Experimental study of unreinforced and reinforced soil retaining wall using shake table facility

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ABSTRACT: This paper highlights the shake table tests carried out on a conventional soil retaining wall model and a reinforced soil retaining wall model in the laboratory. The soil used for this study was mixed soil or c-ф soil. The models for the test setup made in a laminar box and mounted on shake table with instrumental connections. The observations and results of the tests are given in detail. Two soil retaining wall models were constructed: one without reinforcement and the other with reinforcement and were provided with four horizontal acceleration values- 60, 75, 90 and 120 rpm. Jute blanket with latex was used as the reinforcement material for the model. It was observed that settlement in height for the reinforced model was very negligible compared to the unreinforced model. The acceleration, velocity and displacement values obtained at the position where accelerometers were fit very less for the reinforced model. The test results show that the acceleration, velocity and displacement for conventional retaining wall model are amplified with notable ratios. The seismic horizontal coefficients were calculated to find out maximum reinforcement force with respect to slope of the wall and seismic vertical coefficient. Comparison between the two studies showed the reinforced structure is strong enough to withstand any seismic activity below 120 rpm frequency. The amplification ratio compared to establish the efficiency of the reinforced structure over the unreinforced within a specified range of seismic frequency.

1 INTRODUCTION

Retaining walls and geotextiles: Retaining walls are structures constructed for retaining soil mass. However, retaining walls not only constructed to retain soil but also for aesthetic landscape purposes. Retaining walls are built in those places where soil cannot hold back on its own or unable to stand vertically without support. With the help of retaining wall, we can maintain grounds at different levels where there is an abrupt change in level or elevation. Soil retaining walls are structures which are constructed to stabilise the soil in a particular area. Soil retaining walls are generally constructed along the banks of canals and also along the embankments for paths to withstand a certain capacity of load. Reinforced retaining walls have come in to practice now days for their ability to withstand static as well as dynamic loads. The idea of using reinforcement in soil was invented in the 1970s by a French engineer Sir Henri Vidal. The term he used for this type of structure was Teree Armee(reinforced earth) [Tatsuoka et al., 1995; Sandri, 1997; Kramer and Paulsen,2001; Tatsuoka et al., 2007]. In this literature it has been stated about the effectiveness of reinforced soil retaining walls during high magnitude earthquakes. The reinforcement or geo-textiles that are being used in soil retaining walls are either naturally derived or prepared artificially. Geogrids are flexible materials, synthetic meshes specially manufactured for slope stabilization and earth retention. Geogrids are available in variety of materials, sizes and strengths. Conventional geotextiles such as nonwovens, woven, knitted and stretch bonded textiles are naturally derived and special geotextiles are those which are artificially treated with chemicals for higher performance. The drawback of special geotextiles is the availability and its cost effectiveness. The principal requirements of reinforcement are: strength, stability, ductility, and durability, ease of handling, high coefficient of friction, economy and availability. The geogrids affect the tensile strength, tensile modulus and interface shear strength of the soil retaining walls. Synthetic and steel geogrids used in reinforced soil retaining walls are very costly. The jute geotextiles have emerged as a very good alternative to the synthetic geotextiles. They are cheap and very easily available in the market. They are easy to handle and install.

Various studies have been carried out to study the dynamic behaviour using shake table test, here, some of the studies have been discussed such as Ling (2003) have listed various shake table tests on retaining walls. Small and large shake table tests were carried out on reinforced soil retaining walls using metallic reinforcement. In 1975, the Richardson and Lee and Richardson et al. (1977) have carried out the several small scale shake table tests on Geosynthetic Reinforced Soil walls and most of them were performed in Japan due to abundant availability of facilities and requirement for earthquake resistant design structures. Most notable tests were carried out by Japan Railway Technical Research Institute (Murata et al. 1994) and Public works Research Institute (Matsuo et al. 1998). A large scale shaking table tests on modular block reinforced retaining walls was carried out by Ling et al, 2005. In this study a modular block reinforced soil retaining wall was modelled which was backfilled using sand. The walls were provided with acceleration value similar to Kobe earthquake in Japan. The reinforcements that were used: Polyester (PET) geogrid and polyvinyl alcohol (PVA) geogrid. PVA geogrid is highly alkaline resistant. Test was conducted on three samples of retaining walls. Wall 1 showed the largest settlement and the magnitude of settlement reduced in Walls 2 and 3 following a reduction in the reinforcement spacing and length of geogrid. The test result showed that under 0.86g acceleration there was no significant change in the parameters but under 0.4g acceleration the settlement, deformation and acceleration was negligible. With reduction of modular blocks, shortening of geogrid length in other layers except the top, while the top length of geogrid was increased, there was a good performance observed. Under earthquake loading, the lateral displacement was observed to be highest at the top of the wall. A notable settlement occurred in the unreinforced zone.

Similar study on shake table was carried out by Madhavi Lata and Murali Krishna (2007) to study the behaviour of seismic response of reinforced soil retaining wall models about the influence of backfill relative density. In this test they observed the influence of backfill density on reinforced soil retaining walls. The reinforcement used in this test was polypropylene multifilament woven fabric. Three samples of retaining walls were prepared: one with wrap faced without geogrid other wrap faced with geogrid and another rigid faced with geogrid. Initially the samples were tested at low frequency and acceleration at various densities and later at high frequency and acceleration at various densities of the backfill. At low acceleration significant displacement occurred in the wrap faced retaining walls and the density effect was completely pronounced. At high elevations face deformation is increased.

Nova-Roessig and Sitar (2006) studied the behaviour of soil slopes under dynamic loading with geosynthetics and metal grids. it was observed that magnitude of deformation depend upon reinforcement stiffness and spacing as well as slope inclination.

2 EQUIPMENTS USED IN THE EXPERIMENT

2.1 *Shake table*

The equipment comprises of the following:

- Vibration Table: 1m X 1m shake table with 5/8" mounting holes(36 nos) on the surface of the table. The table is capable of taking payload up to 3 Ton.
- Motor: Induction motor with 30HP capacity, 415VAC, 1450rpm, 50Hz
- Gear Box: Reduction Pinion Gear Box with Gear Ratio 4:1 (Input : Output)
- Control Panel: Comprises of Variable Frequency Drive, MCBs, Control Switches, Displays. Made up of MS with power coating.

The equipment requires a three phase power supply to run, 415VAC, 50Hz, 65 Amp. The temperature of the equipment should be around 25^0C and the humidity recommended should be less than 60%. The displacement of the equipment is 100mm (max) and maximum payload is 3000kg. The mode of operation is horizontal.

2.2 *Laminar box*

The models of retaining walls were built in a laminar box to considerably reduce the boundary effects. A laminar box is a large-sized shear box consisting frictionless horizontal surfaces. The laminar box used for the tests is rectangular in cross section with inside dimensions of 1500 X 500 X 1000 mm (length x breadth x height).

3 PROPERTIES OF SOIL

A mixed soil sample, locally available was collected for the experiment. Figure 1 shows the particle distribution for the soil sample. The soil is poorly graded as the criteria, $Cu<4$ and $1<Cc<3$ did not satisfy. For coarse grained soils, the D10 represents a size in mm such that 10% particles are finer than this size and D60 represents soil particles finer than this value are 60% of the total mass of the sample. D10 is also called the effective size or effective diameter. Cu = (D60 /D10). The shape of particle size curve is represented by the co-efficient of curvature,Cc=[(D30)2/(D10XD60)].

