Analysis Of Dynamic Response Of A Railway Vehicle Due To Dipped Rail Joints Using Multibody Dynamics Simulation

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Abstract. Many aspects influence railway vehicle dynamics. One common aspect is the track defect, as the condition of the rail itself will interact directly with the wheel of the train when passing the rail. Dipped rail joint, which is practically impossible to eliminate its existence from the entire track, is the common track defect. The correlation between dipped rail joints with the vehicle response dynamics will help to have a better understanding to ensure safety and passenger comfort when the train is passing the dipped rail joint. While dipped rail joint was developed using MATLAB with different length and depth, dynamic simulation was performed using Universal Mechanism software to obtain quantitative data that represents the train dynamic response in the form of vertical acceleration of the train. The analysis was conducted using several parameters to see the effect of dynamic response due to dipped rail joint. The dyanmic response due to dipped rail joint changed as changes in several parameters occurs, e.g. dipped rail joint with depth of 2.5 mm resulting in a response with amplitude of 1 m/s^2 and if the depth is increased to 5 mm the amplitude of the response is 2 m/s^2 .Therefore, a better understanding of the relationship between dipped rail joint and the changes in parameters, will enhance the dipped rail joint detection and monitoring process in the future.

Keywords: Dipped rail joint, railway vehicle dynamics, train dynamic response, track defect, wheel-rail interaction.

1 INTRODUCTION

Rail defects occur in railroad rails which are practically impossible to prevent or eliminate their existence in the entire track [1]. These defects, if not inspected or monitored regularly, might affect the passenger comfort and safety when the train is passing. This study analyzes the dipped rail joints, where its profile in the longitudinal direction directly affects the vertical acceleration of the train when passing the rail. Fig. 1a shows the actual dipped rail joints and geometry model of dipped rail joints can be generated using Fig. 1b. When passing the dipped rail joint location, a sudden change in the center of spontaneous rotation of the wheel (the wheel leaves contact with the rail for a moment before encountering the rail again) occurs, causing an impact velocity

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on the track in the vertical direction. This results as an impacts and vibrations in the rail wheel system. The impact only occurs for a moment and disappears when the wheel has moved away from the location of the dipped. Wheel of the train will face two peaks of impact force P1 and P2 when passing through the dipped rail joint [2], as shown in Fig. 2. Dynamic force P1 or short peak is the force that occurs when an impact is characterized by a high frequency (≅ 200 Hz – 1000 Hz) while P2 or delayed peak is a force that follows P1 in magnitude smaller and lower frequency (≅ 50 Hz – 200 Hz).

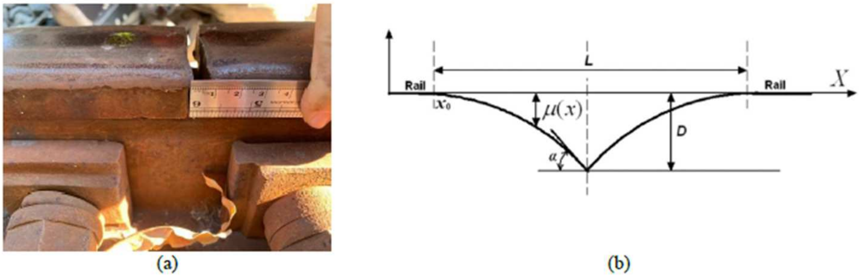


Fig. 1. (a) Dipped rail joint in railway field and (b) geometry model of dipped rail joint [3]

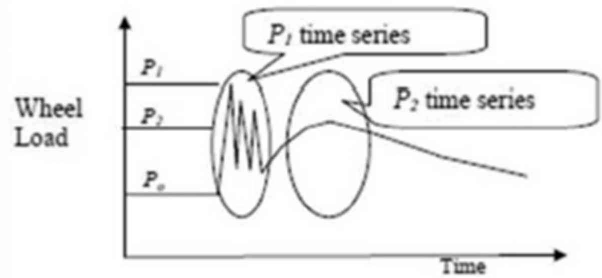


Fig. 2. P1 and P2 of the wheel when passing dipped rail joints [4]

2 TRAIN-TRACK MODELLING

Dipped rail joints are modelled with variation of length and depth using MATLAB as depicted in Fig. 3, combining track irregularity vertical track. As shown in Fig. 4, UIC Bad profile of vertical irregularity is generated from Universal Mechanism library. Rail track is considered flexible rail to define fully functional rail. As shown in Table 1, three variations of rail stiffness parameter were previously researched by Netsyah [5]. The train is modelled as rigid multi- body dynamics consisting of one carbody, two bogies and four wheelsets connected using force elements. The train model referred to one of the passenger trains produced by domestic industry as shown in Fig. 5, that validated in previous research [5] using the parameter as shown in Table 2.

