# SOIL STRUCTURE INTERACTION AND STRUCTURAL RESPONSE USING DYNAMIC TEST SYSTEM

**Mr . Baala Dinesh , M.E.**
Assistant Professor, Dept of Civil Engineering
Adhiyamaan College of Engineering(Autonomous)
Hosur, India

**Keerthan N**
Department of civil Engineering
Adhiyamaan College of Engineering (Autonomous)
Hosur, India

## CHAPTER 1

## INTRODUCTION

### 1.1 General

Reducing the accessibility of real building sites has contributed to an expansion in the usage of smaller areas, in which the bearing limit of the fundamental sediments is exceedingly limited. The conventional strategy would be to get a deep and exclusive base for these weak stores. There is a necessity to create real-world provisions that have made ground improvement a significant exploration area. The settlement of shallow foundations and bearing capacity as a cost-effective foundation system. The foundation beds are laid on the thin soil in low-lying, poorly-drained soil. The resulting improved granulated layer decreases the settlements by providing a better pressure distribution and strengthening the performance to bear the underlying weak soil's load. To support shallow foundations, the use of reinforced soils has received considerable attention during the past 35 years. Various researchers have expanded knowledge of strengthenedsoil's support possible benefits on bearing capacity, shallow base settlement, and failure mechanisms. Several empirical and experimental experiments have been shown to test the bearing ability of strengthened soil footings.

### 1.2 Scope and Objective of Research

The behaviour properties of soil, such as settlement and bearing capacity, could be enhanced by adding a compact over granular bed lying on weak soil. The degree of improvement generated by several embedment depths of a footing resting on soil medium is a subject of investigation in this proposed work, Dynamic loads of broadband excitation are selected 2 in this proposed work to study the influence of it on the interaction between the soil and the footing (SSI) and to determine the performance under static loads and lateral excitations.

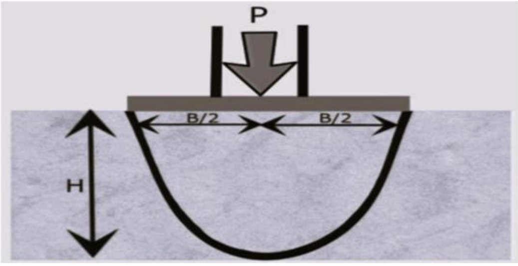



FIG 1.1 LOADED FOOTING

Due to initial settlement, the strain in the Reinforcement is insufficient to assemble the requisite tensile tension. Hence, a technique is needed to increase the soil's load-bearing ability to eliminate the incidence of huge settlements. A promising technique called pre- stressing the reinforcement eliminates the incidence of large settlements and the load- carrying capacity of a soil. Lovias et al. (2010) does a study on the strength of an unclamped clamp, clamped footing, a two-phase finite element analysis, and a laboratory testing model study. Placing reinforcing pre-stress led to a substantial decrease in base settlement and increased carrying capacity. The bearing capacity of the footings is increased by supplying strengthened granulated beds over the poor soil. Instead of a circular base, square or rectangular foundations are widely utilized. Therefore, a study is developed to enhance the bearing capacity of granulated slabs on poor soil and determine the effects of reinforcing pegs. The core objectives of the present research are:

i. Impact of void formation in the GB besides the weak ground.

ii. The association of granular beds with weak soil.

## 1.3 EFFECTS OF SSI

The three main effects of SSI which need to be addressed in any SSI model are categorized as inertial interaction effects, kinematic inertial effects and soil foundation flexibility effects.

**Kinematic Interaction**

The soil displacement caused by the earthquake ground motion is called as the free-field motion. This free field motion is not followed by the foundation that is located on the soil. The kinematic interaction is caused by the inability of the foundation to sink with the free field motion of the ground.