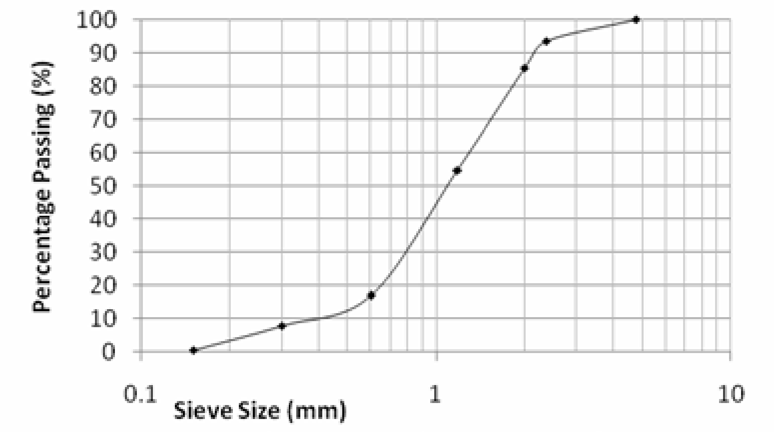


Figure 1. Particle distribution curve

The optimum moisture content for the soil was found by carrying out Standard Proctor test. Developed by R.R.Proctor in 1933, the set up consists of a cylindrical metal mould of internal diameter of 10.15cm, height of 11.7cm and a capacity of 0.945litre, detachable base plate, collar of height 5cm and rammer of 205kg with free fall of 30.5cm height. Figure 2 shows the graph plotted from the results of Standard Proctor test to determine the Optimum Moisture content for the soil sample. The OMC for the soil was 15%. After the determination of angle of friction the experimental model was set up. The slope of the retaining wall was designed at 45^0 ($<47^0$). The dimensions of the retaining wall are given in figure 10 which shows a schematic diagram of the structure. The dimensions for the retaining wall were selected with respect to the size of the laminar box available in the laboratory.

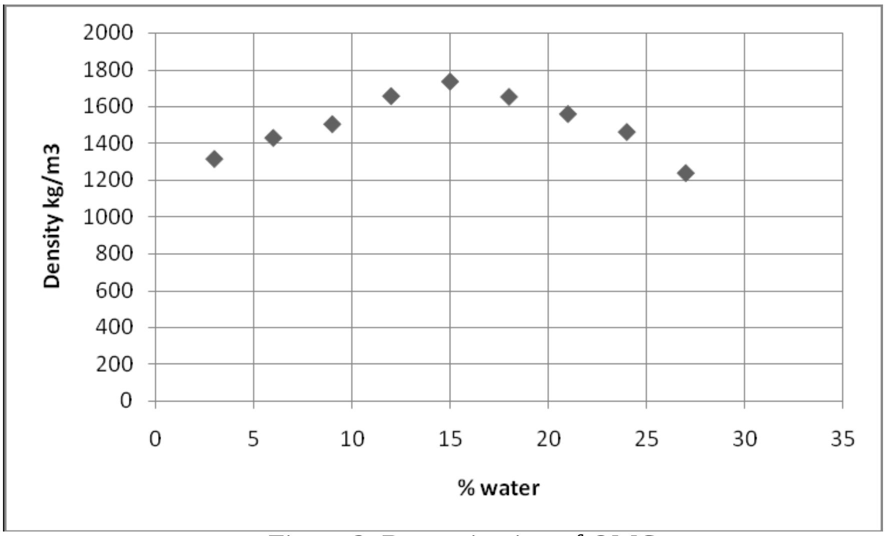


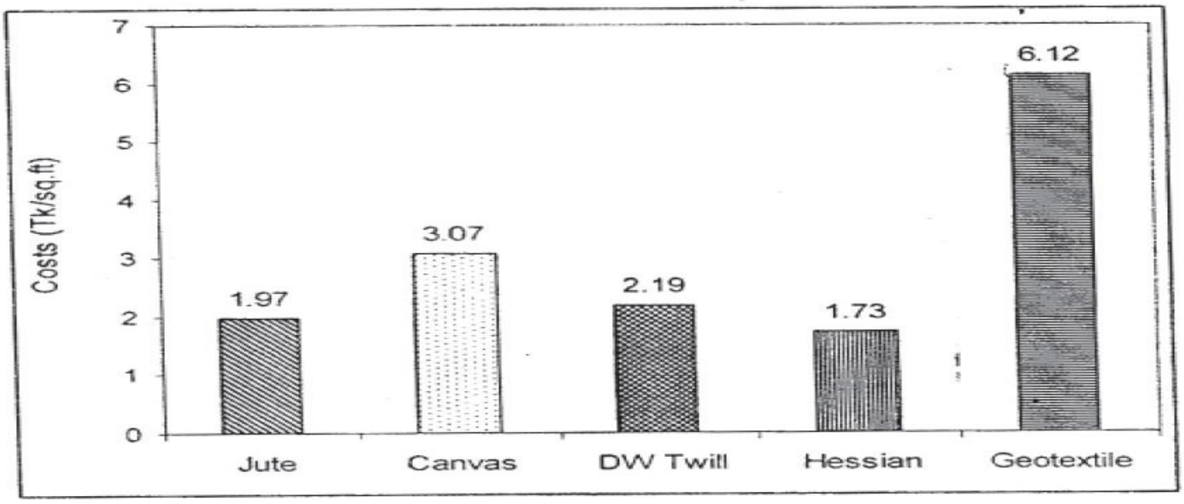
Figure 2. Determination of OMC

4 PROPERTIES OF GEOTEXILE

Property	**Range of value**
Fibre length, mm	180-800
Fibre diameter, mm	0.10-0.20
Specific gravity	1.02-1.04
Bulk density, kg/m^3	120-140
Ultimate Tensile Strength, N/mm^2	250-350
Modulus of elasticity, kN/mm^2	26-32
Elongation at break, (%)	2-3
Water absorption, (%)	25-40
Thread diameter, mm	1.75-1.85
Mesh size, cm^2	3x3
Weight, g/m^2	680-750
Grab Tesnsile Strength (wet), N	800-900
Elongation at break(wet), %	15-20
Trapezoidal shear strength, N	300-350
Permeability, cm/sec	
i)under unstressed conditions	10^{-2}
ii)under all round pressure of 500 kN/m^2	10^{-3}-10^{-4}

Fibre	Density, g/cc	Young's modulus, GPa	Tensile Strength, MPa	Elongation at break (%)
Cotton	1.5-1.6	5.5-12.6	287-597	7-8

Type	Composition	Possible durability	Bio degradability	Moisture content	Wt/Unit area	Tensile Strength (lb)
Woven jute in different structure	Jute	2-6 month	Quick	12-14%	220-800	120-140
Woven jute in different structure	Jute, Coir	5-12 month	Slow	7-10%	220-800	240-660
Woven jute but treated composite	Jute bitumen carbon	6-48 month	Long run	3-8%	Var.Wt	140-700
Non woven	Jute Blanket	6-18 month	Slow	8-12%	800	300-800
Non woven	Jute blanket+ latex	5-20 year	Long run	5-7%	>800	>800
Woven with different construction	Jute Latex	5-20 year	Long run	5-7%	>800	300-800



Product	Condition	Mass per unit area (g/m^2)	Thickness (mm)	Wide width tensile strength (kN/m)	Grab tensile strength (N)	CBR puncture resistance (N)	Burst strength (kPa)	Permittivity (S^{-1})	AOS (mm)
Jute	Treated Untreated	1600 800	3.5 2.8	15/18 10/12	800/700 400/220	4000 1500	1500 1250	0.06 0.28	0.0 to < 0.75 0.28
Synthetic	Non-woven geotextiles	240-640	2.0-4.5	(18-48)/(15-31)	(1160-2590)/(780-1900)	2660-5450	3800-4500	0.4-1.8	

5 MODEL SET UP

Figure 3 shows the experimental model set up for the test with accelerometers fit to the structure. There were three accelerometers available. One was fit to the tank and the others were positioned at heights Z_1 and Z_2 respectively. The height of Z_1 was 500 mm and height of Z_2 was 400 mm from the base structure. The accelerometers were connected to find out the acceleration, velocity and displacement parameters with respect to time.

