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Study of Railway Ballast Compactness under Tamping Operation

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Abstract: Railway ballast tamping operation is an important work in the railway line maintenance and renewal operation, which is employed to restore the initial geometry of railway track distorted by train traffics. The main goal of tamping operation is to compact the stone ballasts under the sleepers supporting the railway squeezing and vibrations. The ballast compactness is the most direct index for evaluating the quality of tamping operation. This paper presents an experimental method used to measure the ballast compactness under the sleeper before and after tamping operation based on water-filling method and creates a discrete element analysis model of railway ballast which analyzes the change of ballast compactness under tamping operation based on discrete element method. The simulation results are very similar with experimental results, which verify that the discrete element method is an effective method to evaluate the change of railway ballast compactness under tamping operation.

Key words: Ballast compactness, tamping operation, water-filling method, discrete element method

INTRODUCTION

Railway ballast is the railway track foundation which is composed of graded stone ballast. With the increasingly busy, high speed and heavy load of railway transport, the railway line will be inevitably deformed or damaged (Zhai *et al*., 2004; Indraratna *et al*., 2010). In order to ensure train safety, smooth, fast running and extend the service life of various components of the railway track, the maintenance work of the railway line need strengthen to keep the railway line equipment in good condition (McDowell *et al*., 2005; Vale *et al*., 2011).

Because the newly-built railway ballast or just after overhaul of railway ballast is relatively loose, the bearing capacity and stability of railway track is very poor, the ballast compactness is a very important index of the railway ballast. In order to improve the railway ballast compactness, the tamping operations are used. As the graded stone ballast of railway is granular media of different shapes and sizes, during tamping process, the railway ballast compactness is difficult to measure, the quality of tamping operation is difficult to assess and the selection of tamping parameters is usually dependent on field trials and practical experience, for lack of theoretical basis.

In order to study the change of ballast compactness under tamping operation, this paper presents an experimental measurement method used to measure ballast compactness based on water-filling method. Because the measurement based on water-filling method needs to lift the sleeper, we can't measure the ballast compactness during the process of tamping operations. In this paper, the ballast compactness are measured respectively before and after tamping operation and the results of the measurement are compared to judge the quality of tamping operation.

In recent years, the rapid development of discrete element method offers a new means of studying the response characteristics of railway ballast under tamping operation (Saussine *et al*., 2009; Liu *et al*., 2013a). The discrete element method was developed based on the principle of molecular dynamics by the American scholar Cundall P.A. in 1971, which is used to study the discrete particle materials. After more than forty years, continuous in-depth study, the discrete element method is more widely used in research areas involving solid particles (Lu and McDowell, 2007; Potyondy and Cundall, 2004; Lobo-Guerrero and Vallejo, 2006; Kim, 2008). It is regarded as a new attempt that the use of discrete element method for creating discrete element model of railway ballast and simulating the change of railway ballast compactness under tamping operation.

TAMPING PRINCIPLE

The schematic diagram of tamping operation is shown in Fig. 1. Tamping operation is a continuous cycle process. The cycle itself has five phases: the first phase

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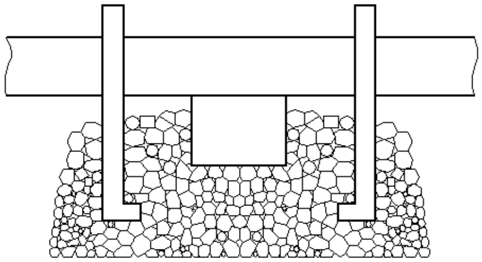

Fig. 1: Schematic diagram of tamping operation

is that the tamping tines are inserted into the ballast around the sleepers, the second phase is that the tamping tines squeeze the ballast to fill the voids under the sleeper, the third phase is keeping the squeezing, the fourth phase is loosening the squeezing and the fifth phase is that the tamping tines are removed, as well as the tamping tines always maintain the vibration throughout the tamping operation process (Brown *et al*., 2007; Liu *et al*., 2013b).

During the process of tamping operation, the vibration force is transferred to the stone ballasts through tamping tines, then the stone ballasts generate vibration and move to stable direction, which increase the railway ballast compactness; reuse of the clamping force provided by tamping tines, the stone ballasts between sleepers are squeezed to the voids under sleeper, which further increase the railway ballast compactness under sleeper, so as to improve the stability of the railway track.

Experimental program: In order to study the change of ballast compactness under tamping operation, this paper presents an experimental method used to measure the railway ballast compactness based on water-filling method.

Water-filling method: The schematic diagram of water-filling method is shown in Fig. 2. In order to measure the ballast compactness, the steel rails and sleepers in measurement zone should be lifted. The ballast bed under sleeper is packed into a flat, as shown in the Fig. 2a. A certain volume stones are taken out and a hole is leaved in the ballast bed, as shown in the Fig. 2b. A plastic bag is placed in the hole and filled with water, as shown in the Fig. 2c.

