COMBINED EFFECT OF SOIL STRUCTURE ITERACTION ON FRAME STIFFNESS OF DIFFERENT SEISMIC ZONES OF BUILDING.

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ABSTRACT

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.

Keywords—*interaction,boundaries, Mesh, displacement, infinity, stiffness, responses, interface, damping.*

1.INTRODUCTION

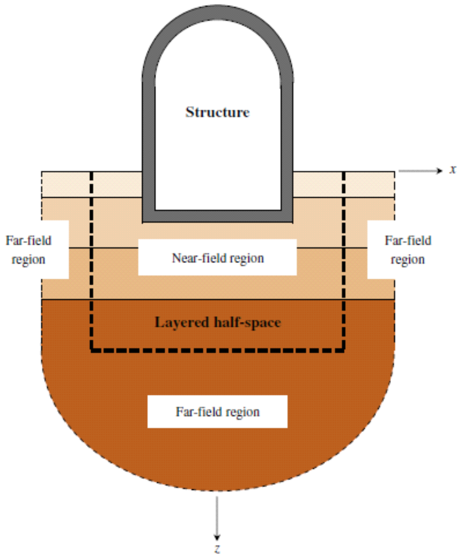
Asymmetric buildings are more vulnerable to earthquake hazards compared to the buildings with symmetric configuration. The recognition of this sensitivity has led the researchers to concentrate their studies on earthquake characteristics, evaluation of the structural parameters and validity of the system models in the engine cylinders, and inherent unbalances in the reciprocating components of the engine. Material selected for the form spring is SS316 (0.4 to 0.7 mm) thick and Polueura the An accurate modeling of the soil–structure interaction is expected to incorporate the major

effects of the response of complex systems such as torsional coupled system. On the other hand, recent studies show that the location of CM and CR affect the dynamic response of asymmetric building significantly (such as: Myslimaj and Tso 2001) .In this study an attempt has been made to consider the above effects by formulating soil–structure interaction system in order to evaluate the seismic response of asymmetric wall-type system. An accurate method of soil–structure interaction in time domain has been used by finite element method and also, different position of stiffness and strength eccentricity are assumed.

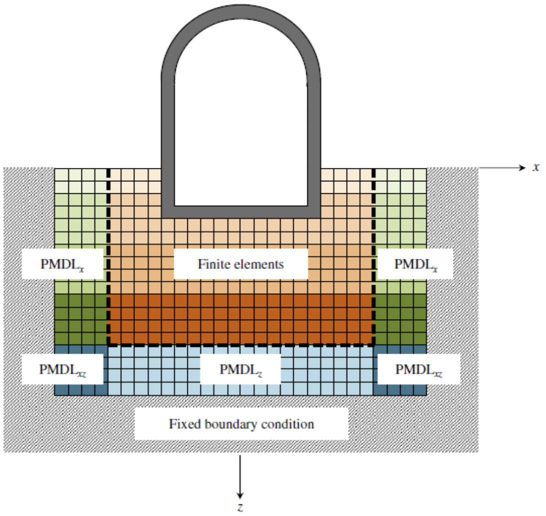
2.DESIGN APPROACH

Wave propagation is a research topic with many applications in a variety of areas including seismology, meteorology, oceanography, mechanical engineering, civil engineering, and naval engineering.

Typical examples are subsurface imaging, weather prediction at local and global levels, non-destructive testing, dynamic fluid–structure interaction, dynamic soil–structure interaction, and underwater acoustics. Among these applications, the dynamic soil–structure interaction is one of the most complex physical phenomena because structural vibration and elastic wave propagation in soil are deeply involved. Therefore, many researchers have studied this phenomenon and developed various approaches to understand the physics that underlies it. A typical soil–structure interaction system is shown in Fig. 1a.The structure is placed on or embedded in a layered half-space or layered soil on a rigid bedrock. As sketched in Fig. 1a, the soil can be divided into two regions, i.e., near- and far-field regions. Although a near-field region can have an irregular geometry and be inhomogeneous in elastic properties, a far-field region is assumed to be regular in geometry and has homogeneous elastic properties in the direction of infinity. Conventional finite elements



(a) Schematic view



(b) Numerical model

Fig. 1. Soil–structure interaction system in a layered half-space.

