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# Performance Comparison of Two Freight Bogies when Passing Through Different Turnouts

**Shahin Yousefi[1], Mohammad Mahdi Naseri Taheri[2], Majid Shahravi[3*]**

[1,2,3]School of Railway Engineering, Iran University of Science and Technology, Tehran, Iran, 16846-13114

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**A B S T R A C T**

The aim of this research is to investigate the dynamics and safety of a bogie of a freight wagon when passing through turnouts with different rail profiles and radii. Variety of turnouts that are used in Iranian railway tracks obviously affect the dynamic performance of the rail vehicles. Statistics prove that 40% of rail vehicle derailments are due to the defects of the turnouts. Vibrant interface between a railway freight vehicle and switches and crossings is studied through simulations. The Universal Mechanism (UM) Engineering software is used for the dynamic simulations. Some of the studies include examining the wheel and rail contact dynamics when crossing the turnout nose. It then results in acquiring the wheelset lateral and vertical forces and the corresponding derailment quotients. Via increasing the vehicle speed of travel through the turnout, safety related issues and wheelset forces are studied. Practically, geometrical features of the turnouts such as the rail profile and radii have major influences over the dynamics of the wagon.

## 1. Introduction

Rail track turnouts are used to divert the incoming railway traffic into the desired routes. They consist of three main parts including turnout panel, closure panel and crossing panel. Turnouts are amongst the most critical parts of the railroads where their maintenance is also considered as a major task for the related departments.

Safety in rail transport, on the other hand, has interfaces with both infrastructure and rolling stocks. Turnouts are considered as sub-sections of the railways that have great influences on the safety of the rolling stock. The occurrence of various failures in turnouts of railways can endanger safety of the fleet by causing incidents that may end up to derailments. The costs imposed by the damage caused by turnouts to the railroad will not only involve financial losses but it can also cause loss of lives of the passengers and the crew alike. The turnout as a crucial component of the rail track is also a major player in the derailment scenarios.

Lagos et al [1] by simulating the dynamic behavior of the wagon using SIMPACK engineering software, examined the effect of different wheel profiles when crossing the turnout. Santos and barbosa [2] have studied the effect of speed of rolling stock on the safety parameters of the wagon as a derailment factor. The effect of worn wheel profile on derailment factor was reviewed in these studies. Hiensch and Burgelman [3] studied the impact of the turnout taking into account the wheel adhesion coefficient in two trailer and trailing bogies. Palsson and Nielsen [4] measured the wear of wheel profile by dynamically simulating the worn profiles of Y25 bogie when passing through the turnout. Lateral displacement of wheelset, vertical and lateral contact forces and

*Corresponding author, Assistant professor
Email: m_shahravi@iust.ac.ir

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wear index of wheel with leading damage in turnout panel and crossing panel were extracted.

Also, the study of the wheel and rail contact geometry when crossing the turnout is a vital issue in terms of rolling stock safety. In this regard, Casanueva et al [5] examined the newly installed S1002 wheel profile when crossing the turnout. Considering the different sections of the turnout, they examined the amount of wear of new and worn profiles when crossing the turnout Frog. They then extracted wheel wear depth when passing through turnout and examined the effect of each part of the turnout on wear. Sun et al [6] examined the wheel impact force while crossing the turnout. They also studied the transverse and vertical dynamic forces of the wheel and rail interface when passing the turnout nose. Bruni et al [7] studied wheel/rail vertical impact forces on turnouts in subway lines. They initially developed a multibody dynamic model of wagon for extracting dynamic forces and by using the finite element model extracted the vertical acceleration for the wheel/rail interface in turnouts. Ren et al [8] studied turnouts as Bernoulli beams and developed an analytical solution to extract the vertical and transverse wheel/rail contact forces.

A method to facilitate the passage of the wheel in turnouts, and in particular the turnout nose and its blade, is to optimize the wheel profile. In this regard, Crosbee et al [9] tried to optimize the wheel profile to pass through two different infrastructures. In this study, the parameters of the wheel/rail contact geometry, such as the wheels rolling radius differences were analyzed. It provides the ability to be used on two infrastructures of trams and urban trains. Concerned with the concept of contact energy of wheels at the turnout point, with the optimization of turnout profiles in the nose, Palsson [10] reduced wear between the wheel and the turnout rail.

