Investigation of impact behavior of HDPE pipes with geocell protective layer

G. Babagiray
Gazi University, Turkey (gunesaydin@gazi.edu.tr)

S. O. Akbas
Gazi University, Turkey (soakbas@gazi.edu.tr)

O. Anıl
Gazi University, Turkey (oanil@gazi.edu.tr)

ABSTRACT: A free-fall impact apparatus was used to examine the behavior of 160 mm diameter HDPE pipe systems with geocell-based protective layers, considering both the efficiency and the energy adsorption capacity under impact loading. The protective layers considered in this study are a granular soil layer of constant relative density, i.e., the reference case, and sand layers reinforced with a geocell layer with different sheet thicknesses and placement depths. In addition, the effect of the addition of a single layer of geotextile, geogrid, and geonet as an additional protection under the geocell was considered. The magnitudes of impact load as well as the resultant accelerations on the pipes were measured as a function of time during the experiments. Time histories of accelerations recorded in each test were used to calculate the displacements, which in turn led to the estimation of the level of energy absorbed by the protective layer systems. This enabled a fair comparison of the relative performance of each protective layer-pipe system under impact loading conditions. Thus, the results are indicative of the significance of the sheet thickness and placement depth of the geocell, as well as the collaboration potential of other geosynthetics with geocell when used as a protective layer. It was observed that all of the geocell-based protective systems contributed significantly to the pipe safety. When compared with the reference case, the reductions in the measured acceleration values on the pipes range between about 40% and 60% with the use of geocell protective layers only. On the other hand, the experimental results indicate that the most successful pipe protection performance under impact loading was achieved through the use of an additional 4 mm thick geotextile reinforced soil layer under a shallow geocell. A reduction of more than 90% in the measured accelerations was obtained for this system compared to the reference case.

Keywords: Geocell, pipe systems, impact load, experimental study

1 INTRODUCTION

Transmission pipe lines that span large distances are often under the threat of dynamic loads induced by natural hazards such as landslides and rock falls with significantly higher intensities compared to the predicted design loads. It is clear that, as a system in series, failure at a certain point in a transmission pipe network will result in serious economic consequences. Therefore, it is beneficial to have a better understanding of pipe behavior and possible ways of its improvement under impact loads.

Although the beneficial effect of the geosynthetics as reinforcement have been extensively studied (e.g., Indraratna et al. 2010; Rowe and Taechakumthorn 2011), research on the use of geosynthetics as reinforcement for the protection of buried pipelines or other underground utilities is rare. In a study conducted by Moghaddas Tafreshi and Khalaj (2008), a significant reduction was observed in the deformation of small diameter HDPE pipes buried in geogrid reinforced sand under repeated load. Tavakoli Mehrjardi et al. (2012) reported that a combination of geocell with 5% rubber-mixed soil as reinforcement provides a successful performance considering pipe and backfill settlement. A more recent experimental study was performed by Hegde et al. (2014) on the use of a combination of geocell and geogrid reinforcement to protect buried pipelines under static loads. The results of that study indicates an above 50% reduction in the pressure and more than 40% reduction in the strain in the reinforced bed compared to the unreinforced condition at different depths.

As can be seen from the brief literature review summarized above, no results have been reported concerning the merit of geocell use on the impact behavior of buried pipelines. In this context, a free-fall impact apparatus was used to examine the behavior of 160 mm diameter HDPE pipe systems with geocell-based protective layers, considering both the efficiency and the energy adsorption capacity under impact loading. For this purpose, the obtained accelerations and deformations on the pipe under a granular soil layer of constant relative density were compared with those that were measured when the sand layers are reinforced with a geocell layer with different sheet thicknesses and placement depths, as well as when an additional layer of geotextile, geogrid, or geonet is placed under the geocell.

2 EXPERIMENTAL STUDY

2.1 *Test setup and instrumentation*

A free-fall impact apparatus, which is designed to drop a constant weight of 5.25 kg from a height of 500 mm, applying a constant energy impact loading (5.25x9.81x500/1000=25.751 J) to simulate rock fall or other similar effects on the pipe-reinforced soil system was utilized in the experimental study (Figure 1). The base part on which the specimens are placed is made up of a 1000×1000×70 mm steel plate that stands on a rigid pedestal. In this way, the base part, which weighs about 500 kg, also acts as an absorber. In order to minimize the friction forces on the hammer, it is guided by cestamide rollers on four sides. The pipe and, when present, the protective layer were systematically placed in a 1000 mm x 500 mm x 400 mm steel container with a plexiglas front side for observation purposes that was situated directly under the free-fall impact apparatus.

