Influence of Geocell Reinforcement on Damping Properties of Trench With Pipe

Gh. Tavakoli Mehrjardi & S.N. Moghaddas Tafreshi
K.N. Toosi University of Technology,Tehran, Iran

A.R. Dawson
University of Nottingham, UK, Nottingham, andrew.dawson@nottingham.ac.uk

SUMMARY:
During seismic loading, the change in the stress–strain properties of material induced by transmitting seismic forces may have a significant influence on the stability of lifelines. So, in the aftermath of vertical element of earthquake forces, a semi shock can cause the buried pipelines to damage, tending heavy loss of functionality with the consequence of interfering with the economic and social recovery in the areas involved in breakage and eventually illnesses and epidemics may emerge. So, in order to protect the buried pipe, using Geocell reinforced trench is investigated. This research aims to assess the damping ratio alteration by using Geocell reinforcement with different opening area and height placed on the buried pipe as a material to prevent transferring the applied repeated loading onto the pipe which can provide insight into its behaviour under seismic loads. It seems that the reinforced layer can attenuate the transferred energy produced by vertical cyclic loadings onto the buried pipe. So, by the proposed protection system, the pipe deflection and soil surface settlement can be reduced.

Keywords: Trench; Settlement; Pipe; Repeated loading; Damping ratio

1. INTRODUCTION

Geotechnical earthquake engineering explains different combination of loadings and unloadings which engineers need to consider in design of structures. A substantial part is vertical cyclic loading with different frequencies and amplitudes. For example, particular attention must be given to transmitting forces between horizontal seismic elements and vertical seismic elements. Also, heavy traffic loading may cause damage to water and sewer pipelines buried beneath roads. In the case of sewer systems, their failure is linked to potential problems of soil and water contamination, particularly when the water level is close to the ground surface or the water main is close to the sewer pipeline that failed.

In recent decades, due to engineers' desire to optimize geotechnical structures, planar and 3D reinforcement (geocell) are widely used, particularly in the form of geosynthetics. Their economy, ease of installation, performance and reliability have led to the use of reinforced soil in geotechnical engineering applications such as in the construction of roads, railway embankments, stabilization of slopes, and improvement of soft ground, etc. Some researchers have studied the behaviour of pipes in planar reinforced soil (e.g. Zhang et al., 2006; Sitharam et al., 2007; Moghaddas Tafreshi and Khalaj, 2008; Moghaddas Tafreshi and Tavakoli Mehrjardi, 2008). Also, Tavakoli mehrjardi et al. (2012) proposed an effective method, using combination of rubber-soil mixture and geocell reinforcement, to protect the trench and pipe system under heavy cyclic loadings.

In addition, the beneficial ability of cellular geosynthetic mattress constructions to improve the bearing capacity and settlement of footings was reported (Cowland and Wong, 1993; Krishnaswamy et al., 2000; Dash et al., 2004; Sitharam et al., 2005; Dash et al., 2007; Sitharam et al., 2007, Moghaddas Tafreshi and Dawson, 2010a; Moghaddas Tafreshi and Dawson, 2010b).

Nowadays, many buried pipes are made of thin, flexible walled material, such as uPVC, and are liable to deform when a trench backfill is loaded onto them. The reinforced layer beneath the footing is able to exhibit a higher capacity to absorb energy than soil alone so it is expected to reduce the energy applied on the pipe due to cyclic loading and is expected to decrease the transfer of stress and shocks to the pipes. Together, the ability to absorb stresses and impose less pressure would mean that the pipe could be set higher in the ground for the same stress level, thereby reducing excavation and backfilling compaction requirements for the trench. Conceivably, it is expected that the backfill settlement in the reinforced status can be reduced considerably.

2. RESEARCH OBJECTIVES

Use of geocell reinforcements in the trench above the pipe has the potential to limit deformation of the pipe and to prevent its premature cracking under load. This study aims to develop further an understanding of the influence of geocell reinforcement with different cell opening area and height on the buried pipes under repeated loads and also, particularly, to study the behaviour of the overall system. The specific aims are:

- To study the effects of geocell height and the opening area of the geocell on damping ratio of the system,
- To investigate the effect of repeated loading on the pipe and trench modulus,
- To assess the beneficial effects of geocell on stress reduction exerted on the buried flexible pipes

The study has been performed on three-dimensional full-scale installations and appears as a first study on the behaviour of pipelines buried under soil supported by geocell inclusions.