When strong external forces are applied to the soil–structure interaction system, two kinds of nonlinear behaviors are expected in the system. The first one is nonlinear material behaviors of the structure and soil. The material nonlinearity can be represented by nonlinear constitutive equations of the materials. The other nonlinearity is associated with sliding and a partial uplift of the foundation and separation of its wall from the soil. Contact elements can be employed for the nonlinearities on an interface between the foundation and soil. In the nonlinear soil–structure interaction analysis, the radiation of elastic waves into infinity must also be considered rigorously. Therefore, the soil is divided into the near- and far-field regions in the same way as mentioned above. Usually, nonlinear behaviors are confined within the nearfield region, and the far-field region is assumed to be linear. Since the conventional finite elements for the near-field region can represent nonlinearities accurately, a rigorous model for the far-field region that can represent the radiation effect is required for an accurate nonlinear analysis.

A time-domain formulation of PMDLs is given when they represent the far-field region of the soil. Usually, three kinds of PMDLs are employed for a representation of the half-space (Fig. 1b). One is a PMDL for the vertical edge, another is for the horizontal edge, and the other is for the corner. In this study, the PMDLs will be referred to as PMDLx, PMDLz, and PMDLxz because they represent the far-field regions that are infinite in the x-direction, z-direction, and both directions, respectively. It is assumed in this study that the vertical and horizontal edges form a right angle. Therefore, the PMDLs are rectangular in shape. The same approach can be applied when the boundaries make any convex polygon and the PMDLs in a parallelogram are employed. The dynamic stiffness of the rectangular PMDLs shown in Fig. 2 can be obtained

$$\mathbf{S} = \int_{-1}^{1}\int_{-1}^{1}\left[\frac{b}{a}\mathbf{B}_{rr}^{T}\mathbf{D}_{rr}\mathbf{B}_{rr} + \frac{a}{b}\mathbf{B}_{ss}^{T}\mathbf{D}_{ss}\mathbf{B}_{ss} + \mathbf{B}_{rs}^{T}\mathbf{D}_{rs}\mathbf{B}_{rs} + \mathbf{B}_{sr}^{T}\mathbf{D}_{sr}\mathbf{B}_{sr} - ab\rho\omega^{2}\mathbf{N}^{T}\mathbf{N}\right]drds \tag{1a}$$

$$\mathbf{N} = \begin{bmatrix} N_1 & 0 & \cdots & N_4 & 0 \\ 0 & N_1 & \cdots & 0 & N_4 \end{bmatrix} \tag{1b}$$

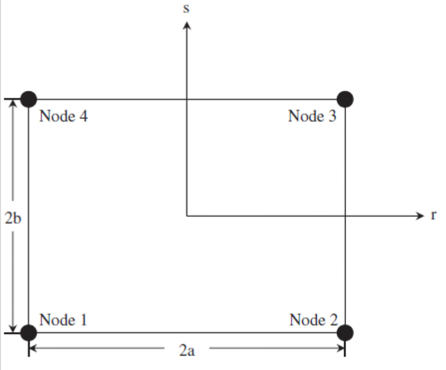


Fig. 1.1 Rectangular PMDL element.

$$\mathbf{B}_{rr} = \begin{bmatrix} \frac{\partial N_1}{\partial r} & 0 & \cdots & \frac{\partial N_4}{\partial r} & 0 \\ 0 & \frac{\partial N_1}{\partial r} & \cdots & 0 & \frac{\partial N_4}{\partial r} \end{bmatrix}$$

$$\mathbf{B}_{ss} = \begin{bmatrix} \frac{\partial N_1}{\partial s} & 0 & \cdots & \frac{\partial N_4}{\partial s} & 0 \\ 0 & \frac{\partial N_1}{\partial s} & \cdots & 0 & \frac{\partial N_4}{\partial s} \end{bmatrix}$$

