Potential of Vibration Studies for Soil Characterization around Proposed High Speed Track near Surat City

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Abstract. High speed corridors are necessary for national growth and hence are inevitable for the economic development of the country. The level of train induced ground vibrations depends on various factors including the wave propagation at a site based on type of soil. Due increase in population, industrialization and lack of space in the urban areas numerous buildings are constructed near the vicinity of the railway tracks. Thus, dynamic analysis of such structures to evaluate its response to dynamic stresses induced due to train, are finding increased application in civil engineering practice. In this study the ground vibrations and its attenuation during the operation of the train at various frequencies is considered. The finite element modelling for the dynamic analysis is tackled here using conventional modelling capabilities normally available in most of the finite element programs. In this study the computer program SAP2000 (CSI, 2000) is used for modelling. The passage of train over the track structure considered is idealized as a sinusoidal harmonic load. As vertical amplitude attenuates less and continues to exists for large distances compared to the horizontal amplitudes, vertical components are selected for the study. The vibration through the soil is found to follow the Bornitz equation and thus the attenuation coefficient for material damping is determined.

Keywords: Bornitz equation, High speed train, Attenuation.

1 Decay of Motion in Soil Medium

Considering motion of train harmonic and sinusoidal in nature, if harmonic sine load is applied to a point load resting on an initially unloaded elastic medium, three types of waves will originate from the loading point. One is a surface wave whose horizontal and vertical amplitude decreases exponentially normal to the surface, while, in the far field, it decreases with distance along the surface at a rate inversely proportional to the square root of the surface distance. These waves are commonly known as Rayleigh(R) wave. The other two waves are termed as body waves, one of which propagates at the longitudinal wave speed of an elastic solid commonly known as Primary(P) wave and the other body wave travels at the shear wave speed of the medium and is known as Shear(S) wave. Both body waves fall off in amplitude inversely proportional to the spherical distance from the source point when monitored in the interior of the elastic space. The Rayleigh waves propagate radially outwards along a cylindrical wave front. The vertical ground displacement due to the Rayleigh wave arrival is much greater than that for P- and S-waves. Since P-waves are the fastest, they will arrive first followed by S-waves and then the Rayleigh waves. Out of these, Rayleigh waves carry a much larger portion of the total input energy about 67% compared to shear waves or primary waves which carry about 26% and 7% respectively.

Maximum destruction caused to the nearby structures by vibratory energy, is carried by Rayleigh(surface) waves traveling from the source of vibration. Generally, the decay or attenuation of vibrations with surface comprises of two factors namely geometric damping and material damping. A portion of this attenuation is caused by the distribution of constant amount of vibration energy on continuously increasing area of wave front. This type of damping is termed as radiation/geometric damping. The geometric damping depends on the type and location of the vibration source on the other hand material damping is related with ground properties and vibration amplitude.

Mathematically radiation or geometric damping is usually described by the following equation [1].

$$A_2. = A_1. \left[\frac{R1}{R2}\right]^n \tag{1}$$

Where A1 is the amplitude of vibration at distance R1 from the source and A2 is the amplitude of vibration at distance R2 from the source and n is the decay or attenuation coefficient due to geometrical damping. The value of attenuation coefficient, n, depends on the type of seismic wave, the location and type of the source as shown in Table.1.

Table 1. Attenuation geometric damping factor (n) with the source on the surface [4]

Source Type	Induced Wave	n
Point	Body Wave	2.0
	Surface Wave	0.5
Infinite Line	Body Wave	1
	Surface Wave	0

Decay in the amplitude or vibration energy of the seismic waves is also associated with the material damping capacity of the geomaterials. Since soil is not perfectly elastic, the vibration energy is reduced due to friction and cohesion between the soil particles. The decay or attenuation due to material damping is affected by the soil type and frequency of vibration [2]. The combined effect of radiation damping and material damping can be described by the following equation.

$$A_2 = A_1 \left[\frac{R_1}{R_2}\right]^n e^{-\mathrm{a}[R_2 - R_1]} \tag{2}$$

Where a is known as decay or attenuation coefficient due to material damping. The equation (2) is known as Bornitz Equation and is used when amplitude of vibration is known at a small distance ‘R’ from the source. Damping of any vibrating system is a complicated parameter and comprises of two parts, namely, material damping which is due to the hysteresis effect on the material and radiation damping due to dissipation of energy within the unbounded soil medium.

Material damping of soil ranges between 1% and 10% of the critical damping depending on material type, whereas radiation damping depends on several factors, and its value can be as high as 50% of the critical damping. Based on the results of measurement of man-made ground vibrations, researchers [3] have reported recommended values of attenuation coefficient ‘a’ for soil materials. Values of ‘a’ recommended by [3] for two values of vibration frequency (5 and 50 Hz) are given in Table.1. Subsequently [4] provided ranges of blow count values N_{SPT}, for each of the four classes of soils which are also included in Table.2.

