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Optimising performance of discrete element method modelling of railway tracks

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Abstract

Numerical simulations based on Discrete Element Method (DEM) are normally used for railway ballast related researches. However, the efficiency of DEM simulation is very low due to the algorithm and the huge number of elements. Facing to the efficiency problem, a multi-layer ballast track model is introduced. By simulate the lateral resistance tests, the efficiency and accuracy of this model is validated. Results show that this multi-layer model building method largely improves the efficiency, and it can provide accurate data.

Keywords: discrete element method, ballast, railway, efficiency.

1 Introduction

Discrete Element Methods (DEM) is one of the modern numerical methods that allows to describe the motion of a large amount of small particles and to analyse their interaction. The method becomes extremely useful when it comes to analysis of the dynamic behaviour of the systems involving granular materials, such as e.g. bulk material handling equipment and railway systems. The methods to be developed in this project will be applied but not limited to the railway engineering problems.

The attractiveness of analysing the system behaviour on a particle level comes with the price of high computational costs, primarily due to the large amount of the particles that results in a large amount of the equations of motion (describing the particles behaviour) to be solved. These computational costs are increasing tremendously as the shape of the particles becomes more complex (realistic) than a simple disc (in 2-D) or a sphere (in 3-D), primarily, due to increase of the contact points between the particles. Moreover, in order to describe the long-term behaviour of the system, repeated loading must be applied that further increases the computational costs of the DEM analysis.

The other cause of the high computational costs is the multiple simulations involved in the DEM analysis. Due to the stochastic nature of the DEM simulations (related to varying initial relative position and orientation of the particles), the simulations needs to be repeated several times in order to obtain reliable results. The number of the simulations will increase when uncertainties (e.g. in material/geometrical properties, and loading) are involved, and the methods of probabilistic design are to be applied. Finally, in order to further improve the system performance, numerical optimisation methods are to be used, which require multiple calculation of the objective and constraint functions wherein the DEM simulations are involved.

All the above-mentioned makes the computational efforts of the DEM simulations prohibitive (up to several months), especially in the context of longer time horizon problems such as wear in bulk handling and degradation of particles due to cyclic loading of railway ballasted track. That is why the DEM methods are still not widely used. The mesoscopic results is well-suited with the ballast research, that also highlight the importance of the efficiency optimisation to get the behaviour of ballast track.

2 Methods

The DEM model is normally simplified with 2 methods: the upscaling method is normally used for powder material, reference[1] uses up-scaling method to reduce the element number, the efficiency increase of 55 times. However, the macroscopic results are good, the contact between tool and particle is inconsistent with mesoscopic results. Those contact loss is unacceptable for ballast research.

Another method uses a mathematical relation to calculate a relation between results obtained from the simplified model (low-fidelity) and results of accurate model (hi-fidelity). In reference[2], a 2D DEM model is used to simulate cyclic loading process. This dimensional simplification can highly improve the efficiency, but the problem of accuracy of 2D model is obvious due to 1-dimension loss. In addition, the irregular shape("clump", which consists of several basic element) of particle can be simplified to decrease the number of element, in reference[3], the sub-ballast is simplified to "ball" shape(1 element), because the number of particles are too large. However, the shape of ballast is important for the reliability of results[4], and the mesoscopic behaviour of low-fidelity is nearly impossible to fit the high-fidelity results, such as the data of force-chain, the particle displacement.

As mentioned, those methods are unsuitable for ballast research, based on the characteristic of ballast, In this paper, a multi-layer model is introduced, it is illustrated by a single sleeper section model, and the lateral resistance simulation. The model contains 2 layers, in the bottom layer the particle is simplified to “ball” shape to reduce the calculation cost, a rolling resistance is added on the ball-ball contact to simulate the interlock within the irregular particles[5,6]. And, the upper layer uses irregular shape, it makes sure that the contact between ballast and sleeper is hi-fidelity. As shown in Fig.1.

