Results of full-scale field impact load tests on HDPE pipes with geogrid protective layer

Gunes Babagiray, Sami Oguzhan Akbas & Ozgur Anıl
Gazi University, Turkey

ABSTRACT: Considering the limitations due to scale issues with laboratory experiments, field impact load tests were conducted on 600 mm diameter instrumented HDPE pipes of 2000 mm length, protected with geogrid layers of varying properties. The impact load was obtained by the free fall of a 3125 N concrete block from a height of 3 m. The behavior under impact loads was investigated considering both the efficiency in terms of reducing the impact load transmitted to the pipe and the pressure adsorption capacity. The protective layers considered in this study are a granular soil layer of constant relative density, i.e., the reference case, and sand backfill reinforced with geogrid, strip geogrid, and strip composite geogrid layers. In addition, a geotextile layer with a density of 600 g/m^2 was also used. The magnitudes of accelerations on the pipe and pressure in the soil at various depths were measured during the experiments with two sets of accelerometers and pressure cells. The results demonstrate the efficiency of geosynthetics-based protection systems under impact loading conditions, with significant reductions both in the accelerations and the loads transmitted to the pipes compared to the reference case. It was observed that geotextile in general performed superior to geogrids under impact loads for the specific types employed in this study. The reductions in the measured acceleration values on the pipes range between 50% and 60% for the load tests that involve geogrids, whereas a reduction of more than 80% was measured for those that employed geotextile. However, the use of geotextile and non-strip geogrid resulted in similar efficiencies when the cost was also taken into consideration.

Keywords: Full-scale load tests, pipe systems, impact load, geogrid, geotextile

1 INTRODUCTION

Impact type dynamic loads due to natural hazards such as landslides and rock falls pose significant threat to lifelines. Geosynthetics have been extensively utilized as a means of reinforcement in a wide variety of engineering applications. However, research on the use of geosynthetics as reinforcement for the protection of buried lifelines is relatively limited.

The majority of research activities on improvement by geosynthetics is concentrated on static loading conditions (Dong et al. 2010, Corey et al. 2014). In addition, considering the widespread use in transportation infrastructure, studies that focus on the performance under repetitive loading can also be found (Moghaddas Tafreshi & Khalaj 2008). In Moghaddas Tafreshi and Khalaj's (2008) study, a significant reduction in the deformation of small diameter HDPE pipes buried under geogrid reinforced sand was reported. Limited number of laboratory-scale impact load tests on pipes protected by various geosynthetics-based systems (Anıl et al. 2015, Babagiray et al. 2016) indicate promising results. However, it should be mentioned that small-scale load tests always have the potential to produce erroneous results mainly due to scale and boundary-related issues.

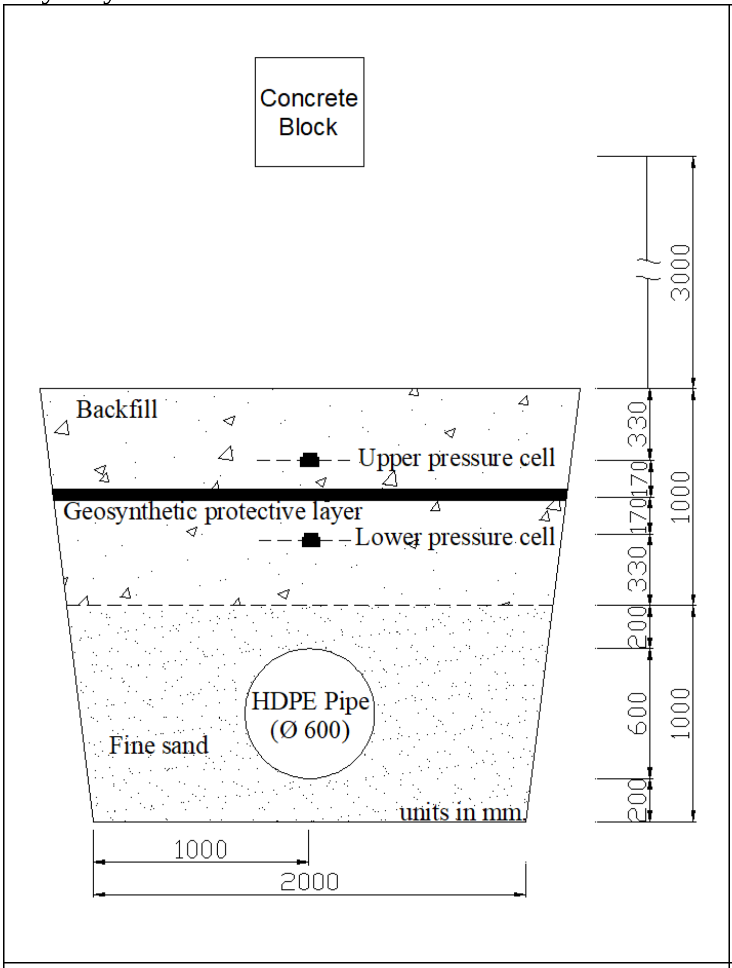
Considering the limitations above, this study was planned to investigate the relative merit of protective layers composed of geogrids against impact loading on buried pipelines. For this purpose, full-scale instrumented field impact load tests were conducted on geosynthetics-reinforced 600 mm diameter HDPE (High Density Polyethylene) pipes, which are commonly employed within underground utility systems.

