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Numerical analysis of new pre-installed steel modular railroad track assembly

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HIGHLIGHTS

- A new pre-installed steel modular railroad track assembly was introduced.
- A 3-D FEM of the new steel modular railroad track assembly was established.
- The mechanical characteristics of the new structure was analyzed and compared with traditional track.
- Recommendation of the cross section of the cross ties was put forward.

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ABSTRACT

Due to the modularity of the traditional track and the discreteness of the ballast bed, the application of the repeated and random train load would inevitably result in the accumulation of residual deformation and the track damage. A new steel pre-installed modular railroad track assembly was designed to provide better stability and reduce deformation. It includes a plurality of spaced-apart cross-ties, two side ties, intermediate ties and a pair of rails road track rails. In order to figure out the mechanical performance of this new steel pre-installed modular railroad track assembly, the 3-D finite element model of the steel modular railroad track including with the track, ballast bed, sub-ballast and the sub-grade was built. In this model, the load distribution and the vertical deformation of ties with different cross sections were discussed, and the stresses of the steel modular railroad track and the ballast bed were analyzed. The results indicate that, compared with the traditional track, the single wheel load will transfer to more ties of the new steel modular railroad track and the integrality of the new steel modular railroad track is much better. The maximum deflection of the steel modular railroad track located at the point of load application (under the wheel load). It is much smaller than that of the traditional track. As a result, it can be concluded that the new steel modular railroad track is more likely to induce less deflection under the series wheel load and have better rail regularity.

1. Introduction

Railroad as one of primary types of transportations modes, which can transport goods and people efficiently, has proven to be popular in last century all around world. The traditional railroad (as shown in Fig. 1) currently in use is a complex system which consist of rails, crossties and ballast bed that interact to provide a smooth running surface for rail traffic [1]. Rail was made of steel to guide the wheel in the lateral direction. Crossties, which are the main component of railway track structure, are responsible for providing support for rail, sustaining rail force and transferring them to ballast bed [2]. Ties also play a very important role in keeping the track geometry, especially keeping rail gauge. The traditional railway crossties are manufactured by wood, concrete and in some cases steel [3–5].Wood was firstly introduced as the material of crosstie and has been widely used worldwide. It has the excellent dynamic and sound-insulating properties, but the wood crosstie is at the risk of rotting, splitting and scarcity [6,7]. With the development of heavy haul, concrete crosstie gradually took place of wood crosstie in many countries. While in North America, wood crosstie still accounts for more than 90% of the ties in track. Concrete crosstie has the problems of high initial cost, low impact resistance and susceptibility to chemical attack. Ballast bed made

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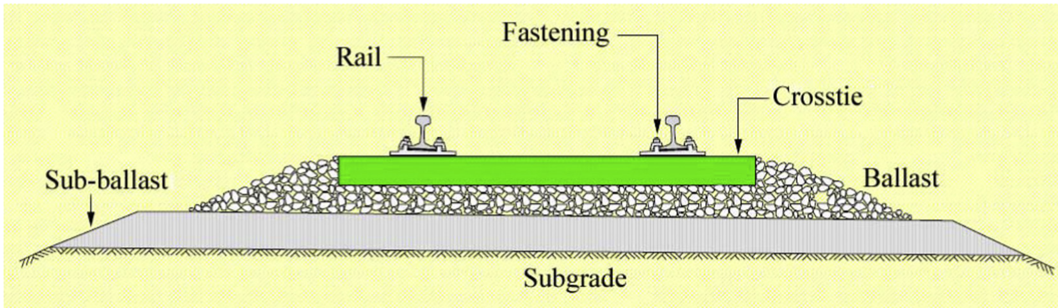

Fig. 1. Composition of traditional track structure.

of crushed stone provides the foundation to support the sleepers and the main source of the track elasticity [8].

Due to the modularity of the traditional track and the discreteness of the ballast bed, the application of the repeated and random train load would inevitably result in the accumulation of residual deformation and the track damage [9], such as ballast crushing, lateral spreading of the ballast and deterioration of the ties [10]. To avoid temporary speed restrictions to normal train running, maintaining the performance of the railway and reducing unforeseen and cumulative delays should be scheduled [11]. Even though the construction cost of ballasted track is relatively low, there is a great expense in ballast maintenance and renewal each year [12].

