EXPERIMENTAL STUDY ON THE SEISMIC WAVE PROPAGATION IN GEO-MATERIALS

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Abstract: Ground response to seismic action is a prime concern in geotechnical earthquake engineering. The estimation of this response to earthquakes is therefore a very essential phase of the design or retrofit of a structure. The paper presents the experimental work carried out in the University of Easy London laboratory to determine the dynamic and seismic response of different geo-materials (sand, peat, rubber and wood). An educational, one dimensional, shaking table was used for this purpose. The influence of parameters of these materials, such as density and layer thickness, and the frequency of the input load applied to them were also investigated.

1. Introduction

In civil engineering the knowledge and control of the seismic action is essential in order to be able to foresee and prevent the terrible effects that may occur. In the last period of time, numerous earthquakes are causing significant damage all around the world. This major problem of mankind sometimes produces death and destruction in a wide variety of ways, from building collapse to conflagrations, tsunami and landslides. Due to the world wide fast development, a lot of structures are being built on various types of foundation soils. This can be a problem when these construction sites are also in seismic active areas.

Earthquakes are naturally occurring phenomena, causing ground motions within various ranges of vibrations, which can result from tectonic ground motions, volcanoes, landslides, rock falls and man-made explosions (Chen, 2003). From all of these causes, the earthquakes produced by tectonic ground motions are the most frequent and important ones. Due to tectonic faulting, a sudden release of energy is produced in the rock masses in the Earth's crust fracture. As a consequence, elastic seismic waves will result from the propagation of the released energy outward from the source. These waves are characterized by duration, amplitude and frequency, which depend on the magnitude of the earthquake, the distance from the epicentre, and the soil materials through which the waves travel (Chen, 2003). The nature of these soil materials plays a very important role in determining the characteristics of the ground surface motion (Kramer, 1996).

Geotechnical earthquake engineering is studying the internal behaviour of the earth as well as the nature of seismic waves generated by earthquake. Ground response to seismic action is a prime concern in geotechnical earthquake engineering. By using ground response analyses, the ground responses can be predicted, and afterwards,

they can be used for creating design response spectra. An essential part in the development of a ground response analysis is to be able to establish the manner in which the stress waves propagate through a certain site. This aspect can provide an insight in determining how the types of geologic materials at that site are influencing the ground surface motions (Kramer, 1996).
The San Francisco (1906) and Mexico City (1985) earthquakes underlined the importance of local soil properties on the earthquake response of structures. These earthquakes proved that the rock motion could be highly amplified at the base of a structure (Semblat et al, 2000).
In this paper an experimental investigation using an educational shaking table is described in order to study the dynamic and response of four different geo-materials (sand, peat, rubber, wood).
This investigation is an attempt to analyse the dynamic and seismic response of these of geo - materials in order to foresee the rate of amplification of the maximum acceleration produced by the input excitation.

2. Description of the shaking table and of the geo-materials used in the experiment

Shaking tables are used for experimental research and investigation in earthquake engineering. By using these experimental testing equipments, the motion of the ground during an earthquake can be reproduced and then applied on structural models. Apart from applying recorded ground motions, shaking tables can also reproduce synthetic accelerograms or simple seismic-signals as sine waves (Filiatrault, 2002).
The shaking tables can be used, also, in geotechnical earthquake engineering experimental studies through the means of the soil box. Mainly all the tests on physical models for research in geotechnical earthquake engineering were performed on various types of shaking tables providing valuable insight on various earth-related phenomena.

2.1. Description of the shaking table testing equipment:

The experimental investigation presented in this paper was carried out at the testing laboratory of the University of East London on the Quanser Shake Table II (Figure 1).
This is a one-dimensional shaking table, consisting of a 45x45cm aluminum plate which slides on high precision linear bearings. Two seismic excitations were applied using the shake table, such as the Kobe earthquake, Japan 1995, and the Northridge earthquake, California, 1994. Additionally, a set of sine waves, of different frequencies and amplitudes, were also applied to the tested samples.

