CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Multistorey frames are simple discrete structures and their analysis has been a part of structural engineering ever since. However classical and finite element analysis of multistorey frames incorporating the modeling of soil and its interaction with the structure have been in practice for only a few years. The literature available in this field has been reviewed and presented here.

2.2 SOIL STRUCTURE INTERACTION

Lee and Harrison (1970) have conducted studies on structure-foundation interaction and proposed two analytical methods for the analysis of combined footing and two dimensional raft foundation. The methods take into account the effect of the rigidity of the superstructure on the distribution of forces and moments transmitted to the foundation. In the first method rotations and sways at the column foundation junctions have been treated as unknowns. The superstructure alone has been analysed and the displacements and rotations obtained at each junctions have been equated to the corresponding values obtained by considering the foundation to be a beam on Winkler medium subjected to a system of forces and moments. The second method involved the successive modification of an assumed contact pressure distribution. The superstructure and foundation have been treated as a single compatible unit and column forces and moments were evaluated from a conventional structural analysis. In the next step, the foundation has been isolated from the superstructure and structural analysis repeated with a new estimate of contact pressure distribution. The procedure has been repeated till acceptable accuracy has been achieved.

Lee and Brown (1972) have conducted a comparative study on a three bay multistorey frame resting on raft foundation. Interaction studies have been
done using two models (1) the conventional method using the Winkler ‘spring’ concept assuming the foundation to be rigid (2) the linear elastic model. An advancement on the conventional method called the ‘soil - line – method’ which considers the stiffness of the foundation relative to the soil in addition to the Winkler model and loading for a rigid foundation, when calculating moments, shearing forces and deflections has also been evaluated. It has been observed that the difference in maximum bending moment in foundation by the use of the Winkler model and linear elastic models have been relatively small, and the maximum moment has decreased when the flexibility of the foundation increased. It has also been observed that for structures with more than three bays, the difference in maximum foundation bending moment is large which necessitates a thorough interaction study.

Krauthammer and Chen (1988) have investigated the relationships between the type and accuracy of the free field input motion generation and the resulting effects on the corresponding structures. The general finite element computer program ADINA has been utilized for obtaining the numerical information. Three types of free field simulations have been employed for the analysis of three typical soil-structure configurations namely no embedment, partial embedment and full embedment. The results have showed that simulation accuracy is a critical factor in such studies.

Gazetas et al. (1993) have outlined a general methodology for a complete seismic- soil – pile – foundation – structure interaction analysis. A Beam – on – Dynamic –Winkler foundation simplified model and a Green’s function based rigorous method have been utilized in determining the dynamic response of single piles and pile groups. A systematic parametric study has been conducted on the effect of pile group configuration upon dynamic impedances of piles embedded in homogeneous as well as heterogeneous soils. It had been shown that the cross interaction between piles in different rows controls the dynamic response of a rectangular pile group and that increasing the number of piles in a line group has very little effect on the dynamic stiffness and damping factors. It has been demonstrated that the predictions by the static interaction factor method are acceptable only for
static and low frequency cases and that they may be very conservative or very unsafe at higher frequencies. It had been concluded that at intermediate and high frequencies it is better to ignore pile to pile interaction altogether than to use static interaction factors.

Viladkar et al. (1994) have analysed a plane frame combined footing soil system subjected to biaxial loading. An isoparametric interface / joint element has been used to model the interface characteristics of the foundation beam and the soil medium. It has been observed that interface elements are essential for understanding the realistic nature of a laterally loaded structure and that bending moments are not only relieved but also reversed due to the interacting behavior of the framed structure footing soil system.

Yang et al. (1996) have demonstrated that the condensation technique in structural mechanics can in reality be employed to formulate the soil-structure interaction problems. The method has been used to calculate the equivalent seismic forces exerted by the far-field soil on the near-field soil.

Wu (1997) has utilized a single – degree – of freedom replacement oscillator to represent an SSI system with SDOF structural model. A methodology is then proposed to determine the equivalent fixed – base models of general multi degree of freedom SSI system using simple system identification techniques in the frequency domain.

Lu (2002) carried out comparative study on the non-linear behaviour of reinforced concrete multistorey structures. Experimental and numerical analysis on a scaled model has showed that the distribution of storey shear over strength is an indicator of the general inelastic behavior of the frames. Regular base frame, discontinuous-column frame, partially masonry infilled frame and a wall-frame system have been used for the study.

