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To Overcome Lateral Earth Pressure on Buried Cast Iron Pipeline Using Geofoam

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ABSTRACT:

The load deformation behavior of buried cast iron pipeline to shallow foundation loading is presented in the present study. Response of buried pipes to the prescribed displacement of the strip footing with and without compressible inclusion was modeling on software test. A series of test were conducted on buried cast iron pipe maintaining the constant embedment depth, soil type, pipe type, pipe diameter, displacement due to the strip footing and rate of displacement. Plastic soil (ϕ-soil) fine sand was used for all models tests. A 0.05m diameter cast iron pipe was used to represent the prototype pipes.10mm, 20mm and 50mm thick geofoam panel with varying density and length was used as a compressible inclusion. The parameters considered in the present study were length of the geofoam, thickness of the geofoam and density of the geofoam. A software analysis technique was used to evaluate the performance of the geofoam and deformation behavior of the buried cast iron pipe. Displacement was applied with constant rate of prescribed displacement of the strip loading of 0.03m using PLAXIS software. This facilitates the correct evaluation of dissipation of the energy due to geofoam through soil arching and compression of the geofoam. The study should propose an effective solution to the distressing of buried cast iron pipeline. The deformation in buried cast iron pipeline was calculated to reduce when geofoam was placed below strip footing. This reduction was found to be significant with increase in thickness of the geofoam and decrease in density of the geofoam. However, the density of the geofoam was found to have less effect on deformation reduction than that of the geofoam thickness.

Keywords –Buried cast iron pipe, Geofoam, prescribed displacement of the strip footing, Small-scale modeling on PLAXIS software

I. INTRODUCTION

Today, majority of the important financial operations are mainly related to the transport and use of oil, gas and water. Several kilometers of pipelines are needed to install from a source location to the target locations. These pipelines are generally buried under the soil depending on the leveling profile of the existing ground, maintaining a constant slope towards the target location.

These pipelines are subjected to different loading from the soil as well as the surface loading due to traffic loads, embankment load, superstructure above the ground surface and/or the surcharge due to seasonal changes in water conditions and other depositions. Behavior of the pipelines also varies depending on the level and pressure of the transporting fluid or gas within it. Soil type would also impose different types of loading on these pipes. Several authors have put forward their studies to evaluate the amount and nature of forces acting on the pipelines buried under the subsoil Watkins(2004), Johnson et al. (2010), Stephen(2011), Lin and Chou(2012), Corey et al. (2014), Anirban De & Zimmie(2016). Pipes under the soil face different soil profiles along the length depending on the territory and original parental strata formation at these locations. Due to changes in soil stratum along the run and change in consistency or the relative density of such soils, it is very necessary to protect the buried pipelines against differential actions of loading. Such type of loadings may induce excessive differential deformation in pipes, which may further result in breakage of such pipes, and interruption in the

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transportation. Some of the authors have suggested the use of geofoam to protect these pipes from surrounding soil (Bilgin & Stewart (2012)). Buried pipes could be protected using geofoam inclusion and several factors such as density, thickness of geofoam and placement location of the geofoam and soil type. Present study demonstrates the modeling of geofoam on the basis of software with and without geofoam. Three different densities of the geofoam were adopted in the present study along with three different thicknesses. The model pipe diameter, type, soil type, placement position of the geofoam and loading type was kept constant throughout the study. A prescribed displacement of the strip footing vertically 0.03m was applied on each of the model test at the top surface of the soil.

