Bespoke test rig to measure dynamic contact behaviour of railway ballast

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Abstract. Coarse granular materials, such as railway ballast are used to disseminate dynamic loads onto ground. Long-term performance of the ballast requires understanding of resistance at contact scale, which can then be used to calibrate contact models used in Discrete Element Modelling. Bespoke test rig was designed and built to test large granular particles using compressed air for application of dynamic loads in normal and tangential direction. Photogrammetry technique was used to capture the displacement of the ballast nearer to contact, which significantly improved the accuracy of displacement measurements. Repeated cyclic load tests on railway ballast of different mineralogies were carried to evaluate the differences in contact behaviour, both in the normal and lateral directions. Granite ballast exhibited very different contact behaviour in comparison to the limestone ballast.

Introduction

The behaviour of geotechnical structures made of coarse granular materials such as railway ballast is complex**.** Therefore, it is necessary to assess in detail the mechanical characteristics and cyclic loading behaviour of the grains**.** Discrete element modelling can simulate and characterise the stress distribution at contact points of granular materials, however it is very challenging to input/capture the deformation due to abrasion of granular materials. Research work of Harkness et al [1] produced evolving contact model called 'conical damage model' that could capture the behaviour of ballast under cyclic loading, however they pointed out the need for defining the load-displacement response/evolution and the contact area change with load cycles. Very few studies have been carried out towards measurement of the load-displacement response and evolution of contact area of granular materials [e.g.,2, 3], mainly because of accuracies in measuring load displacement relationship due to compliance issues arising from the load frame and fixtures to hold the granular materials in place. We have developed a bespoke device to measure dynamic contact behaviour of large granular materials such as railway ballast. This paper presents description of the new bespoke apparatus, its measurement system and application for use to measure dynamic contact behaviour of railway ballast.

Bespoke Particle Contact Apparatus

A purpose-designed apparatus was built at Southampton University's geomechanics lab (fig 1a). The apparatus consists of a solid steel frame, two compressed air actuators to control vertical and horizontal displacement/loads and a pair of jaws to hold the particles. Appropriate high sensitivity load cells within the load range to test large granular particles were mounted in between the actuator and the particle holders to measure horizontal and vertical loads. The vertical and horizontal displacements were also measured with linear variable displacement transformers (LVDTs). National instruments hardware and software was used to apply, control (PID feedback) and measure the load/displacement. Two specially modified cameras were adapted to measure the displacement of the particles (fig 1b). The grains were placed into robust steel jaws and centred within the holder to have a locally pointed surface and a at surface directed against each other (fig 1c). Coupons of specific spots (Fig 1d) were used to calibrate the images at point of the focus patch of the particle from pixels to displacement down to 100 nm resolution.

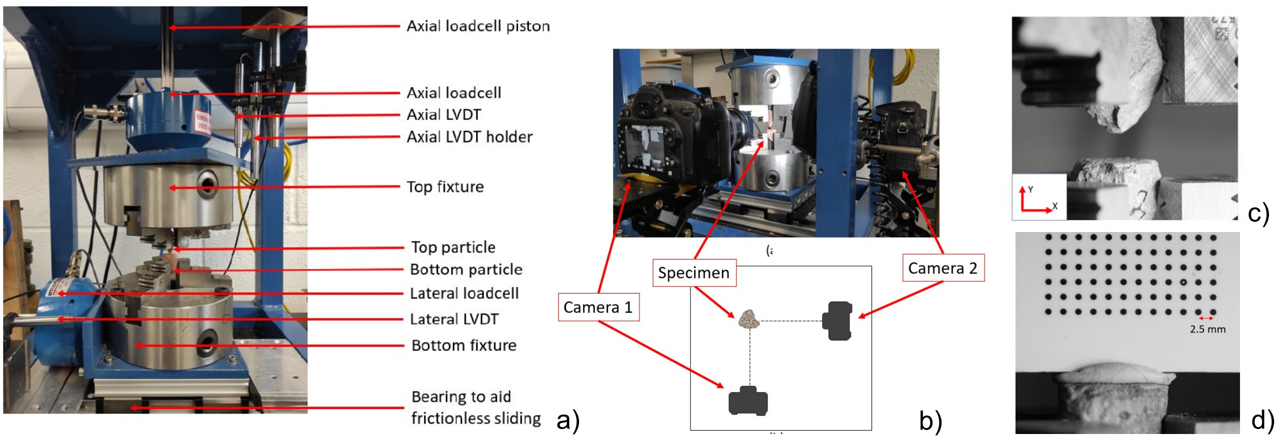

Fig. 1. a) Bespoke Particle Contact Apparatus. b) Photogrammetry to measure displacement using images of the particles. c) Particles before contact; and d) calibration of the displacement from images.

Methodology

Railway ballast particles of granite and limestone mineralogy of sizes ranging between 20 - 80 mm were selected and fixed to the particle holders using a torque wrench. The ballast particles were initially brought into contact by applying load of 10 N to ensure stable contact. Cyclic normal (vertical) loading tests were carried out on the ballast particles by applying appropriate load amplitude ranges at a frequency of 1 Hz, calculated from DEM simulations [1]. Four stages of cyclic normal load tests were carried out and after each stage static lateral load tests were carried out. The test results were analysed at selected load cycled to assess the evolution of particle contact normal and tangential stiffness. Variable focus microscope was used to measure the damaged contact area of the ballast after the contact tests.

