MODELLING AND ANALYSIS OF AN IRREGULAR RAILWAY TRACK SYSTEM FOR COMPUTATION OF CRITICAL VELOCITY FOR LIMITING VERTICAL ACCELERATION

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ABSTRACT

The irregularity in the railway tracks is a very common topic of interest among the researchers in recent times. The trains run on the tracks with very high velocities to meet the demands of the passengers. But due to the unevenness of the track, the body of the train car faces vertical accelerations, which in turn causes discomfort to the passengers sitting inside the train car. In the present report, vertical acceleration is analyzed for uneven tracks by taking the car body as a single degree of freedom model. The investigation shows a clear explanation of the critical velocity values for the train, so as to maintain the passenger comfort conditions. Random sinusoidal curves were generated using MATLAB to analyze the random unevenness of the track. It is observed that the vertical accelerations in the car body are directly proportional to the speed of the train. Finally, a critical velocity is proposed for a train running on uneven sinusoidal profile track such that, the vertical acceleration not exceeding 0.2g.

KEYWORDS

Track irregularities, Passenger comfort, Sinusoidal track profile, Vertical accelerations in the train, Random sinusoidal curve generation

INTRODUCTION

Passenger comfort studies in a fast moving train is a very important issue to be taken into consideration by the designers of railway systems [1-3]. In recent times, many nations are inaugurating the fast-moving trains running at very high speeds. When the train system runs at such a high speed on an uneven track, the vertical accelerations are imposed on the system resulting in passenger discomfort. The comfort of the passengers depends on the value of vertical accelerations generated in the car-track system. The present article investigates into the important aspect of determining a critical speed of the train, on an irregular track, such that the vertical accelerations do not exceed beyond the passenger comfort limit of 0.2g [4].

For the analysis purpose, the train car body is taken as a single degree of freedom system which moves on an uneven track. The dynamic load of the system depends upon the vehicle speed. It was seen that, if the dynamic acceleration has a proportional relationship with the speed of the train i.e. as the speed increases, the dynamic acceleration also increases accordingly. For computing the vertical dynamic acceleration, the train-track interaction analysis is done to ensure the comfort of the passenger on the fast-moving train. A random variable was generated on MATLAB and different curves were plotted randomly, by taking the maximum value of amplitude and wavelength accordingly [5]. Ten random tracks were generated, and vertical accelerations of the wheel were computed. The random tracks were overlapped to each other, as shown in Figure

1. Thus, the analysis is applicable in general for any random nature of track irregularities, which is an important aspect of this work. The wheel vertical accelerations are also taken into account in the current work as heavy accelerations may result in the derailment of the train.

The single degree of freedom system is impounded with a spring having spring constant ‘k’ and a damper having damping coefficient ‘c’ between the car body and the axle. The jerks which are felt by the passengers sitting in the car body also depend on the stiffness of the spring, i.e. the damping coefficient. Although the comfort condition is not dependent only on the velocity of the system, velocity, the most vital factor, is considered here for the current work. For the study of vertical accelerations in the car body, the movement of single degree of freedom system under base excitation was studied [6], and the critical velocity was computed, keeping in view, the limits of vertical acceleration for passenger comfort conditions [4].

