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EFFECT OF NONLINEAR STRUCTURAL RESPONSE ANALYSIS FOR SSI

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ABSTRACT

Liquefaction engineering is one of the challenging areas in geotechnical earthquake engineering. Especially after urban areas are struck by big earthquakes which cause considerable damage in structures due to liquefaction, it has been realized that more efforts should be made to understand the interaction between structural performance and geotechnical aspects. The state of the practice in the assessment of liquefaction beneath a structure is to treat the soil as if it in the free-field. This practice has been developed as it is believed to be a conservative approach and easy to perform. In addition, it does not require structural properties. However, it is observed after recent earthquakes (e.g. Kobe 1995, Kocaeli 1999), that liquefaction in the free-field is closer to foundation structure-induced liquefaction. The aim of the present study is to improve the analyses involving SSI, with the soil being represented as a continuum approximated with solid elements. It is to investigate various structural approaches and reliability to model SSI. The response in the superstructure and influence on the outcomes of simplifications in the SSI with springs performing the subgrade are also analysed

KEYWORDS: Soil-structure interaction, structural response,

INTRODUCTION

Generally, the engineering structures directly have connection with the earth. All engineering structures undergo earthquake ground motions and the ground displacements to one and another. At the time of Earthquake, seismic waves affect the structure with the input free-field ground motion. The difference between ground motion and soil geological medium including soil with superstructure is known as Soil-Structure Interaction (SSI).

In engineering practice, in the design of the superstructure, some researchers consider SSI with the structural element model with the subgrade. Structural engineering and Geotechnics are mutual to the analysis of civil engineering structures. To know the real conduct of the super structures, the subgrade must be modelled. Structural engineers and Geotechnical engineers use software with advanced soil and structural model. The end user should have a adequate knowledge in both the subjects to practice the model in SSI. The common conception of the earthquake simulation is like dropping a stone in a lake. When the stone hits the water, one can see a uniform ripple effect on the water surface and it gets weaker as it travels from the center to far the earth surface is not uniform as of the water in this comparison. An earthquake in one area can experience over 10 times the effects as compared to a surrounding area would be at the same distance from the fault line. This is due to “Site Effects”. These site effects are variations that occur in the geologic conditions of a particular area. Two main reasons account for these changes which are softness of the soil or rock and the total thickness of the sediment above the bedrock. When an earthquake occurs, seismic waves travel though the ground and travel faster through hard rock compared to soft soil. Due to this, when the seismic waves travel from hard rock to soft soil, they become slower and must become bigger in amplitude to carry the same amount of energy. This concept accounts for the site effects of sediment thickness. The deeper the sediment above bedrock, the softer soils the seismic waves to travel through, thereby creating stronger amplifications.

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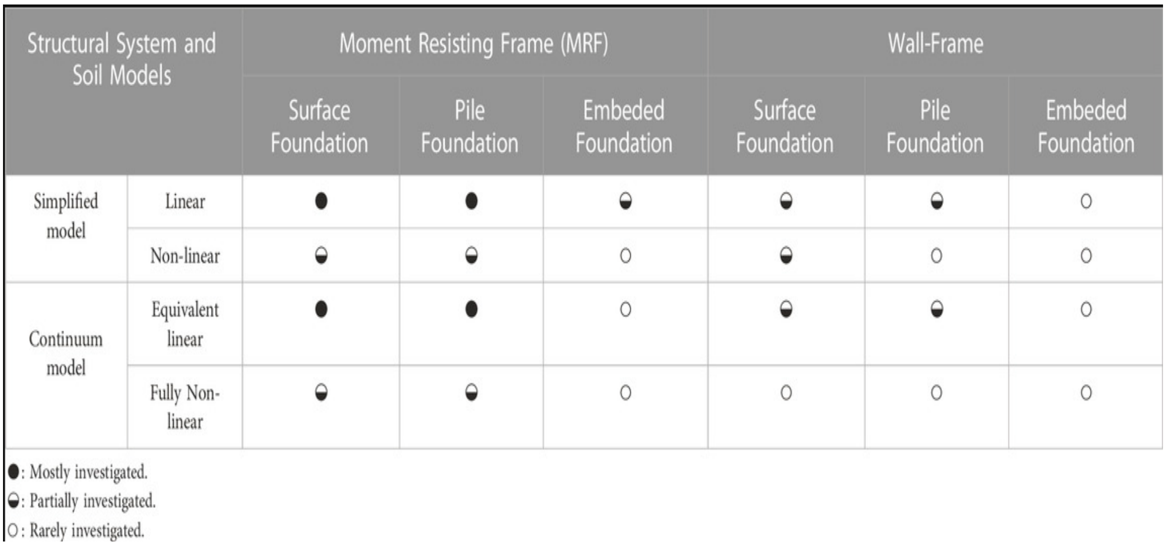
The exact ground motions, suggested by the code, generate the need to consider the effect of soil on the seismic motion at ground surface. Time history analysis of a structure can perform translations and rotations, under site-specific ground motions. There is a lack of drawback to develop the SSI effects. The effects of SSI between the geology and the structure under seismic load become more distinguished for heavy structures. In this case, neither the structural displacements nor the ground displacements are independent of each other. The structure–soil–structure dynamic interaction is presented based on the history. An attempt has made to outline the major computer programs in SSI problem. Soil reaction influences the structural behavior under external loading and it is vice versa. The motion of the structure can affect the soil behavior, dynamic of the SSI. SSI can be simplified on the design phase by means of springs like transitional, rotational and torsional and dashpot or by a more accurate analysis with Finite Element Method (FEM). Dynamic SSI is related to flexible structure under cyclic loading which may change the soil behavior during its lifetime and hence it changes, the structural response like natural frequencies, damping and stress redistribution. The accurate evolution of the dynamic SSI on a long-term basis is still a challenge.

