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Effects of Particle Size Distribution in the Response of Model Granular Materials in Multi-ring Shear

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ABSTRACT: Rail track undergoes complex loading patterns under moving traffic conditions compared to roads due to its continued and discontinued multi-layered structure, including rail, sleepers, ballast layer, sub-ballast layer, and subgrade. Particle size distributions (PSDs) of ballast, subballast, and subgrade layers can be critical in cyclic plastic deformation of rail track under moving traffic on frequent track degradation of rail tracks, especially at bridge transition zones. Conventional test approaches: static shear and cyclic single-point load tests are however unable to replicate actual loading patterns of moving train. Multi-ring shear apparatus; a new type of torsional simple shear apparatus, which can reproduce moving traffic conditions, was used in this study to investigate influence of particle size distribution of rail track layers on cyclic plastic deformation. Three particle size distributions, using glass beads were examined under different loading patterns: cyclic single-point load, and cyclic moving wheel load to evaluate cyclic plastic deformation of rail track under different loading methods. The results of these tests suggest that particle size distributions of rail track structural layers have significant impacts on cyclic plastic deformation under moving train load. Further, the limitations in conventional test methods used in laboratories to estimate the plastic deformation of rail track materials lead to underestimate the plastic deformation of rail tracks.

1 INTRODUCTON

Appropriate understanding of track deterioration mechanisms under moving traffic conditions can optimise design, maintenance, and renewal works and subsequently total operating cost of each railway. Cumulative cyclic plastic deformation of engineered layers of rail tracks is one of key triggering factor of track deterioration. Conservative guidelines in designing both free tracks and bridge transition zones provides insignificant consideration on impacts of cumulative cyclic plastic deformation of engineered layers (Burrow et al., 2011; Dareeju et al., 2014). Particle size distribution (PSD), stress history, fabric, hysteresis, and confinement of ballast, subballast, and subgrade control the rate of cumulative cyclic plastic deformation of rail tracks (Chin et al., 2010; Fredlund et al., 2002). Plastic deformation of subgrade of rail track, especially under unsaturated conditions is governing factor to dominate soil water characteristics of subgrade, which is a function of particle size distribution (Fredlund et al., 2002; Yang et al., 2004). Impacts by particle size distribution on cyclic plastic deformation of soil are investigated mostly using conventional test methods such as cyclic triaxial and cyclic direct shear tests, which are unable to replicate actual stress-strain state of rail track engineered layers under moving train traffic.

This study therefore evaluates effects of particle size distributions of engineered layers of railway track under moving wheel load condition on their plastic deformation using multi-ring shear apparatus, which was proved its capability to replicate stress strain state under moving wheel load (Inam et al., 2012; Ishikawa et al., 2011).

2 TEST METHOD

As conventional laboratory test methods are unable to replicate actual stress-strain state under moving train traffic conditions, Ishikawa et al. (2011) developed a new type of torsional simple shear apparatus called multi-ring shear apparatus to replicate stress state of underneath layers of rail tracks and roads under moving wheel load, introducing shear component into soil specimen. This study used this multi-ring shear apparatus to evaluate effects of particle size distributions of rail track engineered layers under moving wheel load, using same stress states. Maximum axial stress was selected as 80kPa, while the maximum value of shear stress is 12.8kPa. To avoid influence of material fabric using different materials, only Grass beads, which are normally used as a type of transparent soils for geotechnical laboratory modelling with two different diameters as 5mm and 2.5mm, were chosen to estimate effects of PSD on plastic deformation under moving wheel load (Ezzein & Bathurst, 2011). Fig. 1 illustrates the sample geometry used in this study and stress-strain definition of soil specimen. Sample was prepared with 60mm width with 120mm inner diameter and 240 outer diameter, and 100mm height. Definitions of above terms of stress state of sample can be found in Ishikawa et al. (2011) and Inam et al. (2012).

