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Repeated loading of soil containing granulated rubber and multiple geocell layers

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ABSTRACT

Sandy soil/aggregate, such as might be required in a pavement foundation over a soft area, was treated by the addition of one or more geocell layers and granulated rubber. It was then subjected to cyclic loading by a 300 mm diameter plate simulative of vehicle passes. After an initial study (that established both the optimum depth of the uppermost geocell layer and of the geocell inter-layer spacing should be 0.2 times plate diameter), repeated loading was applied to installations in which the number of geocell layers and the presence or absence of shredded rubber layers in the backfill was changed. The results of the testing reveal the ability of the composite geocell-rubber-soil systems to 'shakedown' to a fully resilient behavior after a period of plastic deformation except when there is little or no reinforcement and the applied repeated stresses are large. When shakedown response is observed, then both the accumulated plastic deformation prior to a steady-state response being obtained and the resilient deformations thereafter are reduced. Efficiency of reinforcement is shown to decrease with number of reinforcement layers for all applied stress levels and number of cycles of applied loading. The use of granulated rubber layers are shown to reduce the plastic deformations and to increase the resilient displacements compared to the comparable non-rubber construction. By optimal use of geocells and granulated rubber, deformations can be reduced by 60–70% compared with the unreinforced case while stresses in the foundation soil are spread much more effectively. On the basis of the study, the concept of combining several geocell layers with shredded rubber reinforcement is recommended for larger scale trials and for economic study.

1. Introduction

Geosynthetic-reinforced soil offers economy, ease of installation, performance and reliability in many areas of geotechnical engineering e.g. construction of footings over soft soil, stable embankments, slope and earth stabilization, road construction layers, and pavement system (e.g. Hufenus et al., 2006; Dash et al., 2007; Bathurst et al., 2009; Madhavi Latha and Somwanshi, 2009; Zhang et al., 2010; Pokharel et al., 2010; Moghaddas Tafreshi and Dawson, 2012; Boushehrian et al., 2011; Lambert et al., 2011; Koerner, 2012. Yang et al., 2012; Thakur et al., 2012; Tavakoli Mehrjardi et al., 2012; Leshchinsky and Ling, 2013; Tanyu et al., 2013; Chen et al., 2013).

Boushehrian et al. (2011) investigated the cyclic behavior of three-dimensional (a grid-anchor reinforcement system) reinforced sand by conducting a series of field tests. They reported the benefit of the three-dimensional reinforced system over the conventional geomesh system in reducing the settlements of foundations rested on sand bed. Thakur et al. (2012) investigated the performance of single geocell-reinforced recycled asphalt pavement (RAP) bases, reporting that the geocell-reinforced RAP bases had much smaller permanent deformations and smaller vertical stresses than unreinforced base, at the interface between base and subgrade.

Overall, geosynthetic inclusions would be most effective if used in the zone significantly stressed by the loading surface (e.g. footing or tire wheel) – which may be over a depth of 1 or 2 width/diameters beneath the footing/tire wheel – i.e., over a depth of approximately 0.6–2 m for typical footing widths and over a depth of 0.3–0.6 m for typical tire wheel widths. Since, the heights of commercially produced geocells are usually standard and manufacturers of geocell produce them at heights less than 200 mm (available cell depths produced by two key manufacturers in Europe and the USA), using a 0.6–2 m single thick layer of geocell beneath the footing and tire wheel is not possible for field

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construction. Even if it were, such a thick geocell layer would likely make compaction of cell-fill extremely difficult (Thakur et al. (2012) and as has been demonstrated by the authors' observation and the result of tests not reported here), consequently decreasing the performance of a thick single layer of geocell. Hence, if such a thickness of soil were to be reinforced by geocells, it would require, say, 3 or 4 layers with thickness ≤200 mm.

In the last decades, the volume of used tire rubbers in the world have been significantly increased due to the developing industry and growing population (WRAP, 2007; RMA, 2007; RRI, 2009) and their disposals have, therefore, become a major environmental problem worldwide. Large numbers of scrap tires are either dumped in landfills or stockpiled across the landscape in huge volume (Cetin et al., 2012; Chiu, 2008). It makes them harder and more expensive to dispose of safely without threatening human health and environment. For instance, stockpiled waste tires are flammable, prone to fires with toxic fumes and may then cause a major health hazard for both human beings and animals (Attom, 2006).