II. MOTIVATION BEHIND PRESENT STUDY

Figure 1 shows the schematic cross section of the buried cast iron pipes with and without geofoam inclusion. When a prescribed displacement of the strip footing is applied on the soil surface the pressure would transfer in the soil mass according to the Terzaghi's general bearing capacity theory. Forming a zone of elastic equilibrium and the plastic equilibrium. The elastic equilibrium zone directly transfers the load on the pipeline buried underneath and causes the deformation in the pipe. However the zones of plastic equilibrium extend the deformation of soil towards the surface of the soil resulting in formation of the heave. Geofoam when placed below the prescribed displacement of the strip footing at a depth of just below 50mm of the prescribed displacement of the strip footing, geofoam compresses and the settlement due to displacement of the strip footing gets distributed in the surrounding soils. Because of this the arching in soil occurs which develops the shear strength of the above the pipe. This ultimately would result in lesser displacement of the strip footing transfer on pipe from the prescribed displacement of the strip footing to settle and the displacement of the given strip footing gets distributed over wider soil mass below the surface. This dispersion in displacement of the strip footing transfer should enhance with compressibility of the geofoam as well as the available volume for compression under the foundation. Higher compressibility can be achieved by decreasing density of the geofoam and the higher volume could be obtained by increase in thickness of the geofoam. The increase in thickness of geofoam could show possible effective results in displacement of the strip footing dispersion. This is because wide the cushion below prescribed displacement of the strip footing wider the spread of displacement and higher opportunities for soil arching and shear strength development of soil.

1 Sand:

Sand was classified as fine sand (SF). The properties of sand have internal frictional resistance of 27^0 for 17% relative density. Table 1 summarizes the properties of model sand used in the present study.

2 geofoam:

Expanded polystyrene (EPS) geofoam was used in the present study as a compressible inclusion behind reinforced zone. Three types of geofoam were used in the present study EPS8, EPS16 and EPS24 with varying density 8, 16 and 24 kg/m^3 respectively.

3. Cast Iron pipe:

A commercially available 0.05m diameter flexible cast iron pipe was used in the present study. The model pipe represents the flexible buried pipelines used for gas and oil transportations. Correlation of vertical displacement of the strip footing to the deformation was further used in the analysis and interpretation to evaluate the displacement transferred on the pipe with and without geofoam inclusion.

MODEL TEST PACKAGE AND TEST PROCEDURE

Model test package:

We constructed a two dimensional box having a length of 1m and height of 0.5m and fixed rigidly from three sides. We kept soil in this box having a density of 17 KN/m^3 and insert a cast iron pipe with diameter of 0.05m. Then prescribed displacement of the strip footing of 0.03m was applied on the surface of the soil. We were calculated that axial force and deformation of the cast iron pipe with and without geofoam. In calculations of with-geofoam we were taken different parameters like density of 8, 16 & 24 KN/m^3, length of 50, 100 & 150mm and thickness of 10, 20 & 50 mm. Test procedures:

All the experimental buried cast iron pipe models were tested on prescribed displacement of the strip footing of 0.03m with the help of PLAXIS software. We were taken three densities of geofoam, three lengths of geofoam & three thicknesses of geofoam and calculated axial force & deformation for 27 numbers of test. Also one test for without geofoam.

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TEST PROGRAM

Table 2 shows the details of model tests performed in the present study. Total 28 model tests were performed with and without geofoam inclusion below described displacement of the strip footing. Model M001 was tested without any geofoam inclusion and was treated as the base models for evaluation of the efficiency of the geofoam inn reduction of pressure on buried cast iron pipeline.

ANALYSIS AND INTERPRETATION

We were used plastic type of calculation under the control parameter having a 350 additional steps with manual setting with different parameter such as tolerated error of 0.100, over relexation of 1.200, maximum itreations 60 with minimum 6 and maximum 15 iteration respectively. A reference measurement could be made at various points in the image with the help of comparative sequentioal analysis in consecutive images.

III. INDENTATIONS AND EQUATIONS

Model test package:

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PARAMETRIC ANALYSIS

The plastic markers were tracked with the help of image analysis over sequence of images. Deformation was observed to reduce significantly when geofoam was includes below the shallow foundation. The primary deforming zone was found to be concentrating in and around the foundation area when geofoam was introduced in the geometry. Further, these deformations were observed to be reducing the visible heaves at the surface as well as the deformations in the buried cast iron pipe. Figure 2 shows the displacement vector diagrams for buried pipeline models without and with geofoam having different length and thickness. Comparison is made between to identical models with and without geofoam at a maximum displacement of 0.03m. The soil deformations carry further to the buried pipe and the zone of plastic equilibrium moves away and form a heave on both side of the described displacement of the strip footing. When geofoam was placed below described displacement of the strip footing at depth D these heave were observed to decrease with increase in thickness of geofoam and length of geofoam. Geofoam inclusion provides a compressible bed below described displacement of the strip footing which compress according the load transferred (maximum at the center and minimum at the corner) forming an invert arch. Due to this the load transfer divert from axial direction to the outward diagonal directions. At the same time majority of the moments in the soil occurs well above the buried cast iron pipe. This facilitates the shear strength enhancement of the soil and thus transfers lesser loads on the buried pipe.

