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A Study on Derailment at Railway Turnout Using the Multi-body Dynamics Simulation

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ABSTRACT

In this study, the locomotive and the turnout were simulated with three-dimensional models. The purpose of this study is prediction the derailment phenomenon of the locomotive running on the turnout in Vietnam. Multi-body simulations were implemented by SIMPACK software to determine the derailment coefficient, the wheel unloading factor, and the lateral force. The interaction between the locomotive and the track structure at turnout was considered unified. The derailment coefficient, the wheel unloading factor, and the lateral force were calculated for locomotive-D19E at turnout (tg0.15) for 1000 mm gauge according to QCVN 18:2011/BGTVT, EN 14363:2016, and TCVN 8784:2011. The derailment coefficient, the wheel unloading factor, and the lateral force for the locomotive at max speed V=27.8 km/h are 0.94, 0.61, and 67.46 kN, respectively. These results show that the locomotive will not derail when it passes the turnout at a speed V < 27.8 km/h.

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1 Introduction

Derailment not only causes damage to property and people, but also seriously affects the operation and exploitation. Nadal first researched the derailment coefficient in 1986 [1]. He studied the phenomenon of the tendency of the wheel to climb over the rail to give the condition of quasi-static situation force balance as shown in Fig. 1. The wheel and the rail are in contact at one point. Based on the relationship between the lateral (Y) and vertical (Q) wheel loads, and the normal (N) and (T) tangent forces, respectively to give a criterion of the wheel climb threshold such as:

$$\frac{Y}{Q} = \frac{tg\beta - \mu}{1 + \mu tg\beta} \tag{1}$$

Where μ is the friction coefficient, and β is the contact point angle of the wheel flange with the horizontal line.

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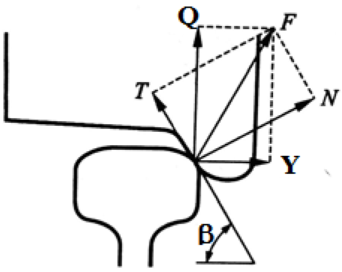

Fig. 1 – Forces acting on the wheel

Formula (1) began to become the standard of safety evaluation derailment. Since then, countries around the world have relied on this Y/Q coefficient to conduct experiments and set various evaluation values. In 1984, at the American Society of Mechanical Engineers, Weinstock [2] proposed a derailment criterion by summing the absolute values of Y/Q on two wheels on the same axle and coefficient of friction.

$$\sum \left| Y / Q \right| \le \mu + \text{Nadal limit} \tag{2}$$

Since 1978, The Association of American Railroads (AAR), as stipulated in the Manual of Standards and Recommended Practices, the total using limit value of derailment of a single wheel and the value of the limit of derailment of Weinstock of the whole axle is[3]:

$$\begin{cases} Y / Q < 1.0 \\ \sum \left| Y / Q \right| < 1.5 \end{cases} \tag{3}$$

In the late 60s and the early 70s of the 20th century, researchers at the Japanese National Railway suggested a modification to Nadal’s criterion. They proposed another coefficient by adding a time duration[4].

$$\frac{Y}{Q} \le \begin{cases} \lambda, & t \ge 0.05 \\ \dfrac{0.05}{t} \lambda, & t < 0.05 \end{cases} \tag{4}$$

where t is the time duration of the impact or side thrust (s), and λ is the standard value of the derailment coefficient.

According to in Railway Vehicles - Specification for Dynamic Performance Evaluation and Accreditation Test (GB 5599-1985[5]) of China Railways, the derailment coefficient of the wheel on the rail-mounting side is as follows:

$$\begin{cases} Y / Q \le 1.2 \left(\text{Limit1, acceptable} \right) \\ Y / Q \le 1.0 \left(\text{Limit2, increased safety margin} \right) \end{cases} \tag{5}$$

Currently, Vietnam Railways uses derailment coefficients such as[6]:

$$\begin{cases} Y / Q \le 1.2 \left(\text{Limit for freight train} \right) \\ Y / Q \le 0.8 \left(\text{Limit for passenger tran} \right) \end{cases} \tag{6}$$