Osinov (2003) has presented a mathematical model for the deformation of soil under irregular cyclic loading in the simple shear condition. The model incorporated (1) the possible change in the effective pressure in saturated soil
due to the cyclic shearing, (2) the reciprocal influence of the effective pressure on the response of the soil to the shear loading and (3) the pore pressure dissipation due to the seepage of the pore fluid

Kokusho (2003) has focused on the mechanism involved in the void redistribution and water film effects in layered sand deposits to study the lateral flow mechanisms during liquefaction. It has been found that sand deposits in the field consist of sub layers with different particle sizes and permeability; and these readily developed water films by post liquefaction void redistribution at sub layer boundaries.

Takewaki et. al. (2003) have presented a simple and fast evaluation method of soil structure interaction effects of embedded structure via cone model. The cone model has been used to evaluate the impedances and the effective input motion at the bottom of an embedded foundation.

Takewaki(2005) has developed a new critical excitation method for soil-structure interaction system. The input energy to the soil-structure interaction system during an earthquake has been introduced as a new measure of criticality. Two kinds of input energy have been defined, one to the overall soil-structure interaction system and the other to the super-structure only. The differences between these two energies indicate the energy dissipated in the soil or that radiating into the ground.

Tokimatsu et al. (2005) have conducted studies on inertial and kinematic forces on pile stresses based on large shaking table tests on pile – structure models with foundation embedded in dry and liquefiable sand deposits. The horizontal subgrade reaction acting on the pile and the earth pressure acting on the embedded part of the foundation have been treated as kinematic forces. An artificial ground motion called Rinkai, produced as an earthquake in southern Kanto district in Japan, has been used as an input base acceleration to the shaking table. The maximum values of bending moment and displacement of the pile and soil has showed considerable variations for dry and liquefiable sand deposits. The bending moments after liquefaction
have been considerably larger than that before. The results have showed that if the natural period of superstructure is less than that of the ground, the kinematic force tend to be in phase with the inertial force from the superstructure, increasing the stresses in the piles and if the natural period of the superstructure is greater than that of the ground, the kinematic force tend to be out of phase with the inertial force, restraining the pile stresses from increasing. Further in the study, a pseudo – static analysis based on Beam – on Winkler – springs method has been conducted to examine its effectiveness in estimating pile stresses in the large shaking table tests. It has been observed that the estimated bending moment and deformation of the pile from the pseudo – static analysis have been in good agreement with the observed values and hence the method has been suggested for estimating pile stresses and deformation mode with accuracy.

Yang et al. (2005) have observed that direct integration of the ground acceleration data is firstly base line – corrected in the time domain using the latest square curve fitting technique, and then processed in the frequency domain using a windowed filter to remove the components that cause long period oscillations in the desired displacement.

Krishna et.al (2006) assessed the liquefaction mitigation of ground treated by granular piles. Pore pressure generation and dissipation accounting for both densification and drainage effects of granular piles have been considered. It has been observed that both the coefficients of volume change and permeability are affected by densification.

Foundation impedance functions provide a simple means to account for soil-structure interaction when studying seismic response of structures. Impedence functions represent the dynamic stiffness of the soil media surrounding the foundation. Impedence functions have been frequency dependent and hence it is difficult to incorporate SSI in standard time-history analysis software. Safak(2006) has introduced a method to convert frequency dependent impedance functions into time domain filters. The method has been based on least-squares approximation of impedance functions by ratios of two
complex polynomials. Such ratios are equivalent, in the time domain, to discrete- time recursive filters, which are simple finite difference equations representing the relationship between foundation displacements and forces.

2.3 SEISMIC SOIL STRUCTURE INTERACTION

Hoshiya and Ishii (1983) have used a stochastic model to evaluate the kinematic interaction of embedded rectangular foundations by the random vibration theory. The formulation has been based on the fact that statistical correlation of ground motions at different points decreases as the distance between the points increases when components of high frequency are contained in the ground motion. For the stochastic model, earthquake records at a large scale inground tank and a foundation, made of cement – mixed soil improved – ground has been used as examples of deep and shallow embedded foundations. It has been observed that the foundation slab, which is relatively stiff compared with the soil, constrain the ground motions and hence short period components of the ground motion whose wave length has been less than the dimension of the slab are weakened. Hence the kinematic interaction effect of the slab has been like a low pass filter on the ground motions.