Compared with the traditional ballasted track, the slab track systems or continues concrete track have numerous structural advantages such as a higher longitudinal and lateral permanent stability, the impossibility of rail buckling and reduced sensitivity to differential settlements. It has been widely applied all around the world for high speed railway lines [13,14]. But after a short operation, interface damages and cracks has been found on Chinese railway lines [15]. Once the damage of slab track occurs, more complicated maintain technology and much longer maintain time may cause temporary speed restriction. On the other hand, the slab track is costly in construction and in essence not favoring noise reduction [16].

Increasing traffic speed and heavy weights motivated the global engineers looking for the track structure with more stable, low cost, less maintenance and longer durability. Many of them chose new materials as an alternative timber or concrete. Such as the FFU (Fiber-reinforce Foamed Urethane) synthetic crosstie invented by Sikisui company has been applied in many countries [17,18]. Hameed [19] made the experiment investigation of the suitability of rubber concrete crosstie and found that the rubber concrete has higher impact resistance and lower compressive strength compared with concrete crosstie. Some of them proposed new techniques for improving the mechanical characteristics of railroad track. Esmaeili [20] invented the nailed crosstie to enhance the lateral resistance of concrete crosstie. Domingo [21] designed a new crosstie with wings at bottom to provide higher lateral resistance. The Frame crosstie designed by Ciotlăuş [22] and Y-Steel crosstie applied on German Railway network [23] can efficiently improve the railway stability. Scrutinizing all the presented new material sleeper or new sleeper structure, some of them are costly, and some of them can be applied on limited area.

All the aforementioned issues motivated authors to develop a new steel modular railroad track assembly that simplifies railroad construction. In this paper, a new steel modular railroad track assembly was introduced, with 3D finite element model, its load distribution, the vertical deformation and stress with different crosstie cross sections were carried out under train load through 3D finite element model.

2. New steel modular railroad track assembly

Instead of wood crosstie or concrete crosstie in traditional track, the new steel modular railroad track assembly (as shown in Fig. 2) is made of steel with corrosion protection measures. It includes a plurality of spaced-apart cross-ties, side ties, intermediate ties and a pair of railroad track rails. Each cross-tie includes a planar edge with the plurality of cross-ties being arranged such that each planar edge lies in a common plane. Each cross-tie is T-shaped in cross section all along its length. Cross tie has a planar top to which rails are coupled, and a planar leg defined by an inverted isosceles trapezoid whose base angles are defined acute angle α. The angle α is in the approximate range of 65°–80°. The bases of the isosceles trapezoid are 95.92″ and 103.11″, the height of the isosceles trapezoid is 12″. Side ties are coupled joined to cross ties to define a rigid assembly. Each intermediate tie is a generally rectangular plate spanning and coupled to two cross tie. Once the assembly is installed in ballast bed, portions of the ballast bed are locked into compartments A, B and C defined between adjacent ones of cross-ties are bounded by side ties. The length of the steel modular railroad track assembly is 262″, each track assembly concludes 9 cross ties, the gap between two steel modular railroad tracks is 2″.

The new modular railroad track assembly has many numerous advantages. Firstly, the new track assembly is an integrated continuous unit structure because the crossties are connected by side ties and intermediate ties, while the traditional track is a discrete system because each crosstie is independent with each other. For track structure, the better integrality means better stability. Thus the new structure with better integrality will have better stability which is the main influencing factor in terms of the maintenance cost. Secondly, because the new structure is a pre-installed structure, it can reduce the construction time spent on the laying and adjusting ties. Meanwhile by retaining ballast bed within assembly, compartment A, B and C can greatly reduce or eliminate shifting of ballast bed to reduce the frequency of track maintenance. At the same time, once damage occurs on the track assembly, the damage area can be partly cut-off and welded with replacement as soon as possible. Compared with replacing wood tie or concrete tie, the maintenance time is shorter. So it may simplify construction/maintenance of railroad tracks and greatly reduce off-line time for a railway line. Then compared with the traditional track, compartments A and C can efficiently reduce ballast lost.

3. FEM model of new steel modular railroad track

3.1. 3D FEM model

In order to figure out its stress and deformation under the train load, the new steel modular railroad track was modeled as a three-