For the purposes of this research, in order to examine the safety of freight wagons, the dynamic behavior of two types of freight bogies including type 18-100 and type Y25 on travelling over track turnouts are investigated. The selected turnouts are compatible with the infrastructure on Iranian national railroad tracks. The designated types of bogies are also common in Iranian freight fleet. The nominated bogies are presented in Figure 1.

(a) Rail vehicle bogie type 18-100

(b) Rail vehicle bogie type Y25

Figure 1. Two common types of railway vehicle bogies

The dynamic behavior of the two selected freight bogies on travelling over turnouts with different geometries are explored. Vital parameters such as the derailment quotient, vertical and lateral forces within the wheel/rail contact areas for two turnouts of type 46E2 and 60E1 standard rails with turnout radii of 190 and 300 are examined. Since the safety of the travelling rolling stock over the turnouts is also important, the dynamic behavior of the trains are also evaluated. The effect of the turnout geometrical specifications on the dynamic behavior of the freight fleet on four types of conventional turnouts are also explored. The dynamic analyses are based on the fully dimensional simulations that are performed by using the UNIVERSAL MECHANISM multibody dynamic software (MBS).

In operations within the national Iranian railway networks, all types of freight and passenger wagons and locomotives run through the aforementioned turnouts. While there seems to be a lack of national survey on this subject, this research is concentrated with the dynamic behavior of two freight wagons when travelling over turnouts with different specifications. The processes of simulations and analyses that are performed through this research are presented in Figure 2.

## 2. Turnout Simulation

When a wheel runs over the turnout, dynamic behavior of the wheel that passes through the switch rail remains stable, but the opposite wheel that passes through the wing rails encounters

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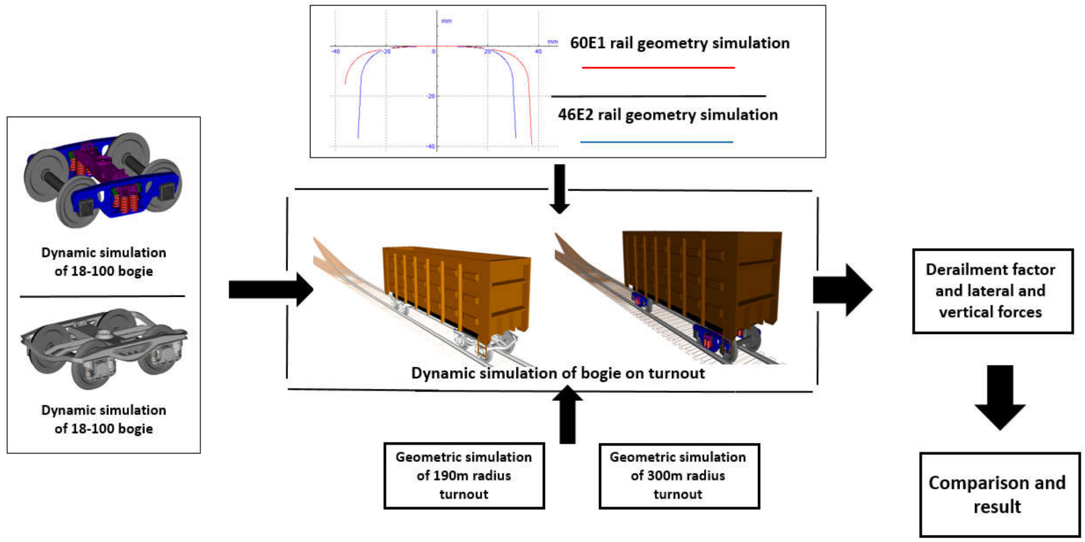


Figure 2. Procedure for the simulation and analyses of the dynamics of fleet on turnouts

dynamic changes due to the changing geometric characteristics of the contact points. Also, when the wheel passes from the wing rail and jumps on to the crossing nose, it causes impact on the turnout nose and the geometrical characteristics of the wheel/rail contact patches change.