In the world, Japan, China and European countries, in addition to using the Y/Q coefficient, also use the wheel unloading factor $\Delta Q/Q_0$as an additional criterion for the evaluation of derailment. According to China's national standard GB5599-1985 [5], the wheel unloading factor is specified.

$$\begin{cases} \dfrac{\Delta Q}{Q_0} \le 0.65 \left(\textit{Limit value} \right) \\ \dfrac{\Delta Q}{Q_0} \le 0.60 \left(\textit{Safety value} \right) \end{cases} \tag{7}$$

where ΔQ is the deviation from Q_0 at the maximum twist condition (kN), and Q_0 is the average wheel force for the tested wheelset on the level track (kN).

The EN 14363:2016 standard [7] also stipulates that in the case of trains operating at low speeds on small radius curves, the following criteria will respect $\frac{\Delta Q}{Q_0} \le 0.6$.

When the lateral force between the wheel flange and the gauge side of the rail $\sum Y$ exceeds the allowable limit, it can break the connection between the rails and the sleepers or cause the gauge to widen. This reason leads to the derailing of trains on the curves. Therefore, the lateral force should not be too great. According to the Chinese standards[5]:

$$\begin{cases} \sum Y \le 19 + 0.3Q_t\ (\mathrm{kN})(\text{Limit value}) \\ \sum Y \le 29 + 0.3Q_t\ (\mathrm{kN})(\text{Safety value}) \end{cases} \tag{8}$$

where Q_t is a static load of a wheel (kN).

When the sum of the guiding forces is too large, the rail will be deformed, so the sum of the guiding forces $\sum Y$ should not be too great. According to standard UIC code 518 [8] and TCVN 8784:2011[9], specifically as follows:

$$\sum Y \le \alpha\left(10 + \frac{P_0}{3}\right) \qquad (\mathrm{kN}) \tag{9}$$

where P_0 is an axle load, and α is an adjustment factor ($\alpha = 1.0$ for traction units and passenger vehicles, and $\alpha = 0.85$ for wagons).

In this study, the authors study the derailment when the locomotive-D19E runs diverging route on the turnout type of tg0.15 for 1000mm gauge according to QCVN 18:2011/BGTVT[6], EN 14363:2016 [7] and TCVN 8784:2011[9].

2 The Model of the Turnout, the Locomotive, the Rolling Surface of the Wheel and the Rail

2.1 The Model of the Turnout

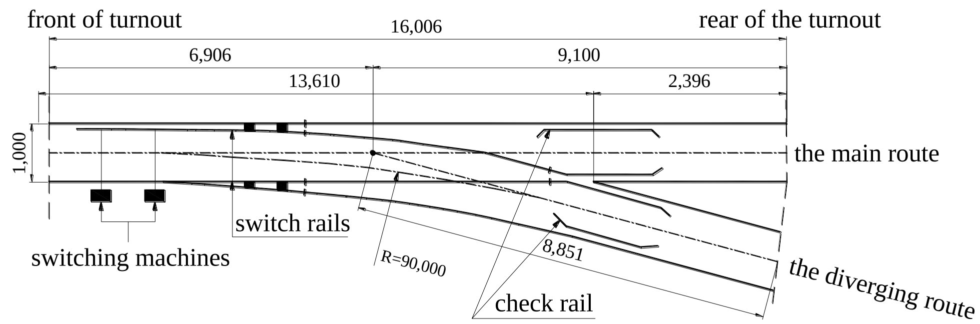

Fig. 2 – Geometric dimensions of a turnout (dimensions in meters)

The model of the turnout is an arrangement of points and crossings with lead rails by means of which the rolling stock may be diverted from one track to another[10]. In this study, the turnout type of tg0.15 for 1000 mm gauge is used in the model. The dimensions of the turnout are shown in Fig. 2.

