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Technical note

Evaluation of tensile load-strain characteristics of geogrids through in-soil tensile tests

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ABSTRACT

This paper evaluates in-soil tensile load-strain characteristics of geogrids with the help of a custom designed and developed in-soil tensile setup in the laboratory. Displacement controlled in-soil tensile tests were carried out to evaluate the effect of normal stress, soil type, and presence of sand-sandwiched layer, on the tensile load-strain characteristics of geogrid. Confinement of geogrid within the soil and application of normal stress were found to increase the mobilized tensile load and secant tensile stiffness of geogrid. Secant stiffness improvement factors were determined to quantify the improvement in tensile load-strain characteristics of geogrid under confinement, on comparison to in-isolation values. Geogrid was observed to exhibit lower secant tensile stiffness when embedded in marginal soil, moist-compacted at wet of optimum. However, the concept of sand-sandwiched geogrid was found to improve the tensile load-strain behaviour of geogrids embedded in marginal soil compacted at wet of optimum.

1. Introduction

Proper assessment of soil-geogrid interaction within the reinforced zone is important for design of geogrid reinforced soil walls. The deformation behaviour of geogrid reinforced soil walls depends on adequate direct sliding resistance along soil-geogrid interface, pullout resistance along soil-geogrid interface, and tensile resistance of geogrid layers. The schematic cross-section of a typical geogrid reinforced soil wall at the onset of failure is shown in Fig. 1. The internal stability of the geogrid reinforced soil wall is affected due to attenuation of failure of geogrid layers under tension, and lead to excessive deformations or wall failure. The failure surface is observed to pass through toe of the geogrid reinforced soil wall (Fig. 1). It is marked by well-defined shear plane that passes through rupture points of geogrid layers along the height of wall.

Consider an element 'A' within the reinforced zone of geogrid reinforced soil wall (Fig. 1). It can be observed that the tensile strain is developed over a very narrow distance along geogrid length within soil, leading to tensile or rupture failure of geogrid layers. Field studies (Christopher and Holtz, 1985) and centrifuge model tests (Porbaha and Goodings, 1996; Zornberg et al., 1998a; Viswanadham and Mahajan, 2007) have indicated the development of strain over a narrow distance in geosynthetic reinforcement layers. Rupture of all geotextile reinforcement layers along the height of reinforced soil-slope was reported by Zornberg et al. (1998a) and Viswanadham and Mahajan (2007). Tears in geotextile layers occurred in direction perpendicular to the loading, which is reflective of straining occurring over a narrow distance. Geotextile layers that are stiffer (Zornberg et al., 1998a) or extensible in nature (Viswanadham and Mahajan, 2007) undergo excessive straining before failure. In such cases, post-investigations have revealed that the measured peak strain is located within the localized band of straining in geotextile layers. These observations indicate that the tensile load-strain characteristics of geosynthetic reinforcement layers are influenced by soil confinement and straining occurs over a narrow distance of 1.5–6 mm (Porbaha and Goodings, 1996; Zornberg et al., 1998a). However, tensile load-strain characteristics of geogrids are generally determined by performing wide-width tensile tests as per ASTM D6637 (2015), wherein gauge length of 100 mm is fastened between the end grips and is not representative of field conditions. Therefore, tensile load-strain characteristics of geogrids have to be tested under in-soil conditions, in order to predict deformations of geogrid reinforced soil walls.

Christopher and Holtz (1985) proposed non-standard zero-span tensile tests on geosynthetic reinforcement, by maintaining a

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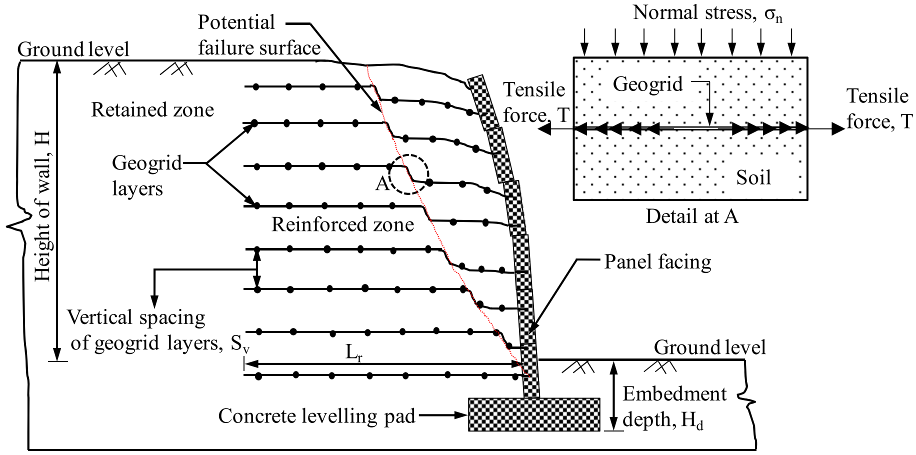

