# ANALYSIS OF VIBRATION LEVELS AT NEARBY STRUCTURES DUE TO ROAD CONSTRUCTION ACTIVITIES

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Master of Engineering in Highway & Traffic Engineering

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# DECLARATION OF THE CANDIDATE AND SUPERVISOR

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# ABSTRACT

## Analysis of Vibration Levels at Nearby Structures Due to Road Construction Activities

The purpose of this research is to analysis of vibration levels at nearby structures due to road construction activities.

Vibration caused various types of structural damages and it may finally affect the project progress. Although, there are systems to control these issues, it is reported that available systems are not reliable, effective and systematic. Even though, there are many research studies about quantitative vibration studies, nobody presented systematic holistic solution for these problems. Main Objectives of this research is propose a vibration management plan prior to the start of construction and evaluate current vibration standards of Sri Lanka and propose suggestion to improvements. Firstly, existing vibration and structure damage monitoring systems of Sri Lanka and other countries were studied. Secondly data regarding existing system from experience site and Highway engineers were collected. Finally, vibration was monitored when do major vibration generation road construction activities which used heavy vibrator rollers.

Damages due to vibration depends on structure type, vibration value and affected time period. Those factors are taken into account to establish a vibration management plan. This vibration management plan will provide fair solution to both parties who take vibration consequences in construction and contractors. For the survey, hilly terrain area road section with various subgrade conditions is used.

On the basis of the results of this research, it can be concluded that vibration limits are exceeded its damage limits in nearby structure and current boundary limits are not in optimum range and it should change with structure condition and subgrade strength. Furthermore, Sri Lanka standard of vibration limits for construction vibration should be revised after proper analyze. According to this research analyze Type 1, Type2 and Type 3 structures prescribed limits easily can be increased up to higher limits. It will be helpful to contractor to do undisturbed work without contradicting government rules and regulation. As a result, sustainability of the road project can be improved. According to questionnaire survey 84 % engineers think existing system should improve to meet sustainable road development and 85% engineers think vibration monitoring system is required for construction activities.

This research generated two major outcomes which are very valuable to road construction sector. Those are vibration contour map for various type of compaction activities and various subgrade conditions. Secondly, vibration management plan which can use to minimize vibration related structures damage in road construction.

Key words: Vibration, Compaction, Structure.

# TABLE OF CONTENTS

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF ABBRIVIATIONS

ABC - Aggregate Base Course

PPV - Peak Particle Velocity

DT -Dump Truck

BS -British Standards

DCP -Dynamic Cone Penetrometer

CBR -California Baring Ratio

# LIST OF APPENDICES

# 1. INTRODUCTION

## 1.1. Background

Ground vibration is the main factor that cause structural damage due to road construction activity. Ground vibration is generated due to road construction activities such as excavation work and progress until operational stage of the road. Ground Vibration affects to various types of structural and cosmetic damages such as cracking of drywall or plaster, doors and windows out of alignment due to shifting of the structure. Subsequently, ground vibration also raises many conflicts between stakeholders of the project, such as contractor and community. Furthermore, it will affect the project progress. Systematic vibration monitoring system and remedial method to minimize the vibration will be helpful to minimize the potential damage due to vibration on the community.

## 1.2. Problem Statements

There are many vibrations related structural damage issues in road construction sector and most of them are continue several years after completion of the project. Even though, there are many research studies about quantitative analyst vibration effects, nobody presented a systematic holistic solution for the problems listed below.

I. Poor reliability of the available systems of the industry.
II. Unavailability of effective vibration monitoring method.
III. Poor public awareness.

Proper vibration and damage monitoring scheme can improve the project progress by eliminating conflicts between stakeholders of the project (contractor and community).

## 1.3. Objectives

Objectives of this research are to minimize the nearby structure damage issues in road construction projects. The key objectives of the research were to:

I. Acquire sufficient information on measured ground-borne vibration levels arising from various forms of road construction operations.
II. Propose a vibration management plan prior to the start of construction.
III. Evaluate current vibration standard of Sri Lanka.

## 1.4. Hypothesis

Existing systems to monitor and control the ground vibration are less effective for sustainable highway projects. Ground vibration is exceeded than allowable limits in nearby structures due to road construction activities.

# 2. LITERATURE SURVEY

There are considerable bodies of local and international research related to ground-borne vibrations generated from road construction activities. For example, Hiller and Crabb (2000) and Crabb and Hiller (2002) measured vibrations from several types of construction equipment in a controlled experiment and at construction sites in the UK. Jackson et al (2007), Hanson et al (2006), Jones & Stokes Associates (2004) and Hendriks (2002) provide state and federal approaches to assessing vibrations from construction equipment in the USA.
The main findings are summarized sub-sections 2.1 of ‘Ground-borne.

## 2.1. Ground- borne Vibration

Three main types of waves are generated when a vibration generated activity is initiated. They include: Compression waves (P), shear waves (S), and surface waves (R). These wave types can be further categorized into body or surface waves. Body waves, which include P and S-waves, propagate through a body of soil or rock while surface waves, also called Rayleigh waves, generally travel along the ground surface. P-waves involve successive compression and dilatations of the materials through which they pass. They are similar to sound waves and the direction of particle motion is in the direction of travel. P- Waves have the ability to travel through both solids and fluids. Shear waves, or S-waves, cause shearing deformations as they travel through a medium. The direction of particle motion is perpendicular to the direction of travel. S-waves cannot travel through fluids, as fluids have no shearing stiffness. [1]

Surface waves result from the interaction between body waves and the ground surface. Surface waves produce large ground motions and transmit large amounts of energy, when compared to body waves. Rayleigh waves are produced by an interaction between S and P-waves and the ground surface. Rayleigh waves have both vertical and horizontal components of particle motion. Construction induced vibrations propagate through the ground primarily by means of Rayleigh waves.

The amplitude of these waves diminishes as the distance from the source increases. This attenuation is due to geometrical spreading and material damping. Geometrical spreading is described as the decline in energy of the expanding surface over which the energy is spread.

Material damping is thought to be the energy required to overcome friction for each cycle of motion, or wavelength. Material damping in soil is related to soil type, moisture content, and soil temperature. Attenuation generally increases with higher frequencies, as a higher frequency will pass through more cycles in the same distance as its lower frequency counterpart. [1]

Rayleigh waves dominate over body waves at large distances for blasting and construction vibrations. As Rayleigh waves only travel on the surface, their energy is spread over a cylindrical area rather than the spherical surface characteristic of body waves, resulting in less attenuation.

### 2.1.1. Vibration Motion

In describing vibration in the ground and in structures, the motion of a particle (i.e., a point in or on the ground or structure) is used. Vibration is an oscillatory motion, which can be described in terms of displacement, velocity, or acceleration. As this motion is oscillatory, there is no net movement of the vibration element, and the average of any of the motion descriptors is zero. Displacement is the easiest descriptor to understand for a vibrating floor, the displacement is simply the distance that a point on the floor moves away from its static position. The velocity represents the instantaneous speed of the floor movement, and acceleration is the rate of change of the speed.

Although displacement is easier to understand than velocity or acceleration, it is rarely used to describe ground-borne vibration. This is because most transducers used for measuring ground-borne vibration measure either velocity or acceleration. Furthermore, the response of humans, buildings, and equipment to vibration is more accurately described by using velocity or acceleration. [17]

### 2.1.2. Vibration Monitoring

The function of vibration monitoring equipment is to measure and record ground motion. Vibration instrumentation consists of a sensor and a recorder. The sensor, or geophone, is made up of three independent units placed at right angles to one another, one in the vertical direction, and the other two in orthogonal horizontal directions (Figure 1). The sensor is essentially an electromagnetic transducer, which converts ground motion into electrical voltage. A wire coil suspended in a magnetic field is contained within the sensor. The coil is suspended in the magnetic field by springs or hinges and is free to move. Ground motions will cause the unit in the geophone to vibrate. Movement of the coil relative to the magnetic field will generate an electrical voltage proportional to the velocity of coil movement. The recorder functions as a transfer mechanism by changing the electrical voltage back into motion. Most portable field equipment combine a small computer with an oscilloscope to serve as the recorder. The oscilloscope can display real time events, while the computer serves as long-term storage. Seismographs typically measure particle velocity, but there are displacement and acceleration seismographs too. Some velocity seismographs can be equipped to produce either a displacement or acceleration record. A typical seismograph produces a visual record of three wave traces, one for each direction of motion. An additional acoustic wave trace may be produced if the seismograph is equipped with a microphone [7]

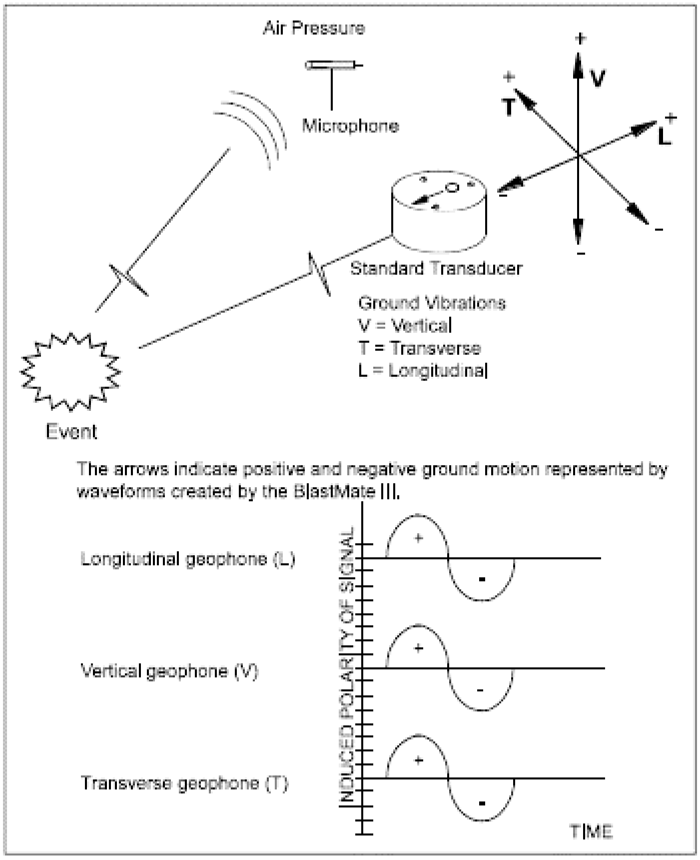



*Figure1 : How the Monitoring instrument monitors an event*

## 2.2. Effects of Ground-borne Vibration

Building vibrations caused by mechanized construction activity are unlikely to be a health and safety concern provided that the distance between the vibration source and the building is sufficiently long.

Vibrations are more likely to cause annoyance and 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 and loose objects

• Fear of damage to the building and its contents.

Experience has shown that people living in buildings are likely to complain even if vibration levels are only slightly above the perception threshold., the major concern being fear of damage to the building or its contents. This tolerance level varies widely from person to person and area to area.

Ground-borne vibration is less disturbing to people who are outdoors. Although the motion of the ground may be perceived, without the effects associated with the shaking of a building, the motion does not provoke the same adverse human reaction.

Vibration levels that cause damage to buildings are an order of magnitude greater than the human perception level. Therefore, the occupants of buildings would find potentially damaging vibrations to be extremely annoying because of high level of vibration. As a consequence, the focus is on managing vibrations to a level in residential environments that is unlikely to cause complaints or less disturbing to residents.

### 2.2.1. Effects of Vibration on Structures

Building components usually have residual strains as a result of uneven soil movement, moisture and temperature cycles, poor maintenance or past renovations and repairs. Therefore, even small vibration levels induced by nearby construction activity could trigger damage by ‘topping up’ residual strains. Consequently, it is difficult to establish a vibration level that may cause building damage and so controversy continues to surround the issue.

In addition to damage cause directly by vibration, indirect damage may result from differential movements caused by soil settlement due to densification. Loose sandy soils are particularly susceptible to densification when subjected to vibration.

Several countries have adopted standards for evaluating the effect of vibration on buildings. A review of international standards identified the following as being the most suitable for providing guidance as to possible building damage from mechanized construction activity: [2]

- German Standard DIN 4150-3:1999 *Structural vibration – part 3: Effects of vibration on structures*.
- British Standard BS 7385-2:1993 *Evaluation and measurement for vibration in buildings, part 2. Guide to damage levels from ground-borne vibration*.
- Swiss Standard VSS-SN640-312a:1992 *Effects of vibration on construction.*
- Sri Lanka standard – Central Environment Authority

#### 2.2.1.1. German Standard DIN 4150-3:1999

Whitlock (2010) found ‘the use of DIN 4150-3:1999 is widespread in New Zealand and it has a history of successful implementation in projects that involve construction activities and/or blasting’. The DIN 4150-3:1999 standard is written around the PPV metric and provides guideline values which, ‘when complied with, will not result in damage that will have an adverse effect on the structure’s serviceability’. For residential buildings, this standard considers serviceability to property have been reduced if:

- Cracks form in plastered surfaces of walls
- Existing cracks in the building are enlarged
- Partitions become detached from load bearing walls or floors.

These effects are deemed to be minor or superficial damage.

