Development of Technology to Replicate Soil System-Structure Interaction Under Broad Band Excitations

*M. ASMITHA, #DR.S. SURESHBABU

*Post Graduate student, #Professor and Head of the Department, Department of Civil Engineering, Adhiyamaan College of Engineering, Hosur, Tamil Nadu, India.

*asmithamoorthi18@gmail.com, #sunisurp@gmail.com

***Abstract*— This paper presents dynamic response characteristics of footings resting on geosynthetic reinforced soil. The Soil-Structure Interaction effect is bit complicated, the dynamic forces adds much more complications. The effort on evaluating the effect of soil-structure interaction has been continuing for a few decades. In this study, the dynamic behavior of structures considering the soil-structure interaction effect is presented. Several parameters including depth of geotextile layer from the basement of the footing, degree of prestressing and the amplitude of dynamic loads are selected in this papers, to study the influence of it on the interaction between the soil and the footing (SSI) and to determine the performance under static vertical loads and lateral excitations. The main aim of the current study is to assess the dynamic behavior of soil reinforced with prestressed geosynthetics in promoting stability of the structure taking advantage of their reinforcing effects. The main conclusions are highlighted from the experiments conducted.**

Keywords: Geosynthetic, Dynamic load, lateral excitations, prestressing, Soil-Structure Interaction, static vertical loads.

I. INTRODUCTION

Soil-structure interaction analysis evaluates the collective response of these systems to a specified ground motion. The terms Soil-Structure Interaction (SSI) and Soil-Foundation Structure Interaction (SFSI) are both used to represent the analysis of building structures. Problems associated with the practical applications of SSI for building structures are rooted in a poor understanding of fundamental SSI principles. Once the decision to implement SSI has been made, a basic level of understanding of the physical phenomenon and a practical analysis methodology for simulating its effects are needed.

Considerable research has been carried out using small-scale footing models placed on both reinforced and unreinforced foundation soils. Of note are the reported research of **Jia-QuanWanga[3] et al (2018),** presented the settlement and dynamic response characteristics of shallow square footings on geogrid-reinforced sand under cyclic loading. It is found that fracture of geogrid could occur under cyclic loading if the reinforcement is too shallow, i.e. for the cases with the first layer of reinforcement at 0.3B depth.

S. Saha Roy and K. Deb[10] (2017) conducted model plate load tests of rigid rectangular footings observed that the load-spread angle in the lengthways direction of a footing is smaller than that in the width ways direction, and it is more pronounced in the case of reinforced soil compared to unreinforced soil.

B. Durgaprasad[2] et al (2016), carried out experimental studies to obtain the load-settlement response of a model square footing resting on unreinforced and reinforced granular beds and found the optimum depth of reinforcement for the case of aggregate layer overlying sand layer decreased to 0.30 times the width of the footing from 0.45 times the width of the footing for sand only case.

R.Sahu[11] et al (2016), conducted a number of laboratory model bearing capacity tests with rectangular surface foundations supported by multi-layered geogrid and subjected to eccentric loading and found that rigid soil block is formed under the foundation and this block behaves as if it were an embedded foundation. This is generally referred to as the ‘deep foundation mechanism.

Murad Abu-Farsakh[7]et al (2013), investigated the behavior of geosynthetic-reinforced sandy soil foundations and to study the effect of different parameters contributing to their performance using laboratory model tests. It is inferred that the inclusion of reinforcement can redistribute the applied footing load to a more uniform pattern, hence reducing the stress concentration, which will result reduced settlement.

A. F. Zidan[13] (2012), investigated the behavior of circular footings over reinforced sand under static and dynamic

DOI : 10.35291/2454-9150.2020.0217

loading and concluded that the footing settlement varies linearly with the value of amplitude of repeated loading. For reinforced system (N>2) the large portion of the plastic settlement is achieved in the first few cycles.

Julie Lovisa[4] et al (2010), concluded that addition of prestress to the geotextile reinforcement results in significant improvement to the settlement response and the load-bearing capacity of the foundation.

S.N. Moghaddas Tafreshi & A.R. Dawson[8](2010), this paper describes a series of laboratory model tests performed on strip footings supported on 3D and planar geotextile-reinforced sand beds under a combination of static and repeated loads. They concluded that 3D geotextile reinforcement system behaves more effectively than planar reinforcement as a retardant for the effects of dynamic loading. Thus, a specific improvement in footing settlement can be achieved using a lesser quantity of 3D geotextile material compared to planar geotextile.

II. MATERIALS AND SPECIFICATIONS

RED SOIL

The red soil used in the current study was collected from Hosur region. The red soil 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.