**Inertial Interaction**

The additional deformation caused in the soil due to the transmission of inertial force to the soil by the superstructure is called as the inertial interaction. When the ground shaking is of low level, the kinematic effect of SSI is more prominent. This results inthe lengthening of period and there is increase in the radiation damping. When stronger shaking commences, the radiation damping is limited by the soil modulus degradation in the near field and the soil pile gaping. At this situation, the inertial damping is more prominent. This will hence cause excessive displacements near the ground surface. This will bring damage of the pile foundations. These effects can be related to structural analysis in terms of:

**Foundation stiffness and damping**

As compared to the normal assumption of rigid foundation, the inertial forces (base shear, moment and torsion) generate lateral displacement and rotation at the foundation level. These effects introduce flexibility in the structure and lead to period elongation.

**Foundation deformations**

Flexural, axial and shear deformation of structural foundation elements occur as result of forces and displacements applied by the superstructure and the soil medium. These represent the seismic demand for which foundation component should be designed and they could be significant, especially for flexible foundations such as rafts and piles.

**Variation between foundation input motions and free filled ground motion**

Kinematic effects of SSI represent the change in response of structure when response is obtained using free-field motions and when the presence of structure is considered. It doesn't depend on the mass of the structure and is affected by the geometry and configuration of the structure, the foundation embedment, the composition of incident free-field waves, and the angle of incidence of the waves. This effect is called kinematicinteraction effect as it does not involve any inertial forces.

## 1.4 SOILS-STRUCTURE INTERACTION AND STRUCTURALRESPONCE

Based on conventional theories it has been said that the soil structure interaction has effects that are beneficial for the structural response. Most of the design codes for structures recommend neglecting the effect of SSI in the seismic analysis of the structure. This recommendation is because of the false myth that the SSI brings good response of the structure and hence has chances to increase the safety margins.

More flexible structural design can be obtained if we consider the effects of soil structure interaction. This helps in increasing the natural period of the structure. This provides an improved structure when compared to a corresponding rigid structure.Incorporation of SSI effects on the structural design helps in increasing the damping ratio of the structure. This study is limited or neglected for conservative design procedures.

The SSI analysis is very complicated in nature. The neglection will reduce the complexity in the analysis of the structures. This means that the myth put forward that the SSI effects are good for structures is not true. In fact, SSI can bring detrimental effects to structures. Neglecting SSI effect can bring unsafe design of the superstructure and the substructure.

## 1.5 CONSIDERATION IN SOIL-STRUCTURE INTERACTION EFFECTS

A structure, when analysed by considering its foundation to be rigid, is said to have no soil-structure interaction effects. Now, this case is considered even if the interaction force impacts the foundation. The influence on the soil motion by the interaction forces will depend upon:

- The magnitude of the force
- The flexibility of the soil foundation

The base mat acceleration and the inertia of the structure can be used to estimate the value of interaction forces. The heavier the structure the more is the soil-structure interaction effects for a particular soil site and for a given free-field seismic excitation. Most of the civil structure, whether it is lying on the hard or medium soil does not show any sign of SSI effects.

We can conclude that the soil interaction in earthquake engineering study was mainly developed and applied for these fields of construction industry. Another conditionconsidered the soil-structure interaction effects are the soil flexibility. Softer is the soil, more is the chances for the occurrence of SSI effects.

This is for a given structure and a site that have a free -field seismic More flexible structural design can be obtained if we consider the effects of soil structure interaction. This helps in increasing the natural period of the structure. This provides an improved structure when compared to a corresponding rigid structure.

Incorporation of SSI effects on the structural design helps in increasing the damping ratio of the structure. This study is limited or neglected for conservative design procedures. The SSI analysis is very complicated in nature. The neglection will reduce the complexity in the analysis of the structures. This means that the myth put forward that the SSI effects are good for structures is not true. In fact, SSI can bring detrimental effects to structures. Neglecting SSI effect can bring unsafe design of the superstructure and the sub structure.

### 1.6 DYNAMIC SOIL-STRUCTURE INTERACTION

One of the fundamental problems in dynamic soil-structure interaction is the characterization of the dynamic response of surface foundations resting on a soilmedium under time-dependent loads.

Earthquake ground motion causes soil deformation known as free-field motion. Such ground motions that are not influenced by the presence of structures are called free fieldmotions. When they interact owing to very presence of structure, soil structure vibrationas a process becomes very important.