The resulting acceleration transmitted to the pipe, the pressure exerted on the soil, and the resulting relative adsorption capacities were measured and compared for various protection configurations, taking also the cost component into the consideration. Geogrid, strip geogrid, and strip composite geogrid layers, as well as a geotextile layer were used for the development of protective layers on the HDPE pipe.

2 EXPERIMENTAL FIELD STUDY

The field load tests were conducted in the factory yard of Geoplas Ltd. Company, which is located in Ankara, Turkey. The test pit, which was prepared in accordance with Turkey Petroleum Pipeline Corporation (BOTAŞ) – Natural Gas Main Transmission Branch Lines Guidelines Ditch Dimensions and Backfilling specifications, is 2000 mm deep, 2000 mm wide, and has a length of 4000 mm (Figure 1). In conformity with the specification mentioned, a 200 mm sand cushion layer was prepared before the HDPE pipe was placed in the excavation pit. The pipe that was decorated with the necessary instrumentation devices was then symmetrically placed on the cushion layer, and the test pit was consequently backfilled with clean fine sand up to a height of 1000 mm from the excavation bottom, which is 200 mm higher than the top of the HDPE pipe. The direct shear test results indicate an effective stress friction angle of 32^{o} for the fine sand. The remaining 1000 mm height of the excavation was then backfilled with the excavated material in accordance with the BOTAS specifications. The excavated material is a high plasticity clay with an average plasticity index of 29 and an average undrained shear strength of 80 kPa.

The upper and lower pressure cells were placed at about 330 mm and 670 mm depth, respectively, such that the 1000 mm soil layer above the pipe was divided into three nearly equal intervals. As can be seen from Figure 1, the HDPE pipe was instrumented with two accelerometers, i.e., the front and middle accelerometers, which are located at 500 mm and 1000 mm from the front end of the 2000 mm long pipe, respectively. After the HDPE pipe was placed in the test pit, and the instrumentation, the backfilling operations, as well as the construction of the protective layer are completed, so that the impact load test can then be conducted by dropping a concrete block from a specified height on the pipe-backfill-protective layer system.