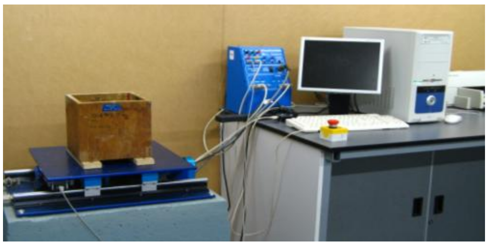


Figure1. Shake table and instrumentation

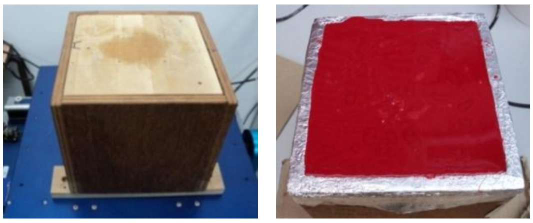
2.2. General description of the tested geo-materials

A soil box was used in order to reproduce the ground conditions, as shown in Figure 2. The box was made of wood, having the dimensions of 200x200x200 mm and weighing 2.888 kg. The soil box was fixed on the shaking table using bolts.

In order to perform the experiment, two different types of materials were used: “ideal” materials and “real” materials. Wood and elastic rubber were used as “ideal” materials. A cohesionless material (sand) and an organic material (peat) were used as “real” materials.

The first test was performed on a solid wood cube of 200x200x200mm, weighing 3.1349 kg which can be assimilated with rocks, being a rigid type of material – Figure 3a.

Figure 2. Wooden soil box



(a) wood (b) rubber

Figure 3. Ideal materials

The second test was performed on a cube made of rubber which was moulded in the shape of the soil box. The dimensions of the cube were 200x200x200 mm and the weigh of the cube was 8.287 kg. The rubber can be associated with cohesive soil due to its elastic characteristics – Figure 3b.

In order to perform the tests on the shaking table for real materials, two types of sand where chosen, namely a fine sand and a coarse sand – Figure 4a and Figure 4b. For these two types of sand, the maximum and minimum densities, the void ratios and the specific gravities were determined prior the experimental work. The two types of sand were tested using different densities.

The third test was carried out on loose fine and coarse sand. The box was filled with sand up to the top. After that the soil box was vibrated for 1 minute to achieve a relative density and, consequently, the volume of the sand changed. Then the same sand was vibrated for 5 minutes to obtain the maximum density of the initial volume of sand. The void ratios of the sands are presented in Table 1 and the volumes and the densities for each tested sample are shown in Table 2.

In addition to these cohesionless soils, an organic soil was tested on the shaking table, namely a Malaysian peat - Figure 4c. Peat is known as a material with high compressibility and low bearing capacity. In peat layers, low frequencies with higher energy capacities can be transmitted due to low wave velocities (Zainorabidin et al., 2007).

The peat was tested in 3 different states: a) in its natural state, wet and undisturbed, b) wet and compacted and c) dried and undisturbed. Table 3 presents the volumes, weights and densities for each case.

(a) fine sand (b) coarse sand (c) peat

Figure 4. Real materials

Table 1. Sand densities and void ratios

No.	Type of sand	Weight of the soil box (g)	Weight of the sand (g)	Volume of sand (cm^3)	Minimum density of sand (g/cm^3)	Maximum density of sand (g/cm^3)	Minimum void ratio e_{min}	Maximum void ratio e_{max}
1	fine sand	2915.5	11982	8000	1.497	1.701	0.599	0.816
2	coarse sand	2915.5	11619.5	8000	1.452	1.693	0.565	0.824

Table 2. Weight, volume and density for each tested sand sample

No.	Type of sand	Weight of the sand (g)	Initial volume of sand (cm^3)	Settlement after first vibration (cm)	Volume of sand (cm^3)	Relative density of sand (g/cm^3)	Settlement after maximum vibration (cm)	Volume of sand (cm^3)	Maximum density of sand (g/cm^3)
		m	V_i	h_1	V_1	ρ_{rel}	h_2	V_2	ρ_{max}
1	fine sand	11982	8000	2	7200	1.6641	2.8	6880	1.7415
2	coarse sand	11619.5	8000	3.1	6760	1.7188	3.6	6560	1.7712

Table 3. Geotechnical characteristics, volume and weight of the tested peat

Variables	Wet peat	Dry peat	Wet compacted peat
Weight of the soil box(g)	2942.5	2942.5	2942.5
Volume of wet peat(cm3)	8000	-	8000
Volume of dry peat (cm3)	-	5240	-
Volume of compacted wet peat(cm3)	-	-	5520
Weight of peat (g)	5626	1644.5	5626
Water content [%]	346.35	0	346.35
Minimum density	-	0.313	-
Maximum density	0.702	-	-