SOIL	PROPERTY
Specific gravity	2.64
Sieve analysis Cumulative mass retained	27gm
Plastic limit	11
Liquid limit	27.29
Optimum Moisture Content(OMC)	12%
Maximum dry density	1.78g/cc

Fig 1- sieving of red soil

GEOTEXTILE

The geotextile used for testing is Non-woven geotextile made of raw material polypropylene with a durability of 2weeks from the period of installation. The application standard of geotextile is EN 15381:2008.

Fig 2- non oven geotextile

GEOTEXTILE	PROPERTIES
Weight	150g/m^3
Thickness	1.2mm
Tensile strength	6kN/m
Elongation	55%
Static puncture (CBR test)	1500N
Dynamic penetration resistance	25mm
Alkaline resistance	>50% of residual strength

III. EXPERIMENTAL SETUP

DYNAMIC TEST SYSTEM

The system consists of portal frame with cubic box 750mm*750mm*750mm with base plate and hydraulic actuator fixing arrangement for applying vertical and horizontal loads. A servo-hydraulic actuator capacity of 10 KN is provided to apply designed static vertical load. Another servo-hydraulic actuator of capacity 5kN is to be operated to provide dynamic loading while vertical load has been applied, the type of actuator is double ended, double acting. The rated pressure is 215kg/cm^2. The stroke length that can be applied is ± 50mm.

Two LVDT’s are installed to measure movements which it can convert into corresponding electrical signals. The safe overload capacity is 150%. Application software for computerized setup, operation, data storage, online and offline graph plotting and generation of test reports is achieved in pre-specified formats. Hydraulic jack for pulling geotextile of capacity 3kN is provided to induce prestressing in geotextile. Universal load cell of capacity 500kg with load indicator for tension measurement system using 4no’s of accelerometers and data acquisition system with lab top is provided.

Fig 3- experimental setup

IV. SAMPLE PREPARATION

The cubic box of size 750*750*750mm is filled with the red soil which is sieved using 4.75 mm IS sieve. The soil is well compacted inside the container. The geotextile to be used is placed at middle height of the cubic box and is filled with the help of anchoring setup provided in the frame. 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 to transfer the vertical static load into the soil. Prestressing of geotextile is achieved by means of hydraulic jack provided.

DOI : 10.35291/2454-9150.2020.0217

The dynamic load is applied by means of servo-hydraulic actuator whose intensity can be varied up to 5KN. The horizontal load is given in the form of stroke to induce dynamic motion in the soil. The graphs are recorded for the proposed testing with the help of pre-specified plotter setup.

V.METHODOLOGY

Initially the static vertical load of 5KN is applied, with a prestressing force of 2KN given to the geotextile 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.

ASSUMPTIONS

1. Boundary effects of the test chambers are neglected

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

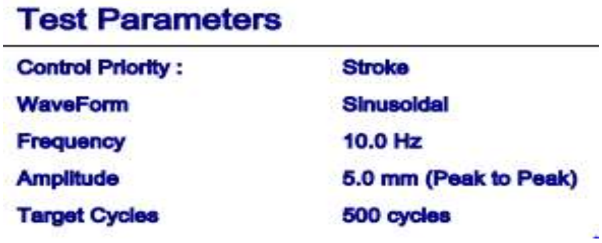
Fig 4- hydraulic jack for pulling geotextile

Fig 5- setup for applying dynamic load on the walls of the test chamber.

VI. RESULTS

GRAPH OBTAINED FOR VERTICAL LOADING

Load intensity=5KN
Prestressing force=1KN



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	10.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	500 cycles

Fig 6 test parameter for 500 cycles(vertical load)

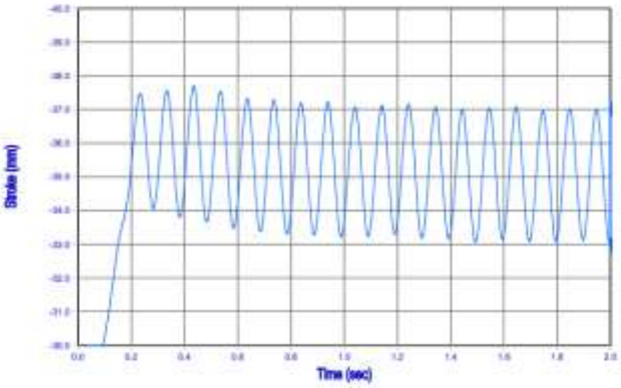


Fig 7 stroke vs time graph for 10 Hz frequency & 500 cycles(vertical load)

The prestressing force given to the geotextile during both horizontal and vertical loading is of 1KN intensity given by means of hydraulic jack.

GRAPHS OBTAINED FOR DIFFERENT INTENSITIES OF HORIZONTAL LOADS.