In Iranian Railroads, the most common types of turnouts have curve radiuses of 190 and 300 m. Generally, these turnouts are of types 46E2, and 60E1 rail profiles. The cross sections of the types 46E2 and 60E1 rails and turnouts and their three-dimensional models are presented in Figure 3.

The results for the dynamic simulation of the freight wagons that are equipped with Y25 and 18-100 bogies traveling over turnouts 46E2 and 60E1 with radii of 190 and 300 meters are provided in this section. The vital parameters such as the derailment quotient and the vertical and lateral forces of the wheelset for two types of turnouts with 46E2 and 60E1 rails and 190 and 300 turnout radii are examined. The turnouts that are used for the purposes of theses simulations have a fixed nose. In order to also simulate the dynamic behavior of wagons, the selected wheels are of type S1002 profile. The algorithm for solving the equilibrium of wheel/rail lateral contact forces is FASTSIM. The speed of the wagon when passing through the turnout for the 190 meters arc turnout is 40km/h and for the turnout with an arc radius of 300 meters is 50km/h. In order to simulate for the elasticity of the track, the rail and ballast are connected to the infrastructure by a spring and a damper. The specifications for the model spring and damper are presented in Table 1.

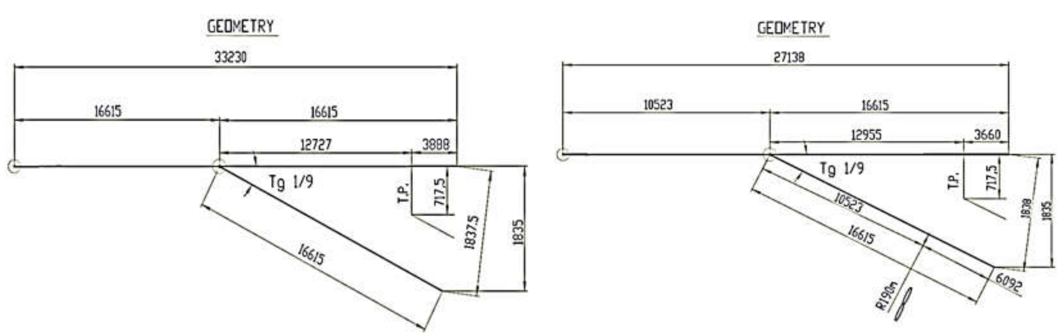


Figure 3. Geometrical specifications for turnouts with radii of 300m (left) and 190m (right)

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Table 1. Track foundation flexibility

| Track flexibility | size |
|---|---|
| vertical stiffness(N/m) | 4.40E+07 |
| lateral stiffness(N/m) | 1.80E+07 |
| vertical damping(Ns/m) | 4.00E+05 |
| lateral damping(Ns/m) | 1.00E+05 |

## 3. Dynamic Modeling of Rolling Stock

The dynamic model of the selected wagon is structured by using UM INPUT software and for the simulations is then transferred to UM SIMULATION software. The turnouts type 46E2 and 60E1 turnouts are also modeled by using this software. The dynamic motion equations of the wheelsets, bogies and the wagon are solved in UM software.

Initially, the dynamic properties of bogies type Y25 and 18-100 are extracted from Molatefi et al [11], Ghazavi and Taki [12]. The same references are used to validate the simulations for the two designated bogies.

In order to validate the dynamic simulation of bogie type 18-100 in UM software, the derailment coefficients of the second wheelset of the first bogie are extracted and compared. The results are presented in Figure 4.

In order to validate the simulations for the vehicle on bogie type Y25, the lateral movement of the bogie frame at different travelling speed along with its hunting frequency (V=22km/h is used for the comparison) is acquired. The corresponding results are presented in Figure 5.