2.2 Model of the Locomotive

Diesel locomotive-D19E is the basis of the contract between CSR Ziyang Locomotive Co., Ltd and Virasimex company to manufacture diesel locomotive for 1000 mm gauge used to pull freight and passenger trains in Vietnam. The locomotive is using 2 bogies with 3-axle each. Its axle load is 13.5 tons. The locomotive-D19E such as Fig. 3.

2.3 Model of the Rolling Surface of the Wheel

The wheel is directly subjected to the shock effects of horizontal, and vertical forces. The structure and technical parameters of the rolling surface of the wheel of the locomotive-D19E are shown in Fig. 4.

2.4 Model of the Rail

The rail is the main part of the superstructure used to guide the locomotive to move, and transmit the entire load to the sleepers, the ballast, and the roadbed. Currently, Vietnam has 3 types of rails: P43 (43kg/m), P50 (50kg/m), and P60 (60kg/m). In this study, rail-P43 was used to install for turnout. The dimensions of rail-P43 are shown in Fig. 5.

Fig. 3 – Locomotive-D19E

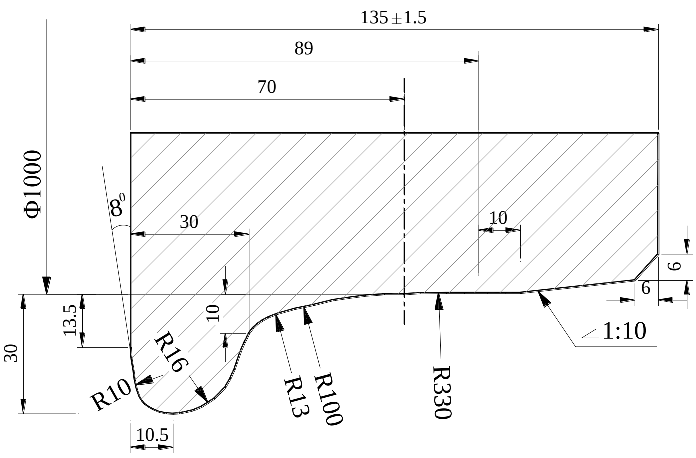

Fig.4 – The rolling surface for the wheel of locomotive-D19E [11]

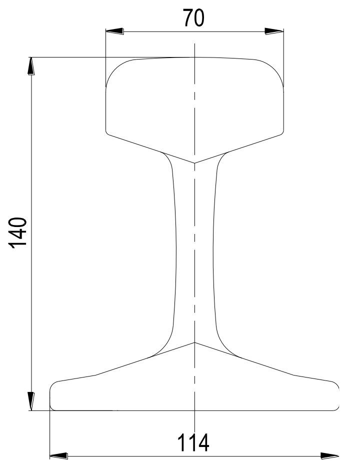

Fig.5 – The profile of rail-P43 [12]

3 Multi-body Dynamics Simulation to Calculate the Derailment Coefficient

3.1 Multi-body Dynamics Simulation Process to Determinate the Derailment Coefficient

Authors used SIMPACK software [13] to simulate multi-body dynamics.

3.1.1 Simulation of the Locomotive

Locomotive-D19E was simulated the three-dimensional (3D) with parts: wheel axle, bogie, locomotive body, and total locomotive (Fig. 6-Fig. 9).

