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Investigation on Ground Vibration Induced by Construction Traffic and Normal Traffic

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Abstract: With the development of infrastructure facilities all over the country, many construction activities are carried out causing the construction traffic increased. As a result of movement of heavy vehicles, people feel annoyances so that many complaints against this construction traffic have been arisen. Objective of this study is to investigate the characteristics of the ground vibrations induced by construction traffic and normal traffic.

A road construction site and a road near to stone crusher were selected. Ground vibrations induced by five dump trucks and one vibrating roller at 1m away from the edge of the road were measured using the four channel seismograph. Ground vibration levels experienced during period of construction traffic were greater than that for normal traffic and dominant in vertical direction. When operating a dump truck, Peak Particle Velocity (PPV) of the ground vibration in the vertical direction was in the range of 0.127-1.400mm/s while transverse and longitudinal directions ranges were 0.079-0.730mm/s and 0.127-0.825mm/s, respectively. Maximum vibration range experienced was 2.70-4.16mm/s induced by vibrating roller in vertical direction. Their transverse direction and longitudinal directions vibrations levels ranged from 1.41 mm/s to 2.05mm/s and from 1.49 mm/s to 3.35 mm/s, respectively. Vibrations induced by passenger vehicles ranged from0.079 mm/s to 0.143mm/s in all three directions. People may feel annoyances from construction traffic because the construction traffic moves continuously and induced greater PPV compared with normal traffic.

Key words: Construction traffic, Ground vibration, People annoyance, Seismograph

1. Introduction

Construction traffic has been widely increased in Sri Lanka with the development of infrastructure facilities around the country. Heavy vehicles are moving and several construction activities are performing in construction processes. Significant ground vibration levels were reported from construction activities including rock blasting [1] pile driving and soil compaction [2], although movements of heavy vehicles including dump trucks, vibrating rollers, excavators and backhoe loaders are very common in and around construction sites. Due to these unlimited movements of heavy vehicles, vibrations are induced on the ground. Those vibrations propagate towards the building as well as humans.

There are three types of seismic waves; compression waves (P), shear waves (S) and surface waves (R). Among these waves, surface waves propagate with high intense towards humans and buildings and result annoyances and failures on them [3]**.** It has been found that 26% of the energy transmitting through these waves goes into shear waves, 7% goes into compression waves (longitudinal waves) and 67% of input energy goes into surface waves (Rayleigh waves) [4]. It proves that higher amount of input energy transmits through Rayleigh waves.

People, who live in the area, where infrastructure facilities are being developed, experience annoyances due to ground vibration induced by construction traffic. Among the annoyances and damages that people have to face, 37% of the people have experienced annoyances and damages due to the vibrations induced by construction traffic and 8% were seriously bothered [5]. Therefore many complaints have been arisen against the vibrations induced by construction traffic. When implementing the Southern Transport Development Project (STDP) in Sri Lanka, among 424 complaints which were received to the contractor of this project, China Harbour Engineering Company, upto December, 2008, 61 complaints (14%) have been recorded due to the vibration induced by movement of heavy vehicles. It was only seconded to the complaints arisen

against ground vibrations due to pilling, heavy machinery (91 complaints, 21%) [6]. As part of the resource consent process, there is an increasing requirement for road controlling authorities and their consultants to establish whether or not vibrations generated during road construction will be problematic to structures, buildings and occupants of these buildings so that management of such vibrations can be specifically addressed in the construction management plan.

Typically, these vibrations are more likely to cause annoyance. Vibrations may be unacceptable to occupants of buildings because of annoying physical sensations produced in the human body, interference with activities such as sleep and conversation, rattling of window panes, loose objects and fear of damage to the building and its contents. This emphasizes the need to investigate characteristics of ground vibrations induced by construction traffic, in order to reduce the annoyance to people.

2. Objectives

Objective of the current study is to investigate the characteristics of the ground vibration induced by construction traffic and to compare them with the characteristics of ground vibration induced by normal traffic.

3. Methodology

The ground vibrations were measured using a four channel seismograph (Figure 1) which is capable of measuring ground vibrations in all the three directions (i.e., transverse, vertical and longitudinal). Seismograph consists of a standard transducer which senses the ground vibrations propagating through the ground where the transducer is located. The ground spikes were screwed into the bottom of the standard transducer and pushed fully into the ground. The standard transducer, geophone, was leveled on the ground and the arrow mark located on the top of the standard transducer was pointed in the perpendicular direction to the movement of a heavy vehicle which induces the ground vibration. Before measuring vibration, the instrument was set up to the standard mode.