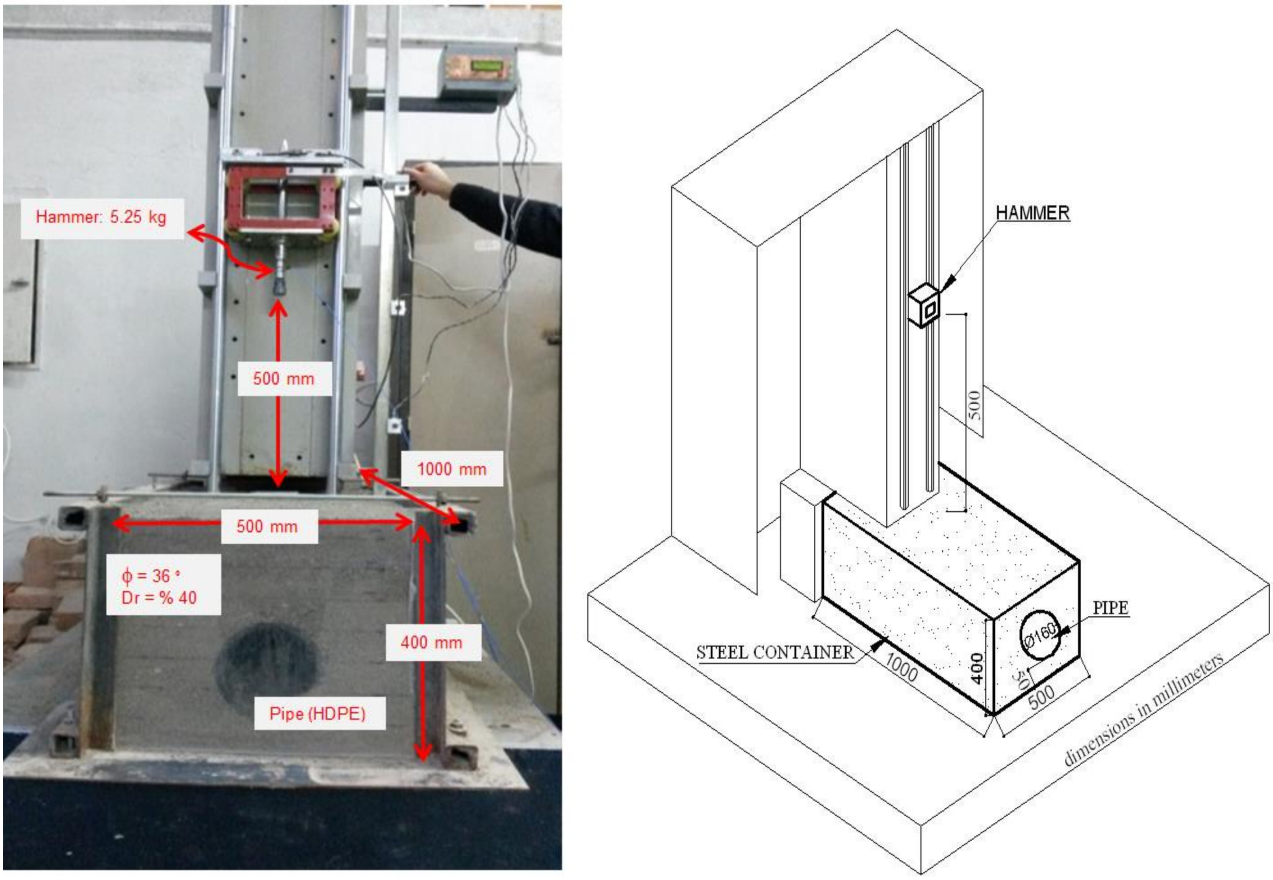


Figure 1: Free-fall impact test mechanism

No variation was induced to the hammer weight, drop height or the hammer shape during the experiments. Applied impact load was measured using a 40 kN capacity dynamic load cell connected to the hammer and acceleration time histories were measured by ±560 g capacity piezoelectric accelerometers located at two different locations as shown in Figure 2. Note that the presented data belongs to the larger accelerations measured at the middle accelerometer, which is closer to the impact point. Data obtained from the dynamic loading and acceleration measurements were transferred to the special software using a dynamic data logger system. This special software was also used during the tests and calibration of the sensors. Acceleration-time, load-time and load-displacement relationships were obtained from the measurements and the energy absorption capacities of different pipe-protective layer systems were calculated using load-displacement graphs.

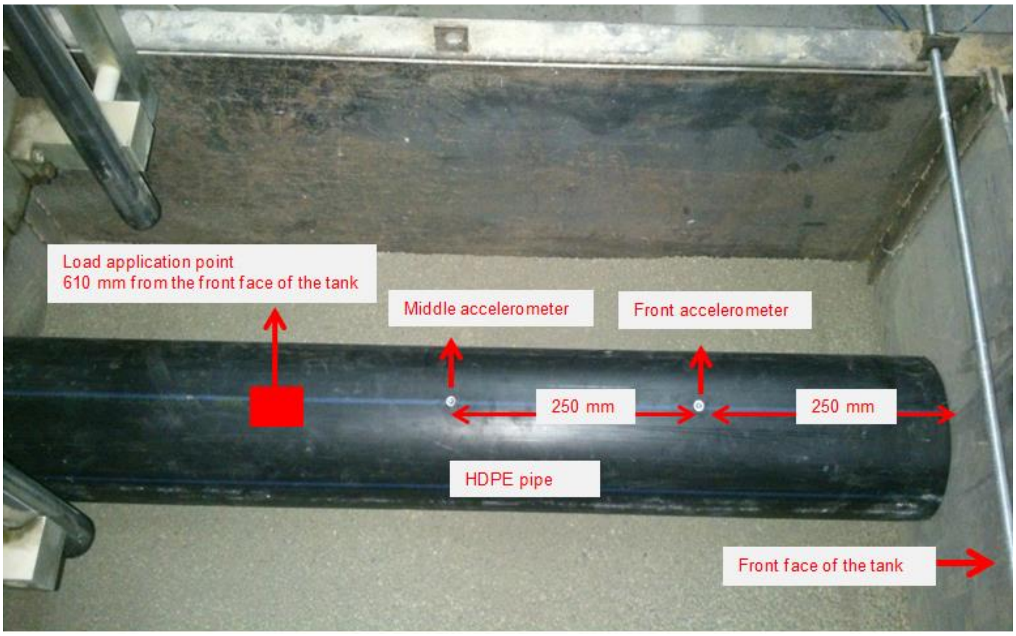


Figure 2: Instrumentation on the pipe

2.2 *Test specimens, materials, and procedure*

The main variables investigated in the test series are the geocell properties as characterized by the sheet thickness, the placement depth of the geocell, and the effect of additional geosynthetics layers within the protective system. Commercially available high density PE100 (HDPE) pipes with 160 mm diameter were used in the experiments. The properties of the pipes as specified by the manufacturer are given in Table 1.

