Field investigation of variation of loading pattern of concrete sleeper due to ballast sandy contamination in sandy desert areas

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Abstract

Sleeper is one of the most important components in a railway track system. Thus, for accurate analysis and design of concrete sleepers, knowledge of imposed loading pattern is necessary. Sandy desert areas are critical regions where loading status of concrete sleeper is different from other areas. In these areas, the influence of flowing sand grains between the ballast aggregates increase the stiffness of ballast layer; consequently, rail support modulus increases, so the received share of total axle load subsequently increases on the sleeper which is placed under the wheel load. On the other hand, the pressure distribution underneath the sleeper changes considerably. In this paper, the results of a field investigation about the variation of rail support modulus and also variation of loading pattern of concrete sleeper followed by the variation of bending moment of sleepers in sandy desert regions were presented.

Keywords: Field investigation; Railway; Desert areas; Loading pattern; Concrete sleeper; Moving load

1. Introduction

Sleeper is one of the most important components in the railway track system. This structural element has several functions; for example, transmitting the rail load to the ballast layer, providing mechanical resistance in lateral and vertical directions and maintaining track gauge [1]. Awareness of applied forces is the most important task in analysis, design and maintenance of concrete sleepers. Various hypothetical and theoretical opinions about the loading pattern of sleeper have been presented up to now; but, there is a lack of experimental investigations on the load transfer mechanism by the concrete sleepers in different conditions of tracks [2].

Sandy desert areas are one of the critical areas, through which railway track may pass. In these regions, accordingly, the rail support modulus and loading pattern of concrete sleeper change considerably due to influence of flowing sand grains between ballast aggregates, so-called ballast contamination.

The investigation presented here was conducted to provide the understanding of variation of the rail support modulus and load transfer mechanism and the resulting variation on bending moments of the sleeper. Also, these results were compared with the similar results in non-sandy areas.

The field tests of this research were as follows:
(1) Ballast sampling in different test locations to determine ballast contamination.
(2) Determining the rail support modulus in test sites.
(3) Determining the rail-seat load and distribution of sleeper-ballast contact pressure.

In this paper, first, theoretical background related to the loading pattern of concrete sleeper was presented. Then, ballast layer contamination and determination method of the rail support modulus was described. Next, the process of field tests and the results of them were explained and compared with results of the similar field study related to non-sandy areas.

2. Theoretical basics of applied load to the sleeper

In common methods of analysis and design as recommended by AREMA, analysis steps of concrete sleeper include: (1) calculation of dynamic load transferred from wheel to the concrete sleeper, (2) determination of the maximum rail-seat load, (3) determination of pressure distribution status underneath the sleeper, and (4) attainment of bending moment along the sleeper (especially, at the rail seat position and sleeper center) [3].

2.1 Maximum load at rail seat position

Several factors affect axle load distribution on adjacent
sleeper which include rail support modulus, sleeper distance, weight of rail, characteristics of fastening system, type and dimension of sleepers and quantity and quality of maintenance operations. Among these factors, rail support modulus is more important than other factors because the effects of other factors are hidden within this factor [4, 5].

Table 1 indicates several formulas which have been proposed to determine the maximum rail seat load thus far. In these formulas, \( q_s \) and \( P \) are the rail seat load and wheel load, respectively.

### 2.2 Pressure distribution under the sleeper

Under sleeper, stresses are the response of the ballast layer against the applied load from the sleeper. Numerous factors affect the contact pressure distribution underneath the sleeper which includes aggregation quality of ballast, mechanical properties of concrete sleeper (rigidity), quality of track maintenance operations, volume of passing traffic and time passed after tamping operation. After the tamping operation and creating the mass density of ballast in two end sections of the sleeper, the largest share of bearing receives these sections and central part of the sleeper has negligible contribution of the bearing. Over time and with traffic passing, the accumulation of ballast material is reduced at two ends of the sleeper and therefore the pressure distribution gets more uniform underneath the sleeper [1].

In order to analyze and calculate the loading and bending occurred in concrete sleepers, various railway regulations consider a simple form of stress distribution beneath the sleeper. A number of hypothetical distributions of sleeper-ballast contact pressure are presented in Table 2. For example, AREA proposed that, to calculate the average of contact pressure between the concrete sleeper and ballast layer, the maximum rail-seat load is deemed to double and then the calculated average pressure should be considered for the entire sleeper [14].

### 3. Rail support modulus and its measurement methods

Rail support modulus is defined as the support load being imposed on rail length unit per vertical deflection of rail unit. This parameter is measured in Pa and is indicated by \( u \) [20]. Rail support modulus is an important parameter which affects track performance and maintenance costs. A low amount of this modulus causes the track differential settlements and high value of rail support modulus leads to the reduction of displacement and stress in rail support. But, on the other hand, a low amount of rail support modulus causes axle load to be distributed over a fewer number of sleepers and therefore the received share of axle load for any sleeper finally increases [21].

Ballast layer condition such as contamination of ballast is an effective factor for the rail support modulus because the ballast layer stiffness and subsequently rail support modulus increase when the fine grain particles penetrate between ballast aggregates [22].

There are several methods for measuring rail support modulus: theoretical, theoretical-experimental and experimental. Talbot-Wasiutynski method is one of the theoretical-experimental methods which is accepted for many railroads and has reliable accuracy despite its high costs [1]. This method that was used in this field investigation to determine the rail support modulus in sandy desert areas was provided by the Talbot committee in 1918 [23] and was developed by Wasiutynski twenty years later [24]. According to this method, the rail support displacements should be measured at the locations of several adjacent sleepers; then, considering the vertical