For measuring the vibration induced by construction traffic, it was selected three sites: a highway construction site, a road near to stone crusher and a normal transportation road. The selected sites were free from vibrations induced by other sources.

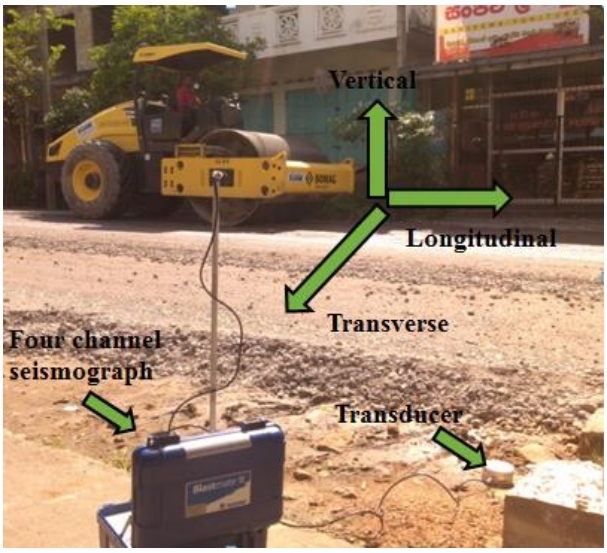

Figure 1 : Measuring ground vibration induced by a vibrating roller

To investigate the vibration induced by construction traffic, it was mainly considered two types of heavy vehicles: dump truck and vibrating roller. In the case of measuring ground vibrations induced by normal traffic, it was selected 4 types of vehicles; car, van, three wheel and bus. The vehicle induced ground vibration was measured at 1m away from the edge of the road. This distance was selected because if the distance to the measuring point was more than 1m away from the road, there were many obstacles which might be capable of damping the vibrations propagating through them.

For investigation of vibration induced by dump truck, measuring was performed for 5 types of dump trucks. When measuring the vibration, it was ensured that the minor vibration from the other sources and the disturbances from the surrounding environment were controlled up to minimum level. . When measuring vibration induced by a vibrating roller (Figure 1), only one vibrating roller was selected and vibration induced at five different working capacities was measured. The working capacities were based on the induced vibration levels and the moving speeds of the vibrating roller. The operator was instructed to move the vibrating roller by changing the speed and the level of vibrations induced on the road. Among the ground vibrations induced at various working capacities, it was selected highest five vibrations records induced by the vibrating roller. The magnitude of vibration is presented by peak

particle velocity (PPV) in the unit of mm/s. However, as the effect of vibrations induced by movement of heavy vehicles lasts for a certain time, in addition to PPV, root mean square (rms) value was also determined. PPV presents the maximum velocity of the vibrations propagated during the time period of one second while rms presents the root of square of all the vibration induced during the period of one second. It might not be appropriate to relay on only the PPV induced by vehicles since during the time of one second which the seismograph records, it is possible that the surrounding vibrations may superimpose with the vibration induced by vehicle at the time when the vibrations are measured. As a total representative of the vibrations induced by vehicles throughout one second, rms indicates reliable and acceptable results.

4. Results and Discussion

Peak particle velocity (PPV) and root mean square (rms) of the ground vibration induced by five different types of dump trucks are shown in Tables 1 and 2, respectively. The ground velocity waves induced by dump truck 4 (i.e., DT4) is shown in Figure 2.

Table 1 : Peak particle velocity of vibration induced by dump trucks

Dump Truck	Trans. (mm/s)	Vert. (mm/s)	Long. (mm/s)
DT 1	0.730	1.400	0.825
DT 2	0.079	0.143	0.143
DT 3	0.127	0.222	0.254
DT 4	0.460	1.290	0.825
DT 5	0.111	0.127	0.127

