ANALYSIS OF VIBRATION BY RAIL TRAFFIC USING PLAXIS 3D

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Abstract - *This study investigates the behavior of ground vibrations induced by trains moving on embankments using finite element software, PlAXIS 3D. The track system such as sleeper and rail are modeled as beam element and rail clips are modeled as node-to-node anchors. The loads were applied on the rails directly to simulate the real moving loads of trains. For this purpose, several static point loads were applied along the railway track. The amount of load is equal to the axle load of the train. For each point load, a dynamic multiplier is assigned as a time-shear force signal. A beam under unit loads on the elastic foundation was modeled for calculation of shear forces. The resulting shear forces in the beam were applied to the 3D model as factors of the dynamic multiplier. The effects of dynamic response with distance due to passage of trains were studied. The effect of material parameters, especially the modulus changes of ballast, is taken into account to demonstrate the effectiveness of strengthening the ballast for mitigating system vibration. The numerical results show that the model is reliable for predicting the amplitude of vibrations. Stiffening of fill under the embankment can reduce the vibration level. Different fill modulus of 18, 1000 and10,000MPa were taken. The effect of axle load on dynamic response was studied by using three different axle loads. For this study axle load of passenger train and goods trains BCX and BCNA were considered.*

Key Words: Train induced ground vibrations, Railway embankment, Track, Moving load, Finite element model, etc…

1.INTRODUCTION

High-speed trains represent a convenient and environmentally friendly alternative to road and air transportation. The last two decades have been marked by rapid development of high- speed railway systems in many countries throughout the world. The rapid uptake of high speed rail has been in-part due to its superior economic, social and environmental benefits in comparison to other modes of transport. As many other means of transportation, high-speed trains are not free of environmental problems. In particular, ground vibrations generated by high-speed trains are one of the major environmental problems that must be mitigated to allow high-speed trains to be used in densely populated areas.

It is well known that, if train speeds increase, the intensity of railway-generated vibrations generally becomes larger. For modern high-speed trains the increase in generated ground vibrations is especially high when train speeds approach certain critical velocities of elastic waves propagating in a track-ground system, the most important of them being the velocity of Rayleigh surface wave in the supporting ground.

The vibration caused by the rail traffic often resulting in damage to buildings and monuments. The prevention of damage from vibrations and/or earthquakes damage requires a technical approach which becomes more complex with the increasing cultural value of the affected buildings and monuments and the expected time of conservation. For these reasons a numerical method for modeling the components of rail track strictly connected to the dynamic analysis of the soil-structure interaction produced by external action due to the transit of trains is proposed here.

In terms of structural dynamics, a moving load changes its place during the time and compared to a static load, it can significantly increase displacements in the structure. Moreover, it causes different soil behavior, which has not been fully investigated so far. The dynamic deformation that is caused by trains is normally inelastic. The cumulative plastic deformations during track's lifetime increase progressively and its amount depends on several factors, among them on the subsoil parameters. Irregularities in the track level are common phenomena due to the spatial variation of subsoil and, to some extent.

1.1 Need for the Study

Vibration assessments alongside of train tracks are becoming of paramount importance in recent trend of speeding up operation of trains even at soft grounds. The demand for investigation comes from viewpoints of safe train running and keeping better built-up environment alongside the track. Therefore the geotechnical engineer investigated the behavior of ballasted railway track foundations for high speed trains, with special reference to critical speed.

1.2 Objectives

Since the earliest days of railways in urban areas, there have been complaints of house vibration caused by the passage of trains. Here the problem of the vibration caused by traffic on is taken as the objective of the study. The objective of this study to analyse the track-embankment –ground system analyze the track- embankment-ground system subjected to moving train loads based on Indian conditions.

2. ANALYSIS OF TRAIN VIBRATIONS IN INDIAN CONDITION

In this study, the dynamic three-dimensional (3D) finite element program PLAXIS 3D was chosen for creating the models used to simulate the vibration of track-embankment ground system induced by train moving on the track system. The elements on the rail top are referred to as loading unit, and the moving loads were applied on the loading unit directly to simulate the train moving load. The superfast train, Mangala Lakshadweep express was considered for this study. The Mangala Lakshadweep is a daily running superfast express train of Sothern railway and runs between Hazrat Nizamuddin railway station in Delhi and Ernakulum junction in Kochi, Kerala via the Konkan railway route. This train currently holds the record of being the longest running daily superfast train in India. The average speed of train is 63kmphr. The train consists of 23 numbers of bogies. In order to reduce the model length, only three bogies are considered in the analysis. The average weight of the train was considered as 48.95T.