IV. FIGURES AND TABLES

TABLES

Table 1. Properties of the model materials used in present study

Properties	Values		
Sand			
Material model	Mohr-Coulomb		
Material type	Drained		
Specific gravity	17.00 KN/m^3		
Elastisity	9000 KN/m^2		
Poissions ratio	0.3		
Cohession	1		
Angle of interfraction	27		
Inter interface	0.8		
Cast Iron Pipe			
Outer diameter	0.05		
Inner diameter	0.48		
Rigidity of pipe	6.74 x 10^-4 KNm^2/m		
Geofoam			
Geofoam type	(Expanded polystyrene)	(Expanded polystyrene)	(Expanded polystyrene)
Geofoam legend	EPS8	EPS16	EPS24
Density(Kg/m3)	8	16	24
Elastisity	250	450	800
Poissions ratio	0.012	0.092	0.137
Cohession	3 (KN/m^2)	4 (KN/m^2)	8 (KN/m^2)
Inter interface	0.8	0.8	0.8
Specific gravity unsaturated	0.008	0.016	0.024
Specific gravity saturated	0.01	0.019	0.027

Table 2. Details of the model test performed in the present study

Test legend	D (mm)	L (mm)	t (mm)	density (kg/m3)
M001	50	* N.A	* N.A.	* N.A.
M002		50	10	8
M003		50	10	16
M004		50	10	24
M005		50	20	8
M006		50	20	16
M007		50	20	24
M008		50	50	8
M009		50	50	16
M010		50	50	24
M011		100	10	8
M012		100	10	16
M013		100	10	24
M014		100	20	8
M015		100	20	16
M016		100	20	24

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M017		100	50	8
M018		100	50	16
M019		100	50	24
M020		150	10	8
M021		150	10	16
M022		150	10	24
M023		150	20	8
M024		150	20	16
M025		150	20	24
M026		150	50	8
M027		150	50	16
M028		150	50	24
* Not applicabel as test was performed without geofoam inclusion				
NOTE: D=depth at which geofoam place, L=length of geofoam, t=thickness of geofoam				

Table 3 Summary of the model tests performed in the present study

Test legend	D (mm)	L (mm)	t (mm)	density (kg/m3)	displacement in pipe(mm)	axial force on pipe (KN/m)
M001	* N.A.	* N.A.	* N.A.	* N.A.	0.276	0.174
M002	50	50	10	8	0.244	0.154
M003		50	10	16	0.275	0.168
M004		50	10	24	0.277	0.172
M005		50	20	8	0.286	0.173
M006		50	20	16	0.306	0.181
M007		50	20	24	0.241	0.204
M008		50	50	8	0.151	0.96
M009		50	50	16	0.186	0.122
M010		50	50	24	0.288	0.177
M011		100	10	8	0.289	0.183
M012		100	10	16	0.27	0.17
M013		100	10	24	0.288	0.181
M014		100	20	8	0.252	0.159
M015		100	20	16	0.266	0.165
M016		100	20	24	0.3	0.188
M017		100	50	8	0.19	0.127
M018		100	50	16	0.206	0.133
M019		100	50	24	0.308	0.185
M020		150	10	8	0.309	0.189
M021		150	10	16	0.307	0.187
M022		150	10	24	0.322	0.192
M023		150	20	8	0.275	0.176
M024		150	20	16	0.296	0.184
M025		150	20	24	0.31	0.191
M026		150	50	8	0.18	0.121
M027		150	50	16	0.26	0.134
M028		150	50	24	0.3	0.179
* Not applicable as test was performed without geofoaminclusion						
NOTE: D=depth at which geofoam place, L=length of geofoam, t=thickness of geofoam						

