Effectiveness of a Trench Filled with Waste Material in Reducing the Propagation of Ground Vibration Induced by Soil Roller Compaction

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Abstract: The vibration generated by construction activities is transferred through soil media to the surroundings and has influence on the surrounding structures. However, the response of the structures may depend on the amount of energy received by them. The objective of this study is to investigate the characteristics of ground vibration induced by soil roller compaction and the effectiveness of waste material in reducing the propagation of the ground vibration.

Several construction sites where soil compaction has been done by rollers were selected for this study. A site with a stone crushing machine which induces ground vibration similar to roller compaction (i.e., frequency and magnitude) was selected for the investigation of the effectiveness of waste material in reducing the propagation of ground vibration. A trench was introduced in the path of vibration wave propagation. The ground vibration was measured by using a four channel seismograph in the open trench and for the trench filled with locally available waste material such as rice husk and bottom ash. When operating a soil roller compactor, ground vibration in the horizontal directions (i.e., transverse and longitudinal directions) are greater than those in the vertical direction. Rice husk, compacted rice husk and bottom ash contributed to the reduction of ground vibration by 38%, 42% and 49% respectively in the transverse direction and by 14 %, 22 %, and 47 %, respectively in the longitudinal direction indicating that rice husk and bottom ash can be effectively used as in-filled damping layers.

Keywords: Waste Material, Ground Barriers, Ground Vibration

1. Introduction

Soil compaction by rollers is common in any construction site. The compaction induces ground vibration causing annoyance to occupants and damages to structures in the surroundings. Due to uncomfortable living conditions induced by construction activities, the number of complaints from the residents near construction sites has recently increased. For example, during the construction work of the southern transport development project, many public complaints were received. The annual environmental impact monitoring report of the Asian Development Bank (ADB) funded section (2009) [1] summarized that the total complaints received up to 30th October 2008 were 1636 in the southern section (Pinnaduwa to Godagama) and 5251 in the northern section (Kurundugahahetekma to Pinnaduwa). Furthermore, it was stated that the highest number of complaints was received for vibrations and damages caused by rock blasting and soil compaction. Residents used to complain about their difficulties in living under the circumstances induced by construction activities. Most significantly, ground vibration

induced by these activities tends to minimize the effective lifetime of the nearby structures.

Ground and structural vibration can be reduced by decreasing dynamic loads from the construction sources (Svinkin [2]). During construction activities, some precautions should be taken to minimize vibration levels. For example, pre-drilling or pre-jetting can be done when pile driving, and small weights can be used for dynamic compaction. However, such precautions may not be applicable to construction activities due to the particular nature of the construction industry. Therefore,

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ground barriers can be used to reduce the propagation of ground-borne vibrations induced by different sources including construction activities.

The screening of elastic waves by using ground barriers in the path of wave propagations can be divided into two categories, viz., active isolation and passive isolation. Active isolation involves a barrier introduced close or near to the vibration source to reduce the wave energy radiated away from the source. Passive isolation involves a barrier located at a point remote to the source but near the site where the amplitude of the vibration has to be reduced. The isolation by ground barriers is based on reflection, scattering, and diffraction of wave energy.

Open trenches are also effective wave barriers because of the minimum transmission of wave energy (Soni [3]). Alzawiet al. [4] have found that for a sinusoidal wave, an open trench and a geo foam barrier have a protective effectiveness up to 84% and 69% respectively. Hunaidi [5] has mentioned that in trenches that are either left open or filled with a material (such as bentonite or concrete) that has stiffness or density significantly different from that of the surrounding soil can also perform effectively as wave barriers. Since this study (Hunaidi [5]) was conducted based on traffic vibrations, permanent in-ground barriers were suggested as preventive strategies. However, in the case of construction activities including soil compaction, the introduction of permanent in-ground barriers is not effective. For practical reasons, it is often difficult and impossible to install and maintain open trenches to the required depths, especially in a country like Sri Lanka where there is heavy rain during the monsoon period. Therefore, it has become essential to provide in-filled trenches. The availability and the properties of the in-filled material are vital factors for the implementation and effectiveness of vibration attenuation.