2.1 Geometry of the Model

The length of the model in X direction was taken as 60m, to analyze the effect of vibration waves with distance. The length in Y direction is taken as 118.05m. The borehole details of the model are obtained from [1]. The length of the model in Z direction was taken as 10.5m. The material properties of the model are given in Table -1.

The embankment and ballast layer were constructed by 'create surface 'option in the Plaxis3D and extrude in Y direction. The embankment has been constructed with a side slope of 2:1 and the ballast surface has been constructed with a side slope of 1:5:1. Table 6.2 shows the model parameter for modeling the moving loads. The rail is modeled as a beam and given properties of UIC 60 rail. Indian railway most commonly uses 1.676m Broad Gauge. The sleepers are modeled as standard B70 sleeper and the length of the sleeper is taken as 2.4m. The rail clips are modeled as node-to-node anchor and the material properties are taken from [2]. As per schedule of dimensions, the minimum center to center distance of tracks is taken as 5.3m.

For each point load, a dynamic multiplier is assigned as time shear force signal. These load multipliers represent the shear forces in the beam due to the static load along the rail in the specific time. To estimate the shear forces in the rail, a static analysis based on the theory of beam on elastic foundation has been computed by using PROKON.

Table -1: Material properties of the model

Material	Shear wave velocity (m/s)	E (kN/m^2)	ν	γ (kN/m^3)
Ballast	165	1.345E+5	0.3	18.64
Embankment	209	1.7E+5	0.36	14
Fill	60	1.8E+4	0.4	16.67
Clay	49	1.050E+4	0.4	14.22
Sand	167	1.6E+5	0.4	20

Table -2: Model parameter for modeling moving loads

Distance between first and last axle of a vehicle, L	73.781m
Additional length	La=0.3L=22.1343m
Total additional length(Left and right)	La total=2*0.3L=44.2686m
Length of the model, Lm	118.05m
Spacing of sleeper	0.6m
Total number of sleeper	196
Dynamic loads distance	0.6m
Total dynamic multiplier	196
Number of dynamic multiplier for whole model	392

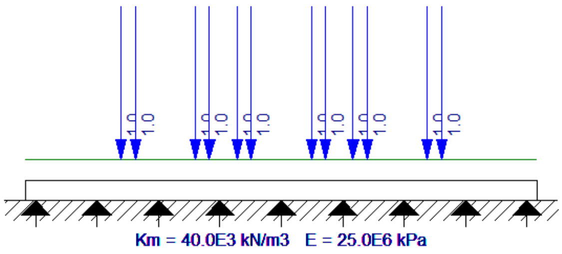

Fig -1: Scaled static model of loads of the beam in Prokon

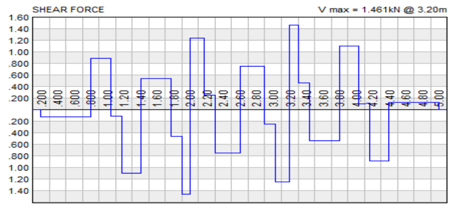

Fig -2: Shear force in the beam

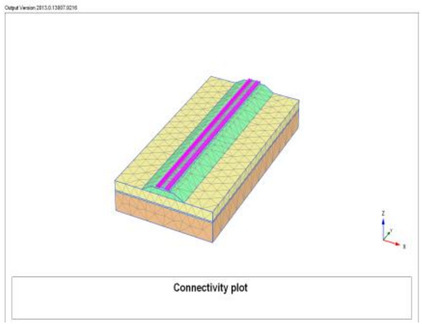

Fig -3: Geometry and mesh

3. RESULTS AND DISCUSSION

The results of the analysis are presented under two subheading ie, dynamic response of track embankment-ground system and parametric study. The parametric study includes the effect of ballast modulus, fill modulus, train axle load and train speed.

