Construction and Building Materials 153 (2017) 481–495

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Experimental investigation on loading pattern of railway concrete slabs

Javad Sadeghi *, Hassan Liravi, M. Hassan Esmaeili

School of Railway Engineering, IUST, Tehran, Iran

HIGHLIGHTS

- Currently used rail-seat-load expressions are not reliable for design of railway slab tracks.
- New nonlinear expression (model) was developed for rail seat load in railway slab tracks.
- Wheel load distribution over railway concrete slab was derived for the first time.
- Current practice in design of railway concrete slabs was considerably improved.

ARTICLE INFO

Article history:
Received 21 January 2017
Received in revised form 31 May 2017
Accepted 2 July 2017

Keywords:
Ballast-less track
Design
Concrete slab
Laboratory testing
Field measurement
Loading pattern

ABSTRACT

Although construction of ballast-less track is booming in recent years, there is a lack of sufficient researches into the design and construction of this system. This research addresses this limitation by investigating the amount of loads transferred from the rail to the support slabs as the main parameter in the design and construction of railway concrete slabs. A comprehensive experimental investigation was conducted in various light and heavy passenger transit lines. The effects of the main influencing parameters including sleeper spacing, rail bending modulus, track stiffness, train speed, and wheel load on the amount of rail seat loads were investigated. The results were analyzed, leading to derive a mathematical expression for the rail seat load and the loading pattern of concrete slabs. The reliability and accuracy of the loading patterns currently used in the analysis and design of concrete slabs were evaluated by comparisons of the experimental results obtained here with those of the current practice. The results obtained have made considerable improvements in the analysis and design of railway concrete slabs.

1. Introduction

There is a substantial increasing interest in the construction of the ballast-less track system in the world due to its advantages over the convectional ballasted tracks [1]. However, there is a lack of sufficient researches into the design and construction of this system when compared with the ballasted tracks. In this paper, the rail seat load (RSL) as the main parameter in the design and construction of slab tracks is investigated. The RSL is the load transferred from the rail to the underneath slabs via the rail-seat plates and sleepers. It plays an important role in the design of rails and the underneath concrete slab. A review of the available literature indicates that there have been various studies into the rail-seat loading pattern of the ballasted railway tracks. Talbot was the first who made an investigation into the RSL [2]. Talbot's research was followed by Clarke in 1957 and Magee in 1965–1971 [3,4]. They used the theory of beam on an elastic foundation to derive an expression for the RSL. The well-known and mostly used suggestion of "wheel load distribution over three adjacent sleepers" was made by Cottram and Heath in 1966, Eisenmann in 1969, and Raymond in 1971 [5–7]. Further developments to this suggestion were made by O'Rourke and Brown [8,9]. Due to the unrealistic assumptions made in the development of the track theoretical models, the recent investigations of the RSL have been made based on experimental results. In 2008 and later on in 2012, Sadeghi and his colleagues conducted a thorough field investigation and derived a comprehensive mathematical model for the rail seat load distribution pattern of the ballasted railway track [10,11]. In 2014, a field test was performed by Grasse to determine the load transferred to the underneath three adjacent sleepers, taking into consideration the track stiffness [12]. In 2013 and later on in 2015, Askarinezhad et al. made a thoroughly field and laboratorial test to measure the vertical impact force at insulated rail joint using strain-gage [13,14]. Giannako and his colleague presented an

* Corresponding author.
E-mail addresses: javad_sadeghi@iust.ac.ir (J. Sadeghi), h_liravi@rail.iust.ac.ir (H. Liravi), m_h_esmaily@rail.iust.ac.ir (M.H. Esmaeili).

http://dx.doi.org/10.1016/j.conbuildmat.2017.07.025
0950-0618/

RSL model, considering most of the train and track parameters [15]. More recently, he evaluated the effect of different rail pads on the rail seat load in heavy-haul railroads [16]. The extensive recent research works on the RSL were made by Greve and his colleagues who carried out field and laboratorial investigations in the North American railway lines by which the effects of rail-seat wear depth, the wheel lateral to vertical force ratio, rail cant, particle intrusion and train speeds on the RSL were obtained [17–20]. Rap and his colleagues indicated that localized crushing of the concrete in the rail seat is one of the potential mechanisms that contribute to the rail-seat failure mode [21]. Younesian and his colleagues made an attempt to predict vertical and lateral rail contact forces, using neural network technique [22].Investigations on the vertical load path in the rail seat and the fastening were made by Manda and his colleagues [23]. Kernes and his colleagues used a laboratory test to simulate the train normal and horizontal loads on the rail-seats [24–26]. Wei and his colleagues performed a laboratory tests at the Transportation Technology Center (TTC) to propose a mathematical expression for the rail seat load based on measured strains [27]. The study of the effect of design rail cant on pressure distribution across the rail seat was made by Ghosh and his colleagues [28]. Romero and his colleagues performed full-scale severe-service laboratory testing of concrete sleepers and their fastening systems at the University of Illinois to evaluate the effect of different pads with various vertical stiffness and overall rigidities on the rail-seat loads [29]. Akira Aikawa has investigated dynamic characterization of a ballast layer subject to traffic impact loads using three-dimensional sensing stones and a special sensing sleeper [30]. A thorough comparison of the rail seat load expressions was presented by Van Dyk and his colleagues [31,32] and more recently by McHenry and his colleagues [33].