These interactions have little effects on some systems and larger influences on the response of other system. Stiff or heavy structures resting on relatively soft soil are more prone to such influence. On the other side, for flexible or light structures on stiffsoils soils-structure interaction effects are generally smaller.

Under the influence of such interactions the natural frequency of a soil- structure system shall be lower than the natural frequency of the structure itself. Despite its importance to various soil dynamics and earthquake applications, a clear understanding of the problem has yet to be established owing to the complexity of real soil behaviour and its constitutive modelling, the in-situ and stress-induced heterogeneity in the soil’s modulus, and the three-dimensional nature of the underlying wave propagation phenomenon.

### 1.7 OBJECTIVES

- To study the propagation potential of dynamic waves across the soil medium
- To study the performance of footing subjected to a constant vertical load underthe above conditions

# CHAPTER 2 LITERATURE REVIEW

## 2.1 GENERAL

In this chapter, an elaborative discussion making regarding works done so far in this area as literature review on Soil-Structure Interaction under broad band excitation.

## 2.2 LITERATURE REVIEW

**Effect of soil structure interaction on dynamicbehaviour of buildings**

**A Parvathy Karthika, V Gayathri**

International Research Journal of Engineering and Technology (IRJET) 5 (04), 2522-2525,2018
Soil Structure Interaction (SSI) is the response of soil which influences the motion of the structure or the motion of the structure which alters the response of soil.Soil structure interaction is prominent for heavy structures, especially for high rise buildingslocated on soft soil.

**Analysis of Different Shaped Footing Under Soft Soil Condition: A Review**

**Manawar Ali, Pratiksha Malviya**

As the total load of a building is directly transmitted to the soil beneath footing.Shape offooting plays a vital role in distributing load to the soil, thus shape of footing should be ideal to distribute maximum load to the soil. . Foundations provide support for structures,transferring their load to layers of soil or rock that have sufficient bearing capacity and suitable settlement characteristics.

**Study and analysis of pile foundation supported on sandwich soil strataunder dynamic condition**

**Dr.S. Suresh Babu, M Kathirvel, V Naveen Nayak**

The concept of soil structure interaction was analysed and the settlement on the pilefoundation on sandwich layered soil under dynamic loading. A layer of sand is placed between the soil specimen and the settlement can be found by applying dynamic loading and to retrieve the wave propagation data using the accelerometer and data logger. During the testing, the frequency of the dynamic loading was kept about 5 Hz, 10 Hz, 15 Hz. Based on the observed results the graphical conclusions are obtained regarding the behaviour of the soil.

**Embedded foundation in layered soil under dynamic excitations**

**KP Jaya, A Meher Prasad**

Soil Dynamics and Earthquake Engineering 22 (6),485-498, 2002

The critical step in the substructure approach for the soil–structure interaction (SSI) problem is to determine the impedance functions (dynamic- stiffness coefficients) of thefoundations. In the present study, a computational tool is developed to determine the impedance functions of foundation in layered soil medium. Cone frustums are used to model the foundation soil system. Cone frustums are developed based on wave propagation principles and force-equilibrium approach.

**Madhav & Sharma (1991) [22]**

The author indicated that the applied stress is spread over a greater width by the stifferlayer to the underlying soft soil for a foundation placed on rigid upper layer overlying soft clay. It is assumed that the loading on soft clay is homogeneous over a breadth B and then declines linearly as well as exponential with distances. Madhav and Datye (1993) found the bearing limit for remaining on an undrained soil with an increasing overload. They proposed conditions for the expansion in bearing limit with respect to every one of the three cases.

**Vinod et al. (2009) [42]**

It was concluded that the support for a single layer interwoven coir rope should be adjusted to 0.4 inch. They oversaw a recurrence inquiry and developed an observational

association in order to determine the strength improvement. They observed that theresilience of unbound sand may be increased several times, and by slowly buildingusing twisted coir rope, researchers could reduce the settlement by down to 90%

**Sadoglu et al. (2009) [31]** The author concluded that the strip footing reached theultimate load- bearing capacity. The lower maximum bearing capacity was in good agreement with the Meyerhof analysis. The reinforced case was by and large in greatconcurrence with the standard analysis.