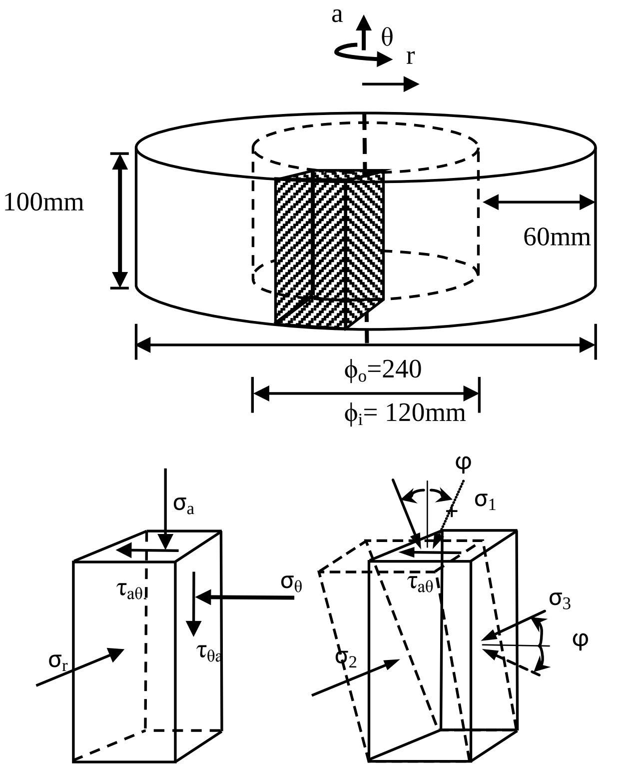

Fig. 1 Sample geometry and stress state of specimen

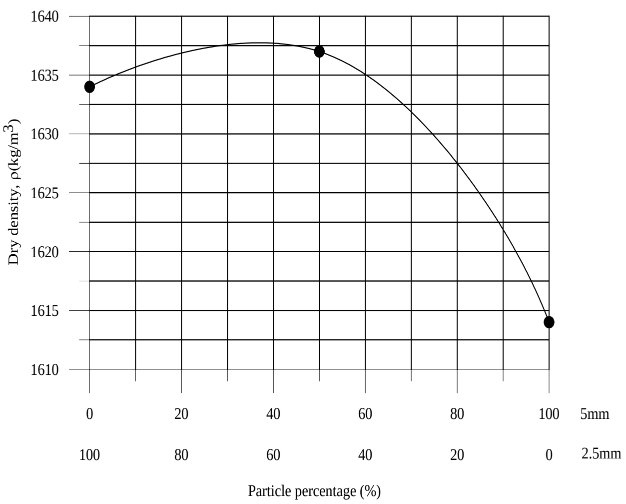

Fig. 2 Density variations of PSDs

Sample was prepared using three equal layers and initial density was achieved by one dimensional tamping, using a wooden rammer. Final densities shown in Fig. 2 were obtained by applying one-dimensional consolidation conditions under monotonic load. Initial void ratio of three particles size distributions are 0.438, 0.437, and 0.434 for 5mm only, 5mm and 2.5mm glass beads mixture, and 2.5mm only respectively. Three different PSDs were investigated, changing proportion of two particle sizes by using mass proportion as shown in Fig. 2.