In order to properly understand the dynamic behavior of the wheelset, it is necessary to study the motion equations of the wheelset. The wheelset lateral and yaw motion equations are presented in Equations (1)&(2) [13]. y represents the lateral displacement of the wheelset and $\psi$ represents its yaw motion.

$$m\ddot{y}+\frac{2f_{11}}{V}\left[\dot{y}+r_0\frac{\lambda}{a}\dot{y}-V\psi\right]+\frac{2f_{12}}{V}\dot{\psi} +W_A\frac{\lambda}{a}y=F_{sy} \quad (1)$$

$$I_{wx}\ddot{\psi}+I_{wy}\frac{V}{r_0}\frac{\lambda}{a}\dot{y}+\frac{2af_{33}\lambda}{r_0}y-\frac{2f_{12}}{V}(\dot{y}+r_0\frac{\lambda}{a}\dot{y}-V\psi) +2a^2f_{33}\frac{\dot{\psi}}{V}-aW_A\lambda\psi+2f_{22}\frac{\dot{\psi}}{V}=M_{sz} \quad (2)$$

where $f_{11}$, $f_{12}$, $f_{22}$ and $f_{33}$ are the creep coefficients that are used for the calculations of contact forces. $V$ is the longitudinal speed of wheelset, $a$ is half the wheelset length and $\lambda$ is the

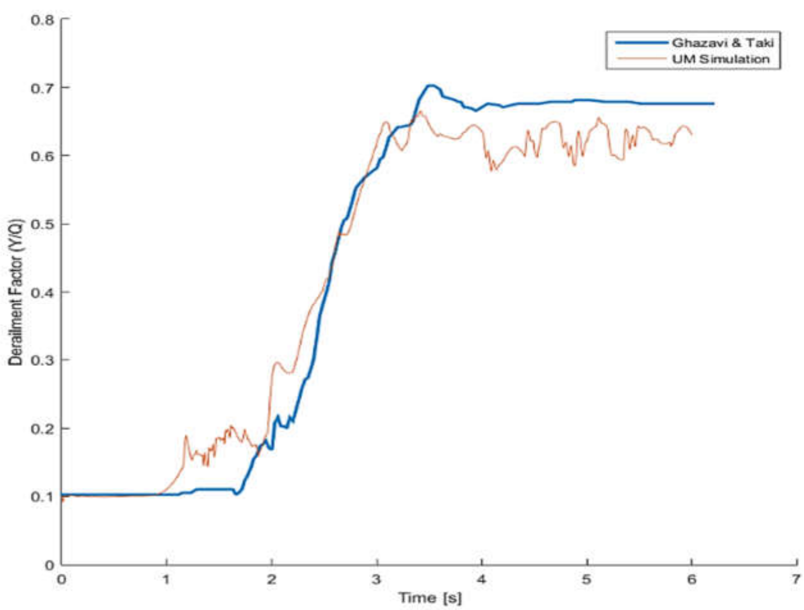


Figure 4. Comparison of derailment quotient for a vehicle on bogie type 18-100



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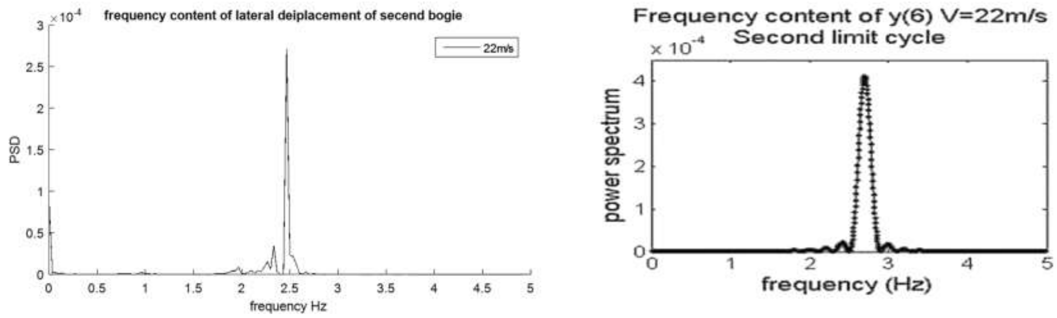


Figure 5. Comparison for the power spectrum of wheelset lateral movement(left: UM simulation, right: [11)

equivalent conicity of wheel profile. $W_A$ is the weight of the wheelset. $F_{sy}$ and $M_{sz}$ are the force and moment that are applied by the primary suspension on the wheelset.