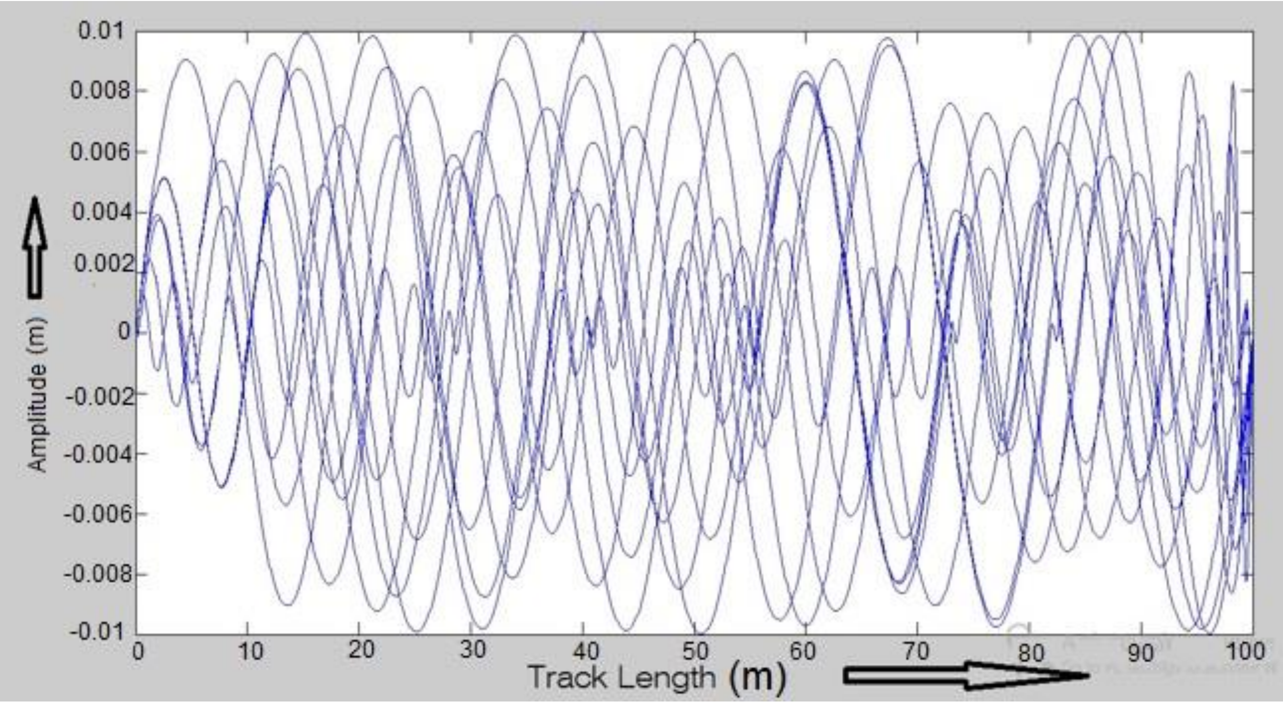

Fig. 1 – Ten random track generation overlap

In the present report, the track irregularities are considered for a running length of 100 meters. The dynamic effects of the irregular tracks are seen and iterated for ten times for ten random track generations. Then critical velocity for the system is suggested below, the system should be kept for the comfortable ride of the passengers.

TRAIN-TRACK INTERACTION

Train-track interaction studies include the modelling of the track [7-11], modelling of the single degree of freedom (SDOF) car body system [12-17], and the general equations on which the study of passenger comfort conditions is based. The stiffness, damping and other system parameters are also taken into consideration [12].

Modelling of the track

A random track irregularity was modeled using MATLAB with a track length of 100 meters and the maximum amplitude value of 0.01 meters [5]. These values were analysed in MS-Excel and then the wheel vertical accelerations were computed, due to the sinusoidal track defects. It was seen, that whenever the train runs with higher speed, the wheel vertical accelerations become higher than 0.5 g, which can result in the heavy discomforts for the passengers. A randomly generated track with MATLAB is shown in Figure 2.

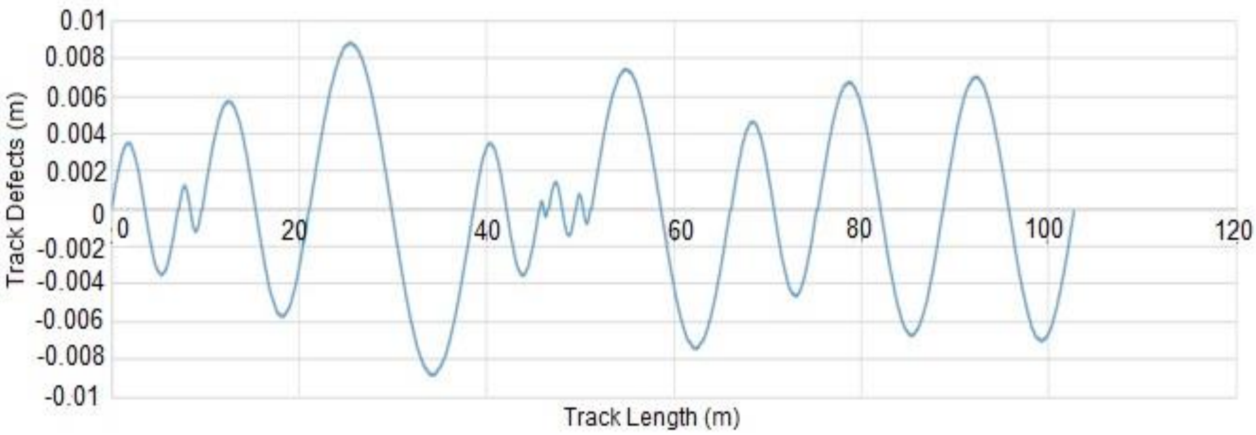

Fig. 2 – Randomly generated track profile

This is a randomly created track with amplitude values within 0.01 meters for a track length of 100 meters. When the SDOF system runs on this track with high velocities, the track induces dynamic force in the car body of the system. The general equation of motion of the dynamic force is obtained as:

