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Study of Vibration on Ballasted and Non-Ballasted Railway Steel Bridge

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Abstract: Interaction of running wheels and rails on the railway steel bridge will produce vibration. However, too much vibration produced from dynamic movement of train along the railway steel bridge can cause a problem to the safety of the bridge itself. In Keretapi Tanah Melayu Berhad (KTMB), there are two types of tracks on railway steel bridge which are ballasted track and non-ballasted track that can give different values of vibration to the structure of railway steel bridge. So, in order to define the value of vibration on both railway steel bridges, a vibration test plan will be conducted by using a 4-channel portable sound and vibration analyzer. The vibration test plan also can spot the highest vibration produced along the railway steel bridge by comparing the peak of vertical acceleration of each sample data. Thus, the highest value of vibration in terms of vertical acceleration is at the approach point of non-ballasted railway steel bridge and the ballasted tracks is proven to be able to absorb more vibration and become more cost-effective in terms of maintenance.

Keywords: Vibration, Railway Steel Bridge, Ballast and Non-Ballast

1. Introduction

Vibration is a periodic motion of a rigid or elastic body or medium forced from a position or state of equilibrium[1]. In railway, the rotation of the wheel that interact with the rail will produce vibration. Besides, vibration to the bridge structure happen due to the movement of train and small-scale undulations between the train wheel, railway, and bridge railway contact surfaces. Furthermore, the railway steel bridges which have different speed of trains can amplify the production of vibration which in result could harm the structure of the railway steel bridge. In addition, due to the increase traffic and bigger axle load, the railway steel bridge frequently needs to be maintenance to be able to withstand the

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vibration that being produced. Nonetheless, the ballasted and non-ballasted railway steel bridge need to be safe in terms of its structure for the purpose of the operational of train. The ballast track along the railway bridge also can reduce the vibration that being transmitted to the bridge structure because the ballast will act as a damping to reduce the vibration energy that being produce by the interaction of wheel and rail[2].

The vibration that being produced when a train is moving along the railway steel bridge can be affected by the different types of tracks. It because the tracks which does not have ballast or have a directly-fastened track [3] will directly transmit the vibration from the interaction of wheels and rails toward the bridge structure. Due to the softer rigidity of the wooden sleepers (compared to concrete sleepers) and the better damping efficiency of wood, this will cause the vibrations of the wheel-rail interaction to be led to the bridge structure, but it will not be enough to produce a perceptible reduction of the vibrations [4].
The following are the objective of this paper's: -

i. To study the vibration characteristics of ballasted and non-ballasted railway steel bridge.
ii. To determine the vibration characteristics of the approach, middle and end point of ballasted and non-ballasted railway steel bridge.
iii. To analyse the contribution factors of vibration on ballasted and non-ballasted railway steel bridge.

2. Methodology

2.1 Methodology

The step to find the value of vibration on ballasted and non-ballasted railway steel bridge starts with making procedure for the vibration test plan as in Figure 1. Next, the setup of equipment must be done before conducting the vibration test which starts by putting the measurement value at the sound and vibration analyzer through DewesoftX software as in Figure 2. The measurement that will be used in the vibration test is acceleration and IEPE standard for the accelerometer. Afterwards, the calibration of the accelerometer or sensor by using the DewesoftX software with calibration value of 10.2mV. So, dynamic testing is reliable way to evaluate technical condition of bridge in that such test results display exact behavior of the construction exposed to static or dynamic load [5]. Thus, the vibration test plan will be conducted to verify the safety of bridge. This testing of vibration will conduct on two types of tracks which are ballast track (Plate Girder) and non-ballast track (Pratt Truss Girder). In order to compare the data to measure the vibration for both of railway bridges, the accelerometer will be placed at the main girder of the bridge. The vibration will be measure according to the vertical acceleration and frequency.