The guideline values are different depending on the vibration source and are separated on the basis of short-term and long-term vibration. The DIN 4150-3:1999 standard defines short-term vibration as ‘vibration which does not occur often enough to cause structural fatigue and which does not produce resonance in the structure being evaluated' (reference). Long-term vibration is defined as all other types of vibration not covered by the definition of short-term vibration. In the context of road construction projects, Whitlock (2010) illustrates the difference between short- and long-term vibrations as follows:

*'… the short-term vibration definition would be applied to activities which follow the form of a single shock followed by a period of silence such as blasting, drop hammer pile-driving (ie non-vibratory), dynamic consolidation etc. All other construction activities can be considered as long term'.*

Guideline values for evaluating short-term and long-term vibration on structures from DIN 4150-3: 1999 have been combined in Table 01, as in Whitlock (2010). As shown in Table 01 The DIN 4150-3: 1999 standard recognizes commercial buildings can withstand higher vibration levels than residential and historic buildings. Also, the guideline PPV values increase as the vibration frequency increases. [2]

*Table 1: Vibration guidelines from DIN 4150-3:1999*

| Type of structure | Vibration thresholds for structural damage, PPV (mm/s) | | | | |
|---|---|---|---|---|---|
| | Short term | | | | Long term |
| | At foundation | | | Uppermost floor | Uppermost floor |
| | 0 to 10 Hz | 10 to 50 Hz | 50 to 100 Hz | All frequencies | All frequencies |
| Commercial/industrial | 20 | 20 to 40 | 40 to 50 | 40 | 10 |
| Residential | 5 | 5 to 15 | 15 to 20 | 15 | 5 |
| Sensitive/historic | 3 | 3 to 8 | 8 to 10 | 8 | 2.5 |

The standard also contains criteria for buried pipework as a function of pipe material and the effects of vibration on floor serviceability. , the standard warns that vibration-induced foundation settlement can occur at vibration levels that are normally not expected to cause structural damage. For this to occur, the underlying soil has to be very sensitive to vibration (as in non-cohesive, uniformly graded sand or silt for instance) and the vibration has to be continuous or frequent. Since few investigations have been made regarding dynamically induced settlement, the DIN 4150-3: 1999 standard recommends that expert advice be sought whenever this is considered to be a possible issue. [2]

#### 2.2.1.2. British Standard BS 7385-2:1993

‘BS 7385-2:1993 sets vibration limits based on an extensive review of international case histories. The introduction states that despite the large number of UK case studies involved in the review, “very few cases of vibration-induced damage were found [ 18]
The guideline values in BS 7385-2:1993 are also in terms of PPV and have been summarized in Table 2.

*Table 2: Transient vibration guide values for cosmetic damage in BS 7385-2:1993*

| Building category | Type of building | Peak component particle velocity in the frequency range of predominant pulse | |
|---|---|---|---|
| | | 4Hz to 15Hz | 15Hz and above |
| 1 | Reinforced or framed structures. Industrial and heavy commercial buildings. | 50mm/s at 4Hz and above | |
| 2 | Unreinforced or light framed structures. Residential or light commercial type buildings. | 15mm/s at 4Hz increasing to 20mm/s at 15Hz | 20mm/s at 15Hz increasing to 50mm/s at 40Hz and above |

Note 1. Values referred to are at the base of the building

Note 2. For building category 2, at frequencies below 4Hz, a maximum displacement of 0.6mm (zero to peak) should not be exceeded.

Comparing the guideline values in Table 1 with those in Table 2, it is apparent that the BS 7385-2:1993 standard is significantly less stringent than the German standard DIN 4150-3: 1999. Also, there is no specific provision for historic or sensitive structures in British Standard. These types of structures are addressed by the following clause in the British standard:

*"Important buildings which are difficult to repair may require special consideration on a case-by-case basis. A building of historical value should not (unless it is structurally unsound) be assumed to be more sensitive."*

This approach to historic structures is quite different from that of DIN 4150-3:1999, which is less definitive with its definition of such buildings and more stringent in its criteria' [18]. Furthermore, The BS 7385-2:1993 standard also provides guidance regarding building damage due to soil compaction. Annex C of the standard states 'soils which have S-wave propagation velocities at around 100m/s start to become vulnerable at PPV values of about 10m/s'. Attention is drawn to loose and especially water-saturated cohesion less soils as these are particularly vulnerable to vibration, which may result in liquefaction. [2]

#### 2.2.1.3. Swiss Standard VSS-SN640-312a:1992

The Swiss Consultants for Road Construction Association (SCRCA) have developed a standard for assessing both transient (blasting) and continuous (other construction equipment) vibrations as shown in Table 3 [19]. The standard takes into account the type of construction and frequency of the vibration source. A category for historic structures is also included.

The vibration level guidelines given in the Swiss standard are regarded as being very conservative [19]. Despite this, the Federal Transit Administration (FTA) has promoted their use during the environmental impact phase to identify potentially problematic locations.

*Table 3: Swiss Standard VSS–SN640–312a construction vibration damage criteria*

| Building Class | Vibration Source | Frequency Range (Hz) | PPV (mm/s) |
|---|---|---|---|
| I | Machinery Traffic | 10-30 | 12.7 |
| | | 30-60 | 12.7 -17.8 |
| | Blasting | 10-60 | 30.5 |
| | | 60-90 | 30.5 -40.5 |
| II | Machinery Traffic | 10-30 | 7.6 |
| | | 30-60 | 7.6 -12.7 |
| | Blasting | 10-60 | 17.8 |
| | | 60-90 | 2.5 -25.4 |
| III | Machinery Traffic | 10-30 | 5.1 |
| | | 30-60 | 5.1 -7.6 |
| | Blasting | 10-60 | 13.7 |
| | | 60-90 | 12.7 -17.8 |
| IV | Machinery Traffic | 10-30 | 3.0 |
| | | 30-60 | 3.0 -5.1 |
| | Blasting | 10-60 | 7.6 |
| | | 60-90 | 7.6 -12.7 |

Key for building Class:

I Building of steel or reinforced,such as factories,retaining walls,bridges,steel towers,open channels,underground cahmbers and tunnels with and without concrete lining.

II foundation walls and floors in concrete,walls in concrete or masonry; stone masonry retaining walls;underground chambers and tunnels with masonry lining;conduits in loose material

III Buildings as previously mentined but with wooden ceilings and walls in masonry.

IV Construction very sensitive to vibration;object or historical interest.

### 2.2.1.4. Sri Lanka standard – Central Environment Authority

In the Sri Lankan Standard related to ground vibrations, buildings are categorized into four different categories (Table 4). Even though the classifications given by international standards are almost same to this standard, the same categories have been divided into sub categories to suite the Sri Lankan situation. [3]

*Table 4: Categorization of Structures according to types of Buildings (Sri Lankan Standards)*

| Category of the structure of the building | | Description |
|---|---|---|
| Resistance to the vibration decreasing ↓ | Type 1 | Multi storey buildings of reinforced concrete or structural steel, with in filling panels of block work, brick work or precast units not designed to resist earthquakes |
| | Type 2 | Two-storey domestic houses & buildings constructed of reinforced block work, precast units, and with reinforced floor & roof construction, or wholly of reinforced concepts or similar, not designed to resist earthquakes. |
| | Type 3 | Single and two-storey houses & buildings made of lighter construction, using lightweight materials such as bricks, cement blocks etc, not designed to resist earthquakes |
| | Type 4 | Structures that, because of their sensitivity to vibration, do not correspond to those listed above 1,2 & 3, & declared as archeologically preserved structures by the Department of Archaeology |

According to that building type vibration limits are defining as in table 5.

*Table 5: Interim Standards for vibration of the Operation of Machinery, Construction Activities and Vehicle Movements Traffic*

| Category of the structure as given in Table 1.1 | Type of Vibration | Frequency of Vibration (Hz) | Vibration in PPV (mm/Sec.) |
|---|---|---|---|
| Type 1 | Continuous | 0 –10 | 5.0 |
| | | 10-50 | 7.5 |
| | | Over 50 | 15.0 |
| | Intermittent | 0 –10 | 10.0 |
| | | 10 –50 | 15.0 |
| | | Over 50 | 30.0 |
| Type 2 | Continuous | 0 -10 | 2.0 |
| | | 10-50 | 4.0 |
| | | Over 50 | 8.0 |
| | Intermittent | 0 –10 | 4.0 |
| | | 10 –50 | 8.0 |
| | | Over 50 | 16.0 |
| Type 3 | Continuous | 0 -10 | 1.0 |
| | | 10 - 50 | 2.0 |
| | | Over 50 | 4.0 |
| | Intermittent | 0 - 10 | 2.0 |
| | | 10 – 50 | 4.0 |
| | | Over 50 | 8.0 |
| Type 4 | Continuous | 0 - 10 | 0.25 |
| | | 10 – 50 | 0.5 |
| | | Over 50 | 1.0 |
| | Intermittent | 0 – 10 | 0.5 |
| | | 10 - 50 | 1.0 |
| | | Over 50 | 2.0 |

#### 2.2.1.5. Summary of all standards

As a summary, all international and local standards can be summarized as table 6 and all structure types generally divided into four categories as in table.

*Table 6: Summary of countries vibration standards 01*

| Type of structure | Indian (>24 Hz) ppv | Australian (ppv) | Hungarian (ppv) | German (10-50 Hz) | British (>15 Hz) (ppv) | AASHTO (ppv) | Swiss (30 -60 Hz) (ppv) | Sri Lanka (ppv) |
|---|---|---|---|---|---|---|---|---|
| Historic interest or other sensitive structures | 5 | 2 | 3 | 3 to 8 | 20 to 50 | 2.5 | 3 | 0.5 |
| Houses and Low rise residential Buildings | 10 | 10 | 5 to 8 | 5 to 15 | | 5 to 7.5 | 5-8 | 2.0 |
| Commercial and industrial Buildings (Two story) | 25 | 25 | 8 to 12 | 40 to 50 | 50 | 10 to 12.5 | 8-12 | 4.0 |
| Commercial and industrial Buildings (Multi story) | | | | | | 25 to 37.5 | 12-18 | 7.5 |

It is clearly see that Sri Lanka vibration standards are very low for all category of buildings.

# 3. METHODOLOGY

The following methodology was adopted to compile a more comprehensive approach to measure ground –borne vibrations and possible remedies.Fistly, literature survey was done studding about vibration standard of world and current practice methods. Moreover, past research also studied to gather knowledge to direct into right direction.

Secondly, questionnaire survey was done under three sections to gather information about current system of the Sri Lanka.After that, acquire sufficient information on measured ground -borne vibration level arising forms of road construction operation.

Finally, develop a system to minimize issues producing vibration management plan and vibration contour maps.

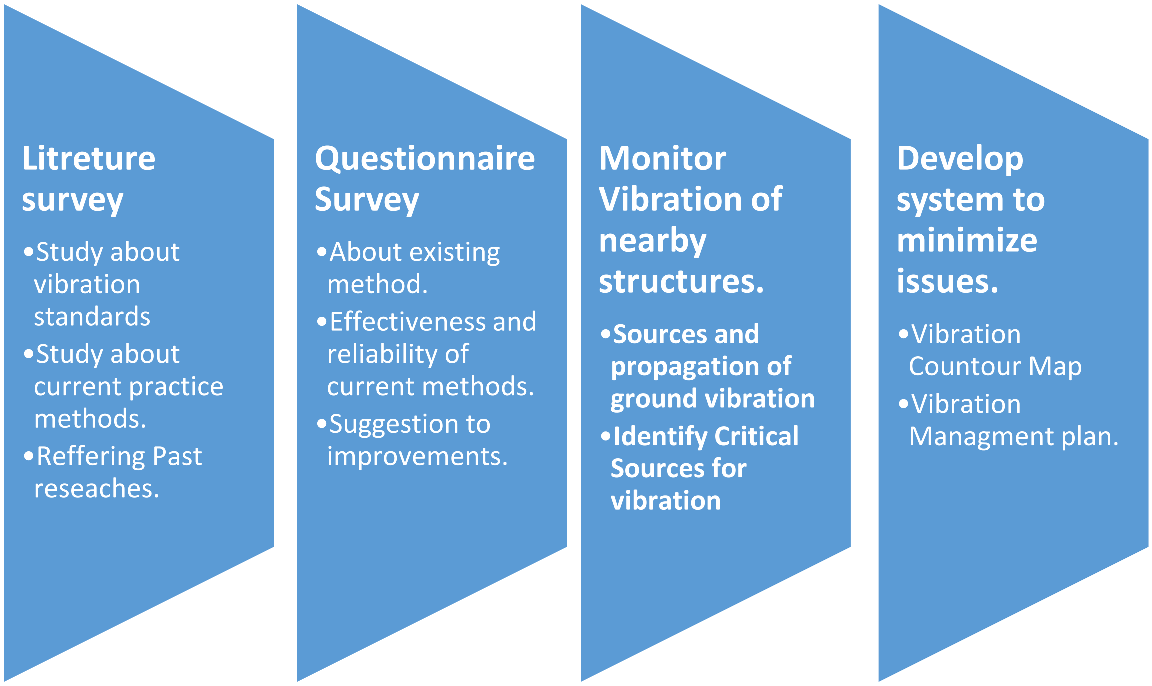



*Figure 2 : Methodology*

### 3.1. Questionnaire Survey (Collect Data from Experience Site/Highway Engineers.)

As per the first phase of the methodology, the following data collected from experience site/Highway engineers, via a questionnaire, under three sub categories.

I. About existing method.

II. Effectiveness and reliability of current methods.

III. Suggestion to improvements.

#### 3.1.1. About existing method.

In this section of the questionnaire, data was collected to understand the current situation related to construction vibrations. The questionnaire consisted of 10 questions for this section and some of are in Figure 3. Complete questionnaire is attached in Appendix 05.