3.1 Dynamic response of track-embankment-ground system

The time histories of vertical displacement at selected points 1.25, 2.9, 4.35, 10.35, 14.94, 20.53, 23.94, and 27.35m at different distance from the track center are shown in **Fig-4**. It is noted that the vertical displacement at the rail is larger than that at embankment, and the displacement peak coincide with the instantaneous position of the train load. However, the displacement peak at other points appear to gradually get more out of phase and decrease as the distance from the track center increases. Thus, the vibration waves spread out from the track center and decrease for the vibration attenuation, which shows that the three dimensional model is suitable for simulating the dynamic response of track-embankment-ground system.

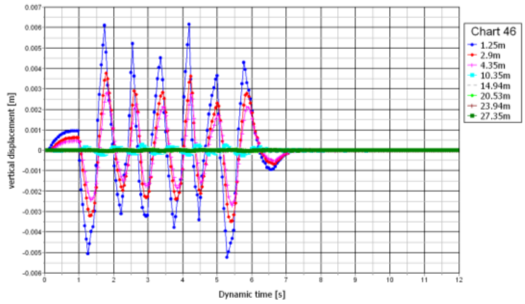

Fig -4: Time history of vertical displacement at different distance from the track center

Fig-5 shows the time history vertical velocity at selected points for train travelling with a speed of 63kmph. It can be seen from the figure that with increase of distance to the track center the velocity level of embankment and ground decreases gradually. The peak value of velocity at point 1.25m from the track center is 0.134m/s, which decreases gradually with the increase of distance. It reaches 0.001262 m/s at 27.35m from the track center.

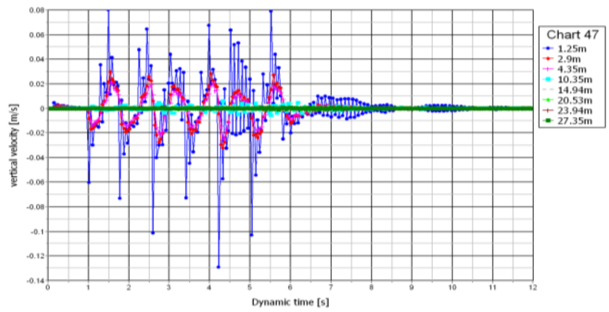

Fig -5: Time history of vertical velocity at different distance from the track center

Fig-6 shows the time history vertical acceleration at selected points. The maximum acceleration is 26.897m/s^2. The acceleration amplitudes of the points located on the embankment and ground surface decrease with the increase of distance from the track center, which show attenuation according to the geometrical damping and internal damping of the soil. At a distance 27.35m from the track center, the maximum acceleration is 0.044 m/s^2.

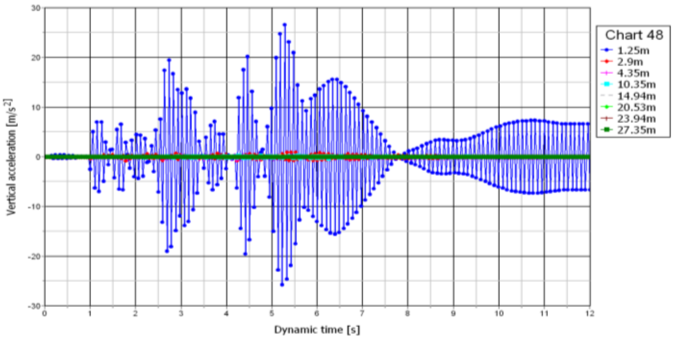

Fig -6: Time history of vertical acceleration at different distance from the track center

3.1 Parametric study

Due to high speed train passage, track-ballast-embankment ground properties play an important role in the ground vibration. Their effects can be evaluated by representing the actual ballast and embankment properties using the FEM. The effects of train axle load are also discussed in the following section.