Table 2. Values of frequency dependent attenuation coefficient ‘a’ for four classes of soil material [2]

Class	**Material Damping Coefficient a (m-1)**		**Description of Material**
	5Hz	**50Hz**	
I	0.01-0.03	0.1-0.3	Weak or Soft soils (NSPT<5)
II	0.003-0.01	0.03-0.1	Competent soils (5<NSPT<50)
III	0.0003-0.003	0.003-0.03	Hard soils (15< NSPT<50)
IV	<0.0003	<0.003	Hard, Competent rock (NSPT>50)

Alternatively, considerably conservative results are obtained if, it is assumed that the absorption coefficient is linearly depends on frequency. Wave propagation due to train vibrations generate low strains where the soil can be assumed as a linear elastic medium. The non-linear behaviour of the soil is often neglected when the shear strain is <10−5 [6]. Also, the value of shear wave velocity (V_S) of geomaterials decreases with increasing value of cyclic shear strain. However, for cyclic strain amplitudes less than 10-5, the value of Vs remains practically constant. Surface waves include both Rayleigh and Love waves, however for near-surface site characterization, the methods utilize only Rayleigh waves. The estimated value of the attenuation coefficient obtained using the R-wave velocity (V_R), the frequency of the vibration and the damping ratio (ζ) using the following equation.

$$a = \frac{2\pi f \zeta}{V_R} \quad (3)$$

From the above equation, the attenuation coefficient linearly increases with the operating or vibration frequency and is inversely proportional with the Rayleigh wave velocity. Alternatively, the independent-frequency attenuation coefficient [7] can be obtained from the following equation.

$$a_o = \frac{a}{V_R} = \frac{2\pi\zeta}{V_R}\ (\text{s/m}) \tag{4}$$

Where a_o is the frequency-independent of attenuation coefficient in s/m.

2 Need for Current Study

National High-Speed Rail Corporation Limited, India (NHSRCL) for the first time is implementing the project of high-speed train corridor between Ahmedabad and Mumbai. This high-profile bullet train will be designed for an operating speed of 320kmph to cover the distance of 526km in just two hours fifty-eight minutes which currently is covered in seven to eight hours. Since this project is first of its kind in India there has been no sufficient comprehensive literature available on the impact of train speed above 200kmph on the vibration response of the track foundation soil in Indian terrain. Based on the research conducted in the past, FEM approach is adopted herein to study attenuation of motion of the surface waves resulting from geometrical and material damping properties of the underlying soil layer near the proposed railway track in the Surat city. The properties of the soil based on laboratory assessment is presented in Table 3. The bedrock for the current study is presumed to be at the depth of 6m from the ground level. A quarter car model was developed to simulate CRH3 type high speed train so as to simulate dynamic effect of load-moving on the ballastless track. The moving train is simulated by a sequence of moving wheel loads that may vibrate with certain frequency. The transmissibility of soil for vibrations induced by trains moving at different speeds was used to identify the cut-off frequency of the train. Two train speeds are considered in the study, one is smaller and the other is greater than the Rayleigh wave speed of the single-layered soil resting on a rock mass. The results of measurements were analyzed in the frequency domain and the attenuation characteristics of foundation soil were studied in term of frequency-independent attenuation coefficient, by applying Bornitz equation.

Table 3. Properties of soil near proposed high-speed track site

Description	Value	Unit
Density	15.57	kN/m3
Water content	15	%
Liquid Limit	30	%
Plastic Limit	Non-Plastic	
Poisson's ratio	0.31	
Modulus of Elasticity	38.59	MPa
Shear Modulus	15871	kN/m2
Shear wave velocity	100	m/sec

IS classification	soft to medium stiff inorganic sandy clays of low plasticity, CL

3 Critical Velocity of Single Layered Soil Resting on Bedrock

Due to symmetry in the section along vertical plan, only half of the section is considered for analysis which has reduced analysis time considerably. To simulate the effect of bedrock, it is assumed that the bottom of the model is fixed and to represent infinite extend in horizontal direction, transmitting boundaries are connected with the elements Fig. 1. These boundaries, which can fully absorb body waves propagating normal to the boundary, were initially proposed by Lysmer and Kuhlemeyer (1969). Accordingly, the damping coefficient for the horizontal and the vertical dampers are defined in the following by equations 5 and 6.

$$C_h = -\rho VpA \quad \& \quad C_v = -\rho VsA \tag{5}$$

$$V_p = \sqrt{\frac{\mathrm{K}}{\rho}} \quad \& \quad V_s = \sqrt{\frac{\mathrm{G}}{\rho}} \tag{6}$$

In these equations Ch and Cv are the horizontal and vertical coefficients of viscous dampers, Vp and Vs are the compressive and shear wave velocities in the soil, respectively, and A is effective nodal area for the node that is connected to the damper. Also, ρ, G and K are mass density, shear modulus and bulk modulus of soil.