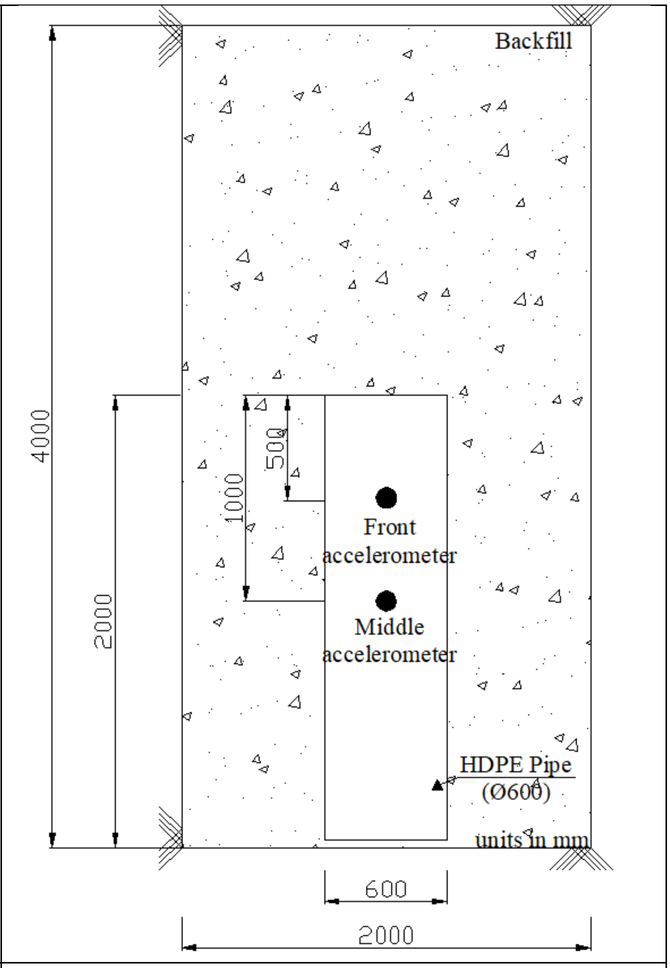


Figure 1. Illustration of the field load test

2.1 *Properties of the concrete block*

The concrete block (500 mm x 500 mm x 500 mm) that was dropped from a height of 3000 mm in each experiment has been reinforced in order not to sustain any damage, and has been cured for seven days in water after it was cast. The energy that is exerted by this concrete block of 3125 N that free-falls from a height of 3 m on the pipe system can be calculated as 9375 Joules.

2.2 *Properties of high density polyethylene (HDPE) pipe*

PE 100 type HDPE pipe was selected to be used in the field experiments due to its durability, flexibility and its ease of transportation and installation. The pipe has an exterior diameter of 600 mm with a wall thickness of 20 mm, and a length of 2000 mm. The properties of the HDPE pipe are summarized in Table 1.

Table 1. Properties of PE100 HDPE pipes (pilsa.wavin.com, 2017)

Property	Unit	Value	Test Method	Photo
Density (23℃)	g/cm³	0.950-0.960	ISO 1183	
Melting flow rate (MFR) 190℃-2.16 kg	g/10 min	0.04-0.07	ISO 1133	
Melting flow rate (MFR) 190℃-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℃ - 5kg)	%	>2	ISO 6964	
Hardness	Shore D	59-60	ISO 868	
Thermal resistivity	min.	>20	EN 728 ISO/TR 10837	
Vicat softening temperature	℃	126	ISO 306 (Method A)	
Crack temperature	℃	< -70	ASTM D-746	
Thermal conductivity (20℃/150℃)	W/Mk	0.4/0.2	DIN 52612	
ESCR (at 50℃), F50	Hour	>10000	ASTM D-1693	

2.3 *Properties of geosynthetics*

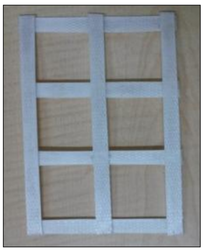
The protective sand layer was reinforced with geosynthetic materials produced by Geoplas Company (www.geoplas.com.tr). The properties of the geogrid, strip geogrid, geotextile, and the strip composite geogrid that is a laminated combination of geotextile and strip geogrid materials are presented in Table 2, Table 3, Table 4, and Table 5, respectively.

Table 2. Properties of the geogrid (www.geoplas.com.tr)

Property	Unit	Geogrid	Tolerance	Method	Photo
Material	Polypropylene				
Unit weight	g/m^2	240	10%	EN ISO 9864	
Tensile strength (Dop/Vd)*	kN/m	20/20	10%	EN ISO 10319	
Elongation at maximum load (Dop/Vd)	%	≤8/≤8	10%		
Tensile strength at 2% elongation (Dop/Vd)	kN/m	7/7	-		
Tensile strength at 5% elongation (Dop/Vd)	kN/m	14/14	-		
Aperture size (Dop/Vd)	mm x mm	40x40	10%	-	

(*Dop: In the direction of production; Vd: Vertical direction)