Effect of ballast modulus

The dynamic response of ballast-embankment-ground is analyzed based on Young's modulus changes of ballast. The young's modulus of ballast is taken as 134,500 and 1000MPa for this analysis. Time histories of vertical displacement and velocity at point 2.9m from the track center for different ballast modulus are shown in **Fig-7.**

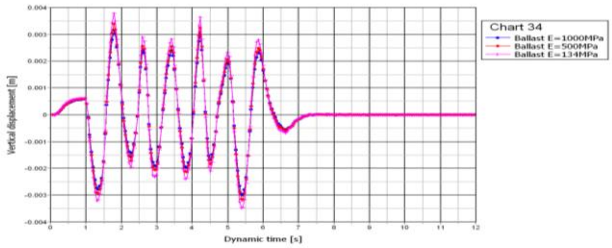

Fig -7: Time history of Time history of vertical displacement at 2.9m distance from the track center for different ballast modulus

The vertical displacement and velocity both decrease with the increase of modulus. Thus, stiffening of ballast can reduce the vibration level and be realized by either installing a concrete slab under the sleeper or replacing the ballast with material with higher stiffness. The variation of vertical velocity and acceleration with ballast modulus are shown in **Fig -8 and Fig -9**respectively.

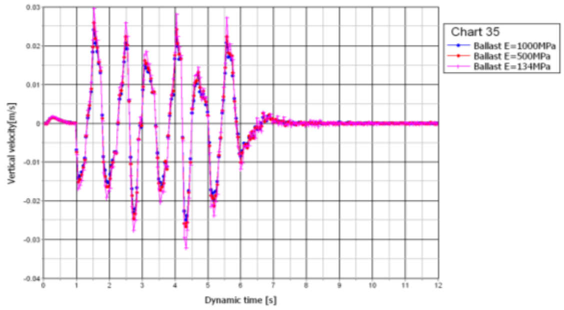

Fig -8: Time history of Time history of vertical velocity at 2.9m distance from the track center for different ballast modulus

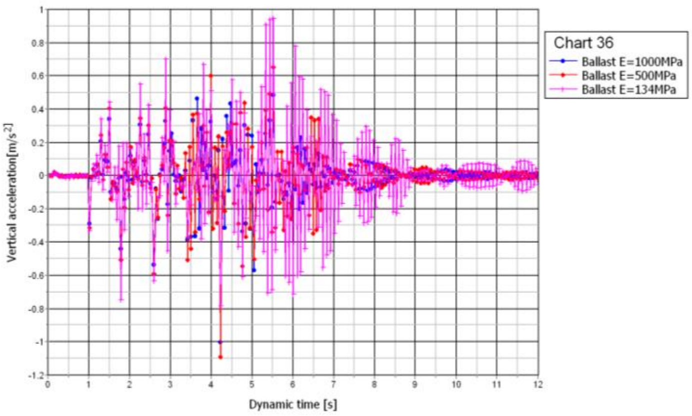

Fig -9: Time history of Time history of vertical acceleration at 2.9m distance from the track center for different ballast modulus

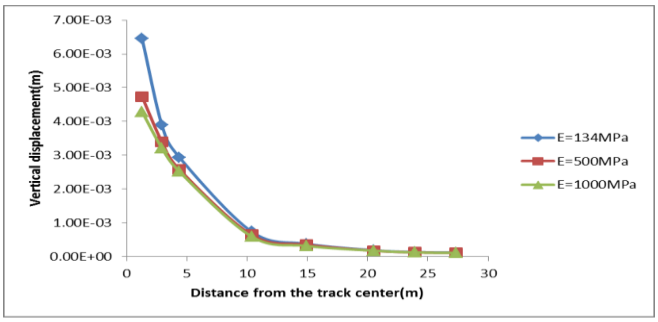

Chart -1: Variation of vertical displacement at selected points with different ballast modulus

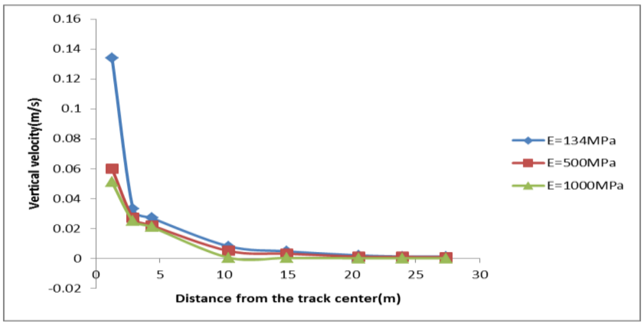

Chart -2: Variation of vertical velocity at selected points with different ballast modulus

