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# Scientific Analysis of Ground Vibrations from Traffic Loads on Silt Soil

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***Abstract:*** *Ground vibration is one of prime interests to geotechnical and geological engineering. The main concerns of ground vibrations involve annoyance, damage, disruption of vibration sensitive operations or activities triggering of landslides. Measurement and analysis of ground vibrations is a necessary procedure to determine their effect on structures and humans. The vibrations induced from traffic loads are real and complex but are least addressed. Traffic induced ground vibrations are a result of repetitive cyclic loading and needs screening for long term basis which need to be addressed in the design stage itself. This article aims to gain knowledge on ground vibrations induced by road and rail vehicles over silty soils. Field study is carried out using vibration sensors and data recorded is analyzed for vibration characteristics and its effect on soil properties. The factors affecting vibration intensity and vibration isolation properties of different materials are also studied in this paper. When the loads enter the infrastructure during vibration monitoring, it was observed that the vibration intensity increased irrespective of compressive strength of soil. Also, the distance from the source is also an important parameter. The trend shows that the attenuation of vibration was low with distance because low frequency vibrations are produced. High speed movement, heavy vehicles and rapid urbanization increases the vibration intensity and hence this research gain importance in the future.*

***Key Word :*** *– Cyclic loading, ground vibration, peak ground acceleration, peak particle velocity, vibration isolation.*

## I.INTRODUCTION

This article provides a detailed study of traffic induced vibration measuring instruments, field vibration monitoring procedures, vibration assessment criteria and standards. The factors influencing ground vibrations are also identified and the vibration screening methods are also studied. Transportation related ground vibrations are real and complex in urbanized areas with high speed transit systems. Most of these fall into highway traffic vibrations, construction vibrations and rail vibrations. The main concerns of ground vibrations involve annoyance, damage, disruption of vibration sensitive operations or activities triggering of landslides. While a surcharge or an increase in pressure, including strain or settlement, comes when an infrastructure such as road embankment and bridge approach is constructed over soil. In case the additional surcharge load due to filling and construction is over the top close the ultimate bearing capacity of the supporting soft ground in the vertical and lateral direction, immediate yield or plastic deformation may occur followed through tension crack, deep seated rotational slip when massive and significance deformation occurs. A geotechnical engineer's advice is mandatory and challenging, as soil has different properties and also varying with climatic changes on it. Field study is carried out to determine the characteristics of ground vibration and its propagation through soil. The particle motion is utilized to study vibration levels and expressed in terms of peak particle velocity and peak ground acceleration. Wave propagation is different for different density or medium which is studied in this paper. Vibrations are a result of repetitive cyclic loading and needs screening for long term basis which need to be addressed in the design stage itself. Thus screening efficiency is tested for different materials placed in wet and dry soil conditions.

If a vehicle speed becomes larger than Rayleigh wave velocity in the ground, an additional very large increase in generated ground vibrations takes place. This phenomenon is termed ground vibration boom, and it is similar to sonic boom generated by supersonic aircraft. Measured vibration, amplitude and frequency, can be used in further analysis to determine the effect of dynamic loading due to traffic induced ground vibration on structures as shown in Fig. 1.

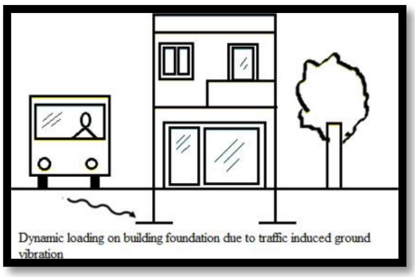



*Fig. 1 Traffic-induced vibration effect on foundation of structures*

Vibration energy spreads in all directions, even though it does not necessarily spread equally in all directions, unless the transmission is through a single isotropic material. Most materials, especially the ground, are anything but isotropic. Different types of rock and soil transmit vibrations differently, in intensity, frequency, and speed. Clay soils, because of their greater coherence, transmit vibration more efficiently than sandy or loamy soils. Even soils with different amounts of moisture can behave differently in vibration transmission. Layering of the soil can produce both reflections and amplifications of the ground vibration, due to an effect similar to intensification of light by a lens. Seismic profiling is a geophysical technique used by geologists to reveal underlying rock structures and search for possible oil deposits. Being at a greater distance from a vibration source can't always be seen as much comfort, lesser vibrations at a greater distance can be more damaging than those closer in. This is due to the lowering of the ground vibration frequency with distance, a result of the soil absorbing selectively the higher frequency components. These lower frequency vibrations often have more efficient interactions called resonance that other, higher frequency vibrations lack.