SSI STUDIES ON BUILDINGS

Investigation of soil-structure interaction effects on the seismic response of building structures has been very well established and the literature covers at least 50 years of computational and analytical developments in this area. Nevertheless, due to the advancements in computational power, the last two decades is witnessing a vast improvement in SSI studies with various modelling approaches. Generally, these investigations are categorized into two main parts: firstly, researchers who tried to examine detrimental and beneficial effects of soil-structure interaction on the seismic response of buildings, and secondly, researchers who tried to find the parameters and different factors that influence the criticality of the SSI effects. In this section, a review of the advancements and most recent findings from researchers will be presented. The summary of these studies is presented in Table 1

TABLE 1: SUMMARY SSI STUDIES ON BUILDINGS WITH DIFFERENT STRUCTURAL SYSTEMS AND SOIL MODELLING



Structural System and Soil Models		Moment Resisting Frame (MRF)			Wall-Frame		
		Surface Foundation	Pile Foundation	Embeded Foundation	Surface Foundation	Pile Foundation	Embeded Foundation
Simplified model	Linear	●	●	◒	◒	◒	○
	Non-linear	◒	◒	○	◒	○	○
Continuum model	Equivalent linear	●	●	○	◒	◒	○
	Fully Non-linear	◒	◒	○	○	○	○

●: Mostly investigated.
◒: Partially investigated.
○: Rarely investigated.

BASICS OF INVESTIGATION OF PRESENT STUDY

Soil classification shall be based on observation and any necessary test of the materials disclosed by borings, test pits or other subsurface exploration made in appropriate locations.

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Additional studies shall be made as necessary to evaluate the soil strength, position, adequacy of load bearing soils, effect of moisture variation on soil bearing capacity, compressibility, liquefaction and expansiveness.

REVIEWS OF THE LITERATURE

Hamdy HA Abd el-Rahim & Ahmed Abd El- Raheem Farghaly (2011) During discovered that seismic excitation structures are more sensitive to the impacts of SSI because to changes caused in the dynamic properties of the soil; in particular, many buildings have been constructed on soft soil. The spring and dashpot coefficients are computed using a medium soil profile underneath and along the foundation's buried depth, as suggested by Newmark and Rosenblueth (1971). SSI will be a significant increase in the displacement of three models. Top is equal to the height of the contribution Building SSI displacement, while this effect is harmful with fixed base positions.

Shakib & Fuladgar (2012) Asymmetric buildings are three-dimensional propagation of linear analysis of dynamic SSI. Asymmetric building rests on different soil conditions. Asymmetric buildings responded to verify the impact of SSI, is studied in detail for a perfect three-dimensional single-storey system. The relationship between the peak of SSI displacement and eccentricity ratio in Tx = 2.0 which various soil conditions (Tx- structural period). The impact on the asymmetric system of singularities reaction ratio of SSI system and it is strongly based on the SSI system flexibility and structural period. Very harsh soil conditions (= 33: 3 or v = peak response of flexible base system for the extreme response of the system is 1000 m / sec) increases with the increase in structural period.

Habib Akhundi (2014) Vs. empirical relationships to predict, After that, neural networks are used in conjunction with multivariate regression techniques. The neural network can be trained fast, and it can forecast shear wave velocity using a static model. In comparison to multi-regression, this approach is known as "dynamic regression." Multi-regression analysis using the correlation between the various well logging data and the desired parameters. The parameters for the estimate of a parameter in multiple regression, initially expected to be reported for several other parameters.

Shehata (2015) In multi-storey buildings examined variation in SSI effects based on the use of different demand calculation methods. Their research showed that if they ignore the effects of SSI are not within the seismic performance evaluation reliable range. The growing number of academic studies and engineering reports, meaning that you'll need SSI modeling for the next generation of code and would essentially considering SSI effects design However, a building constructed before these findings are still prone to be the weak point of those cities that seismic risk.

Hokmabadi and Fatahi (2016) Reported that drift lower story than a deep due to low rocking components in the structure supported by the foundation surface foundation-supported structure.

Nguyen (2017) Due to SSI, the kind and size of pile foundations might affect the performance of mid-rise structures in soft soil locations during earthquakes.

Jahangir Khazaei, Azadeh Amiria and Mehrdad Khalilpour (2017), The effect of seismic soil-foundation-structure interaction (SFSI) on the dynamic response of diverse structures, he explained. Using the ABAQUS software, a 3D finite element approach was used to investigate two methods: direct and taper models. The Sfsai cone model was designed as an approximation way to analyse the phenomena, and high and low growth for both structures were studied. During seismic stimulation soil non-linearity, which examined the effect of friction coefficient between the soil-foundation interface as well as the hardness of the foundation and embedding. Infinite boundary conditions, soil non-linearity, and using a cone model and reference graphs for the amplification factor for the direct method is used to evaluate the validity of both approaches and performance. Instead earthquake had went to hold a series of calculations by Deep soil record modification.

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TBEC-2018 Add the rules that define the seismic performance evaluation of existing buildings. However, both do not include definitions or formulations in Turkish earthquake code that explains how to model SSI in design and evaluation.

Kalkan A. (2019) In this study, residential RC buildings that form the three-, four-, five-and six-story buildings, was selected, and they are mainly two groups of "old" and "new" buildings was classified according to their creation date.

Hossein Tahghighi and Ali Mohammadi (2020) Their goal was to see if soil-structure interaction (SSI) influenced seismic performance and reinforced concrete (RC) structures, thus they built a set of RC frames based on three soil types. The open seej finite-element structure was modelled. To simulate the interaction, a soil-foundation Nonlainiyr Winkler-based approach was used. Nonlainiyr static analysis was incremental dynamic analysis in terms of rigid and flexible base assumptions for the RC to analyse the seismic behaviour and susceptibility of structures. The function of SSI in altering the susceptibility and exposure of stiff foundation structures was proven numerically. Finally, by changing the spectral acceleration, the fundamental mode provides a straightforward way to go right to the vulnerability value for flexible-based architectures.