$$\mathbf{B}_{rs} = \begin{bmatrix} \frac{\partial N_1}{\partial r} & 0 & \cdots & \frac{\partial N_4}{\partial r} & 0 \\ 0 & \frac{\partial N_1}{\partial s} & \cdots & 0 & \frac{\partial N_4}{\partial s} \end{bmatrix}$$

$$\mathbf{B}_{sr} = \begin{bmatrix} \frac{\partial N_1}{\partial s} & 0 & \cdots & \frac{\partial N_4}{\partial s} & 0 \\ 0 & \frac{\partial N_1}{\partial r} & \cdots & 0 & \frac{\partial N_4}{\partial r} \end{bmatrix}$$

$$\mathbf{D}_{rr} = \begin{bmatrix} \lambda + 2\mu & 0 \\ 0 & \mu \end{bmatrix}$$

$$\mathbf{D}_{ss} = \begin{bmatrix} \mu & 0 \\ 0 & \lambda + 2\mu \end{bmatrix}$$

$$\mathbf{D}_{rs} = \begin{bmatrix} 0 & \lambda \\ \lambda & 0 \end{bmatrix}$$

3.MESHLESS ANALYSIS OF SOIL–STRUCTURE INTERACTION USINGAN MFS–MLPG COUPLED APPROACH

When analyzing the soil structure interaction and vibration induced by underground transportation systems, the study of wave Propagation phenomena in elastic media and the interaction between Different solid heterogeneitie sand the elastic hostmedia are impor-tant research subjects.

A significant number of numerical methods have been developd in recent decades that have enhance dourability tosolve Increasingly complex and realistic wave propagation and vibration Transmission /reduction problems .Numerical methods based on an element mesh ,such as the finite element method(FEM) and the Boundary element method (BEM),have been widely applied for several decades in engineering and sciences to solve a broad range of boundary value problems .

The generation of a finite element mesh for complex engineering problems can be very expensive computationally. The use of coarse element meshes may restrict the models to low frequencies if the accuracy needs to be maintained. The BEM is an efficient and popular alternative to FEM, which is particularly use ful for problems with large-scale unbounded domains since the far field boundary conditions are automatically satisfied. However, it can Only be applied to more general geometries and media when the Relevant fundamental solutions or Green's functions required in the boundary integral equation ,are known. This is usually not the case for problems involving non-homogenous media with spatial variation of material properties .Moreover ,the BEM also requires the correct integration of the resulting singular and hypersingular integrals to ensure its efficiency. Therefore ,in recent years, another class of numerical methods, Known as meshless or element free methods ,has been developed as an alternative to the well established mesh-based methods. A good example is the material point method (MPM), which is efficient for analyzing problems such as metal forming. The method uses Lagrangian material points and a back ground Eulerian mesh for spatial approximation. The mesh is fixed and does not move with the material, thereby rendering remeshing unnecessary and preventing mesh distortion. Meshless methods are seen as a powerful alternative to the traditional mesh-based techniques for solving boundary value problems in engineering and physics since they use nodal points instead of element meshes for the approximation of unknown quantities. Meshless methods are also characterized by their high adaptivity and the low cost of preparing input and output data for numerical analysis. Among the many meshless methods developed so far are: the element-free Galerkin (EFG) method proposed by Belytschko et al. the method of fundamental solutions (MFS); the method of particular solutions (MPS); partition of unity finite element method(PUFEM); the meshless local Petrov–Galerkin (MLPG) method ; local boundary integral equation (LBIE) method, and the reproducing kernel particle method (RKPM) introduced by Liu,Jun and Zhang . Major advances in meshless methods and successful applications are summarized in recent reviews. The meshless local Petrov–Galerkin method is one of the most popular of these methods as it does not require the creation of a mesh for the approximation or integration of unknown quantities. The MLPG method is the basis of many meshless formulations since It allows choice from a number of trial and test functions. It is based on a local weak formulation over as et of overlapping sub domains with simple geometrical shapes. Because no back ground cells are required for the integration of the weak form the MLPG is often labeled a sa 'truly meshless' method. The moving least-squares (MLS) approximation is one of many Schemes used to interpolated is creted atain meshless methods. Other meshless approximation techniques include partition of unity (PU), Shepard function, and radial basis function (RBF) types of interpolation. The MLPG has been shown to successfully avoid some major drawbacks of the mesh-based techniques such as shear locking phenomena, modeling of continuously non-homogeneous media, stress singularities in cracks and stabilized fluid flow modeling . In a recent work by Trobec et al. the accuracy, convergence rate and computational cost of the MLPG and the meshless diffuse approximate method (DAM) are compared with the behavior of mesh-based methods, such as the finite difference and finite element methods. The authors observed similar accuracy and the same convergence rate for the meshless approaches, and a simpler numerical implementation and alower computational cost advantages were highlighted for the DAM, when solving the diffusion equation in two dimensions. Another truly meshless method within the scope of analysis of this work is the MFS. The MFS solution is found by means of alinear combination of fundamental solutions, generated by a set ofvirtual sources placed outside the analysis domain.