3. TEST MATERIALS

3.1. Soil

Two types of granular soil namely native soil and backfill soil are used (see Figure 2). The soil is classified as SW in unified soil classification system and the grading of both soils is presented graphically in Figure 1.

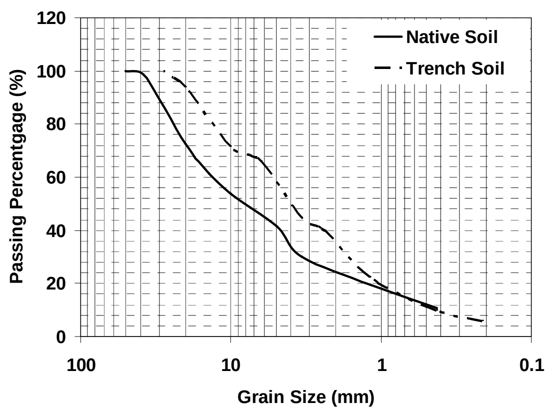

Figure 1. Grain size distribution curves for both native and backfill soils

3.2. Pipe

The tests were conducted on uPVC pipe that complies with BS 4660 for underground sewer and drainage services. The pipe has an outer diameter (D) of 160 mm and a wall thickness (t) of 4 mm and hence a Standard Dimension Ratio (SDR) = D/t =40. The tensile strength at 10% axial strain and the Poisson's ratio of the pipe were 22 MPa and 0.46, respectively.

3.2. Reinforcements

In this paper it is referred to a particular 3D geosynthetic formed from "concertina" expansion of polymeric geosynthetic strips that are fixed at discrete points to adjacent strips in a staggered fashion to form a honeycomb-like structure of cells. The characteristics of the geocell used in this study are tabulated in Table 1.

Table 1. The Engineering Properties of the Geocell

Description	Value (Size 1)	Value (Size 2)
Area weight (g/m2)	690	470
Tensile strength (kN/m)	21	13
Height (cm)	10	5
Pocket size (approx.) (cm)	11×11	5.5×5.5

4. TESTS AND RESULTS

A full-scale model was developed at University of Nottingham with plan dimensions of 100 cm ×110 cm (100 cm in width in X direction and 110 cm in length in Z direction, the longitudinal axis of the pipe) and a re-instatement trench (backfill soil) with plan dimensions (50 cm in width in X direction and 110 cm in length in Z direction, Figure 2). The base of the PTF is at about 100 cm depth, but only 48 cm of this was excavated to install the pipe and backfill (see Figure 2).

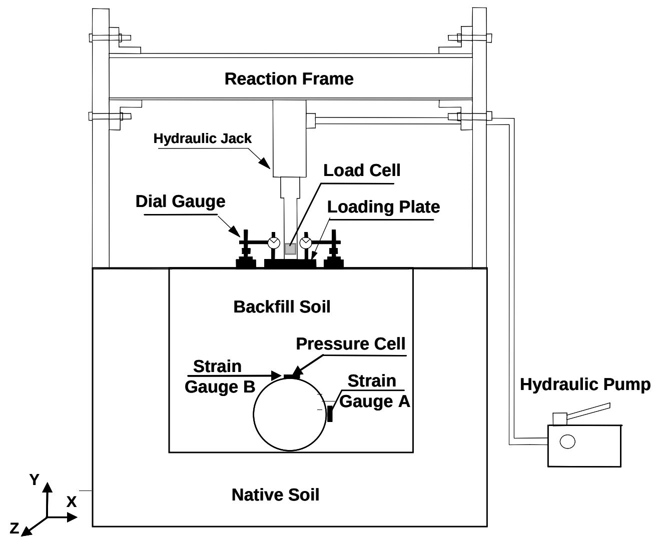

Figure 2. Schematic test model

Figure 3 depicts two photos related to the test installations. The backfill soil was compacted in three layers at 80, 200 and 320 mm from the crown of the pipe with 1, 1 and 3 passes of the vibrating compactor, respectively.

According to Table 2, in order to study the application of trench reinforcement by the geocell and its attenuating effect on buried pipe movements, a set of tests was arranged. The overall arrangement of those tests is depicted in Figure 2. According to Table 2, two different heights of geocell and two different geocell's opening areas were used.

