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The lateral displacement response of geogrid-reinforced ballast under cyclic loading

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ABSTRACT

Ballast being an unbounded granular medium spreads laterally when subjected to high-frequency cyclic loading. To reduce lateral movement of ballast and to optimize track performance, rail tracks can be reinforced with geogrid. In this study, a novel large-scale process simulation test (PST) apparatus that can capture the lateral strain variation upon loading is described. Laboratory tests were conducted to explore the deformation and degradation response of both unreinforced and reinforced ballast under high-frequency cyclic loading. Fresh Latite basalt having an average particle size (D_{50}) of 35 mm, and geogrids with different aperture sizes were tested. The laboratory experimental results reveal that the ballast deformation (both lateral and vertical) and the breakage during cyclic loading are influenced by the geogrid type and its placement location. Moreover, the lateral strain profiles along the ballast depth have been measured and the geogrid influence zone (GIZ), defined as the distance to which the effect of geogrid in arresting the lateral displacement of ballast exists, has been determined. The GIZ is found to vary from 160 mm (4.60D_{50}) to 225 mm (6.45D_{50}) depending on the location of the geogrid. In addition, the optimum geogrid position in the track has been identified to be 65 mm above the subballast. The test results also exemplify the ability of geogrid to arrest lateral displacement of ballast, reduce settlement and minimize particle degradation under high-frequency cyclic loading.

1. Introduction

Ballast is an important component of the rail track and it is responsible for maintaining track alignment, distributing the load to the subgrade, and providing track drainage. However, the large vertical train loads combined with relatively small horizontal confining stress lead to lateral flow of ballast under cyclic loading conditions (Baessler and Rucker, 2003). This lateral flow of particles can reduce the horizontal stresses that confine the ballast, hence reducing the track stability (Selig and Waters, 1994). It is well known that the settlement of a track is attributed to both particle degradation followed by recompaction, as well as the lateral spreading of ballast in the absence of sufficient track confinement parallel to the sleepers (Indraratna et al., 2005; Lackenby et al., 2007). In a typical track, lateral displacement of ballast and the associated particle breakage increase progressively with the increase in train speed and with the impact loads generated due to the wheel and rail irregularities thereby increasing the risk of track instability (Nimbalkar et al., 2012). To ensure the smooth functioning of tracks, railway organizations are compelled to carry out frequent maintenance operations that consume millions of dollars annually. For instance, the maintenance costs are estimated to be about 15 million dollars per annum in the state of NSW, Australia. Therefore, it is essential to restrain the lateral spreading of ballast to optimize the track performance and reduce the maintenance costs. To attain this, it is important to realistically simulate the behaviour that allows free lateral movement of ballast at relatively low confining pressure when subjected to cyclic loading.

The studies conducted in the past to examine the cyclic behaviour of ballast using large-scale model testing facilities had either immovable (rigid) or semi-confined boundaries that restricted the free lateral movement of ballast. This is not a major concern for loading frequencies in the range of 5–10 Hz (train speeds < 60 km/h) where the magnitude of lateral strains is small. Although the lateral deformations do occur at lower loading frequencies, Indraratna et al. (2010b) have reported that the extent of lateral deformations and the particle breakage increase significantly with the increase in the loading frequency. The breakage of latite basalt aggregate becomes considerable under high cyclic and impact loads. Recently, Indraratna and co-researchers have performed extensive research on the breakage of ballast under static,

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cyclic and the impact loading conditions, based on both laboratory and the field studies (e.g. Indraratna et al., 2005; Lackenby et al., 2007; Nimbalkar et al., 2012). The ballast in the studies conducted by Le Pen and Powrie (2011) was not constrained artificially. While the large-scale cubical triaxial apparatus (Indraratna et al., 2000; Fig. 1(a)) designed and built at the University of Wollongong (UOW) allowed lateral movement of ballast, it still did not permit a more realistic non-uniform lateral displacement with depth owing to the side plate that could move only as a rigid body in the horizontal direction. However, the lateral strains are not only a function of axle load and the loading frequency, but they also vary with depth. Therefore, the modification of the existing prismoidal triaxial equipment was necessary to capture a more realistic lateral displacement of ballast with depth under high-frequency loading. A key objective of this study is to evaluate the effect of confining pressure due to the crib and shoulder ballast, on the behaviour of load bearing ballast. Although conventional tracks have only the shoulder and crib ballast to provide a small confining pressure to the load bearing ballast, increased confining pressure through side restraints and special sleeper shapes have been trialled in Australia (Lackenby et al., 2007).