However, like mesh-based techniques, the meshless methods Have their own disadvantages and limitations. Their interpolations And the algorithm implementation tend to be computationally Expensive and they can be inefficient for problems with infinite And semi-infinite domains. Therefore, many researchers have Been proposing the coupling of appropriately selected methods to Mitigate specific limitations of individual methods and improve efficiency, accuracy and flexibility. The MLPG has been coupled with the FEM for problems involving elasticity problems, potential problems and electromagnetic field computations. Tadeu et al. used a coupled BEM–MLPG approach for the Acousticc analysis of non-homogeneous media. Direct coupling with The use of an MLS approximations cheme was employed. Other Examples include combining BEM or MFS with the meshless Kansa's method, FEM with the EFG method and BEM with the EFG method. Alves Costa et al. proposed coupling the FEM–BEM for the 2.5D analysis of track-ground vibrations.The Environmental impact of railway traffic and mitigation of track Vibration have been studied and the results compared with experimental measurements. Coupling the BEM and MFS for the 2.5D Analysis of elastic wave propagation in frequency domain is described in . Godinho et al. have recently proposed an MFS–FEM coupled formulation for soil–structure interaction analysis that allows an efficient and accurate an alysis of wave propagation in the presence of buried structures.

4. LITERATURE REVIEW

Konduru V. Rambabu et al Experimented the problem of seismic structural design reduces ultimately to estimating the response of the structure to an assumed forced motion imposed on the ground. For multiple supported structures, in most cases, it is generally sufficient to assume that the arrival time of each component of the base motion is the same for each support point, making the transmission time zero (i.e., uniform or rigid base excitation). The inappropriateness of this assumption has been established for long structures like bridge spans. In the current study, the effect of wave passage on the response of an open-plane frame building structure on isolated column bases has been examined for a few selected horizontal accelerograms. Soil–structure interaction has also been considered. The results indicated that a multiple supported excitation approach yields significantly different peak column shear compared to uniform base excitation. Further, the peak column shear mobilized is affected by soil–structure interaction. The pseudo-static contribution to the peak response was seen to be very significant (490%) particularly for low wave velocities even though the span was only 6.0m for the non-interactive structure. When soil–structure interaction was considered, the pseudostatic contribution was found to be (for certain accelerograms depending on the ground displacement record) in excess of 25% for the structure founded on hard soil. These results suggest that is prudent to consider wave passage effects when determining the response to seismic excitations even of open plane frames with short spans.

Sekhar Chandra Duttaa et al.Observed in the conventional design, buildings are generally considered to be fixed at their bases. In reality, flexibility of the supporting soil medium allows some movement of the foundation. This decreases the overall stiffness of the building frames resulting in a subsequent increase in the natural periods of the system and the overall response is altered. The present study considers low-rise building frames resting on shallow foundations, viz. isolated and grid foundation. Influence of soil–structure interaction on elastic and inelastic range responses of such building frames due to seismic excitations has been examined in details. Representative acceleration–time histories such as artificially generated earthquake history compatible with design spectrum, ground motion recorded during real earthquake and idealized near-fault ground motion, have been used to analyze the response. Variation in response due to different influential parameters regulating the effect of soil-flexibility is presented and interpreted physically. The study shows that the effect of soil–structure interaction may considerably increase such response at least for low-rise stiff structural system.