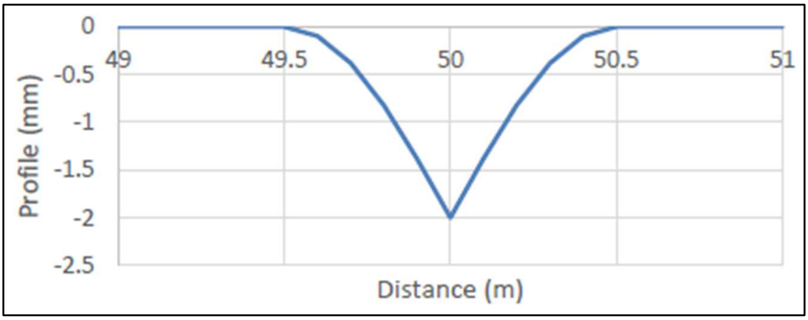


Fig. 3. Dipped rail joints model generated in MATLAB.

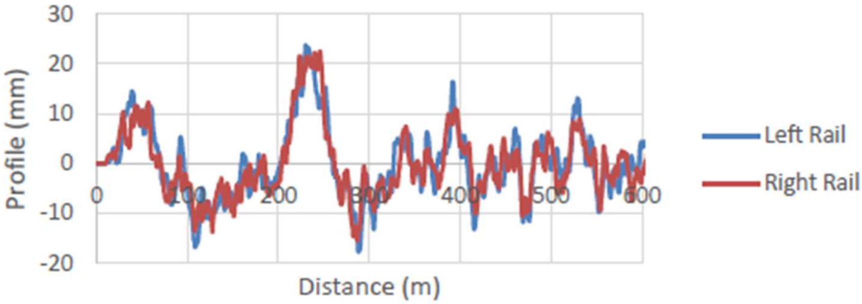


Fig. 4. Track irregularity of UIC Bad profile.

Table 1. Stiffness variation parameter of flexible rail track.

Parameter	Soft	Normal	Stiff
Fastener stiffness (kN/mm)	70	70	500
Ballast stiffness (kN/mm)	10	50	100
Sleeper stiffness (kN/mm)	8.75	29.2	83.3
Characteristic length (mm)	1,175	870	669
Global stiffness (kN/mm)	31.6	78	171.5
Length difference (mm)	3.16	1.28	0.58
Rail moment (kN.mm)	29,400	21,700	16,700
Fastener weight (kN)	27.7	37.4	48.6

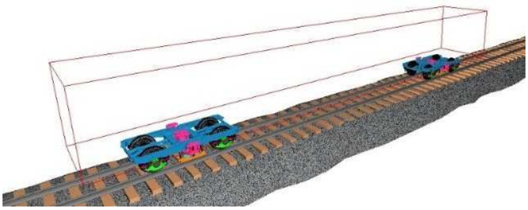


Fig. 5. Graphical model of train in Universal Mechanism Software.

Table 2. Parameter of train dynamic model.

Parameter	Value
Carbody mass (kg)	31,186
Carbody length (m)	20
Carbody width (m)	2.99
Carbody height (m)	7.717
Bogie frame mass (kg)	970
Bolster mass (kg)	491
Sprink plank mass (kg)	173
Wheelset mass (kg)	1,500
Wheelbase (m)	2.2
Bogiebase (m)	14
Tare length of primary suspension (m)	0,216
Vertical stiffness primary suspension ($kN.m^{-1}$)	637
Vertical stiffness secondary suspension ($kN.m^{-1}$)	410
Vertical damper coefficient ($kN.s.m^{-1}$)	500

The simulation was carried out with base parameter train velocity of 80 km/h, rail stiffness normal, dipped rail joint depth of 5 mm, and dipped rail joint length of 1 m. The mass of the train is assumed constant. Using sampling frequency of 400 Hz, the data are recorded in the form of acceleration in the vertical direction of the train carbody on the rear bogie. As shown in Fig. 6, position data is recorded in the center to make it easier to identify the location dipped rail joint by comparing the profile data that has been made.