## II.MATERIAL AND METHODS

### A. Study Area

Study area was approach bridges of Kuthiran Tunnel on NH were vibration issues are prominent and traffic loads are more. In this study, soil used is silty soil samples were collected from Kuthiran hills of Thrissur district. Vibration monitoring instruments are used to measure vibration intensity in terms of peak ground acceleration. Soil collected from Kuthiran was classified under silty soil. Silty soil has flour like texture when dried and while wet becomes fine and slippery. Silt soils are produced when rock is eroded or worn away by water and ice. Figure 2 shows the soil used in this study.

*Fig. 2 Kuthiran Soil*

The basic engineering properties of soil were obtained by conducting various laboratory tests confirming to the corresponding IS codes and the results obtained are provided in table 1.

Table 1: Basic properties of soil

| **Properties** | **Value** |
|---|---|
| Specific gravity | 2.7 |
| Soil classification | ML |
| Liquid limit | 31 % |
| Plastic limit | 29 % |
| Plasticity index | 2 % |
| Shrinkage limit | 20 % |
| Max dry density | 1.4 g/cc |
| OMC | 24 % |
| UCS | 107 kPa |

Accelerometer is a vibration sensor used to measure ground vibrations. A uniaxial piezoelectric accelerometer is designed for analyzing the vibrations of devices with slight to medium excursions. It is also handy and light weight. It can be mounted to the surface under test via the built-in magnet. The accelerometer sensitivity is 100 mV/g. It can measure in a wide frequency range which can be preset prior to testing. The accelerometer is highly sensitive and the magnetic force provides the most accurate results. Figure 3 shows accelerometer model KS901-MF model used for the study.

*Fig. 3 Accelerometer Fig. 4 Vibration Meter*

The vibration meter used for this study is an XL2 analyzer taken for interpreting field vibrations received on accelerometer. The device measures acceleration for frequencies down to 0.7 Hz and determines the speed and displacement. Simultaneously, the XL2 calculates the vibration spectrum as an FFT in the range of 0.8 Hz to 2.5 kHz, while a cursor automatically indicates the dominant frequency. The figure below shows the vibration meter used for the field study of ground vibrations in this research. The vibrations produced at Kuthiran belong to low frequency range.

**B. Study Method**

In this approach the basic properties of the soil were studied first for different laboratory tests as per IS codes. Ground vibrations are site specific and hence field study was carried out using vibration sensors to determine vibration characteristics. Vibration testing was carried out by International Standard specifications. The accelerometer sensor was mounted to the ground with the help of a steel rod having a base plate at its end. The vibrations travelled through soil reaches accelerometer senses and detects the intensity. The vibration magnitude is read on the vibration meter which is connected to the sensor by means of ICP adapter. The data obtained on the meter is stored in its own storage device which can be transferred to a portable computer for analyzing data. Figure 5 shows field test setup at Kuthiran.

*Fig. 5 Vibration Monitoring at Kuthiran*

Effect of vibration for different parameters such as vehicle class, traffic flow, distance from pavement, speed of vehicle were also monitored. The vibration parameters and effects on soil were analyzed by interpreting the test results using an analyzer and portable computer to store and review data. The different parameters studied are as follows:

1) Vehicle class
2) Traffic flow
3) Distance of measurement
4) Soil properties

Vibration parameters are acceleration, velocity, displacement. Peak ground acceleration is the unit of vibration intensity measurement and generally used measurement unit in vibration sensors. Peak particle velocity is more often used in standard guidelines which can be calculated from peak ground acceleration. Even though displacement is easier to understand it is very less often used. Vibration effect on vehicle class was studied by testing vibration obtained from single vehicles under FHWA vehicle classification and averaged.

Vibration monitoring was done for different traffic flow on a single day. The peak time during afternoon was measured as heavy traffic flow while light and medium traffic flow vibration were also measured at site. The particle of motion is utilized to understand vibration propagation and attenuation in soil. Thus vibration propagation and attenuation for Kuthiran soil was studied at three distances from centre of the pavement. The site had two separate bridges with three lanes on single bridge connecting the Kuthiran tunnel. Effect of vibration on soil properties as observed from basic engineering tests were generalized based on the lessons from previous theories. Soil properties such as optimum moisture content, density, strength, liquid limit, plasticity index were studied. Isolation properties of different materials were investigated in detailed manner to propose the best isolation methods for the screening of vibration due to continuous dynamic loads.