Table 2. Testing Programme And Parameters

No	Reinforcement Style	H* (mm)	Opening Dimensions (mm)
14	No	0	0
15	geocell	100	100*100
16	geocell	100	50*50
17	geocell	50	100*100
18	geocell	50	50*50

*H: The Geocell height

With regards to the visual assessment of geocell deformation by the authors, the width of the reinforcement was chosen equal to the width of the trench (Moghaddas Tafreshi and Dawson, 2010a; Dash et al., 2008) (see Figure 2).

(b) (a)

Figure 3. Test installations (a) Geocell installation beneath the footing, and (b) Loading plated located in centreline of the trench

A hand operated hydraulic jack supported against a reaction frame applied loads on a circular plate of 15 cm diameter (as loading surface) located on the centre of the trench surface.

Loading, unloading and reloading were exerted on the loading surface. The maximum applied pressure was divided into four stages which are 200, 400, 600 and 800 kPa. For each stage, several loading and unloading cycles were applied until settlements reached a steady state condition, afterward the loading and unloading continued at the next level, and so on.

Figure 4 illustrates change of vertical pipe deflection under loadings and unloading conditions for all loading levels. In general, the pipe deflection was the maximum value in the unreinforced installation rather than other reinforced installations. It is thought that the benefit is because of reinforcement effect provided by the tensile and passive capacity of the geocell reinforcements. Also, with comparison between the obtained results, the reinforcements "3D (5-5-10)", "3D (10-10-10)" and "3D (10-10-5)" had the same role in pipe deflection reduction and the lowest value in pipe deflection. However "3D (5-5-5)" had the lowest capacity in attenuation of pipe deflection. It may be due to providing the least soil passive strength owing to having small packet size rather to other reinforcements. So, enthusiastically, the geocell-reinforced soil can be utilized to protect the underground structures such as buried pipelines and tunnels from cyclic loadings and attenuate the vulnerability of vertical element of earthquake forces.