**1 Existing method**

1.1 How many structure damage complains do you received per month?

| 0-5 | 5-10 | 10-15 | >15 | No idea |
|---|---|---|---|---|
| | | | | |

1.2 Who collect the complaints?

| | | | |
|---|---|---|---|
| Site Engineer | | safety officer | |
| Client | | Consultant | |
| Other | | No Idea | |

1.3 What is the ground vibration limit that can cause structural damage?

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| >2mm/s | | >5mm/s | | >10mm/s | | >20mm/s | |

1.4 Do you think ground vibration exceed its limits due to your construction activities?

| | | | |
|---|---|---|---|
| Yes | | No | |

1.5 Is there are any construction vibration monitoring system in your work place?

| | | | |
|---|---|---|---|
| Yes | | No | |

*Figure 3: Questionnaire - Existing method*

### 3.1.2. Effectiveness and reliability of current methods.

This section of the questionnaire was designed to analysis the effectiveness and reliability of the existing system related to construction activities. Both parties of the project (project proponent and affected parties) were questioned in this section for reliability and effectiveness. Figure 04 shows part of the questionnaire relevant to the reliability of current method.

| | | | | |
|---|---|---|---|---|
| 2 | **Effectiveness and reliability** | | | |
| 2.1 | Do you think existing controlling method give fair solutions to affected people? | | | |
| | Yes | | No | |
| | Any other idea | | | |
| 2.3 | Do you think existing controlling method give fair solutions to contractor issues? | | | |
| | Yes | | No | |
| | Any other idea | | | |
| 2.4 | Do you use any vibration reduction measures for construction activities? | | | |
| | Yes | | No | |
| 2.5 | Do you have any idea about structures condition which are situate 50m boundary from construction location ? | | | |
| | Yes | | No | |
| 2.5.1 | If yes, how you know that? | | | |
| | By visual inspection | | | |
| | By pre crack survey report | | | |
| | Any other means (specify) | | | |

*Figure4 : Questionnaire - Effectiveness and reliability of current methods*

#### 3.1.2.1. Suggestion to improvements.

In this section of the questionnaire, Suggestions for improvement of the current system were collected. suggestions identified drawbacks and shortcomings during past projects were recorded in this section to established a best fit system to the industry. Part of the questionnaire shows in Figure 05.

**3 Suggetions for improvements**

3.1 Do you think is there any requirement to do vibration monitoring during constriction activities?

| Yes | | No | | No Idea | |
|---|---|---|---|---|---|

3.1.1 If yes ,what are the reasons?

3.1.2 If no,What are the reasons?

3.2 which party is the best to do pre and post crack survey?

| | | | |
|---|---|---|---|
| Contractor | | Consultant | |
| Third party | | Client | |

3.3 What extend do you agree with the condition survey with pre crack syrvey to catogorize house according to stability?

| | | | |
|---|---|---|---|
| Strongly disagree | | Disagree | |
| Agree | | Strongly agree | |

3.4 Do you think existing system should improve to meet sustainable road development?

| Yes | | No | | No Idea | |
|---|---|---|---|---|---|

*Figure5: Suggestions to Improvement.*

## 3.2. Monitor Vibration of nearby structure.

### 3.2.1. Sources and propagation of ground vibration

Ground vibrations induced by road construction processes may be generated by variations in the forces applied to the ground surface by the process or by acoustic coupling of infra-sound into the ground. The magnitude of these forces is determined by the nature of the work being carried out, the type of machinery or plant in use and the applied load. Road construction activities can be divided into the three phases of earthworks, structures and paving. During the earthmoving phase, the major operations are the formation of cuttings and embankments to achieve the planned vertical alignment of the final road. Material is excavated in the cut area, transported along a haul road and placed in the fill area where it is compacted and graded. The ground vibration characteristics of earthworks machine will depend on whether the machine is tracked or wheeled (with rubber tires) and on the type of operation which the machine carries out. The most common types of earthmoving haulage machines are motorized scrapers and off-highway dump trucks. The motor scraper loads by taking a shallow cut using a cutting edge activated by hydraulic pressure and requires assistance from a tracked dozer. Earthmoving by off-highway dump trucks requires excavation machines in the cut, such as wheeled or tracked tractor shovels. In the fill area, the material is dumped and then spread by a dozer and compactor.

Compaction equipment may be self-propelled or towed, and may rely on dead-weight or a vibratory mechanism to achieve the required compaction. The structures phase involves the construction of bridges, culverts and retaining walls. The machines used in these constructions are tipper -trucks, excavators and cranes, and in some circumstances piling equipment. Paving operations are carried out by specialized paving machines, which require materials to be brought into the site, usually by tipper truck. For the purpose of classifying the vibration caused by different road construction operations, it is convenient to categories the construction machines whether they are: -

(1) Tracked machines, such as dozers, tractor shovels and excavators,
(2) Rubber tired machines, such as motor scrapers, off-highway dump trucks
and tipper Lorries,
*and, (3)* Impacting machines, such as compactors, vibratory rollers and piling
Rigs.

### 3.2.2. Identify Critical Sources for vibration

Tracked machines, such as dozers, tractor shovels and excavators are not travel frequently in the road construction sites to generate ground vibration. Normally, those are travel with aid of heavy machine carriers carious such as prime movers.

Rubber tired machines, such as motor scrapers, off-highway dump trucks and tipper Lorries do not generate higher vibration to exceed specific limits. According to study was held by P.H.D.P. Chandarasiri, G.H.M.J.S. De Silva and G.S.Y. De Silva those machines generated vibration below 1.4mm/s, when measured 1m away from the edge of the road (Table 7). However, compaction rollers do generate higher vibrations than other machines. (Table 8) [4]

*Table 7: 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

*Source: Investigation on Ground vibration induced by Construction Traffic and Normal Traffic.*

*Table 8: 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

*Source: Investigation on Ground vibration induced by Construction Traffic and Normal Traffic.*

Trans – Vibration component to transverse direction

Vert – Vibration component to vertical direction

Long – Vibration component to longitudinal direction

Furthermore, another construction vibration study was done by Federal Transit Administration in 1995 and they presented following table.

*Table 9 :Vibration of Construction Equipment*

| Equipment | Vibration (PPV)mm/s, |
|---|---|
| Vibratory Roller | 5.3 |
| Large Bulldozer | 2.2 |
| Caisson Drilling | 2.2 |
| Loaded trucks | 1.9 |
| Small bulldozer | 0.1 |

Therefore, according to above two studies it is clear that highest vibration is generated from vibrating rollers.

### 3.2.3. Equipment used for Monitor vibration and location

Two equipment were used to take vibration value and GPS coordinate of the location and those instruments are listed and describes below.

- INSTANTEL Blast mate vibration detector.

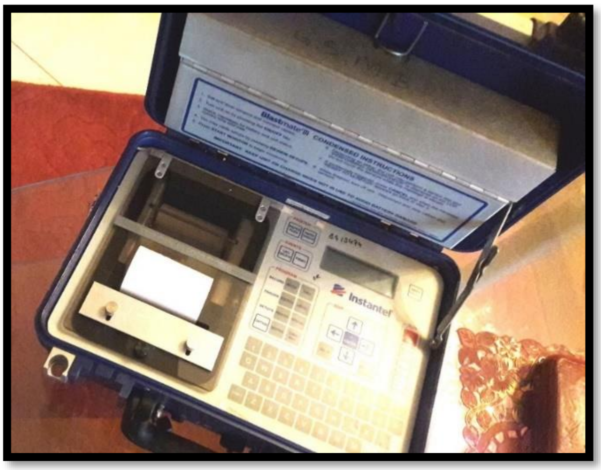


*Figure 6 : Blast mate Vibration detector*

- GPS Instrument

*Figure 7 : GPS co-ordinate monitoring instrument*

## 3.3. Develop sustainable system to minimize issues.

After analyzing all data which was gathered during data collection, the data will be analyzed on the basis of mathematically. Thereafter, an accurate and best fit system will be established to ensure sustainable road development project.

# 4. QUESTINARE SURVEY DATA ANALYSIS

## 4.1. Questionnaire Survey Data Analysis

Questionnaire survey data was analyzed to identify current trends common ideas to develop new system for the industry.

**Question**: How many structure damage complains do you received per month?

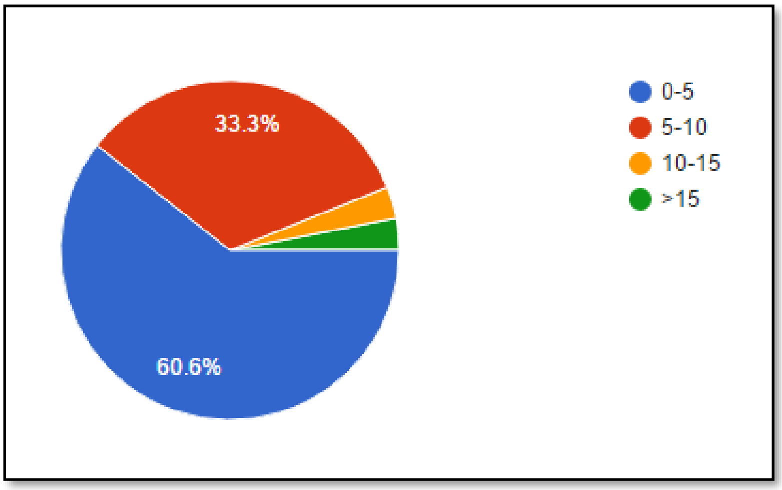



*Figure8 : No of complaint per month*

According to Figure 8, 61 % engineers said they were received 0-5 no of vibration related structure damage complaint per month. Furthermore, 33.3% Engineers received 5-10 vibration related structure damage complaint per month.3% engineers received 10-15 or more than 15, vibration related structure damage complaints per month.

***Question****: Do you think ground vibration exceed its limits due to your construction activities?*

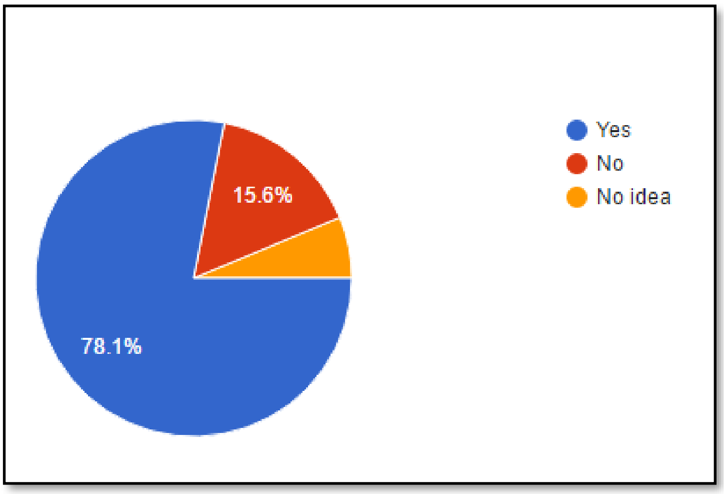



*Figure9 : Vibration exceed its limits or not*

According to Figure 9, 78 % percent of engineers express that vibration exceeds its limits due to their road construction activities. As per the survey most of them understand vibration limits that can cause damage to the nearby structures.

***Question**: Is there are any construction vibration monitoring system in your work place?*

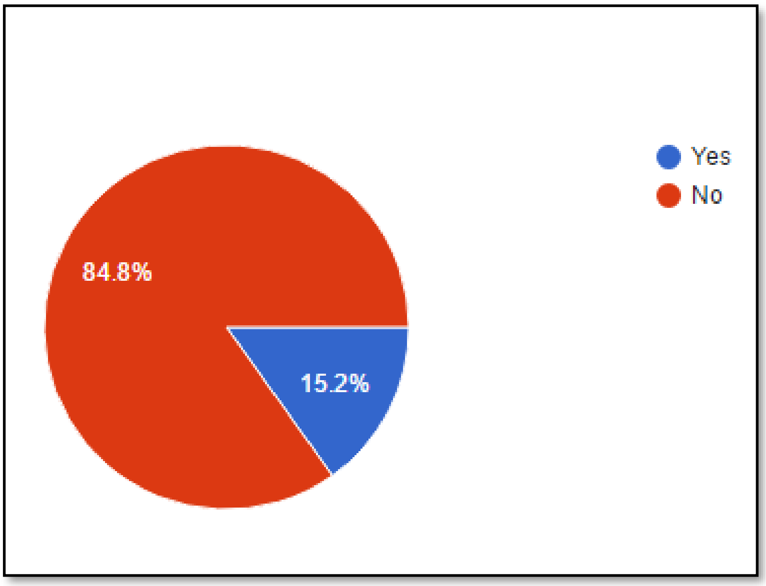



*Figure10 : Availability of vibration Monitoring system*

According to figure 10, 84 % engineers said that they do not have vibration monitoring system in their sites. Some sites are monitor vibration randomly to ensure vibration values are within the range.

***Question**: If your site did pre-crack and post crack survey, who did that?*

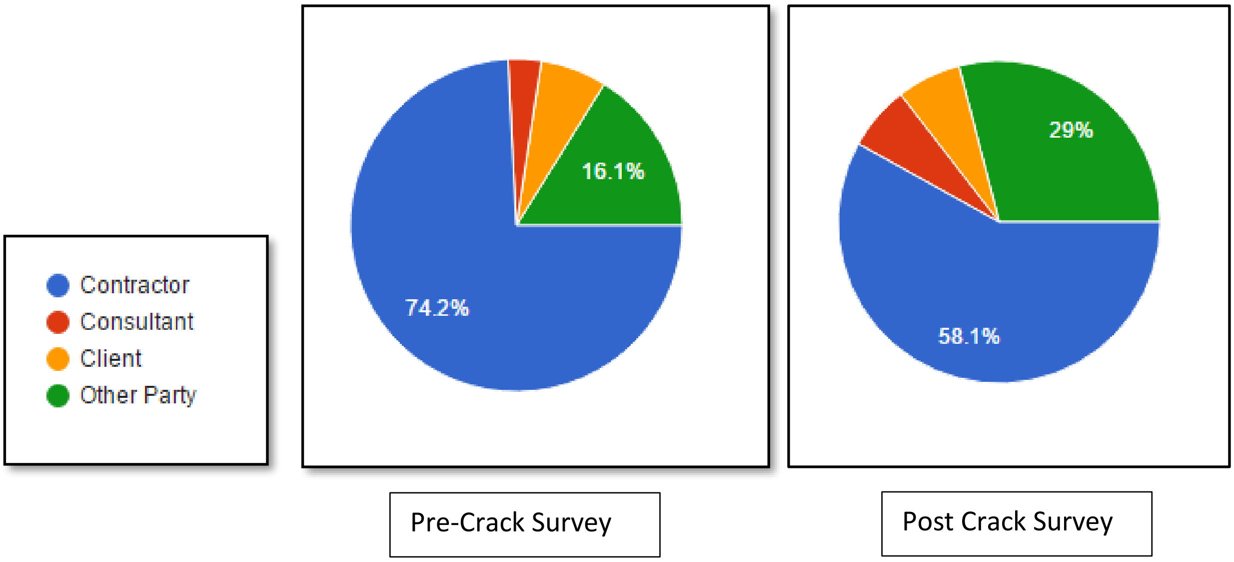



*Figure11 : Party of doing post crack and pre-crack survey*

According to figure 11, it can be said that majority of projects pre- crack survey (Crack observation survey which is done before commencement of the construction works) and post crack survey (Crack observation survey which is done after the construction works) are done by contractor of the project. This can arise unwanted conflicts between project proponent and affected people due to reliability of the data. However, the Sri Lankan road projects follow this above procedure and never get service from an independence third party for the surveys.