## III.RESULTS AND FINDINGS

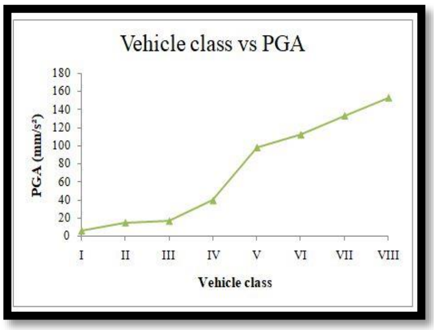
This section includes the results obtained from the field study. Effects on different parameters are represented graphically. All parameters had significant roles in vibration and hence this research is valid and successful. Table 2 shows the result range of vibration produced for studied parameters.

Table 2: Result of vibration intensity for different parameters

| Parameter | PGA (mm/s²) | PPV (mm/s) |
|---|---|---|
| Vehicle Class | 4.41 -153 mm/s² | 0.02 - 0.75 mm/s |
| Traffic Flow | 17 - 227 mm/s² | 0.23 - 3.2 mm/s |
| Distance | 151 - 228 mm/s² | 0.82 - 3.19 mm/s |

**A. Effect of Vibration on Vehicle Class**

The vibration test results monitored for different vehicles are plotted in terms of peak ground acceleration and peak particle velocity. The vibration parameters increased with higher class of vehicles. Figure 6 and 7 shows the PGA and PPV values obtained for each vehicle class. The value is taken as the average of number of vehicles in each class.



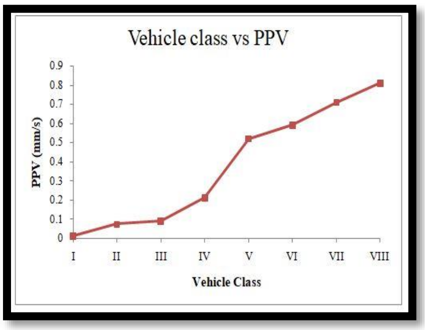
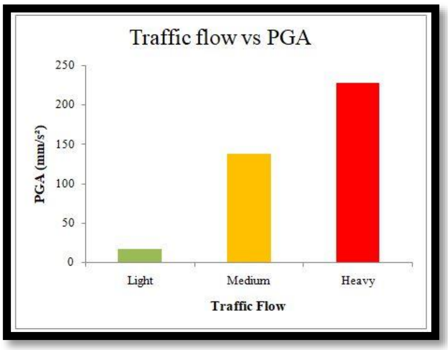




*Fig. 6 Effect of vibration PGA by vehicle class*    *Fig. 7 Effect of vibration PPV by vehicle class*

**B. Effect of Vibration on Traffic Flow**

The effect of vibration depends on the dynamic load at a time. Hence mass movement of vehicles causes vibration in soil. To analyze the intensity of vibration, peak and light movement of vehicles were monitored. Light vehicles include vehicle upto class III, medium vehicles belongs to class IV and heavy vehicles class V and above were monitored. Figure 8 and 9 shows the effect of vibration by traffic flow.



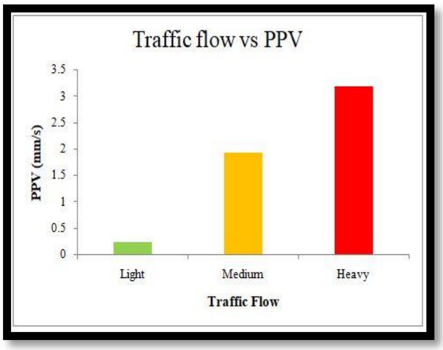




*Fig. 8 Effect of vibration PGA for traffic flow*   *Fig. 9 Effect of vibration PPV for traffic flow*

**C. Effect of Vibration with Distance of Source**

Distance of measurement is an important parameter as to understand the vibration wave propagation and attenuation characteristics in soil or transmitting medium. Distances are selected as 3m, 6m and 10m from the centre of the pavement. Figure 10 to 13 shows effect of peak ground acceleration and peak particle velocity at different distances for vehicle class and traffic flow.