## 4. The Simulation Results

In order to express the results of the simulation for the aforementioned bogies, the modeling simulation results are provided. The results of the simulation for each type of bogies in turnout type 60E1 and 46E2 with radiuses of 190 and 300 m are presented in the following Figures 6, 7 & 8. In these results, the effect of the

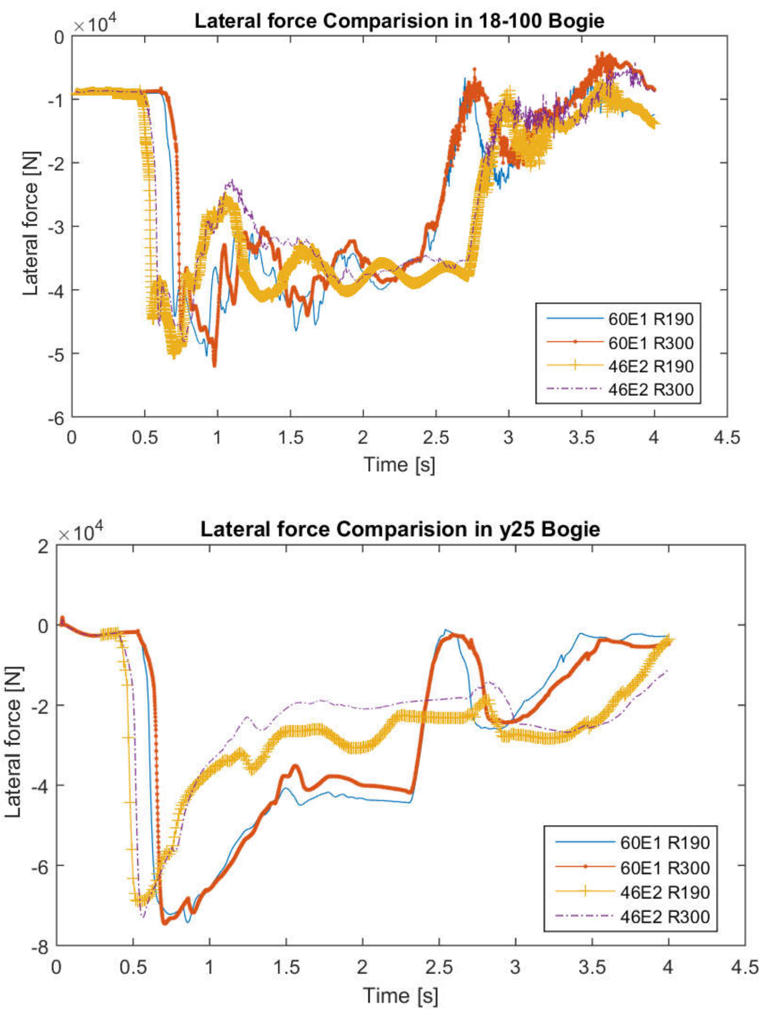

Figure 6. The calculated lateral forces for the two types of bogies on different turnouts



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turnout rail profile and its radius on the dynamic performance of the bogies during the travel over the turnouts are examined. From these results, it is clear that the type of turnout rail, its nose radius and the dynamic properties of the bogie suspension system are effective on the results of the lateral forces and derailment quotient. Also, the effect of different sections of the turnouts on the vertical force on wheelset based on the geometry and profile of the turnouts are studied.

### 4.1. Assessment of Lateral Forces

The estimated lateral forces out of simulations for both bogies are presented in Figure 6. The maximum lateral forces of the first wheelset of Y25 bogie in switches with rail profile of 60E1 and radii of 190m is 10% higher than the switches with rail profile of 46E2 and radii of 190m. On the other hand, the maximum lateral forces of the first wheelset of this bogie in switches with rail profile of 60E1 and radii of 300m is 10% higher than the switches with rail profile of 46E2 and radii of 300m. For the bogies of type 18-100, the maximum lateral forces of the first wheelset in switches with rail profile of 60E1 and radii of 300m is 5% higher than the switches with rail profile of 46E2. For the case of the switches with rail profile of 60E1 and radii of 190m the maximum lateral forces are equal with the case for the rail profile of 46E2 and radii of 190m. Also in crossings, transition to turnout nose causes uplifting of the differences in the maximum sizes of the lateral forces to 4 folds.