Table 3. Properties of the strip geogrid (www.geoplas.com.tr)

Property	Unit	Strip Geogrid	Tolerance	Method	Photo
Material	Polymer				
Unit weight	g/m^2	240	10%	EN ISO 9864	
Tensile strength (Dop/Vd)*	kN/m	≥ 30 / ≥ 30	10%	EN ISO 10319	
Elongation at maximum load (Dop/Vd)	%	≤8/≤8	10%		
Tensile strength at 2% elongation (Dop/Vd)	kN/m	12/12	-		
Tensile strength at 5% elongation (Dop/Vd)	kN/m	24/24	-		
Aperture size (Dop/Vd)	mm x mm	40x40	10%	-	
Strip width	mm	10	-	-	

(*Dop: In the direction of production; Vd: Vertical direction)

Table 4. Properties of the geotextile (www.geoplas.com.tr)

Property	Unit	Geotextile	Method	Photo
Material	Polypropylene			
Unit weight	g/m^2	600	TS EN ISO 9864	
Thickness	mm	4.2	TS EN ISO 9863-1	
Rupture strength (long/trans)	kN/m	31/33	TS EN ISO 10319	
Elongation at rupture (long/trans)	%	50-80	TS EN ISO 10319	
Static puncture strength	N	6000	TS EN ISO 12236	
Dynamic puncture strength	mm	2.0	TS EN ISO 13433	
Aperture size	mm	0.08	TS EN ISO 12956	

Table 5. Properties of the geotextile strip composite geogrid (www.geoplas.com.tr)

Type	Property	Unit	Value	Photo
Strip Geogrid	Material	Polymer		
	Unit weight	g/m^2	240	
	Tensile strength (Dop/Vd)*	kN/m	≥ 30 / ≥ 30	
	Elongation at maximum load (Dop/Vd)	%	≤ 8 / ≤ 8	
	Tensile strength at 2% elongation (Dop/Vd)	kN/m	12/12	
	Tensile strength at 5% elongation (Dop/Vd)	kN/m	24/24	
	Aperture size (Dop/Vd)	mm	40x40	
Geotextile	Material	Polypropylene		
	Unit weight	g/m^2	400	
	Thickness	mm	2.5	
	Rupture strength (long/trans)	kN/m	21/23	
	Elongation at rupture (long/trans)	%	50-80	
	Static puncture strength	N	4000	
	Dynamic puncture strength	mm	8	
	Aperture size	mm	0.11	

(*Dop: In the direction of production; Vd: Vertical direction)

2.4 *Instrumentation*

PCB Group's piezoelectric ICP type Model 353B02 accelerometers were employed in this study. These small sized industry standard covered transducers are capable to be utilized in a wide range of temperatures and applications that include low frequency seismic to very high frequency impact type measurements. The KDE-2 MPA model type pressure cells were produced by Tokyo Sokki Kenkyujo Co. Ltd. (www.tml.jp) and have a capacity of 2000 kPa. These 50 mm outer diameter, double diaphragm, corrosion resistant stainless steel measurement devices are capable of measuring dynamic pressures on soil.

3 FULL-SCALE IMPACT LOAD TESTS AND DISCUSSION OF RESULTS

The depth of the protective geosynthetics layer (500 mm), backfill soil type, 600 mm HDPE pipe properties and dimensions as well as the concrete block weight (3125 N) and free fall height (3000 mm) have been constant in all of the tests. As explained earlier, the acceleration time histories and pressure measurements were recorded by accelerometers and pressure cells that have been mounted at the identical locations in each test.

Figure 2 presents photographs from test pit preparation and test conduct stages. Sample acceleration and pressure time histories that were recorded by the middle accelerometer and the lower pressure cell, respectively, are also given in Figure 3. The measurements by these two instruments have consistently been the maximum recorded values.