Mahir Ülker-Kaustella, et al Explained a qualitative analysis of the dynamic soil–structure interaction (SSI) of a portal frame railway bridge based on the linear theory of elasticity is presented. The influence of SSI on the dynamic properties of the structure and its response due to the high-speed load model (HSLM) of the Euro code is analysed by simple concepts from the finite element theory. The dynamic behavior of the foundations of the structure is introduced by means of dynamic stiffness functions, describing the stiffness and damping of the foundation–soil interface. These frequency dependent functions are used as boundary conditions on a two-dimensional Euler–Bernoulli model of the structure. The equations of motion are solved in the frequency domain and the time domain solution is obtained by the fast Fourier transform algorithm. It is shown that the radiation and material damping of the foundation–soil interface may give a substantial contribution to the modal damping ratio of the structure. A comparison of the dynamic response of the structure, subjected to the HSLM assuming different SSI models shows that fixing the vertical degree of freedom may grossly underestimate the vertical acceleration in the bridge deck.

George Lin Explained the effect of a grade beam and soil interaction on framing stability strength, the influence of foundation depth embedded below ground level is also investigated in this study. The finite element method and elastic spring model are applied to carry out the stability analyses. The results of the closed-form solution from the classical differential equation are used for the purposes of comparison. It has been verified from this study that the soil interaction has a great impact on the buckling strength of framing systems. Providing a grade beam between column bases will normally increase the strength of framing stability. Increasing the embedded depth of column footing improves the rigidity of column base, which will in turn improve the buckling strength of frame. Framing systems have lower buckling strength if the effect of soil interaction is taken into account. Thus, the effect of soil-structural interaction must be considered in stability analyses.

Alper Ucak1 et al Studied the role of soil–structure interaction on the response of seismically isolated bridges . A generic bilinear hysteretic model is utilized to model the isolation system. The behavior of the pier is assumed to be linear and the foundation system is modeled with frequency-dependent springs and dashpots. Two bridge systems were considered, one representative of short stiff highway overpass systems and another representative of tall flexible multispeed highway bridges. Nonlinear time history analyses were employed with two sets of seismic motions; one containing 20 far-field accelerograms and one with 20 near-fault accelerograms. The results from these comprehensive numerical analyses show that soil–structure interaction causes higher isolation system drifts as well as, in many cases, higher pier shears when compared to the fixed-pier bridges.

IzuruTakewaki, M. Studied the input energy to a soil-structure interaction system during earthquake shaking is taken as a structural performance measure and is formulated in the frequency domain. The purpose of this paper is to derive the closed form expression of the sensitivity of the input energy to the SSI system with respect to uncertain parameters representing soil stiffness and damping. It is demonstrated first that the input energy expression can be of a compact form consisting of the product between the input motion component Fourier amplitude spectrum of acceleration and the structural model component so-called energy transfer function. With the help of this compact form, it is shown that the formulation of earthquake input energy in the frequency domain is essential for deriving the closed-form expressions of the sensitivity of the input energy to the SSI system with respect to uncertain parameters in contrast to the time-domain formulation including inevitable numerical error and instability. This formulation is then extended to a multidegree of freedom superstructure model. Numerical examples support the fact that the closed-form expressions enable one to find in a reliable and efficient way the most critical combination of the uncertain parameters that leads to the maximum energy input.

Javier Avilés et al. Have shown that performance based design methodology aimed at controlling the structural damage based on precise estimations of the seismic response of the whole building–foundation system. This work presents a simplified procedure for practical damage analysis of structures considering the soil–structure interaction effects, with potential application to performance-based design of new buildings as well as to performance-based evaluation of existing buildings. A damage model based on maximum displacement and dissipated energy under monotonic loading is proposed, with the effects of cyclic load reversals being estimated by using a modified Park–Ang index. To simplify the consideration of the soil–structure interaction effects, an equivalent fixed-base oscillator with the same yield strength and energy dissipation capacity as the actual flexible-base structure is applied. Selected numerical results are presented in terms of dimensionless parameters for their general application, using a set of appropriate earthquake motions for ensuring generality of conclusions. The significance of soil–structure interaction in the structural performance is elucidated and the adequacy of the approach proposed is examined.