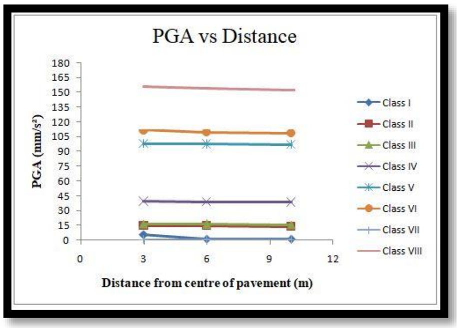



*Fig. 10 Effect of peak ground acceleration with distance based on vehicle class*

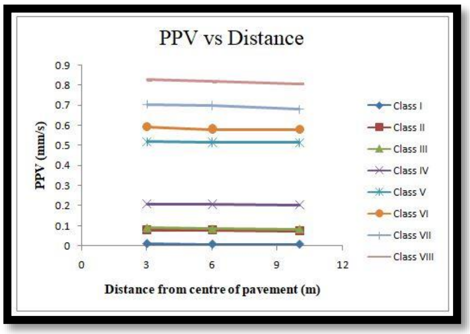



*Fig. 11 Effect of peak particle velocity with distance based on vehicle class*

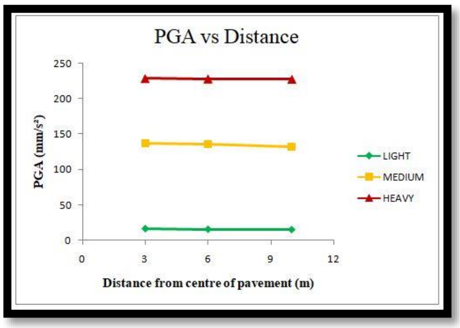



*Fig. 12 Effect of peak ground acceleration with distance based on traffic flow*

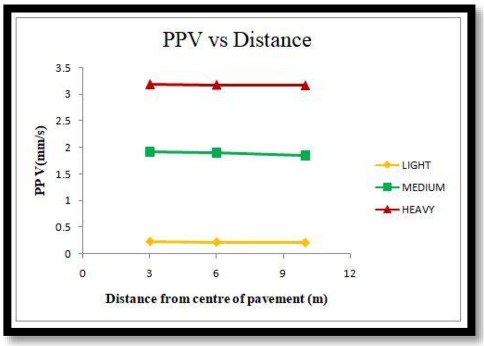



*Fig. 13 Effect of peak particle velocity with distance based on traffic flow*

**D. Effect of Vibration on Soil Properties**

As the soil studied here is of medium strength, medium water content, soil is of nominal profile. The vibration intensities are within safe limits and no nearby structures or buildings present. But, settlement of foundation and soil beneath the pavement might be due to the traffic induced vibration. Since this is not a one-time event, the design stage lacks proper methods to isolate vibrations. As per research, rubber is a material which has excellent resilient properties that makes it suitable to be used under pavements or subsoil to reduce vibration effects. Other methods include trenching, grouting, stabilization, barriers but each method has its own pros and cons. Hence isolation study has to be done specifically at site right during design stage itself, so as to avoid unpredicted fatigue failures and to reduce maintenance costs.

## IV.CONCLUSIONS

[1] Fully loaded trucks and passenger vehicles movement causes heavy vertical and lateral force applied on structure towards geotechnical membrane of the study area.
[2] There is an increase in vibration intensity when vehicle class is higher or load is more. The lightest vehicle had smallest vibration compared to heavier vehicles.
[3] As the traffic flow increases, vibration intensity doubles that of the vibration when single vehicles are passing. Also the speed of vehicle moving is proportional to the intensity of vibration. One can feel the vibration effect on foot when heavy vehicles such as lorries and containers moves by.
[4] The distance of measurement conveys that the vibration reduces with moving distance, but only slower. Vibration does not drops down instead it follows a flat curve trend.
[5] Soil properties are definitely important for analyzing vibration characteristics. Hence vibration parameters can be seen as site specific. In this paper, silt type soil has been studied.
[6] Isolation materials have different properties and they are to be selected based on the site conditions so that the isolation becomes economical and sustainable. Rubber is an excellent isolation material due to its physical and mechanical properties. Rubber derived products can be used in pavement construction to isolate vibrations.

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