2. Modified process simulation test (PST) apparatus

2.1. Apparatus description

The apparatus proposed in the current study is a modification of the existing cubical triaxial apparatus designed and built at the University of Wollongong (Indraratna et al., 2000; Fig. 1(a)). It has plan dimensions of 800 × 600 mm and can accommodate samples measuring 650 mm in height. The modification involved the replacement of the central portion of the side wall of the existing prismoidal chamber with a setup of five independent movable plates each measuring 600 mm in width and 64 mm in height assembled along the depth (Fig. 1(b)). A small gap of 1 mm is provided between the adjacent plates to ensure free lateral movement of each individual plate under the applied loading. The gap between the plates is smaller than the smallest particle size of the ballast. While a greater number of moving plates would mimic the reality even better, it is infeasible to have plates of width less than 60–65 mm owing to the size of actuators needed to apply the confining stress on to these movable plates. Therefore, for a ballast depth of 300–350 mm, a maximum of five movable plates were considered to be sufficient. In a real track, subballast containing smaller particles compacted to a higher density than the overlying ballast does not indicate significant lateral movement. Moreover, the reduced intensity of vertical stresses at the subballast–ballast interface implies a subsequent reduction in the extent of lateral deformations in subballast. However, significant lateral movements do occur for soft subgrades that facilitate the lateral displacement of ballast. Also, the top 150 mm of the specimen should represent crib ballast that does not carry the load but confines the ties (sleepers). This crib ballast rarely undergoes significant lateral movement. In this context, the movable plates are required only at the central portion of the side wall where the load carrying ballast is subjected to lateral movement (Fig. 1(b)).

The lateral movement of plates is facilitated by means of linear bearings mounted on a steel guide rail. These bearings were placed at the ends of each plate, two on each plate, hence totally ten. The allowable lateral displacement is 45 mm, representing a maximum lateral strain of 5.63%. A desired lateral pressure representing the confining effect of shoulder ballast can be applied to each of the five movable plates by means of servo-controlled actuators (see Fig. 1(c)).

The shorter dimension of the PST apparatus (i.e. 600 mm) represents the centre-to-centre distance between the ties while the

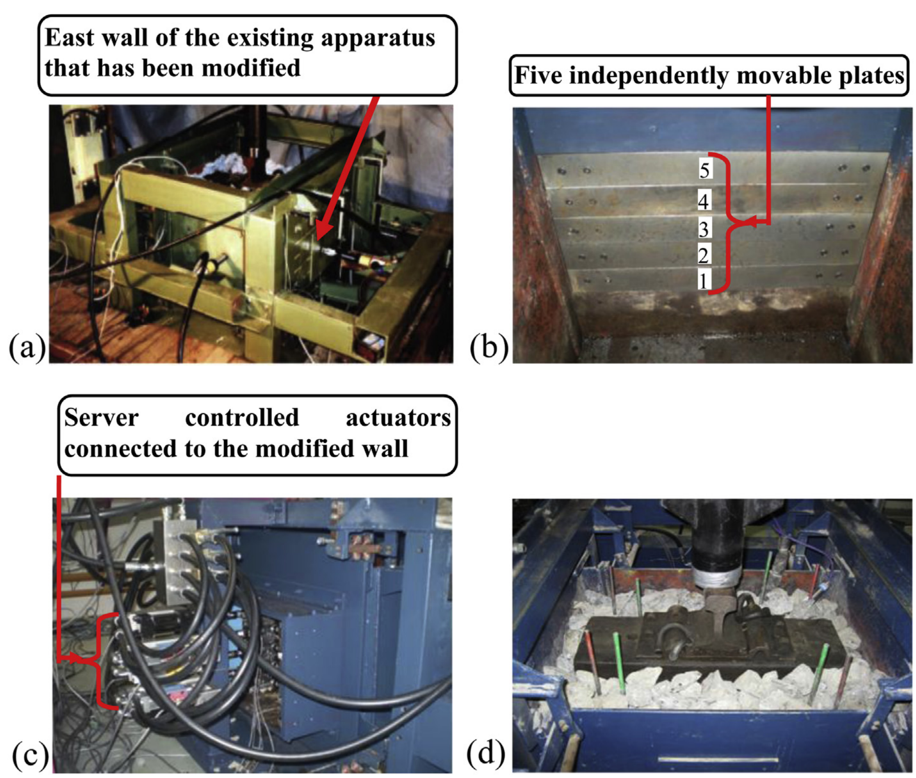

Fig. 1. (a) Photograph showing the side wall (East wall) of the apparatus that has been modified; (b) Internal view of the five-plate setup (numbered 1–5) of the modified PST apparatus; (c) Server controlled actuators used to apply the confining pressure on to the five movable plates; and (d) Plan view of the prepared ballast specimen ready for testing.