Analysis of Ground-Borne Vibrations due to Piling Operations and Risk Zonation

De Seram P.S.P.S.W., Indika L.G.V., Athapattu A.M.H.S.M., *Samaradivakara G.V.I. and Hemalal P.V.A.

Department of Earth Resources Engineering, University of Moratuwa, Sri Lanka

*Corresponding author – drsamaradivakara@gmail.com

Abstract

Due to paucity of land for construction and the highest valuableness of lands in urban areas, construction activities are broadly carried out neighboring to existing buildings. Pile driving is the most common foundation technique used to transfer the load of a building or a structure to the hard layer of soil or rock. These activities are source of ground vibrations affecting human life as well as existing buildings or structures. Ground-borne vibration and noise levels have been monitored at a pre-cast piling site closer to the Thermal Power Station at Kerawalapitiya using a blast vibration monitoring instruments in this study. The main objective of this research is to produce the risk zonation to the surrounding humans, buildings and infrastructures from the pile driving location. Nuisance to human and comfort level of workers are analysed as per British and ISO standards respectively, and possible damages to existing buildings and structures are discussed according to Swedish and Indian Standards, in this study.

Keywords: Ground vibration, Nuisance to people, Piling impact, Structural damages

1 Introduction

References to ancient piling include the Swiss Lake Dwellers around 6000 years ago, thought to have built structures on piled foundations. Greek and Roman engineers used piles for the shore works at many places along the Mediterranean coast. In Britain, a Roman bridge spanned the Tyne at Corbridge, about 20m West of Newcastle on Tyne, using piles to support the structure and a bridge across the Thames, in AD60, was built on timber piles. Piling is an essential part of building works to ensure strong foundations and prevent the risk of any future subsidence or ground movement [1]. Basically, a pile is a cylinder of a strong material such as concrete that is pushed into the ground or generate through the ground vertically to act as a steady support for the structures built on top of it. A weak soil layer cannot withstand the load of a building. Therefore, the loads of the building have to bypass through this weak layer up to a layer of stronger soil or rock present below the weak layer of soil [2].

Vibration from piling operations will always be of temporary nature, but the disturbance caused may result in substantial nuisance to the surrounding population and permanent damage to property. Either factor might lead to restraints on the working method that result in additional costs or even, in extreme circumstances, curtailment of activity. It is vital for the feasibility of piling works to be assessed at all stages in the development of a site (i.e. concept, design, tender, construction) [3].

Peak Particle Velocity (PPV) is a measure of the damage potential of vibration – the velocities themselves do not cause structural damage or human disturbance. In the case of building damage, it is the resulting dynamic strains that are of concern . Human distress is often linked to acceleration level . However, the PPV parameter is easy to measure and correlates well with the measured effects of ground-borne vibrations [4].

Anyhow, ground-borne vibrations due to piling can be reduced by several methods such as provision of cut-off trenches, reduction of energy input per blow, pre-boring for driven piles, use of variable moment vibrators [5].

2 Methodology

2.1 Site Selection

A pre-cast driven piling site using impact piling method near Thermal Power Station at Kerawalapitiya, Sri Lanka, which is surrounded by industrial buildings, was selected for this investigation.

2.2 Data Collection

Radial survey method was identified as the best suitable method for ground vibration and noise surveying. Ground Vibration (GV) and noise data were collected by a vibration monitoring instrument. Three radial lines such that each two having 60^0 angles was proposed to collect data with 5m distance interval as given in Figure 1. For that, three linen tapes were laid from the piling location (Figure 1), and selected locations were marked using metal pegs.

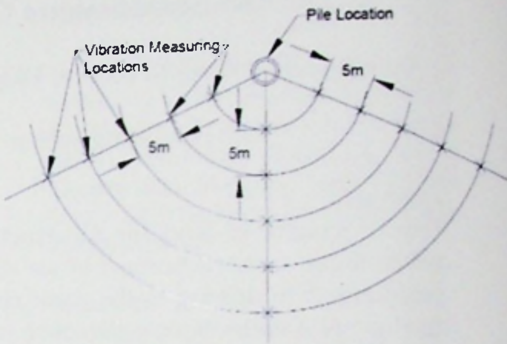

Figure 1: Survey Plan for Measuring Ground-Borne Vibration at Site.