Neuss and Maison (1984) have presented a matrix formulation to account for $p - \Delta$ effects in computer seismic analysis of multistorey buildings. The method has employed a linear solution approach requiring no iteration which can be used for static and dynamic – elastic analyser.

Veletsos and Prasad (1989) have made a study of soil structure interaction for seismically excited simple structures considering both kinematic and inertial interaction effects. The system investigated has been a linear structure which was supported on a circular mat foundation at the surface of a homogeneous elastic half space. The structures have been presumed to have one lateral and one torsional degree of freedom in their fixed base condition and have been excited by obliquely incident, horizontally polarized, incoherent shear waves. The temporal variation of the free field ground motion has been expressed stochastically by a local power spectral
density function (psd), and its special variability has been specified by a cross psd function. The response quantities examined included the ensemble means of the peak values of the lateral and torsional components of the foundation input motion and the corresponding structural deformations. It has been observed that like kinematic interaction, inertial interaction may affect significantly the responses of systems in the medium and high frequency spectral regions and that the effects of the latter are more important. It has also been reported that unlike kinematic interaction, which generally reduces lateral response, inertial interaction may increase the corresponding response of tall, slender structures in the high frequency region of the response spectrum. The inertial interaction effects for low frequency structures have been negligible because such systems consider the half space as a very stiff, effectively rigid medium. It has also been observed that reliable estimates of the effects of kinematic interaction on the peak values of structural response may be obtained from the knowledge of the corresponding values of the acceleration, velocity and displacement traces of the foundation input motion. These quantities may be computed from analysis of the response of the massless foundation to the free-field ground motion. Insofar as the mean maximum values of the responses have been concerned, the kinematic interaction effects due to ground motion incoherence are similar to those due to wave passage and the two effects may be interrelated.

Guin and Banerjee (1998) have developed a methodology for the dynamic analysis of soil-pile—structure system using a generalized coupled finite element boundary element formulation for the entire problem domain. The formulation has been done in the frequency domain and the excitation is defined through a rock outcrop motion causing vertically propagating S-waves. Linear dynamic analysis has been conducted on two super structural systems namely, a bridge and a multistory frame. It has been observed that coupling of the problems facilitates in the preparations of transfer functions for various degrees of freedom in the structure, including the effects of interaction.
Wolf and Song (2002) have formulated a criterion for the presence of radiation damping in a site. The procedures for the analysis of dynamic soil structure interaction have been outlined. The procedures have included simple physical model (cones, spring – dashpot – mass representations) for the soil, the damping – solvent extraction method, the rigorous forecasting method and the scaled boundary finite element method.

Spyrakos and Xu (2003) have studied the seismic response of massive flexible strip foundation embedded in layered soils subjected to seismic excitation. The foundation has been treated with a finite element formulation, while the difficulty in modeling the infinite extend of the soil has been overcome by a boundary element formulation. System responses have been investigated with the help of boundary element – finite element coupled formulations by enforcing compatibility and equilibrium conditions at the soil foundation interface.

Davenne et al. (2003) have developed numerical tools for the modeling of reinforced structures for the non linear transient analysis of RC structures. A multifiber beam element has been used to describe the response of structural components and a macro element to account for soil structure interaction. The method has been applied for various boundary conditions and incorporating soil-structure interaction.

Spyrakos and Loannidis (2003) have conducted studies on the effect of soil structure interaction on seismic analysis and design of bridges. The significance of soil structure interaction on a model with geometric stiffness and seismic response of a bridge with integral abutments has been established. It has been reported that the role of soil structure interaction is of great importance for the post tensioned modular integral bridge system.

Gen-shu and Jin-qiao (2005) have examined the seismic force and modification factor R based on elastic-plastic time – history earthquake analysis of single degree of freedom systems. The constitutive hysteresis models that have been used are elastic- perfectly –plastic, elastic –linearly-
hardening and bilinear-elastic. It has been concluded that $R$ increases linearly with ductility and energy dissipating capacity in short period ranges.

Anandarajah et al. (2005) have demonstrated that soil parameters needed for simplified dynamic analysis of a single pile may be back calculated from the dynamic response of the pile measured in the field. Two methods have been proposed, the first based on Winkler foundation approach and the second based on the equivalent- linear finite element approach, with non linearity of shear modulus and damping accounted for by employing degradation relationships.

