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Minimising lateral impact derailment potential at level crossings through guard rails

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ABSTRACT

Derailments due to lateral collisions between heavy road vehicles and passenger trains at level crossings (LCs) are serious safety issues. A variety of countermeasures in terms of traffic laws, communication technology and warning devices are used for minimising LC accidents; however, innovative civil infrastructure solution is rare. This paper presents a study of the efficacy of guard rail system (GRS) to minimise the derailment potential of trains laterally collided by heavy road vehicles at LCs. For this purpose, a three-dimensional dynamic model of a passenger train running on a ballasted track fitted with guard rail subject to lateral impact caused by a road truck is formulated. This model is capable of predicting the lateral collision-induced derailments with and without GRS. Based on dynamic simulations, derailment prevention mechanism of the GRS is illustrated. Sensitivities of key parameters of the GRS, such as the flange way width, the installation height and contact friction, to the efficacy of GRS are reported. It is shown that guard rails can enhance derailment safety against lateral impacts at LCs.

1. Introduction

Lateral collisions among trains and heavy road vehicles at level crossing (LC) usually lead to severe consequences such as train derailments, fatalities and injuries to passengers and significant financial losses and societal costs. In Australia, on average annually 100 collisions occur at railway LCs involving road vehicles [1]. These incidents cost $32 million on direct damage expenses and result in 37 casualties annually on average. With approximately 10,497 road and pedestrian LCs in Australia, this longstanding safety concern is not only a priority for the Australian rail industry, where it has been identified as one of the top five safety risks [2], but also internationally. The United States National Transportation Safety Board pointed out that more than 2000 accidents occurred at LCs each year from 2006 to 2010 [3]. The United Kingdom also experiences approximately 11 fatalities each year due to accidents at LCs [4]. Statistics show that more than 300 people are killed every year in Europe in more than 1200 accidents occurring at LCs [5].

Of all road crashes, those that involve a collision between a heavy vehicle and a train are the most severe. When a travelling train is collided by a heavy road vehicle, it is easy to result in a derailment with disastrous consequences. Four collision scenarios have been defined in EN 15227 [6], but a road truck crashing laterally onto a train is not addressed in these standards although such incidents are real and frequent. Despite the high incidence rate of LC collisions, the potential loss in financial terms associated with a heavy vehicle–train collision, and the associated potential for delay in the commercial rail network, is far from trivial. Given the safety issues at LCs and their impact on the road and the rail systems internationally, there has been a substantial research effort to understand why these accidents occur and how they might be prevented. Most of these efforts have focused on the behaviour of motorists and traffic laws, communication technologies and warning devices such as boom gates and flash lights [2]. There is a lack of research on design improvement of the civil infrastructures (road/rail at LC) to safer LC operation. This paper provides an insight into the effect of providing guard rails at LCs for the train safety.

Considerable research works are reported on the train stability and derailments due to lateral loads such as earthquakes, crosswinds, and obstructions [7–10]. For instance, Xia et al. [7] investigated the running safety of high-speed trains and the dynamic response of a coupled train–bridge system subjected to transverse collision loads on the bridge piers. Ju [8] conducted finite element (FE) simulations of the improvement of bridge structures to increase the safety of moving trains during earthquakes. It was shown that large pier stiffness enhanced the safety of moving trains running on bridges during earthquakes. Innovative design and stability analyses of structural components

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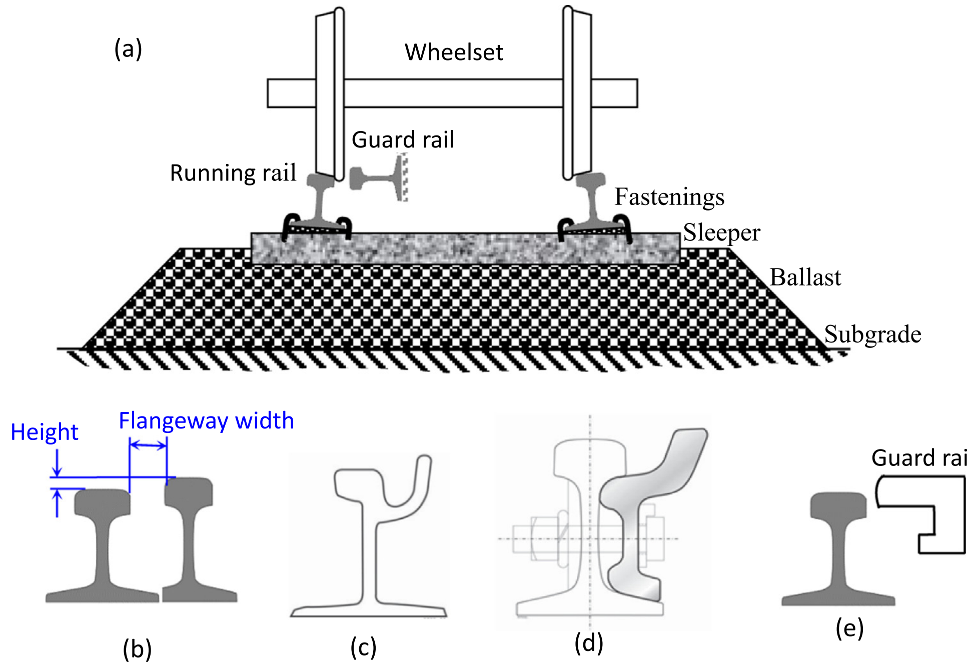