CASE 1- For a target cycle of 500, the input frequency is varied from 5 Hz to 20Hz with 5Hz increments.

a) Test parameters

Control priority= stroke

Frequency=5Hz

Waveform= sinusoidal

Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	5.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	500 cycles
Remarks	500cy 5hz

Fig 8 test parameter 1 for 500 cycles

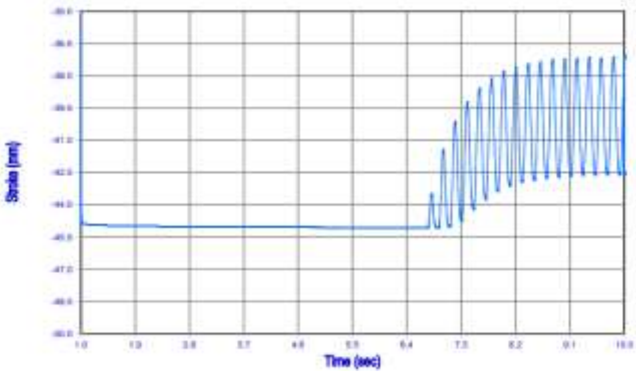


Fig 9 stroke vs time graph for 5 Hz frequency & 500 cycles

Graph plotted for time axis range from 1 second to 10 seconds. The dynamics waves are found to be uniform upto a particular time interval of upto 7 secs and then increases gradually.

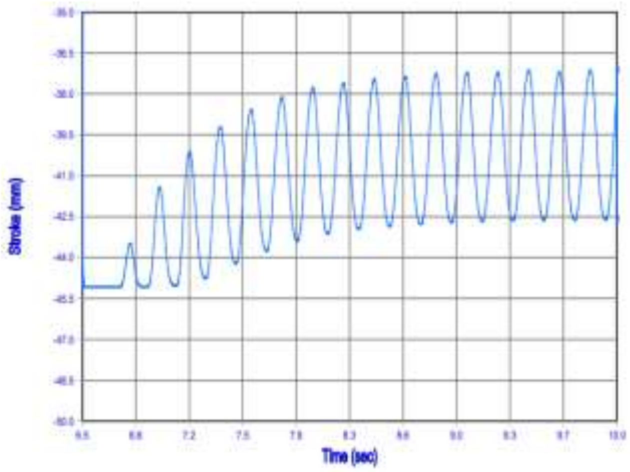
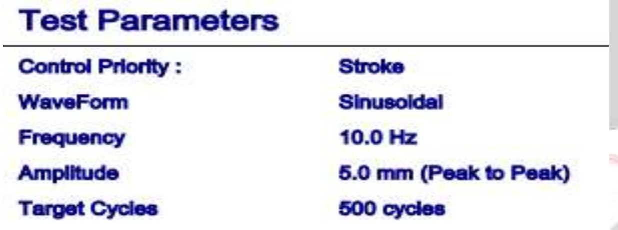


Fig 10 stroke vs time graph for 5 Hz frequency & 500 cycles(magnified)

Figure 5 represents magnified view of figure 4 inorder to show the variations in amplitudes of the dynamic waves.

b) Frequency = 10Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	10.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	500 cycles

Fig 11 test parameter 2 for 500 cycles

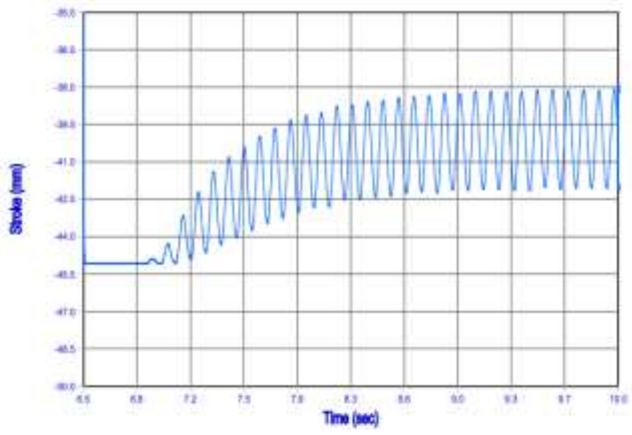
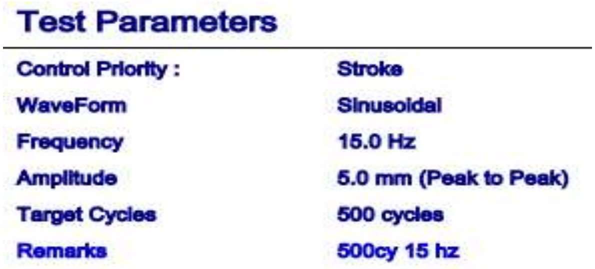


Fig 12 stroke vs time graph for 10 Hz frequency & 500 cycles

Figure 7 – the time interval has been varied from 6.5 secs to 10 secs, which means that upto a time period of 6.5 secs the wave propagation is uniform for a particular stroke and then it increases gradually.