3. Description of the experimental investigation and results

For the initial tests, two real earthquakes (Kobe, Japan, 1995 and Northridge, USA, 1994) were applied to all soil samples. Additionally, a set of sine waves of different frequencies and amplitudes were applied. For the sine wave analysis, a 20 seconds input duration was applied to determine the response of the materials tested. In order to set the conditions of the sine wave analyses, the following combinations of frequencies (F) and amplitudes of the sine excitations (A) were considered:

F=0.625Hz A=0.5m/s^2,F=0.625Hz A=1 m/s^2
F=0.625Hz A=1.5 m/s^2, F=1 Hz A=0.5 m/s^2
F=1Hz A=1m/s^2, F=1Hz A=1.5 m/s^2
F=1.5 Hz A=0.5 m/s^2, F=1.5Hz A=1 m/s^2
F=1.5 Hz A=1.5 m/s^2, F=2 Hz A=0.5m/s^2
F=2Hz A=1m/s^2, F=2Hz A=1.5m/s^2

These combinations were chosen in accordance with some specifications provided in the Romanian P100-2006 Seismic design Code. Based on the seismic activity and the nature of the foundation soils mentioned in this code, the following relevant natural periods of vibration were selected:

T = 0.7s →F = 1.42 Hz (in the experiment F=1.5 Hz was considered)
T = 1s →f = 1 Hz
T = 1.6s →f = 0.625 Hz

An additional frequency of F=2 Hz was also considered.
Two accelerometers were used to determine the acceleration at the base of the soil sample and at the top of the soil sample. One of them was placed at the base of the shaking table, considered being the 'bedrock', and the other one was placed on the top face of the soil.
Figures 5 to 9 show the increase in acceleration from the bedrock level to the top for the tested materials.
In the case of the sand, several tests were carried out on samples having different densities, starting from a loose state of the sand, going to a relative density, to finish with the maximum density. In this way, the effect of the voids ratio on the response of the materials was studied. Furthermore, in the case of peat, several tests were also performed by varying the water content, starting with a sample of peat which was undisturbed and having its natural water content, then a compacted sample with its natural water content and finally a sample of fully dried peat.
Figures 10 to 14 show the rates of amplification of the response in the maximum acceleration for each tested sample.
For the wooden sample, the maximum rate of amplification for a sine action is 1.44 and for the seismic action is 0.35 for the Kobe earthquake.
For the rubber sample, the maximum rate of amplification for a sine action is 0.78 and for the seismic action is 0.66 for Northridge earthquake.
For the fine sand, a higher rate of amplification was noticed in the loose state than in the compacted state. For the coarse sand exactly the opposite was noted, i.e. a higher rate of amplification for the compacted state than for the loose state was obtained. This results show that, apart from the influence of the void ratio on the wave propagation, a significant role is played by the shape and size of the soil particles.
In the case of peat, the maximum rate of amplification was recorded in the case of the wet peat which behaved in the same manner as the ideal material for cohesive soils, namely rubber.