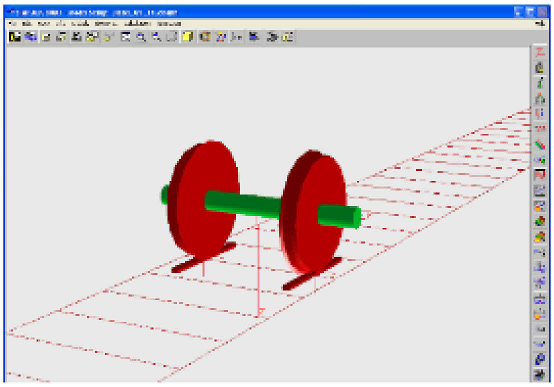

Fig. 6 – Simulation for the wheel axle of the locomotive-D19E

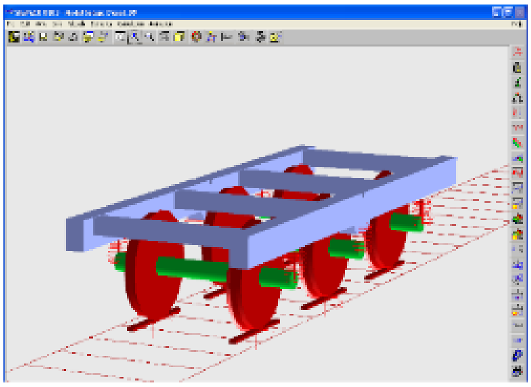

Fig. 7 – Simulation for the bogie of the locomotive-D19E

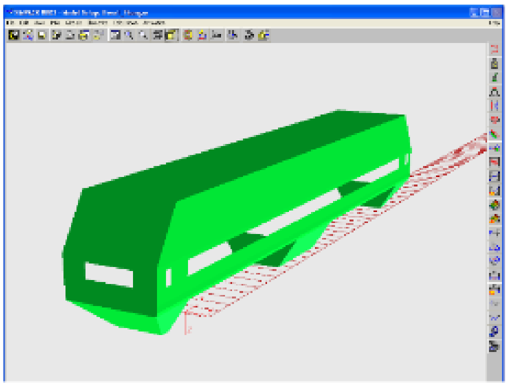

Fig. 8 – Simulation for the locomotive body of the locomotive-D19E

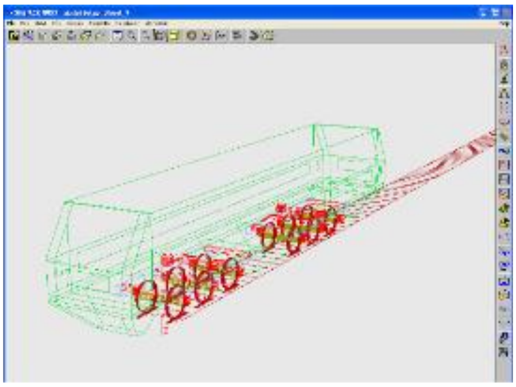

Fig. 9 – Simulation for the locomotive model of the locomotive-D19E.

Simulation of the Track

The track model is a rigid track model with inertially fixed rails. The discrete track model connects elastically to the inertial frame by vertical and lateral stiffness and damping elements. The track model has a wheelset-oriented mass and inertia I_{xx} (Fig. 10.).

3.1.2 Simulation of the Rolling Surface of the Wheel and the Rail

Based on the specifications of the rolling surface of the wheel and the rail-P43, simulations were done such as in Fig. 11 and Fig. 12.

3.1.3 Simulation of Multi-body Dynamic

Multi-body dynamic definitions were modelled on the divergent track of a turnout (tg0.15), locomotive-D19E, and rail-P43. The turnout modelled with a radius of the curve, length of the circular arc, the length of straight track, and the total track length is chosen. A schematic representation of all the modelling elements for contact between wheel and rail is put together. Simulation of the locomotive runs on the diverging route of the turnout (tg0.15), such as Fig. 13.