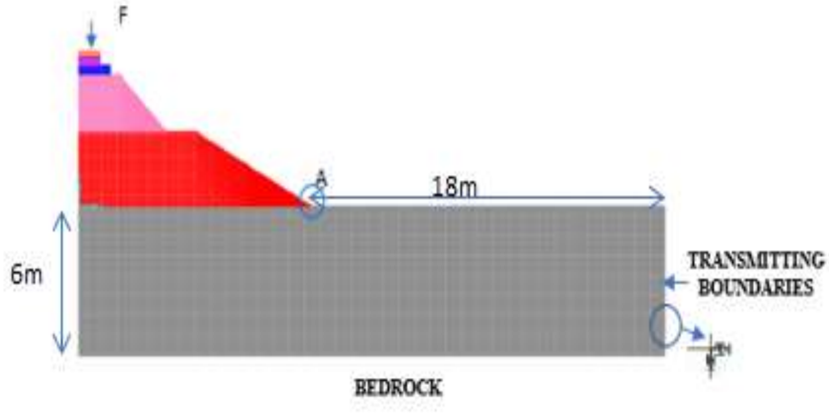

Fig. 1. FEM representation of the site

In view of critical speed to be closely related to the wave velocity of the soil, the train running at a speed that is equal to the surface wave velocities of the supporting soil medium is called critical speed (Vcr) of the train. When train approaches speed equal to critical velocity, Vcr the deflection of track increases drastically. Correspondingly, the magnitude and impact of the vibrations become severe compared with the normal train induced vibration. Frequency response Fig. 2 revealed that maximum amplification occurs when the shear wave of the soil approaches 100m/sec. Thus, the critical velocity of the soil near the proposed site as computed based on dynamic analysis is 100m/sec.

4 Attenuation Characteristics of Soil Layer

Considering the configuration of CRH3-type high speed train, it is simulated for a speed, moving at speed of 88m/sec (speed less than critical velocity of train) and 139m/sec (speed greater than critical velocity of train) is done to comprehend attenuation characteristics of soil. From the table 4 it is observed that as the distance from the source increases, material damping property increases but at a point it is least affected by the frequency of vibration. For the accurate characterization of the soil the readings must be taken as close to the source as possible. As per table 1 it is deduced that the proposed site is characterized as Class I comprising of weak or soft soils with SPT N<5. This goes well with the Indian Standard Classification as shown in table 3

Table 4. Value of 'n' and 'a' as worked out through curve fitting method as measured value through simulation in SAP2000

Distance from the source	**88m/sec**		**139m/sec**	
	n	a	n	a
1m	0.298	0.18	0.206	0.08
4m	0.458	0.407	0.316	0.24

It is established from the present study that as velocity of propagation of waves through soil is vital information regarding the vibration problems of the adjacent buildings, the study helps to predict the vibration amplitude for multiple frequencies at varying distances.

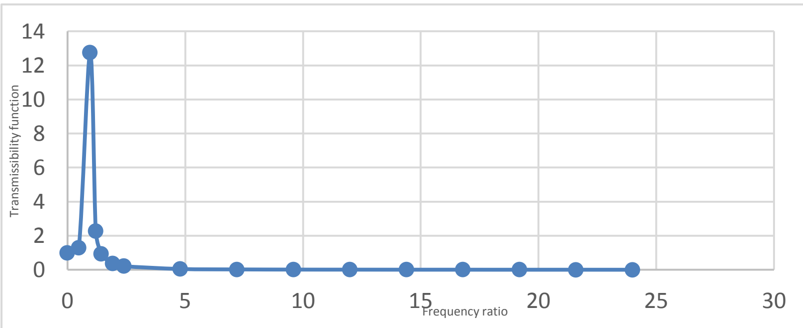

Fig. 2. Frequency response of the soil

5 Conclusion

The current study emphases on measurement of vertical displacement of particles induced by moving train and related geometrical and material damping properties of the surrounding soil. From the study it can be concluded that for ground vibration developed from a periodic vibrating source (low frequency reciprocating type machinery), the attenuation follows Bornitz equation. Characterization of soil is done for the sites considered. The frequency independent attenuation coefficient can be used for setting the vibration limits for buildings for varying distances depending on the soil type.

6 References

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