Ibrahim Oz, Sevket Murat Senel, Mehmet Palanci and Ali Kalkan (2020) To investigate these effects, was was selected 40 existing buildings in Turkey and static-based and rigorous, build non-linear model by considering medium and soft soil conditions. Before Turkish earthquake code of 1998 and the buildings went after the design had been classified as old and new buildings, respectively. The shear wave velocities classify various situations of soil was amplified using substructure method. Non-linear time history went to the inefficient distortion demand using the analysis was done using 20 real acceleration records selected from major earthquakes. The interplay of structure showed results that soil, especially in the soft soil of cases, significantly affect the seismic response of the old buildings. The results correspond to the significant increase in the first stories and fixed-based, rigorous and moderate cases downstream demands are close to each other on the soft soil of cases. Results delivery has indicated that the effects of the interaction of soil-structure seismic performance of new buildings is limited in relation to the old buildings.

Seung Dae Kim (2021) seismic soil-structure interaction (SSI) analysis is conducted on low-rise piloti-type buildings considering Korean geotechnical characteristics, and the effect is analytically evaluated. To achieve this goal, seismic SSI analysis applying the measured Gyeongju earthquake and design response spectrum (DRM) based on the architectural design codes are conducted by constructing three-dimensional structural analysis models with a five-story piloti-type building and four different soil properties: fill (FI), alluvial soil (AS), weathered soil (WS), and weathered rock (WR). From the analysis results, it is found that WS soil is largely affected by the seismic SSI, and the influence of the seismic SSI is different for each soil type regardless of the type of earthquake. Through the parameter study, simple and reasonable estimates are proposed to consider the SSI effect on the base shear in low-rise piloti-type buildings.

Angela Fiamingo et al.(2022) This paper presents a set of finite element method (FEM) analyses on a fully-coupled soil-structure system for a reinforced concrete building located in Fleri (Catania, Italy). These analyses are generally performed in free-field conditions, ignoring the presence of superstructures and, therefore, the effects of dynamic soil-structure interaction (DSSI). Moreover, many studies on DSSI are characterised by a sophisticated modelling of the structure and an approximate modelling of the soil (using springs and dashpots at the foundation level); while others are characterised by a sophisticated modelling of the soil and an approximate modelling of the structure (considered as a simple linear elastic structure or a single degree of freedom system). The building, designed for gravity loads only, was severely damaged during the 26 December 2018 earthquake. The soil was modelled considering an equivalent visco-elastic behaviour, while the

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structure was modelled assuming both the visco-elastic and visco-inelastic behaviours. The comparison made between the results of the FEM analyses and the observed damage is valuable.

STRUCTURAL ANALYSIS

A change in response to the high-rise structure is studied for the structure of soil structure interaction (SSSI) of groups of adjacent pile supported structures under the seismic excitation is discussed various case studies:

- Considered the group effect supported structures on pile-raft; Groups of two groups of similar structures, three similar structures and groups of three separate structures.
- The impact of variability on the height of the structure is considered to be two-story structures.
- The effect of variability on the shape of structure is considered. For each case, SSSI response compared to traditional fixed base feedback to understand the importance of the SSSI. By commenting on the importance of each practice Sssai this study have been extracted outlined some quantitative conclusions below: Sfsai and fixed base analysis on the free area at the SFI, fixed base analysis.

A SSI soil and response of the structure with the change of the natural period of the foundation of presence system significantly changed.

Soil and caused a pile of repeated dynamic contact Sfsai and SFI compression side as seen for both soil stack and becomes the difference between the soil. The interface is quite different behavior on the heap of stress in terms of analysis of elements. SSSI effects were important when there is a group of similar structures with the same dynamic characteristics. The fall of seismic waves between structure attracts more displacement. In case of a group of variable height structures, consider SSI time reduction in response to the 15-story structure in the 10-storey structure that is not seen in the fixed base system. Variable-sized structures will attract more displacement due to the top-floor low hardness in response, but it is not traditional fixed base case, unlike saw behavior.

PEAK GROUND ACCELERATION (PGA)

PGA has been calculated either by using accelerometers or by attenuation relationships given by Iyengar & Raghukanth (2004). The shortest hypocentral distance is observed for each source but largest past earthquakes close to the source. The following is the attenuation relation that was used to compute PGA-

$$\ln y = c1 + c2(M-6) + c3(M-6)2 - \ln R - c4R + \ln(€) \quad \textbf{(1)}$$

where,

PGA (g), moment magnitude, and hypo-central distance are denoted by y, M, and R, respectively. Because PGA is known to provide essentially as a random variable over time, will be normally distributed with almost zero with an average of ln (€). Table 2 shows the Coefficients for the Southern region. The river fault causes a minimum PGA value of 0.0013g and a maximum PGA value of 0.165g. Typical graph for the analysis taken PGA, PGV & PGD is shown in the Figure 1.

Table 2: Coefficients for the Southern region

Coefficients	c1	c2	c3	c4
Value	1.7816	0.9205	-0.0673	0.0035

STRUCTURAL RESPONSE

When considering SSI, ground speed soil properties, exert too much influence on the foundation of the structure of local site effects and compare the dimensions through the soil (Wolfa& Diks 2004). While considering SSI effects on structural response two main reasons one is

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that soil-structure system is increased by degrees of freedom for the alternative dynamic behaviours and another one is soil-structure system may be dissipated either by radiating waves or by material damping on the soil.