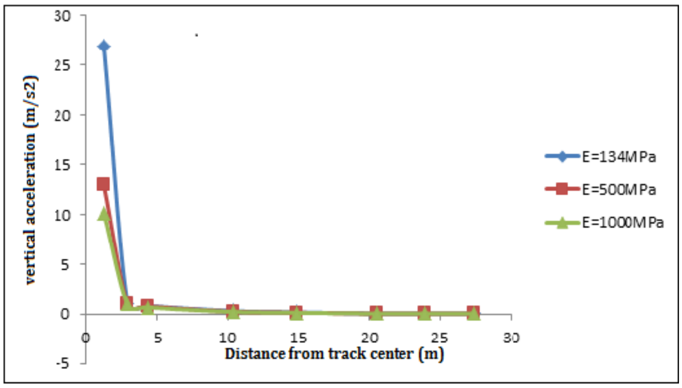

Chart -3: Variation of vertical acceleration at selected points with different ballast modulus

The peak displacement, velocity and acceleration at different distance from the track center are shown in **Chart -1, Chart -2,and Chart -3** respectively. It can be observed from this figures that peak displacement, velocity and acceleration decrease with the increasing of distance, especially at distances from 1.25 to 2.9m away the track center.

For example, the peak displacement at location 1.25m decreases with the modulus of ballast, but this tendency vanished gradually with the distance away the track center. Similar results can be obtained for the peak velocity and acceleration with the changing of ballast modulus.

Effect of fill modulus

To investigate the influence of fill, three moduli 18, 1000, and 10000MPa are chosen. The dynamic response of ballast-embankment-ground is analyzed based on Young's modulus variance of fill under the embankment. Time histories of vertical displacement, velocity and acceleration at point 2.9m from the track center are shown in **Fig -10 , Fig -11** and **Fig -12** respectively.

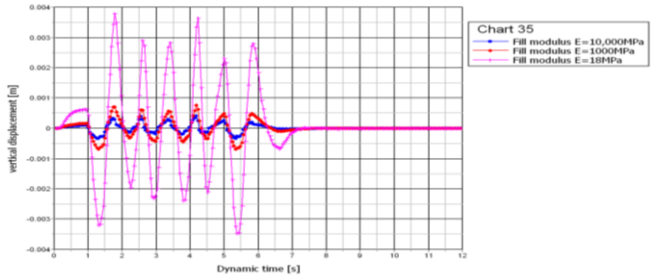

Fig -10: Time history of Time history of vertical displacement at 2.9m distance from the track center for different fill modulus

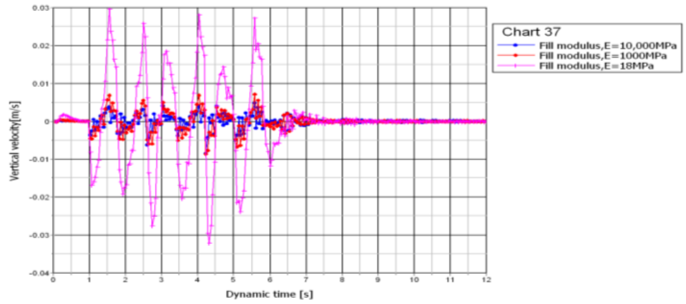

Fig -11: Time history of Time history of vertical velocity at 2.9m distance from the track center for different fill modulus

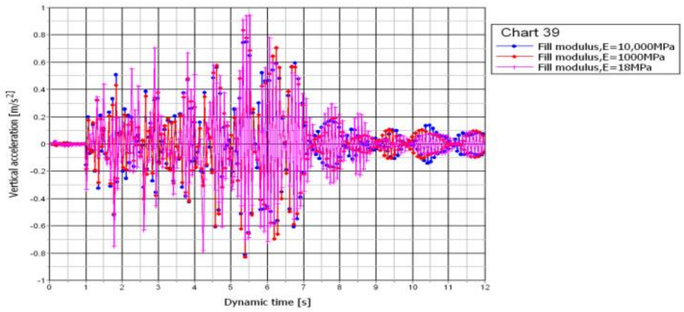

Fig -12: Time history of Time history of vertical acceleration at 2.9m distance from the track center for different fill modulus