A review of the available literature indicates that almost all of the investigations made into the RSL are limited to the ballasted railway tracks and there is no serious study conducted on the slab track systems. Due to the lack of such study, the RSL, obtained for the ballasted tracks, have been used in the design of railway slab. For instance, the International Association of Public Transport (UITP) has suggested the Eisenmann RSL formula for the design of slabs [34]. Since the majority of the RSL influencing parameters of the ballasted tracks are considerably different from those of the slab tracks [10], the reliability of the rail-seat load expressions used in the design of slabs is questionable. For instance, many structural cracks have been reported in the rail-seat positions of the concrete sleepers which can be due to the lack of sufficient understanding of the slab loading pattern [16]. Gautier from Systra (one of the world largest slab-track consulting and construction companies) has made a thorough review of the current stand of the slab track design. He concluded that there are some overestimations in the loading, and therefore, optimization is needed by providing a more accurate loading pattern in the ballast-less tracks [35].

This research is a response to this need. Comprehensive laboratory and field tests were carried out between 2014 and 2016 to measure the load transferred from the rail to the slab via the rail seats in various track and rolling stock conditions. The tests were carried out in various light and heavy passenger transit lines. The results were analyzed, leading to derive a practical expression for the rail seat load and the loading pattern of the concrete slabs. Due to the complexity of the slab track system, which causes several unrealistic assumptions in the theoretical models [36], this research relies only on experimental results.

2. Experimental investigation

The testing method was carefully designed prior to the test. It included the fields conditions, and the testing procedure (i.e., tests setting, instrumentations and data acquisition). Based on the method adapted, rail seat loads in various train speeds and track conditions were computed through multiplying the deflections of the rail pad (the deflections between the rail seat plate and the rail) by the stiffness of the rail pad. The stiffness of the rail pads was measured in the laboratory and the rail pad deflections were measured in the field.

A review of the literature indicates that train speeds, track stiffness, rail bending modulus (i.e., the rail young modulus multiplied by its moment of inertia), rail-seat spacing (or sleeper spacing) and wheel loads are the main influencing parameters in the rail-seat loads [2,37–39,9]. Seven track fields, which cover various possible conditions of these parameters, were selected and used in this investigation. The testing setup for each set of tests was arranged such a way that the influencing parameters (including the vehicle design as well as the train speed) were the same except the parameter for which the RSL was investigated. All the field measurements were conducted in the straight parts of the lines.

2.1. Laboratorial test

The stiffnesses of three types of rail pads used between the rail and the rail seat plates (Fig. 1) were measured, using a Santam universal Testing Machine (STM-150). The test was performed on standard test specimens of the rail pads according to ASTM D575 [40]. The machine applies the loads to the pad by a hydraulic pump and the pad deflections against the applied loads are drawn by a software (Fig. 2-a). The results obtained are presented in Fig. 2-b. This figure indicates that the pads have non-linear mechanical behavior as expected [41].

2.2. Field test

Field measurements were made in seven separate sites. Sites 1–4 are in the Tehran metro network (in the Iranian capital city), Sites 5 and 6 are in the Isfahan metro first line (in the central part of Iran) and Site 7 is in Tabriz (a city in the north-west of Iran). General specifications of the tracks in the fields (sites) are presented in Table 1. The track and rolling stock parameters conditions were either measured in the sites or provided by the metro authorities.

Different types of sensors are used for the rail seat load measurements including strain-gauges [31], matrix based tactile surface sensors (Tekscan sensors) [18,21,42], conventional load cells [10,43] and LVDTs [24]. In this research, LVDTs were selected with the consideration of the possible ranges of the loads. In each site, 3 m of the tracks were instrumented by several LVDTs in two different arrangements. In the first arrangement, LVDTs were set on 5 consecutive rail seats to obtain the pattern of the rail deflections at the rail seats positions (Fig. 3a). The LVDTs were set perpendicularly on the sleeper and securely clamped to a steel rod which was attached to the rail web by a magnet support. Based on the authors' pervious experiences [44,45], a standard magnetic base (MB-B, Kanetec) was used to ensure the accuracy of the measurement. This magnetic base can hold a measuring device with 800 N holding power to ensure the clamp stability [46], meaning that it never let any movement of the magnet relative to the rail web when the trains run over the rail. Note that the surface of the rail web was thoroughly cleaned to increase the rail web and magnet contact surface (Fig. 3b). This fixation method prevents any sliding of the LVDTs within the clamps. By this arrangement, the vertical deflections of the rail relative to the underneath seat-plate were recorded at each pass of the trains (Fig. 3c). In the second arrangements, the absolute rail defections (i.e., the rail deflections relative to the ground) were measured. For this purpose, a concrete bench mark with 1500 mm distance to the rail foot was made and fixed to the tunnel invert. The LVDTs were set between the rail and a solid