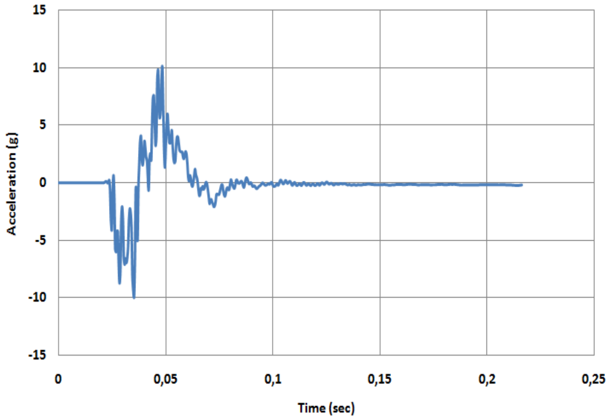
Experiment 1 denotes the reference case in which no geosynthetics protection layer was utilized. The maximum recorded values of acceleration and pressure for this case was 10.08 g and 77.87 kPa, respectively.

Figure 2. Photographs from test pit preparation and test conduct

In field test no. 2, soil was improved by a double-axis geogrid layer with a 40 mm x 40 mm mesh spacing. The recorded measurements indicate maximum acceleration and pressure values of 4.03 g and 58.78 kPa, respectively. Thus, a reduction of 60.0% and 24.5% in the acceleration transmitted to the HDPE pipe and the pressure under the pipe, respectively, have been observed.

The third field test included a 10 mm thick strip geogrid with a 40 mm x 40 mm mesh spacing as the protective layer. This time, the recorded measurements indicated maximum acceleration and pressure values of 5.04 g and 61.24 kPa, respectively. Although these values are higher than those measured in the second experiment, it should be indicated that the protective layer again caused significant reductions of 50.0% and 21.3% with respect to the reference case in the acceleration and pressure, respectively.

Strip composite geogrid layer with 10 mm thickness and a 40 mm x 40 mm mesh spacing laminated with a 2.5 mm thick geotextile layer of unit weight 400 g/m^2 was used in the fourth field test. For this case, the maximum acceleration on the pipe was measured to be 4.58 g, and the maximum pressure recorded in the lower pressure cell was 59.78 kPa. These are 54.5% and 23.2% reductions compared to the reference case with no protective layer in terms of acceleration transmitted to the pipe and the pressure in the soil, respectively.



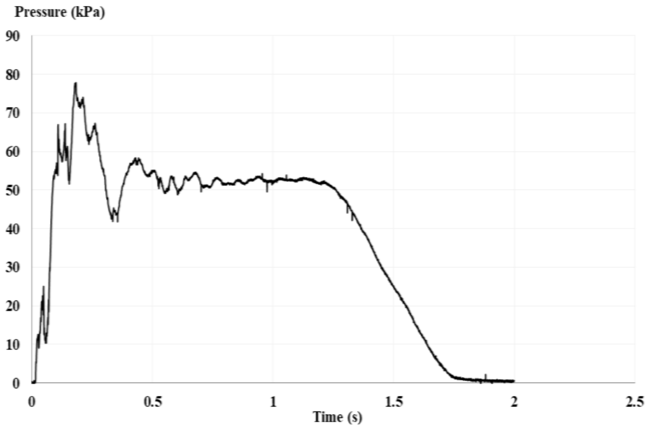


Figure 3. Acceleration time histories and pressure time histories of reference test as recorded during the experiments

Experiment 5 is the only experiment in which the protective system did not include a geogrid layer. Instead, a 4.2 mm thick geotextile layer with a unit weight of 600 g/m^2 was employed for this case. Note that the lowest values of maximum acceleration on the pipe and the pressure in the soil among the five experiments have been measured with this geotextile protection. The maximum acceleration and the pressure values were recorded as 1.83 g and 44.59 kPa, respectively, which corresponds to very significant reductions of 81.8% and 42.7% with respect to the reference case.

Table 6 summarizes the maximum measured acceleration and pressure values as well as the reduction in these with respect to the reference case. In addition, the total cost of each protective layer – HDPE pipe system, which includes workmanship, transportation, and material expenses is also given in Table 6. For an easier comprehension, the reduction capabilities for protective layers is also shown and compared graphically in Figure 4. The system with the lowest cost is the one in the second field load test, in which geogrid layer was employed. It is followed by those with geotextile (filed test 5) and strip geogrid (field test 3).