### 4.2. Assessment of Derailment Quotient

The simulated results for the derailment quotients for both bogies are presented in Figure 7. The derailment factors of the first wheelset of Y25 bogies in switches with rail profile of 60E1 and radii of 190m are 3% higher than the switches with rail profile of 46E2 and radii of 190m. On the other hand the derailment factor of

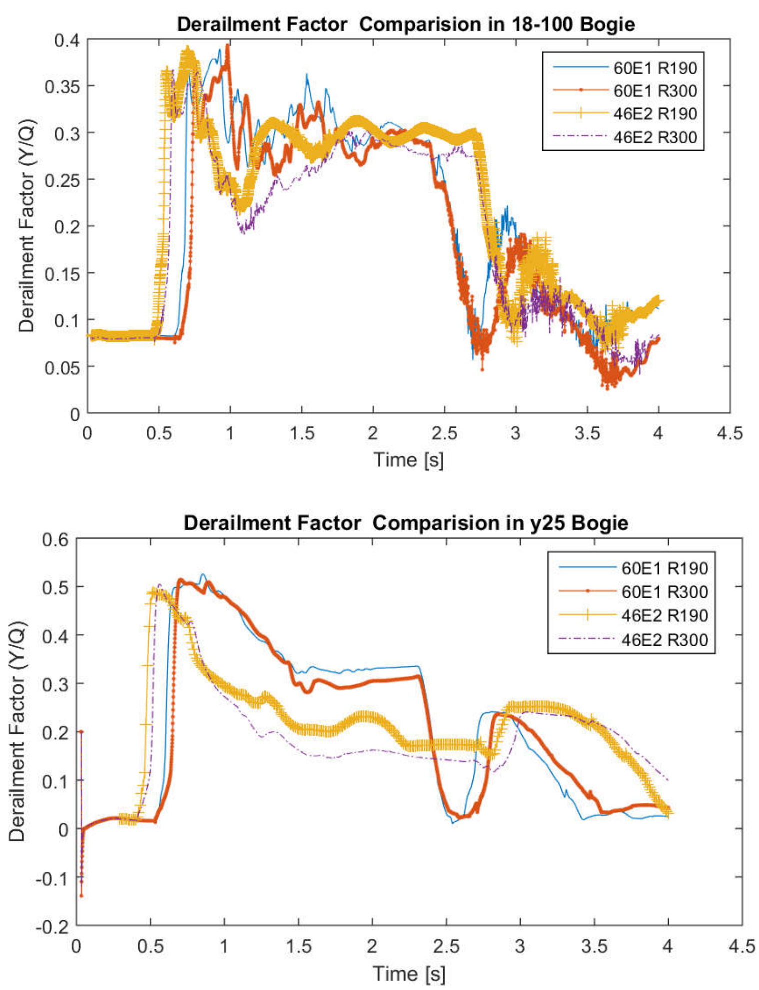


Figure 7. The estimated derailment quotients for the left wheel of the first wheelset in 60E1 and 46E2 turnouts with radiuses of 190m and 300m



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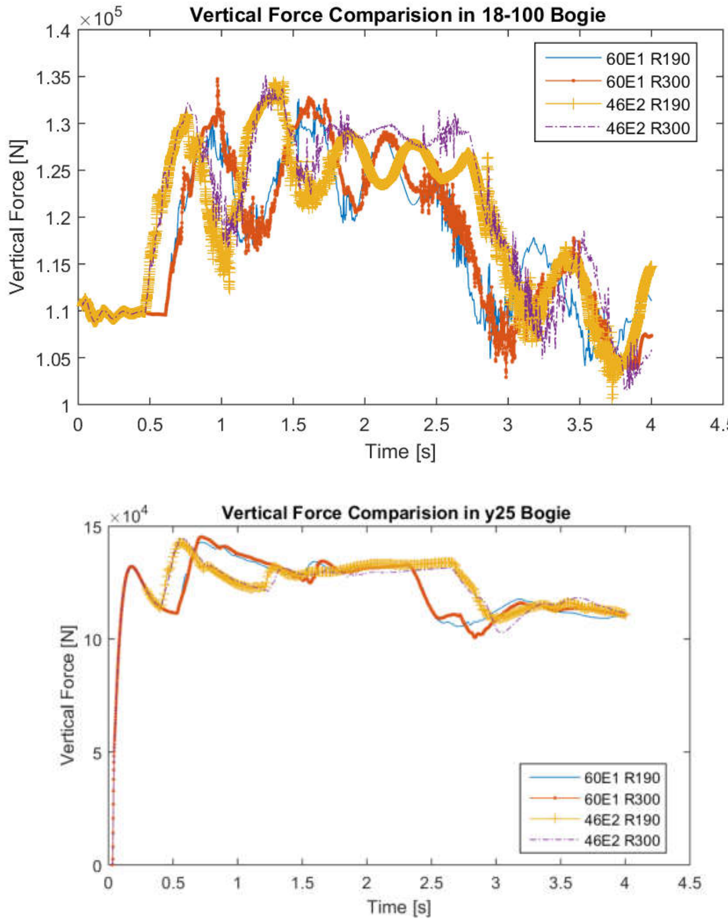