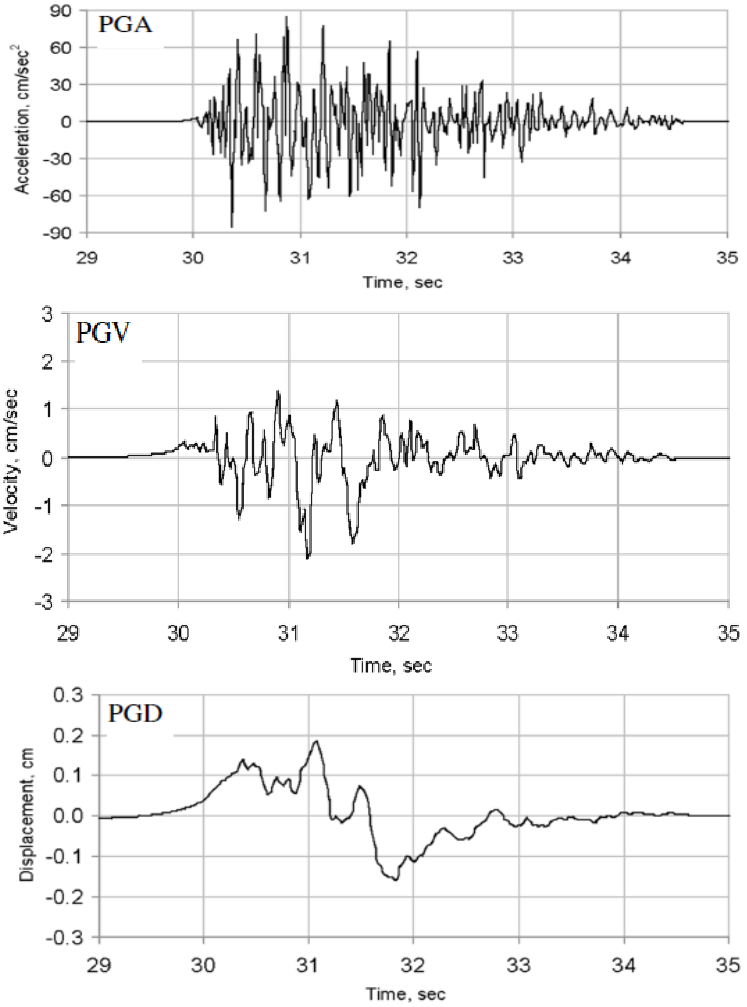

Fig. 1: Typical PGA, PGV and PGD

PGA, the frequency of the most significant factors of the content and duration of earthquakes, is the highest absolute value of ground acceleration, Buildings are subjected to ground motions and dynamic characteristics such as PGA, PGV, PGD, frequency content & duration. To study the behavior of RCC structures under seismic loads These dynamic characteristics play a major rule. The amplitude of the ground motion as well as the softness of the structural stability of the structure of the superstructure, depending on the frequency and duration, It's based on the frequency content, which is the PGA/Pijivi ratio. Three types of land speed records have been established:

- HIGH FREQUENCY CONTENT PGA/PGV > 1.2
- INTERMEDIATE FREQUENCY CONTENT 0.8< PGA/PGV< 1.2
- LOW FREQUENCY CONTENT PGA/PGV < 0.8

Ground acceleration against time for a period of 40 seconds using 0.2 g PGA. The length of following ground motions to see Central and effects of frequency content at high-growth RCC structures has been extended to 0.2 g PGA and 40 seconds. Ground displacement vs time with PGD

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for ground velocity versus time and related ground movements with PGVm for ground acceleration versus time with figure 2 to 3 PGA are shown in statistics.

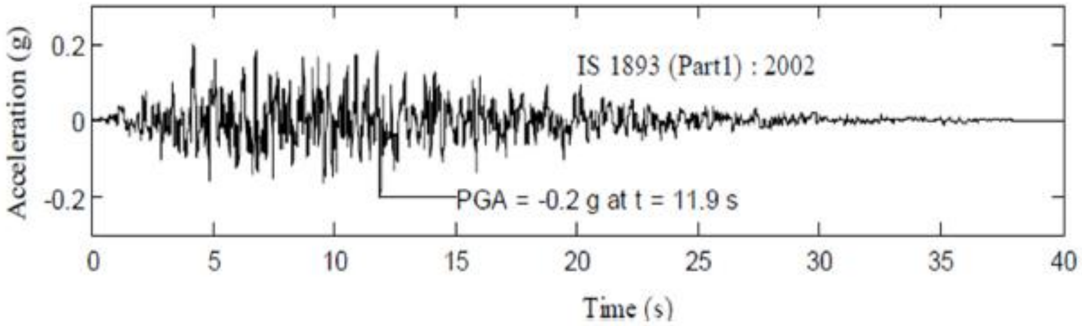

Fig. 2: GMA versus time with PGA scaled to 0.2 g & 40 s duration of IS 1893 (Part1): 2002