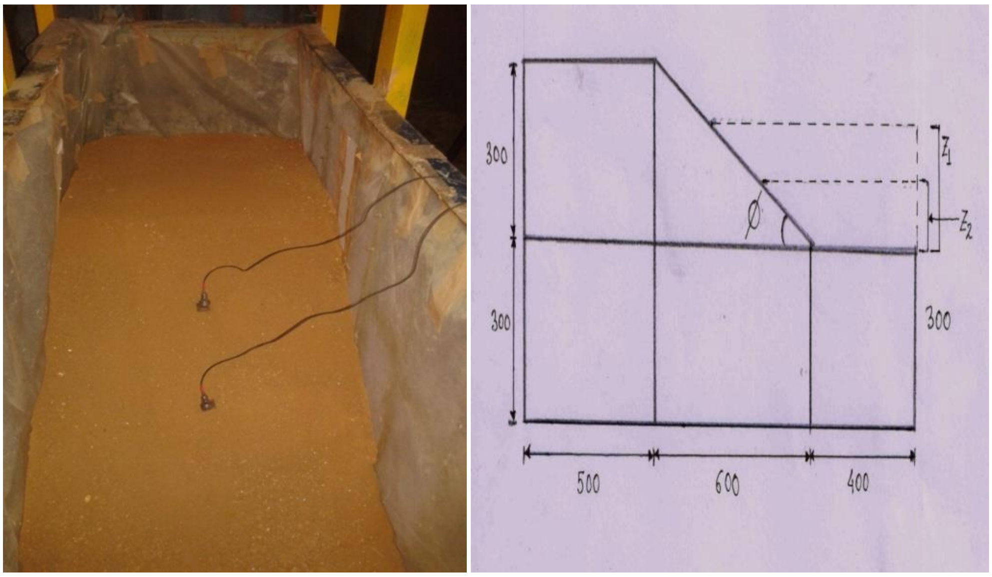


Figure 3. Unreinforced soil retaining wall model

Figure 4. Shake table set up with laminar box

The laminar box was connected to the shake table and dynamic loading was provided at 60 rpm for 10 sec cycle. The test was carried out for both the conventional and reinforced model's at a dynamic loading of 60, 75, 60 and 120 rpm respectively. The dynamic loading provided to the box was randomly selected at 60, 75, 90, 120 rpm according to facility available in the laboratory. Figure 4 shows the arrangement of the laminar box with the shake table.

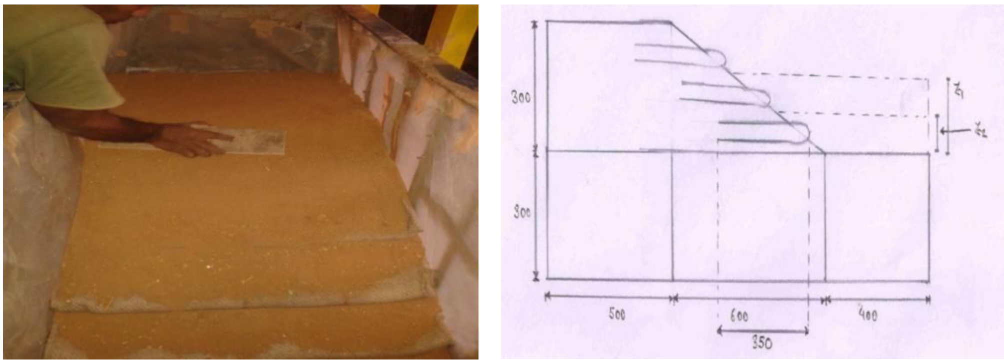


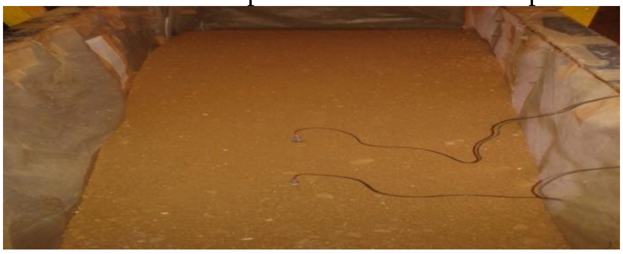
Figure 5 : Reinforced soil retaining wall model

For unreinforced models

Before Test

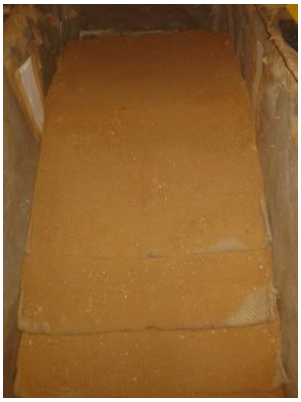
After test at 60 rpm


After test at 75 rpm After test at 90 rpm



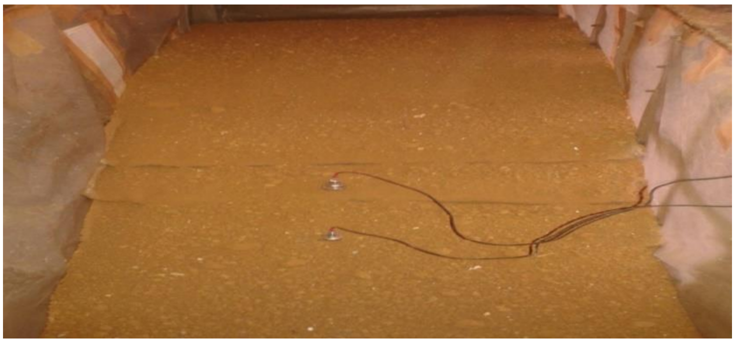
After test at 120 rpm

For reinforced models

Before Test After test at 60 rpm


After test at 75 rpm After test at 90 rpm

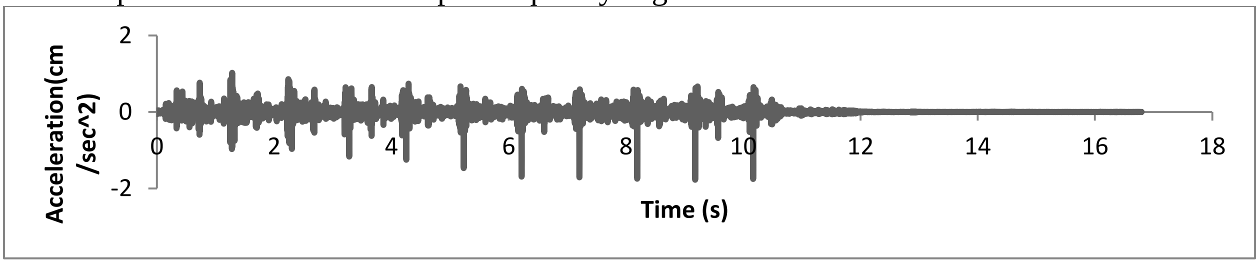


After test at 120 rpm

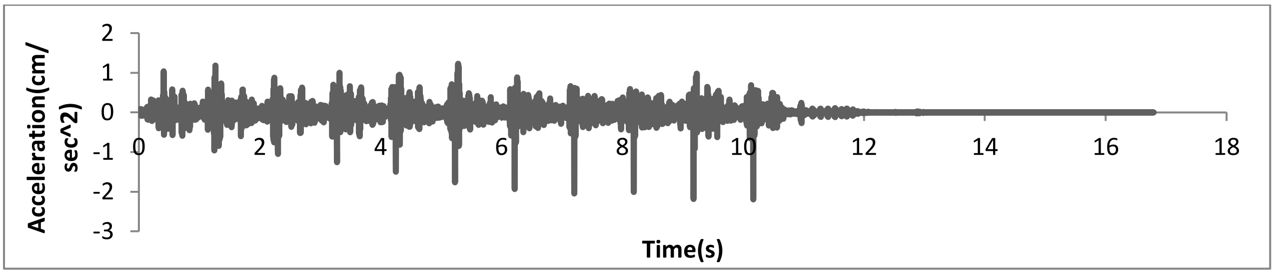
The tests were performed and the observations for acceleration, velocity and displacement recorded by accelerometers were noted to establish a comparative inference for the different models. From the data collected settlement with respect to frequency graph was plotted. The horizontal acceleration co-efficient was calculated for every maximum acceleration value and graph was plotted against frequency to understand the behaviour of the models under dynamic loading. The settlement occurring after each set was measured manually with the help of scale.