Wegner et al. (2005) have developed a numerical procedure for three-dimensional dynamic-soil-structure interaction analysis. Scaled boundary finite-element method has been used for modeling the unbounded soil and standard finite element method is used for modeling the structure. The dynamic response of tall buildings, with multi-level basements, subjected to seismic excitations including $P$, $SV$ and $SH$ waves at various angle of incidence have been arrived at.

Takewaki and Kishida (2005) have developed a method for the analysis of pile-group effects on the seismic stiffness and strength of buildings with pile foundations. A continuous model consisting of a dynamic Winkler-type soil element and a set of pile has been used to express the dynamic behavior of the structure-pile-soil system. The pile group effect has been accounted through the influence of coefficients that have been defined for interstorey drifts and pile-head bending moments. Pile group effect has reduced the interstorey drift of buildings and increased the bending moments at the pile head.

2.4 RESPONSE SPECTRUM ANALYSIS

Newmark (1973) has shown that the response of simple systems to ground motion can be represented by idealizing the linear response spectrum into constant acceleration, constant velocity and constant displacement
response for a given damping factor. Browning (2001) has presented a simple method for proportioning of regular, moderate-rise reinforced concrete building structures. In this method the member sizes have been selected based on the demand defined by the displacement spectrum and criteria specified in relation to different responses.

Ghiocel and Ghanem (2002) have conducted studies on probabilistic analysis of the seismic soil structure interaction problem. The procedure has accounted for the uncertainties in the free field input motion, local site conditions and structural parameters. The uncertain parameters have been modeled using a probabilistic frame work as stochastic processes. The earthquake ground acceleration has been represented by a probabilistic acceleration response spectrum. The procedure has been then applied to the seismic analysis of a nuclear reactor facility and has been observed to have good co-relation with other deterministic methods of risk assessment of hazardous facilities under dynamic loads.

Ambraseys and Douglas (2003) have presented strong motion attenuation relationships for peak ground acceleration, spectral acceleration, energy density, maximum absolute input energy for horizontal and vertical direction and for the ratio of vertical to horizontal of these ground motion parameters. The equations have been derived using a world wide data set of 186 strong – motion records that have been recorded with in 15 km of the surface projection of earthquakes with magnitudes 5.8 to 7.8.

Yuan et.al. (2003) have studied the effect of asymmetry and irregularity of the input seismic waves on the earthquake – induced differential settlement of the buildings on natural subsoil. It has been concluded that these are necessary factors that has to be considered in the evaluation for differential settlement and other problems that have been related to the soil deformation due to earthquakes.

Chintanapakdee and Chopra (2004) have conducted non-linear response history analysis on vertically regular and irregular frames to study
the storey drifts and floor displacements. Drift demands in the upper storeys have been more sensitive to irregularities in the lower storeys than the response of lower storeys due to irregularities in the upper storeys. Irregularity in the base storey or lower storeys has significant influence on the height-wise distribution of floor displacements.

Boore and Bommer (2005) have suggested methods for processing of strong motion accelerograms which have been masked and distorted by noises. It has been important to identify the presence of noise in the digitized time-history and its influence on the parameters for any application of recorded accelerograms in earthquake engineering.

Camiel et al. (2006) have investigated the application of the Singular Spectrum Analysis (SSA) to improve the Nakamura technique. Nakamura technique has been employed to estimate the dynamic characteristics of surface layers by measuring solely the tremor at the surface. The SSA has allowed the time series to be decomposed into different components, like signal itself, various noise components etc.

2.5 COMMENTS

The incorporation of soil structure interaction effects in the analysis and subsequent design of multistorey frames has been the subject of research and, started getting attention in the late seventies. It is observed that research attention has been focused on the soil structure interaction effects of high risk structures like nuclear reactors, bridges etc. However only limited research studies have been carried out on soil structure interaction effects of multistorey building frames, which are common, popular and simple in configuration. Soil structure interaction studies of multistorey frames which generally are provided with pile foundations, is tedious, voluminous and cumbersome due to the possible involvement of large number of nodes and finite elements necessary to model the soil mass. This may be the reason why such analysis are not addressed and reported in considerable numbers. High rise buildings on
pile foundations have become part of regular building construction due to population explosion. From the review of the reported studies it has been felt that a complete soil structure interaction analysis of multistorey building frames with pile foundations using appropriate numerical methods is justifiable.