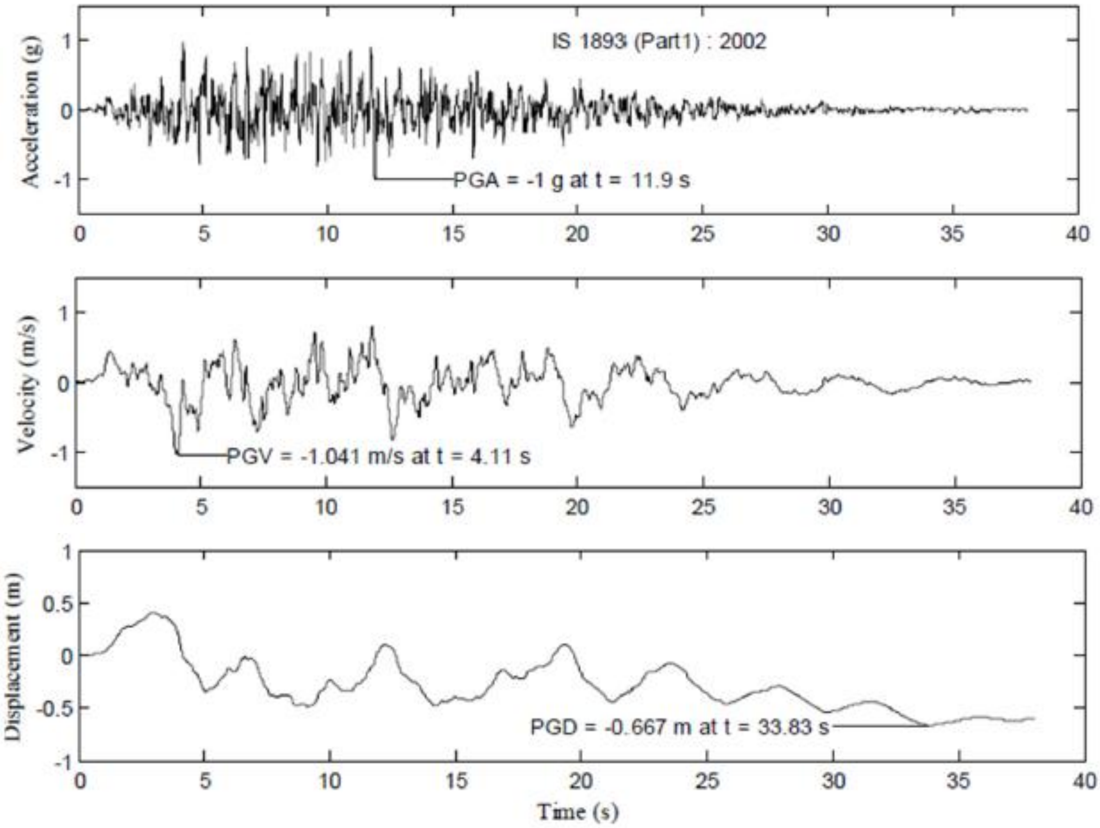

Fig 3: Acceleration, velocity, & displacement of IS 1893 (Part1): 2002 ground motion

PRINCIPLES OF SSI

The effects of SSI are detailed by Wolf (1985). A SDOF is considered for the study, which comprises a structure with mass (m), stiffness (k), and damping coefficient (c) resting on a rigid soil deposit. The natural frequency of fixed base system (ω_0) is based on the mass and stiffness of the structure and it determined in the Equation (2)

$$\omega_0 = \sqrt{\frac{k}{m}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(2)}$$

The equivalent viscous damping ratio (ξ) can be calculated using

$$\xi = \frac{c\omega_0}{2k} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \textbf{(3)}$$

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STRUCTURAL DESIGN OF THE MODELS

Structural design for various types of moment resisting frames is required for seismic designs. For ordinary design, the structural frame can be taken as simple but for seismic design, the frame has to be taken either intermediate (moderately ductile) or difficult (fully ductile) moment resisting structural frame. Considering elastic structural design models, the structural type of model is G + 2 storey frame. It is assumed to intermediate momentresisting structural frames (moderately ductile) with the following data related to AS 1170.4.

STRUCTURAL DUCTILITY FACTOR (μ) = 3.0
PERFORMANCE FACTOR (Sp) = 0.67

ANALYSIS OF SPECTRUM

A spectrum analysis is a dynamic calculation that uses a modal analysis to find out the results like structure displacement and stress. For transient dynamic study of feedback structures, spectrum analysis might be random or compute time-dependent loading conditions. Earthquake loads, wind loads, ocean wave loads, jet engine thrust, and rocket motor vibration are all factors to consider, which is used to calculate the maximum response to the loading position, displacement or strain.

CARTESIAN COORDINATE SYSTEM

Origin of Carteshian coordinate system should be the first stage of the center, which crosses the surface of the building of the center line ground. Z- axis indicates downward half-space. XY plane surface of the ground. Building coordinate planes, X-Z and is symmetrical about the Y-Z. The input ray is used to select the X-Z plane as the input plane. Input angle is measured in the direction of wave propagation in the positive x-axis. In the present study, is input into a seismic original recording coordinate system, which is the control point.

FEM IN STRUCTURAL ANALYSIS - BASIC STEPS

In engineering, there are some basic problems that are not able to be analysed, hence the entire structure can be taken for the analysis. In a practice, more unknowns are infinite. So the unknown parameters are analysed by Finite Element Method (FEM) which reduces more unknowns. A finite element is divided into a number of parts called elements. The material properties and governing equations are taken for analysis. The basic steps are followed for FEM i.e.

- Divide the whole structure into number of elements,
- Stiffness can be evaluated for each element,
- Assemble all the elements at nodes to form a equations for the entire structure,
- Boundary conditions can be introduced,
- Solve the equations involving unknown quantities at each node and
- Calculate the desired quantities at the select elements which are displacements, stress and strain.

FINITE ELEMENT ANALYSIS

In recent years, FEA has grown in importance. FEA may be used to calculate numerical solutions for increasingly sophisticated stress issues. Ray Clough is the first person who introduced a Finite Element procedure. From that time onwards, the mathematical foundations and generalization field problems have been solved in different areas of engineering.

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PLAXIS

A Dutch company developed PLAXIS software based on the uses of FEM for modelling the geotechnical structures. PLAXIS includes two and three dimensional modelling of soil and SSI. It is taken from three main theories deformation, groundwater flow and consolidation based on the FEM code. In addition, an expanded program for the dynamic calculation. Currently working dynamic SSI, Plaxis 2D (version 9) and Plaxis to calculate the 3D Foundation.

MESH GENERATING

Plaxsis has developed an automatic mesh generation Engineers Bureau SEPRA. It makes unstructured mesh for selected structures, either 6-node or 15-node element. Significant elements for the user's convenience, parts create stress and tension gradient without taking a high mesh that time.