6 OBSERVATIONS

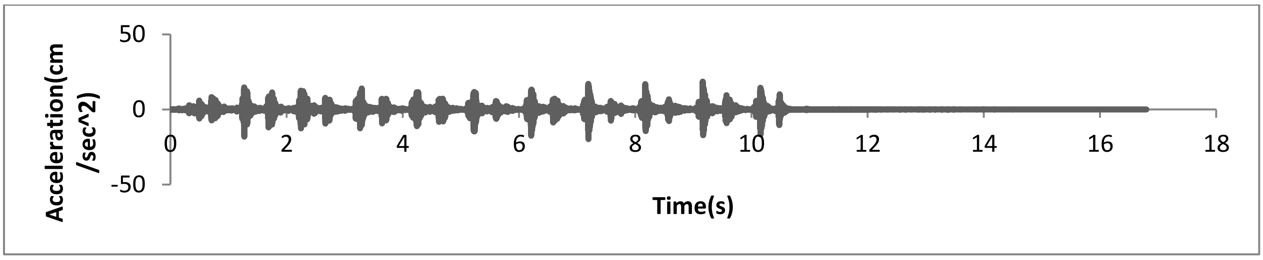
An example of observation at 60 rpm frequency is given here



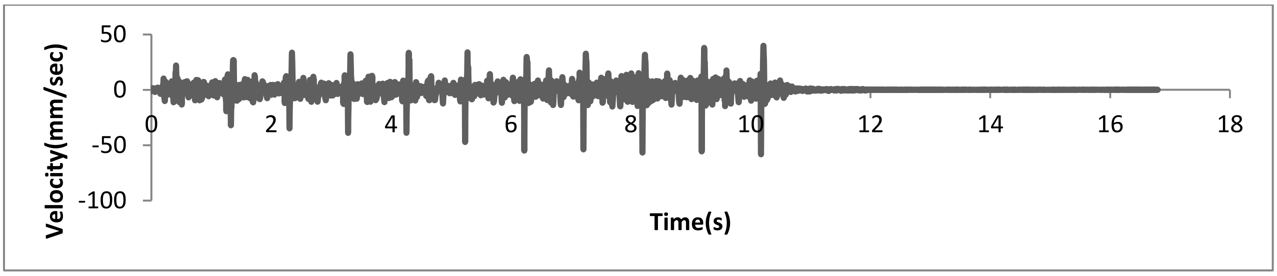
Accelerometer at 500mm from base, 60rpm, unreinforced



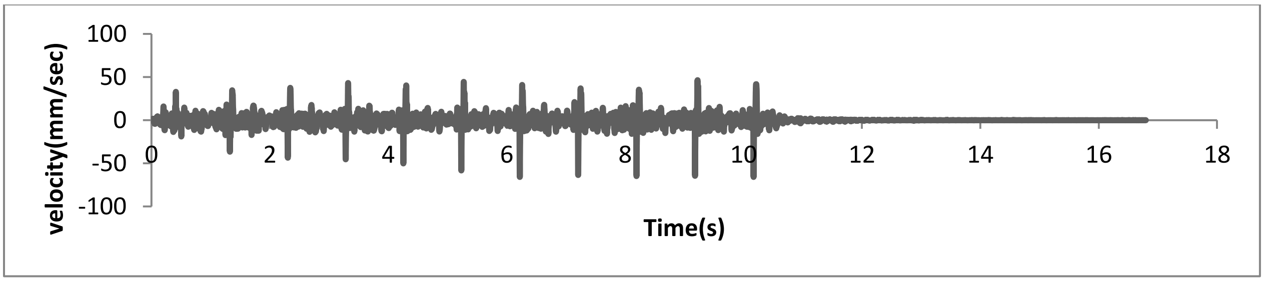
Accelerometer at 400mm from base, 60rpm, unreinforced



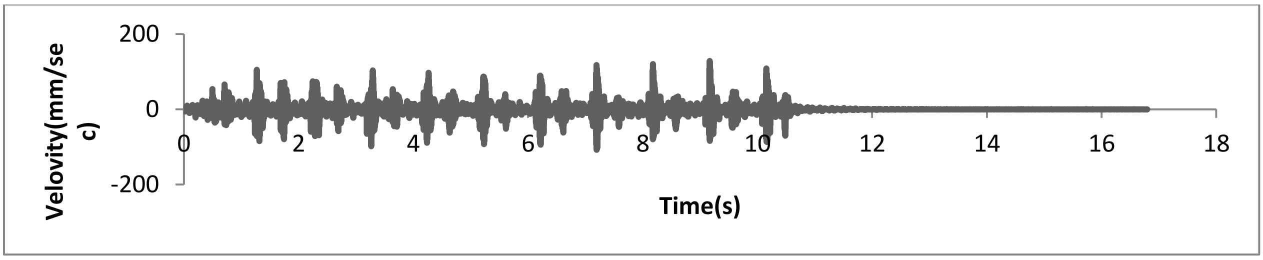
Accelerometer at tank, 60 rpm. Unreinforced



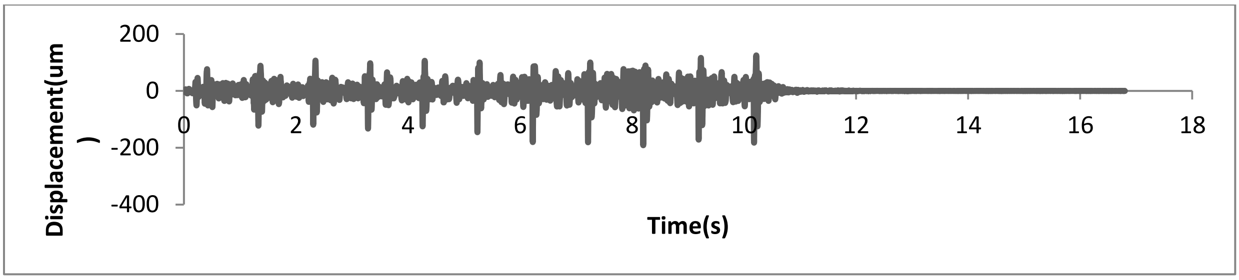
Accelerometer at 500mm from base, 60rpm, unreinforced



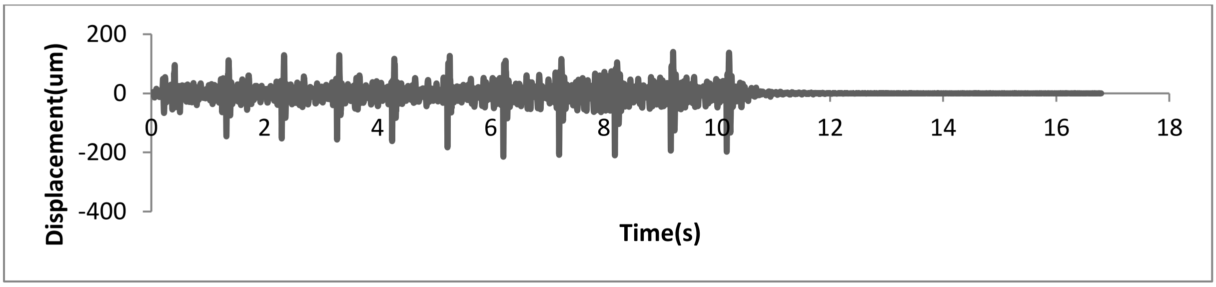
Accelerometer at 400mm from base, 60rpm, unreinforced



