ABSTRACT: The dynamic behaviour of the structure depends on foundation media. The finite element method has been employed to estimate the effect of soil media on the dynamic response of framed structure including the interaction effect. A six-storey framed structure with raft foundation and soil medium has been considered as a system. The soil continuum and raft foundation are discretized using four nodded isoparametric elements whereas superstructure by two nodded beam elements. The dynamic interaction analysis on this system estimated the natural frequency and mode shape of the system under various types of soils. The property of soil medium has been varied by varying Young’s modulus and constant Poisson’s ratio whereas other condition achieved by varying Poisson’s ratio and constant Young’s modulus. The natural frequency and mode shapes of interactive and non-interactive cases compared and it has been observed that varying soil conditions significantly affects the natural frequency and mode shape of framed structure.

1. INTRODUCTION

In earthquake engineering practice, it is well recognized now that the foundation soil, on which a structure is constructed, interacts dynamically with the structure during its response to earthquake excitation, to the extent that they response in term of mode shape, frequency, stress and deformations. The behavior of system modified significantly when foundation soil is neglected and non-interactive condition is induced.

Two different approaches to the problem are commonly found, one group of researchers is concerned with applying rigorous model to the super structure and they try usually consider the soil as a rigid base and others are interested in applying rigorous mechanical model to the soil without coupling it to the superstructure and they just consider a raft on a simple two dimensional frame resting on the deformable soil (Chopra 1974). Dumanoglu & Severn (1976) has worked on influence of foundation media on response of structure to earthquake considering the spring model. Wong & Luco (1978) has studied the dynamic response of rectangular foundation to obliquely incident seismic waves. Gupta & Penzien (1982) worked on developing hybrid model for analysis of soil structure interaction under dynamic condition. Further, the studies on effect of soil on structure under wind and earthquake as well as effect on soil-structure interaction due to damping has also been taken up (Novak & Hifnawy 1983). Recently, Wang & Cheng (2008) have worked on dynamic analysis for evaluating response of structure.

In the present study effect of soil properties on characteristic of framed structure have been analyzed considering soil as homogenous, isotropic and linear continuum. This paper is an attempt to indicate the variation of frequency and mode shape of framed structure for different soil properties.

2. DYNAMIC ANALYSIS

Dynamic analysis is performed to determine the natural frequencies and mode shapes of a structure. The natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions. They are also required if one want to do a spectrum analysis or a mode superposition harmonic or transient analysis. Dynamic analysis does not involve the computation of response due to any loading, but yields the natural frequency and the mode shape of structure when there is no dissipation of energy due to damping. Dynamic analysis of structure is carried out to get the dynamic characteristics of the structure in term of its natural frequency and mode shape, which may be used for computation of the responses in the presence of dynamic load and damping in dynamic analysis (Chopra 2003).

The undamped free vibration case is governed by the following equation of motion,

\[
[M] \{\ddot{u}\} + [K] \{u\} = \{0\}
\]

where, 
- \(M\) = Mass of system (framed structure and foundation media)
- \(K\) = Stiffness of the system
- \(\ddot{u}\) = Acceleration induces in system
- \(u\) = Displacement induced in system

For a linear system, free vibrations will be harmonic of the form,

\[
\{u\} = \{\Phi\}_i \cos \omega_i t
\]

where, \(\{\Phi\}_i\) = eigen vector representing the mode shape of the \(i^{th}\) natural frequency

\(\omega_i\) = \(i^{th}\) natural circular frequency (radians per unit time)

\(t\) = time
Thus, (1) becomes

\[ (-\omega_i^2 [M] + [K]) \{ \phi_i \} = \{ 0 \} \tag{3} \]

This equality is satisfied if either \( \{ \phi_i \} = \{ 0 \} \) or if the determinant of \( ([K] - \omega^2 [M]) \) is zero. The first option is the trivial one and, therefore, is not of interest. Thus, the second one gives the solution,

\[ [K] - \omega^2 [M] = 0 \tag{4} \]

This is an eigenvalue (frequency) problem which may be solved for up to \( n \) values of \( \omega^2 \) and \( n \) eigen vectors \( \{ \phi_i \} \), where \( n \) is the number of degree of freedom. The natural circular frequencies \( \omega \) are then converted into the natural frequencies \( f \) as,

\[ f_i = \frac{\omega_i}{2\pi} \tag{5} \]

Where, \( f_i \) = \( i \)th natural frequency (cycles per unit time).

3. MODELING OF INTERACTIVE SYSTEM

A typical 2-D six storey framed structure with raft foundation resting on soil media has been considered for the purpose of dynamic analysis. The superstructure is resting on raft foundation having thickness of 1.5 m, the height of each storey is 3 m and width of each bay is 4 m. The total height of the framed structure is 18 m and width of framed structure and raft foundation is 8 m. Considering the pressure line, the depth of soil media has been taken twice the height of structure i.e. 36 m and width equal to 40 m.