Kohji Tokimatsua et al. Experimentally investigated effects of inertial and kinematic forces on pile stresses based on large shaking table tests on pile-structure models with a foundation embedded in dry and liquefiable sand deposits. The test results show that, if the natural period of the superstructure, Tb is less than that of the ground Tg, the ground displacement tends to be in phase with the inertial force from the superstructure, increasing the shear force transmitted to the pile. In contrast, if Tb is greater than Tg, the ground displacement tends to be out of phase with the inertial force, restraining the pile stress from increasing. With the effects of earth pressures on the embedded foundation and pile incorporated in, pseudo-static analysis is conducted to estimate maximum moment distribution in pile. It is assumed that the maximum moment is equal to the sum of the two stresses caused by the inertial and kinematic effects if Tb<Tg or the Square root of the sum of the squares of the two if Tb>Tg. The estimated pile stresses are in good agreement with the observed ones regardless of the occurrence of soil liquefaction.

J Rajasankar et al. Extensively discussed investigations conducted based on seismic soil-structure interaction analysis of a massive concrete structure supported on a raft foundation. Linear transient dynamic analysis is carried out using finite element method and imposing transmitting boundary conditions at far field of layered elastic half-space. Analysis is conducted in two phases, namely: (i) free-field analysis of the layered half-space and (ii) seismic analysis of the structure by including soil structure interaction effects. In the first phase, a simple and novel technique is used to establish free-field excitation at a depth in the half-space. In the second phase, seismic soil-structure interaction analysis of the structure is carried out for the free-field excitation determined in phase-I. Stress resultants experienced by the raft and the stresses at the interface between the rock and raft are evaluated. Critical examination of the results indicates tensile stresses of considerable magnitude at few locations in the rock-raft interface. Typical stress responses at the interface are presented and discussed in the paper.

George Mylonakis Explained the role of soil-structure interaction (SSI) in the seismic response of structures using recorded motions and theoretical considerations. Firstly, the way current seismic provisions treat SSI effects is briefly discussed. The idealized design spectra of the codes along with the increased fundamental period and effective damping due to SSI lead invariably to reduced forces in the structure. Reality, however, often differs from this view. It is shown that, in certain seismic and soil environments, an increase in the fundamental natural period of a moderately flexible structure due to SSI may have a detrimental effect on the imposed seismic demand. Secondly, a widely used structural model for assessing SSI effects on inelastic bridge piers is examined. Using theoretical arguments and rigorous numerical analyses it is shown that indiscriminate use of ductility concepts and geometric relations may lead to erroneous conclusions in the assessment of seismic performance. Numerical examples are presented which highlight critical issues of the problem.

5.OBJECTIVE

Till date soil structure interaction has not given that much importance as it should have. Measurably big structures will more effect of SSI. The effect of SSI should be taken into consideration at the load calculations and design stage of structures. Present study will be carried out with following objectives

1. Comparing the total base shear before and after considering effect of SSI
2. Considering the effect of infill wall stiffness during analysis with equivalent diagonal member.
3. Comparing the effect of SSI by considering different types of soils.

6.METHODOLOGY

The effects of nonlinear structure behavior on in structure response factors acceleration and response spectra appears to be significantly less when SSI effects are important at the site. This is principally due to the potential dominating effect of SSI on the response of the soil-structure system. Also if SSI is treated properly the input motion to the system is filtered such that higher frequency motion is removed i.e. frequency content which may not be suppressed by nonlinear structural behavior if the structures were founded on rock. SSI can have significant effect on the energy dissipation characteristics of the system due to radiation damping and material damping in the soil. According for the effect of the inelastic structural behavior on structure response must be done carefully for soil founded structure to avoid double counting of the energy dissipation effects.

In the substructure approach the SSI problem is sdemonstrates the basic concepts of substructure method of soil-structure interaction analysis. The three step solution for SSI problem consist of,

1) Determination of foundation input motion by solving the kinematic interaction problem.