The well-graded sand (SW) that was used in the experiments was characterized by its specific gravity, maximum and minimum void ratios and its grain size distribution (Table 2, Figure 3). Direct shear test conducted on sand specimens that were compacted to a relative density of 40% resulted in an effective stress friction angle of 36^o. This result was obtained at normal stress values between 95 and 500 kPa. Note that all the index and strength, as well as the impact load tests were performed on oven-dried sand samples.

The protective sand layer was reinforced with geosynthetic materials produced by Geoplas Company. The properties of the geotextile, geogrid, geocell, and geonet materials as specified by the manufacturer are given in Tables 3, 4, 5, and 6, respectively.

Table 1. Properties of PE100 HDPE pipes

Property	Unit	Value	Test Method
Density (23°C)	g/cm³	0.950-0.960	ISO 1183
Melting flow rate (MFR) 190°C-2.16 kg	g/10 min	0.04-0.07	ISO 1133
Melting flow rate (MFR) 190°C-5.00 kg	g/10 min	0.2-0.5	ISO 1133
Elongation	%	> 600	ISO 527-2/1B/50,TS1398
Yield strength	MPa	22-27	ISO 527-2/1B/50,TS1398
Elasticity modulus	MPa	950-1400	ISO 527-2/1B/50,TS1398
Carbon black (190°C 5kg)	%	>2	ISO 6964
Hardness	Shore D	59-60	ISO 868
Thermal resistivity	min.	>20	EN 728 ISO/TR 10837
Thermal conductivity (20°C)	W/Mk	0.4	DIN 52612
ESCR (at 50°C), F50	Hour	>10000	ASTM D-1693

Table 2. Properties of the sand used in the experimental studies

G_s (Mg/m^3)	ρ_{min} (Mg/m^3)	ρ_{max} (Mg/m^3)	e_{min}	e_{max}	D_{10} (mm)	D_{30} (mm)	C_c	C_u	γ (kN/m^3)
2.94	1.51	1.86	0.57	0.94	0.19	0.7	1.4	9.5	16.13

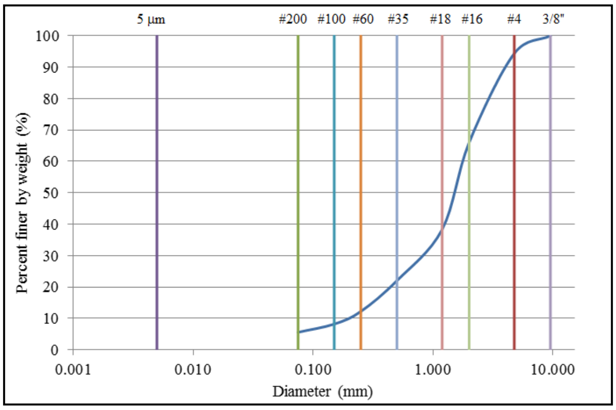


Figure 3: Grain size distribution curve obtained by sieve analysis

Table 3. Properties of the geotextile

Property	Unit	Geotextile	Method
Unit weight	g/m^2	500	TS EN ISO 9864
Thickness	mm	4	TS EN ISO 9863-1
Rupture strength	kN/m	27-29	TS EN ISO 10319
Elongation at rupture	%	50-80	TS EN ISO 10319
Static puncture strength	N	5500	TS EN ISO 12236
Dynamic puncture strength	mm	3	TS EN ISO 13433
Aperture size	mm	0.1	TS EN ISO 12956

Table 4. Properties of the geogrid

Property	Unit	Geogrid	Tolerance	Method
Unit weight	g/m^2	240	10%	EN ISO 9864
Tensile strength	kN/m	>30	10%	EN ISO 10319
Elongation at maximum load	%	<8/<8	10%	EN ISO 10319
Tensile strength at 2% elongation	kN/m	12/12	-	EN ISO 10319
Tensile strength at 5% elongation	kN/m	24/24	-	EN ISO 10319
Aperture size	mm x mm	40x40	10%	-
Sheet width	mm	9	-	-

Table 5. Properties of the geocell

Property	Unit	Geocell
Density	gr/ cm^3	0.94
Carbon black	%	2-3
Tensile strength	kN/m	12
Welding size	mm	400
Cell length	mm	300
Cell width	mm	250
Unit surface area	m^2	5
Thickness	mm	1.0-1.5
Cell depth	mm	50

Table 6. Properties of the geonet

Property	Unit	Geonet	Tolerance	Method
Unit weight	g/m^2	660	10%	EN ISO 9864
Tensile strength	kN/m	13/15	10%	EN ISO 10319
Elongation at maximum load	%	50/40	10%	EN ISO 10319
Thickness	mm	6.5	10%	EN ISO 9863-1
Rupture strength	kN/m	32/32	10%	EN ISO 10319

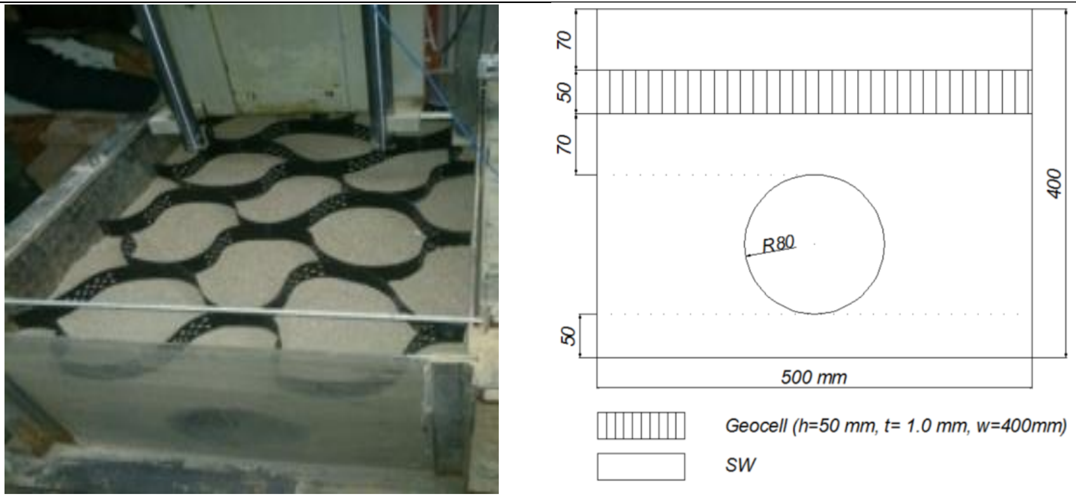
The same well-graded sand with properties and grain size distribution presented in Table 2 and Figure 3, respectively, were used under the pipe as a cushion layer at 40% relative density. The thickness of the cushion layer is a constant 50 mm at all tests conducted.