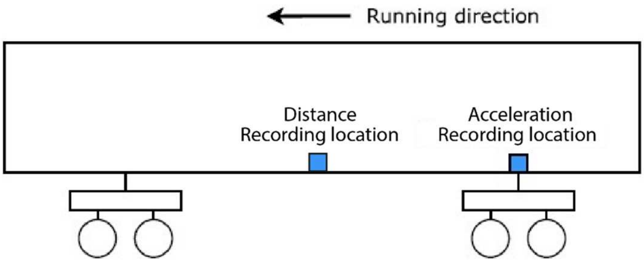


Fig. 6. Recording data location.

3 RESULTS

The data was obtained from dynamic simulation in Universal Mechanism software and analysis was conducted to see the affect of seven different parameters to the dynamic response, due to dipped rail joint. The effect of dipped rail joint location, the effect of measurement location, the effect of dipped rail joint depth, the effect of dipped rail joint length, the effect of train velocity, the effect of rail stiffness, and the effect of vertical irregularity. The dynamic response observe is the carbody vertical acceleration. The effect of dipped rail joint location was to analyze between single dipped rail joint (only left rail) vs both sides, as shown Fig. 7. It is shown that the amplitude of the vertical acceleration response is higher due to dipped rail joint that exist in both sides of the track. The effect of measurement location was to analyze between location in carbody as depicted in Fig. 8a, and between bogie and axlebox, as shown in Fig. 8b. Peak value or the amplitude in measurements from the carbody is much lower due to the effects of primary suspension and secondary suspension, while the peak value in the bogie measurement is lower than the measurement in the axlebox due to the influence of the primary suspension on the wheels.

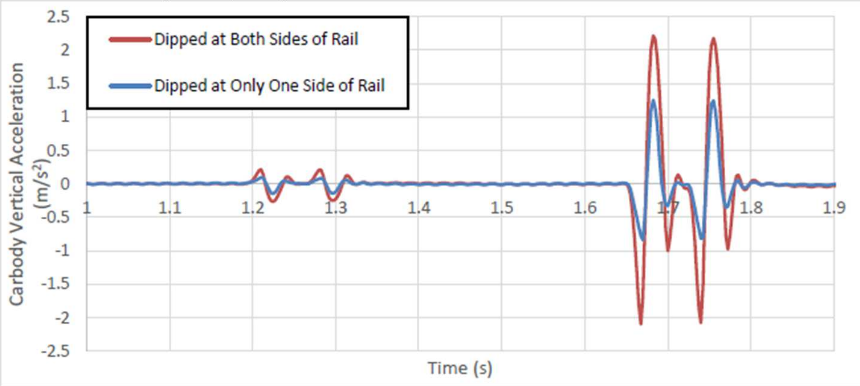
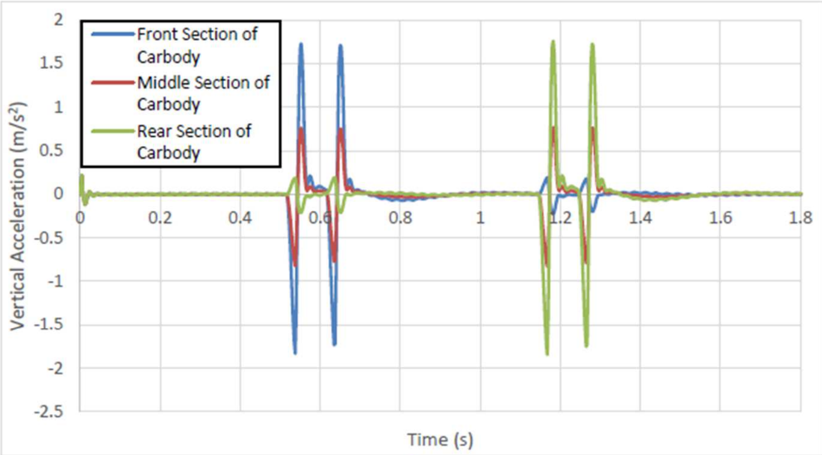
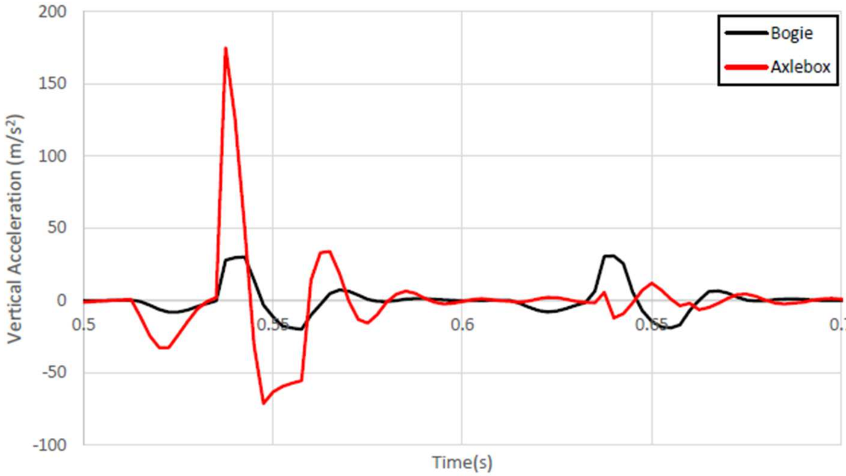