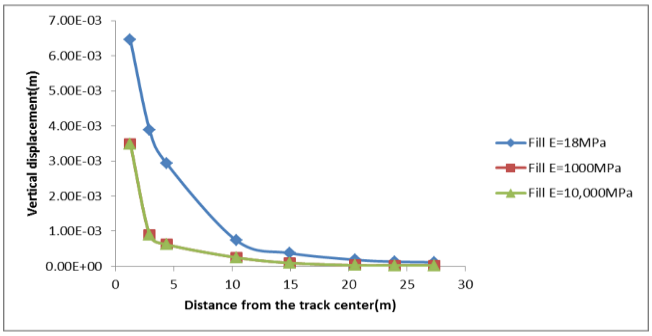

Chart -4: Variation of vertical displacement at selected points with different fill modulus

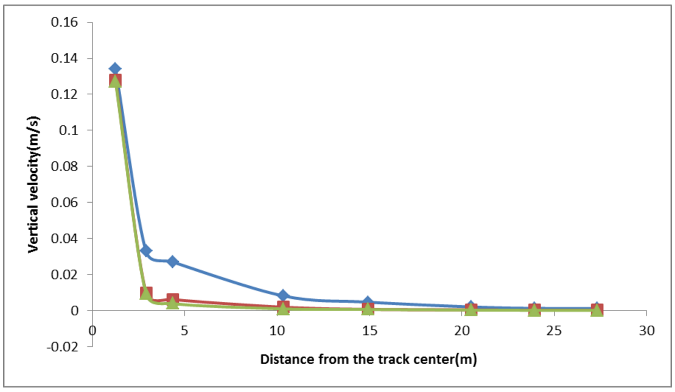

Chart -5: Variation of vertical velocity at selected points with different fill modulus

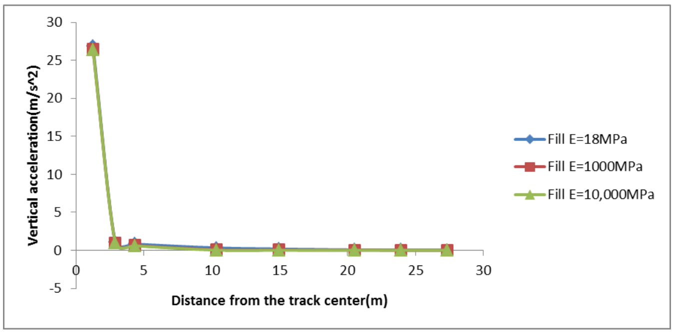

Chart -6: Variation of vertical acceleration at selected points with different fill modulus

The vertical displacement, velocity and acceleration decrease with the increasing of fill modulus. The high value modulus (10000MPa) may reduce the peak displacement by about 50%compared to the low value (18MPa).The peak displacement, velocity and acceleration at different distance from the track center are shown in **Chart -4, Chart -5** and **Chart -6** respectively. A reduction of vertical displacement of about 50% for the high-stiffness fill and 46% for medium-stiffness fill is achieved at point 1.25m from track center. But the influence of modulus on peak velocity and acceleration is not obvious, as seen in **Chart -5** and **Chart -6** respectively. So stiffening of fill under the embankment can reduce the vibration level, on the other hand, it can be realized by installing a concrete slab under the embankment. Moreover, improvement of soft soil ground is another method to reduce the vibration.

Effect of axle load

The average weight of one bogie of the passenger train is taken as 48.95T. And two types of goods train are considered in the analysis. The BCX type is the body covered water tight wagon for loading of food grains, sugar etc. and the weight is taken as 55.5T. The BCNA is a special type of bogie covered wagon with higher carrying capacity and air brake and the weight is 63T. The weights of BCX and BCNA are obtained from Zonal railway training institute, Udaipur (Rajasthan).

The time histories of vertical displacement, velocity and acceleration are shown in **Chart -7, Chart -8** and **Chart -9** respectively. It can be note that the vertical displacement, velocity and acceleration increase with the axle load of high speed train.