***Question**: Do you think existing controlling method give fair solutions to contractor and affected people issues?*

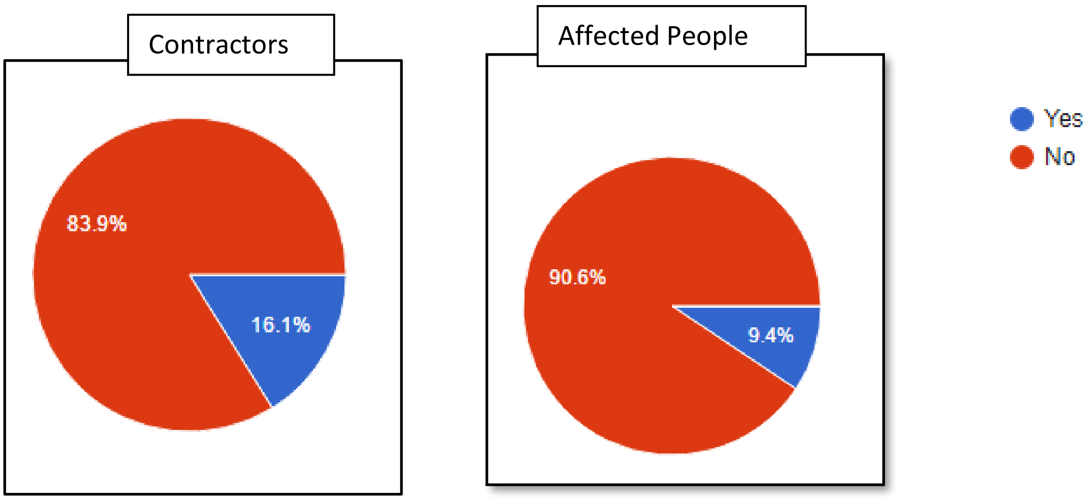



*Figure12 : Effectiveness of the current system*

Figure 12 shows that more than 83 % Engineers emphasize that current system does not provide a fair solution to either affected people or contractor. Therefore. Industry needs a reliable and effective method to overcome the above problems.

***Question**: Do you think is there any requirement to do vibration monitoring during construction activities?*

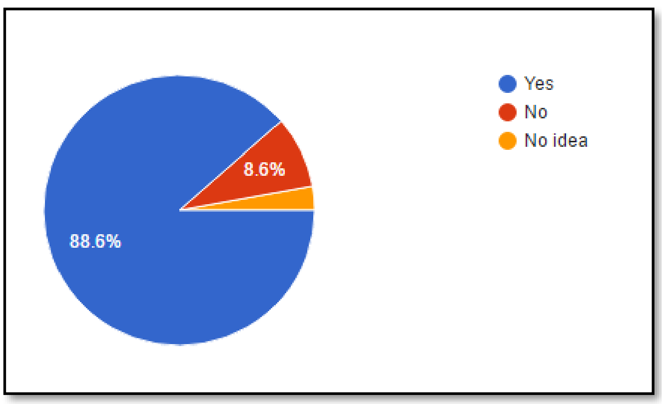



*Figure13 : Construction Vibration Monitoring Requirement.*

Figure 13 shows that about 88 % engineers said that there was a requirement to monitor vibration during construction. Furthermore, they agreed that, with vibration monitoring they can get action to reduced ground borne vibration applying suitable remedial measures.

***Question***: *Do you think existing system should improve to meet sustainable road development?*

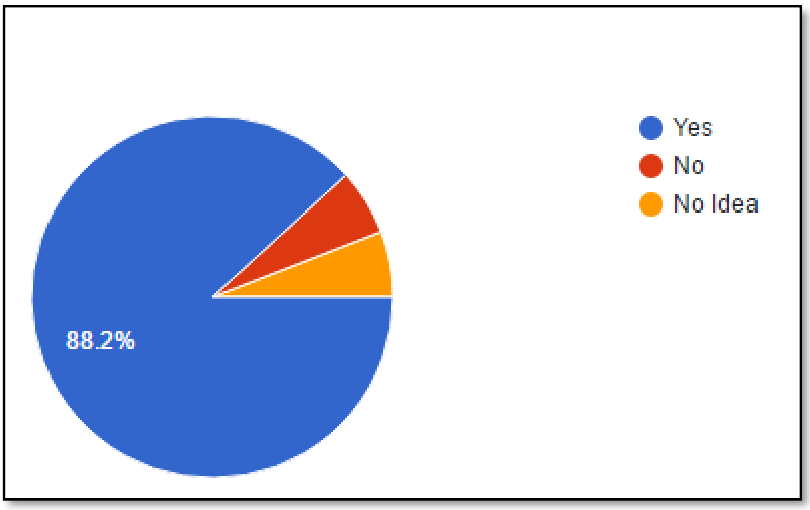



*Figure 14 : Sustainability of the system*

According to Figure14, about 88 % engineers said that existing system should improve to meet sustainable Road development projects.

# 5. STUDY ABOUT CURRENT PRACTICE SYSTEMS

Structures damage complaints data were collected from two past completed projects. Two projects were selected from urban and rural areas. Those data were collected through the safety office of the relevant projects and Both project contractors were Keangnam Enterprises Ltd and Road Development Authority was the Client. Those data were analyzed and understood about the current field practices. In this research, I reviewed about data collected from following projects.

- Gall Road Improvement Project. (Maliban junction to Cross junction )
- Hatton – Nuwaraeliya Road Project

## 5.1. Gall Road Improvement Project. (Maliban junction to Cross junction)

Figure 15 shows that distribution of complaint received by contractor. In this project, contractor received about 62 structural damage complaints and out of 62 complaints 37 are due to construction vibrations. Out of that 37 complains only 10 settled and 27 unsettled. (Appendix 1).

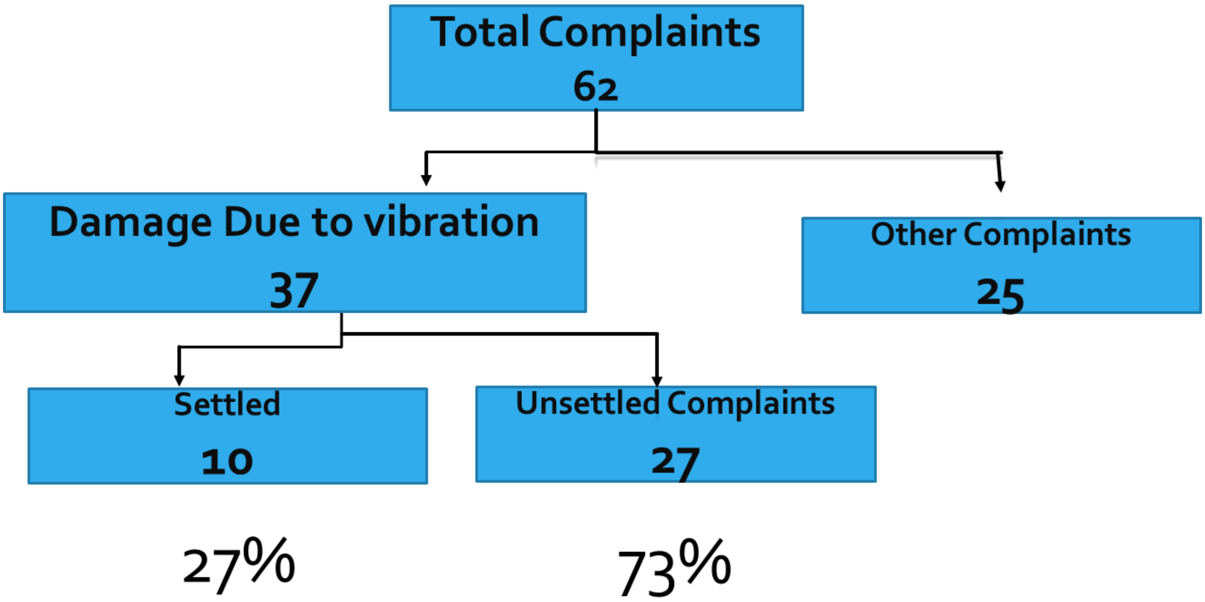



*Figure15 : Complaints categories -1*

According to the data collected from above road projects, available system could not solve conflict between affected parties and contractor.

Some reasons for unsettled issues are,

I. Affected party does not satisfy with the claim amount or compensation.

II. Insurance company rejection due to lack of legal documents. Both parties have not any legal document to prove these damages have happened due to road construction. Contractor has pre-crack survey but it has very low reliability as it is completely done by the contractor itself.

III. Irrational request from affected parties without proper evidence.
Sometimes, affected parties demand very high values without sufficient evidence and contractor rejects those complaints and its leads to long-term legal procedures.

### 5.2. Hatton – Nuwaraeliya Road Project.

Flow chart of the distribution of complaints in Hatton -Nuwaraeliya shows in Figure 16.

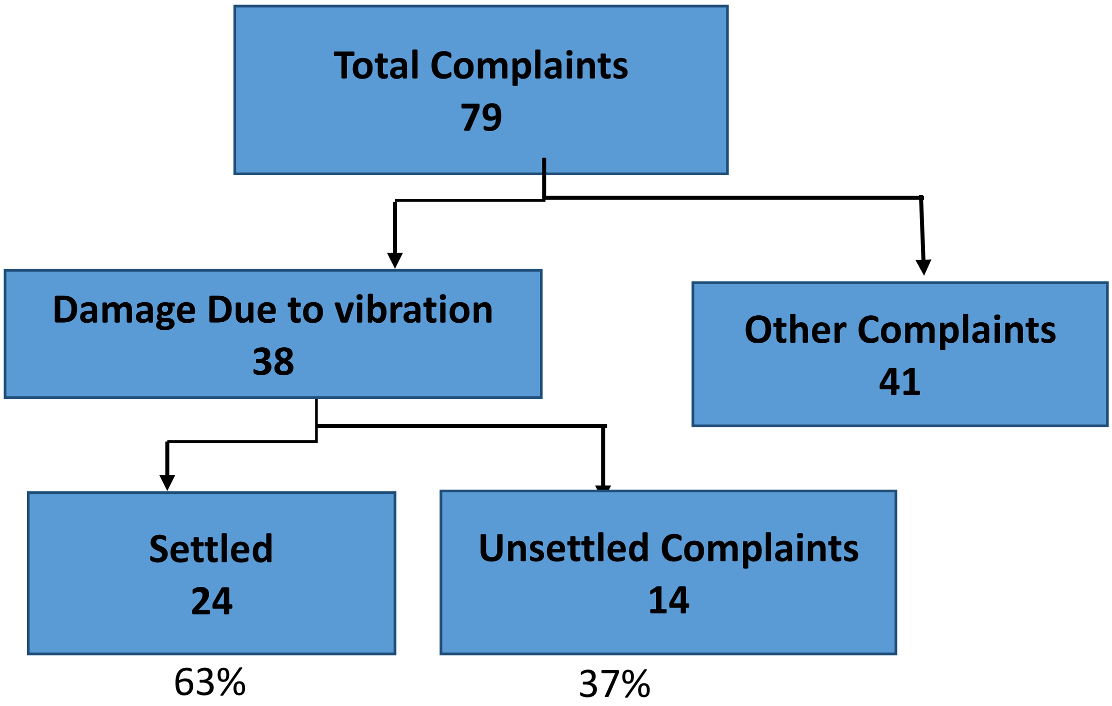



*Figure16 : Complaints Categories - 2*

In this project, they were received about 79 structure damages complaint and 38 complaints out of 79 were due to construction vibrations. Out of the 38 complains, only 24 were settled and 14 were unsettled( Appendix 2). When we compare to previous project data, this project has higher percentage of settlement but still have 14 numbers to settle which can cause some time-consuming procedures to complete settlement.

### 5.3. Problems in existing systems.

Various problems and shortcomings were identified in current practice system and those are listed as follows.

I. Affected area boundary defining.

In above both projects, pre - crack and post crack survey boundary is decided as 30m from the existing center line of the road. This boundary is decided from their experience without considering any engineering evidences. Sometimes structure which situated away from 30m also can damage. If those people lodge complaints, contractor have to face difficulties without having pre-data.

II. Identification of building and ground types.

Most of the vibration limits are categorized into several groups according to stability of the structures. But above two project pre-and post- crack surveys have not considered about the structures type.

III. Less reliability.

Both pre-crack survey and post crack survey were completed by the project proponent. Therefore, reliability of those reports can be less. Affected parties had not any crack survey details or reports to prove or disprove the cause of structural damage or the propagation.