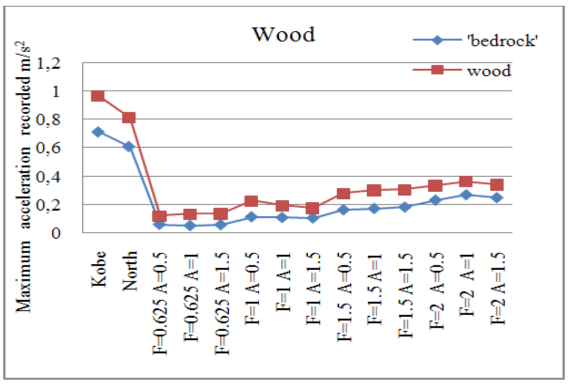


Figure 5. Maximum acceleration-wood sample

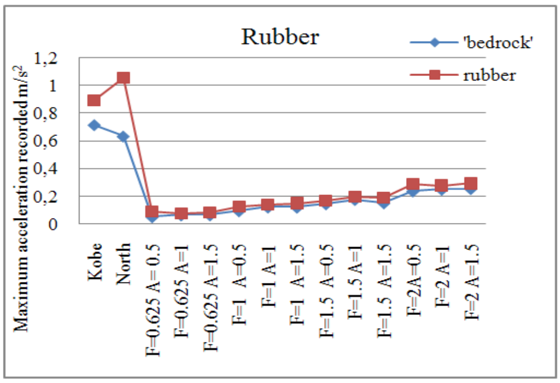


Figure 6. Maximum acceeration-rubber sample

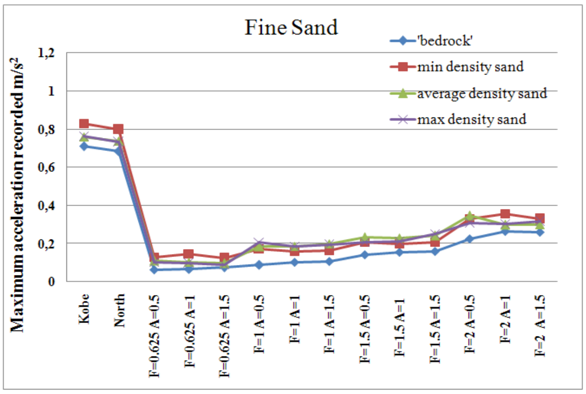


Figure 7. Maximum acceleration-fine sand

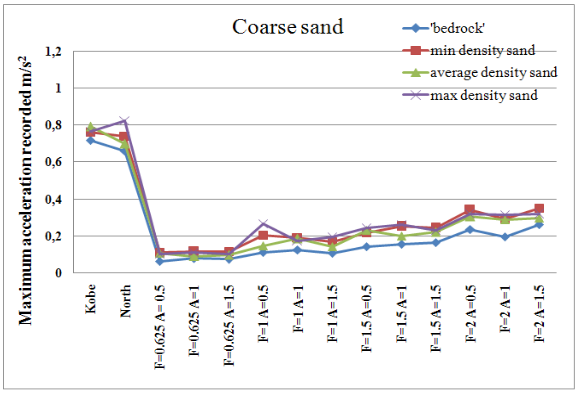


Figure 8. Maximum acceeration-coarse sand

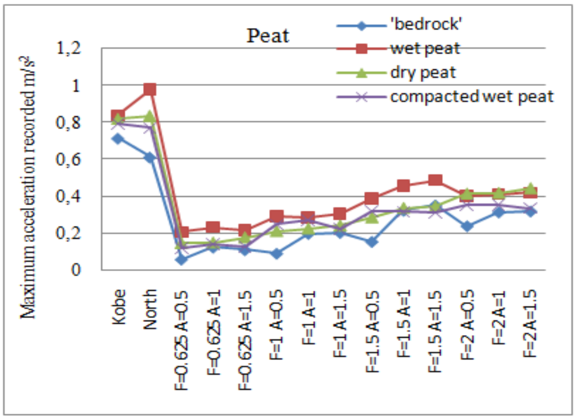


Figure 9. Maximum acceleration-peat

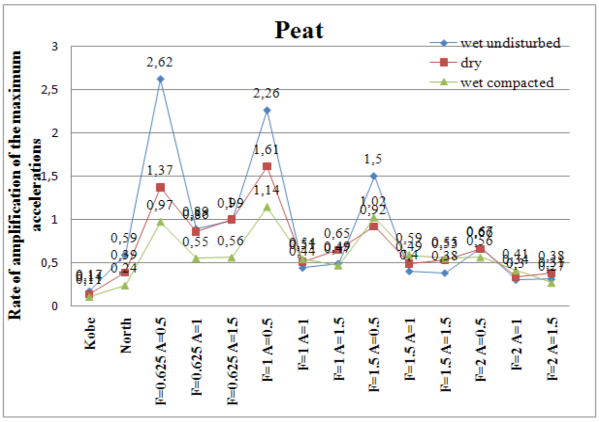


Figure 10. Rate of amplification-peat

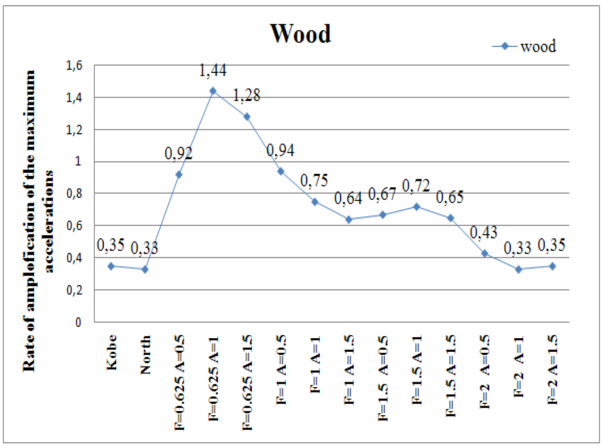


Figure 11. Rate of amplification-wood

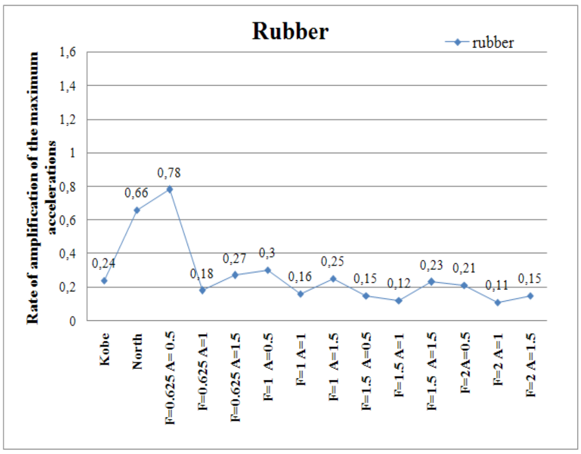


Figure 12. Rate of amplification-rubber

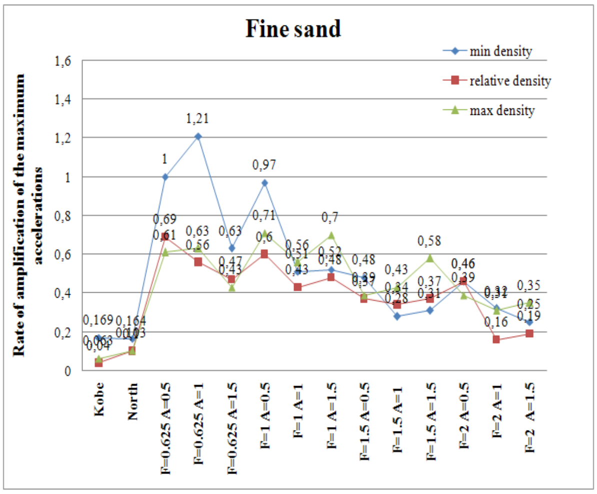


Figure 13. Rate of amplification- fine sand

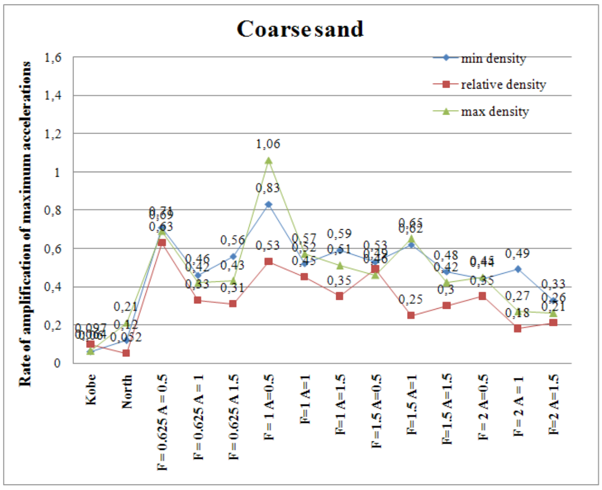


Figure 14. Rate of amplification-coarse sand

4. Conclusions

The paper studies the response in acceleration of four materials (sand, peat, wood and rubber) to seismic excitations and sine waves.

For the wood sample, the rate of amplification of the maximum acceleration varies between 0.33 and 1.44 and in the case of rubber, this rate varies between 0.11 and 0.78. In both cases, the maximum value of the rate of amplification is obtained for the frequency of the sine wave of F=0.625 Hz.

In the case of “real” materials, the rate of amplification depends on both the frequency of the sine wave and the degree of compaction of and the water content in the material.

In the case of the fine sand, the maximum value of the rate of amplification of 1.21 was obtained for the frequency of the sine wave of F=0.625 Hz, for the minimum density of the sand. For the coarse sand, the maximum value of this rate of 1.06 was obtained for the frequency of the sine wave of F=1 Hz for the sand with maximum density.

In the case of the wet peat, the maximum rate of amplification of the maximum acceleration of 2.62 was obtained for a frequency of F=0.625 Hz and the maximum value of this rate for the dry and wet compacted peat was obtained for a frequency of F=1 Hz.

Consequently, based on the results above, two frequencies of the sine waves resulted in the maximum rate of amplification of the maximum acceleration: F=0.625 Hz for wood, rubber, fine sand with minimum density and wet undisturbed peat and F=1 Hz for the coarse sand with maximum density and the dry and wet compacted peat.

The two earthquakes considered resulted in smaller values of the rate of amplification than the sine waves for all the materials considered.

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