Magnification is done to show the clear variation in the amplitudes.

c) Frequency=15 Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	15.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	500 cycles
Remarks	500cy 15 hz

Fig 13 test parameter 3 for 500 cycles

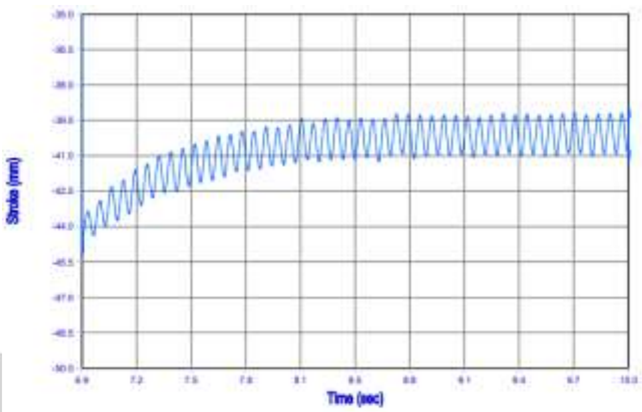
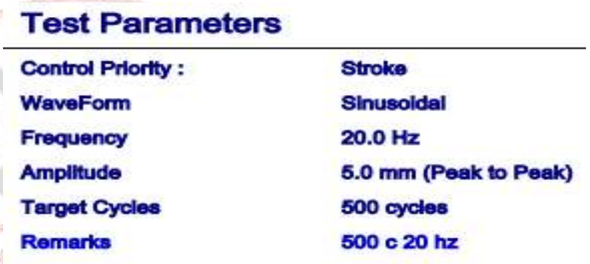


Fig 14 stroke vs time graph for 10 Hz frequency & 500 cycle5

d) Frequency = 20Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	20.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	500 cycles
Remarks	500 c 20 hz

Fig 15 test parameter 4 for 500 cycles

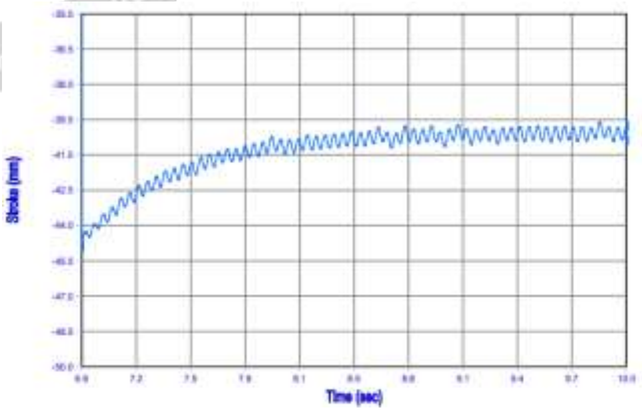


Fig 16 stroke vs time graph for 20 Hz frequency & 500 cycles

It is found that with the increase in input frequency, the intensity of waves through the medium increases tremendously for the same target cycle.

CASE 2- For a target cycle of 750, the input frequency is varied from 5 Hz to 20Hz with 5Hz increments.

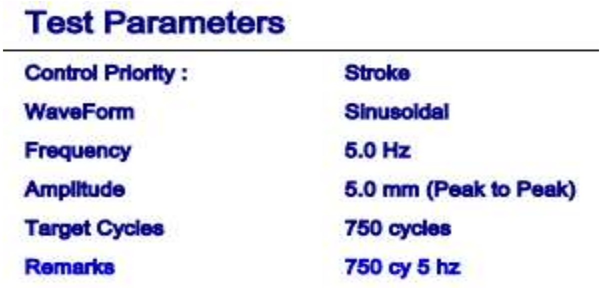
e) Test parameters

Control priority= stroke

DOI : 10.35291/2454-9150.2020.0217

Waveform=sinusoidal

Frequency=5Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	5.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	750 cycles
Remarks	750 cy 5 hz