In the present study finite element method has been applied for modeling and meshing purpose. The finite element idealization of superstructure, raft foundation and soil for interactive model is as shown in Figure 1.

The finite element method treats soil continuum as an assemblage of discreet elements whose boundaries are defined by nodal points. The modeling and meshing of superstructure carried out with two nodded beam elements whereas modeling and meshing of raft foundation and soil continuum, four nodded isoparametric elements has been used.

A convergence criterion has been adopted to decide on the final model of the present study. The selected interactive model has 984 elements which has generated the 1032 nodes (Fig. 1) whereas the total number of elements used for non-interactive model is 153 which has generated 169 nodes without soil continuum. Once the two-dimensional finite element modeling and meshing is over, the boundary condition has been applied on the external nodes of soil continuum.

3.1 Assumptions and Analysis

In case of dynamic analysis of six storied framed structure the mass of superstructure and raft foundation has only been considered. It has been assumed that soil continuum has settled by its own weight hence the mass of soil has been ignored. Subspace iterative process has been adopted for analysis. The analysis of the system has been carried for two conditions, first when Young’s modulus of soil has been varied keeping Poisson’s ratio constant and second when Poisson’s ratio has been varied keeping Young’s modulus of soil constant. The soil media has been varied from existence of hard clay to dense sand.

These conditions have been assumed on the basis of variations found in the field condition for different type of soil. The dynamic analysis of the system has been carried out for the material properties given in the Tables 1 and 2.

The interactive dynamic analysis has been performed and compared with the non-interactive case.

<table>
<thead>
<tr>
<th>Components</th>
<th>Young’s modulus N/m²</th>
<th>Unit weight N/m²</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super-structure</td>
<td>2.25E10</td>
<td>24000</td>
<td>0.15</td>
</tr>
<tr>
<td>Raft foundation</td>
<td>2.25E10</td>
<td>24000</td>
<td>0.17</td>
</tr>
<tr>
<td>Soil Media</td>
<td>1E7 (Hard Clay)</td>
<td>–</td>
<td>Constant Poisson’s Ratio 0.30</td>
</tr>
<tr>
<td></td>
<td>2E7 (Loose Sand)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3E7 (Silty Sand)</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>4E7 (Dense Sand)</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>
Table 2: Varying Poisson’s Ratio and Constant Young’s Modulus

<table>
<thead>
<tr>
<th>Components</th>
<th>Poisson’s ratio</th>
<th>Unit weight N/m³</th>
<th>Young’s modulus N/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superstructure</td>
<td>0.15</td>
<td>24000</td>
<td>2.25E10</td>
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<td>Soil Media</td>
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</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSIONS

4.1 Influence of Varying Young’s Modulus

In the Figure 2 frequency of models for interactive and non-interactive case has been compared for varying Young’s modulus and constant Poisson’s ratio in which $Y$ resembles Young’s modulus of soil medium.

It has been observed from Figure 2 that with the increase in the modulus of elasticity natural frequency of the interactive and non-interactive model is also increasing due to increase in stiffness of system. When soil continuum is considered for different soils the maximum natural frequency of interactive case differs by 30–50% to the natural frequency of non-interactive case. At the sixth mode of vibration for interactive case the natural frequency starts converging.

4.2 Influence of Varying Poisson’s Ratio

Figure 3 represents comparison of natural frequency of structure for interactive and non-interactive case for varying Poisson ratio and constant Young’s modulus.

It is observed that for interactive case when Poisson’s ratio is varied keeping Young’s modulus as constant of the soil, the natural frequency of interactive model is showing insignificant difference between the compared natural frequency for varying Poisson’s ratio. The difference between interactive and non-interactive model has been observed similar corresponding to the previous condition.

4.3 Mode Shapes

It has been found from comparison of mode shapes for interactive and non-interactive case that in case of non-interactive case there is horizontal vibration in the models up to 4th mode (Fig. 4a) where as in 5th and 6th mode (Fig. 5a) vibration in horizontal as well as vertical direction has been observed. In case of soil-raft-structure interactive case horizontal and vertical vibrations have been observed in 1st (Fig. 4b) and 2nd mode. In third mode shape of interactive model rocking vibration has been observed. In 4th mode combination of horizontal and vertical vibration has been observed where as in 5th mode combination of rocking and horizontal vibration has been observed which has been found completely different from 6th mode (Fig. 5b) which implies horizontal and vertical vibration only.

The comparisons of mode shapes for interactive and non-interactive case has established that when soil continuum is considered there is more deformation in the system and the vibration mode shapes with vertical translation, sliding and rocking is predominant in the models for higher mode.
5. CONCLUSIONS

On the basis of present study following points have been concluded:

(a) Variation of Young’s modulus of soil effectively influences frequency response of soil-raft-structure system whereas variations of Poisson’s ratio of soil have a modest influence on the frequency of soil-raft-structure system.

(b) Dynamic interactive analysis of soil-raft-structure consists of horizontal, vertical and rocking modes of vibration where as in non-interactive case horizontal mode of vibration is predominant.

REFERENCES