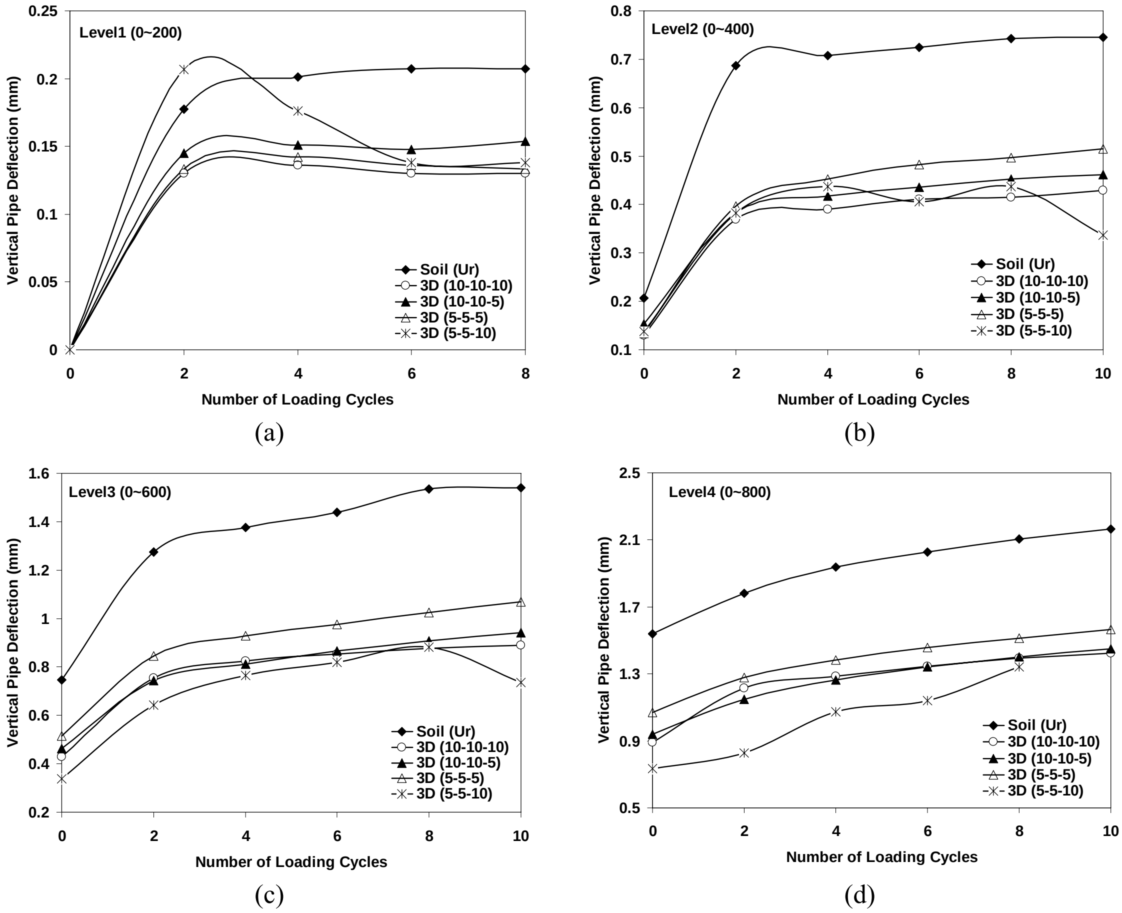

Figure 4. Change of circumferential strain of the pipe under loadings and unloading conditions for different loading levels (a) level 1 (0-200), (b) level 2 (200-400), (c) level 3 (400-600), and (d) level 4 (600-800)

Figure 5 proves a direct relation between the vertical pipe deflection and the pressure exerted on the pipe's crown at first cycle of each loading level. With regards to Figures 4 and 5, it is concluded that the pipe protected by geocell with dimension (5-5-10) has the least deflection due to the minimum exerted pressure on the pipe's crown. It means that the aforementioned geocell could reduce and damp the applied pressure into the trench backfill by using the beam effect under the loading plate. On the other hand, the unreinforced soil could not be able to reduce the applied pressure and cause more stress transferred and exerted onto the buried pipe.

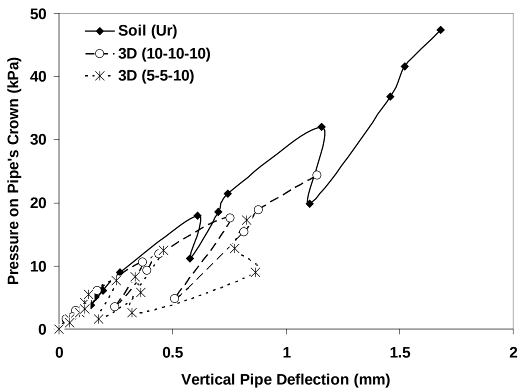

Figure 5. Soil pressure for improved geocell-reinforced and unreinforced installation

Figure 6 shows an idealized stress–strain loop for a sample subjected to symmetric cyclic loading, during the first cycle (Cowland and Wong, 1993). Points A and B define the tips of the loop. The backbone curve has its maximum slope (E_{max}) at the origin; this slope defines the maximum Young's modulus. The secant Young's modulus (E_c) is the slope of the line connecting the origin with the tip of the loop associated with the strain amplitude (ε_c).

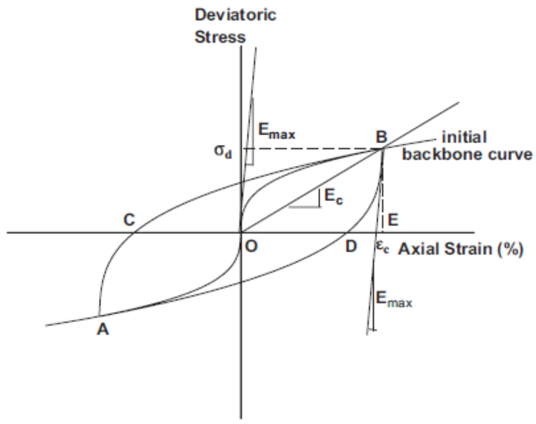

Figure 6. Schematic illustration of a symmetric stress–strain loop during the first cycle

The Ramberg–Osgood formulation was applied in this study to construct initial backbone curves (Richard and Abott, 1975). Hysteretic loops were constructed after the initial backbone function is defined by adopting the rules suggested by Masing et al., 1926. Reconstructing the stress-strain loop, as shown in Figure 6, has been done by programming in MATLAB version 7. Figure 7 shows a typical reconstructed stress- strain loop for the trench containing 3D (10-10-10) reinforcement and pipe.