$$m\ddot{x} + c\dot{x} + kx = f_0 \qquad (1)$$

Where 'm' is the mass of the car body of the SDOF system, $'x'$,$'\dot{x}'$, and $'\ddot{x}'$ are the deformations, velocities and the acceleration of the car body at different points on the track respectively. The force $'f_0'$ is imposed on the car body by the track. This force is responsible for the passenger comfort issues. The force imposed by the track to the car body is dependent upon the speed of the train. As the speed of the system increases the force increases and hence the vertical acceleration of the car body also increases. If the vertical acceleration in the car body exceeds 0.2 g, then it is considered as a discomfortable condition for the passengers sitting inside the system [4].

Modelling of the system

The system is considered as a single degree of freedom system, which is allowed to run on a track having various uneven sinusoidal track defects. The analysis of the vertical accelerations in the system is done at every 0.138-meter distance on the track, and critical velocity for passenger comfort condition is computed. The system is comprised of a spring having stiffness 'k' and a damper having damping value 'c' [12]. The single degree train system used in this study is shown in Figure 3.

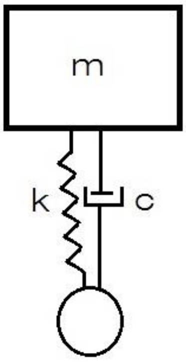

Fig. 3 – Model of a SDOF system

The study is done according to the Indian Railway track permissible defects [5]. Thus, the maximum speed for the train is taken as 100 km/h according to the Indian Railways. The values of mass, stiffness and the damping is taken for an Italian ETR 500Y high-speed train [12]. The values expressed in the Table 1 are also responsible for deciding the comfort conditions for the passengers, as seen in the dynamic equation given (1).

Tab. 1: SDOF system properties

Property	Value
Mass (m) in kg	34,231
Stiffness (k) in KN/m	180,554
Actual Damping (c) in KNs/m	16,250

The values given in Table 1 are used for the analysis of vertical acceleration of the car body of the system. The peak acceleration of the system is restricted to 0.2 g [5]. A study of system moving on a rough track was conducted [6] to find the vertical displacements and excitations. Hence, the vertical accelerations were computed according to the velocity of the system.

VERTICAL ACCELERATIONS IN THE SYSTEM MOVING ON A ROUGH TRACK

Vertical accelerations in the system are dependent upon various factors, which include roughness of the track, the speed of the train system, stiffness of the system and damping value of the system. This is similar to the problem of SDOF system moving on a surface with base excitation. The roughness of the track and the vertical displacements in the train system are given by the following relation [6]:

$$\frac{X}{Y} = \sqrt{\frac{1 + (2\xi r)^2}{(1 - r^2)^2 + (2\xi r)^2}} \tag{2}$$

In the above equation, X and Y are vertical displacements of the system and the track irregularity respectively. The track irregularity values (Y) change with the track length. Thus, the vertical displacements in the system also change accordingly. The effect of vertical displacement due to track defect is managed by the damping ratio (ξ) and the frequency ratio (r). Figure 4 shows the model of an SDOF system with base excitation.

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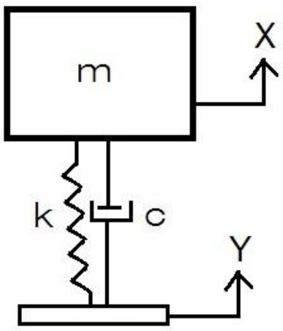

Fig. 4 – SDOF system moving on a rough track

The general equations for damping ratio (ξ) and frequency ratio (r) are explained below. These are the factors to be multiplied by base excitation to get the vertical displacement values in the system at different lengths of the track. In this study, the vertical displacements, velocities and accelerations of the system were analyzed for every 0.138 meters i.e. 0.005 seconds for 100 km/h speed. For 100 km/h velocity, the distance travelled in 0.005 seconds is 0.138 meters. However, for all other speeds the distance travelled in 0.005 seconds time span is different. In the paper the main interest was to study the track length (m) vs vertical acceleration (g) graphical results. The time period for 0.138 meters is 0.0062 seconds if a system is traveling with a velocity of 80 km/h.