Table 6. Results of the experiments

Test No	Geosynthetics	Maximum Measured Acceleration (g)		Maximum Measured Pressure (kPa)		Reduction in Acceleration (%)	Reduction in Pressure (%)	Total Cost/m^2 (USD)
		Middle accelerometer	Front accelerometer	Lower pressure cell	Upper pressure cell			
1	Without any protective layer	10.08	6.03	77.87	37.56	Reference	Reference	Reference
2	Geogrid	4.03	2.23	58.78	35.45	60.0	24.5	1.69
3	Strip Geogrid	5.04	2.71	61.24	34.98	50.0	21.3	2.63
4	Strip Geogrid Composite	4.58	2.53	59.78	37.14	54.5	23.2	4.68
5	Geotextile	1.83	1.09	44.59	36.85	81.8	42.7	2.43

For estimation of the overall merit of each system and for a more fair comparison among them, the measurements recorded in the experiments were also investigated in terms of reduction of acceleration per unit cost. The results are shown in Figure 5. These results indicate very similar overall performances for Tests 2 and 5, in which geogrid and geotextile layers were used, respectively. Note that the efficiency of protective layer with geogrid is even slightly higher when the cost is taken into consideration. The strip composite geogrid protective layer on the other hand has a huge deficit in terms of overall performance, mainly due to its high relative cost.

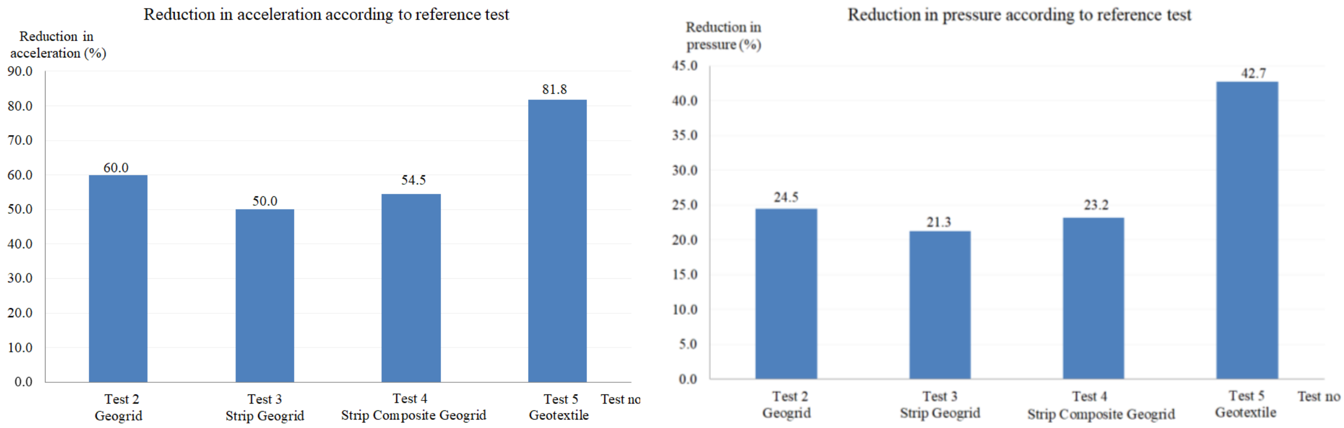


Figure 4. Comparison of acceleration and pressure reduction capabilities for protective systems

