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Characterization of geogrid reinforced ballast behavior at different levels of degradation through triaxial shear strength test and discrete element modeling

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ABSTRACT

Recent research efforts at the University of Illinois have aimed at studying geogrid applications in railroad track structures, specifically focusing on ballast and subballast reinforcement. Ballast, typically comprising large sized aggregate particles with uniform gradation, is an essential layer in the railroad track substructure to facilitate load distribution and drainage. The primary mechanism of load transfer within the ballast layer involves inter-particle contact between ballast particles. Similarly, the effectiveness of ballast reinforcement with geogrids is primarily governed by the geogrid-aggregate interlock. Such interaction and the effectiveness thereof can change significantly as the level of grain size and shape degradation or fouling increases in the ballast layer with accumulation of train traffic. Although several studies in the past have investigated the effects of geogrid reinforcement on ballast shear strength and permanent deformation behavior, the effectiveness of geogrid reinforcement at different levels of ballast degradation needs to be further understood. In this study, monotonic triaxial shear strength tests were conducted on both new and degraded ballast materials with and without geogrid reinforcement. Two geogrid types, with square- and triangular-shaped apertures, were used in the laboratory to calibrate an aggregate imaging-based Discrete Element Method (DEM) modeling approach, which is capable of creating actual ballast aggregate particles as three-dimensional polyhedron blocks having the same particle size distributions and imaging quantified average shapes and angularities. The DEM model was observed to adequately capture the shear strength behavior of geogrid-reinforced triaxial ballast specimens prepared using both new and degraded ballast samples.

1. Introduction

Geogrids have been successfully used in railroad applications to construct railroad track over weak subgrades as well as reinforce ballast layer for improved lateral stability and reduced track settlement. For subgrade stabilization, the geogrids are often placed at the bottom of subballast and on top of the subgrade. Ballast reinforcement benefit of using geogrids is realized by limiting the lateral movement of aggregate particles. For this purpose, the geogrids are commonly installed at the ballast–subballast interface. The degree of interlocking to be maximized between geogrids and ballast particles is governed by several factors acting in combination, e.g., aggregate size and shape properties, geogrid types and properties (such as apertures, shapes and sizes of ribs, etc.), compactive effort during installation, and loading conditions.

The benefits of geogrid reinforcement have been highlighted by several laboratory research efforts, numerical simulations, as well as field implementation programs (Bathurst and Raymond, 1987; Raymond and Ismail, 2003; Indraratna et al., 2006; McDowell et al., 2006; Brown et al., 2007; Tutumluer et al., 2009; Qian et al., 2011, 2013a; Chen et al., 2012; Qian et al., 2013a,b; Mishra et al., 2014). These previous research studies have also identified subgrade conditions, number of geogrid layers, geogrid installation

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depth, presence of moisture, aggregate size to geogrid aperture size ratio, geogrid aperture shape, etc. to be important controlling factors as far as geogrid reinforcement of railroad ballast is concerned. However, most of the current findings reported in the literature primarily focus on the performances of relatively new track sections where clean ballast with not much degradation was used in the beginning of its service life.

With the accumulation of tonnage in the field, ballast layers are progressively “fouled” with finer materials filling the void space within the coarse particle matrix. Although subgrade intrusion as well as spillage of foreign materials such as coal dust can contribute to the fouling phenomenon, degradation of ballast particles has been reported to contribute up to 76% of the total ballast layer fouling (Selig and Waters, 1994). The gradual filling up of voids in a ballast matrix due to particle degradation has been schematically represented in Fig. 1. Note that gradual degradation of ballast particles leads to considerable changes in the aggregate size and shape properties as well as ballast packing. Moreover, increasing degrees of fouling has the potential to significantly affect geogrid-aggregate interlock mechanisms. Such effects of ballast degradation on ballast strength and aggregate-geogrid interlock have not been thoroughly studied.

This paper describes preliminary findings from an ongoing research study at the University of Illinois focusing on triaxial testing of geogrid-reinforced ballast specimens using a large-scale triaxial test device and modeling the micromechanical interactions of geogrid-aggregate systems using the Discrete Element Method (DEM). Cylindrical triaxial specimens were prepared using new as well as degraded ballast materials reinforced with geogrids having either triangular or square shaped apertures. Monotonic triaxial shear strength tests were conducted to evaluate the reinforcement benefits through improved stress-strain behavior and shear strength properties. Unreinforced ballast specimens were also tested to serve as the control sets during this study. To simulate the triaxial tests and investigate geogrid reinforcement mechanisms, a numerical modeling approach based on the DEM was adopted with the capability to create actual ballast aggregate particles as three-dimensional polyhedron elements having the same particle size distributions and imaging quantified average shapes and angularities. Both the laboratory triaxial strength tests and the DEM simulation results are presented in this paper to evaluate the reinforcement benefits and mechanisms governing behavior of the ballast specimens reinforced with different geogrid types.

Fig. 2. Triaxial shear strength test setup.

2. Triaxial test device

A large-scale triaxial test device (The University of Illinois Ballast Triaxial Tester or TX-24) was recently developed at the University of Illinois for testing ballast size aggregate materials (Mishra et al., 2013). The test specimen dimensions are 305 mm (12 in.) in diameter and 610 mm (24 in.) in height. An internal load cell (Honeywell Model 3174) with a capacity of 89 kN (20 kips) placed on top of the specimen top platen measures accurately the applied load levels. Three vertical Linear Variable Differential Transformers (LVDTs) are mounted on the cylindrical test specimen at 120-degree angles to measure the vertical deformations of the specimen from three different side locations. Another LVDT is mounted on a circumferential chain wrapped around the specimen at the mid-height to measure the radial deformation of the test specimen. Fig. 2 shows a photograph of the TX-24 setup having an instrumented ballast specimen ready for shear strength testing.

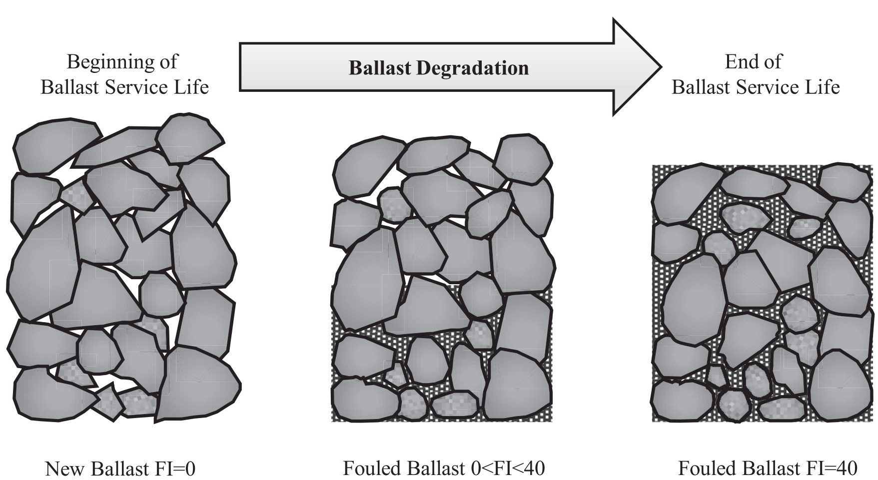

Fig. 1. Schematic drawing of ballast degradation (FI: Fouling Index).