2) Determination of frequency dependent impedance functions describing the stiffness and damping characteristics of the soil foundation interacting system. This step should account for the geometric and material properties of foundation and soil deposits and is generally computed using equivalent linear elastic properties for soil appropriate for the in-situ dynamic shear strains. This step yields the so called soil springs.

3) Computation of response of the real structure supported on frequency dependent soil springs and subjected at the base of these springs to the foundation input motion computed earlier.

It should be noted that if the structural foundations were perfectly rigid, the solution by substructure approach would be identical to the solution by the direct method. Further the superposition principle is valid for linear system only. Since the shear modulus and damping properties of soil are strain dependent principle of superposition can be questioned. However it has been observed that most of the nonlinearity in soil behavior occurs as a result of the earthquake motion and nor as a result of soil structure interaction itself. Therefore the soil properties estimated for the same strain levels as a expected during a postulated design earthquake may be used without any further modification.

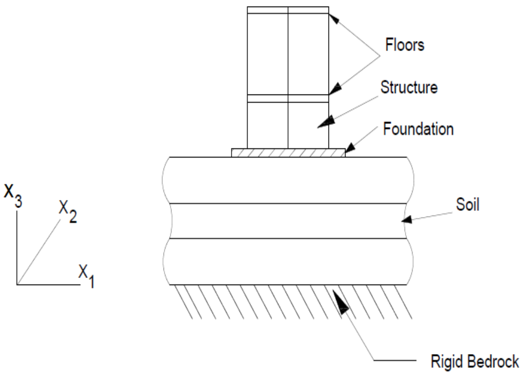


Fig 6.1 soil structure system

Reasonable approximation can be obtained on the basis of one-dimensional wave propagation theory for the solution of step (i) and by using the some correction factors for modifying the springs for a surfaces footing on a layered soil deposit to account for the embedment of foundations as a solutions to step (ii) of the problem. Several investigators of the soil-foundations systems. Generally the foundation input motion is assumed to the same as free-field motion i.e. the effect of kinematics interaction are neglected in SSI analysis for most of the common constructions. Kinematic interaction should invariably be considered if the structure and foundations to be constructed are very massive, rigid and very large Fig. 3.2 shows a simplified model normally used in the analysis of internal interaction effects, The model consist of a single of freedom structure of height h, mass m, stiffness k, and viscous dumping coefficient c. The base of the structure is free to translate relative to the ground uf and also to rotate by amount θ. The impedance functions are represented.In a seismic soil-structure interaction analysis, it is necessary to consider the infinite and layer characteristics of soil strata, and the nonlinear behaviours of soft soil. The objective of this study is to perform a rigorous seismic non-linear soil structure interaction analysis in the time domain to satisfy the above requirements while the results are compared with those of fixed based structural analysis.

$[M]\{\ddot{r}(t)\}+[C]\{\dot{r}(t)\}+[K]\{r(t)\} = -[M]\{\ddot{u}_g(t)\}$in which [M], [C] and [K] are n x n mass, damping and stiffness matrices, respectively, n is the number of degrees of freedom of the structure,{r} is the total displacement vector of the system, and{ ug} is the acceleration vector of the free field ground motion.

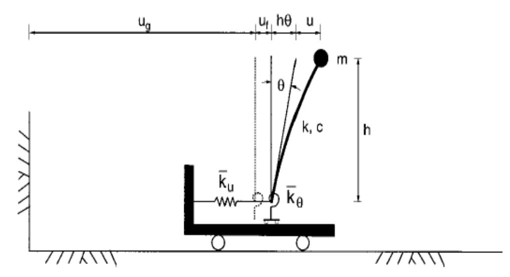


Fig 6.2 Simplified model for analysis of interaction

For the generalized substructure method, the interaction force-displacement relationships in the time domain can be expressed in terms of the relative interaction displacements calculated along the interaction horizon, namely, the difference between total and free-With this formulation, true nonlinearity of soil can be consistently taken into account within the near field by properly defined constitutive models.