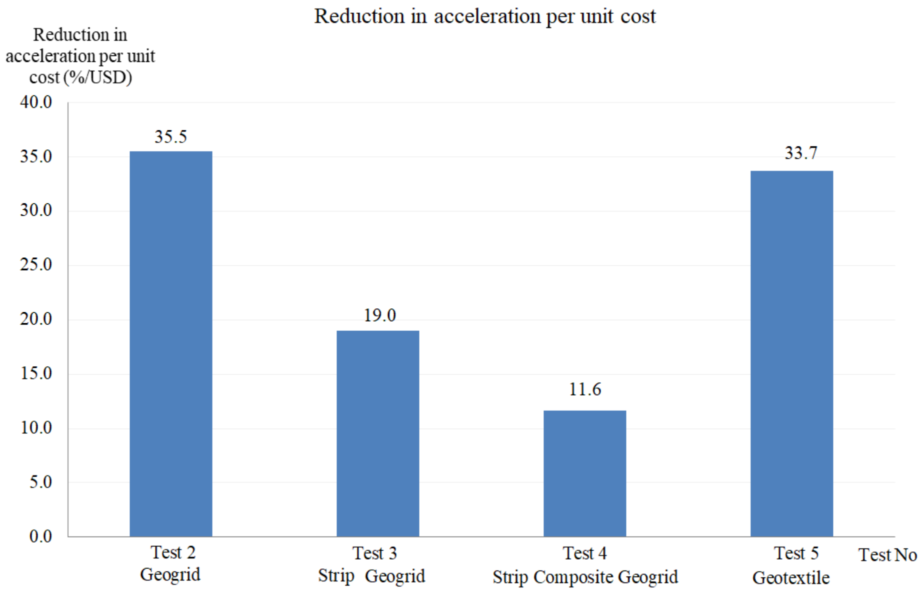


Figure 5. Acceleration reduction with respect to reference case per unit cost in each experiment

4 CONCLUSIONS

In this study, field impact load tests were conducted on 600 mm diameter instrumented HDPE pipes of 2000 mm length, protected with geogrid-based systems and a geotextile layer of varying properties. The impact load was obtained by the free fall of a 3125 N concrete block from a height of 3000 mm. The behavior under impact loads was investigated considering both the efficiency in terms of reducing the acceleration due to impact load transmitted to the pipe and the relative pressure adsorption capacity.

The full-scale field load test results indicate that each utilized protective layer resulted in significant reductions in the accelerations exerted on the HDPE pipe, as well as in the pressures imparted in the soil below. The range of reductions in the accelerations on the pipe is between about 50% and 82% with respect to the reference test where no protective layer was employed. The corresponding range for imparted pressures is between about 21% and 43%.

In limited number of similar small-scale laboratory experiments (Babagiray et al. 2016), the use of a single geocell within the sand as a protective layer resulted in reductions in the accelerations on the pipe that range between 40% and 60%, whereas the corresponding range with the addition of a single geosynthetics layer under the geocell was reported to be between about 75% and 90%. Although a one to one comparison between these results and the measurements reported herein is not possible due to use of different protective systems, it can be concluded that the reductions in the accelerations fall within a similar range of magnitudes.

For a more fair comparison among systems, cost is also included in the analyses. It was then determined that geogrid and geotextile layers are the most effective, with similar overall performances. These two systems are shown to be superior to strip geogrid and strip composite geogrid for protection of HDPE pipes against impact loads.

REFERENCES

Anıl, O., Erdem, R.T. & Kantar, E. 2015. Improving the impact behavior of pipes using geofoam layer for protection, *International Journal of Pressure Vessels and Piping*, (132-133), pp. 52-64.

Babagiray, G., Akbaş, S. O. & Anıl, O. 2016. Investigation of Impact Behaviour of HDPE Pipes with Geocell Protective Layer, *6th European Geosynthetics Congress (EuroGeo6)*, Slovenia, pp.762-773.

Corey, R., Han, J., Khatri, D.K. & Parsons, R.L. 2014. Laboratory Study on Geosynthetic Protection of Buried Steel-Reinforced HDPE Pipes from Static Loading, *Journal of Geotechnical and Geoenvironmental Engineering*, p. 140.

Dong, Y., Han, J. & Hong, X. B. 2010. Bearing capacities of geogrid reinforced sand bases under static loading, *Geo Shanghai International Conference*, pp. 275-281.

http://www.webcitation.org/query?url=http%3A%2F%2Fwww.geoplas.com.tr%2Furunler.html&date=2017-02-11, Last Access Date: 30 February 2017.

http://www.webcitation.org/query?url=http%3A%2F%2Fpilsa.wavin.com%2Fweb%2Fdokumanlar.htm&date=2017-02-11, Last Access Date: 30 February 2017.

http://www.webcitation.org/query?url=http%3A%2F%2Fwww.tml.jp%2Fe%2Fproduct%2Ftransducers%2Fcivil_eng%2Fsoil_pressure%2Fkde_kdf.html&date=2017-02-11, Last Access Date: 30 February 2017.

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