes following generalized conclusions are made

- The seismic safety is to be seen from the performance parameters like roof displacement and drift levels as a global phenomenon. The national codes of various countries recommend taking higher 'sa/g' values for medium and soft soil.

- The analysis results discussed above clearly demonstrates that the lateral roof displacement values consistently exceed permissible values for all the cased considering soil structure interaction.
- Hence, if one considers SSI for multi-storey building the lateral displacement is likely to be larger than allowable and not safe against earthquake. Care should be taken to study soil properties and include them in an SSI study to estimate the seismic performance.
- The natural period of the structure increased when the soil stiffness are considered. Due to this the roof displacement increased considerably.
- This effect will be more predominant when the structure is taller than six stories and the effect may result in roof displacements beyond allowable limits.
- International codes like NEHRP considers soil in five different categories as against 3 by BIS codes which give a better perspective of reality
- The soil classification needs to be changed to five categories in BIS also. Though the base shear is reduced in the cases of SSI study code, recommends conservative estimate of base shear by upgrading the forces by a scale ratio. However the limit on displacement will be governed in design while minimum base shear is good enough to design.
- However, detailed studies are required to evaluate the natural period of the structure with flexible base and their influence on the seismic forces for each of those cases.

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