**Madhavi Latha and Somwanshi (2009) [25]**

The author has studied analytically and theoretically, the influence of reinforcement type on the load carrying capacity 11 of a squared balance upon reinforced sand was examined. FLAC 3D was used to do numerical analyses. They found that the type of reinforcement had an impact on load carrying improvement. They claim both planar reinforcement were superior to arbitrarily scattered grid reinforcement. According to thenumerical results, the footing distributes forces to deeper soil layers, reducing deformations beneath the footing.

**Alamshahi and Hataf (2009) [1]**

The author tested a strip footing which is over the soil that rested on a reinforced sand slope. FE program PLAXIS were used to analyze the slope. The parameters studied are grid form, number of reinforcement layers, vertical reinforcement spacing, and reinforcement layer position. They found that anchor grid augments the reinforcement's strength in pull out condtions and it improves bearing cap.

**Chen et al. (2009) [8]**

The author have studied the impacts of a variety of parameters, including reinforcementlayers and modules. They hypothesized that punching shear failure would begin in the reinforced region and progress to the rest of the structure via general shear failure. To determine the load bearing capacity of reinforced crushed lime stone.

**Tafreshi and Dawson (2010)**

The author have performed strip footings supported on reinforced sand beds andplanar reinforcement shapes. The effects of parameters including reinforcement layer count, reinforcement width, and footing depth were examined. Additionally, while increasing the amount of reinforcement layers, reinforcement distance, height, and other parameters enhances loadbearingcapacity, it decreases reinforcing effectiveness.

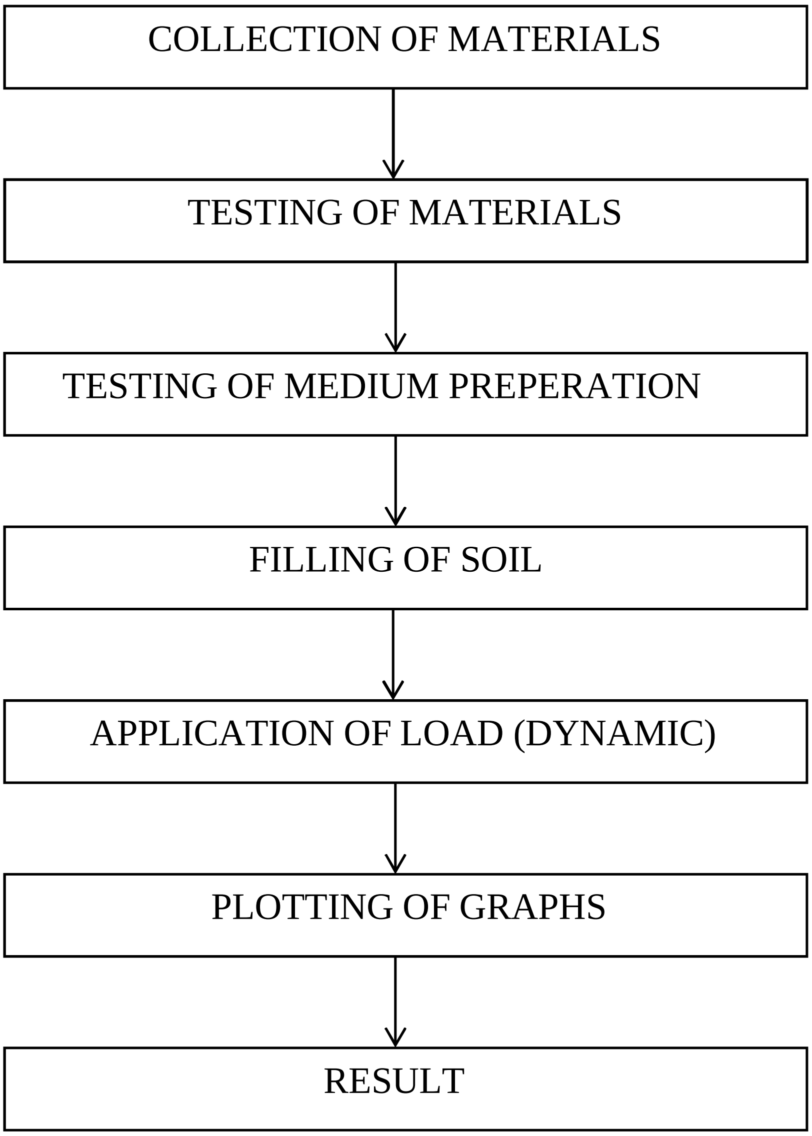
**Deb et al. (2006) [10]** They suggested a prototype model to examine reinforced granular foundation beds. Pasternak's shear layer has been represented as stretched rough elastic membranes. The soft soil is treated as a nonlinear spring sequence. They used the obtained plane strain values in-order to enhance the foundation soil system and loading. Overall soil behaviour was studied. The results are non-dimensional and compare extensible reinforcement to in- extensible reinforcement in terms of reliability.