If the volume of removed stones is measured as V_s and the volume of water is measured as V_w, then the ballast compactness is defined as $D = V_s/V_w$.

Experimental procedure: The experimental procedure consists of three steps: the first step is that the ballast compactness is measured before tamping operation. The steel rails and sleepers are lifted, some stones are taken out and a hole is leaved in the railway ballast. A plastic bag is placed in the hole and filled with water. The volume of removed stones is measured as V_{s1} and the volume of water is measured as V_{w1}. The second step is that the railway track is restored to former appearance and tamping operation is performed. The experimental site of tamping operation is shown in Fig. 3. The third step is that the

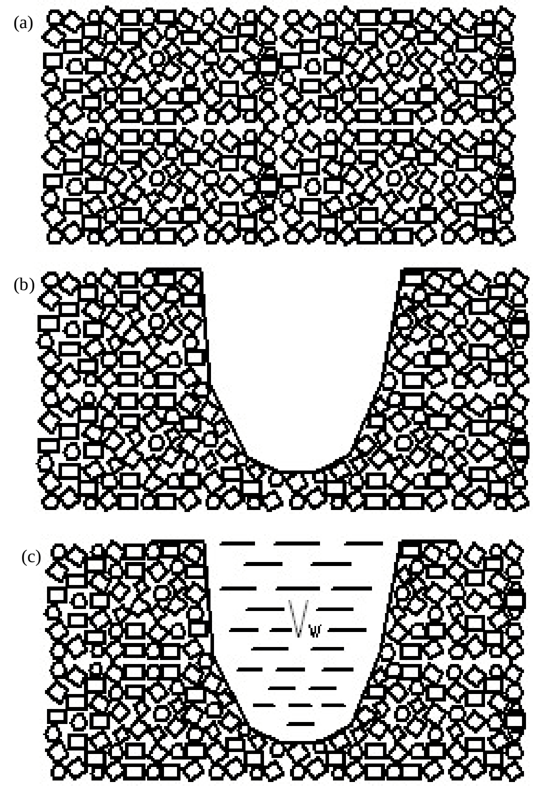

Fig. 2: Schematic diagram of water-filling method

Fig. 3: Experimental site of tamping operation

Table 1: Experimental measurement results

	V_s (m^3)	V_w (m^3)	D
Before tamping operation	0.0053	0.0087	0.61
After tamping operation	0.0058	0.0084	0.69

ballast compactness is measured after tamping operation and the measurement repeats the first step. The volume of removed stones is measured as V_{s2} and the volume of water is measured as V_{w2}.

Experimental results: The ballast compactness was measured respectively before and after tamping operation in Kunming, China. Table 1 lists the experimental measurement results. The ballast compactness before tamping operation is obtained as 0.61. The ballast compactness after tamping operation is obtained as 0.69.

The experimental results show that the ballast compactness under the sleeper is improved after tamping operation.

DISCRETE ELEMENT ANALYSIS MODEL

This paper tries to create the analysis model of railway ballast using discrete element method in the discrete element analysis software EDEM, which was provided by DEM Solutions Ltd. In order to improve the calculation speed, the analysis models need to be simplified. Discrete element analysis model of railway ballast under tamping operation is mainly composed of particle model of stone ballast, contact model of stone ballast, geometry model of sleepers and tamping tines and particle factories of railway ballast and so on.

Particle model of stone ballast: At present the basic particle shape model is sphere in the three-dimensional discrete element analysis software (Jiang and Fan, 2001; Xiao *et al*., 2009; Lu and McDowell, 2010), however, the shape of stone ballast is irregular, the size of stone ballast is also inconsistent and as shown in Fig. 4, which brings some difficulties to simulation analysis.

Fig. 4: Actual shape of stone ballast

In the three-dimensional discrete element analysis software EDEM, overlapping spherical surfaces of different sizes is used to form complex clumps in order to simulate particles of irregular shape, this paper creates two typical particle model to simulate the real stone ballast by mean of overlapping spherical surfaces of different sizes, as shown in Fig. 5