The objectives of this study are:

- To investigate the characteristics of ground vibration induced by soil roller compaction.
- To investigate the effectiveness of a trench filled with available waste material in attenuating ground vibration

2. Methodology

2.1 Measurements of Ground Vibration

Ground vibration was measured using a tri-axial geophone connected to a seismograph (Blastmate III) (Figure 1 (a)), capable in measuring vibration in vertical, longitudinal and transverse directions up to 254mm/s with a resolution of 0.127 mm/s in the frequency range 2Hz - 250 Hz. The geophone was placed on the ground and its ground spikes were inserted (length of a spike is 65mm) into the ground (Figures 1 (b) and (c)). Before measuring, it was programmed to record vibration in the continuous mode and in the fixed time stop mode. Both 'Geo' and 'Mic' trigger sources were selected with the trigger level set up to a moderate value as soil compaction produced a moderate vibration level. This was necessary to avoid recording unwanted minor vibrations induced possibly by walking experimenters. The arrow mark located on the top of the geophone was pointed towards the direction of the source.

Figure 1 - (a) Measuring ground vibration using a seismograph, (b) Installing the geophone using ground spikes, (c) Final installation with ground spikes inserted fully into the ground

2.2 Site Selection

A site where soil compaction was done by operating roller compactors was initially selected for monitoring resulting vibration. Roller compactors have a capacity of 10tons. The geophone was located in such a way that the transverse direction was in parallel to the moving direction of the roller compactor and the longitudinal direction perpendicular to it as shown in Figure 2. In order to identify the change of vibration with distance, ground vibration induced by roller compactors was measured at three different distances (3m, 6m & 8m) from the source (Figure 2). These distances were selected by considering the feasibility of conducting field measurements.

Figure 2 - Measuring ground vibrations induced by soil compaction

A stone crushing site where ground vibration had similar values in frequency and magnitude as those of the vibration induced by soil compaction, was selected for the investigation of the effectiveness of waste material in damping ground vibration. Ground vibration was measured when the crusher was operating without crusher feed. This was necessary because the stone crusher generates continuous ground vibration with steady frequencies and magnitudes when there is no feed. When there is a feed, generated ground vibration varies depending on the size and other properties of the feed and the crushed product.

2.3 Trench filled with Waste Material

A damping layer was introduced by using a trench filled with locally available waste material across the path of the wave propagation. At the selected site, a trench having dimensions 900 mm x 400 mm x 600 mm (Figure 3) was excavated, approximately 2 m away from the source of vibration. The dimensions of the trench were such that it was the largest that could be excavated under practical conditions prevailing at the site. To investigate the effectiveness of the trench with filling material, dimensions were kept constant.

The geophone was located in such a way that the transverse direction was parallel to the length of the trench and the longitudinal direction perpendicular to it. The vibration that was measured before excavating a trench at a particular location (L1) (Figure 3) was considered as the control vibration, in order to determine the effectiveness of the filling material. Ground vibration was measured at the same location (L1) both when the trench was open and when the trench was filled with different materials, viz., rice husk and bottom ash (Figure 4).

Figure 3 - Arrangement of the damping layer

Rice husk used was a light-weight material collected from a local rice mill. When measuring ground vibration, rice husk was fully dry. The trench was filled using rice husk under two different conditions: un-compacted and compacted. Compaction was done by filling the trench with three layers with each layer properly compacted by using a sledge hammer. Bottom ash, which is a waste material obtained from coal combustion, was collected from the Norochcholai Coal Power Plant. It is a hard and light-weight material, identified as a good alternative for sand and cement (Kadametal. [6], Anthony et al. [7]).

Figure 4 - Measuring ground vibration with the damping layer

Since the locations of the source and the measuring station were same throughout the measuring period, (i.e., without the trench, with the open trench, and with the trench filled with

material), it was assumed that constant site conditions (i.e., soil type and soil profile) were maintained throughout the measurements.

2.4 Analysis

In order to determine the attenuation of ground vibration due to the presence of barriers, Root Mean Square (RMS) of the ground acceleration was determined.

For each filling material, ground vibration particle velocities that were measured for a time period of 10 s (ten continuous records of 1 second), were converted into acceleration(a_i : acceleration value of particular time step) using Equation (1).

$$a_i = (v_{i+1} - v_i) / \Delta t \quad \dots\dots\dots(1)$$

Where, v_i and v_{i+1} are particle velocity readings at time step i and $i+1$, respectively, and Δt is the sampling time (i.e., 1/1024 s).