Fig. 7. Effect of dipped location on vertical acceleration response.



(a)



(b)

Fig. 8. Effect of measurement location on vertical acceleration response: (a) carbody and (b) bogie and axlebox.

The effect of dipped rail joint depth was to analyze between 2.5 mm and 7.5 mm. As shown in Fig. 9, As the dipped depth increases, then the amplitude or peak and peak to peak values of the response due to the dipped rail joint rise. The amplitude of the vertical acceleration response due to dipped rail joint with depth of 2.5 mm is approximately 1 m/s2, while due to dipped rail joint with depth of 5 mm is approximately 2 m/s2 and due to dipped rail joint with depth of 7.5 mm is around 3.7 m/s2.

The effect of dipped rail joint length was to analyze between 0.5 m and 2.5 m. Depicted in Fig. 10a, As the length of the dipped rail joint increases from 0.8 m to 1.4 m, the amplitude increases or the peak and peak to peak values of the response due to the dipped rail joint are drop. Depicted in Fig. 10b, the effect of an extreme length of dipped rail joint of 0.5 m and 2.5 m was also observed. The amplitude of vertical acceleration response due to dipped rail joint with length of 0.5 m is 0.1 m/s2 which is lower compared to the vertical response on Fig. 10a. Meanwhile the amplitude of the response due to dipped with length of 2.5 m is approximately 0.8 m/s2 which is lower than due to dipped with length of 0.8 m to 1.4 m. The response due to dipped rail joint with length of 2.5 not only indicating that there is a maximum value of amplitude due to increasing length of dipped rail joint but also a changes in the frequency response is indicated.