Fig. 1. Schematic cross-section of a typical geogrid reinforced soil wall at the onset of failure.

smaller gauge length between the grips. Wu (1991) discussed the details of an 'element test' to determine the load-extension properties of geotextile. Tensile load values determined from zero-span tensile tests of geotextiles were used by Porbaha and Goodings (1996) in stability analyses to successfully predict the behaviour of geotextile reinforced soil slopes, tested in a centrifuge. The values of tensile strength of geotextiles, obtained from non-standard zero-span tensile tests, were found to be roughly twice the value obtained from standard wide-width tensile tests and were assumed to act tangentially to the failure surface. Breakage patterns of exhumed geotextile layers at end of centrifuge model tests (Zornberg et al., 1998a,1998b; Viswanadham and Mahajan, 2007) were observed to resemble that of zero-span tensile test specimens. Zornberg et al. (1998b) and Viswanadham and Mahajan (2007) also reported the effect of confinement on back-calculated tensile-strength values of geotextile layers from centrifuge model tests. But the back-calculated values from centrifuge model tests were found to be lower than zero-span tensile strength values (Zornberg et al., 1998b). Therefore, tensile load-strain characteristics of geosynthetics should be evaluated under in-soil conditions and not under in-isolation conditions, to simulate typical confining conditions in field and also to capture the effect of soil-geosynthetic interaction.

Kokkalis and Papacharisis (1989) performed confined tensile tests on geotextiles using a modified direct shear apparatus. The elastic modulus and ultimate strength of geotextiles were found to increase with confinement. Increase in modulus of elasticity with confinement was more pronounced for needle-punched geotextiles. Juran and Christopher (1989) conducted load-controlled 'confined' and 'unconfined' extension tests on woven polyester strips, non-woven geotextiles and plastic grids. Confinement effect was found to be significant for non-woven geotextiles. Maximum tensile forces in reinforcements from experimental results of model reinforced soil walls were found to correspond fairly with confined reinforcement properties. The need for determining in-soil confined material properties and relevant soil-reinforcement interaction parameters for estimating estimate tension forces in reinforcements and wall displacements accurately was emphasized. Wu and Tatsuoka (1992) reported that the confined tensile properties of geosynthetics were attributed to the coupled response of confined stiffness and frictional resistance at the soil-geosynthetic interface. Ling et al. (1992) obtained higher stiffness and strength for spun-bonded and needle-punched geotextiles under confinement compared to heat-bonded geotextiles. Wilson-Fahmy et al. (1993) observed effect of confinement on needle-punched and heat-bonded non-woven geotextiles. McGown et al. (1995) discussed about 'static interlock' concept, wherein soil particles smaller than geogrid openings penetrate into the grid openings. This interlock mechanism resulted in improved interaction between the soil and geogrid and also contributed towards increase in confinement effect. Boyle et al. (1996) reported that the confined stiffness values of non-woven needle punched geotextiles were approximately four times larger than the in-isolation stiffness values. Zornberg et al. (1998b) attributed the improvement in mechanical properties of geotextiles under soil-confinement to the constrained deformations. Won and Kim (2007) reported that the local strain of non-woven geotextile measured under confinement was approximately half of the local strain measured under in-isolation conditions. Mendes et al. (2007) reported a reduction in mechanical damage of geotextiles, tested under confinement. Confined tensile stiffness of geotextiles was observed to higher at low values of strain and at higher values of normal stress. The relative dimensions of soil particles and geotextile pores were found to influence the tensile behaviour of the geotextiles under confinement.

The effect of confinement of soil on tensile load behaviour was found to be more pronounced for non-woven geotextiles, followed by that of woven geotextiles and geogrids. But the present level of knowledge on the effect of confinement of soil on tensile load-strain characteristics of geogrids is inadequate. Hence, the motivation behind the study is to perform in-soil tensile tests to evaluate tensile load-strain characteristics of geogrids under confinement. A custom-designed and developed in-soil tensile test set-up was used to perform in-soil tensile tests on geogrids to determine its tensile load-strain characteristics in the laboratory. Granular fill material possessing higher sand fraction mobilizes high tensile resistance due to better soil-geogrid interaction, but fill materials possessing high-fines or high-plasticity index (i.e. marginal soils), exhibit lower interfacial shear strength with presence of water (Zornberg and Mitchell, 1994; Mitchell and Zornberg, 1995). In addition to effect of normal stress, the nature of confining material (i.e. overlying soil) can influence the mechanical properties (tensile stiffness and soil-geogrid interaction) of geogrid. Therefore, in-soil tensile tests are conducted on geogrids confined in soil having different percentage of fines. Thuo et al. (2015) reported effective pore water pressure dissipation and enhanced local stability in unsaturated clay slopes on sandwiching nonwoven geotextile drains in thin layers of sand. In the present study, the effect of sand-sandwiched layer on tensile load-strain characteristics of geogrid, embedded in marginal soil, is evaluated. The

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