Test results

Normal contact experiments: From the normal contact load tests, it was observed that the displacements provided by the cameras are lower than those provided by the LVDT and does not have the same load-displacement slope. Consequently, the normal contact stiffnesses derived from the camera data are higher than those obtained from the LVDT data analysis. In general, considering all tests, the normal contact stiffness tends to increase with increasing applied load and number of load cycles (figure 2a). Comparative results from the tests carried out on granite and limestone ballast shown in Table 1 indicates the normal stiffness is higher for the limestone ballast in comparison to granite ballast which is counter intuitive because the hardness of the granite is greater than that of the limestone. This is because the contact area (due to higher surface roughness) is larger for the limestone ballast in comparison with the granite ones.

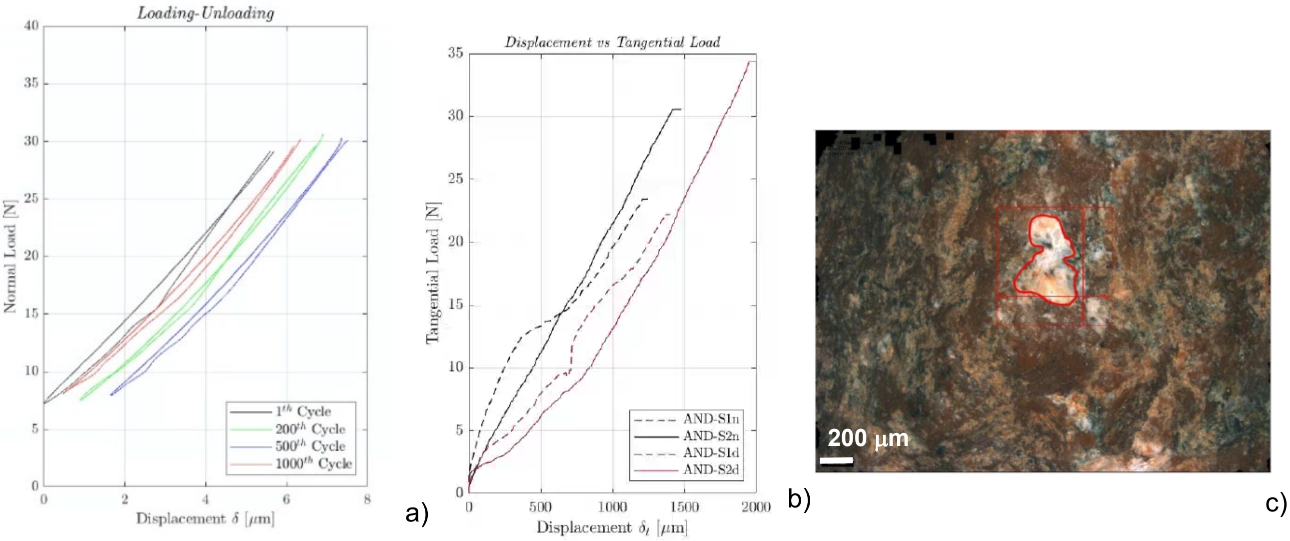

Fig. 2. a) Normal load vs displacement b) Tangential load vs displacement of granite ballast for different load cycles and c) microscopic scan of damaged surface of top granite ballast particle.

Tangential load experiments: From the tangential load tests, it was observed that initially the load displacement curve is affected by asperities on the surface of the particles, thereafter due to smoothening of the surface the curve becomes linear (figure 2b). This influences the interparticle friction of the particles at contact, where initially higher friction is measured, which reduces as the surface smoothens.

Microscope analysis: Figure 2c presents the contact surface area from the microscopic imaging. From the analysis of the images taken before and after tests, softer limestone appear stiffer, probably because they have a larger contact area and are therefore subject to less localised stress. In fact, it was found that for harder granite ballast, had lower surface roughness (contact area) than the softer limestone ballast. This behaviour is probably due to the fact that softer rocks tend to undergo greater degradation.

Table 1. Conclusive results

Ballast type	Normal stiffness, K_N	Initial Friction factor μ_f	Final Friction factor μ_f	Contact area	Contact roughness change, S_q (μm)
Granite	5.6 – 9.5 [N/μm]	0.42 – 0.48	0.30 – 0.34	<0.40 [mm2]	11.8 to 6.8
Limestone	7.3 – 10.9[N/μm]	0.38 – 0.42	0.40 – 0.50	<1.90 [mm2]	22.0 to 11.8

Conclusion

The bespoke contact test apparatus can provide new insights into load-displacement response/evolution and the contact area change of large granular materials. The test results along with microscopic analysis can be used to calibrate contact damage models for better understanding their long-term performance of ballast. The limestone ballast exhibits significantly different contact behaviour than granite ballast.

References

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