$$r = \frac{\omega}{\omega_n} \tag{3}$$

$$\omega = 2 * \pi * \left(\frac{v}{3.6 * l}\right) \tag{4}$$

$$\omega_n = \sqrt{\frac{k}{m}} \tag{5}$$

The equations shown above give the values of frequency ratio. $'\omega'$ is the frequency of the base excitation, $'v'$ is the velocity of the system in km/h and 'l' is the length of track in meters. $'\omega_n'$ is the natural frequency of the vehicle which always remains the same for a particular vehicle. The frequency of the base excitation $'\omega'$ changes with the change in speed of the train and the length of the track.

$$\xi = \frac{c}{c_c} \tag{6}$$

$$c_c = 2 * \sqrt{km} \tag{7}$$

$$c_c = 2 * m * \omega_n \tag{8}$$

Damping ratio $'\xi'$ is a dimensionless quantity. It is a ratio of actual damping and critical damping. It is a constant value for one system, as a system has constant properties like stiffness, mass and actual damping. After computing the results from (2), (3), and (6), the vertical displacements for the system were analysed at every small length 0.138 meters. After obtaining the displacements, the corresponding vertical velocities and vertical accelerations in the system were analysed. Then a critical speed was designed for such type of tracks which holds good for the passenger comfort, and does not exceed the vertical acceleration of the system more than 0.2 g [4].

The graph for the vertical acceleration at every 0.138 meters was obtained using MS-Excel 2016. The critical acceleration value graphical figures for velocities, 30 km/h, 50 km/h, 80 km/h, 90 km/h, and 100 km/h are shown below (Figure 5 – Figure 9).