## 2.3 SUMMARY OF LITERATURE

- The reduced settlements within the loaded area of a footing over soft clay ground can be achieved using low pre-stressing forces in the reinforcement.
- In general, there was larger amplification in the transmission of acceleration in soils of higher relative density and lower pore pressure generation.
- The structural response is greatly influenced by layering and localized hidden soft patch in a dense soil, which can attract shear force 1.5 timesmore than it would have been designed for.
- In terms of bearing capacity improvement, including one layer of reinforcement at the depth of 0.6B was the optimum based on the test results.

# CHAPTER 3

## 3. METHODOLOGY



## CHAPTER 4 MATERIALS AND SPECIFICATIONS

### 4.1 RED SOIL

The red soil used in the current study was collected from Hosur region. The redsoil taken for testing is sieved using 4.75mm IS sieve, since testing was proposed to be conducted using fine grained soil. The moisture content of the soil is varied according to the testing conditions required.

TABLE 1

### 4.2 SOIL PROPERTIES

| **SOIL** | **PROPERTY** |
|---|---|
| **Specific gravity** | **2.64** |
| **Sieve analysis Fineness modulus** | **5.59** |
| **Plastic limit** | **15%** |
| **Liquid limit** | **28%** |

Fig 4. 1 sieve analysis

## 4.3 TESTS CONDUCTED ON SOILSPECIFIC GRAVITY OF SOIL OBSERVATION:

1. Weight of Pyconometer (W1) = 630 g
2. Weight of Pyconometer + Sample (W2) = 1010 g
3. Weight of Pyconometer + Sample Water (W3) = 1630 g
4. Weight of Pyconometer + Water (W4) = 1550 g

**CALCULATION:**

Specific Gravity

= (W2□W1)/ {(W2 □W1) □ (W3□W4)} X 100

= (1010□630)/ {(1010□630)□(1630□1550)}X 100

= 2.64

**RESULT:**

The specific gravity of red soil = 2.64

**SEIVE ANALYSIS**

Weight of Soil Sample taken = 1kg

TABLE 2- SIEVE ANALYSIS

| S. NO | Particle size in mm | Weight retained in grams | % Retained | Cumulative % retained | Cumulative % Finer |
|---|---|---|---|---|---|
| 1 | 4.75mm | 0.30 | 3 | 3 | 97 |
| 2 | 2.36mm | 0.050 | 5 | 8 | 92 |
| 3 | 1.18mm | 0.150 | 15 | 23 | 77 |
| 4 | 600 µ | 0.350 | 35 | 58 | 42 |
| 5 | 425 µ | 0.220 | 22 | 80 | 20 |
| 6 | 300 µ | 0.100 | 10 | 90 | 10 |
| 7 | 150 µ | 0.80 | 08 | 98 | 02 |