IV. Unavailability of vibration monitoring method.

Any of above mentioned two sites did not employed a vibration monitoring system in their site to ensure vibration not exceed its prescribe limits. When some conflicts arised with structure owners, contractors could not come to argument with them due to unavailability of vibration monitoring data of those locations.

# 6. VIBRATION MONITORING AND DATA ANALYSIS

Construction vibrations were monitored in following five road construction sites, when major ground-borne vibration activities were performed. Relevant pictures are in Appendix 06.

- Welioya –Shanon Road.  (41 Road)
- Nawathispane – Harangala Road.(44 Road)
- Dehigasthalawa - Ella uda Road.( 46 Road)
- Hitiyegama –Minuwandeniya Road.(33 Road)
- Stock –Holm Lower Gruden Road.(38 Road)

## 6.1. Major ground vibration generation road construction activates

According to description of the section 3.2.2 roller compaction activities are critical vibration generated activities in road construction project. Therefore, following major contributors are selected for further discussion.

- Subgrade Layer Compaction
- Subcase Layer compaction
- Base (Aggregate Base Course) Compaction
- Asphalt layer Compaction

### 6.1.1. Subgrade Layer Compaction

This work consists of preparation and compacting of existing subgrade to take desired compaction and following machineries used for the activity. Table 10 lists the machinery used in the subgrade layer compaction activity, [5]

*Table 10: Machinery for sub grade preparing*

| No. | Equipment / Machinery. | Qty |
|---|---|---|
| 1. | Backhoe Loader/ Skid Loader | 1 |
| 2. | Dump Trucks/ Trippers. | As required. |
| 3. | 1 ton Roller/ 5 ton roller | 1 |
| 4. | Rammers. | 2 |
| 5. | Motor Grader. | 1 |
| 6. | Water Bowser | 1 |
| 7. | Soil Testing Equipment | one set |

### 6.1.2. Subbase Layer compaction

This work consists of supplying, laying and compacting approved upper sub base and lower sub-base material in layers on a prepared sub grade for widening section or existing road and following set of equipment use for this construction work. Table 11 lists the machinery used in the subbase layer compaction activity. ,[5]

*Table 11: Machinery for sub base preparing*

| No. | Equipment / Machinery. | Qty |
|---|---|---|
| 1. | Backhoe Loader/ Skid Loader | 1 |
| 2. | Dump Trucks/ Trippers. | As required. |
| 3. | 1 ton Roller/ 5 ton roller | 1 |
| 4. | Rammers. | 2 |
| 5. | Motor Grader. | 1 |
| 6. | Water Bowser | 1 |
| 7. | Soil Testing Equipment | one set |

### 6.1.3. Base (Aggregate Base Course) Compaction

This work consists of supplying, laying and compacting approved Aggregate Base Course (ABC) material on prepared sub base or on an existing pavement in accordance to the lines and levels and following set of equipment use for this construction work. Table 12 lists the machinery used in the Base compaction activity. ,[5]

*Table 12: Machinery for ABC layer preparation*

| No | Equipment/ Machinery | Qty |
|---|---|---|
| 1 | Backhoe Loader/Skid Loader | 1 |
| 2 | Dump Trucks / Tippers | As req. |
| 3 | 10 ton Roller | 1 |
| 4 | Motor Grader | 1 |
| 5 | Water Bowser fitted with sprinkler bar | 1 |
| 6 | ABC Testing Laboratory Equipment | One Set |
| 7 | Straight Edges | 1 |
| 8 | Camber Boards | 1 |

### 6.1.4. Asphalt layer Compaction

The asphalt pavement is the layer of asphaltic concrete constructed on the top of the sealed surface of Dense Grade Aggregate Base Course, which is composed of a combination of aggregates such as crushed stone and crushed dust theoretically graded to progressively fill the voids and mixed with bitumen to obtain the desired properties and following set of equipment (Table 13) use for this construction work, [5]

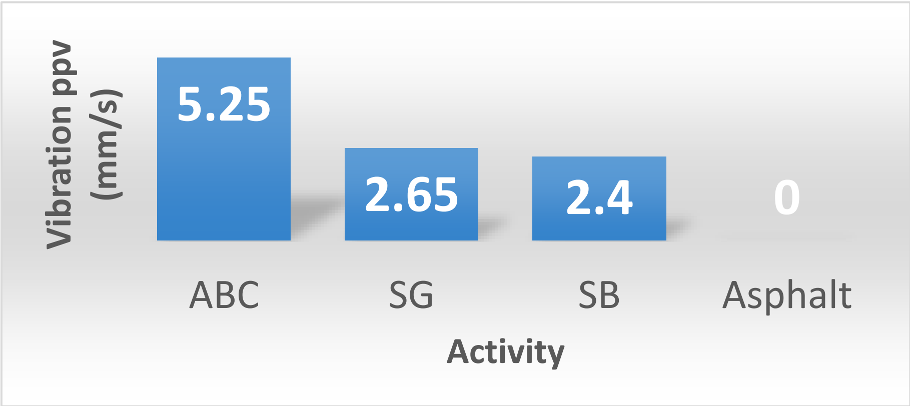
*Table 13: Machinery for Asphalt Laying*

| No | Equipment/ Machinery | Qty |
|---|---|---|
| 1 | Asphalt Paver | 1 |
| 2 | 8 ton vibratory roller | 1 |
| 3 | Bitumen Distributor | 1 |
| 4 | 10 ton Pneumatic roller (Steel drum) | 1 |
| 5 | Water Bowser | 1 |
| 6 | Pneumatic Tired Roller (PTR) | 2 |
| 7 | Testing Equipment | 1 |
| 8 | Dump Truck | As required |
| 9 | "C" channels | As required |

After observation of machinery used for all activities, it can be clearly state that Base course compaction activity is very critical due to use of 10 Ton vibratory rollers. For other activities, light rollers without vibration has been used.

### 6.2. Vibration versus Activity

Ground vibration was monitored using equipment which are described in section 3.2.3 form 10 m offset from EOP in Minuwandeniya road for major vibration generating activities and graph was plotted with activity versus vibration value




ABC =Aggregate Base Course

SG = Sub Grade

SB = Sub Base

*Figure 17: Graph of Activity Vs Vibration*

According to Figure 17, it is evident that vibration of Base Course compaction activity is higher than other activities. Therefore, Base Course compaction activity is selected as the critical activity for further analysis.

### 6.3. Vibration Frequency

Frequency of vibration is automatically recorded in Vibration monitoring equipment and all recorded data was analyzed for determination of vibration frequency of the construction activities. Vibration frequency distribution is shown in Figure 18.

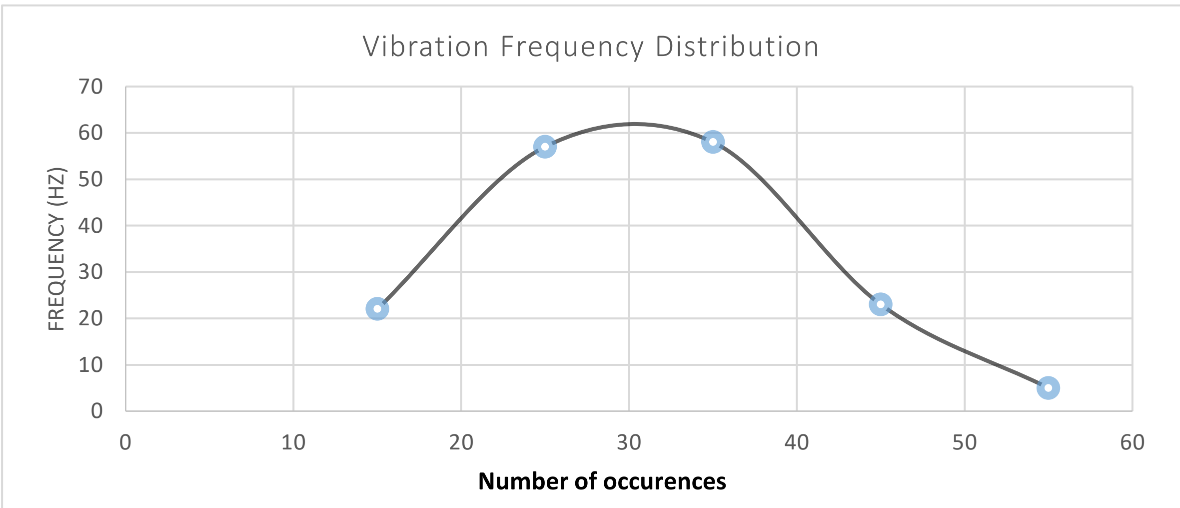



*Figure 18 : Vibration Frequency Distribution*

*Table 14: Determinants of Frequency Distribution*

| | |
|---|---|
| Maximum Value | 51 |
| Minimum Value | 13 |
| Average Value | 31 |
| Standard Deviation | 10 |
| Number of Reading | 165 |

Mathematically it is proved that 95 % of vibration frequencies are between 31 Hz to 41Hz.

### 6.4. Vibration value of constant offset with subgrade strength

Vibration values which were monitored in different subgrade strength form constant offset(10m) are in table 15.

*Table 15:Ground vibration for Different CBR Value*

| Road | Location | Field CBR | Average Vibration in 10 m Offset |
|---|---|---|---|
| 33 | 3+270 -3+300 | 7 | 5.25 |
| 41 | 2+610-2+660 | 5 | 2.98 |
| 38 | 1+150-1+120 | 8 | 7.66 |
| 46 | 1+750-1+800 | 14 | 9.68 |

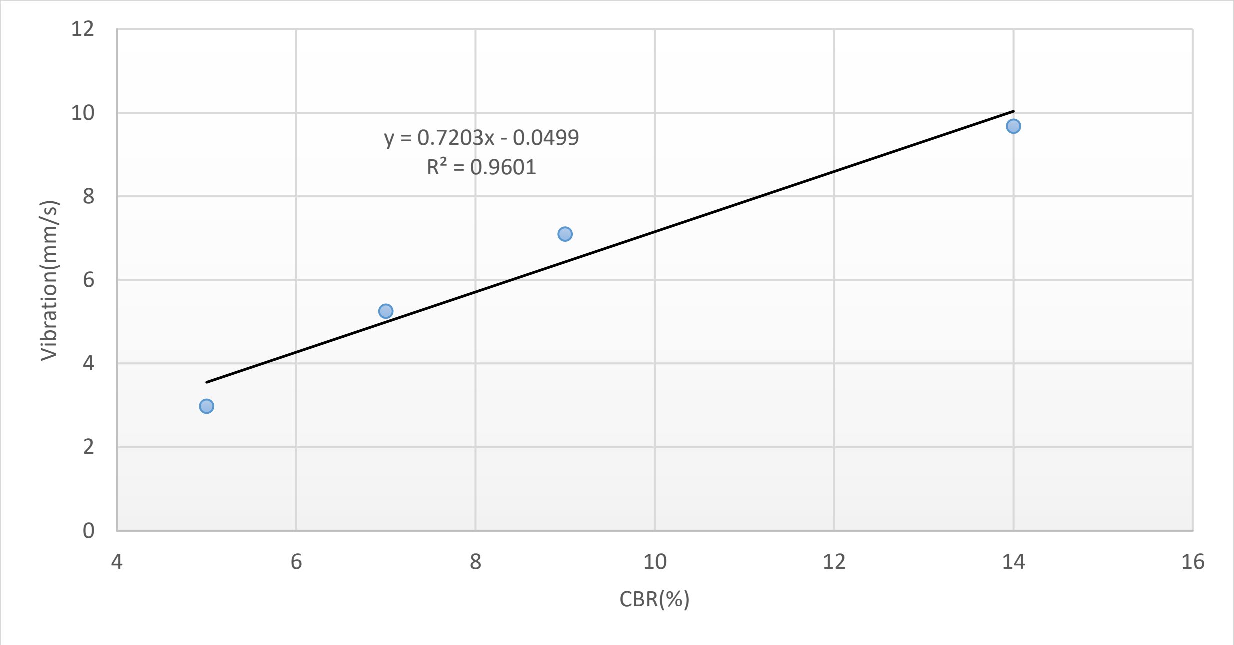
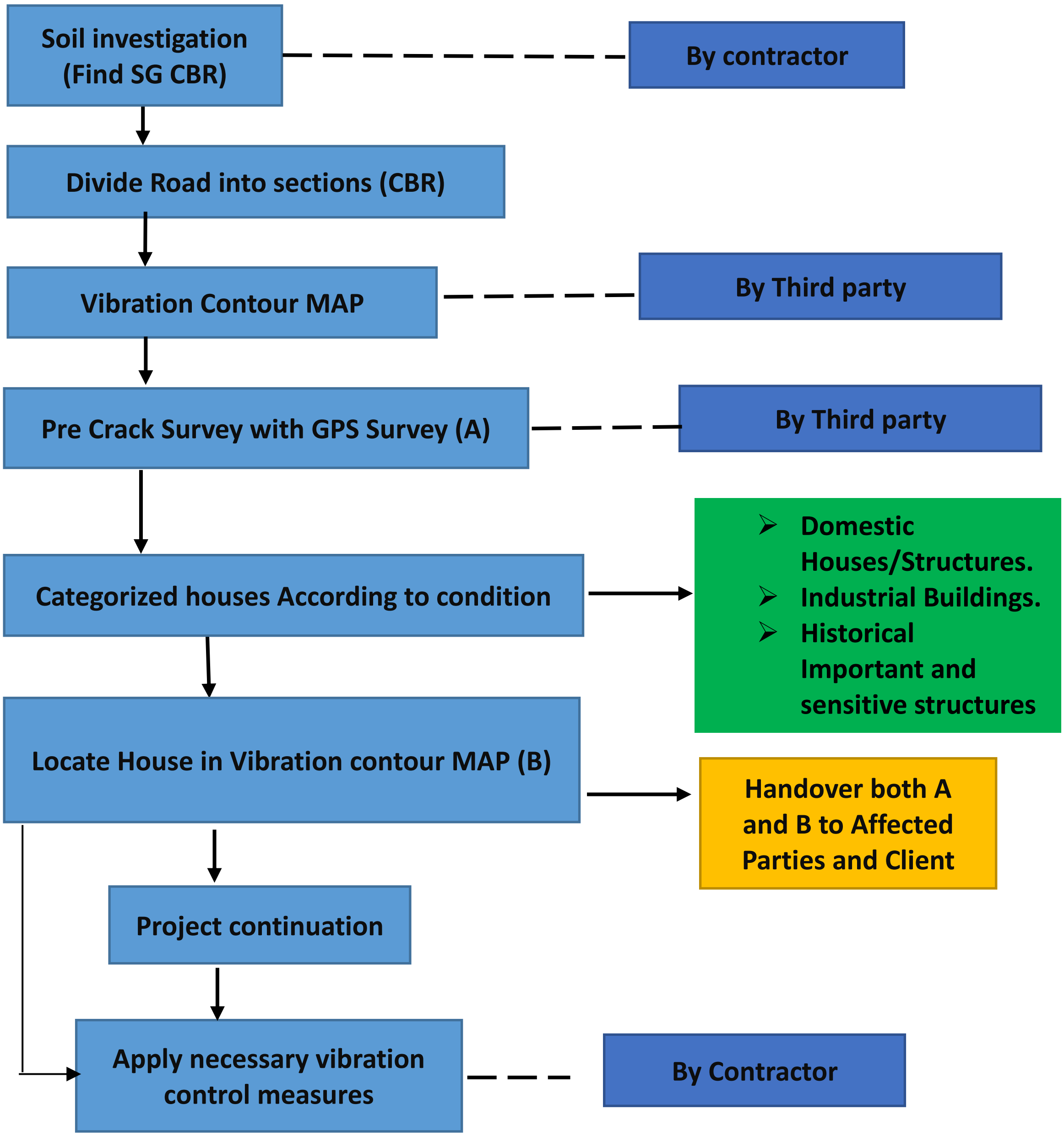