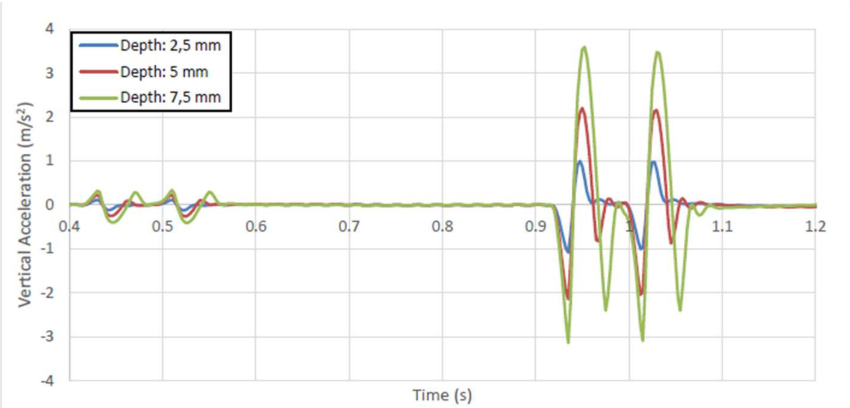
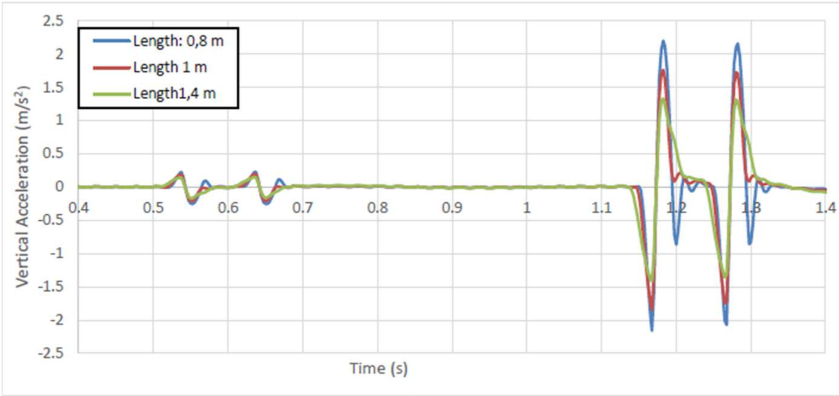
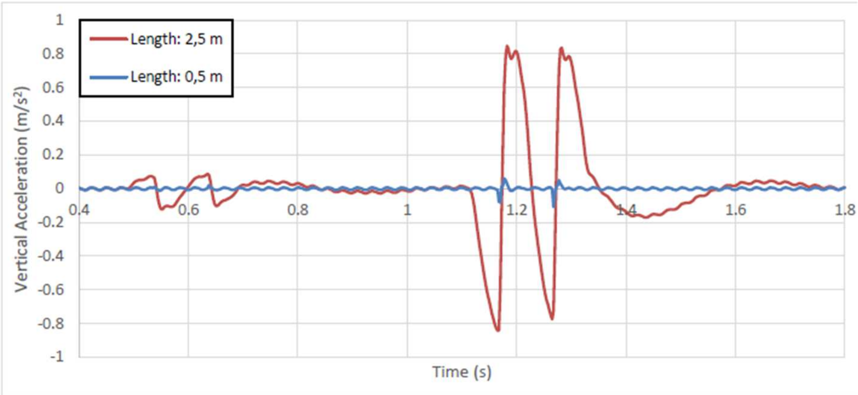


Fig. 9. Effect of dipped rail joint depth on vertical acceleration response.



(a)



(b)

Fig. 10. Effect of dipped rail joint length on vertical acceleration response: (a) 0.8 m to 1.4 m and (b) 0.5 m and 2.5 m

The effect of train velocity was also observed, between 40 km/h to 120 km/h. Fig. 11 shows that the amplitude or peak and peak to peak values of the vertical acceleration response due to the dipped rail joint increases when the velocity up. The effect of rail stiffness was also investigated, between soft, normal, and stiff as shown in Table 1. Fig. 12 shows a vertical acceleration graph with variation of rail stiffness. The peak on soft is smaller than higher rail stiffness.

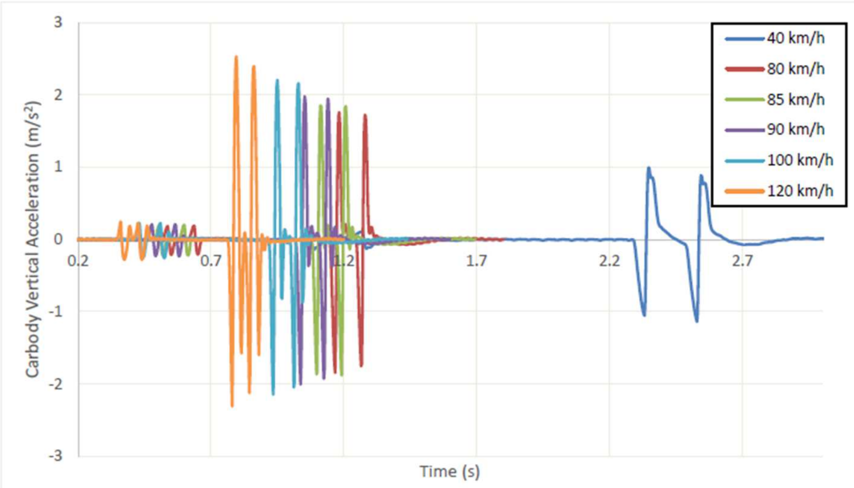


Fig. 11. Effect of train operating speed on vertical acceleration response.