**CALCULATION**:

Cumulative % Retained = 559

Fineness Modulus = Sum of cumulative % retained / 100

= 559 / 100

= 5.59 Fineness modulus of soil

= 5.5

**PLASTIC LIMIT**

Weight of soil sample taken = 30 gm

TABLE 3 – PLASTIC LIMIT

| S.NO | PARTICULARS | SAMPLE |
|---|---|---|
| 1 | Weight of empty container ( W1) | 12 |
| 2 | Weight of empty | 16 |

| | | |
|---|---|---|
| | **container+ Wet soil(w2)** | |
| **3** | **Weight of empty container + drysoil(w3)** | **15** |

**CALCULATION:**

Plastic limit = (W2-W3) / (W3-W1) X 100

= 12%

**LIQUID LIMIT OBSERVATION:**
Weight of soil sample taken = 150g

**TABLE 4- LIQUID LIMIT**

| S.NO | Water Content | | No. of Blows |
|---|---|---|---|
| | % | ml | |
| 1 | 40 | 60 | 55 |
| 2 | 36 | 54 | 46 |
| 3 | 32 | 48 | 29 |
| 4 | 25 | 37.5 | 21 |
| 5 | 21 | 31 | 13 |

The Graph is plotted between water content on natural scale and no of blows on logarithm scale to obtain flow curve. The water content corresponding to 25 blows is the liquid limit.
Liquid limit = 28%

## CHAPTER 5

## EXPERIMENTAL SETUP & SAMPLE PREPARATION

### 5.1 EXPERIMENTAL SETUP

#### DYNAMIC TEST SYSTEM

- The system consists of portal frame with cubic box750mm*750mm*750mm with base plate.
- Hydraulic actuator fixing arrangement for applying vertical andhorizontal loads.
- A servo-hydraulic actuator capacity of 10 KN to apply designed staticvertical load.
- Another servo-hydraulic actuator of capacity 5kN to provide dynamic loading. The rated pressure is 215kg/cm2.
- The stroke length that can be applied is ± 50mm. Two LVDT's are installed to measure movements.
- The safe overload capacity is 150%. Application software for computerized setup, operation, data storage, online and offline graphplotting and generation of test reports is achieved in pre-specified formats.

Fig 5.1 DYNAMIC TEST SYSTEM

## 5.2 EXPERIMENTAL PROGRAMME

Well graded soil in the fabricated steel tank is reinforced. Scaled down model footing on the upper contour of soil surface is subjected to axial loading.

Horizontal dynamic push load (broad band excitation) is applied to the soil at the proposed point of contact. Propagation potential of acceleration at variouslevels in soil mass are measured.

## 5.3 SAMPLE PREPARATION

The cubic box of size 750*750*750mm is filled with the red soil which issieved using 4.75 mm IS sieve. The soil is well compacted inside the container. The footing model made of mild steel of size 150*150mm and 5mm thickness is placed on the surface of the soil to serve as a medium totransfer the vertical static load into the soil.

Fig 5.3 sample preperation

## 5.4. LOAD APPLICATION

Initially the static vertical load of 1KN is applied, by means of hydraulic actuator and this load is maintained constant. Then, the horizontal loading is applied, this load is given in the form of strokes whose frequency and the target cycles can be varied. For the above mentioned conditions, the graphs are plotted and the graphsare recorded for the proposed testing with the help of pre-specified plotter setup.