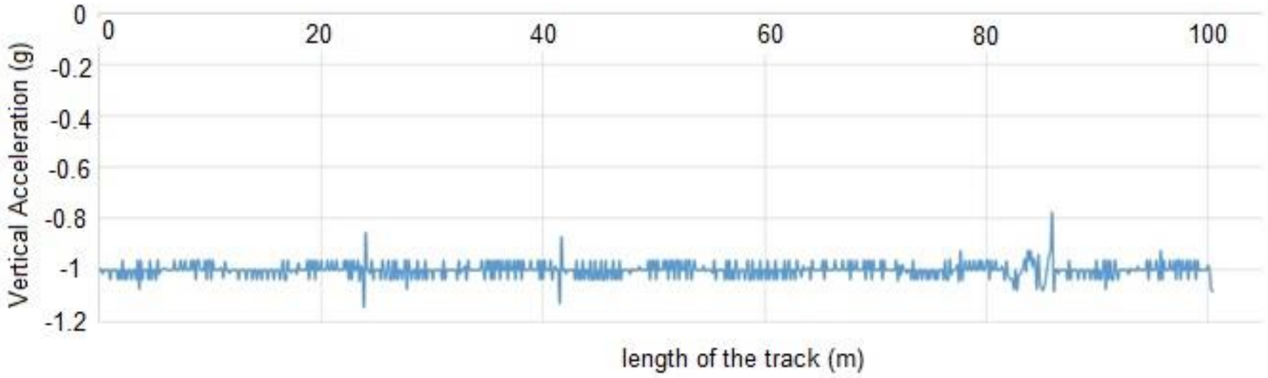

Fig. 5 – Vertical acceleration curve for 30 km/h for a randomly generated track

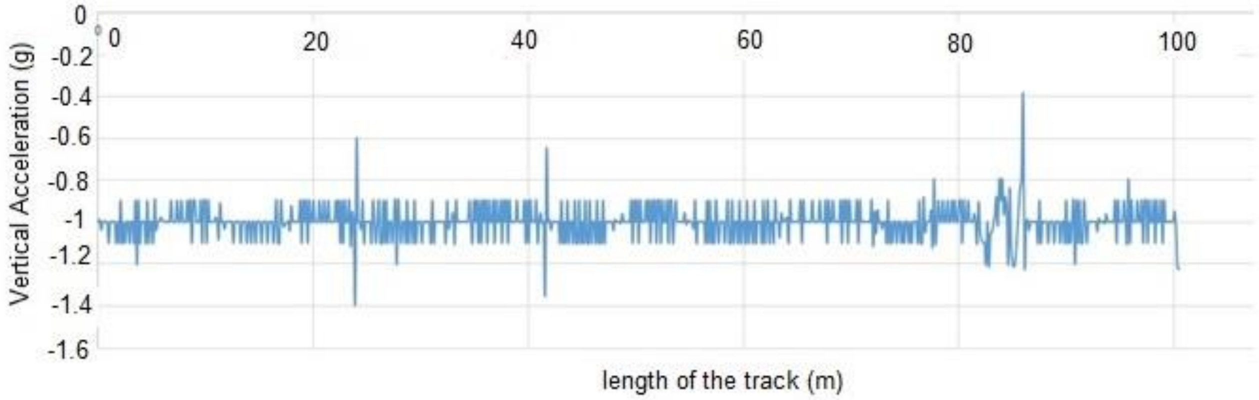

Fig. 6 – Vertical acceleration curve for 50 km/h for a randomly generated track

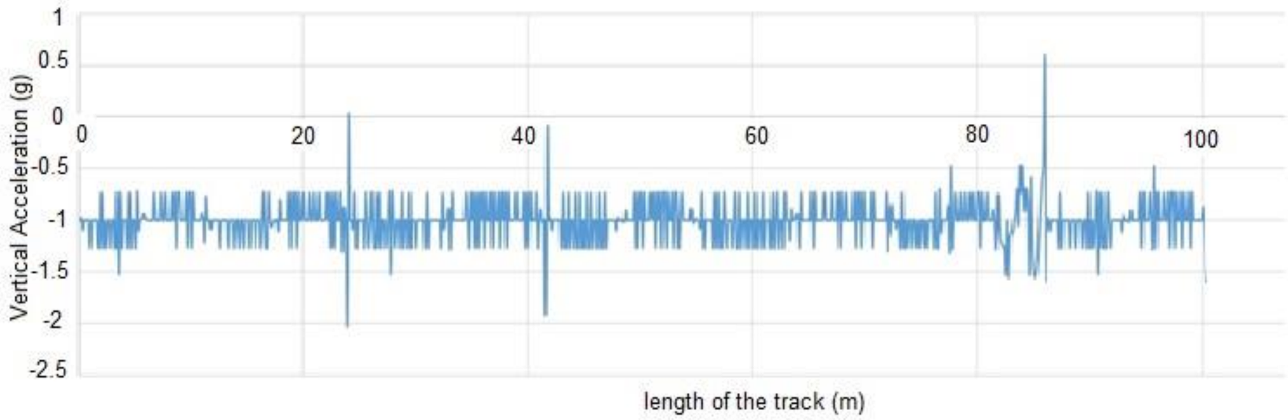

Fig. 7 – Vertical acceleration curve for 80 km/h for a randomly generated track

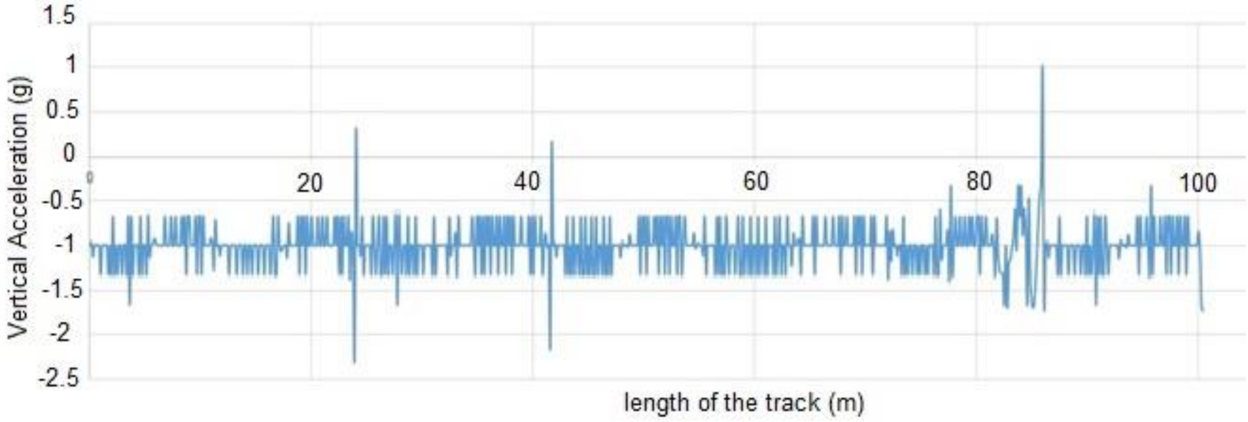

Fig. 8 – Vertical acceleration curve for 90 km/h for a randomly generated track

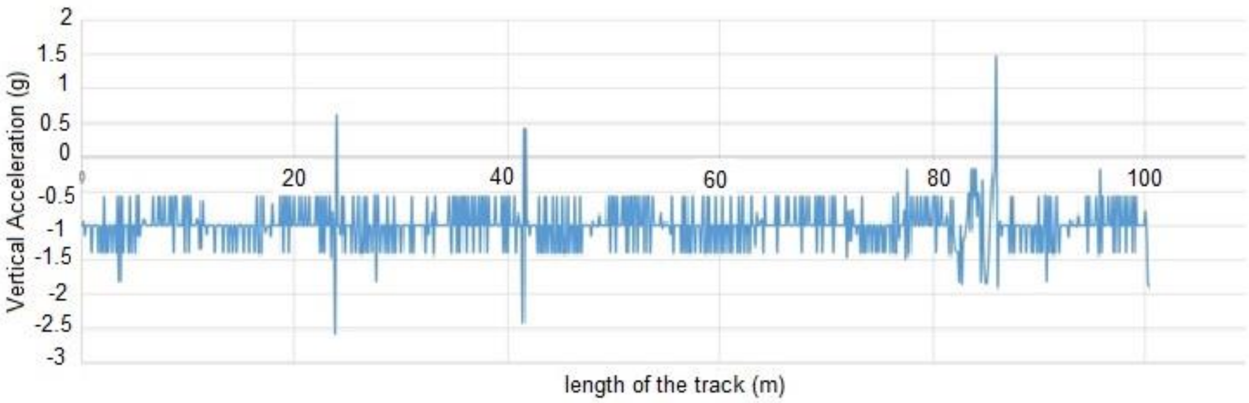

Fig. 9 – Vertical acceleration curve for 100 km/h for a randomly generated track

It is clearly depicted from the plotted graphs that, as we are increasing the velocity of the system, the vertical accelerations in the system increases. The vertical accelerations computed are the input base excitations at every 0.138 meters, which can result in causing derailment discomfort to the passengers, if the vertical acceleration value exceeds 0.2 g [4]

RESULTS

After the analysis was done on MATLAB and MS-Excel, vertical displacements of the system were obtained and hence, the vertical accelerations were computed. The system was allowed to run at various speeds i.e. 30 km/h, 50 km/h, 80 km/h, 90 km/h, and 100 km/h, keeping in view that the vertical accelerations must not exceed 0.2 g. The result obtained at the end of the irregular sinusoidal profile track was that, if the system runs below the speed of 82.42 km/h on the defective track portions, it will be a comfortable speed for the passengers sitting inside the system, regarding vertical acceleration. The time periods and vertical accelerations for different velocities are given in Table 2.