*Figure 19 : Graph of Vibration vs CBR Value*

According to table 15 and figure 19, It can be clearly see that vibration of different grounds with constant offset have increase with subgrade strength. vibration waves propagated longer distance in harder ground than soft (Low CBR) grounds.

# 7. VIBRATION MANAGEMENT PLAN.

Figure 20 shows, system flow chat of proposed vibration management plan and steps are elaborated in following sections.



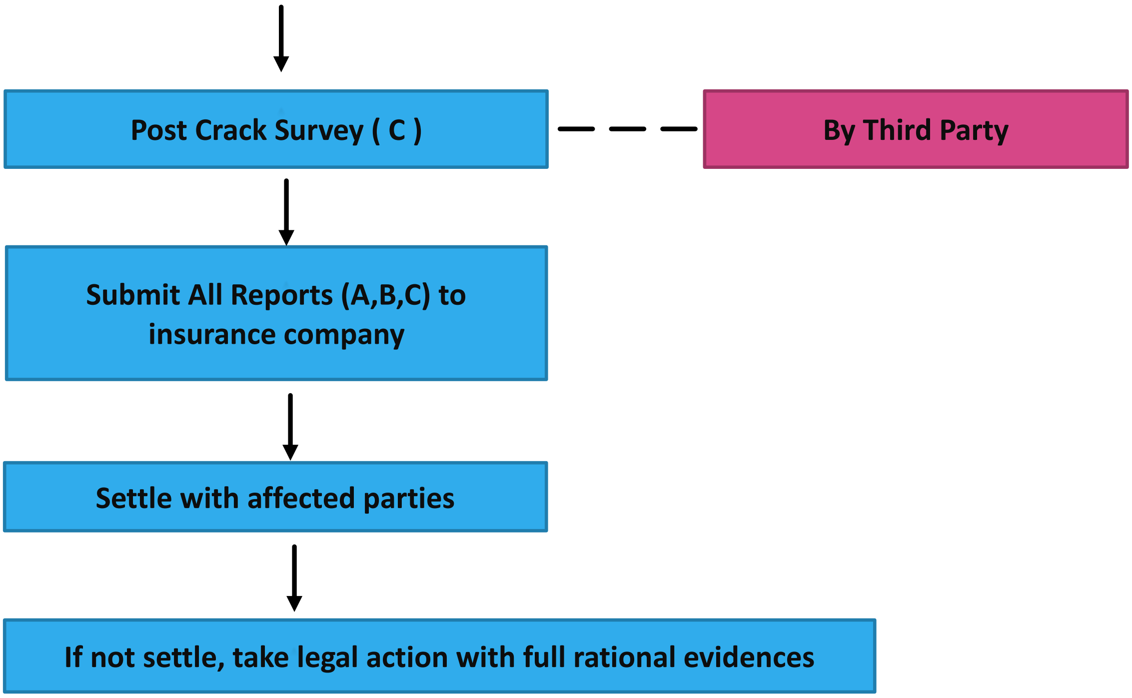



*Figure 20 : Proposed System Flow Chart*

### 7.1. Soil investigation to find subgrade CBR

Subgrade strength need to be determined prior to the start construction work of the site. Normally. soil investigation tests are performed almost all sites for pavement design. Then, it is required to divide road in to subgrade strength categories according to CBR Values. In the table 16 and 16 shows sample subgrade strength categorization. This can be differ according to road project to project and it can be select basis of subgrade strength range of the road.

For Example,:

*Table 16: Subgrade categories according to CBR values*

| Subgrade Category | CBR RANGE |
|---|---|
| S1 | 0-4 |
| S2 | 5-7 |
| S3 | 8-14 |
| S4 | 15-29 |
| S5 | >30 |

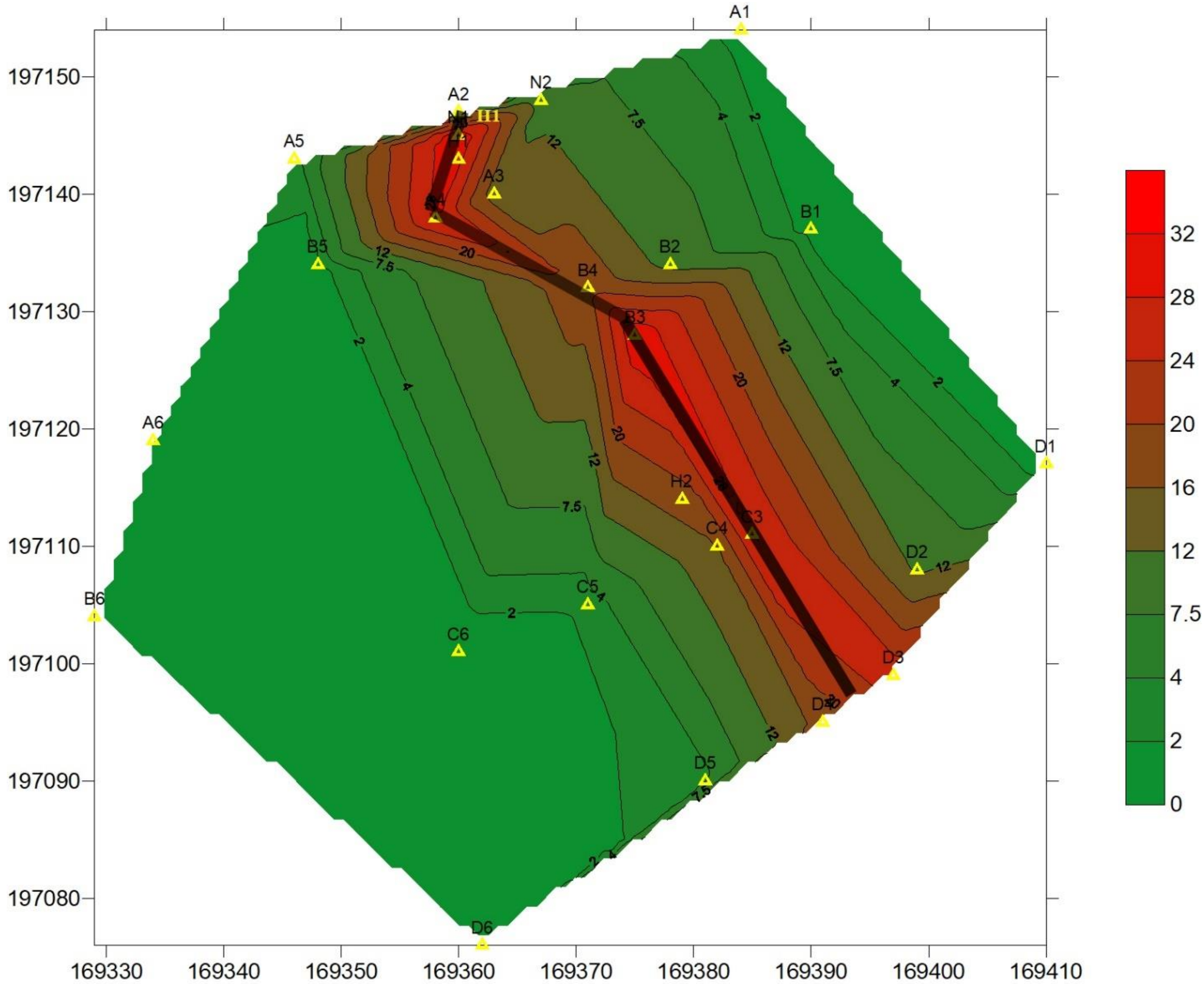
*Table 17: Subgrade Sections of 41 Road*

| Sample No | Chainage | Covering Chainage | Side | Offset [m] | DCP CBR | Subgrade Category |
|---|---|---|---|---|---|---|
| NE3/R41/TP/07 | 2+250 | 2+000 -2+500 | Center | 0 | 5 | S2 |
| NE3/R41/TP/09 | 2+750 | 2+500-3+000 | Center | 0 | 5 | S2 |
| NE3/R41/TP/10 | 3+250 | 3+000 -3+500 | Center | 0 | 3 | S1 |
| NE3/R41/TP/12 | 3+750 | 3+500 -4+000 | Center | 0 | 1 | S1 |
| NE3/R41/TP/14 | 4+250 | 4+000 - 4+500 | Center | 0 | 6 | S2 |
| NE3/R41/TP/16 | 4+750 | 4+500 - 5+000 | Center | 0 | 9 | S3 |
| NE3/R41/TP/18 | 5+250 | 5+000 -5+500 | Center | 0 | 6 | S2 |
| NE3/R41/TP/20 | 5+750 | 5+500 -6+000 | Center | 0 | 4 | S1 |
| NE3/R41/TP/22 | 6+250 | 6+000 -6+500 | Center | 0 | 23 | S4 |
| NE3/R41/TP/24 | 6+750 | 6+500 -7+000 | Center | 0 | 4 | S1 |
| NE3/R41/TP/26 | 7+250 | 7+000 -7+500 | Center | 0 | 4 | S1 |
| NE3/R41/TP/28 | 7+750 | 7+500 -8+000 | Center | 0 | 5 | S2 |
| NE3/R41/TP/30 | 8+220 | 8+000 -8+500 | Center | 0 | 10 | S3 |
| NE3/R41/TP/32 | 8+750 | 8+500 -9+000 | Center | 0 | 5 | S2 |
| NE3/R41/TP/34 | 9+230 | 9+000 -9+500 | Center | 0 | 3 | S1 |

According to table 17, this road can be categorized into four subgrade strengths from s1 to s4.

## 7.2. Vibration Contour MAP

After categorize road into subgrade strength sections, for each section it is required to draw a vibration contour map. As we identified earlier in section 6.2, ABC compaction is critical activity of the site. This activity uses 10 Ton vibratory roller for compaction and the vibration can be measured when this roller is operating. Using these vibration data and co-ordinates of measured locations, the vibration contour map can be plotted (Figure 21) using **Surfer** Software [6] which is designed for plot maps and surfaces. Vibration contour Maps for different location are listed in *Appendix 4*.




H1 5m from EOP
H2 8m from EOP

*Figure 21 : Vibration Contour Map*

### 7.3. **Pre-Crack Survey with GPS Survey (A)**

Pre -crack survey has to do by well-trained person to identify existing cracks in the nearby structures. To define boundaries, they can use vibration contour map. For Example, in Figure 20, H1 house vibration will be over 16 and H2 house vibration over 12 and those houses pre-crack survey we have to do as damage limit exceed it. Using above method, we can select structure need to do pre - crack survey *(Appendix 03).* When we do pre -crack survey, simultaneously we can record GPS Co-ordinated of structure to locate those on Vibration Contour Map. This pre-crack survey and GPS survey should be performed by a third party except contactor, consultant or client and it will helpful to keep reliability of the work.

### 7.4. Categorized houses According to condition

As elaborated in section 2.2, Most of the vibration standards in the world, structures are categorized into several categories according to the nature of the structure. As a summary, all standard structures categorizations can be generalized as in table 18.

*Table 18 : Sri Lanka Structure Categorization*

| **Category of the structure of the building** | | **Description** |
|---|---|---|
| Resistance to the vibration decreasing ↓ | Type 1 | Multi storey buildings of reinforced concrete or structural steel, with in filling panels of block work, brick work or precast units not designed to resist earthquakes |
| | Type 2 | Two-storey domestic houses & buildings constructed of reinforced block work, precast units, and with reinforced floor & roof construction, or wholly of reinforced concepts or similar, not designed to resist earthquakes. |
| | Type 3 | Single and two-storey houses & buildings made of lighter construction, using lightweight materials such as bricks, cement blocks etc, not designed to resist earthquakes |
| | Type 4 | Structures that, because of their sensitivity to vibration, do not correspond to those listed above 1,2 & 3, & declared as archeologically preserved structures by the Department of Archaeology |

Table 19 shows nature of building with categorization.