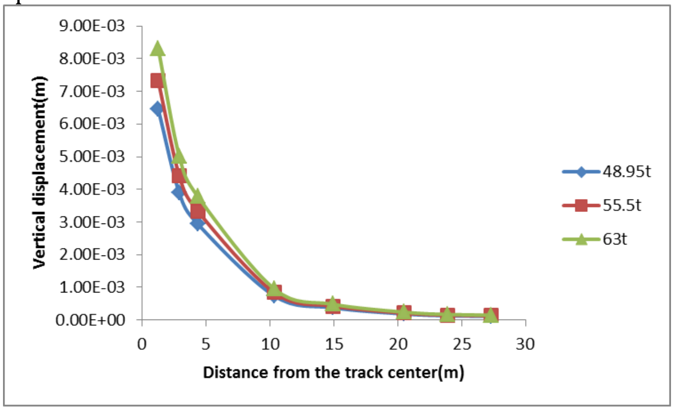

Chart -7: Variation of vertical displacement at selected points with different axle load

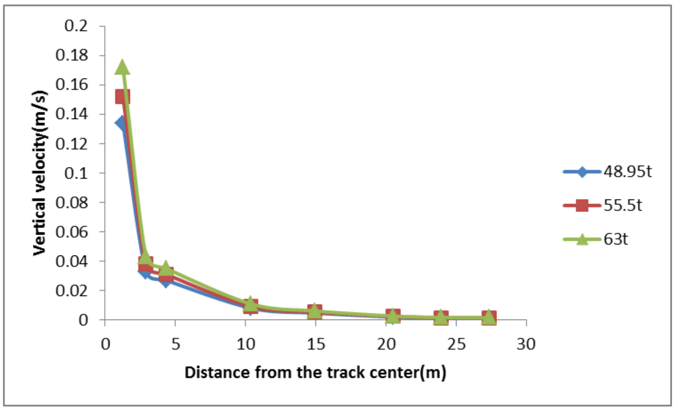

Chart -8: Variation of vertical velocity at selected points with different axle load

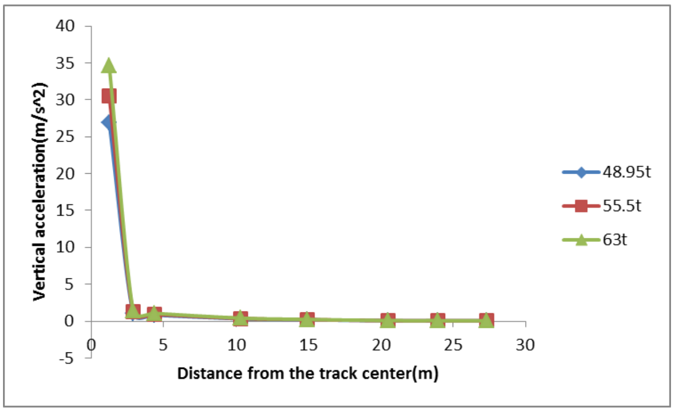

Chart -9: Variation of vertical acceleration at selected points with different axle load

Compared to axle load of passenger train, the vertical displacement, velocity and acceleration for axle load of BCNA increases by about 22%.

3. CONCLUSIONS

In this study, the finite element analysis of train-induced vibration based on Indian condition was studied. The results show that the vertical displacement, velocity and acceleration decreases with increase of distance from the track center. The vibration waves spread out from track center and decreases with vibration attenuation. The value of peak vertical displacement is approximately 0.115mm at a distance of 27.35m from the track center. And for peak vertical velocity and acceleration it is approximately, 1.26mm/s and 4.4mm/s2 respectively.

The numerical results show that the vertical displacement, velocity and acceleration decreases with increase of ballast modulus. This trend is most prominent at a distance of 1.25 to 2.9m from the track center and but this trend vanished gradually with the distance away the track center. Thus stiffening of ballast can reduce vibration level, so replace the ballast with material with higher stiffness.

The other method to reduce the vibration level can be achieved by changing the fill modulus. A reduction of vertical displacement of about 50% for the high-stiffness fill and 46% for medium-stiffness fill is achieved at point 1.25m from track center. But the influence of modulus on peak velocity and acceleration is not obvious

An increase of vibration level can be seen with the increase of axle load. Compared to axle load of passenger train, the vertical displacement, velocity and acceleration for axle load of BCNA increases by about 22%.
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