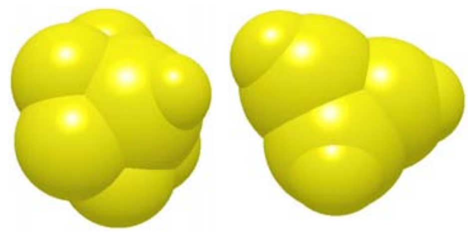

Fig. 5: Particle model of stone ballast

Contact model of stone ballast: The interaction forces acting on the particles of stone ballast contain pressure and friction, the normal force generally uses the Hertz contact model to calculate, the tangential force generally uses the Mindlin-Deresiewicz contact model to calculate. According to Hertz-Mindlin contact theory, the mechanics model of particle uses vibration equations of motion to simulate. In the process of particle contact, the normal vibration equation of motion is given by Eq. 1; the tangential vibration of motion contains tangential sliding and rolling of particle, which is given by Eq. 2 and 3:

$$m_{1,2}d^2u_n/dt^2 + c_n du_n/dt + K_n u_n = F_n \quad (1)$$

$$m_{1,2}d^2u_s/dt^2 + c_s du_s/dt + K_s u_s = F_s \quad (2)$$

$$I_{1,2}d^2\theta/dt^2 + (c_s du_s/dt + K_s u_s)r = M \quad (3)$$

where, $m_{1,2}$ is the equivalent mass of particle 1, 2; $I_{1,2}$ is the equivalent moment of inertia of particle 1, 2; r is the radius of gyration; F_n is the normal component of external force acting on particles; F_s is the tangential component of external force acting on particles; M is the external torque acting on particles.

For the tangential sliding and rolling of particle are influenced by the friction between the particles, in addition to the Poisson's ratio, shear modulus and density of the materials properties of particles, the friction coefficient of particles should be defined in EDEM.

Geometry model of sleepers and tamping tines: Due to the industrial tamping device and railway track are very complex and some parts have no effect on the simulation results, in order to improve the calculation speed, the geometry model need to be simplified. The sleeper and tamping tine are selected as main geometry analysis model

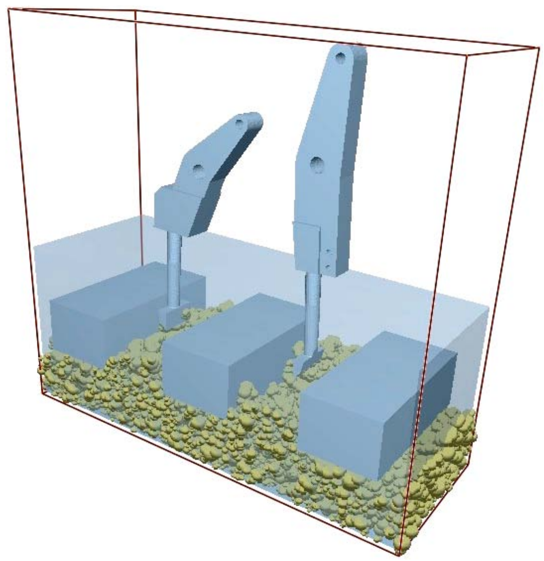

Fig. 6: Analysis model of tamping operations

in this paper, for they contact with stone ballast in the simulation and have key effect on the simulation results.

Geometry model can be defined in EDEM or imported from a CAD package. In this paper, for the structure of sleeper and tamping tine is more complex, the geometry model of sleepers and tamping tines are created in Solid Edge and then imported into EDEM.

After the geometry model of sleepers and tamping tines are created and located, some geometry attributes need to be defined in EDEM. In addition to the Poisson's ratio, shear modulus and density of the materials properties of sleepers and tamping tines, the dynamic properties of tamping tines should be defined in EDEM. In this paper, the dynamic properties of tamping tine are defined through the reference to the actual industrial tamping operation process which recommended by the China Railway Large Maintenance Machinery Co., Ltd. Kunming.

Particle factories of railway ballast: Particle factories are used to define where, when and how particles appear in a simulation. Any virtual surface or volume can be turned into a particle factory. For simulating the railway ballast bed, a virtual box is created to be turned into a particle factory and some associated parameters are defined in this paper.

The discrete element analysis model of railway ballast during tamping process has been created by creating the particle and contact model of stone ballast, the geometry model of sleepers and tamping tines and particle factories of railway ballast and so on, as shown in Fig. 6.

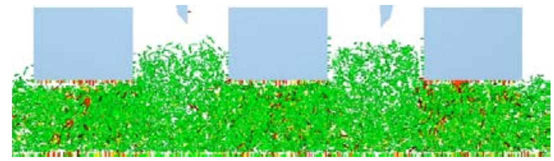

Fig. 7: Motion trend of stone ballasts

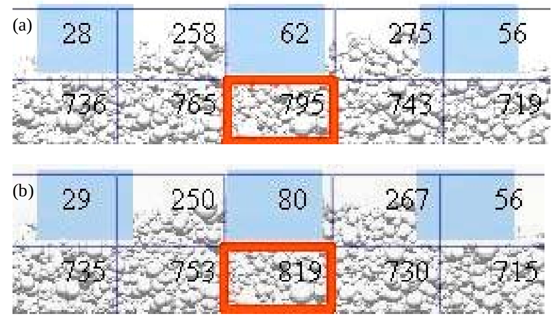

Fig. 8: The number of stone ballasts. (a) Before tamping operation and (b) After tamping operation

Simulation analysis: In this paper, the simulation computations were carried out using the discrete element method to study the ballast compactness under tamping operation. In order to qualitatively study the change of ballast compactness, we extract the motion trend of the stone ballasts during tamping process which reflects the change of ballast compactness. In order to quantitatively study the change of ballast compactness, we extract the number of stone ballasts in the same region respectively before and after tamping operation from the simulation which reflects the change of ballast compactness.