DT: Dump Truck

When moving a dump truck, ground vibration represented in PPV in vertical direction is generally higher than other two directions (Figure 2, Table 1**).** However, dominant vertical ground vibration induced by each dump truck is evident in magnitudes presented by rms. (Table 2). The maximum vibration level induced by a dump truck was 1.4mm/s (PPV) (Table 1) and 0.451mm/s (rms) (Table 2) in vertical direction. The vibration range in vertical direction was from 0.127mm/s to 1.4mm/s (PPV), (from 0.037mm/s to 0.451mm/s (rms)) while for transverse and longitudinal directions they were in the range of 0.079mm/s - 0.730mm/s (PPV) (0.023mm/s - 0.265mm/s (rms)) and 0.127mm/s -0.825 mm/s (PPV) (0.035mm/s - 0.302mm/s (rms)), respectively. Vibrations in the level of 0.3 mm/s to 1 mm/s might be perceptible in residential environment (BS 5228-2 [7]). Since the dump trucks induce the vibration with the magnitude greater than 0.3 mm/s, people who are exposure to the vibrations induced by dump truck will percept the vibration and experience annoyances. It will cause complaints against construction traffic.

Table 2 : Ground Vibrations induced by dump trucks in rms

Dump Truck	Transverse (mm/s)	Vertical (mm/s)	Long. (mm/s)
DT 1	0.265	0.451	0.302
DT 2	0.023	0.037	0.041
DT 3	0.035	0.062	0.057
DT 4	0.138	0.314	0.225
DT 5	0.030	0.039	0.035

DT: Dump Truck

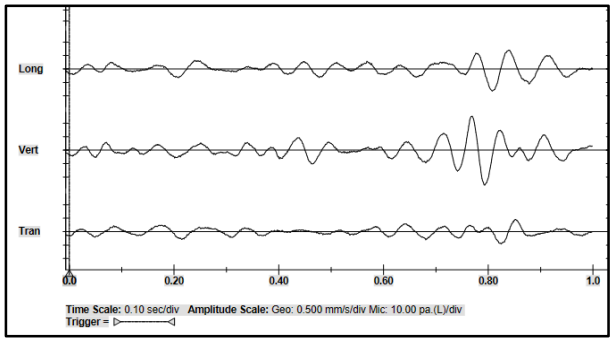

Figure 2 : Ground velocities induced by a dump truck (DT4)

Peak particle velocity (PPV) and root mean square (rms) of the ground vibration induced by a vibrating roller at different working time are listed in Tables 3 and 4, respectively. The ground velocity waves induced by vibrating roller at working time 1 (w.t.1) is shown in Figure 3.

Table 3 : Ground Vibrations induced by vibrating roller in rms

Vibrating roller	Trans. (mm/s)	Vert. (mm/s)	Long. (mm/s)
w.t.1	1.73	3.71	2.40
w.t.2	1.70	3.40	2.25
w.t.3	1.41	2.70	1.49
w.t.4	1.75	4.16	3.35
w.t.5	2.05	4.00	2.78

w.t.: working time

Similar to dump trucks, vibrating roller induced significant ground vibrations in vertical direction

compared with other two directions (Figure 3, Tables 3 and 4). The maximum vibration level induced by a vibrating roller is 4.16mm/s (PPV) (Table 3) (2.808mm/s (rms) (Table 4)) in vertical direction. Vibration level in vertical direction ranged from 2.70mm/s to 4.16 mm/s (PPV) (from 1.207 mm/s to 2.808mm/s (rms)) whilst it was from 1.41mm/s to 2.05mm/s (PPV) (from 0.634mm/s to 1.091mm/s (rms)) and from 1.49 mm/ to 3.35mm/s (PPV) (0.598mm/s to 1.970mm/s (rms)) in transverse and longitudinal directions, respectively. The minimum vibration level induced by vibrating roller is 1.41 mm/s (PPV) which is even higher than the maximum vibration induced by dump truck (1.4 mm/s (PPV)). The vibration induced in the range of 1mm/s to 10 mm/s (PPV) is very hard to tolerate for the people (BS 5228-2 [7]). Even minimum level of the ground vibration (1.41 mm/s (PPV)) induced by vibrating roller is greater than 1mm/s. People who are exposure to this level of vibrations induced by vibrating roller would hardly tolerate the perceptions and annoyances. They will tend to make complaints against the ground vibrations induced by the construction traffic.

