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A passive road-rail crossing design to minimise wheel-rail contact failure risk under frontal collision of trains onto stuck trucks

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ABSTRACT

Derailments of trains often occur due to the wheel-rail contact failure caused by the impact of the trains with road vehicles at road-rail crossings. Frontal collisions of passenger trains onto stuck road vehicles occur frequently at such road-rail crossings even where active warning systems are installed. Such collisions are often fatal and cause significant damages to vehicles and the infrastructure especially when they incur derailments. Innovations in passive railway infrastructure designs for mitigating the severity of collision induced derailments are rare. This paper presents a formulation for a passive road-rail crossing involving stiffened edges of the raised road pavement to minimise the risk of failure of wheel–rail contact using a nonlinear three-dimensional multibody dynamics model. Severe derailment scenarios of trains passing through the passive and normal road-rail crossings have been analysed and presented. The innovative design of the road-rail crossing with passive track structure presented in the paper is shown to reduce the failure of the wheel-rail contact and hence the train-truck frontal collision derailment potential.

1. Introduction

Road-rail crossing collisions involving passenger trains and heavy road vehicles are severe safety issues. These incidents occur more frequently worldwide as seen from the data provided by the Federal Railroad Administration of the United States of America on the train-vehicle collisions, fatalities and injuries at road-rail crossings over the years 2001–2015 [1] displayed in Fig. 1. Although the collision incidents have reduced by a third from 2001 to 2009, fatalities and injuries remain almost unchanged – which indicates the incidents are increasingly becoming more severe. On average annually > 200 fatalities and approximately 1000 injuries occur due to these incidents.

In Australia, about 100 collisions between the trains and the road vehicles at road-rail crossings occur each year, these collisions are estimated to cost $32 million and result in the death of 37 people annually on average [2]. Besides, every year > 300 people across Europe die in > 1200 accidents occurring at road-rail crossings, which accounts for one-third of all rail fatalities [3]. Thus, with the ongoing increase in the number of heavy road vehicles and road-rail crossings worldwide, there is a pressing need to better understand the collisions between the trains and heavy road vehicles so that strategies to minimise the severity of these collisions can be developed.

A variety of countermeasures in terms of traffic laws, communication technology and warning devices such as boom gates and flash lights are used for avoiding road-rail crossing accidents [4,5]; all these measures can be classified as active systems that rely on the strict adherence to the traffic rules, road side instructions/signals by the heavy road vehicle drivers. Passive civil infrastructure solutions that can explicitly force the road vehicle drivers to reduce speed can be more effective in reducing the severity of collisions;

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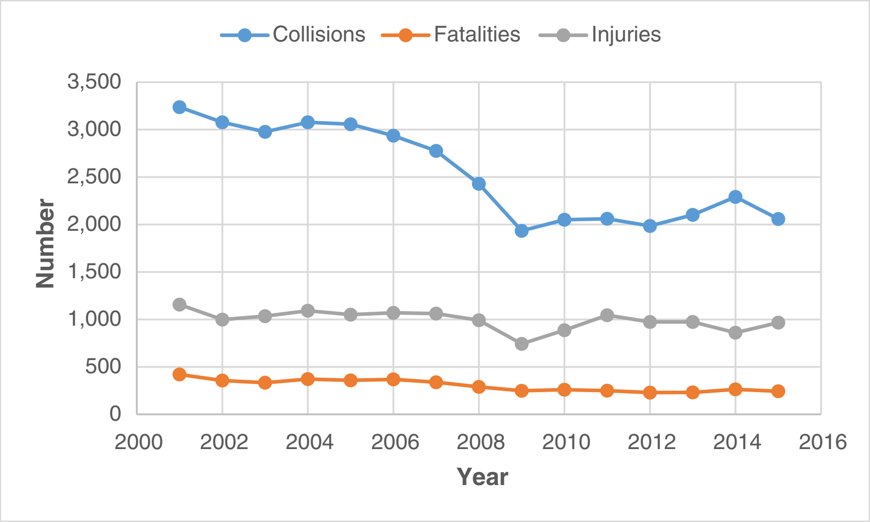

Fig. 1. Road-rail crossing collisions, fatalities and injuries in the USA.

one such measure considered in this paper is raising the level of the road pavement at the section where it crosses the rail track, resembling a road hump. Recently the authors have shown that such a design is effective for minimising derailment potential of trains subject to lateral impacts from road vehicles [6]; the design was, however, found to be less effective for preventing derailments under frontal collision of trains onto stuck road vehicles. The design was, therefore, further improved as presented in this paper; the current and the improved designs are schematically shown in Fig. 2.

In our conceptual design of the passive road-rail crossing structure (Fig. 2b), the raising of the level of the road pavement introduces two ramps and places the rails in deeper recesses. The edges of these recesses are stiffened to offer sufficient resistance to the impact caused by the wheelsets due to the failure of the wheel-rail contact. The stiffened edges are termed as 'guardrails' in this paper for simplicity. Four guardrails and two road ramps are introduced in the proposed raised road-rail crossing infrastructure.

There are several theoretical studies on the wheel/rail contact failure and the derailment mechanism of railway vehicles [7–19]. Guardrails are normally used as a measure for minimising derailment risks of trains running on curved tracks [20,21]. Shu and Wilson [20] reported that the guardrails installed on sharp curves can prevent flange climb derailment and reduce gauge wear on the high rail. However, the clearance between the running rail and the guardrail is critical for the effectiveness of this type of passive safety measure. Sato et al. [21] investigated the derailment process of a light rail vehicle in a curved section of a Japan tramway. The derailment potential of the light rail vehicle was shown to greatly reduce after an improvement to the guardrail installation. Guardrails have also been recently used to stabilise trains when the rail track is vulnerable to earthquake excitations [22,23]. Nishimura et al. [22] examined the efficacy of the inverted L-type guardrails for improved derailment safety of trains running on rocking tracks during large earthquakes through extensive numerical and experimental studies. Tanabe et al. [23] studied the interaction between the train wheels and the guardrails installed in a passive safety track during an earthquake.

In the present paper, a nonlinear three-dimensional (3D) dynamic model of a passenger train running on a passive track fitted with the stiffened edges of the recesses in the raised road pavements shown in Fig. 2(b) is developed. It is then applied to investigate the mechanisms and effectiveness of the proposed passive road-rail crossing design in preventing derailments caused by the frontal

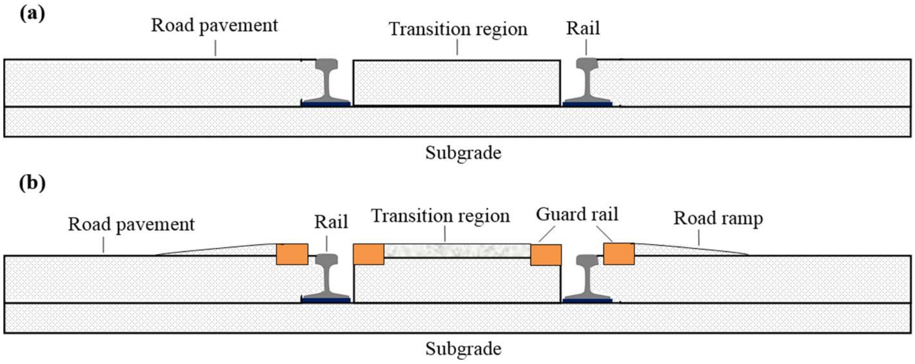

Fig. 2. Track structures at road-rail crossing: (a) normal design; and (b) passive safety design.