3 EXPERIMENTAL RESULTS AND DISCUSSION

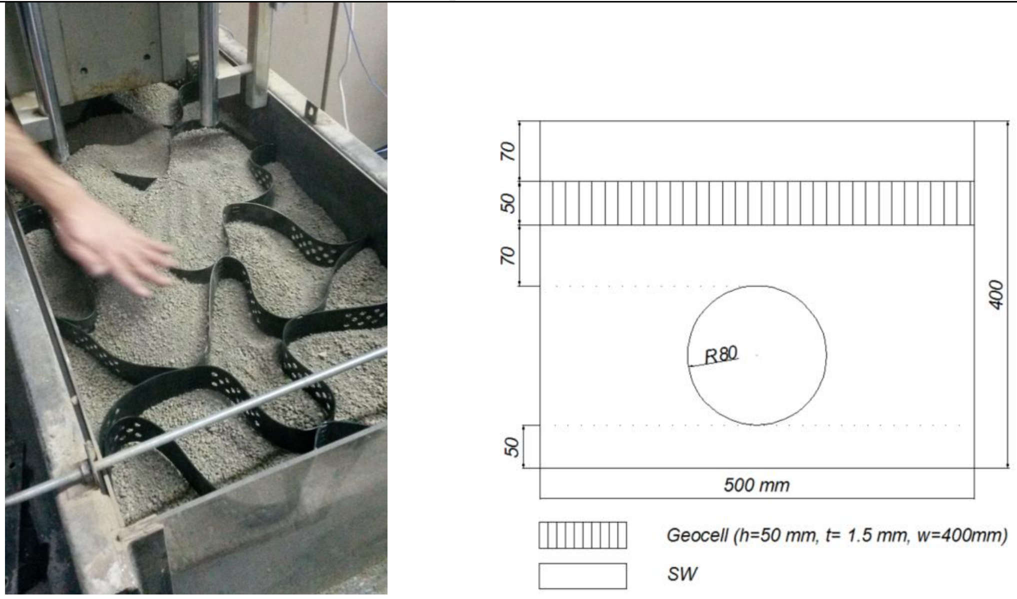
Details of the testing program are schematically shown in Figures 4 and 5. Note that in all of the tests the sand layer was placed at a constant relative density of 40%, and except the reference experiment with no reinforcement, a geocell with a 50 mm cell depth and 400 mm welding length was utilized. Tests 2, 3, and 4 involve only geocell layers as reinforcement, as illustrated in Figure 4. These tests were designed to investigate the effects of sheet thickness and placement depth of geocell on the impact behavior of the pipe. The remaining tests, i.e., 5, 6, 7, and 8, were utilized to examine the relative merit of the addition of geogrid, geotextile and geonet layers separately under the single geocell, as illustrated in Figure 5.

The measured acceleration-time and load-time histories, as well as the calculated load-displacement relationships are presented in Figures 6, 7, and 8, respectively. In addition, Table 7 summarizes the main physical and geometrical testing variables, and the maximum values of the measured acceleration, displacement and load for each test conducted. Note that, the reduction in the acceleration with reference to the unreinforced case and the energy absorbed by the protective layers are also given in Table 7. The absorbed energy values were calculated by means of the calculation of area under the load-displacement curves given in Figure 8.

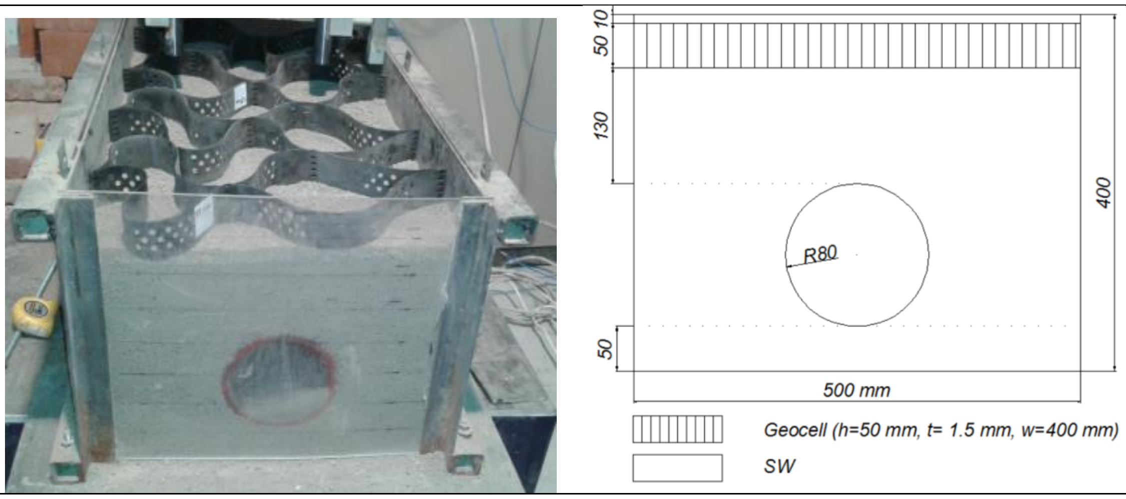
The first series of tests that involve protective layers were performed with a single geocell layer. In tests 2 and 3, the depth to the bottom of the geocell layer was 120 mm, whereas a shallower geocell layer of 60 mm depth was utilized in test 4. Also, geocell sheet thickness was 1 mm for test 2, unlike tests 3 and 4, where it was selected as 1.5 mm. The maximum accelerations were measured as 39.90 g, 30.04 g and 26.46 g on test specimens 2, 3, and 4, respectively. These values correspond to reductions that range between about 40 and 60% compared to the acceleration obtained for the reference case, which is 65.95 g. Thus, it is clear that utilization of geocell layer had a significant positive effect in reducing accelerations experienced by the pipes.