Table 4 : Ground vibrations induced by a vibrating roller in rms

Vibrating roller	Trans. (mm/s)	Vert. (mm/s)	Long. (mm/s)
w.t.1	0.968	2.318	1.370
w.t.2	0.770	1.993	1.085
w.t.3	0.634	1.207	0.598
w.t.4	0.856	2.808	1.970
w.t.5	1.091	2.610	1.606

w.t.: working time

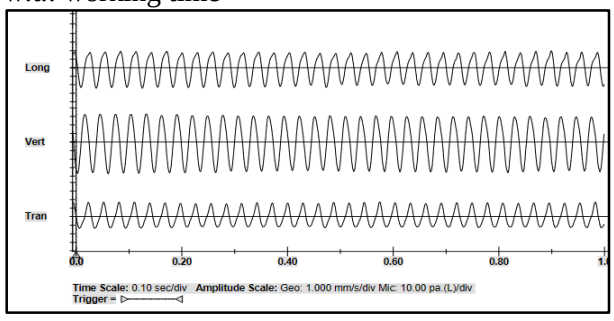

Figure 3 : Ground velocity induced by vibrating roller at working time 1

PPV and rms of the ground vibrations induced by normal traffic (consists of car, van, three wheel and bus) is shown in Tables 5 and 6, respectively.

Table 5 : Ground Vibrations induced by normal traffic in PPV

Vehicle type	Trans. (mm/s)	Vert. (mm/s)	Long. (mm/s)
Car	0.079	0.143	0.127
Van	0.111	0.143	0.143
Three wheel	0.111	0.127	0.111
Bus	0.079	0.127	0.127

Table 6 : Ground Vibrations induced by normal traffic in rms

Vehicle Type	Trans. (mm/s)	Vert. (mm/s)	Long. (mm/s)
Car	0.024	0.035	0.034
Van	0.034	0.036	0.026
Three wheel	0.022	0.029	0.025
Bus	0.025	0.043	0.040

Ground vibration induced by normal traffic (i.e., car, van, three wheel and bus) is approximately equal in all the three directions: transverse, vertical and longitudinal, considering both PPV and rms values (Tables 5 and 6). The maximum vibration level induced by normal traffic was 0.143mm/s (PPV) (Table 5) and 0.043 mm/s (rms) (Table 6). Ground vibrations induced by normal traffic varied from 0.079mm/s to 0.143mm/s (PPV) (0.022mm/s to 0.043mm/s (rms)) considering all the three directions. Vibration up to 0.14 mm/s (PPV) might be just perceptible in the most sensitive situations for most vibration frequencies associated with construction (BS 5228,[7]). Although some components of vibrations (0.143 mms/ (PPV)) induced by normal traffic slightly exceeded the limit recommended in BS 5228 -2 [7] (0.14 mm/s (PPV)), most of the vibrations are below the just perceptible limit.

The dominant vertical frequency contents of the vibrations induced by dump trucks are shown in Table 7.

Table 7 : Frequency content of the ground vibrations induced by dump truck

Dump Truck	Trans. (Hz)	Vert. (Hz)	Long. (Hz)
DT1	2	2	2
DT2	13.5	16	38
DT3	18.5	18.5	53.5
DT4	13	15	15
DT5	16.5	11	12

Unlike vibrating roller, the frequency component of the ground vibrations induced by dump truck is not limited to a single frequency (Figures 4, 6 and Table 8). Vibrating roller induces ground vibration in a single frequency (34.5Hz) (Figure 5 and Table 8) while each dump truck generates frequency range which is unique to particular dump truck. Since dump trucks induced dominant vibrations in vertical directions, the dominant frequency in vertical direction ranged from 2Hz to 18.5Hz which is a lower frequency range that makes high perception to people (Table 7).

Table 8 : Frequency range of the ground vibration induced by construction traffic and normal traffic

Vehicle Type	Trans. (Hz)	Vert. (Hz)	Long. (Hz)
Dump truck	2-18.5	2-18.5	2.53.5
Vibrating roller	34.5	34.5	34.5
Car	95.5	22	54.5
Van	92	90	92
Three wheel	94.5	55	54.5
Bus	12.5	17.5	36.5

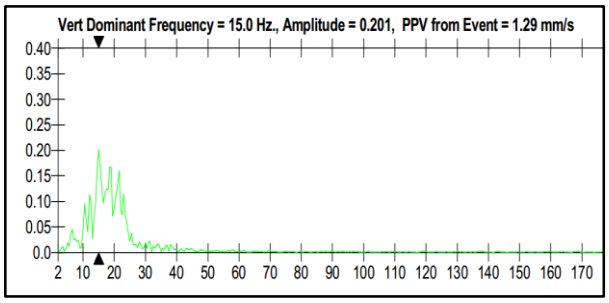

Figure 4 : Fast Fourier Transformation (FFT) of the vertical ground vibration induced by Dump Truck (DT) 4.