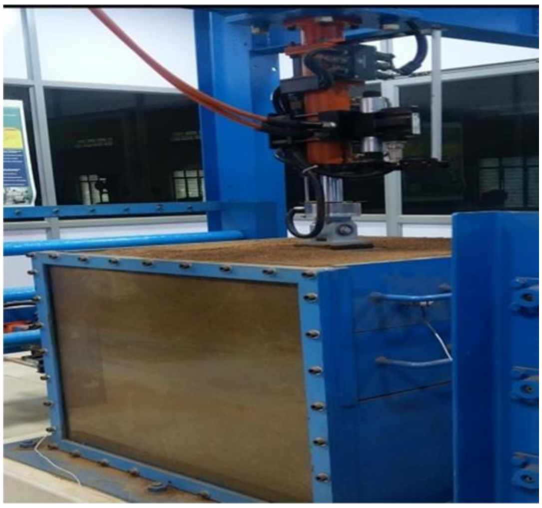


**fig 5.41 Static load**

**Fig 5.42 Dyna**

**mic load**

**ASSUMPTIONS**:

1. Boundary effects of the test chambers are neglected.

2. Down to the depth of influence of stresses, the bearing strata is reasonablyuniform.

**CHAPTER 6 RESULTS AND DISCUSSION**

## 6.1 VERTICAL LOADING

The interaction between soil and foundation of a structure due to static loads acting on the structure may be defined as "static soil-structure interaction". It is common practice to omit the word "static", hence the term "soil-structure interaction" or SSI may be used. he primary difficulty in soil-structure interactionproblem lies in the determination of the contact pressure between the foundation and the soil. Conventional foundation design may overcome this difficulty by adopting some arbitrary simplification such as assuming contact pressure to be linear. While such assumptions may be considered satisfactory for preliminary studies or unimportant foundation elements, they should not be used for the analysisof important structures. Description of the condition of the interface between soil and foundation presents a difficult task. Most structural foundations will exhibit some frictional characteristics at the interface. On the other hand, the frictional forces will also have limiting values due to finite strength of the soil. In addition, factors such as pore water pressure, nature of loads on the foundation, foundation flexibility and time-dependent effects may influence the condition at the interface. It may therefore be prudent to consider the two extreme cases of interface behavior ranging from the completely smooth (frictionless) to the completely adhesive (friction) case. The assumption of smooth contact considerably simplifies the analysis of the interaction problem. In general, the effectof adhesion or friction is to reduce the settlement of a foundation

**Test parameters:**

| | |
|---|---|
| Frequency | : 10.0Hz |
| Amplitude | : 1 KN |

## 6.2 HORIZONTAL STROKE

The interaction between soil and foundation of a structure due to dynamic acting on the structure or due to incident seismic waves (propagating through the supporting soil) may be defined as dynamic soil- structure interaction (DSSI). The importance of considering DSSI effect is briefly discussed. For ease of discussion, hereafter in this chapter, SSI willbe used to represent both static and dynamic loading cases. The dynamic characteristics of a structure resting on flexible soil are different when compared to the same structure resting on a rigid support. The flexibility of soil results in longer fundamental period of the structure. Also part of the vibrational energy of the flexibly supported structure is dissipated into the supporting and surrounding soil by radiation of waves as well as by hysteretic action of soil. Considering the case of propagating seismic waves through the soil, the presence of the relatively rigid foundation may scatter the incident seismic wave therebyproducing a base motion different from the free-field motion.

