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Experimental and numerical studies on protection of buried pipelines and underground utilities using geocells

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ABSTRACT

This paper presents the results of the laboratory model tests and the numerical studies conducted on small diameter PVC pipes, buried in geocell reinforced sand beds. The aim of the study was to evaluate the suitability of the geocell reinforcement in protecting the underground utilities and buried pipelines. In addition to geocells, the efficacy of only geogrid and geocell with additional basal geogrid cases were also studied. A PVC (Poly Vinyl Chloride) pipe with external diameter 75 mm and thickness 1.4 mm was used in the experiments. The vehicle tire contact pressure was simulated by applying the pressure on the top of the bed with the help of a steel plate. Results suggest that the use of geocells with additional basal geogrid considerably reduces the deformation of the pipe as compared to other types of reinforcements. Further, the depth of placement of pipe was also varied between 1*B* to 2*B* (*B* is the width of loading plate) below the plate in the presence of geocell with additional basal geogrid. More than 50% reduction in the pressure and more than 40% reduction in the strain values were observed in the presence of reinforcements at different depths as compared to the unreinforced beds. Conversely, the performance of the subgrade soil was also found to be marginally influenced by the position of the pipe, even in the presence of the relatively stiff reinforcement system. Further, experimental results were validated with 3-dimensional numerical studies using FLAC^{3D} (Fast Lagrangian Analysis of Continua in 3D). A good agreement in the measured pipe stain values were observed between the experimental and numerical studies. Numerical studies revealed that the geocells distribute the stresses in the lateral direction and thus reduce the pressure on the pipe. In addition, the results of the 1-g model tests were scaled up to the prototype case of the shallow buried pipeline below the pavement using the appropriate scaling laws.

1. Introduction

Underground conduits or utility pipelines form a complex network in the urban areas and are often laid below the pavements and the temporary structures. Often, these conduits or pipelines are buried at shallow depths in trenches with the help of flowable fills. These pipes tend to deform and damage due to application of repeated traffic loads or heavy static loads from the vehicles. The damage leads to the discomfort of the consumers of the utility and also to the travelers on the road. In this research, it is proposed to design a shallow reinforcement system using geocells to bridge these utility lines. Many researchers in the past have studied the design and installation aspects of the buried pipes through small and large scale tests (Brachman et al., 2000; Mir Mohammad Hosseini and Moghaddas Tafreshi, 2002; Arockiasamy et al., 2006; Srivastava et al., 2012).

Nowadays, reinforcing the soil in the form of geosynthetic reinforcement is gaining popularity in geotechnical engineering. These reinforcements increase the overall performance of the foundation bed by increasing the load carrying capacity and reducing the settlement. Many researchers have studied the beneficial effect of the geosynthetic reinforcements in various geotechnical applications (Indraratna et al., 2010; Rowe and Taechakumthorn, 2011; Demir et al., 2013; Bai et al., 2013; Almeida et al., 2014 etc.). However, the use of geosynthetic reinforcement to protect buried pipes and underground utilities is relatively a new concept. Moghaddas Tafreshi and Khalaj (2008) conducted the laboratory studies on small diameter HDPE pipes buried in the geogrid reinforced sand subjected to repeated load. Researchers observed the significant reduction in the deformation of the pipe in the presence of geogrids. Palmeira and Andrade

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(2010) used the combination of geotextile and geogrid to protect the buried pipelines in their model studies. Researchers observed that the reinforcement offers significant resistance to sharp, penetrating object and helps to protect the buried pipes from the accidental damages.

In recent times, geocells are showing its efficacy in geotechnical engineering applications. Geocells are 3-dimensional expandable panels made up of ultrasonically welded high strength polymers or the polymeric alloy such as Polyethylene, Polyolefin etc. The interconnected cells in the geocell form a slab that behaves like a large pad that spreads the applied load over a wider area. Many researchers in the past have highlighted the advantages of using the geocells in geotechnical engineering applications (Moghaddas Tafreshi and Dawson, 2010; Pokharel et al., 2010; Lambert et al., 2011; Yang et al., 2012; Thakur et al., 2012; Sitharam and Hegde, 2013; Mehdipour et al., 2013; Hegde and Sitharam, 2014a, b; Moghaddas Tafreshi et al., 2014; Hegde et al., 2014; Indraratna et al., 2014). Tavakoli et al. (2013) highlighted the beneficial use of geocells in protecting the buried pipelines in their studies. Researchers emphasized the importance of selection of the suitable compaction technique to compact the backfill soil above and below the geocells. Tavakoli et al. (2012) used the combination of geocell reinforcement and rubber soil mixture to protect buried pipes. It was observed that the combination of geocell reinforcement and 5% rubber mixed soil (irrespective of the size or type of the rubber) provides the best performance in terms of reduction in the pipe deformation and backfill settlement.