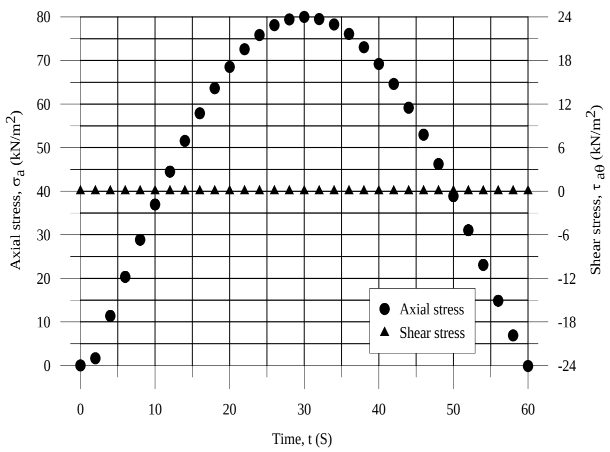

Fig. 3 Stress state for single point test

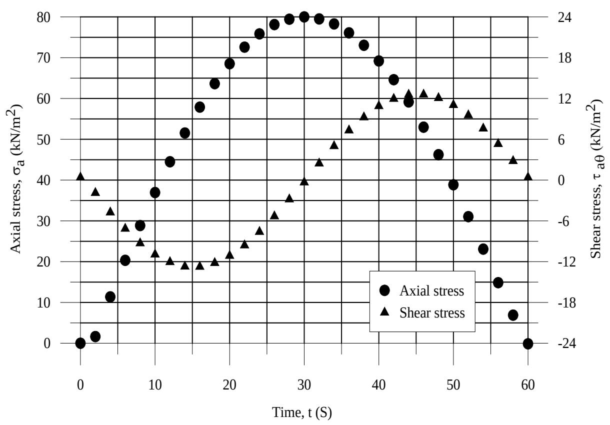

Fig. 4 Stress state for moving wheel test

To estimate cyclic plastic deformation characteristics under moving wheel load, two different tests; cyclic single point test and cyclic moving wheel test were performed. To replicate conventional triaxial compression test, cyclic single point test was performed, by changing only axial stress in a half sinusoidal waveform after consolidation step as in Fig. 3. Both axial stress in a half sinusoidal waveform and shear stress in a sinusoidal waveform were simultaneously varied into consolidated sample, by introducing two-way traffic conditions of moving wheel load as given in Fig. 4. More details of two way traffic used in this study are available in Ishikawa et al. (2011), and Inam et al. (2012). In both cyclic single point load tests and cyclic moving wheel tests for each particle size distribution, 200 cycles with 0.017Hz loading frequency were selected.

3 INFLUNCE OF FINE PARTICLES

Fig. 5 illustrates axial strain variations of three different PSDs; only 5mm glass beads, only 2.5mm glass beads, and 50%-50% glass beads mixture of 5mm and 2.5mm under cyclic single point load tests. Since coarse grain soil contains with higher porosity compared to fine grain soil, only with 5mm glass beads specimen has a higher degree of deformation than 2.5mm specimen as given in Fig. 5. Total axial strain increase by nearly 24% due to change in porosity of specimen from 2.5mm to 5mm. Cyclic plastic deformation of both samples however shows similar degradation rate pattern as illustrates in Fig. 5.

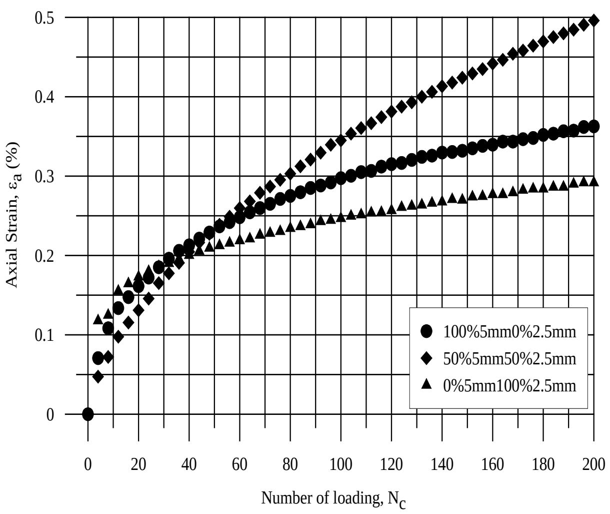

Fig. 5 Axial strain variations of cyclic single point tests

Presence of fine particles, especially in Ballast layer and subballast layer in rail track can introduce higher compaction at construction stage or higher deformation at operating stage. Influence of fine particles in rail track designing are however neglected under moving wheel load conditions (Dareeju et al., 2014). To estimate influence on fine particles therefore, 50% of 2.5mm glass beads were introduced for 5mm glass beads specimen, using mass portion. After introducing fine particles compared to 5mm glass beads, cyclic plastic deformation dramatically increases by nearly 39%. Deformation rate after introducing 2.5mm grass beads also diverts from other two variations as shown in Fig. 5. Within initial loading cycles up to 40, deformation rate of mixture has a lower rate than other two, which contain only 5mm and 2.5mm glass beads. After 40 cycles however, cyclic plastic deformation of mixture shows a higher rate compared to rest. Specimen with only 5mm glass beads and 2.5mm glass beads deformed rapidly, when loading cycles commenced due to higher void ratio. As specimen with glass beads mixture however contains a lower void ratio since fine particles fill the voids between coarse particles, cyclic plastic deformation of mixture is lower compared to other two different specimen types within first 40 cycles as shown in Fig. 5. Since cyclic axial loading however rearranges coarse particles with loading number, moving fine particles into these voids between coarse particles results a higher deformation in specimen with glass beads mixture with increasing cycle numbers.