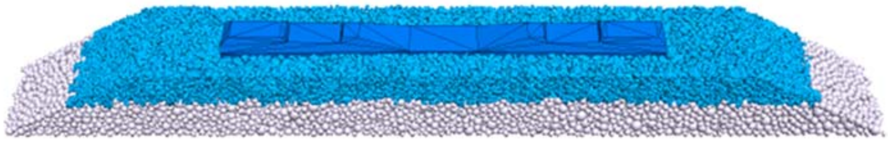


Fig.1 Single sleeper section model with multi-layer method

As a reference, a model, using clump for all particles, is shown in Fig.2. Related research with this model by the author can be seen in reference[7-9]. Thus, its reliability and accuracy has been validated. All the parameters are listed in Table 1.

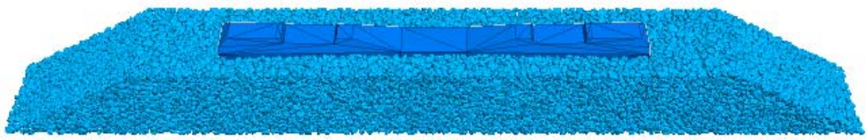


Fig.2 Single sleeper section model with clumps

Table 1 key parameters

Parameters	Ballast (Clump)	Ballast (ball)	Sleeper
Tangential stiffness(N/m)	2e7	2e7	5e9
Normal stiffness(N/m)	2e7	2e7	5e9
Friction coefficient (Linear contact)	0.5	0.5	0.5
Friction coefficient (Rolling resistance)	-	0.3	-
Mass density(kg/m^3)	2800	2800	NA
Weight (kg)	-	-	380

3 Results

The clump-built model is hi-fidelity model, the particle is obtained from 3D scanning data of real ballast. this is the normally used model building method, it contains 647323 elements of particles, 86 elements as the sleeper and boundary wall. In comparison, the simplified model contains 647323 elements of particles, also 86 elements as the sleeper and boundary wall. Comparing with the model build with clump, this multi-layer model reduce the number of elements by 59%.

To validate the optimised model, the single sleeper pushing test is simulated using above 3 models, a lateral velocity is applied to the sleeper, which is 4e-3mm/s, this low speed ensuring the simulation is in a quasi-static state. The simulation is stopped when the sleeper displacement reaches 5mm. during this process, the contact force-displacement data of sleeper is recorded. In addition, the force distribution at the end state is save to show the difference of each model, thus providing the validation. The efficiency is compared by the time consuming. key results are shown in following Table 2, Fig.3, Fig.4 and Fig.5. Results show that the multi-layer model increases the efficiency and provides a relative hi-fidelity results.

From the results, the multi-layer model is 2.75 times quicker than the reference model. The sleeper displacement and lateral contact curve is in the similar trend, also the distribution of ballast displacement and ballast contact force-chain are both in the same level. It means that the aiming of get the mesoscopic behaviour is achieved. However, the value of results show deviations, those deviations can be diminished by further fitting or model adjusting.

Table 2 Key performance of lateral resistance simulations

Particle type	Time consuming	Peak lateral force (Sleeper)	Maximum contact force (Particles)
Clump (Reference model)	43h 23 min	12.03kN	2.18kN
Multi-layer model	15h 45 min	9.92kN	1.56kN