Fig 17 test parameter 1 for 750 cycles

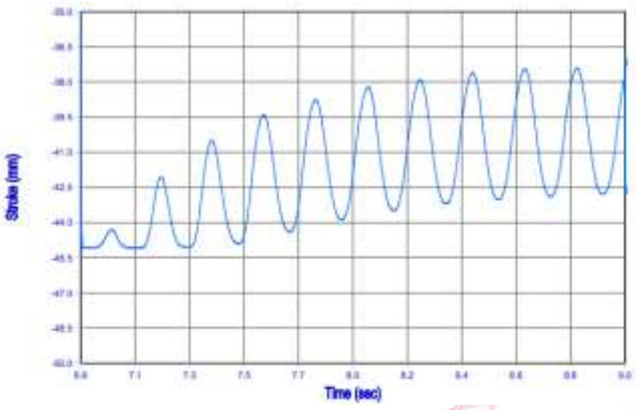
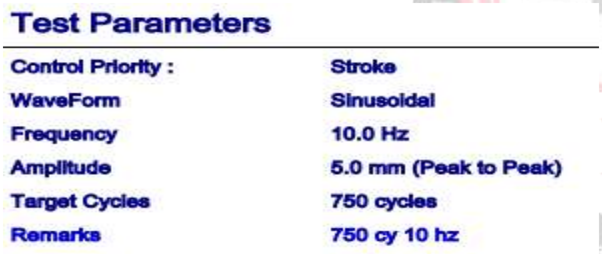


Fig 18 stroke vs time graph for 5 Hz frequency & 750 cycles

f) Frequency=10 Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	10.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	750 cycles
Remarks	750 cy 10 hz

Fig 19 test parameter 2 for 750 cycles

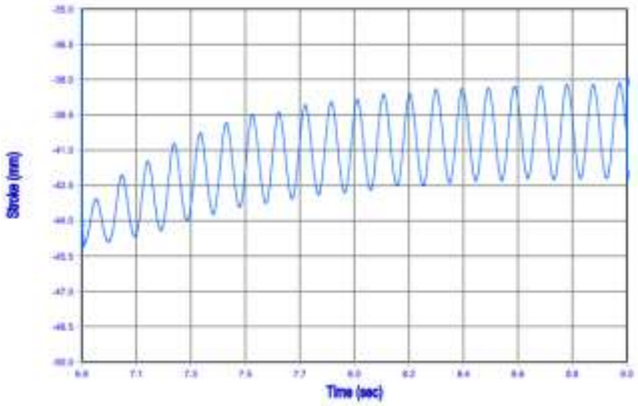
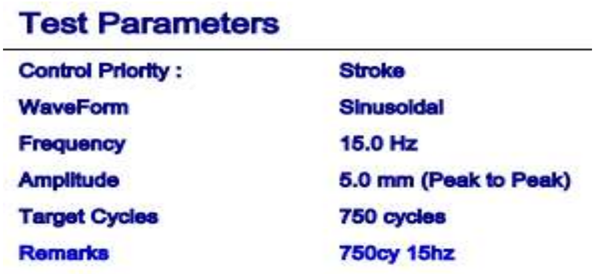


Fig 20 stroke vs time graph for 10 Hz frequency & 750 cycles

g) Frequency=15 Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	15.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	750 cycles
Remarks	750cy 15hz

Fig 21 test parameter 3 for 750 cycles

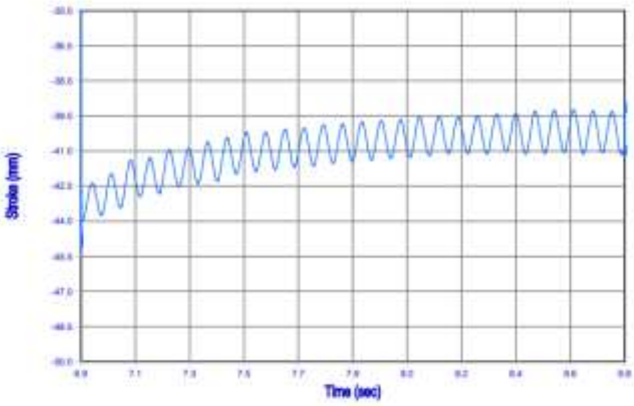
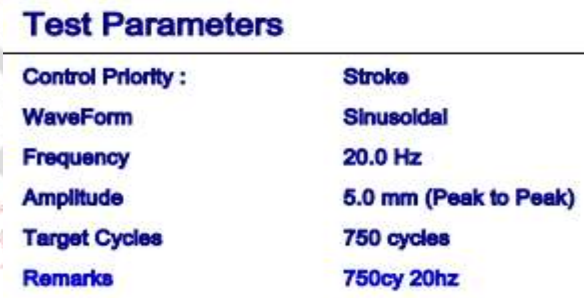


Fig 22 stroke vs time graph for 15 Hz frequency & 750 cycles

h) Frequency=20 Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	20.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	750 cycles
Remarks	750cy 20hz