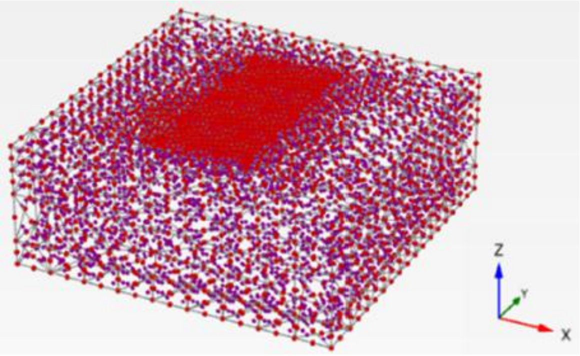

Fig. 4 Mesh generation in various layered soil

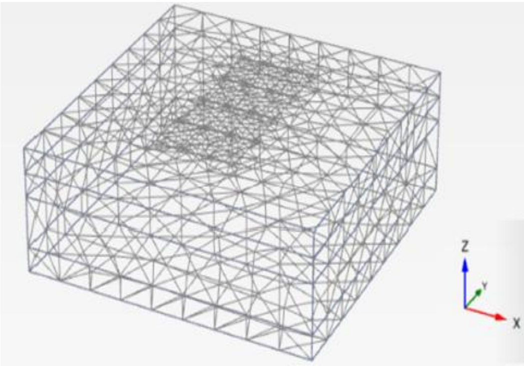

Fig. 5 Nodes in various layered soil

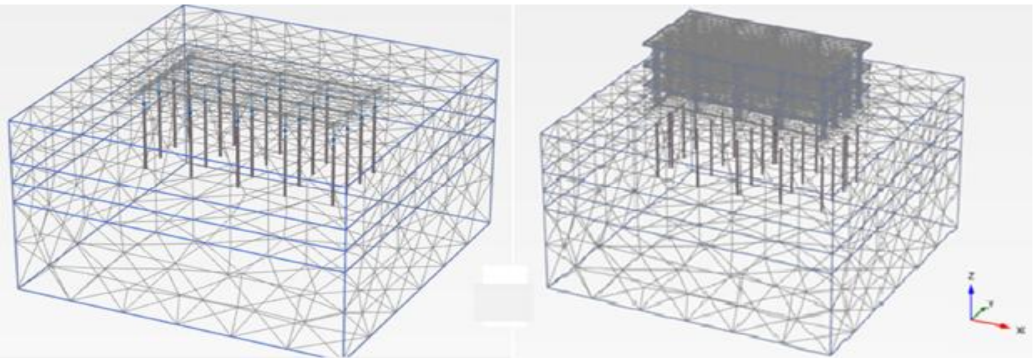

Figure 6 Mesh Generation for Piled-Raft foundation

PLAXIS 3D FOUNDATION

3D Foundation is a FEM software for deformation analysis of SSI. The normal work process in 3DFoundation, it reminds the work process in Plaxis 2D. The load-settlement behaviour of the SSI for isolated, mat, raft and piled raft are illustrated

THE BEHAVIOUR OF THE ISOLATED FOUNDATION FOR THE SSI

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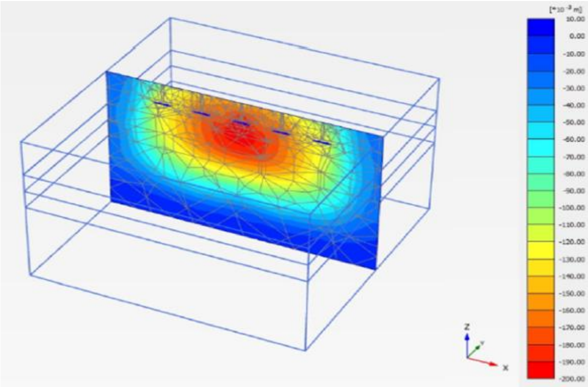
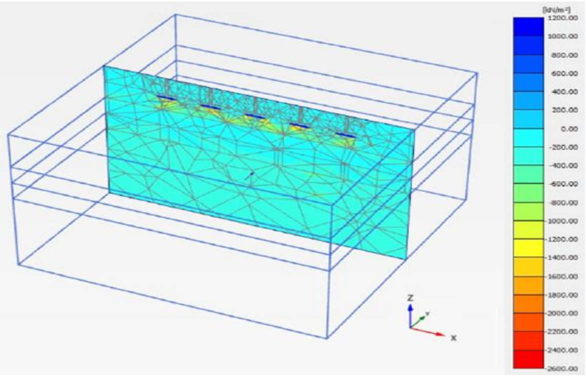
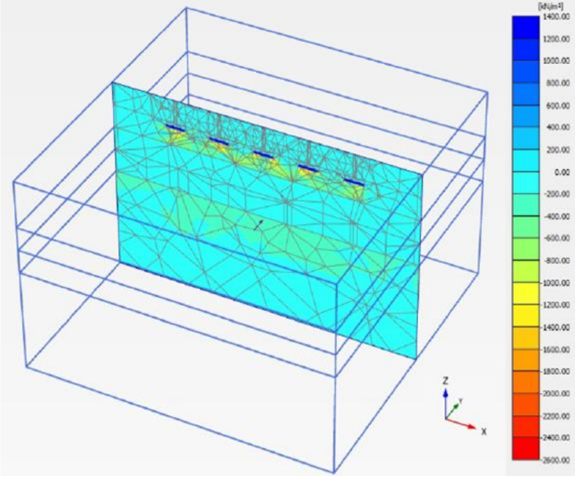