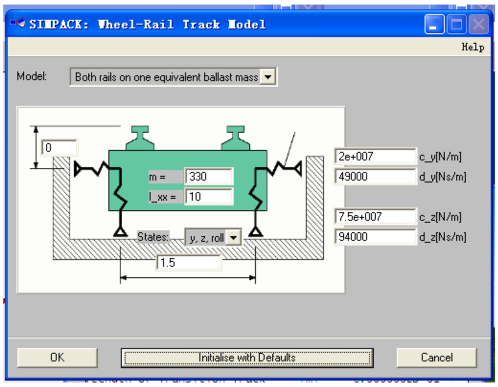

Fig. 10 – Simulation of track structure

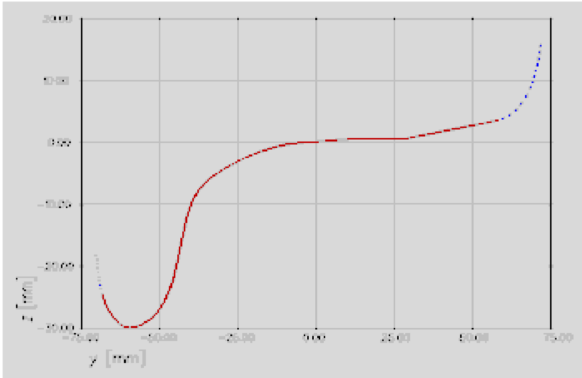

Fig. 11 – Simulation of the rolling surface of the wheel

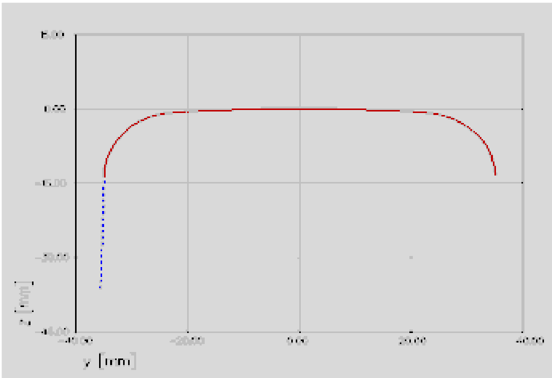

Fig. 12 – Simulation of the rail

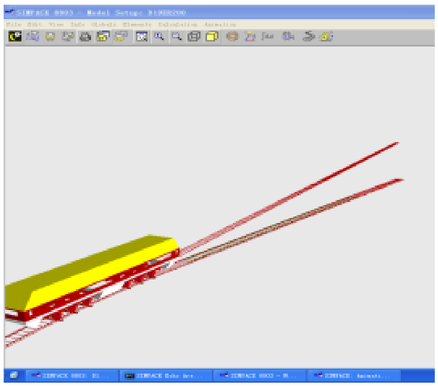

Fig. 13 – Simulation of the locomotive running through the turnout

3.2 Results

The derailment coefficient, the wheel unloading factor, and the lateral force when the locomotive moves on the turnout at speed V = 27.8 km/h are respectively 0.94, 0.61, and 67.46 kN. These results are shown in Fig. 14, Fig. 15, and Fig. 16.

Table 1 –The maximum values of the dynamic parameters when the locomotive runs through the diverging route of the turnout at a speed of V=27.8 km/h

No.	Dynamic parameters	Acceptance Criteria	Results	Conclusion
1	Derailment coefficient	≤ 0.8	0.94	Unsatisfactory
2	Wheel unloading factor	≤ 0.6	0.61	Unsatisfactory
3	Lateral force	≤ 46.02kN	67.46kN	Unsatisfactory

Based on simulation results, the locomotive can run at a max speed of 27.8 km/h. The results are shown in Table 1. These values were compared with values in the QCVN 18:2011/BGTVT [6], EN 14363:2016 [7], and TCVN 8784:2011 [9]. These values indicate that the locomotive can run safely through the turnout with a speed V < 27.8 km/h. According to the standard[14], the allowed max speed of the locomotive on the turnout is 15 km/h. We recognize that there is a speed reserve when the locomotive runs through the turnout.

4 Conclusions

In this paper, the derailment coefficient, the wheel unloading factor and the lateral force are calculated by multi-body dynamics simulation. Base on simulation examples, the derailment coefficient, the wheel unloading factor and the lateral force of locomotive are predicted. Therefore, we can control the train running through the turnout safely. These results show that the maximum speed for the train to move safely through turnout (tg0.15) is V = 27.8 km/h. This value is greater than the allowable value of the standard V = 15 km/h. So, there is a considerable reserve in the allowed speed of the locomotive running through the turnout, which means that the locomotive can be run at a greater speed. The authors proposed to increase the allowed speed of the train running through the turnout to improve the operating efficiency of the track.

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