In this paper, a rather simple technique was used. Contrary to the previous studies, the combination of geocell and geogrid was used to protect the underground utilities and buried pipelines. The first part of the manuscript deals with the 1-g model plate load tests while the second part of the manuscript demonstrates the 3-dimensional numerical modeling of the problem.

2. Laboratory tests

2.1. Experimental setup

The experiments were conducted in the test tank of size 900 mm in length, 900 mm in width and 600 mm in height, made up of cast iron. The tank was fitted to the loading frame which was connected to manually operated hydraulic jack. The vehicle tire contact pressure was simulated by applying the pressure on the top of the bed with the help of a steel plate. A square shaped steel plate with 20 mm thickness and 150 mm sides was used for the purpose. The load was applied through a hand operated hydraulic jack. A pre-calibrated proving ring was used to measure the imposed load. To avoid the eccentric application of the load, the ball bearing arrangement was used. Two dial gauges (D_1 and D_2) were placed on the either side of the centerline of the steel plate to record the settlement of the plate. Another set of dial gauges (S_1 and S_2) was placed at the distance of 1.5B (B is the width of the steel plate) from the centerline of the plate to measure the deformation underwent by the fill surface. Schematic representation of test setup is shown in Fig. 1.

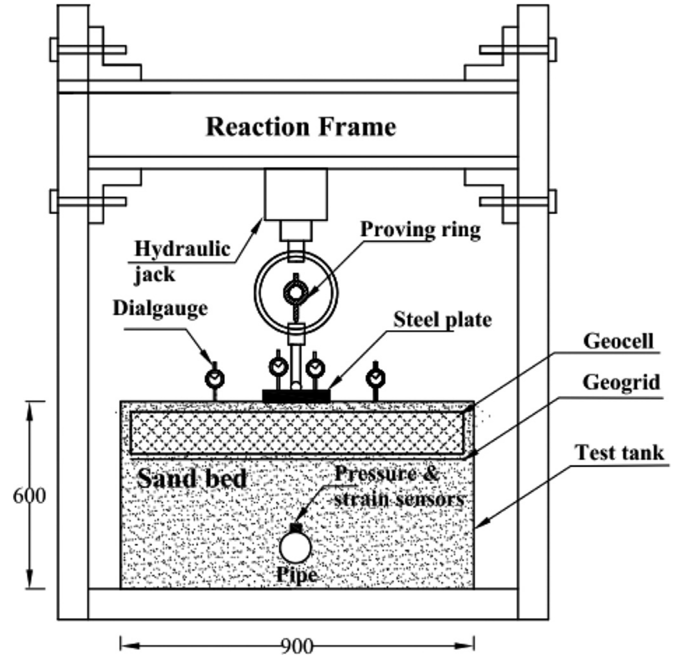

Fig. 1. Schematic view of the test setup.

2.2. Materials used

Sand used in the investigation was dry sand with specific gravity 2.64, effective particle size (D_{10}) 0.26 mm, coefficient of uniformity (C_u) 3.08, coefficient of curvature (C_c) 1.05, maximum void ratio (e_{max}) 0.81 and minimum void ratio (e_{min}) of 0.51. According Unified Soil Classification System (USCS) the sand was classified as poorly graded sand with symbol SP. Fig. 2 represents the grain size distribution of sand. The geocell used in the study was made of Neoloy.

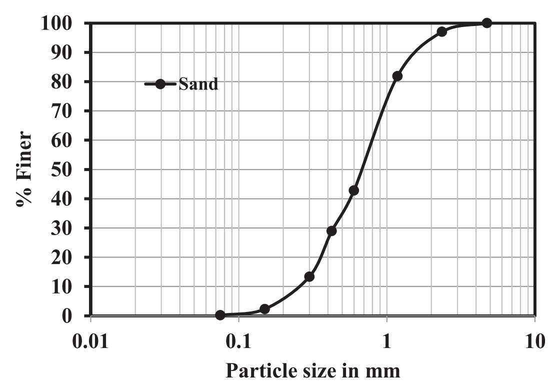

Fig. 2. Grain size distribution curve of sand.

Biaxial geogrid made up of Polypropylene with aperture size 35 mm × 35 mm was used. The properties of the geocell and the geogrid are summarized in Table 1. Pipe used in the study was made up of PVC (Polyvinyl Chloride) with external diameter 75 mm and

Table 1
Properties of the geocell and geogrid.

Parameters	Quantity
Geocell	
Material	Neoloy
Cell size (mm)	250 × 210
No. of cells/m^2	40
Cell depth (mm)	150
Strip thickness (mm)	1.53
Cell seam strength (N)	2150(±5%)
Density (g/cm^3)	0.95 (±1.5%)
Short term yield strength (kN/m)	20
Geogrid	
Polymer	Polypropylene
Aperture size (mm)	35 × 35
Ultimate tensile strength, (same in MD and XMD (kN/m))	20
Mass per unit area (g/m^2)	220
Shape of aperture opening	Square

MD-Machine direction; XMD-Cross machine direction.