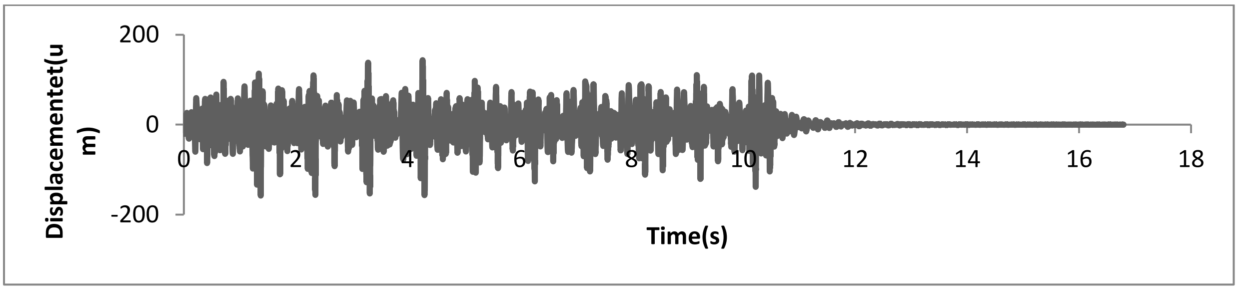
Accelerometer at tank, 60rpm, unreinforced



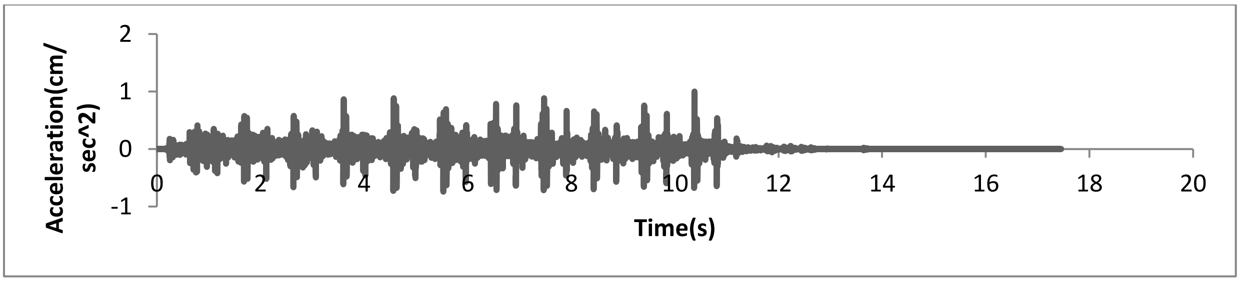
Accelerometer at 500mm from base, 60rpm, unreinforced



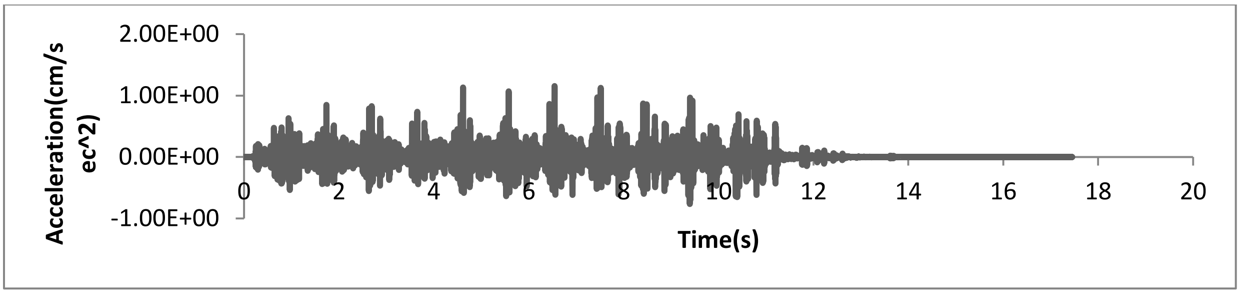
Accelerometer at 400mm from base, 60rpm, unreinforced



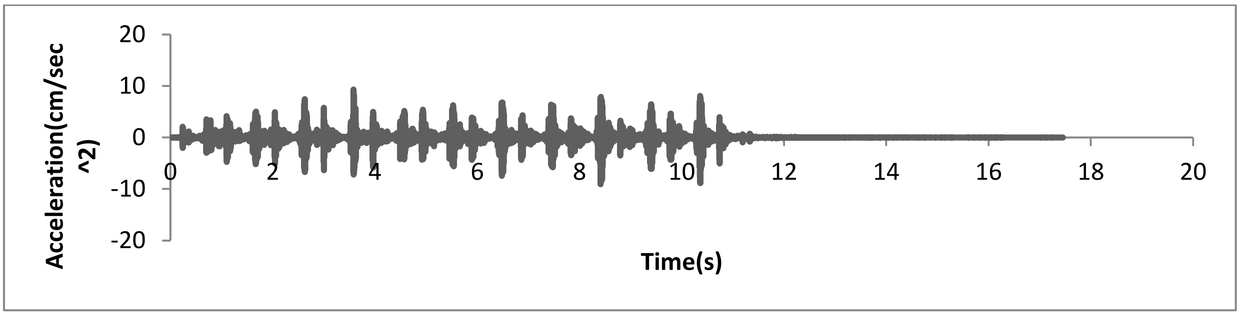
.Accelerometer at tank, 60rpm, unreinforced



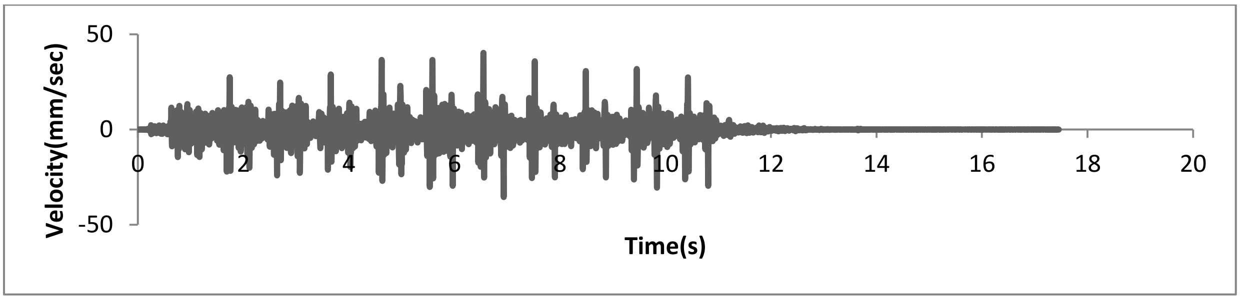
Accelerometer at 500mm from base, 60rpm, reinforced



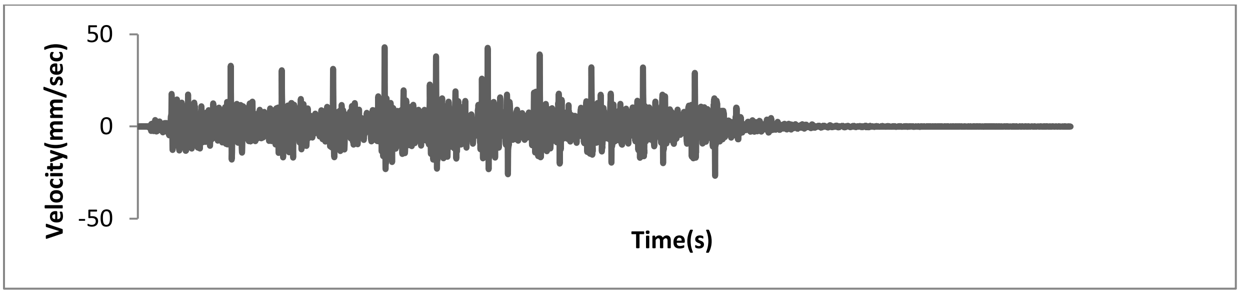
Accelerometer at 400mm from base, 60rpm, reinforced