Since the ground vibration is continuous, in order to obtain a more reasonable comparison among the dynamic characteristics of filling material, the Root Mean Square (RMS) value was considered. The Root Mean Square (RMS) of particle acceleration in each direction was determined using Equation (2).

$$RMS = \sqrt{\sum_{i=1}^n a_i^2 / n} \quad \dots\dots\dots(2)$$

Where, a_i is the acceleration value of a particular time step and n is the number of steps within the measured time period. All vibration measurements were retrieved using Blastware 10 software and time responses and frequency responses were determined. The attenuation of vibration was quantified by calculating the percentage in the reduction of the RMS acceleration in each direction with respective to the ground acceleration determined for the control condition (i.e., no trench)

3. Results and Discussion

3.1 Characteristics of Ground Vibration

Characteristics of ground vibration induced by soil roller compaction were investigated and compared with ground vibration induced by a stone crusher in time history (Figure 5) and frequency spectrum (Figure 6). Both sources of vibration induced continuous ground vibration at similar magnitudes (Figure 5) and a similar

range of frequencies(i.e., low frequencies) (Figure 6). For both sources, the vibrations in the horizontal directions (i.e., transverse and longitudinal directions) was greater compared to the vibration in the vertical direction (Figure 5(a) and (b)). A dominant ground motion in the horizontal directions is also evident in the frequency response spectrum: the highest amount of energy is observed in transverse and longitudinal directions (Figure 6(a) and (b)). Therefore, any method that effectively attenuates ground vibration induced by stone crushers will also be effective in attenuating ground vibration induced by soil roller compaction, which is a frequent source of ground vibration in civil engineering construction sites.

Figure 5 – Time history of induced ground vibration (a) by roller compaction (b) by stone crusher

Figure 6 (a) – Frequency spectrum of induced ground vibration (a) by roller compaction at 6m distance from Roller Compactor 1; (b) by stone crusher

The magnitudes of ground vibration induced by the two roller compactors are found to be similar. For example, at a 6m distance the Roller compactor 1 induced peak particle velocities (PPV) in the range of 2 mm/s - 7.41 mm/s (RMS of acceleration in the range of 0.2 m/s^2 - 0.7 m/s^2) while that induced by the Roller compactor 2 is 2.13 mm/s - 3.92 mm/s (RMS of acceleration is in the range of 0.2 m/s^2 - 0.4 m/s^2), considering all three directions. Similar magnitudes of ground vibration have been reported in previous studies (Wanniarachchi et al. [8], Hanson et al. [9]). At the 1m to 20m distance range, peak particle velocities (PPV) of ground vibration induced by soil compacting were found to be in the range of 0.64 mm/s - 2.60 mm/s. (Wanniarachchi et al. [8]). At 7.6m distance, the PPV of ground vibration induced by a vibratory roller was found to be 5.3 mm/s (Hanson et al. [9]). Therefore, measuring ground vibration induced by two roller compactors might be adequate to ascertain the characteristics of ground vibration.

3.2 Effectiveness of Waste Material as a Damping Layer

When the trench was filled with different materials, energy in the ground motion concentrated at a frequency same as that of the control vibration, at 15.5 Hz for transverse

direction and at 20.5 Hz for vertical and longitudinal directions. Therefore, a direct comparison with the Root Mean Square (RMS) value of ground motion with different filled materials is appropriate and will indicate the effectiveness of the damping layer. RMS values of ground accelerations which were determined for a time period of 10 s, with different ground barriers are presented in Table 1. The layer that has been introduced on the path of the vibration propagation contributes to a reduction in the magnitude of ground vibration in all three directions: vertical, transverse and longitudinal.

In the transverse direction, the ground acceleration of $108.79 \text{ mm/s}^2(\text{rms})$ has been reduced to 88.86 mm/s^2 with an open trench. The transverse ground vibration is further reduced to 67.06 mm/s^2 , 63.24 mm/s^2 and 55.21 mm/s^2 , with the trench filled with rice husk, compacted rice husk and bottom ash respectively. For all materials, the trend in reducing ground vibration was also found in longitudinal direction. For example, without a damping layer, ground acceleration is 140.43 mm/s^2 while it was reduced to 134.53 mm/s^2 with an open trench. Longitudinal ground vibration was further reduced to 120.63 mm/s^2 , 108.92 mm/s^2 , and 74.40 mm/s^2 , with the trench filled with rice husk, compacted rice husk and bottom ash respectively.

Table 1 - Ground acceleration for different filling materials

Filling material	Transverse		Longitudinal		Vertical	
	Ground Acceleration r.m.s. (mm/s ²)	% reduction	Ground Acceleration r.m.s. (mm/s ²)	% reduction	Ground Acceleration r.m.s. (mm/s ²)	% reduction
No trench (control)	108.79	-	140.43	-	57.52	-
Open trench	88.86	18	134.53	4	55.62	3
Rice husk	67.06	38	120.63	14	49.77	13
Rice husk (compacted)	63.24	42	108.92	22	47.10	18
Bottom ash	55.21	49	74.40	47	44.61	22

In the vertical direction, the ground acceleration of 57.52 mm/s² was reduced to 55.62 mm/s² with an open trench, and to 49.77 mm/s², 47.10 mm/s² and 44.61 mm/s², with a trench filled with rice husk, compacted rice husk and bottom ash respectively.