Hence, to consider the environmental concerns and a greater willingness, the use of waste tires in the form of strips, chips, and granules, are now considered as construction materials (Tanchaisawat et al., 2010; Lovisa et al., 2010; Tavakoli Mehrjardi et al., 2012; Moghaddas Tafreshi et al., 2012; Edincliler and Cagatay, 2013). When the chipped, shredded and granulated tire rubbers are mixed with soil (or the strips of tire used as reinforcement), the mixture can behave as a composite material. It becomes a form of reinforced soil, similar to geosynthetic-reinforced soil, that can be advantageously employed to increase soil strength (Yoon et al., 2008; Tavakoli Mehrjardi et al., 2012). The cyclic load response of rubber-soil mixtures (e.g. as identified by Bosscher et al., 1997; Feng and Sutter, 2000; Edincliler et al., 2004; Prasad and Prasada Raju, 2009) has shown the material's potential as a composite material, particularly in applications in roads, highways, and embankments. Bosscher et al. (1997) used tire-chips in soil to form a laboratory model embankment which was then subjected to simulated, repeated traffic loads. Less surface plastic displacement was reported when the tire-chips were covered by a relatively thick soil-only layer than when the tire-chips were placed in the whole of the fill. The soil cap over the tire-chips not only reduces the on-going settlement, but also prevents tire shreds from possible ignition.

On the basis of this review, the present authors considered that there could be potential for combining these two techniques (combining the layers of geocell with rubber-soil mixture layers) to improve the strength and to reduce the deformation within pavement foundations and, specifically, weak locations in these layers (e.g. trench reinstatements).

However, the economic evaluation of a complex rubber-soil mixture together with multiple geocell layers would be an essential consideration of any practical project. So far this has not been investigated in any recent research and, regrettably, space doesn't allow this aspect to be investigated here. In Europe at least, the ban on land-filling of old tires makes, in principle, economic sense of the beneficial reuse of rubber and the economic incentive to provide safe, post-consumer uses of rubber may be sufficient to partially finance the geocell reinforcement. This possibility should be studied further. With the evident benefit of using multiple geotextile or geogrid layers (e.g. Sitharam and Sireesh, 2005), the use of multiple geocell layers could be effective. Although it might be anticipated that more geocell layers in a foundation bed reduce the deformations, but there is much detail of the use of multiple geocell layers with and without rubber-soil combinations under repeatedly applied loads which has not been investigated by researchers. Consequently, this paper seeks to address the concept of the reinforcing benefit of the added rubber in association with the geocell layers which would have application, potentially, to pavement foundation (or machine support) systems.

2. Objectives

The overall goal was to demonstrate the benefits of introducing multi-layered geocell and combining this with rubber reinforcement to address weak spots in pavement foundations (e.g. at trench reinstatements). Cyclic loading conditions were selected as these are of particular concern for pavement (or machine foundation) problems where localized soil reinforcement might be appropriate. Thus a total of 21 independent cyclic plate load tests (plus 13 repeated tests) of a pavement foundation supported on unreinforced soil or soil reinforced with geocell and rubber were performed in a test pit measuring 2000 × 2000 mm in plane and 700 mm in depth using a 300 mm diameter rigid steel plate. Testing was arranged so as to determine the parameters controlling best usage. The specific aims were to study (The numbers in parentheses indicated the relevant results section):

- the optimal depth of the top geocell layer (6.1),
- the optimal vertical spacing between successive layers of geocell (6.2),
- the effects of the number of geocell layers on residual and resilient settlements (6.3.1 and 6.3.2),
- the effects of the geocell layers on the stress profile with depth (6.3.3), and
- the additional effect of the rubber-soil mixture layers on the residual and resilient settlements (6.4.1 and 6.4.2) and on the stress profile (6.4.3).

3. Test materials

3.1. Soil materials

The backfill soil selected for the testing program was sourced from a local quarry and satisfies the criteria and limitations recommended in ASTM D 2940-09. It was a sandy soil passing through the 38 mm sieve (see Fig. 1) with a specific gravity, G_s, of 2.65. According to the Unified Soil Classification System (ASTM D 2487-

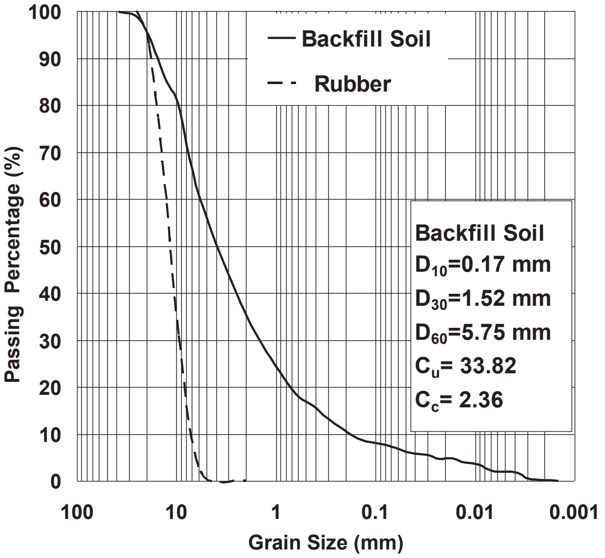

Fig. 1. Particle size distribution curves for backfill soil and granulated rubber (determined according to ASTM D422-07).