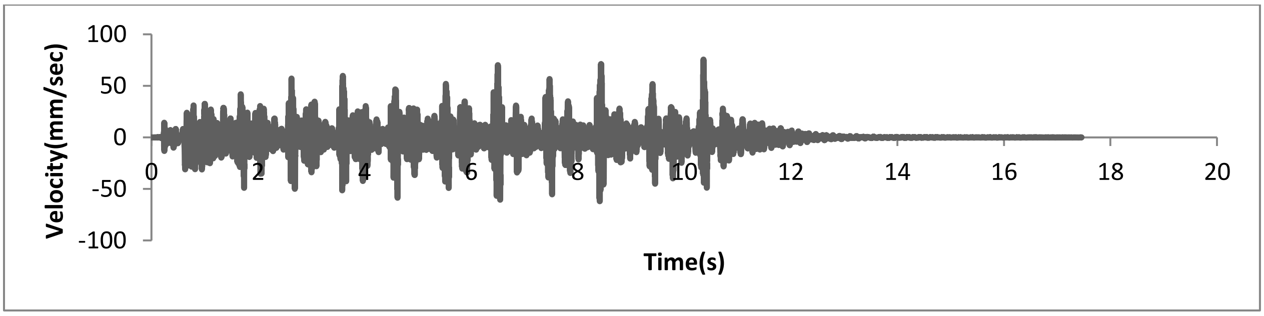
Accelerometer at tank, 60rpm, reinforced



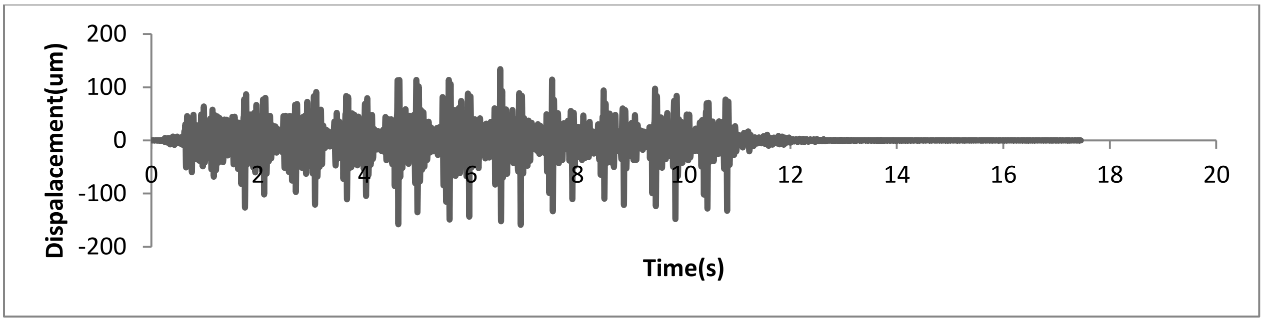
Accelerometer at 500mm from base, 60 rpm, reinforced



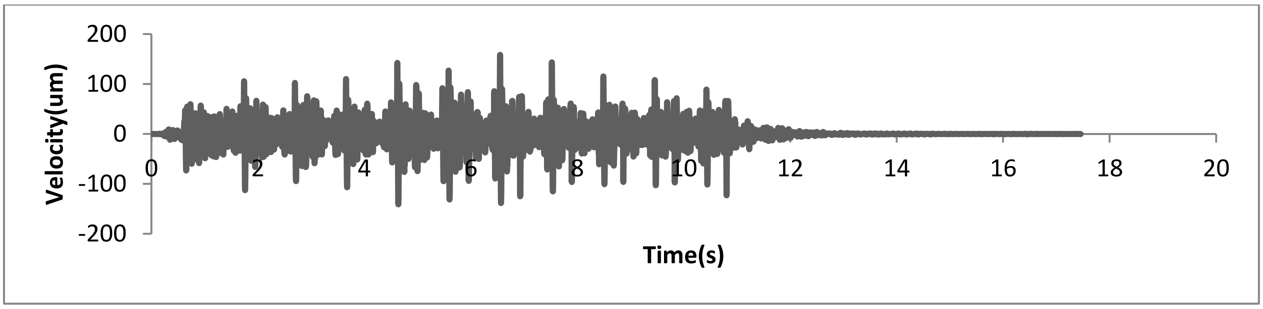
Accelerometer at 400mm from base,60 rpm, reinforced



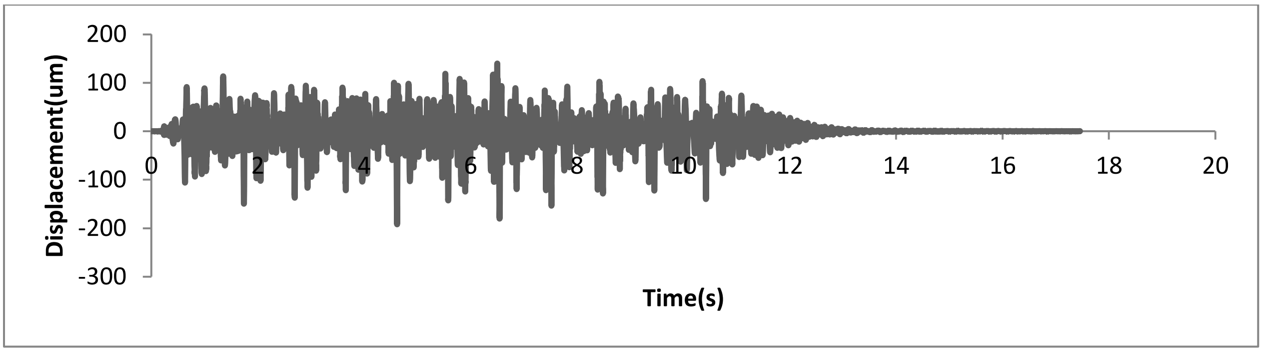
Accelerometer at tank, 60rpm, reinforced



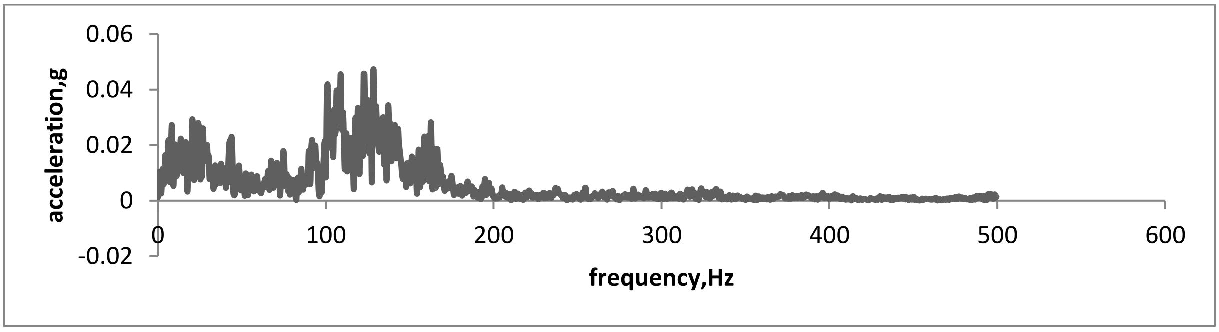
Accelerometer at 500mm from base, 60rpm, reinforced



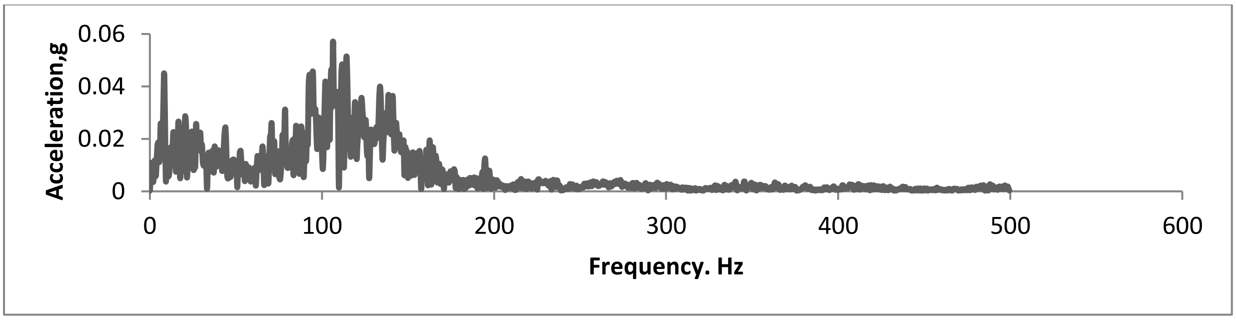
Accelerometer at 400mm from base, 60rpm, reinforced