Specimen-2



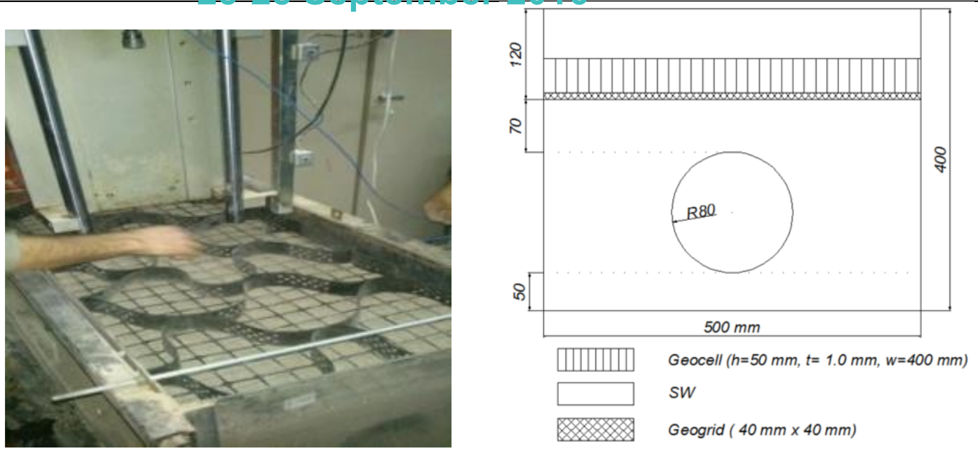
Specimen-3



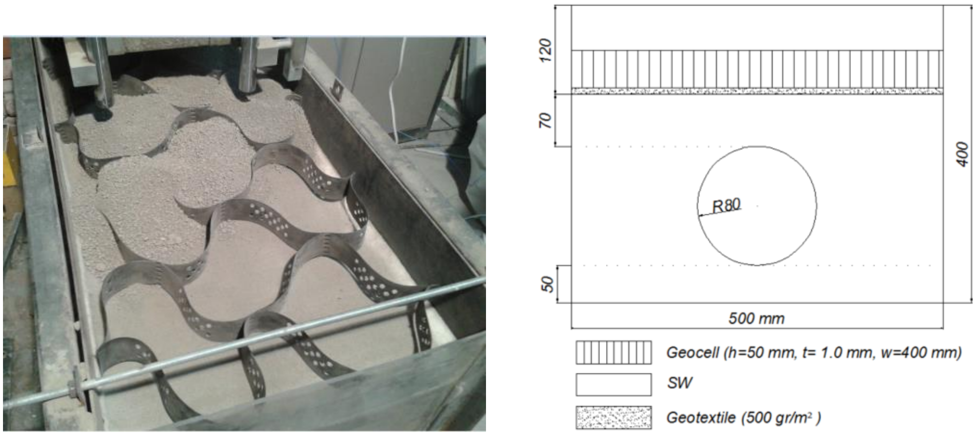
Specimen-4

Figure 4. Details of the protective layer systems that involve only geocell layers

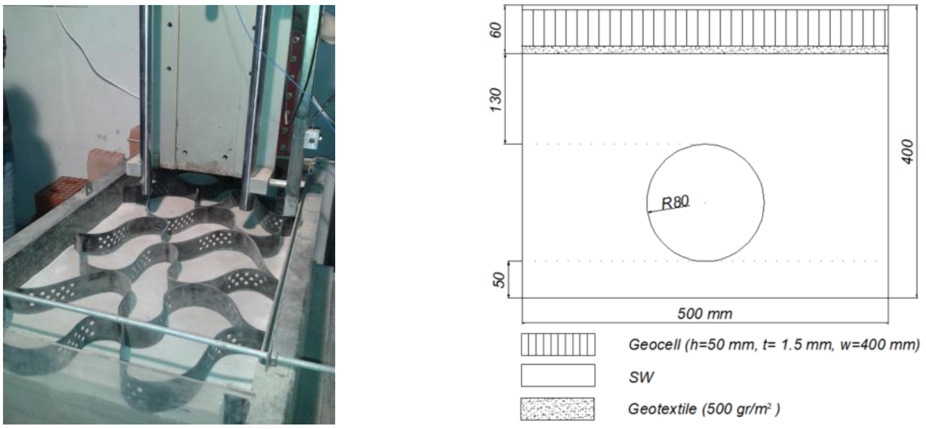
In addition, a further reduction in the recorded maximum accelerations was observed with decreased depth of placement of the geocell layer. The maximum displacements followed a very similar pattern with accelerations. The maximum displacement experienced by the pipe was calculated to be only 0.59 mm in test 4, which is a significant reduction from the 5.10 mm of the reference test. Similarly, the absorbed energy of the protective layer system showed a consistent increase from test 1 to test 4.