Fig 23 test parameter 4 for 750 cycles

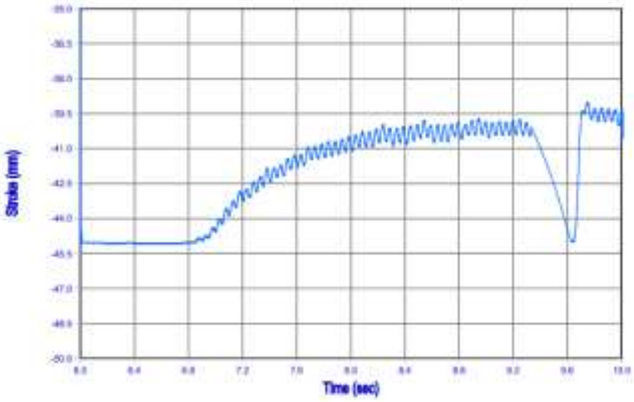


Fig 24 stroke vs time graph for 20 Hz frequency & 750 cycles

For the same number of target cycles increase in frequency enhances the dynamicity of the test medium. From the figure 19, for higher frequencies it is found that the dynamic waves increases more or less linearly from a time period of 6.8 to 9.3 seconds followed by being uniform for a time period of 1 to 6.8 seconds. After which there is a

DOI : 10.35291/2454-9150.2020.0217

sudden fall and rise in the waves. Thus, at this stage permanent onset of structural failures occurs during sesmicity where before that shaking effect is felt with uniform wave propagations, the increase in time period results in structural failures like cracking and spalling of structural members.

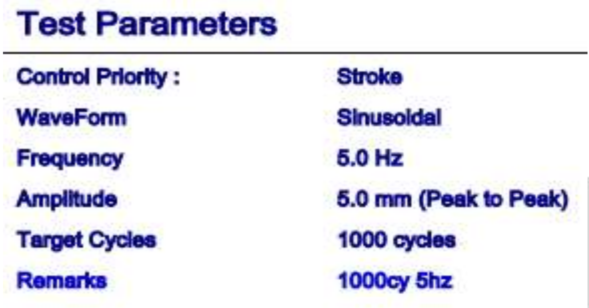
CASE 3- For a target cycle of 1000, the input frequency is varied from 5 Hz to 20Hz with 5Hz increments.

i) Test parameters

Control priority= stroke

Waveform=sinusoidal

Frequency=5Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	5.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	1000 cycles
Remarks	1000cy 5hz

Fig 25 test parameter 1 for 1000 cycles

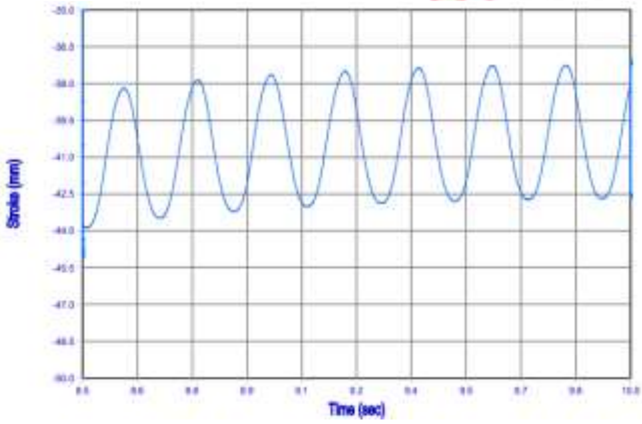
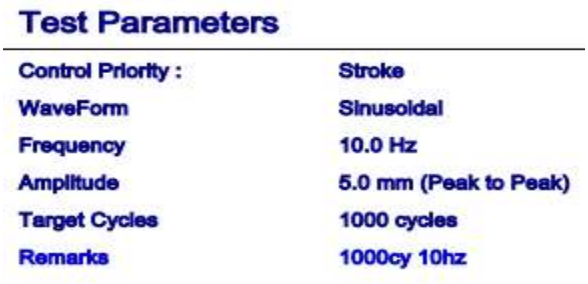


Fig 26 stroke vs time graph for 5 Hz frequency & 1000 cycles

j) Frequency=10 Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	10.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	1000 cycles
Remarks	1000cy 10hz

Fig 27 test parameter 2 for 1000 cycles

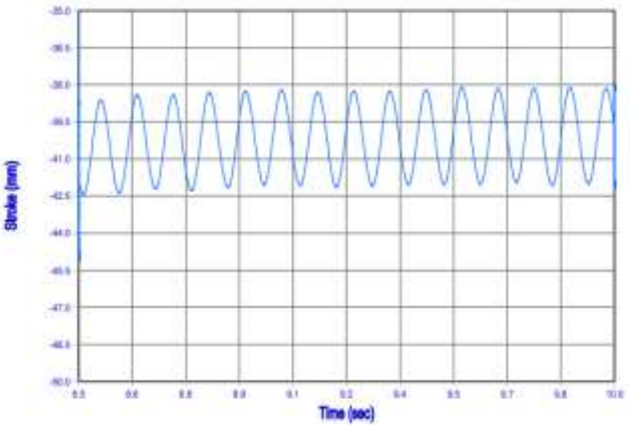
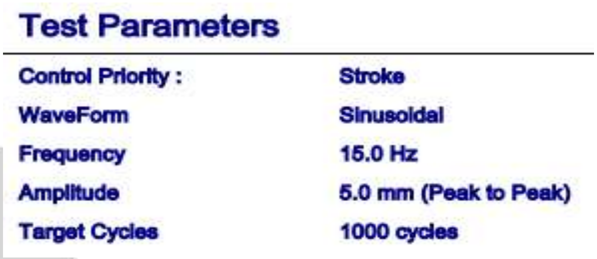