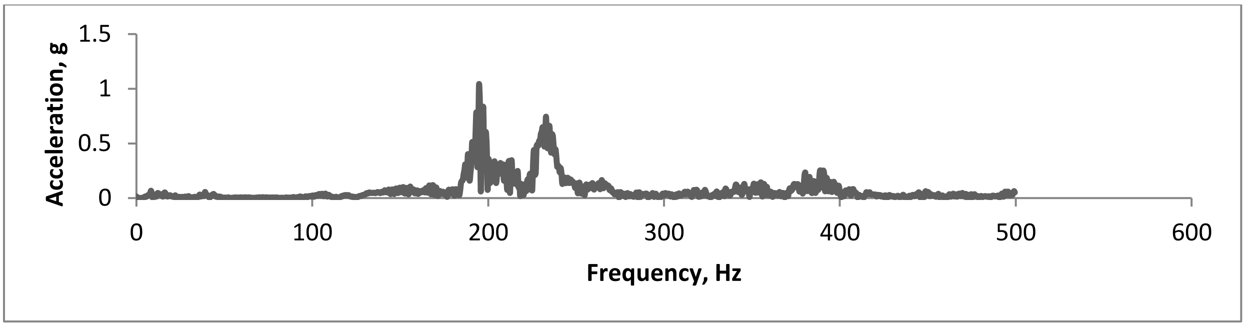
Accelerometer at tank, 60rpm, reinforced



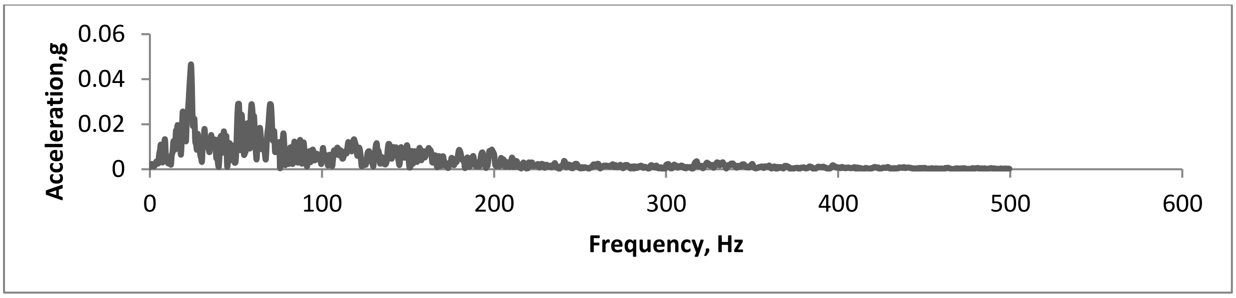
Accelerometer at 500mm from base, 60 rpm, unreinforced



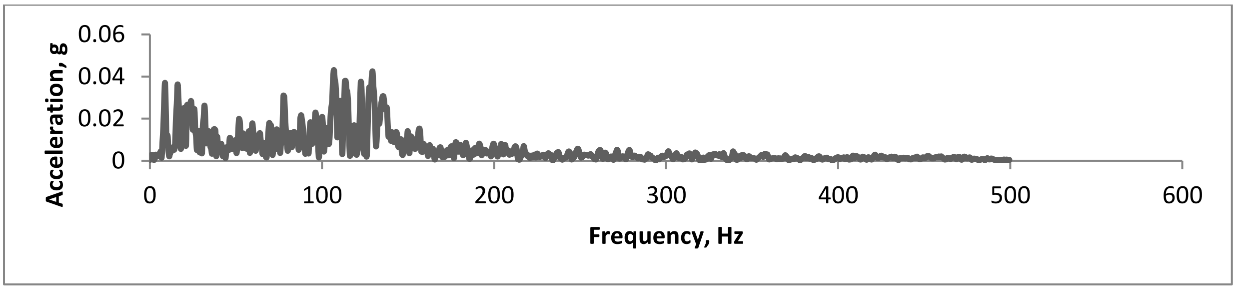
Accelerometer at 400mm from base, 60 rpm, unreinforced



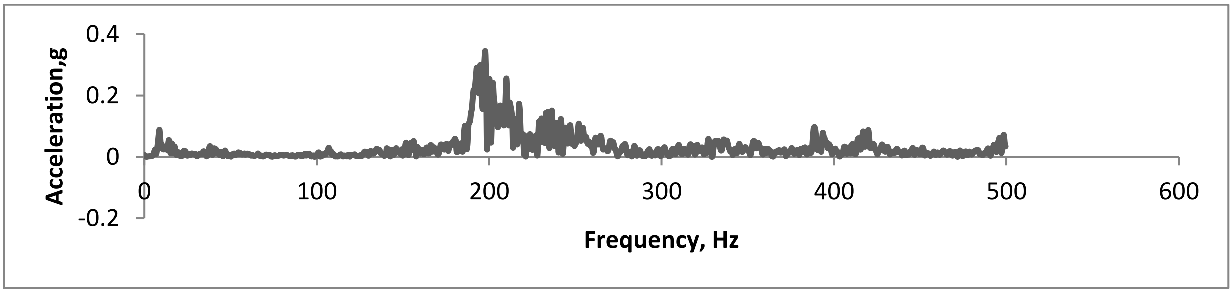
Accelerometer at tank, 60 rpm, unreinforced



Accelerometer at 500mm from base, 60 rpm, reinforced

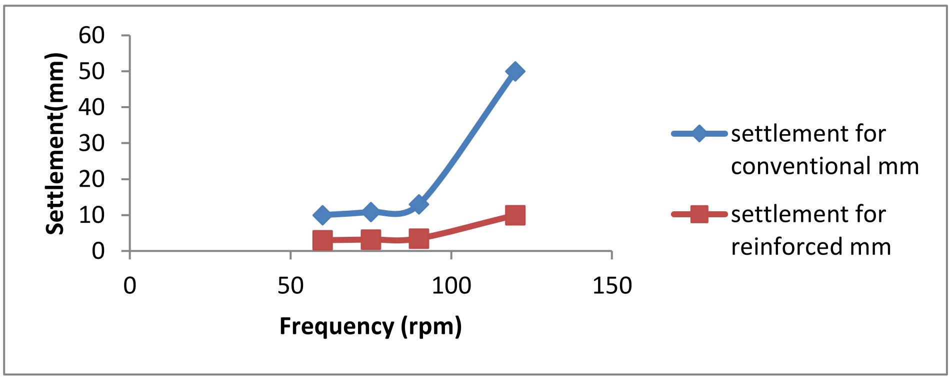


Accelerometer at 400mm from base, 60 rpm, reinforced



Accelerometer at tank, 60 rpm, reinforced

7 RESULTS AND DISCUSSIONS



The settlement along the height of the retaining wall was noted manually and a graphical relation was established with frequency.

Rpm	Settlement under unreinforced condition (mm)	Percentage of settlement under unreinforced condition (%)	Settlement under reinforced condition (mm)	Percentage of settlement under reinforced condition (%)
60	10	1.67	3	0.5
75	10.9	1.82	3.2	0.53
90	13	2.16	3.5	0.58
120	50	8.33	10	1.67

It is seen that in case of reinforced condition, the settlement occurring along the height of the wall is very less compared to the unreinforced condition. Hence it could be concluded that the geogrids provide resistance against the lateral earth pressure exerted by the soil. The deformation along the slope is also resisted with the application of reinforcement.