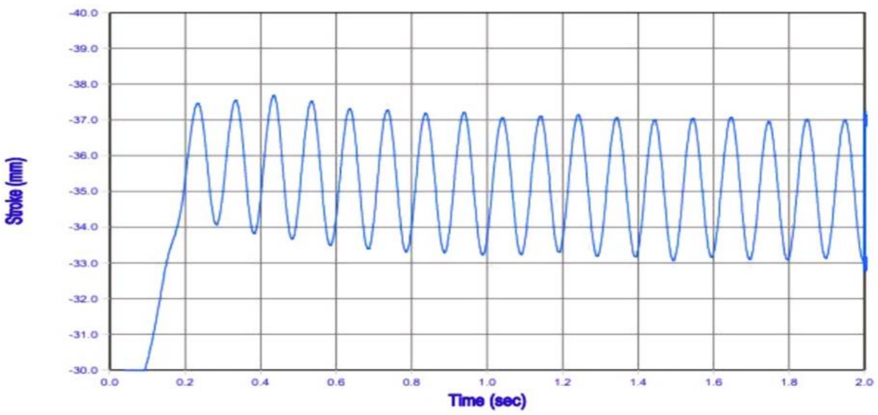
**Test parameters:**

Control priority : Stroke Wave form : Sinusoidal
Frequency : 10.0Hz

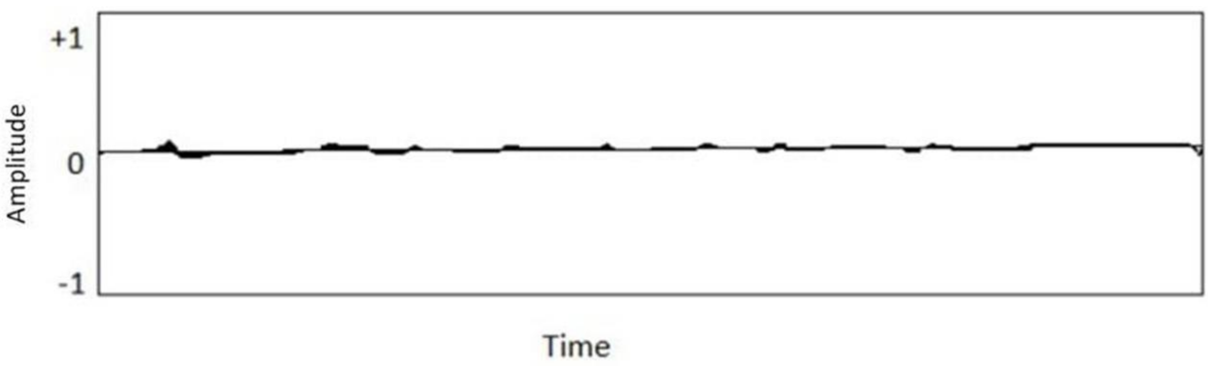
Stroke : 10 mm (peak to peak)

No. of cycles 500

## 6.6 GRAPHS




Vibration observed at the location of stratum




Vibration obtained at the exterior of the soil stratum

**CHAPTER 7 CONCLUSION**

- This project deals with the study of propagation potential of dynamic waves across the soil medium. The dynamic waves propagating through the medium remains uniform for a particular time period and raises gradually until the applied load has been released. There has been slight variation in their amplitudes at a particular frequency.

- The stability of the foundation has been assessed.

**CHAPTER 8**

**REFERENCES**

1. Freddie Theland (2020), "Prediction and experimental validation ofdynamic soil-structure interaction of an end-bearing pile foundation insoft clay", Stockholm, ISBN 978-91-7873-796-3.

2..Uma Maheswari R, Boominathan A and Dodagoudar G.R (2010), "Development Of Empirical Correlation Between Shear Wave Velocity And Standard Penetration Resistance In Soils Of Chennai City", The 14th World Conference on Earthquake Engineering.

3. Deepashree R , S Kavitha, Mamatha P G and Vishal B V (2020), "Evaluation of Effects of Soil-Structure Interaction on a multi-story RC building" Journal of Physics: Conference Series, doi:10.1088/1742-6596/1706/1/012136

4. Julio A. Garcia 2008, "Soil Structure Interaction in the Analysis and Seismic Design of Reinforced Concrete Frame Buildings", The 14th World Conference on Earthquake Engineering

5. Abhijeet Swain, Priyanka Ghosh (2016), "Experimental study on dynamic interference effect of two closely spaced machine foundations",Canadian Geotechnical Journal, Vol 53, No 2

6.. Al-Hussaini, T.M. and Iqbal, A. (1998) SSI effects on seismic response on tall buildings on mat foundations, Proc. 12 Engineering Mechanics Conferenc (CD-ROM), H. Murakami and J.E. Luco (Editors), 466-469 [This paper present numerical study on effects of dynamic soil-structure interaction on seismic forces on tall buildings on mat foundations]

7 .Celebi, M. and Crouse, C.B. (2001) Recommendations for soil structure interaction (SSI) instrumentation, COSMOS Workshop on structural instrumentation, Emeryville, Ca. [This workshop proceedings recommendations and current status of SSI experiment]

8. Clouteau D., Ishizawa, O.and Mezher, N. (2002). Seismic wave propagation in a random city, 7th National Conf. on Earthquake Eng., Boston. [This paper presents results from 3D boundary-element method computations to characterize site-city interaction effects]

9. Ibrahim Oz, Sevket Murat Senel, Mehmet Palanci and Ali Kalkan (2020),"Effect of Soil-Structure Interaction on the Seismic Response of Existing Low and Mid-Rise RC Buildings", Applied Science, 10, 83