Abstract

The vibrations of railway track occur because of extreme impact load conditions due to the train operations with either wheel or rail irregularity. The vibrations result in track deterioration and severe environmental influences. Therefore, an urgent need exists to manufacture a sleeper/tie to mitigate these effects. This study used a full-scale model with different kinds of sleepers to measure the vibration mitigation attributes and dynamic characteristics of recently recycled rubber composite sleepers (RCSs) when applied to ballasted railway tracks and compared them with well-established concrete sleepers (CSs). A high-capacity drop hammer weight impact test was used to achieve this purpose, and the vibration effects on the track structural elements were analyzed. Two cases and a series of interaction force height (IFHs) impacts for both sleepers were applied.

As a track component, a sleeper is one of the most critical parts of ballasted railway track structures. Due to the significant effects of sleepers on the long-term performance of the ballasted track resistance, stiffness, and stability, there exists an urgent need for in-depth research on the resistance characteristics and stiffness of ballasted track for recently made RCSs with aims to reduce carbon dioxide (CO_2) emissions and finding eco-friendly alternative sleeper. It should be noted that no previous study has been carried out on the effect of vibration mitigation and resistance characteristics of this sleeper in complete track structure elements and a large enough laboratory model as an actual track. An appropriate test support equipment also was invented. First, the longitudinal resistance was examined at different loading stages of the track panel longitudinal test (TPLT) and single-sleepers longitudinal test (SSLT). Then, the single-sleeper push test (SSPT) was applied with various depths of sleepers and different shoulder heights and widths of the ballasted track to investigate the lateral resistance. Then, the vertical stiffness test (VST) was carried out on both left and right rails as actual rail tracks. Finally, the Discrete Element Method (DEM) was used to model SSLT, SSPT, and VST to verify and determine the specific characteristics of longitudinal, transverse, and vertical resistance of RCS and CS, and their effectiveness parameters were exhaustively compared. The results of the study revealed the following:

(1) RCSs under the various impacts of the IFHs can reduce the peak acceleration of ground-borne vibration between 38.35%-66.23%, and can decrease vertical vibration by 63.12%-96.09%. However, the RCS showed high peak acceleration on the rail and sleeper. This is due to the smaller mass of the RCSs when the impact forces were applied to the rail, resulting in a larger vibration acceleration on the upper surface of the RCSs.

(2) The time and frequency domain investigations over the lateral and vertical directions of the track showed that the track with RCSs had lower vibration acceleration peaks, fewer frequency peaks, decreased velocity, and shorter vibration cycles than the track with CSs. Due to the different stiffness of each type of sleeper, the stiffness/rigidity sleeper (CSs) transmits vibration waves to the ballasts faster and produces a higher vibrational response in the rail, sleeper, and ground compared to the RCSs.

(3) RCSs significantly reduced vibration levels by −5.04 dB, 1.71 dB, and −2.46 dB (and 11.77 dB in case two) for the rails, sleepers, and ballast, respectively. Moreover, the RCSs decreased the VAL of ground-borne vibration between 10.6 dB-18.6 dB. Thus, in this research RCSs have shown the advantageous ability to minimize environmental issues, track deterioration, and noise.

(4) The results of the long-term performance of RCSs showed that the RCSs increased the ballasted track longitudinal resistance by 12% for track-panel loading and 24% for single-sleeper loading, the lateral resistance of the ballasted track with RCSs is lower than the ballasted track with concrete sleepers due to the light weight of the aforementioned sleepers weighing merely 1/3 that of the concrete sleepers. However, this study suggests 500 (mm) width and 150 (mm) height for the ballast shoulders to meet the lateral resistance requirements.

(5) The vertical resistance of the ballasted track with RCSs increased by 17.06%. This study recommended adding additional bending stiffness elements to the RCSs to make them better alternative sleepers. The results from this study developed novel RCSs using rubber waste materials from environmental and cost points that make them eco-friendly and commercially. Moreover, make them meet the structural performance requirement to replace existing sleepers.

(6) The fastener system of the RCS had a better longitudinal resistance than the fastener system of the CS. The fasteners of the CS shared part of the longitudinal load before the rest was then transferred to the sleeper. In comparison, the fasteners of RCS completely transformed this load into the sleeper. In addition, the RCSs showed a more significant longitudinal resistance than concrete sleepers. Moreover, RCSs contain rubber materials which are highly durable, resisting deterioration from abrasive and tearing forces, impact loads, low temperatures, and moisture or water.

(7) The modeling of SSLT, SSPT, VST were carried out using the Discrete Element Method (DEM) in order to validate and determine the mesoscopic characteristics of the longitudinal, lateral, and vertical resistance of RCSs and CS. This chapter establishes the DEM of a single sleeper on ballasted track with a three-dimensional model. Therefore, the creation

of ballast particles, sleepers, and validation of models were explored for each test in detail. The results of the simulation are compared with the findings of the tests to confirm the model's reliability and validate the DEM simulation results with experiments. The analysis of the contact force chain and microscopic mechanism distribution of the ballasted track in longitudinal, lateral, and vertical directions of the ballasted track with RCS and CS were discussed. The main finding is that the contact forces between sleepers and ballast particles RCS are smaller than that of CS in longitudinal, lateral, and vertical resistance of model simulation.