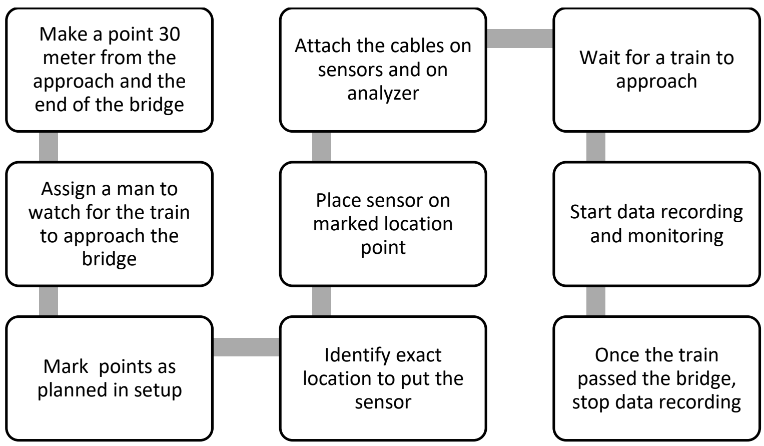

Figure 1: Procedure of Vibration Test Plan

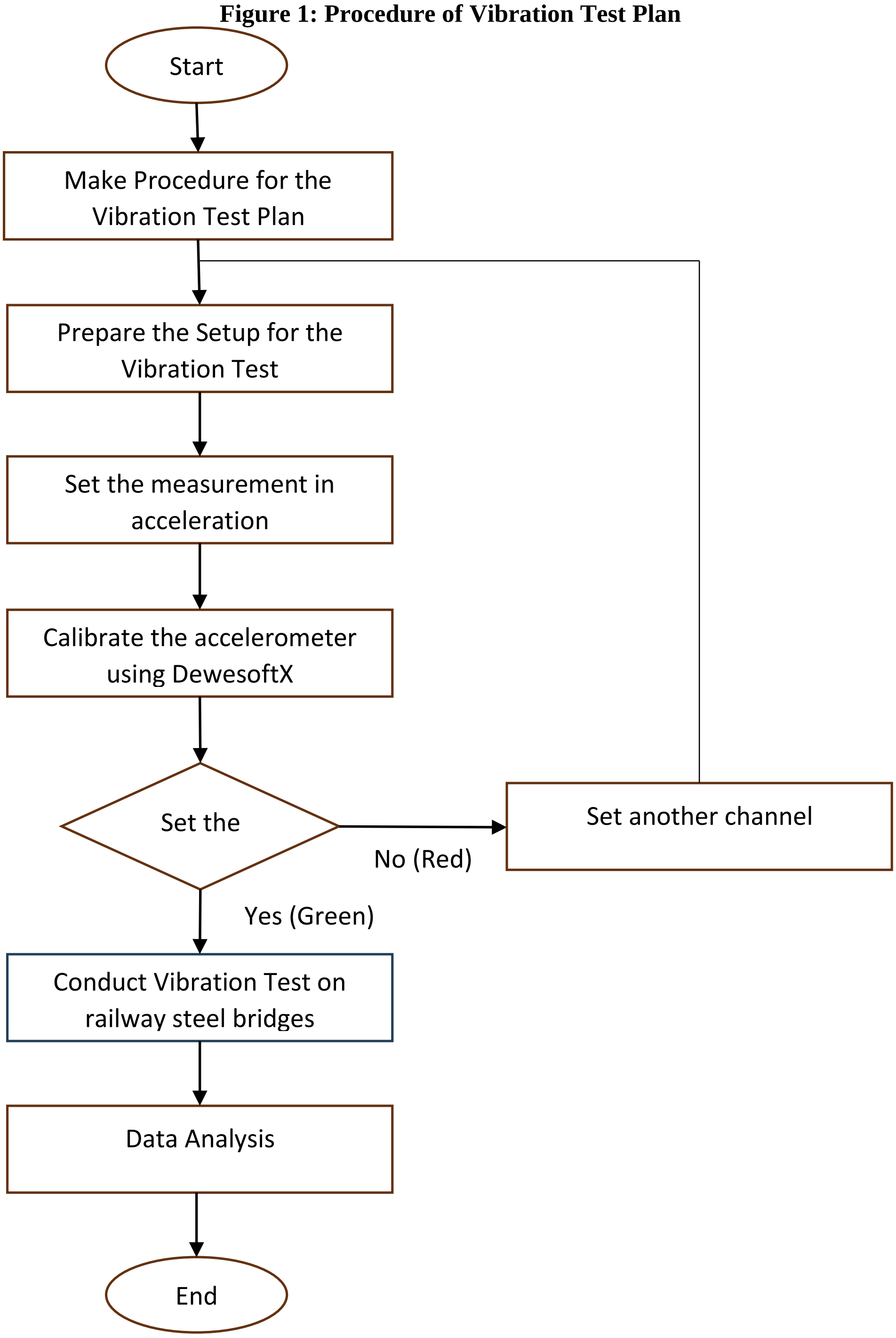

Figure 2: Methodology Flowchart

2.2 Vibration Test Plan

The step of defining the vibration on ballasted and non-ballasted railway steel bridges is by conducting a vibration test plan. The test plan equipment and measuring equipment are:

i. 4-channel sound and vibration analyzer

ii. Uniaxial (1 axis) piezoelectric ICP accelerometers with the sensitivity of $10.2 mV/ms^2$, measuring range of 0.5 to 10000 Hz and $\pm 490 m/s^2$

iii. Laptop
iv. Cables
v. Magnet
vi. Measuring tape

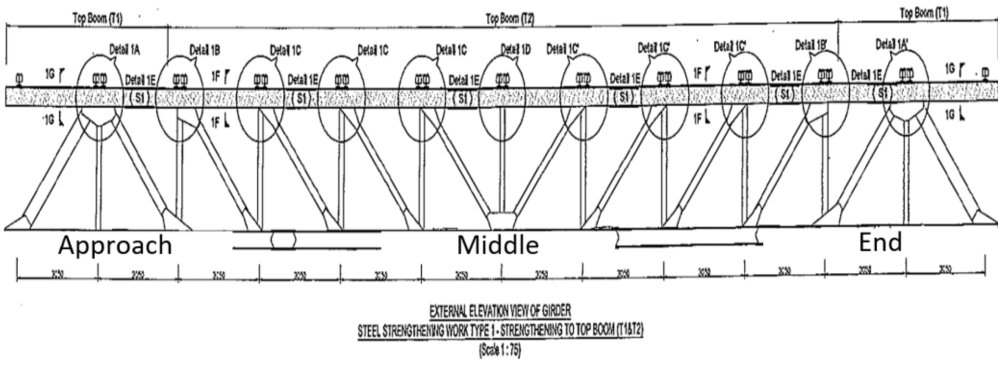

Figure 3: Location of Accelerometer on the Railway Steel Bridge

The testing for the vibration on the railway bridge will be taken 2-3 times. The data will be recorded when the train is about to approach the railway bridge approximately about 30 meters away. Next, the accelerometer will be placed at different measured point on the railway bridge which are at approach, middle and end of the railway steel bridge as in Figure 3. The accelerometers will be connected to the portable 4-channel sound and vibration analyzer by using cables and are tied with magnet to keep the sensor in contact with the measurement point. Furthermore, the vibration test will also be taken on different parameter to analyse the contribution factor toward the vibration on railway steel bridge. So, the different parameter that will be taken in this vibration test are different axle load of train and different speed of train. Based on different axle load of train which are commuter and freight train, the load is different that can affect the vibration that being produced. The commuter has load of 16 tan per axle and freight train have load of 20 tan per axle. The specification of the train that will be use for the vibration test are as above with the commuter has 6 cars set and the freight train has transported the 60 freight wagon. The maximum load that being carried by the freight train is 2400 t while the commuter has carried load of 240 t. The difference between load of these two trains can influence the vibration produced along the railway steel bridge. Besides, different speed of train between commuter and Electric Train Service (ETS) can also influence the vibration when the commuter travel 30 km/h while ETS travel 50 km/h.

2.3 Data Analysis

Based on Figure 1, the data of vibration that have been recorded on both types of railway steel bridges which are ballasted and non-ballasted will be analyse using DewesoftX software. The data that being collected will be converted from time domain to frequency domain by using the constant percentage bandwidth (CPB) or octave band. The octave bands are the source of the standard 1/3 octave bands, which are centred on the same frequencies. The audible frequency range is covered by a total of 31 bands, each of which is further divided into three 1/3 octave bands. By multiplying the octave band centre frequencies by the cube root of 2, one may determine the centre frequencies of the 1/3 octave bands.