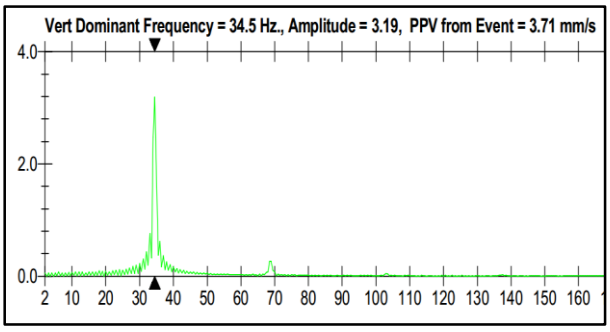

Figure 5 : Fast Fourier Transformation (FFT) of the vertical ground vibration induced by a vibrating roller at working time (w.t.) 1.

Therefore, people might have felt annoyances due to ground vibration at these low frequencies and tended to make complains against ground vibrations induced by construction traffic.

In previous studies, the significant component of ground vibration has been found in transverse direction for construction activities [8]. However, this study confirms that construction traffic induced ground vibration, which is dominant in vertical direction. Unlike ground vibration induced by normal traffic (0.079mm/s-0.143mm/s (PPV)) people may experience more annoyances due to ground vibrations induced by construction traffic (exceed even 4mm/s (PPV)).

5. Conclusion

In this study, the ground vibrations due to construction traffic were investigated and compared with that of normal traffic.

It was found that when construction traffic is on the move, it induces dominant vertical ground vibration. Unlike construction traffic, the ground vibrations induced by normal traffic show minor discrepancy between three directions (i.e., transverse, vertical and longitudinal). Among dump truck and vibrating roller, vibrating roller induces greater PPV of 4.16 mm/s compared to that of dump truck (1.4 mm/s). The ground vibration induced by construction traffic exceeds the minimum perceptible level of 0.3mm/s. The normal traffic induces vibrations range from 0.079 mm/s to 0.143 mm/s (PPV) which is significantly lower magnitude compared to ground vibrations induced construction traffic.

Dump trucks generate ground vibrations in the frequency range of 2-53.5H while vibrating roller owns single frequency of 34.5 Hz, when they are on the move. People may feel annoyances because construction traffic moves continuously and induced ground vibration with greater magnitude at lower frequencies compared that with normal traffic.

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References

[1]. Wickramasinghe,S.A.N.S.,Masakorala,S. R., Jayasinghe, E.A.T.P., Subashi De Silva, G.H.M.J. and De Silva,G.S.Y.,"Effect of Blast Vibration on Wall Panels", Transactions, Annual Sessions of the Society of Structural Engineers, Sri Lanka, November, 2011, pp. 23-28

[2]. Jayawardhana, W.A.P.D., Jayawardhana, B.M.B.H.,Subashi De Silva, G.H.M.J. and De Silva, G.S.Y., "Investigation on Characteristics of Vibration Induced by Soil Roller Compaction and Effectiveness of Damping Layer to Reduce the Vibration", Special Session on Design & Construction, Proceedings of 5th International Conference on Sustainable Built Environment (ICSBE-2014),Kandy, Sri Lanka, December, 2014, pp. 129-136.

[3]. Haramy, K.Y. and Henwood, J.T., "Vibrations induced by Construction Traffic", Case study, Federal highway administration, Denver ,2002.

[4]. Gutowski, T.G. and Dym, C.I., "Propogation of Ground Vibration", Sound and Vibration, 1976, vol. 49, pp 179-193.

[5]. Watts, G.R., "Traffic Induced Vibrations in Buildings", Research, Department of transport, Berkshire, 1990.

[6]. Southern Transport Development Project, "Environmental Impact Monitoring", Annual report, 2008.

[7]. BSI, "Code of practice for noise and vibration control on construction and open sites – Part 2 : Vibration (BS 5228-2:2009)".

[8]. Wanniarachchi, W.A.M., Welhena, C.M., Subashi De Silva, G.H.M.J.and De Silva, G.S.Y., "Investigation of Characteristics of Vibration induced by Construction Activities and its Effects on Structural Responses", Proceedings of International Conference on Structural Engineering and Construction Management (ICSECM-2013), Kandy, Sri Lanka, December 13-15, 2013, paper no. SBE/13/141.