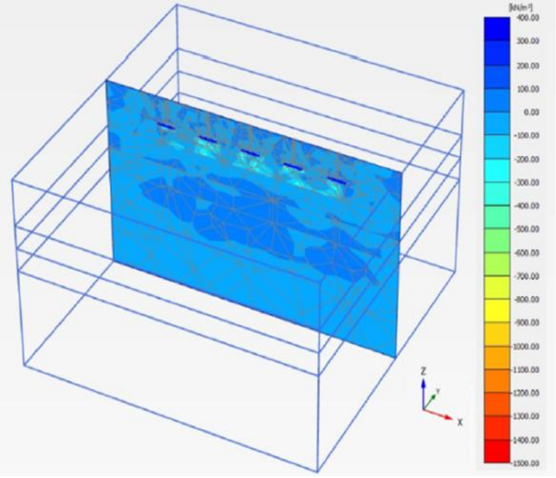
(a) Total displacements



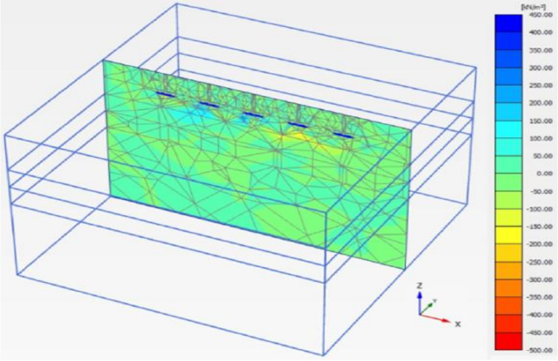
(b) Total Normal Stresses



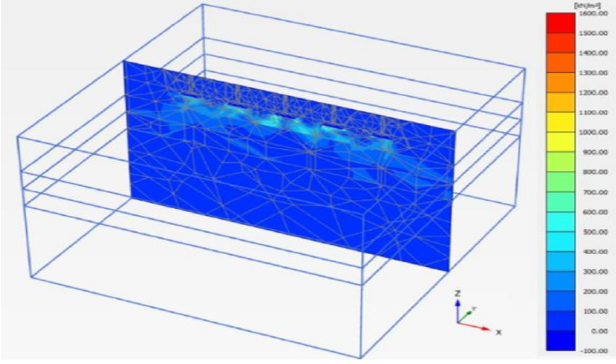
(c) Effective Normal Stress



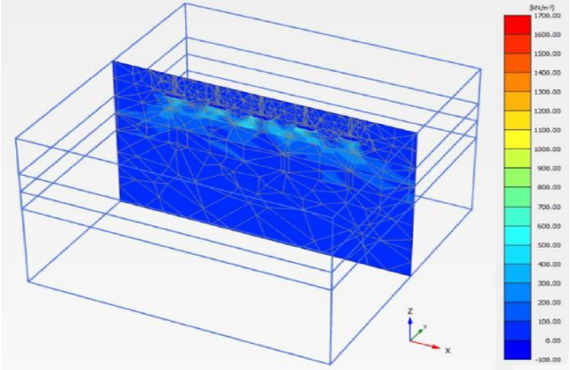
(d) Vertical Shear stress



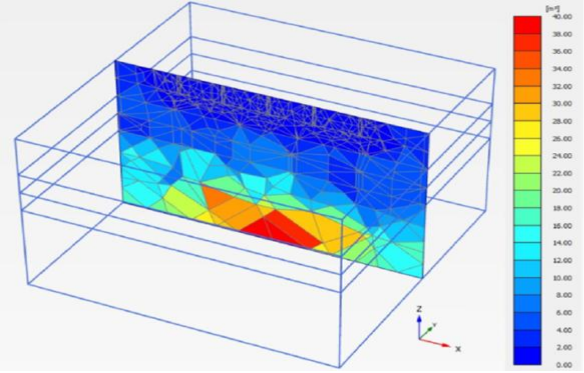
(e) Horizontal shear stress



(f) Maximum shear stress



(g) Mobilized shear strength



(h) Volume

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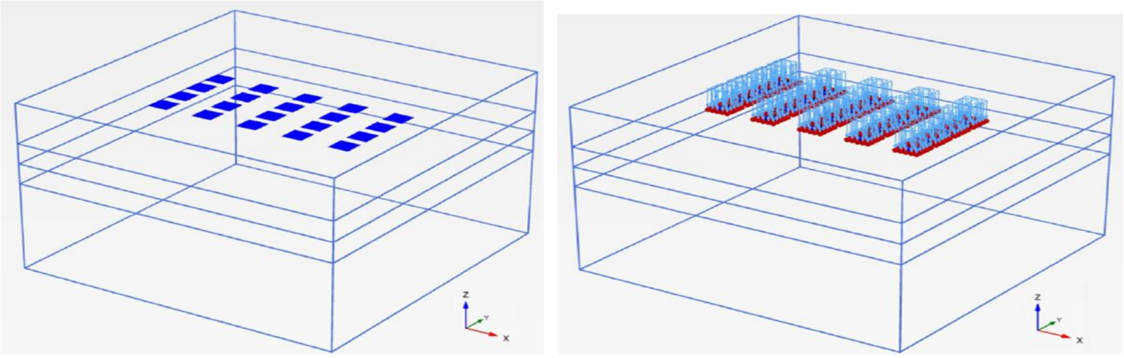


(i) Maximum shear stress **(j) Maximum shear stress load preview**

Figure 7: The behaviour of the Isolated Foundation for the SSI

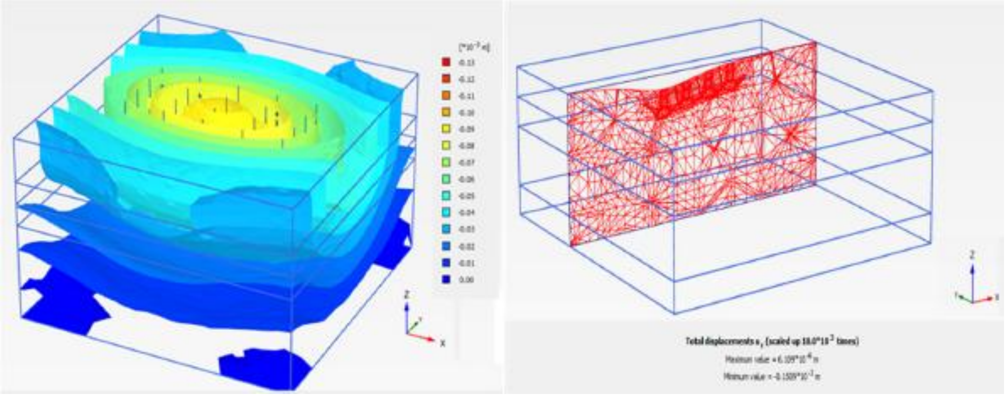
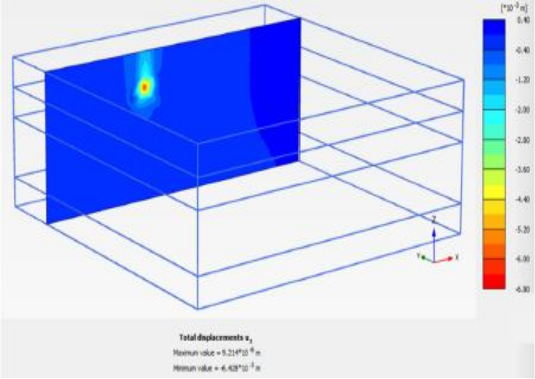