Fig 28 stroke vs time graph for 10 Hz frequency & 1000 cycle1

k) Frequency=15 Hz



Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	15.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	1000 cycles

Fig 29 test parameter 3 for 1000 cycles

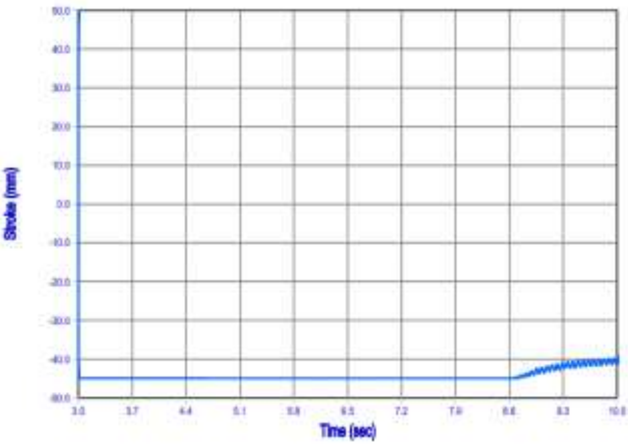


Fig 30 stroke vs time graph for 15 Hz frequency & 1000 cycles

l) Frequency=20 Hz

Test Parameters

Control Priority :	Stroke
WaveForm	Sinusoidal
Frequency	20.0 Hz
Amplitude	5.0 mm (Peak to Peak)
Target Cycles	1000 cycles
Remarks	20hz 1000 cyc

Fig 31 test parameter 4 for 1000 cycles

DOI : 10.35291/2454-9150.2020.0217

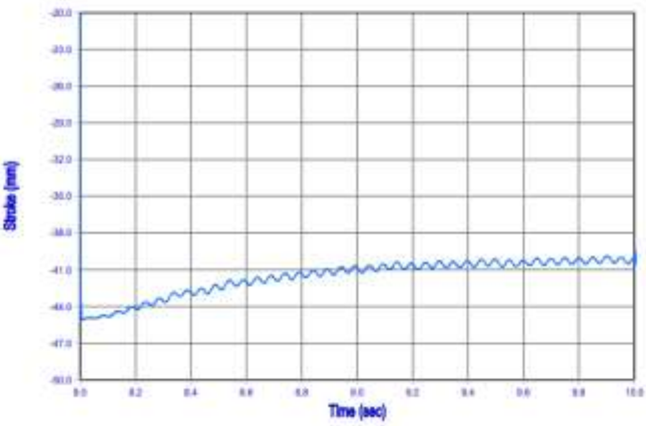


Fig 32 stroke vs time graph for 20 Hz frequency & 1000 cycles

The number of cycles when increased to 1000 cycles the waves are uniform upto a time of less than 8 secs for a particular stroke value. Where the dynamic waves starts propagating at a time of more than 8 secs which is prolonged compared to the above 2 cases.

Note: The axis reference values has been snipped to the required values in order to show the variations in amplitudes clearly.

VII. PERFORMANCE ANALYSIS

The analysis is made keeping the vertical static load constant and gradually increasing the magnitude of dynamic load, this is because for any structure the load from the structure to the foundation remains much or less uniform with respect to time. From the stroke vs time graphs plotted for varying test parameters, it is found that the dynamic waves propagating through the medium remains uniform for a paticular time period and raises gradually until the applied load has been released(as in Fig 4). However there has been slight variation in their amplitudes at a particular frequency. With the increase in the frequencies, the number of wave cycles increases rapidly(eg: Fig 21 and 22) for the same time period. The negative value of stroke indicates reference used is below the FRF(Frequency Response Function). The main aim of this study is to reduce the dynamicity of the test medium which is achieved by reducing the number of wave cycles by the use of geotextiles reinforcement.

VIII. CONCLUSION

The purpose of this study was to assess the behaviour of soil medium reinforced with geotextile upon dynamic excitations. The use of geotextile is found to be promising under seismic forces. General, conclusions drawn from the experiments are highlighted displayed in this paper as graphical charts.