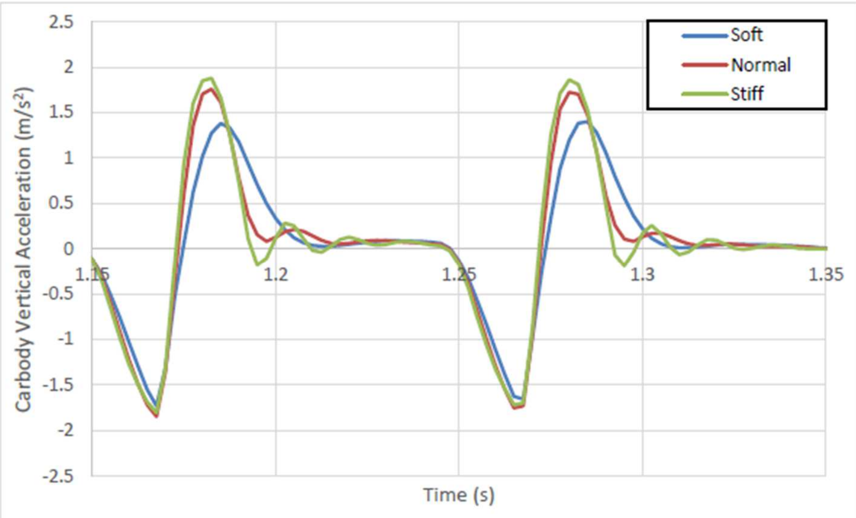


Fig. 12. Effect of railway stiffness on vertical acceleration response.

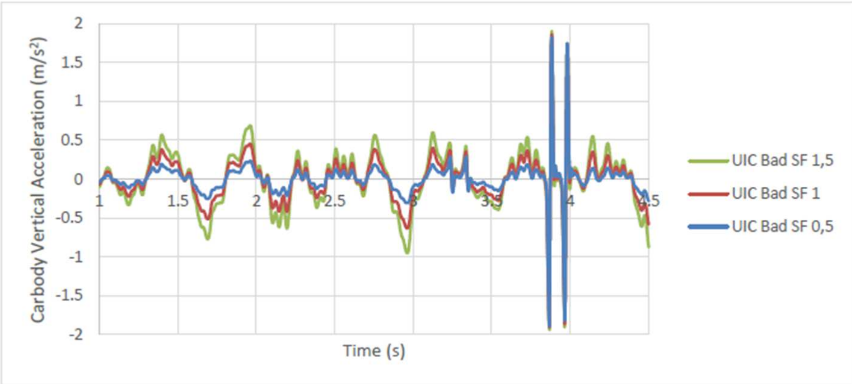


Fig. 13. Effect of vertical irregularities on vertical acceleration response.

Fig. 13 shows the resulting vertical acceleration graph dipped rail joint and vertical irregularity with three variations in scale factor (SF). Irregularity profile used is UIC Bad for the vertical direction (Z-axis). Irregularities are varied by a scaling factor of 0.5, 1, and 1.5. This scale factor is used to increase or decrease the severity of an irregularity profile. It is shown that the response due to dipped rail joint is still recognizable while the response itself is mixed with responses due to vertical irregularities. As the scaling factor increases, the amplitude of vertical acceleration response due to dipped rail joint slightly increases.

4 CONCLUSION

Dipped rail joint profile has been successfully modeled and simulation dynamics was successfully carried out using this model. From the results of dynamic simulations a number of quantitative data were obtained that show the relationship between dynamic responses a train body with a dipped rail joint defects. Seven parameters are analyzed to see the effect of variation of parameters. The result acknowledge that vertical acceleration response due to dipped rail joint that exist in both side of the rail is bigger than due to dipped rail joint that only exist on one side. The location of measurement affect the vertical acceleration measured because the effects of primary suspension and secondary suspension of the train vehicle. With the increasing depth of dipped rail joint the vertical acceleration response also increasing while increasing length resulting in lower vertical acceleration reponse. The speed of the vehicle also affects the dynamic response due to dipped rail joint, the faster the operating speed the higher the amplitude of the vertical acceleration measured. Dipped rail joint size and operating vehicle's speed are not the only parameters that affect the dynamic response due to dipped rail joint, stiffness of railway track and the existence of vertical irregularities contributes to the dyanimc response measured. As the stiffness of railway track increases, the vertical acceleration response increases and the higher the severity of the vertical irregularities, the higher the vertical acceleration measured. This analysis is the early stage of vehicle dynamics analysis, and future works will enhanced the dipped rail joints analysis, such as comparison with the actual field measurements, and conduct more-in-depth research into sensitivity of the simulation to other parameters directly related to vibration like primary suspension and secondary suspension.

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