Motion trend of stone ballasts: In the process of tamping operations, stone ballast under the action of vibration force and clamping force will produce motion. In order to qualitatively study the change of ballast compactness during tamping process, In the process of simulation, we extract the motion trend of the stone ballasts as shown in Fig. 7. It clearly shows that the stone ballasts between sleepers are moved to fill the voids under sleeper during the process of tamping operation, which increases the ballast compactness under sleeper.

The number of stone ballasts: When the size of stone ballast is constant, the number of stone ballasts in appointed region can reflect the ballast compactness. In order to compare with the previous experimental results, the number of stone ballasts in the same region is extracted respectively before and after tamping operation, as shown in Fig. 8.

In the Fig. 8, the number in the red box is the number of stone ballasts in the tamping region. In the Fig. 8a, the number of stone ballasts in the tamping region is 795 before tamping operation. In the Fig. 8b, the number of stone ballasts in the tamping region is 819 after tamping operation. The simulation results show that the ballast compactness is improved after tamping operation.

CONCLUSIONS

This study presents an experimental method based on water-filling method which studies the change of ballast compactness under the sleeper before and after tamping operation. The experimental measurement results show that the ballast compactness under the sleeper is improved after tamping operation.

This study presents numerical simulation using discrete element method which studies the change of ballast compactness under tamping operation. This study shows that the stone ballasts between sleepers are moved to fill the voids under sleeper during tamping process and the ballast compactness in the tamping region is improved after tamping operation.

The simulation results are very similar with experimental results, which verify that the discrete element method is an effective method to evaluate the change of railway ballast compactness under tamping operation. The present study may be helpful for the analysis of the change of railway ballast compactness under tamping operation. Future work will be further in-depth study the change of railway ballast compactness during tamping process under different tamping parameters.

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REFERENCES

Brown, S.F., B.V. Brodrick, N.H. Thom and G.R. McDowell, 2007. The Nottingham railway test facility, UK. Transport, 160: 59-65.

Indraratna, B., P.K. Thakur and J.S. Vinod, 2010. Experimental and numerical study of railway ballast behavior under cyclic loading. Inter. J. Geomechanics, 10: 136-144.

Jiang, W. and J. Fan, 2001. Using of distinct element method to analyze granular ballast bed. J. China Railway Soc., 23: 98-101.

Kim, Y.M., 2008. A granular motion simulation by discrete element method. J. Mech. Sci. Technol., 22: 812-818.

Liu, X., K. Zhang and M. Li, 2013. Discrete element method simulation of mesomechanics of railway ballast during tamping process. Adv. Mater. Res., 90-693: 2726-2729.

Liu, X., K. Zhang and M. Li, 2013. Study on motion parameters of tamping operation. Adv. Mater. Res., 694-697: 154-157.

Lobo-Guerrero, S. and L.E. Vallejo, 2006. Discrete element method analysis of railtrack ballast degradation during cyclic loading. Granular Matter, 8: 195-204.

Lu, M. and G.R. McDowell, 2007. The importance of modelling ballast particle shape in the discrete element method. Granular Matter, 9: 69-80.

Lu, M. and G.R. McDowell, 2010. Discrete element modelling of railway ballast under monotonic and cyclic triaxial loading. Geotechnique, 60: 459-467.

McDowell, G.R., W.L. Lim, A.C. Collop, R. Armitage and N.H. Thom, 2005. Laboratory simulation of train loading and tamping on ballast. Proc. Institution Civil Eng.: Trans., 158: 89-95.

Potyondy, D.O. and P.A. Cundall, 2004. A bonded-particle model for rock. Inter. J. Rock Mech. Mining Sci., 41: 1329-1364.

Saussine, G., E. Azema, R. Perales and F. Radjai, 2009. Compaction of railway ballast during tamping process: A parametric stud. Powders Grains, 1145: 469-472.

Vale, C., I. Ribeiro and R. Calcada, 2011. Integer programming to optimize tamping in railway tracks as preventive maintenance. J. Trans. Eng., 138: 123-131.

Xiao, H., L. Gao and B. Hou, 2009. Analysis of ballast dynamic behavior with 3D discrete element method. J. Railway Eng. Soc., 9: 14-17.

Zhai, W.M., K.Y. Wang and J.H. Lin, 2004. Modelling and experiment of railway ballast vibrations. J. Sound Vibration, 270: 673-683.