1) The uniformity and gradual increase of dynamic waves at a particular frequency with respect to time is similar to that of seismic waves, where soon after the onset of dynamic waves slight shaking of the structure occurs initially and once the frequency of wave matches with the buildings natural frequency, then the structure will sway tremendously.

2) Higher is the frequency, greater is the number of waves at a particular interval of time period. However the use of geotextile is found to be a confinement for the soil present in between the foundation and geotextile,which reduces the dynamic wave amplifications.

3) As in Fig 19, for increased number of target cycles increase in frequency enhances the dynamicity of the test medium. At such higher frequencies onset of structural element failure occurs.

4) The results drawn are limited to the inputs which are given as sinusoidal waves.

5) The settlement of the footing under the application of the above loads is found to be 2mm measured manually for the reinforced soil, whereas the settlement is found to be 5mm for the unreinforced case of same loading conditions. Thus, use of geosynthetics as soil reinforcement found to minimize the settlement in weak foundation soils.

6) The amount of prestress required varies according to the type of soil in the settlement reduction. The amount of prestress given is 1KN to the reinforcement used here in the red soil.

At present, the use of geosynthetics as reinforcements are found to be significant in reduction of destructions and post earthquake maintainence of structures in high seismic zones

Acknowledgment

This project is a sponsored project funded by TDT division of department of science and technology (DST), GOI. The principal investigator of this project is DR. S.Suresh Babu.

REFERENCES

[1] Ahmed M. Eltohamy, “The Effect of Geogrid Reinforcement Pre-Stressing on the Performance of Sand Bed Supporting a Strip Foundation”, International Journal of Civil and Environmental Engineering, Volume-10, issue-8,pp: 1037-1042, June 2016.

[2] Durga Prasad. B, C. Hariprasad & B. Umashankar, “Load-Settlement Response of Square Footing on Geogrid Reinforced Layered Granular Beds”, International Journal of Geosynthetics and Ground Engineering, Volume-2, issue-4, pp:1-10, 07 November 2016.

[3] Jia-QuanWanga, Liang-Liang Zhanga, Jian-Feng Xueb & Yi Tang, “Geotextiles and Geomembranes”, volume-46, issue-5 pp: 586-596, October 2018.

[4] Julie Lovisa, Sanjay Kumar Shukla &NagaratnamSivakugan, “Geotextiles and Geomembranes”, volume-28, issue-1 pp:23–32, February 2010.

[5] Liyan Wang, Shangkun Chen & Peng Gao, "Research on seismic internal forces of geogrids in reinforced soil retaining wall structures under earthquake actions", International Journal of Vibroengineering, Volume 16, Issue 4, June 2014.

[6] Madhavi Latha. G, Sujit Kumar Dash, and K. Rajagopal, "Numerical Simulation of the Behavior of Geocell Reinforced Sand in Foundations", International Journal of Geomechanics, volume-09, issue-4, pp: 143–152, August 2009.

[7] Murad Abu-Farsakh, Qiming Chen &Radhey Sharma, "An experimental evaluation of the behavior of footings on geosynthetic-reinforced sand", Soils and Foundations, Volume-53, Issue-2, pp: 335-348, January- 2013.

[8] Moghaddas Tafreshi S.N& A.R. Dawson , "Behaviour of footings on reinforced sand subjected to repeated loading – Comparing use of 3D and planar geotextile", "Geotextiles and Geomembranes", volume-28, issue-5 pp: 434-447, October 2010.

[9] Patra C.R, B.M. Das & C. Atalar, "Bearing capacity of embedded strip foundation on geogrid-reinforced sand", Geotextiles and Geomembranes, volume-23, issue-5, pp: 454-462, October 2005.

[10] Saha Roy.S and K. Deb, "Effects of aspect ratio of footings on bearing capacity for geogrid-reinforced sand over soft soil", Geosynthetics International, Volume-24 Issue-4, pp: 362-382, August- 2017.

[11] Sahu.R, C. R. Patra, B. M. Das & N. Sivakugan "Ultimate bearing capacity of rectangular foundation on geogrid-reinforced sand under eccentric load", International Journal of Geotechnical Engineering, volume-10, issue-1, pp:52-56, March 2016.

[12] Werkmeister S , Dawson A R and Wellner F, "Permanent Deformation Behavior of Granular Materials and the Shakedown Concept" Transportation Research Record Journal of the Transportation Research Board, volume-1757, issue-1, pp:75-81, January 2001

[13] Zidan A.F, "Numerical Study of Behavior of Circular Footing on Geogrid-Reinforced Sand Under Static and Dynamic Loading", Geotechnical and Geological Engineering, volume-30, issue-2, pp:499-510, April 2012.

DOI : 10.35291/2454-9150.2020.0217