Vibration and noise data were collected using two methods:

- Analysis of ground-borne vibration and over noise data with increasing of distance from the piling location.
- Analysis of ground-borne vibration and noise data at 20m distance from piling location (fixed) with respect to the subsoil layer types.

2.3 Ground-Borne Vibration Level Analysis

Ground vibration data was analysed using three methods:

1. Comparing PPV values recorded according to British Standards for assessing of human nuisance from pile driving.
2. Calculating Vibration Dose Values (VDV) using recorded PPV values to asses workers comfortability as per ISO Standards.
3. Analysing PPV values to asses probable effects on nearby buildings or structures according to Swedish and Indian Standards.

According to BS 5228-2:2009, Peak Partical Velocity values are divided in to four conditions as per different human sensitivity levels (Table 1).

Table 1: Human Sensitivity Level for Ground Vibration as per BS 5228-2:2009.

Condition	Vibration Level (mm/s)	Effect
1	0.14 - 0.3	People are less sensitive to vibration.
2	0.3 - 1.0	Vibration might be just perceptible in residential environments.
3	1.0 – 10.0	Cause complaints, but can be tolerated if prior warning and explanation has been given to residents.
4	>10.0	Vibration is likely to be intolerable for any more than a very brief exposure to this level.

Vibration Dose Value (VDV) is a parameter that combines the magnitude of vibration and the time for which it occurs, which it gives a more representative value for the exposure of workers to vibration. It is calculated by Equation (1).

$$VDV = 51.6 \times PPV \times t^{0.25} \text{......Eq. (1)}$$

Where,

VDV = Vibration Dose Value ($m/s^{-1.75}$)

PPV = Peak Particle Velocity (m/s)

t = Total duration of vibration exposure (s)

According to ISO 2631, VDV are divided in to five conditions with different comfort reaction to workers.

Table 2: VDV Level for Workers Comfortability, as per ISO 2631.

Condition	VDV ($m/s^{-1.75}$)	Comfort reactions
A	< 0.315	Not uncomfortable
B	0.5 - 1	A little uncomfortable
C	0.8 - 1.6	Uncomfortable
D	1.25 - 2.5	Very uncomfortable
E	> 2.0	Extremely uncomfortable

Swedish Standards SS 02 542 11 (SIS 1999) defines the limit value V, which is taken to be the maximum acceptable value. If this value is not exceeded, damage to buildings and their foundation is unlikely to occur. Here, vibration must be measured at the building foundation level in the closest location from the piling site. There are four factors that are considered for the Guidance Level of vibration velocity, V(mm/s) calculation.

$$V = V_0 F_b F_m F_g \text{........................Eq.(2)}$$

Where,

- V = Guidance level of vibration velocity (mm/s)
- V_0 = Vibration velocity based on soil type (mm/s)
- F_b = Building Factor
- F_m = Material Factor
- F_g = Foundation Factor

Table 3: Vibration Velocity (V_0) for Different Soil Types as per SS 02 542 11 (SIS 1999).

Soil type	Piling, Sheet piling or Excavation	Compaction work
Clay, Silt, Sand or Gravel	9	6
Glacial till	12	9
Bedrock	15	15

Table 4: The Building Factor (F_b) Depends on the Susceptibility of the Building as per SS 02 542 11(SIS 1999).

Class	Type of structure	Building factor
1	Heavy structures such as bridges, quay walls, defense structures etc.	1.70
2	Industrial or office buildings	1..20
3	Normal residential buildings	1.00
4	Especially susceptible buildings and buildings with high value or structural elements with wide spans. Eg; Church or museum	0.65
5	Historic buildings in a sensitive state as well as certain sensitive ruins	0.50

Table 5: The Material Factor (F_m) Depends on Vibration Sensitivity of the Structural Material as per SS 02 542 11 (SIS 1999).