4 INFLUNCE OF LOADING METHOD

Presence of principal stress axis rotation (PSR) in laboratory experiments can replicate stress state of engineered layers of rail track under moving wheel load. As conventional test methods used by conservative guidelines in designing both free tracks and bridge transition zones provide insignificant attention on moving wheel load effects on cyclic plastic deformation of rail track layers, moving wheel tests with different PSDs were performed to estimate influence of principal stress axis rotation of soil layers with different PSDs. Fig. 6 shows the variations axial strain with number of loading under moving wheel loading conditions.

After introducing cyclic shear component into specimen, while keeping same conditions used in cyclic single point test, axial strain of each PSD type significantly increases as shown in Fig. 6. Axial strain of PSD only with 5mm glass beads increases by nearly 28% and it is 176% in PSD only with 2.5mm glass beads than cyclic single point test after 200 cycles. Higher particle arranging rate by a combination of cyclic shear load and cyclic axial load is the key reason for such higher sample deformation under moving wheel load conditions. Absence of fine particles in specimen only with 5mm glass beads results a lesser plastic axial strain than specimen only with 2.5mm glass beads because there is no fine particles to fill voids generated by particle rearranging.

Presence of fine particles in rail track engineered layers creates critical impacts on the track deterioration process under moving wheel load conditions, where axial strain increases by 476% after introducing 50% of 2.5mm glass beads into 5mm glass beads mixture as shown in Fig. 6. Key reason for such higher deformation is moving fine particles into voids created by particle rearranging due to principal stress axis rotation of particles of specimen by cyclic moving wheel load.

There is a similar deformation rate pattern of PSDs with only 5mm and 2.5mm glass beads between both cyclic single point load test and cyclic moving wheel load test as illustrated in Figs. 5 and Fig. 6. Glass beads mixture with 50% of 5mm glass beads and 2.5mm glass beads has a higher deformation rate under moving wheel load compared to rest under cyclic moving wheel load and under cyclic single point load test.

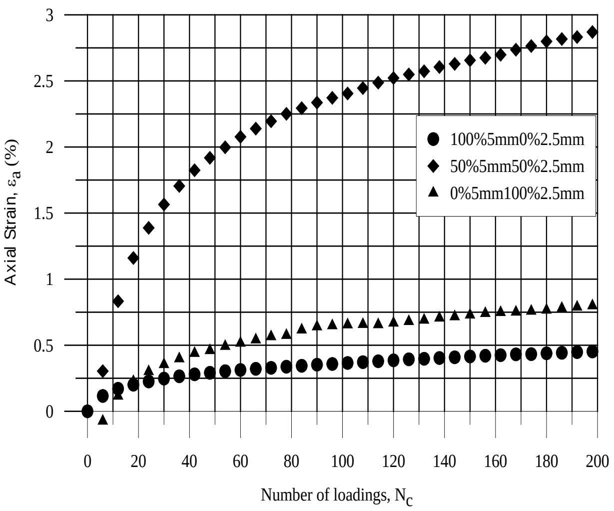

Fig. 6 Axial strain variations of cyclic moving wheel tests

CONCLUSION

Understanding of mechanisms behind track deterioration of rail track under real stress-strain state is important in designing long-term performing free tracks and track transition zones. This paper evaluates effects of particle size distribution of rail track engineered layers on track deterioration mechanism under moving wheel load. Based on experimental results and discussions, following conclusions are obtained:

1. Particle size distributions of rail track engineered layers critically influences on cyclic plastic deformation under both with and without principal stress axis rotation.
2. Presence of fine particles with coarse material introduces a higher deformation rate into rail tracks under both with and without principal stress axis rotation.
3. Cumulative cyclic plastic deformation of cyclic single point load test is much smaller compared to cyclic moving wheel load test.

All these critical findings lead to conclude that combination of presence of fine particles in engineered layers in rail tracks with moving wheel load conditions is one of key triggering factors on track deterioration process of free track and track transition zones. Effects of particle size distributions of such layers under moving wheel load conditions should be therefore addressed at designing, constructing, and operating stages to maintain long-term performing rail tracks.

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