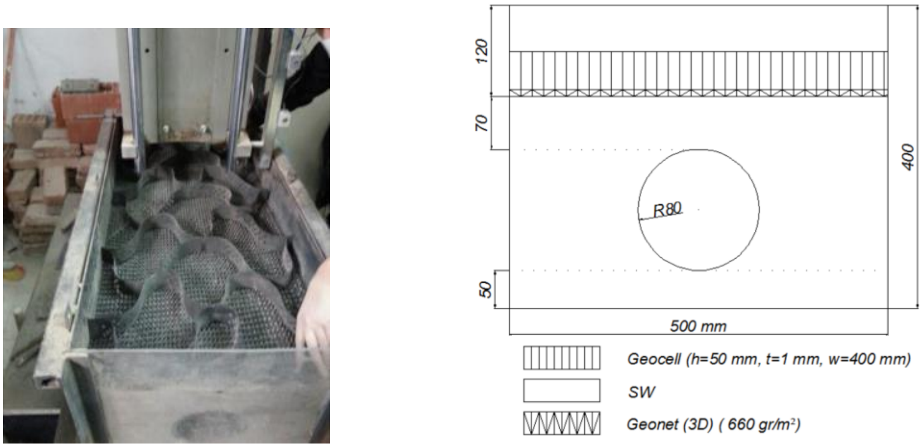
Specimen-5



Specimen-6



Specimen-7



Specimen-8

Figure 5. Details of the protective layer systems that involve composite protective layers

The second test series involve composite protective layers that consist of a geocell layer combined with a single layer of geogrid, geotextile, or geonet. As shown in Figure 5, test setups 6 and 7 were constructed by placing a 4 mm thick protective layer of geotextile under geocell layers with sheet thicknesses of 1 mm and 1.5 mm, respectively, whereas 40 mm x 40 mm geogrid and geonet layers were utilized along with a 1 mm thick geocell in tests 5 and 8, respectively. Much higher reductions in the accelerations that change between about 75 and 90% with respect to the reference test were obtained in these tests compared to those measured during the first test series. Consequently, all test setups also resulted in significant reductions in the maximum displacement value of the pipe. The maximum calculated displacements range between only 0.21 and 0.33 mm. A close look at the measurements from tests 6 and 7 indicates the importance of placement depth and the thickness of the geocell, again. A shallower placement depth and a thicker geocell brings along a significant decrease in both the maximum accelerations and displacements. All of the tests in this series absorbed very similar levels of energy, as also indicated by the similar low levels of deformations.

4 CONCLUSIONS

An experimental study was undertaken to investigate the relative merit of using only a geocell layer and employing a combination of geocell with a single layer of geogrid, geotextile, and geonet on the behavior of buried pipes under impact loading conditions. From the results, the following conclusions can be drawn:

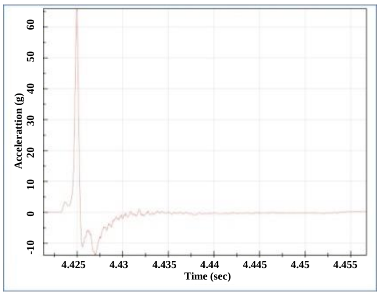
- The use of a single geocell within the sand as a protective layer resulted in significant amount of reductions in the accelerations on the pipe that range between 40% and 60%. The change in the resulting displacements followed a similar pattern with accelerations. These improvements were enhanced with shallower placement depth and larger sheet thickness.
- Accelerations on the pipe drastically decreased by the addition of a single geosynthetic layer, regardless of its type, under the geocell. Measured reductions range between about 75% and 90%, with a 1.5 mm thick, shallow geocell and a 4 mm thick geotextile demonstrating the highest efficiency.
- Implementation of geotextile, geogrid or geonet also helped significantly higher reductions in the maximum displacement of the pipe. In terms of displacements, combination of geocell with geonet was found to be a very effective system.

Table 7. Results of the experiments

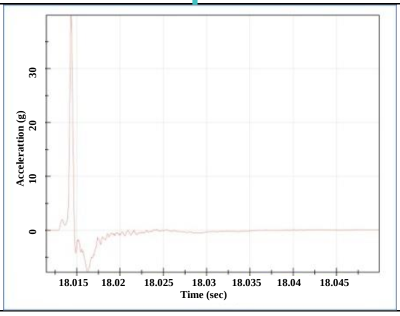
Test No	Outer Diameter of Pipe (mm)	Geosynthetics h:height t:wall thickness w:weld interval	Depth of * Geosynthetics (mm)	Maximum Measured Acceleration (g)	Maximum Displacement (mm)	Maximum Load (kN)	Reduction in Acceleration (%)	Calculated Energy on the Pipe (J)	Absorbed ** Energy Capacity of Protective Layer (J)
1	160	Without any protective layer	Reference	65.95	5.10	10.06	Reference	4.39210	21.36
2	160	GEOCELL (h=50 mm, t =1 mm, w=400 mm)	120	39.90	2.11	10.68	39.5%	2.26020	23.49
3	160	GEOCELL (h=50 mm, t =1.5 mm, w=400 mm)	120	30.04	1.01	9.98	54.5%	1.95564	23.80
4	160	GEOCELL (h=50 mm, t =1.5 mm, w=400 mm)	60	26.46	0.59	11.52	59.9%	1.18246	24.57
5	160	GEOCELL (h=50 mm, t =1 mm, w=400 mm) GEOGRID (40 mm * 40 mm)	120	16.03	0.33	11.49	75.7%	0.55078	25.20
6	160	GEOCELL (h=50 mm, t =1 mm, w=400 mm) GEOTEXTILE (h=4 mm)	120	12.03	0.29	11.27	81.8%	0.13679	25.61
7	160	GEOCELL (h=50 mm, t =1.5 mm, w=400 mm) GEOTEXTILE (h=4 mm)	60	5.48	0.21	11.09	91.7%	0.06461	25.69
8	160	GEOCELL (h=50 mm, t=1 mm, w=400 mm) GEONET	120	7.89	0.23	11.36	88.0%	0.09688	25.65

*As measured from the top of the test container to the bottom face of the geosynthetics layer

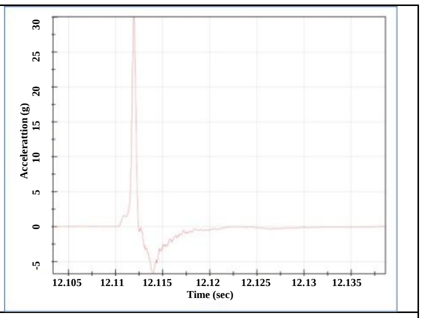
** Absorbed energy is the difference between the applied energy (5.25x9.81x500/1000=25.75125 Joule) and the energy calculated at the top of the pipe.