3. Results and Discussion

The results of the vibration test plan will be present in vertical acceleration and frequency to verify the value of vibration produced along the ballasted and non-ballasted railway steel bridges. This will help in comparing the vibration produced on both railway steel bridges. Next, it can determine the worst point which produced highest vibration on the railway steel bridge and the contributing factor that influence the vibration produced.

3.1 Vibration Analysis on Ballasted and Non-Ballasted Railway Steel Bridge

Results show the difference of vibration in terms of vertical acceleration and frequency when the train moves along the ballasted and non-ballasted railway steel bridge.

Table 1: Average Maximum of Vertical Acceleration According to the Movement of Train on Ballasted and Non-Ballasted Railway Steel Bridge

Railway Bridge	Measure Point	Vertical Acceleration (m/s^2)	Frequency (Hz)	Average of Acceleration (m/s^2)
Ballasted Upline	Approach	0.0497	800	0.0786
	Middle	0.0994	200	
	End	0.0866	500	
Ballasted Downline	Approach	0.1030	800	0.1066
	Middle	0.0597	200	
	End	0.1570	500	
Non-Ballasted Upline	Approach	0.1580	200	0.5198
	Middle	0.0713	200	
	End	1.3300	1000	
Non-Ballasted Downline	Approach	2.2900	1000	0.8690
	Middle	0.2000	200	
	End	0.1170	200	

Based on Table 1, the data shows the peak of vertical acceleration of every movement of train that moves along the railway steel bridges. The peak of each measure point was being collected. Furthermore, there are significant values of the vertical acceleration and frequency at approach point where the non-ballasted railway steel bridge has 2.29m/s^2 (1000Hz) and the ballasted railway steel bridge has 0.1030m/s^2 (800Hz). This happens because of the type of track which the ballasted railway bridge has ballasted track that can reduce the vibration when the train passes along the steel bridge as the average of maximum vertical acceleration is 0.1066m/s^2. It acts as a filter for the high-frequency components [6]. Evidently, the non-ballasted railway steel bridge has no ballasted track which makes the steel bridge have higher vibration as the average maximum of vertical acceleration is 0.8690m/s^2.