Fig. 1. Typical guard rail designs: (a) horizontally mounted guard rail, (b) vertically mounted guard rail, (c) girder rail, (d) strap guard rail, and (e) L type guard rail.

such as columns, beams, and other structures under lateral impacts have attracted extensive research [11–14].

Guard rails (also called restraining rails) have been frequently applied in railway lines on sharp curves to prevent flange climb and rocking derailments due to earthquakes. Fig. 1 shows five type of commonly used guard rails, including the horizontally mounted guard rail, the vertically mounted guard rail, the girder rail, the strap guard rail, and the L type guard rail.

Shu and Wilson [15,16] studied the effects of installation parameters of three common guard rails (horizontally mounted guard rail, vertically mounted guard rail and girder rail, see Fig. 1) on the efficacy of preventing the flange climb derailment at sharp curved tracks. In their reports, the effects of 3D wheel-guard rail contact geometry and guard rail installation parameters including flangeway width and height (see Fig. 1b), lubrication, track curvatures, track gauge, and vehicle types on the wheel/rail forces and wear were investigated. Nishimura et al. [17] carried out various numerical and experimental analyses of the effectiveness of an L-type guard rail on preventing derailments caused by large earthquakes. A turnover type system was adopted for track maintenance and installed on one segment of the Tokaido Shinkansen line in 2009. With respect to the development of other passive and active safety technologies to prevent train derailments (not due to lateral impact), several studies can be also found [18,19].

This paper presents a formulation of a three-dimensional (3D) model of a train running on a ballasted track fitted with guard rail subjected to a lateral collision impact by a of road truck, with a view to investigating the efficacy of the GRS. The proposed model has been used to investigate the dynamic behaviour of the lateral collision induced derailments with and without GRS at LCs. Particular attention is provided to the mechanism of prevention of derailments by the GRS. Key parameters that influence the efficacy of the GRS have been examined in detail; these include the flange way width and the installation height of the GRS and the contact friction between the guard rail and the wheel. The results provide some insight into the potential countermeasures against lateral impact derailments at LCs through minor modifications to the track structure (installation of guard rail).

2. Numerical modelling

Lateral collision-induced derailments at LCs can only be investigated through field tests or laboratory experiments by incurring huge costs. Numerical simulation using advanced train–track interaction models is a cost-effective approach for this purpose. Based on the theory of multi-body dynamics, a 3D train–track model under truck impacts is developed to simulate the efficacy of the GRS to prevent lateral collision-induced derailments at LCs. The proposed model mainly consists of four sub-models: (1) the model for passive track dynamics, (2) the model for train dynamics, (3) the model for wheel–rail interaction, and (4) the model for truck–train collision.

2.1. Model for passive track dynamics

In this investigation, the track structure installed with GRS to provide passive safety function is defined as the "*passive track*". The passive track model consists of two running rails, two guard rails, sleepers, and the subgrade, as shown in Fig. 2.

In this model, both the running rails and the guard rails are treated as Euler beams supported on discrete sleepers. The lateral and vertical bending deformations and torsion of the rails are considered. The sleeper is modelled as a rigid rectangular beam supported by the uniformly distributed stiffness and damping of the ballast layer. The lateral, vertical, and rolling motions of the sleepers are taken into consideration. The ballast and the subgrade are modelled as continuous viscoelastic elements and their motions are neglected. Linear spring and damper elements are used to simulate the rail pad and fasteners that connect the sleepers with the running rails. The sleepers are fixed to the ground via continuous viscoelastic elements. The guard rails are assumed to be supported on periodic discrete spring and damper elements that are fixed to the ground.

The equations of motion in three Cartesian coordinates (Eqs.