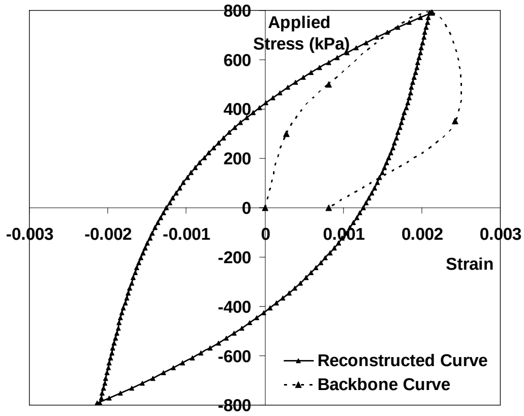

Figure 7. Reconstructed stress- strain loops for 3D (10-10-10)

According to Eqn. ١, the damping ratio, D can be calculated for all the tests.

$$D = \frac{1}{4}\frac{A_1}{\pi A_2} \quad (١)$$

Where A_1 is the area of the loop ACBDA and A_2 is the area of the triangle OBE, as shown in Figure 6. Figure 8 shows the damping ratios for all the tests at different loading levels. One of important parameter to study energy absorbs and damping the transferred stress, produced by any possible cyclic loadings such as vertical element of earthquake force and traffic loadings, is the pressure on the pipe's crown.

As Figure 5 shows, the pressure on the pipe for 3D (5-5-10) is less the either shown tests. So, According to Figure 8 in the applied stress 800 kPa, the damping ratio of three installations 3D (5-5-10), 3D (10-10-10) and soil only has a straightforward relation to the exerted pressure on pipe's crown.

Therefore the geocell reinforcements are able to exhibit a higher capacity to absorb energy than only soil so it would reduce the applied energy of cyclic loading and it tends to decrease transferring stress and shocks on the pipes.

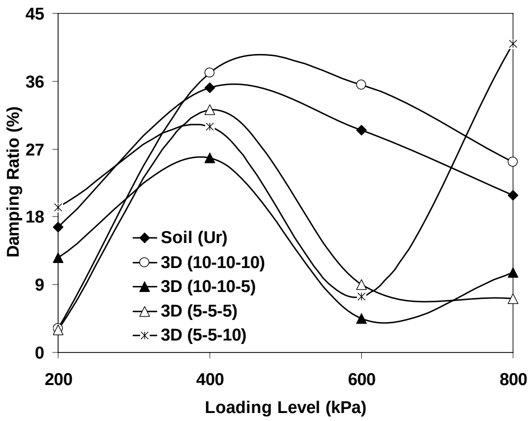

Figure 8. Damping ratios for all the tests at different loading levels.

4. CONCLUSIONS

During seismic loading, soil layers are subjected to cyclic shear stresses with different amplitudes and frequencies that will induce transient and permanent deformations. The structures located on and the infrastructures such as buried pipes, located in these layers, are going to be affected from these deformations and may be damaged. In addition, the change in the stress–strain-strength properties namely ‘‘dynamic properties’’ of soil layers during cyclic loading may have a significant influence on the stability of these lifelines. Therefore, it is necessary to take into account the changes in dynamic characteristics of natural soil layers to decrease the vulnerability (Okur and Ansal, 2007). The results prove that the geocell reinforced layer beneath the footing is able to exhibit a higher capacity to absorb energy, developed by the exerted vertical element of earthquake forces or traffic loadings, than soil alone so it is expected to reduce the energy applied on the pipe due to cyclic loading and is expected to decrease the transfer of stress and shocks to the pipes. Consequently, decrease of soil surface settlements and the pipe's deflection by 65 and 35 percent respectively is seen to be a consequence of the superior performance that is, thereby, developed. In the case of geocell reinforcement, the total reinforcing system, being an interconnected cage, appears to derive substantial anchorage from both sides of the loaded area due to the frictional and passive resistance developed at the soil-geocell interfaces. From visual observations of the deformation pattern, it seems that this action is similar to that of a beam or raft spreading the loading to remote positions. Apparently, the proposed protection system, using geocell-reinforced soil under footings or pavement surface and upper buried pipelines, is able to attenuate the failure vulnerability of lifelines under cyclic loading.

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