Pseudo-dynamic method proposed by Steedman and Zeng (1990) is a method with which we can establish stability criteria for reinforced soil mass with respect to different parameters. In this method they considered the accelerations as sinusoidal. Nimbalkar et al (2006) in their journal have discussed about the variation of horizontal and vertical seismic co-efficient with respect to angle of friction, time period, required reinforcement strength after performing a detailed study for cohesive soil. Tafreshi and Rahimi (2012) also carried out a study with pseudo dynamic approach and established variations with different conditions and parameters. The horizontal seismic coefficient K_h was calculated using the equation proposed by Sargoni(1983)

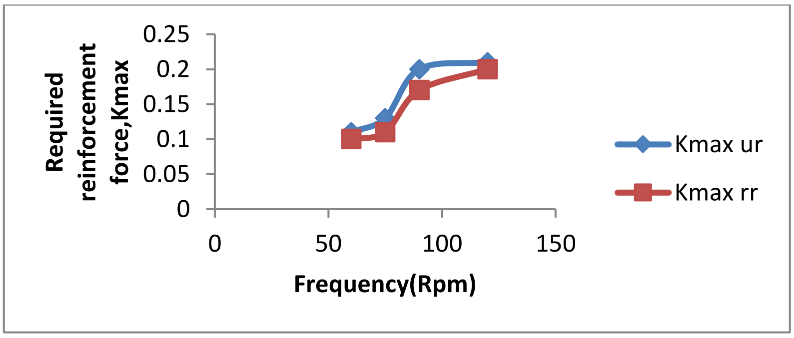
$$K_h = 0.33(a_{max}/g)$$

And, $K_v = 0\ (K_h)$

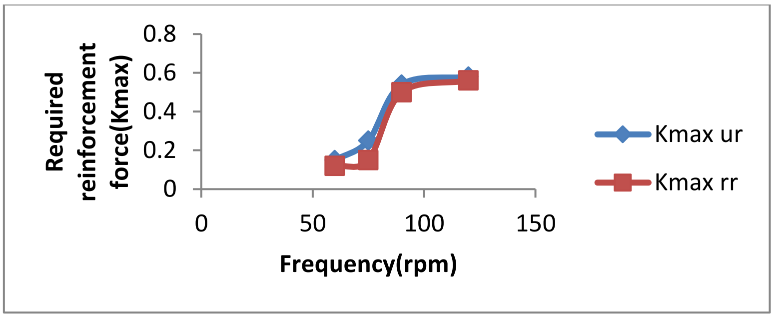
$$K_v = 0.5(K_h)$$

$$K_v = 1(K_h)$$

Comparing the values for K_h aganist K_v from the graph (Nimbalkar et al 2006) the corresponding K_{max} values were found and plotted. Similarly comparing the values for K_h with angle of friction{Tafreshi & Rahimi (2012)}. the corresponding K_{max} values were found and drawn in a figure against frequency. The K_h values noted with respect to angle of friction were 0.12, 0.1, 0.065, 0.08, 0.03, 0.04, 0.02, 0.018, 0.2, 0.09, 0.08, 0.05, 0.06, 0.01, 0.02, 0.015, 0.014 and the values with respect to vertical seismic coefficient 0.12, 0.1, 0.065, 0.08, 0.03, 0.04, 0.02, 0.018, 0.09, 0.08, 0.05, 0.06, 0.01, 0.02, 0.015, 0.014. The maximum K_h values were considered and corresponding K_{max} values were found out.



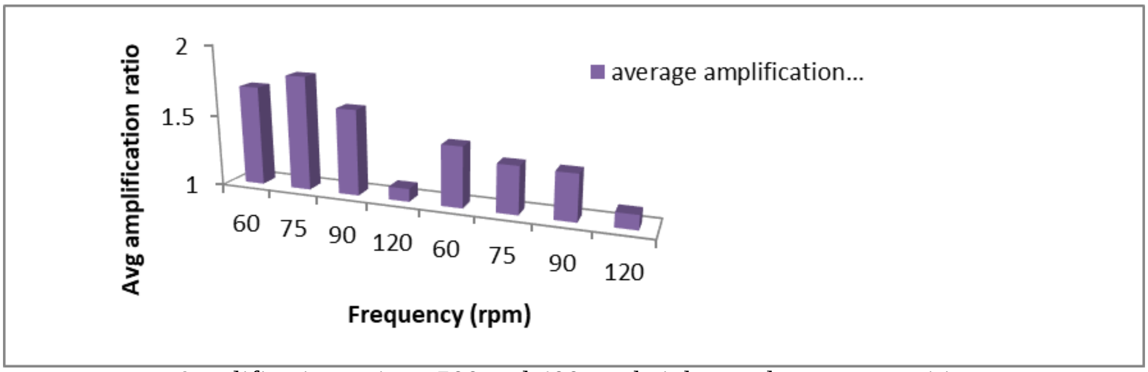
K_{max} values with respect to ϕ= 45’



K_{max} values with respect to K_h and K_v values

From both the figures 110 & 111, we can say that the reinforcement force required to overcome the reinforcement resistance is almost equal at 120 rpm. At 60, 75 and 90 rpm the force value is reduced due to the application of reinforcement in the soil mass. The lateral earth pressure in successfully countered till rpm below 120.

The amplification ratio for all the observations corresponding to respective dynamic loading is given. This factor says how much the mentioned parameter values are amplified in unreinforced soil retaining walls compared to the reinforced soil retaining wall. This factor determines the efficiency and effect of the geotextile used for the reinforcement of the soil structure for this soil. From figure 112, it can be understood that for lower rpm value, the reinforcement force is high enough to withstand the lateral force and deformation but at high rpm the reinforcement is not capable to withstand the lateral acceleration



Amplification ratio at 500 and 400mm height accelerometer position.

Rpm	Height (mm)	Condition	Peak acceleration (cm/s^2)	Amplification ratio	Peak velocity (mm/s)	Amplification ratio	Peak displacement (um)	Amplification ratio
60	500	unreinforced	1.72	1.56	59	1.47	190	1.23
		reinforced	1.1		40.1		155	
	400	unreinforced	2.2	2.09	62	1.54	220	1.45
		reinforced	1.05		40.3		152	
75	500	unreinforced	1.8	1.29	60.1	1.47	192	1.22
		reinforced	1.4		41		157	
	400	unreinforced	2.7	2.45	63	1.51	223	1.44
		reinforced	1.1		41.5		155	
90	500	unreinforced	2.2	1.29	69.5	1.45	220	1.23
		reinforced	1.7		48		179	
	400	unreinforced	3	2	72	1.44	250	1.37
		reinforced	1.5		50		183	
120	500	unreinforced	3.1	1.04	197	1.13	875	1.03
		reinforced	2.96		199		850	
	400	unreinforced	3.3	1.09	175	1.13	743	1.05
		reinforced	3.05		176		710	

From table we can say that the acceleration, velocity and displacement parameters for low frequency values are notably amplified in unreinforced structure. But at 120 rpm frequency the amplification can be stated negligible and both the structure undergo considerable deformation.

8 CONCLUSION

A comparative study was carried out between a conventional soil retaining wall model and a reinforced soil retaining wall model. Two models were set up and tested at four different frequencies in rpm values for this study. The results and observations are explained in detail. The main objective of this work was to find out the efficiency of the reinforced retaining wall model in comparison to conventional retaining wall model by comparing the acceleration, velocity, displacement and required reinforcement force parameters, and to note settlement in elevation occurring in both the cases. From the results it can be said that the acceleration, velocity and displacement values in conventional retaining wall models under dynamic loading is far more amplified than the reinforced retaining wall model. Deformation and slope and settlement in height are very notable for unreinforced model but in reinforced model the effect is much less. Settlement in reinforced structure was less than the conventional one. So we can say that reinforcement contributes more capacity to the structure against seismic activity. Therefore during seismic activity the reinforced model can offer high resistance to the acceleration and displacement occurring within the structure. The lateral earth pressure acting on the retaining wall is reduced due to the use of reinforcement. It is understood that for lower rpm value the reinforcement force is high enough to withstand the lateral force and deformation but at high rpm the reinforcement is not capable to withstand the lateral acceleration. This model proves effective for low seismic excitation but at high frequency the reinforcement fails as observed from the study. Therefore this model is cheap and economically effective providing a descent resistance for low to medium seismic activity or external vibration.

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