7. EVALUATION OF SOIL-STRUCTURE INTERACTION

Effects using system identification analyses the objective of system identification analyses is to evaluate the unknown properties of a system using a known input and output from. For analyses of seismic structural response, the system has an unknown flexibility that generates a known difference between pairs of input and output strong motion recordings. parameters describing the fixed-base system are evaluated from input/output pairs that differ only by the structural deformation u. Likewise, parameters describing the flexible base system are evaluated from strong motion pairs whose difference results from foundation flexibility in translation uf and rocking u, as well as structural flexibility.

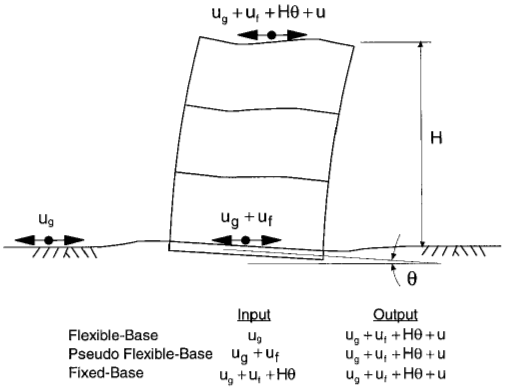


Fig.7.1 Motions used as inputs and outputs for system identification of structures

A comparison of fixed- and flexible- base modal parameters provide a direct quantification of SSI effects. There are two principal systemidentification procedures

1. Nonparametric procedures evaluate complex-valued transmissibility functions from the input and output recordings without fitting an underlying model. These transmissibility functions represent an estimate of the ratio of output to input motion in the frequency domain and are computed from smoothed power and cross-power spectral density functions of the input and output motions. Modal frequencies and damping ratios are estimated from peaks in the transmissibility function amplitude

2. Parametric procedures develop numerical models of transfer functions, which represent the ratio of output to input motion in the Laplace domain. The amplitude of the transfer function is a surface in the Laplace domain. Peaks on this surface are located at poles which can be related to modal frequencies and damping ratios. Parameters describing transfer function models are estimated by minimizing the error between the model output and recorded output in the discrete time domain using least squared techniques. The transfer function surface can be estimated by minimizing cumulative error for the entire time history (Safak 1991a) or by recursivel minimizing error for each time step using a window of time immediately preceding that time step (Safak 1991b). The evaluation of vibration frequencies and damping ratios from transmissibility functions can be problematic (especially for damping), because the shape of the functions is dependent on details associated with the computation of the spectral density functions such as the number of points in the fast Fourier transform and the windowing procedures used (Pandit 1991). Parametric procedures provide a relatively rigorous modeling of system response, because the transfer function for a given set of time histories is only dependent on two user-defined parameters:

- The delay between the input and output
- The number of modes used in the analyses (i.e., the order of the model).

When these parameters are selected judiciously, the modal frequencies and damping ratios can be reliably evaluated for linear structures. Hence, parametric identification techniques were used for the evaluation of structural modal vibration parameters in this study.

8..CONCLUSION

When nonlinear behaviors of soil are important in a soil–structure interaction system, the energy radiation into infinity of the soil as well as the nonlinearity must be considered rigorously. In this study, perfectly matched discrete layers (PMDLs) were employed to represent the radiation of energy because they are effective in modeling wave propagations in various unbounded domains. A time-domain formulation for soil–structure interaction was given using PMDLs. To represent a layered half-space effectively and accurately, how to determine the PMDL parameters was proposed. It was demonstrated that the proposed PMDL system can be applied successfully to problems of soil–structure interaction. It was observed from example applications that the material nonlinearities can strongly influence the dynamic responses of the soil–structure interaction system. Therefore, the nonlinearities must be considered accurately for a rigorous soil– structure interaction analysis. In the present study, only the material nonlinearity in two dimensional problems was considered. Based on the same time domain formulation, nonlinearities such as the sliding and partial uplift of a foundation and separation of a foundation wall from the soil can also be studied. In addition, the system can be extended to three-dimensional problems without difficulty. These topics will be the subject of future studie**s.**

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