*Table 19: Baring Capacities of structures*

| Type | Bearing Capacity | Remarks |
|---|---|---|
| **Historical Important and sensitive structures. (Type 4)** | Low | Weak Structure, low intensive vibration can harmful to the structure |
| **Domestic Houses/Structures (Type 2 and 3)** | Medium | Stable than Historical Buildings but disturbance is High, More complaint may receive. |
| **Industrial Buildings.** (Type 1) | High | Engineering Foundation, can bare high vibrations, |

After the pre -crack survey and GPS survey, we need to categorize the structure according to above groups. Then we can decide vibration limit which can harmful to each and every structure. As road construction vibration frequency lies between 21 -41 Hz (Average 31, Standard Deviation 10), from Sri Lanka standards, we can select 10-50 Hz range and vibration is continuous type. Accordingly, table 06 can be summarized as follows.

*Table 20: Summary of Vibration Standard Sri Lanka*

| Type of Structure | Vibration Limit ( PPV ,mm/s) |
|---|---|
| Type 01 | 7.5 |
| Type 02 | 4.0 |
| Type 03 | 2.0 |
| Type 04 | 0.5 |

For an example consider following contour map which was plot for the Dehigasthanna - Allauda (46) Road. All houses which are named as H1, H2, H3 and H4 are domestic houses (Type 03).

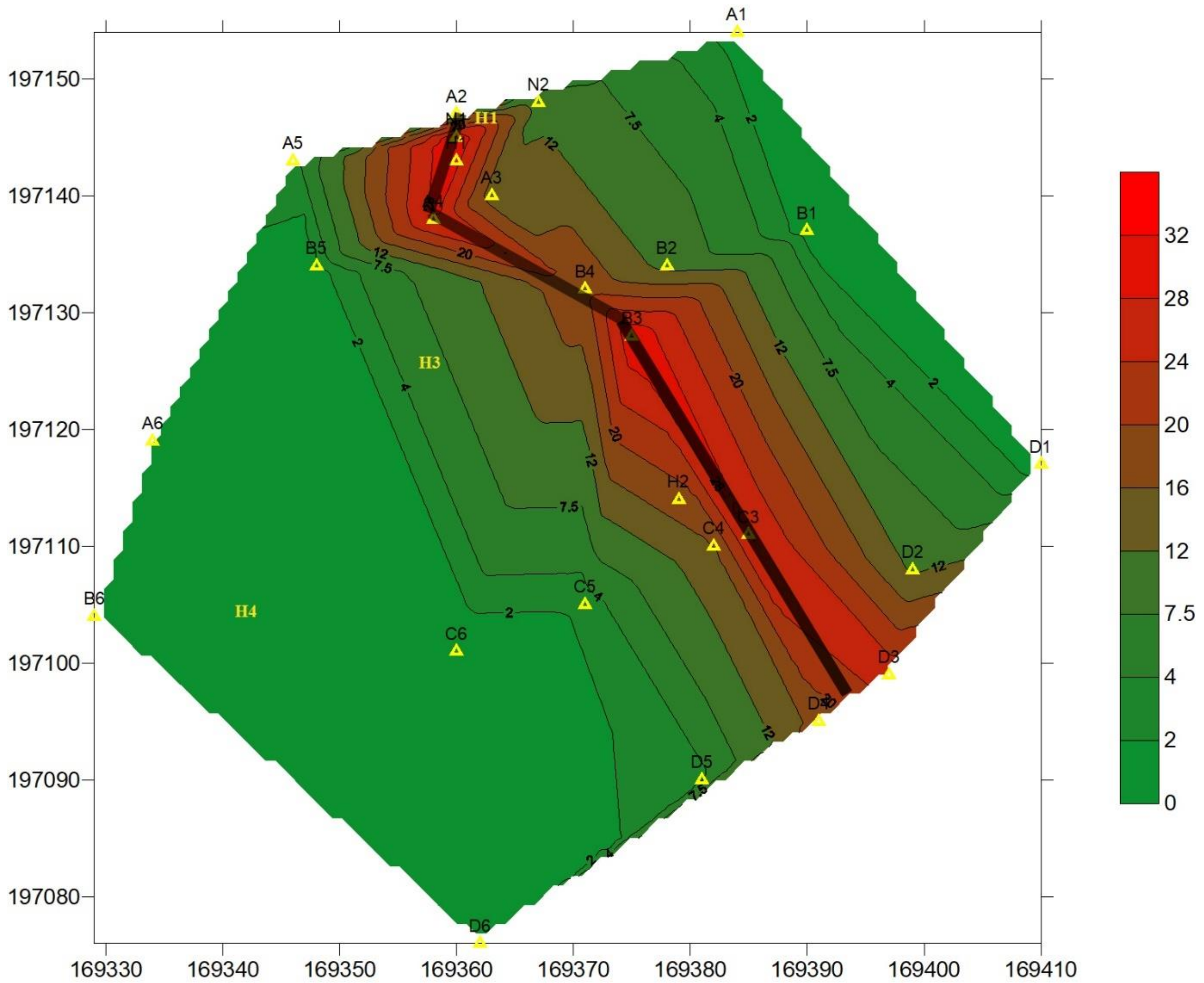



*Figure 22 : Vibration Contour Map*

In the above map, **H4** is a domestic house it has no problem from construction vibration as it is in 0-2 vibration region. If it is a Historical building (Type 04), vibration can damage it as type building damage limit is 0.5mm/s.

### 7.5. Apply necessary vibration control measures

If there are any critical structures are situated inside the vibration exceeded area, the contractor can apply some vibration control measures to minimize damages. Some of those measures as follows,

1. Use lighter roller with more roller passes.
2. Change the Design. (Rigid pavement instead of flexible Pavement)
3. Protect the Structure using vibration absorption structures.

### 7.6. Post Crack Survey

After the end of all construction work of the project post crack survey has to done by third party. Houses which have made complaints need to be given the priority as well as other selected houses also should include in the post crack survey report.

# 8. EVALUATION OF CURRENT VIBRATION STANDARD OF SRI LANKA.

According to Table 6 in section 2.2.1.5 and Figure 23, it can be clearly see that vibration limits of Sri Lanka are very low among the other international standards. Even though, it was given extra safety margin to the nearby structures, contractors have to give extra effort to follow prescribe limits.

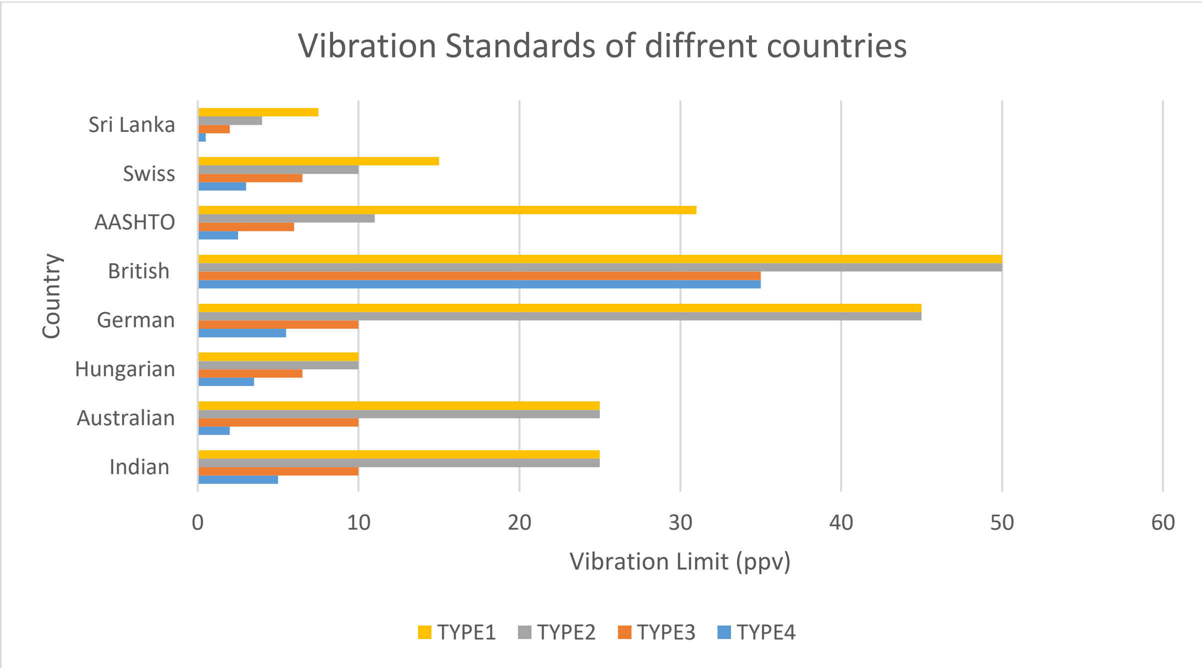



*Figure 23 : Vibration standard Comparison*

According to figure 23, Sri Lanka vibration standards are far lower than Indian vibration limits. In my data analysis, I analyzed complained houses vibration values with those situated locations. Those analysis are elaborated in following sections.

## 8.1. Relation between complaints and vibrations

For this analysis, I used two road projects from rural situation and one from urban situation.

I. Dehigasthalawa - Ella uda Road. (46 Road)

II. Hapugasthalawa -Dambagala Road (45 Road)

### 8.1.1 Dehigasthalawa - Ella uda Road. (46 Road)

This road is a rural road with 6.5 km length and 3.0m width. This road has 401 houses which is in pre-crack survey (property condition survey). All houses are Type -03 houses and pre-crack survey had done for 30m boundary from EOP. Only one complaint is received from this project. Vibration contour map from 1+750 to 1+800 shows in figure 24.

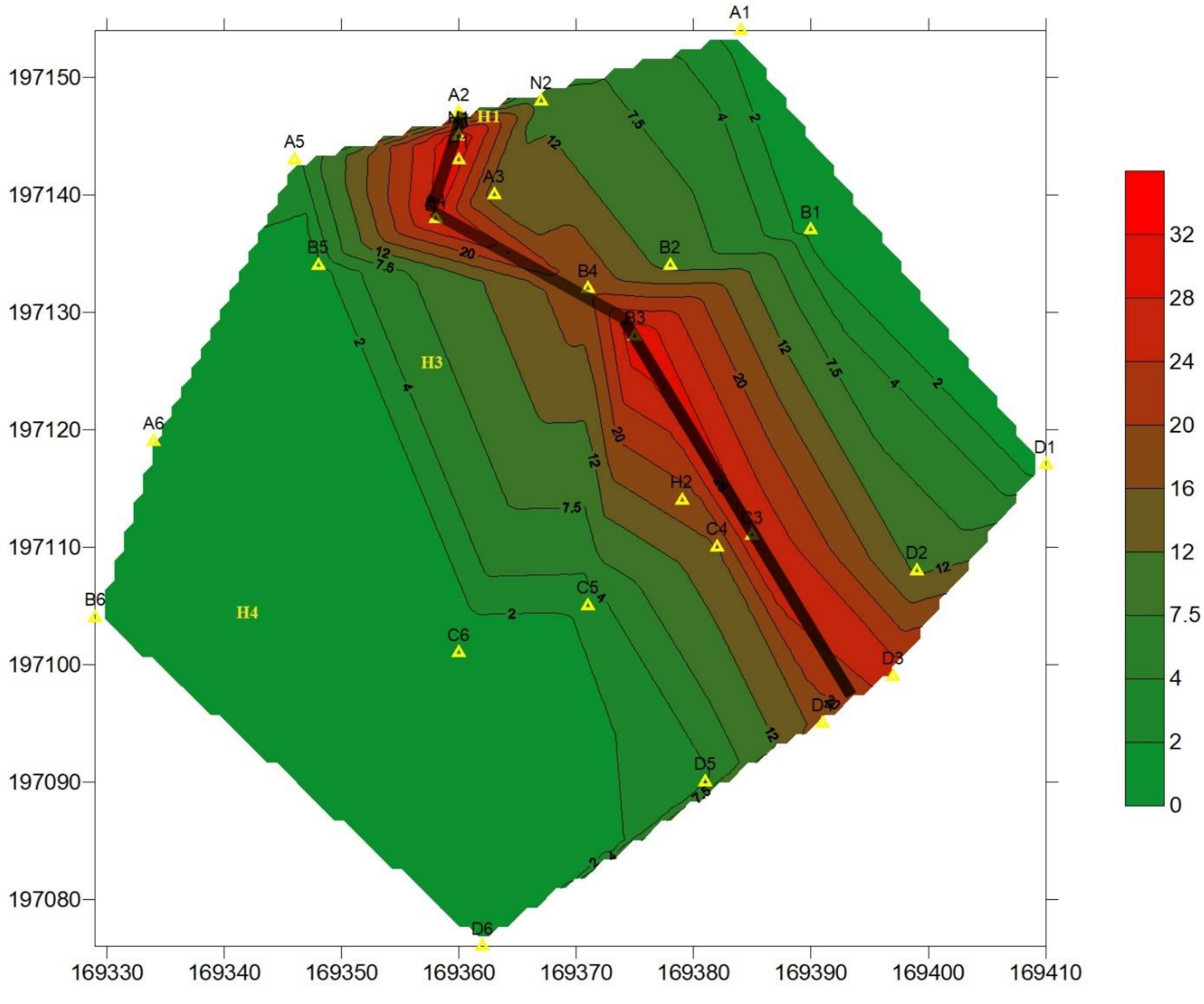



*Figure 24 :Vibration contour Map 1+750 to 1+800*

According to Figure 24, Vibration on nearby houses as follows,

*Table 21 : Vibration values of houses (46 Road)*

| House No | Type | Vibration (ppv) | Sri Lanka Standard Limit (ppv) | Distance From EOP(m) |
|---|---|---|---|---|
| H1 | Type 3 | 18 | 2 | 2.5 |
| H2 | Type 3 | 13 | 2 | 2.5 |
| H3 | Type 3 | 06 | 2 | 15 |
| H4 | Type 3 | 0.5 | 2 | 35 |

Table 21 shows that H4 is within the vibration limit and other houses vibration exceeds its limits. But this project contractor did not receive any structural damage complaints from other three houses. According to these results it can prove that type 3 hoses can bare more vibration than 2mm/s without structural or cosmetic damages.