For each filling material, transverse and longitudinal vibrations were significantly reduced (e.g.: a maximum of 49% and 47% reduction in transverse vibration and in longitudinal vibration respectively) compared with vertical vibration (e.g.: a maximum of 22% reduction). Variations in vertical vibration with different materials were less compared to those in transverse and longitudinal vibrations (Table 1). For bottom ash, vertical vibration was reduced by 22%, while for rice husk and compacted rice husk it was reduced by 13% and 18% respectively. Transverse vibration was significantly attenuated by the trench that was filled with compacted rice husk and bottom ash.

Vibration reduction can be attained by increasing the damping capacity (expressed by loss tangent) and/or by increasing the stiffness (expressed by storage modulus) of the material (Chung [10]). The loss modulus, which is defined as the product of the above two quantities, is an indicator of the vibration attenuation. In the present study, it was found that rice husk was effective in screening vibration in all three directions (Table 1). This might be due to the dynamic and viscoelastic properties of rice husk. It has been found that a composite made of rice husk with granulated cork showed appreciable dynamic properties and the composite could well be a promising

material for vibration isolation (Antonio et al. [11]). Further, Chung [10] mentioned that materials that can be used for vibration damping are mainly metals and polymers due to their viscoelasticity. Ershad-Langroudi et al. [12] found that chopped rice husk affects the viscoelastic properties of polypropylene. Therefore, the performance of rice husk in vibration attenuation in the present study can be due to its viscoelastic properties. All three direction acceleration components were reduced more by compacted rice husk (28% reduction) than by un-compacted rice husk (21% reduction). Therefore, the efficiency of rice husk in vibration screening can be further increased using it in the compacted form instead of the un-compacted form.

When bottom ash was used as a filling material for the trench, vibration propagation was significantly reduced in all three directions (Table 1). This might be due to the higher storage modulus and cementations properties of bottom ash. The major constituent of the bottom ash is Silicon dioxide (SiO₂). Fly ash, which is having a comparable composition to bottom ash was found to increase the storage modulus of compounds (Thanunya et al. [13]). Therefore, bottom ash can also have a higher storage modulus. Although bottom ash is often treated as waste material, it is having appreciable properties to replace part of the cement in a cementitious material (Hopkins et al. [14]). Normally cement based materials have less damping capacity than polymers but their loss modulus is comparable due to high storage modulus (Chung [10]). Therefore, bottom ash may create a stiffer layer in the propagation

path of ground vibration contributing to the screening of the vibration.

During experimentation, the ground vibration generator (e.g. stone crusher) function was assumed to be even. Although a perfect control in ground vibration can be achieved by a mechanical shaker, it would be very expensive because the mechanical shaker artificially generates regular ground vibration. It was not possible to maintain control conditions (e.g. temperature, moisture content of soil) in an open environment throughout the experiments since ground vibration measurements were conducted during different time periods depending on the availability of the materials and the stone crusher. However, these effects will be very small on the characteristics of ground vibration.

4. Conclusions

Characteristics of ground vibration induced by soil roller compaction, and the effectiveness of waste material in reducing the vibration were investigated in this study.

Roller compactors induced continuous ground vibration which is greater in the horizontal direction compared to the vertical direction. Peak particle velocities of horizontal ground vibration can be as high as 7.41 mm/s at a 6m distance from the source.

For a trench that has been introduced in the path of the propagation of ground vibrations, rice husk, compacted rice husk and bottom ash were used as filling material. Bottom ash reduced ground vibration by 49%, 42%, and 29% while rice husk reduced vibration by 38 %, 14%, 13%, in transverse, longitudinal, and vertical directions respectively, indicating a better damping ability of bottom ash when compared with rice husk. The efficiency in vibration screening of rice husk can be increased using it in compacted form instead of un-compacted form. Rice husk and bottom ash can effectively be used as in-filled damping layers to reduce ground vibration induced by soil compaction. The reduction in ground vibration could be achieved with an open trench, although it is not practical to be used.

Acknowledgement

Assistance and permissions given by the staff of construction sites and stone crushing site, to collect the ground vibration measurement were

appreciated. In addition, the financial support provided by National Research Council (Grant No 11-193) was greatly appreciated.

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