Figure 8. The vertical wheel dynamic forces for the left wheel of the first wheelset in 60E1 and 46E2 turnouts with radiuses of 190m and 300m

the first wheelset of this bogie in switches with rail profile of 60E1 and radii of 300m is 2% higher than the switches with rail profile of 46E2 and radii of 300m. For the case of the bogies of type 18-100, the maximum derailment factors of the first wheelset in switches with rail profile of 60E1 and radii of 300m are 7% higher than the switches with the rail profile of 46E2. The maximum derailment factor occurs in the switches with the rail profile of 60E1 and radii of 300m with the bogies of type 18-100. When the wagon enters the curved section of the switches sharp increases in the derailment quotient are clearly noticeable.

### 4.3. Vertical Forces

The simulated results for the estimation of the vertical wheel dynamic forces are presented in Figure 8. These forces increase when the wheel enters the switch panel. The maximum vertical forces for the case of the rail profile of 46E2 for both radiuses of 190m and 300m curves are within the proximity of each other.

## 5. Conclusions

Within the railway systems, the fleet and the infrastructure have many particulates that can also be specific to the designated organizations. The national Iranian railway is a combination of a variety of fleets as well as a selection of turnouts. Concerned with the issue of travel safety, it is important to have proper insights into the dynamic behavior of the fleet when crossing railroad turnouts. This research was concerned with the dynamic effects on the vehicles of some particulates of the bogies and the geometrical specifications of some of the turnouts that are in common use through the nominated networks. Consequently, dynamic simulation and comparison of the behavior of two freight wagons equipped with two different types of

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bogies namely of type Y25 and 18-100 was initiated.

The UNIVERSAL MECHANISM engineering software is used for the purposes of the dynamic simulations. The simulated wagons travel along railroad turnouts. The results include estimations of the lateral and vertical wheel/rail contact forces that assist in concluding the derailment quotients as measures for the assessment of the travel safety. Two freight wagons equipped with two different types of bogies travelling over four different types of turnouts are examined.

The first part of the analysis included examining the effect of the geometrical specifications of the turnouts on the dynamic behavior of two types of wagons. The wheel/rail lateral contact forces and the corresponding derailment coefficients were estimated. In the second part of the research, the influences of the dynamic particulates of the vehicles and the safety related derailment coefficients are compared.

The following important remarks are concluded:

The root mean square (RMS) of the derailment coefficient in turnout with the radius of 190 m is 8% higher than the turnout with the radius of 300 m.

The rail profile of the turnout does not cause great differences in the dynamic consequences. As an example, the derailment coefficient on a vehicle that is equipped with Y25 bogies when passing through the turnout with a radius of 300 m over a rail with the profile of 60E1 is only 7% higher when compared with the results for the same vehicle on a turnout with a rail profile of 46E2.

The dynamic behavior of the vehicles that are equipped with Y25 bogies is preferred over the use of 18-100 bogies.

The type of the bogies used do not cause much differences for the simulated predictions for the wheel/rail vertical contact forces.

The simulations predicted the safe passage for all cases that are considered in this research.

The procedures and the results that are considered are credits to the accuracy of the results and to the reliability of the methods that are developed.

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