Tab. 2: Vertical acceleration values for different velocities

Velocity (km/h)	Time Period (sec)	Average Vertical Acceleration (g)
30	0.01656	-0.837271
50	0.009936	-0.553746
80	0.007097	0.1571
82.42	0.005998	0.1998
90	0.00552	0.465
100	0.005	1.25497

CONCLUSION

This paper explained the idea of the uneven sinusoidal nature of the track and its effect on the comfort conditions of the passengers. Following conclusions were drawn from the above study:

1) The critical velocity of the system after rigorous analysis was found to be 82.42 km/h. The velocity should be maintained within this reported velocity limit on the defective tracks having sinusoidal unevenness within 0.01 meters for every 1000 meters, which is within the permissible limit [4,5]. The tracks having irregularity more than 0.01 meters for every 1000 meters should be replaced by the new tracks. All tracks should not be replaced by new tracks, as it will not be an economical project.
2) For increasing the speed of the train, an additional damper may be used, which will help in decreasing the values for the vertical accelerations in the system, and hence increasing the comfort for the passengers.
3) For the passage of trains on longer bridges, the speed of the train will be restricted, because bridges are flexible in nature and hence the bridge vibrations are very high, so it is also responsible for the accelerations in the system. The bridge study is not taken in this study. This paper only deals with the trains moving on general ground having track irregularities.

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