Figure 8: Displacements in various layered soil



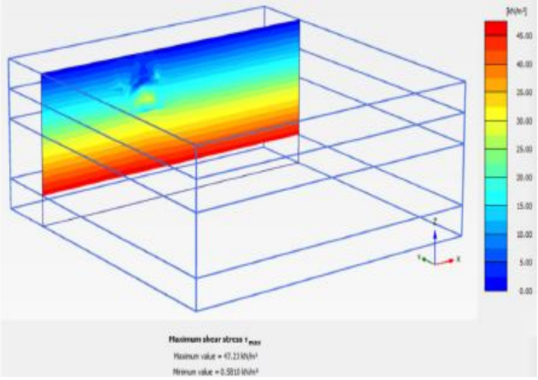


Figure 9: Total displacements in the applying load Figure 10: Maximum shear stress due to bearing capacity

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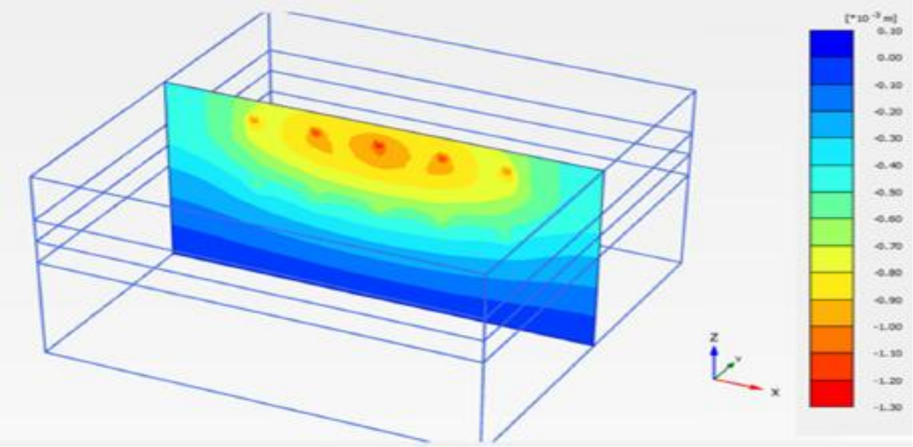

Figure 11 Layered settlement

LOAD SETTLEMENT FOR VARIOUS FOUNDATIONS

The load settlement was plotted between the load and settlement for various foundations the settlement figure as shown in the Figure 12.

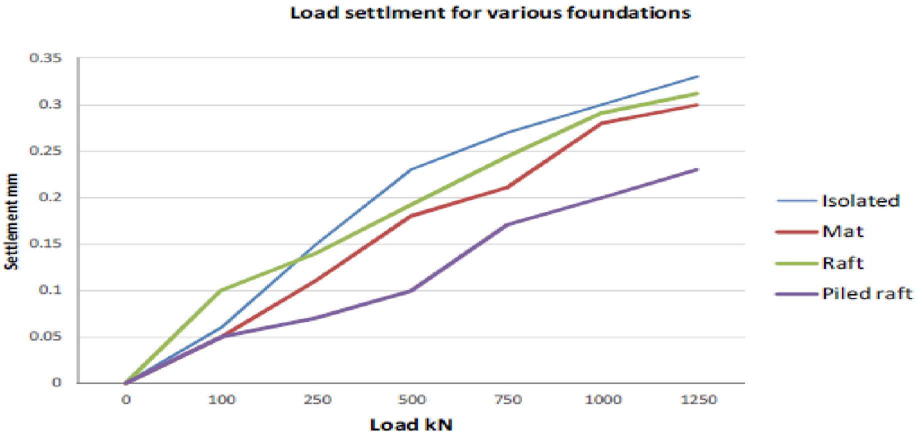

Figure 12: Load settlement with various layered soils

RESULT

At the very initial stage itself the importance of SSI should be evaluated and it can be decided it is suitable or not. The final results are based on the soil data like shear wave velocities in the soil, base mat size embedment and moment of inertia of the structure. For obtaining the good results in SSI, the winkler model can be introduced for foundation stiffness towards the superstructure edges. The influence of SSI on the earthquake response of multi-story structures appears to occur mostly in the basic mode and for a wide range of structures, including tall skyscrapers. The behaviour has been seen for the whole depth of a piled-raft foundation. If the basic mode of the fixed-base structure is roughly at a straight line, the effects of interaction may be minimal for higher modes. Fixing the structure at the ground line with free-field translation and applying free-field movements as input at the base level utilising horizontal foundation springs with their end condition set to the free-field ground motion are frequent SSI approximations.

CONCLUSION

Based on the results of the investigation, the following conclusion is arrived. The objective of the research is performing SSI effects with the data collected from test site as well as

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earthquakes. Theoretical models that describe the effects of SSI exist in the literature review. Correlation is beneficial to the quality of the data it is based on. The objective is to create a database with the highest possible quality and quantity of field data. In assessing the possibility of initiation for layered soils, the connection of seismic field performance with in-situ index testing has shown promising results. The suggested models are verified against field data and the reliability with applied actual circumstances in the field is determined based on the screening of the obtained data results based on information content and reliability of each instance. Piled-raft foundation gives reliability to this type of soil. In the present study, structural analysis methods are rigorously verified with SSI problems. The flexibility of the foundation soil causes SSI, which is a collection of phenomena in the response of soil-foundation structure systems.

For analysing the SSI effect, the finite element approach has proven to be extremely effective. The impact of the interaction coefficients on the response of select structures is calculated. The select ground motion sets based mainly on PGA are used as an intensity measure. The amplification factors of fully saturated, partially saturated and unsaturated conditions soil are computed. Similarly, the effect of SSI under the influence of static and dynamic loads must be assessed depending on the structure's reaction. The total and differential settlements are considerably altered by load redistribution. Settlements are more prevalent in non-linear analysis. The seismic base shear of low-rised building frames sitting on different foundations may be significantly increased as a result of SSI.

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