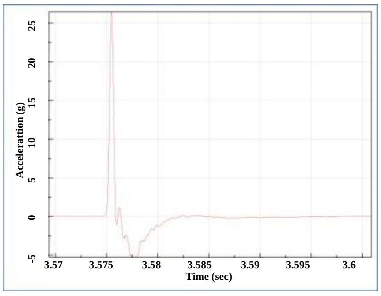
Specimen-1



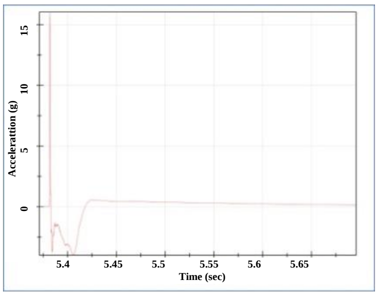
Specimen-2



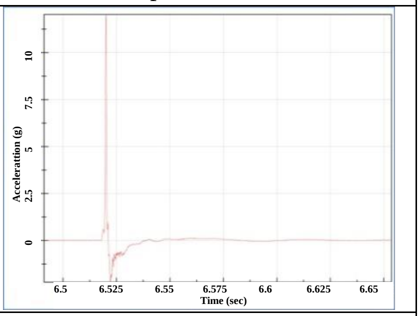
Specimen-3



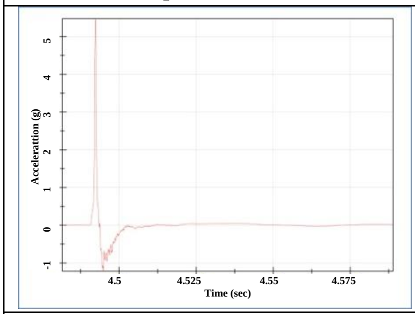
Specimen-4



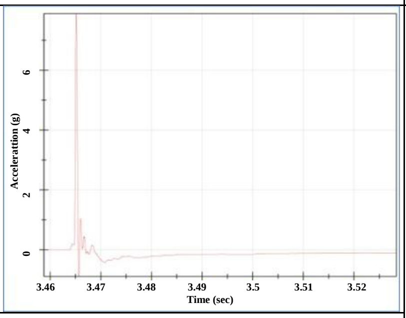
Specimen-5



Specimen-6

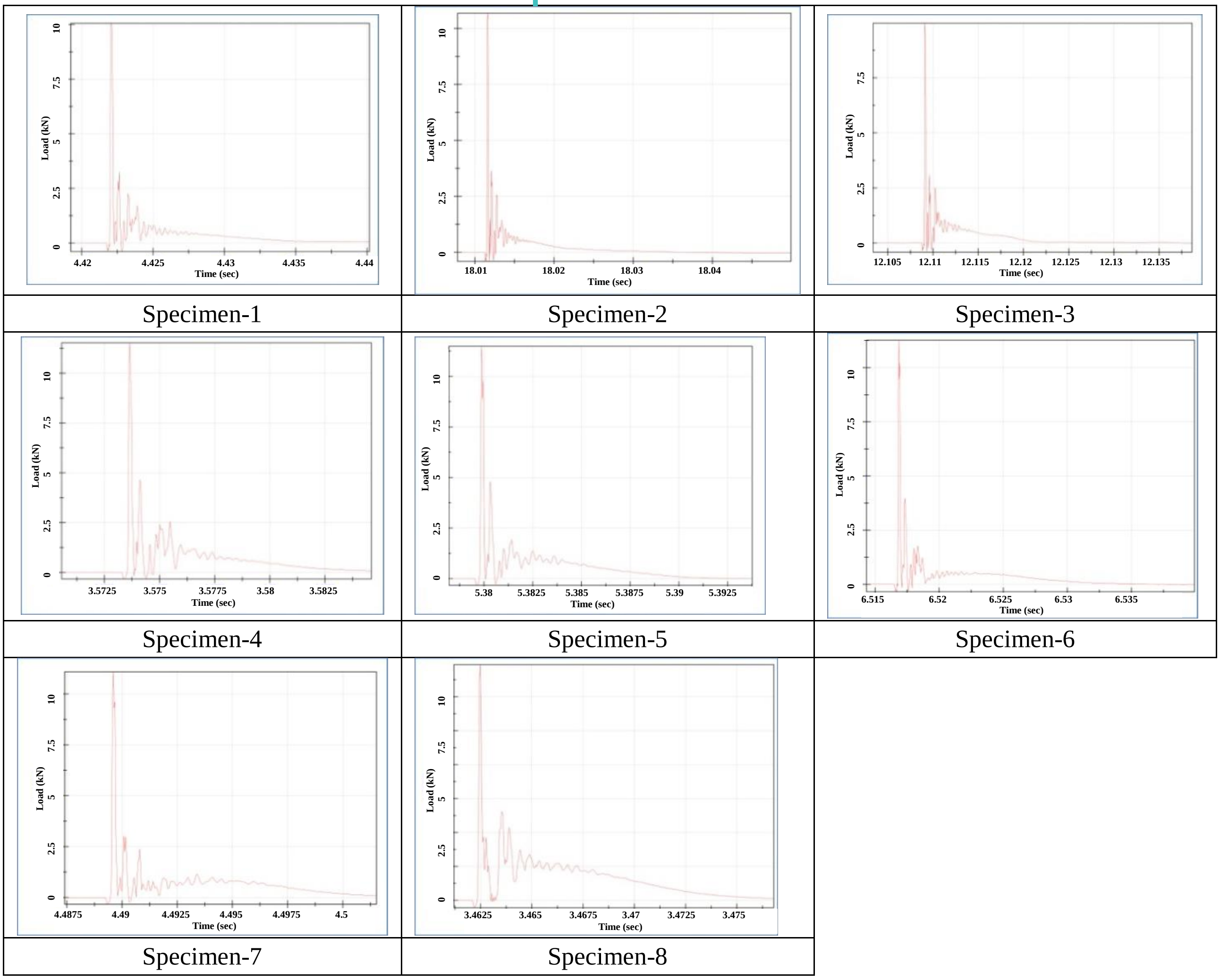


Specimen-7



Specimen-8

Figure 6. Acceleration time histories as recorded during the experiments



Specimen-1

Specimen-2

Specimen-3

Specimen-4

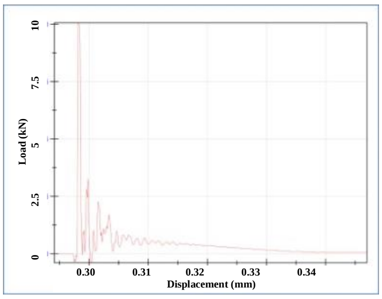
Specimen-5

Specimen-6

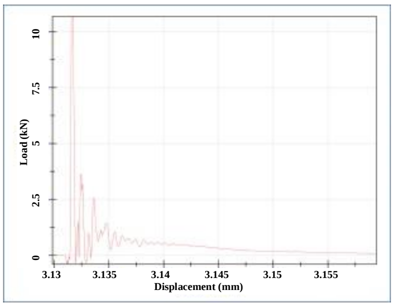
Specimen-7

Specimen-8

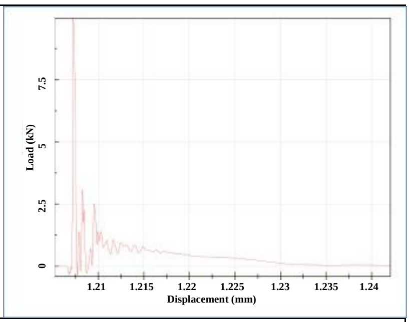
Figure7.Load time histories as recorded during the experiments



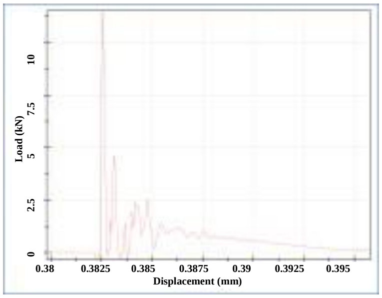
Specimen-1



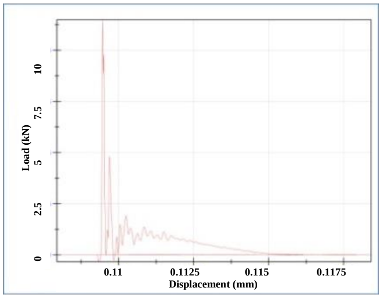
Specimen-2



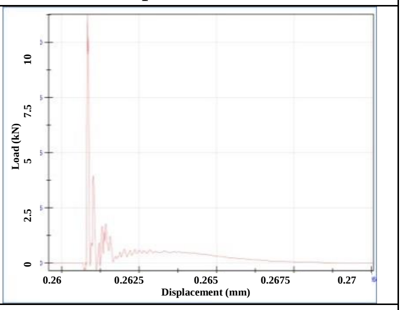
Specimen-3



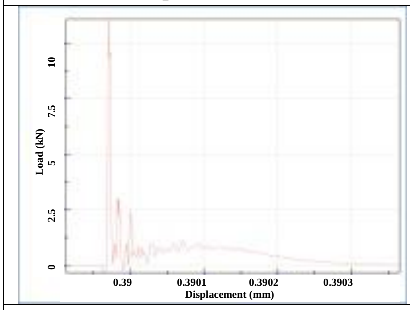
Specimen-4



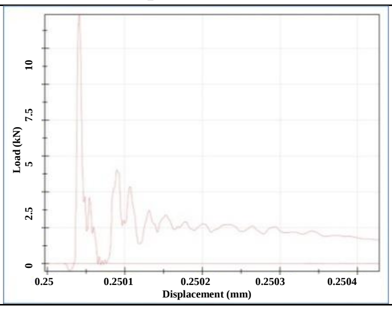
Specimen-5



Specimen-6



Specimen-7



Specimen-8

Figure 8. Calculated load-displacement relationships

5 REFERENCES

Hegde, A., Kadabinakatti, S. and Sitharam, T.G. (2014). Protection of buried pipelines using a combination of geocell and geogrid reinforcement: experimental studies. *Ground Improvement and Geosynthetics*, *ASCE*, 289-298.

Indraratna, B., Nimbalkar, S.S., Christie, D., Rujikiatkamjorn, C. and Vinod, J. (2010). Field assessment of the performance of a ballasted rail track with and without geosynthetics. *Journal of Geotechnical and Geoenvironmental Engineering*, Vol. 136, No. 7, 907-917.

Moghaddas Tafreshi, S.N. and Khalaj, O. (2008). Laboratory tests of small-diameter HDPE pipes buried in reinforced sand under repeated-load. *Geotextiles and Geomembranes*, 26, 145-163.

Rowe, R.K. and Taechakumthorn C. (2011). Design of reinforced embankments on soft clay deposits considering the viscosity of both foundation and reinforcement. *Geotextiles and Geomembranes*, 29, 448-461.

Tavakoli Mehrjardi, Gh., Moghaddas Tafreshi, S.N. and Dawson, A.R. (2012). Combined use of geocell reinforcement and rubber soil mixtures to improve performance of buried pipes. *Geotextiles and Geomembranes*, 34, 116-130.