3.2 Vibration Analysis on Approach, Middle and End of Ballasted and Non-Ballasted Railway Steel Bridge

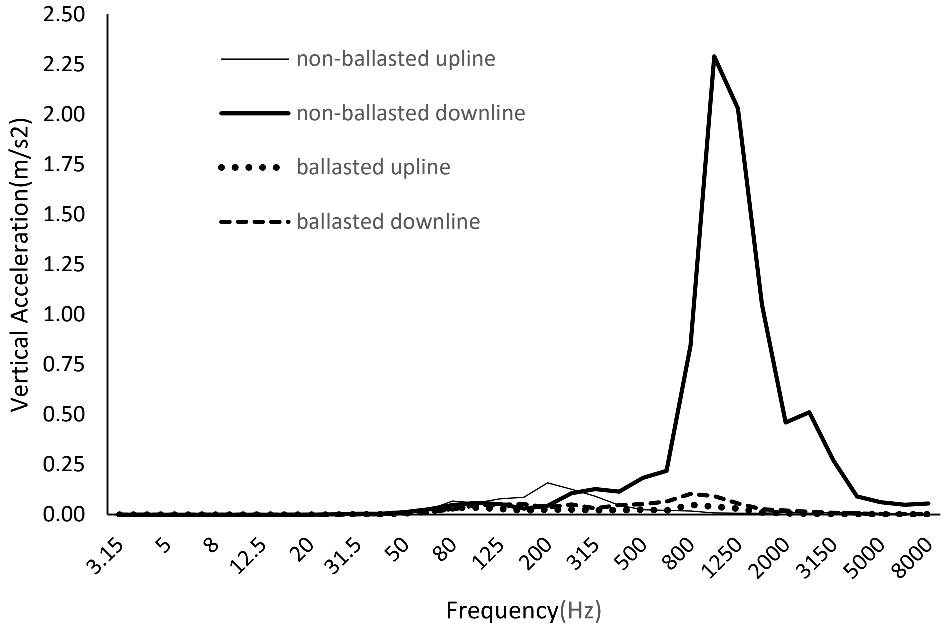

Figure 2: Approach Point

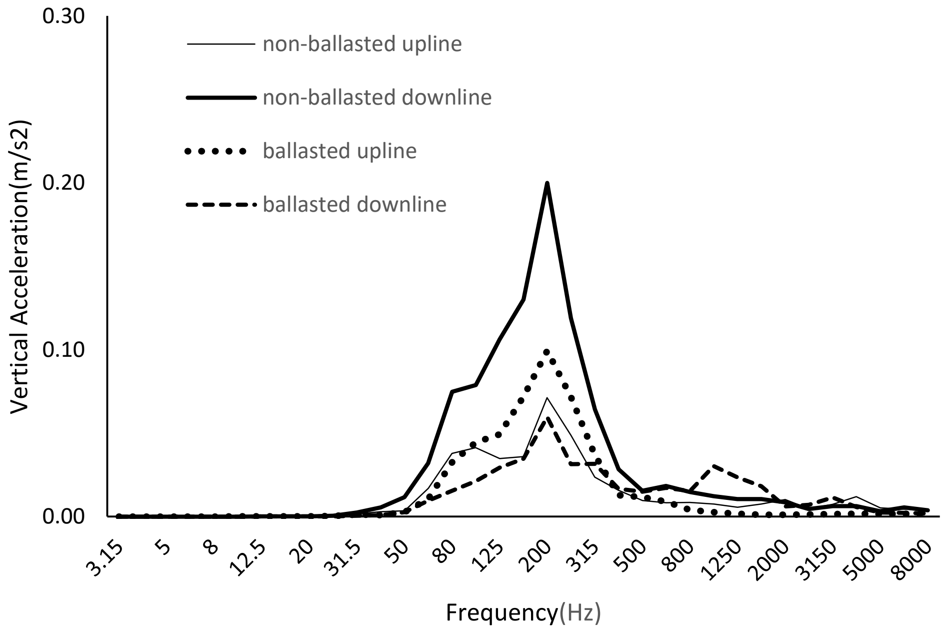

Figure 3: Middle Point

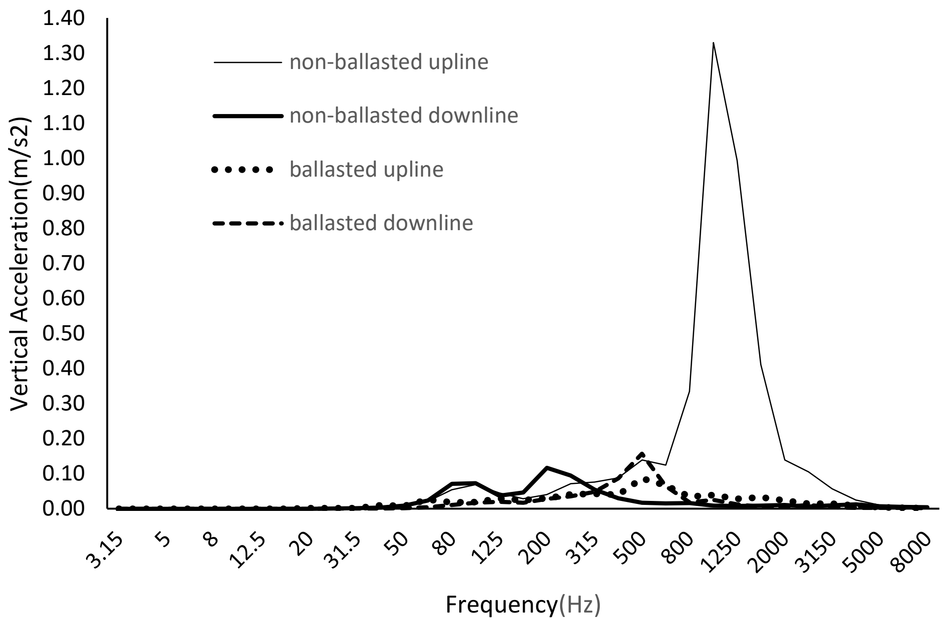

Figure 4: End Point

Based on Figure 2, 3 and 4, the line charts show the different locations where the data of vibration were recorded on both of railway steel bridges. The data were collected at three locations which are approach of bridge, middle of bridge and end of bridge. So, according to Figure 2, the maximum vertical acceleration is 2.29m/s^2 at non-ballasted bridge (downline). As shown in Figure 3, the maximum vertical acceleration is 0.2m/s^2 at non-ballasted bridge (downline). The maximum vertical acceleration is 1.33m/s^2 at non-ballasted bridge (upline) according to Figure 4. So, this indicate that the non-ballasted railway steel bridge has higher vibration than ballasted railway steel bridge according to each point that being measured. As the result, the highest peak of vertical acceleration is at approach point of non-ballasted bridge (downline). This happened because the of the bridge defect (pumping) where there is a space between the bridge bearing and the bed block which influence the value of vibration.

3.4 Factor that Contributes to the Vibration

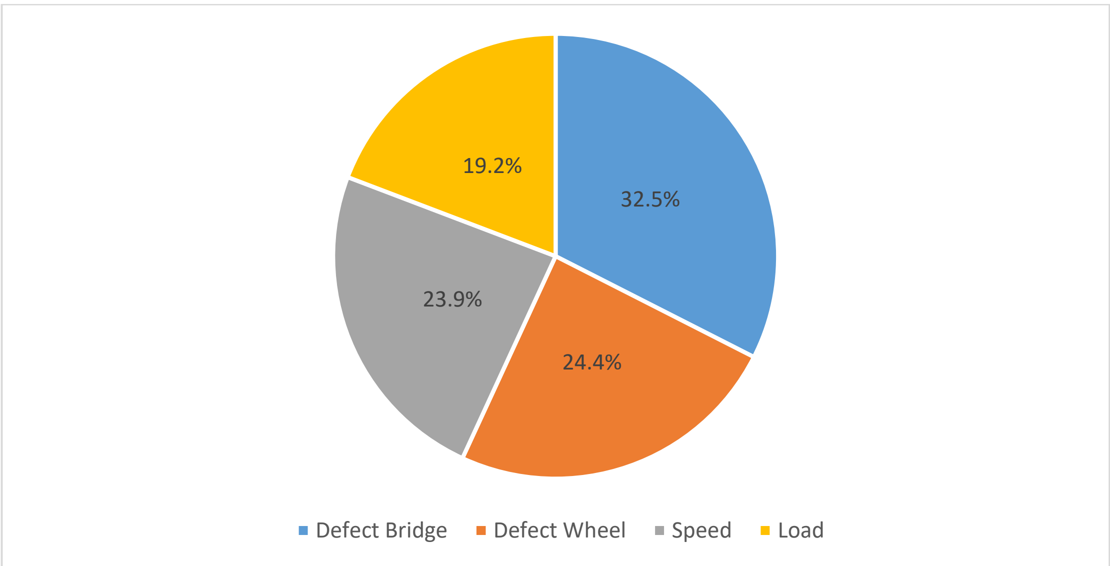

Figure 5: Factor that Contributes to Vibration

As shown in Figure 5, the defect of the steel bridge has a percentage difference of 32.5%. Besides, a train with higher speed can affect the vibration more than heavier load of a train. It is proven as the percentage difference for heavier load of freight train and commuter is 19.2% while faster train has percentage difference of 23.9%. So, a faster train with heavy load tend to produce more vibration. In addition, the vibration can also be influenced by defected wheel or bridge. A defected wheel has percentage difference of 24.4%.

4. Conclusion

This project's objective is to investigate the vibration properties of ballasted and non-ballasted railway steel bridges, identify the vibration properties of the approach, middle, and end, and evaluate the contribution of vibration to each type of bridge. It was determined through the execution of the vibration test that the ballasted railway steel bridge created less vibration than the non-ballasted bridge. Additionally, the approach point of the steel non-ballasted railway bridge was the worst location and created the most vibration. The flaw on the bridge is what causes the most vibration. This project finds that the ballasted and non-ballasted railway steel bridges that being use for this study are safe to be use according to EN 1990 (2006), the maximum peak of bridge deck acceleration are $3.5 m/s^2$ for ballasted track and $5.0 m/s^2$ for non-ballasted track [2].

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