Class	Type of building material	Material factor
1	Reinforced concrete, steel or wood	1.20
2	Unreinforced concrete, bricks, concrete blocks with voids, light weight concrete elements and masonry	1.00
3	Light concrete blocks and plaster	0.75
4	Limestone	0.65

Table 6: The Foundation Factor (Fg) Depends on Type of Foundation as per SS 02 542 11 (SIS 1999).

Class	Type of foundation	Foundation factor
1	Spread footings, raft foundations	0.60
2	Buildings founded on shaft – bearing piles	0.80
3	Buildings founded on toe – bearing piles	1.00

According to IS 14881 - 2001, effect on nearby buildings/structures was analysed due to ground-borne vibration, based on vibration frequency values (Table 7).

Table 7: Effect on Nearby Buildings or Structures Due to Ground-Borne Vibration Depends on Frequency as per IS : 14881-2001.

Structure type	Frequency Value(Hz)	PPV Value(mm/s)
Older homes and Historic buildings	Below 10	5
	10-100	5 - 30
Engineered Structures	Below 40	5 - 30
	40-100	25 - 75

3 Results and Discussion

3.1 Assesing of Nuisance to Surrounding People from Pile Driving

Analyzed PPV levels from different distances to asses human sensitivity and nuisance due to ground vibration is given in Table 8.

Table 8: Human Sensitivity to Different Level of Ground Vibration Conditions.

Distance from piling location(m)	PPV(mm/s)	Condition
5	17.212	4
10	9.859	3
15	4.683	3
20	2.605	3
25	2.018	3
30	1.600	3
35	1.421	3
40	1.451	3
45	1.391	3
50	1.156	3
55	1.009	2
60	0.942	2
65	0.791	2
70	0.647	2
75	0.552	2

The variation of PPV with the distance from the piling location is graphically represented in Figure 2.

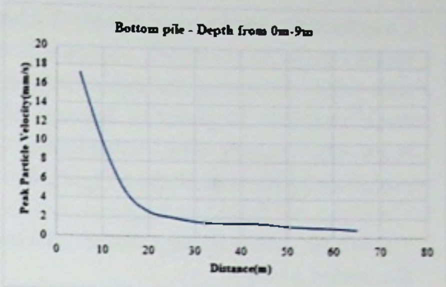

Figure 2: Variation of PPV with Distance from the source of GV.

Human sensitivity zone in response to the ground-borne vibration in the piling site investigated is graphically represented in Figure 3.

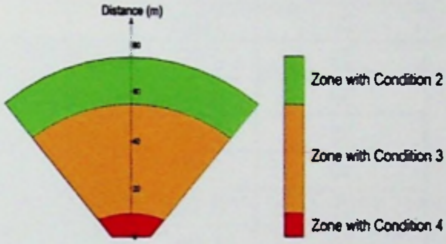

Figure 3: Human Sensitivity Zones at the Piling Site.

Preferable comfort level according to British Standards is below 1 mm/s. As per data analysis, the allowable PPV level is recorded from 55m from the piling location. Therefore, minimum separation between piling location and the people who lives in the surrounding area should be 55m to ensure least disturbance to them.

3.2 Assesing Workers' Comfortability from VDV Calculations

- Total time taken for driving one pile = 25 minutes
- Amount of piles driven per day= 3
- Total exposure time to ground vibration = 25 × 3 × 60 = 4500s

Calculated Vibration Dose Values from recorded PPV values from different distances to asses workers comfortability is given in Table 9, and comfort zone for workers is graphically represented in Figure 4.

Table 9: Vibration Dose Values Recorded at Site.