### 8.1.2 Hapugasthalawa -Dambagala Road (45 Road)

This road is a rural road with 2.0km length and 4.0m width. This road has 138 houses which is in pre-crack survey (property condition survey). All houses are Type -03 houses and pre-crack survey had done for 30m boundary from EOP. Only one complaint is received from this project. Vibration contour map from 0+000 to 0+100 shows in figure 25.

A3 Map Included

*Figure 25 : Vibration contour Map 0+000 to 0+000*

According to Figure 25, Vibration on nearby houses as follows,

*Table 22 : Vibration values of houses (45 Road )*

| House No | Type | Vibration (ppv) | Sri Lanka Standard Limit (ppv) | Distance From EOP(m) |
|---|---|---|---|---|
| H1 | Type 1 | 12 | 7.5 | 1.0 |
| H2 | Type 3 | 14 | 2 | 1.2 |
| H3 | Type 3 | 12 | 2 | 4.5 |
| H4 | Type 3 | 12 | 2 | 3.5 |
| H4 | Type 3 | 15 | 2 | 1.8 |
| H4 | Type 3 | 13 | 2 | 1.9 |
| H4 | Type 3 | 11 | 2 | 1.6 |

Table 22 shows that all structures exceed its prescribed vibration limits. But this project contractor did not receive any structural damage complaints from these structure owners. That means structures can bare more vibration than prescribed limits without damage.

## 8.2 Comparing with Sri Lanka safe distance for House and Low rising residential building with other countries

In this section, I compare Sri Lank prescribed safer distance from road to House and Low rising residential building with and other countries. Table 23 shows that vibration stands of different countries for the House and Low rising residential building.

*Table 23 : Vibration limits for house and low rising buildings*

| Country | Vibration Limit (ppv) |
|---|---|
| Sri Lanka | 2.0 |
| AASHTO | 7.5 |
| Hungarian/Swiss | 8 |
| India/Australia | 10 |
| German | 15 |
| British | 50 |

After that, distances were calculated from road center to above mentioned standard boundaries using vibration contour maps.

For No 46 road,

*Table 24 : Safer distance for house at no 46 road*

| Country | Safer Distance (m) |
|---|---|
| Sri Lanka | 32 |
| AASHTO | 21 |
| Hungarian/Swiss | 22 |
| India/Australia | 17 |
| German | 12 |

According to table 24, it is clear that Sri Lankan vibration limit is affected to a larger distance than the others. This is illustrated in Figure 26

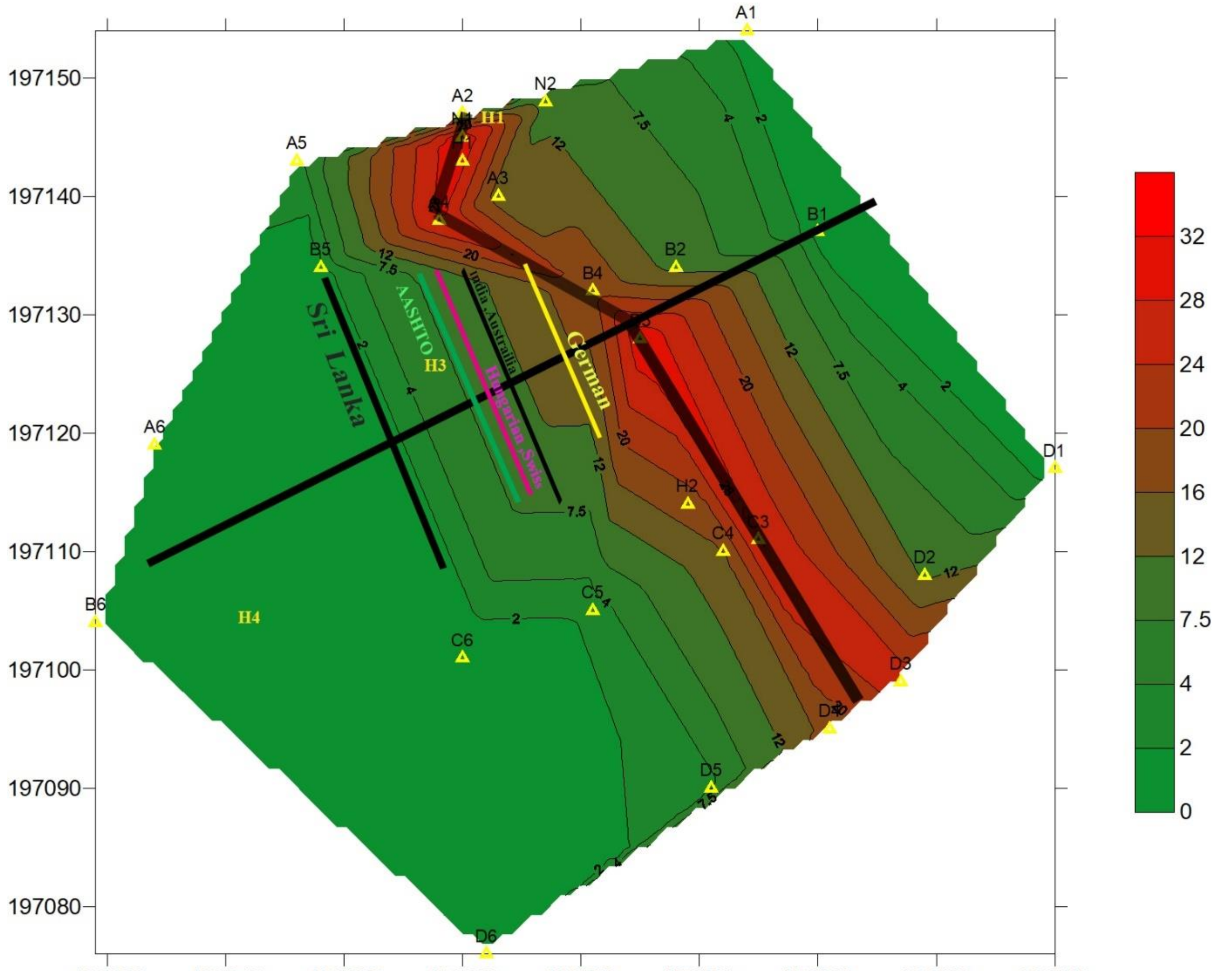



*Figure 26 : Safer distance for house at no 46 road*

For No 33 road,

*Table 25 : Safer distance for house at no 33 road*

| Country | Safer Distance (m) | Remarks |
|---|---|---|
| Sri Lanka | 25 | |
| AASHTO | 11 | |
| Hungarian/Swiss | 10 | |
| India/Australia | 8 | |
| German | 3 | |

According to table 25, it is clear that House and Low rising residential building which are situated 25m away from road have no risk to damage as per Sri Lankan standards. However, boundaries can be further reduced as per other structures. Boundaries are illustrated in Figure 27.

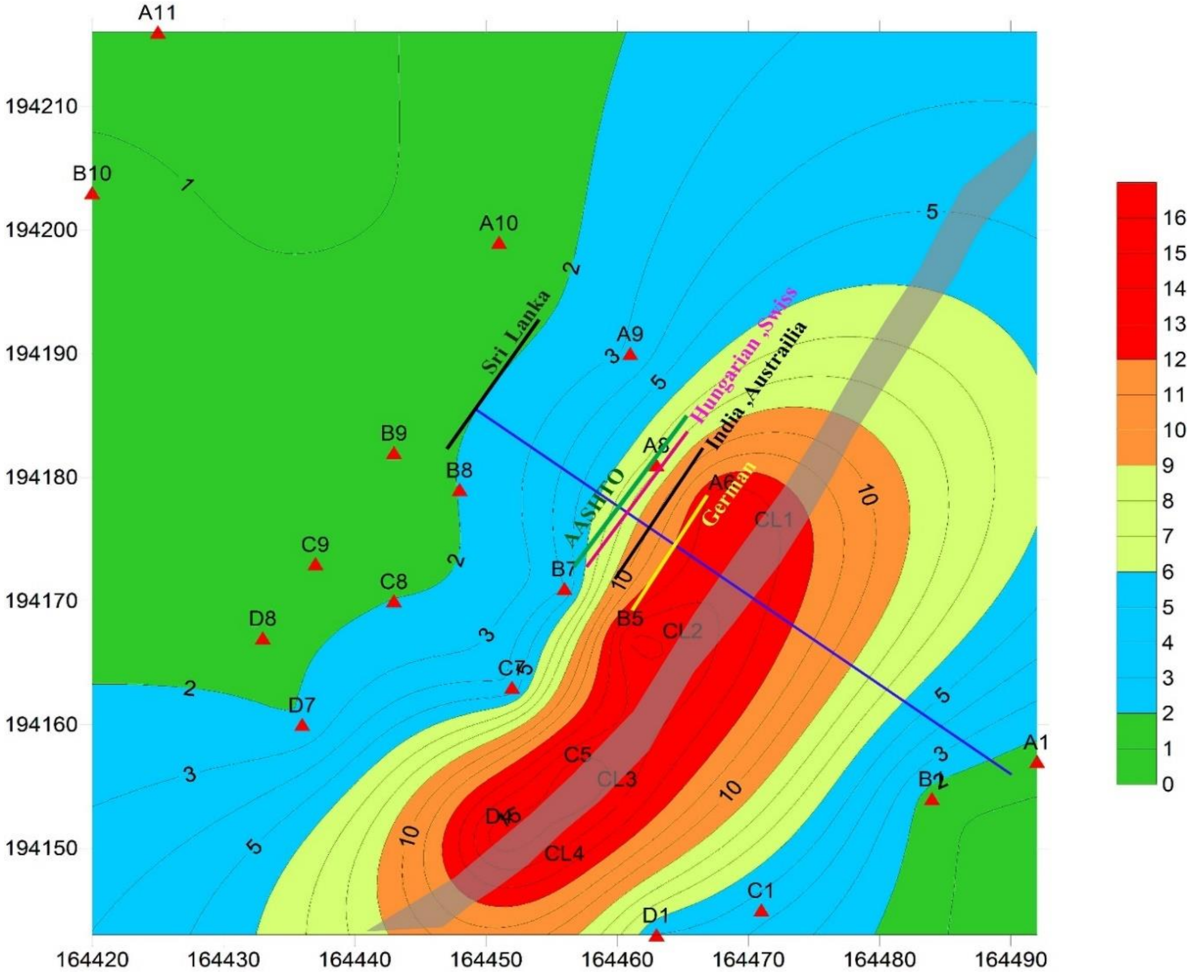



*Figure 27: Safer distance for house at no 33 road*

According to above analysis, it is very clear that safer boundary is depend on subgrade strength of the road. Therefore, to decide pre-crack survey boundary, vibration map can be used as base document.

After analyzing Figure26 and Figure 27, it can be concluded that vibration standards of Sri Lanka are lower than the selected countries in this study. Therefore, vibration monitoring should be extended to a larger distance.

# 9. CONCLUSION AND RECOMMENDATION

Construction vibration is common phenomenon in road construction projects in the world. However, Sri Lankan Highway engineers do not possess relevant knowledge about vibration standards and other monitoring in road projects. Even though most of highway engineers have concerns about excess vibration is problematic in construction field, they rarely use vibration control measures in the field. Most of Sri Lankan contractors conduct post and pre-crack survey by themselves and the reliability of data questionable.

Many road construction projects of Sri Lanka have post project problems regarding structure damages. However, contractors are unable to solve those issues due to proper evidence to negotiate with complained parties. Finally, both affected parties as well as project proponents end up with unwanted legal issues.

Vibration is generated due to many road construction activities. However, activities, which use heavy rollers, are very critical for structural damages. It could observe that rollers generated higher continuous vibration with 21-41 Hz frequency. Static rollers do not generate noticeable vibration. Asphalt layer compaction generated negligible vibration due to static rollers are use in construction. Therefore, base course compaction vibration is critical in the road construction activities. Furthermore, Vibration waves are propagated greater distance on hard subgrade than weak subgrade. Therefore, subgrade strength was very important parameter to establish a system to monitor and minimize the ground borne vibrations.

As per the vibration monitoring plan described in the report, it is suggested to divide road into sections according to subgrade CBR value. For each individual section vibration contour map need to be prepared prior to the construction works. These maps can be referred to determine the vibration levels of the structures. These maps will be very helpful for the site engineers to control and negotiate site complaints too. Furthermore, pre-crack survey is the most important documents in this plan and these reports should be prepared by a third party. One set of copies may be given to structure owners for their reference. It will be helpful to conduct transparent agreement between both parties.

In the road construction works, it is very difficult and not feasible to apply vibration control measures to all structures. It is suggested a suitable damage monitoring and minimizing system for very valuable and conservative structure. Questionnaire survey reveals that 61 % of engineers received 0-5 complaints per month and others are received more than that. Moreover, more than 84 % emphasize that current system does not provide a fair solution to either affected parties or contractors.

Furthermore, Sri Lanka standard of vibration limits for construction vibration need to be revised as per our study. According to this research analyze Type 1, Type2 and Type 3 structures prescribed limits can be increased to a higher limit.

However, proper study should be conduct to established the vibration management plan for road project taken in to account the findings of this study.

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