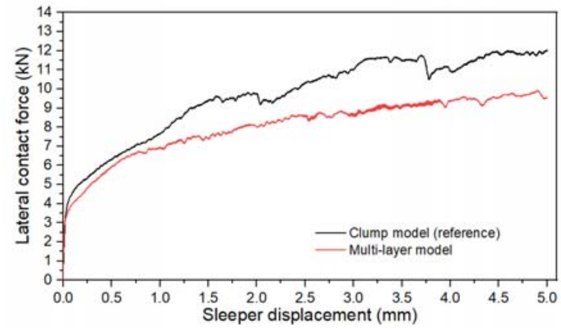
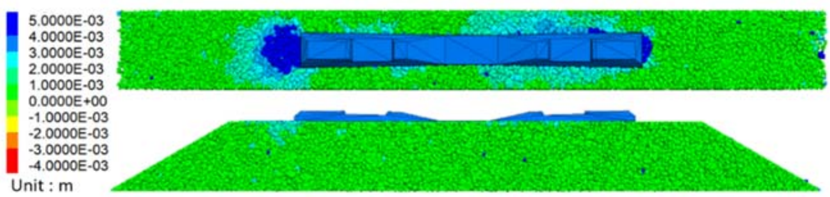
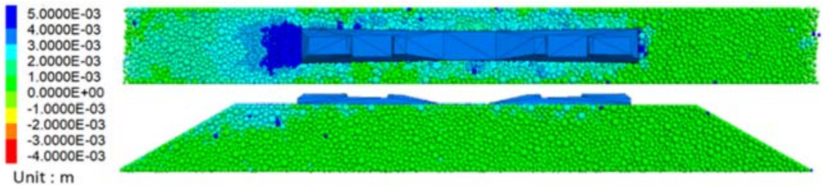


Fig.3 Sleeper displacement- lateral contact force curve

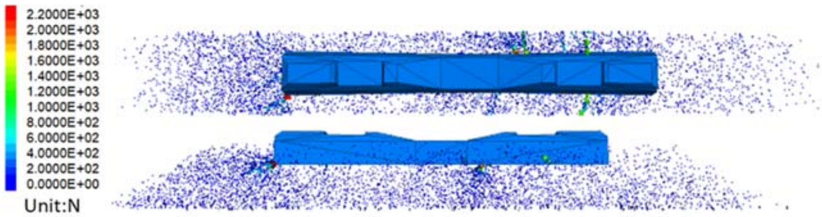


a) Reference model (all particles are clump)

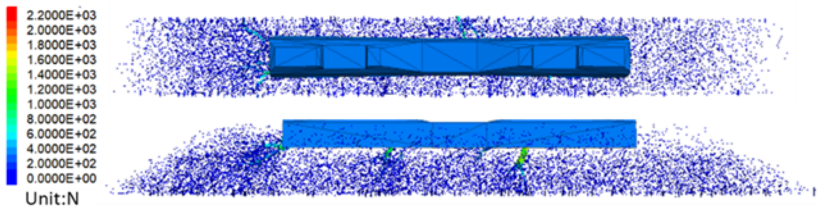


b) Multi-layer model (Half clump and half ball)

Fig.4 Ballast displacement under 5mm sleeper displacement



a) Reference model (all particles are clump)



b) Multi-layer (Half clump and half ball, by height)

Fig.5 Force-chain under 5mm sleeper displacement

4 Conclusions and Contributions

For ballast researches, the DEM simulations can provide the mesoscopic results, however the efficiency problem restricts the feasibility of this method. To improve the calculation efficiency of DEM, several methods can be used, but all those methods is not proper for ballast researches. With this consideration, this paper introduced a multi-layer model building method. This method uses the irregular shape of particles, where the ballast is close to sleeper, and it simplifies the irregular ballast shape to ball shape in the other area. As an example to show the accuracy and efficiency of the optimised model, later resistance simulations are used. The results of different model is validated by comparing with a reference model (clump-build), which is used in author's previous work. The main conclusions and perspectives are listed as below:

(1) In the single sleeper section model, the multi-layer model reduces the number of elements by 59%, thus increase the efficiency 2.75 times, comparing with a clump-built model.
(2) In the bottom layer, a rolling resistance should be used to simulate the interlock of irregular shape.

(3) The multi-layer model can provides a relative accuracy results in contact force distribution, ballast displacement, and the trend of sleeper displacement-lateral force.
(4) The layer of this model is simply defined by height, it can be further refining to fit different type of models.

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