Distance from the piling location (m)	VDV ($m/s^{-1.75}$)	Condition
5	7.274	E
10	4.167	E
15	1.979	D
20	1.101	C
25	0.853	B,C
30	0.676	B
35	0.601	B
40	0.613	B
45	0.588	B
50	1.489	B
55	1.426	B
60	0.398	B
65	0.334	A
70	0.273	A
75	0.233	A

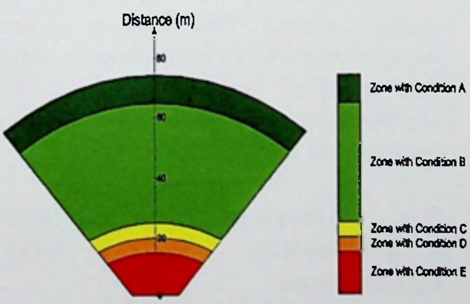

Figure 4: VDV Zone in the Site.

Assessing of workers comfortability is done by Vibration Dose Value calculations which depends on total exposure time to ground vibration as per ISO standards. Calculated total exposure time is 4500s. Preferable comfort level with least uncomfortability to workers is 0.5 $ms^{-1.75}$ - 1 $ms^{-1.75}$. Allowable VDV level was recorded at a distance of 25 m from the piling location as per the data analysis.

3.3 Effect on Nearby Buildings According to Swedish Standards

- Velocity of vibration based on soil type (Vo) - Clay, silt, sand or gravel = **9** mm/s (Table 3)
- Type of building material (Fm) - Reinforced concrete, steel, or wood =**1.20** (Table 4)
- Type of structure (Fb) - Industrial or office buildings = **1.20** (Table 5)
- Type of foundation (Fg) - Buildings founded on toe-bearing piles (Up to bed rock) = **1.00** (Table 6)
- V = (9 * 1.20 * 1.20 * 1.00) = **12.96 mm/s.**

Therefore, recorded value of GV of 12.96 mm/s was within the distance of (5-10)m from the pile driving location.

3.4 Effect on Nearby Buildngs According to Indian Standards

Vibration frequency value data were collected by means of a "Micromate" instrument and observed frequency range during piling at this site was 17-38Hz. Since all the buildings around the site are well-engineered structures, the favourable frequency range is 40-100Hz (Table 7).

4 Conclusions and Recommendations

As per the findings of this study, following conclusions and recommendations can be made.

- Minimum distance from the source of GV to avoid human nuisance = 55m

As per BA 5228-2:2009 code, vibration level greater than 1mm/s is caused nuisance to surrounding people. Therefore, at this site, that allowable vibration level was recorded at 55m distance from the piling point. So the recommended separation between piling location to surrounding people on this site is 55m.

- Minimum distance for workers comfortability from piling point = 25m.

As per ISO 2631 code, Vibration Dose Value level greater than 0.8 $m/s^{-1.75}$ affects badly for workers health. Therefore, the minimum distance of 25m should be maintained between piling location and workers. VDV level would be lesser if the workers exposure time to the GV could be minimized.

- Minimum distance to nearby buildings/structures from piling point to avoid damages = 5-10m [Swedish standards].

As per SS 02 542 11 code, calculated particle velocity value of soil is 12.96 mm/s considering soil type at the building site, building type, material type and the foundation type of the building/structure. Hence, 12.96 mm/s is generated from 5-10 m distance from the piling location.

- Acceptable ground vibration to nearby buildings/structures from piling point to avoid damages = 25mm/s [Indian standards].

As per IS 14881-2001 code, although the vibration level is higher, if its frequency is in the given frequency range, it would not cause damages to buildings/structures. The measured frequency during piling at this site is 17-38 Hz. Since all the buildings around the site are well-engineered structures, and the favourable frequency range is 40-100 Hz. The PPV value as per Indian Standards recommendations is in the range of 25 mm/s - 75 mm/s. The maximum ground vibration recorded at the site is 19 mm/s. Therefore, it would not cause any structural damages to the buildings near this site. Hence, even higher frequency could be applied to the site investigated in this study.

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