FIGURES

Fig.1 Schematic cross section of buried pipe with and without geofoam

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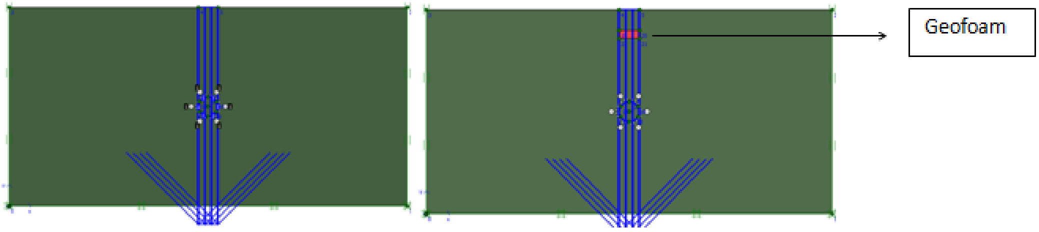
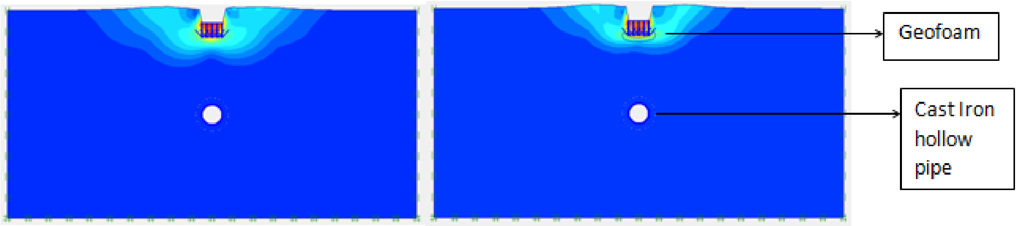
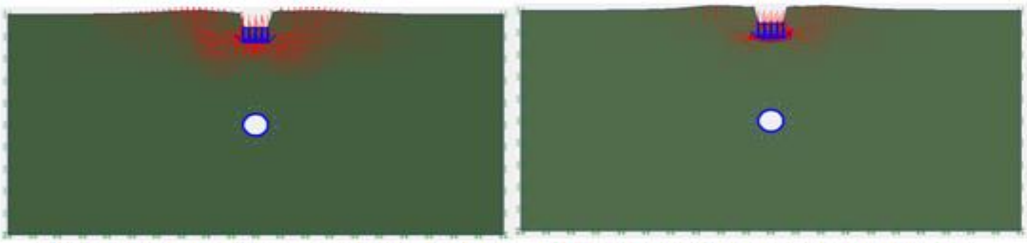


(a) Profile at the beginning of the test

MODEL MATERIALS

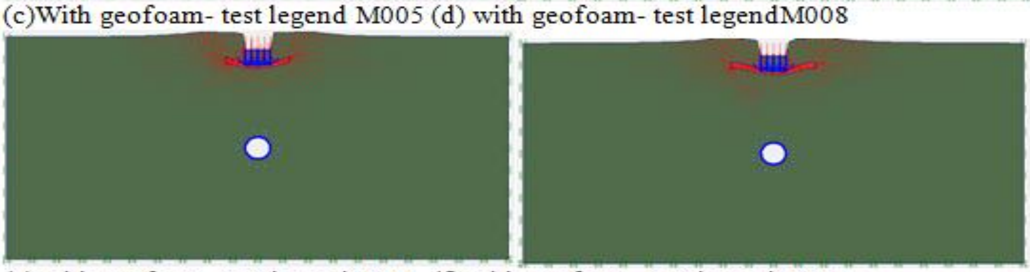


(b) Deformed profile



(a) Without geofoam- test legend M001 (b) with geofoam- test legend M002

(c)With geofoam- test legend M005 (d) with geofoam- test legendM008



(e) with geofoam- test legendM011 (f) with geofoam- test legendM020

Fig. 2 Displacement vectors for test models without and with geofoam

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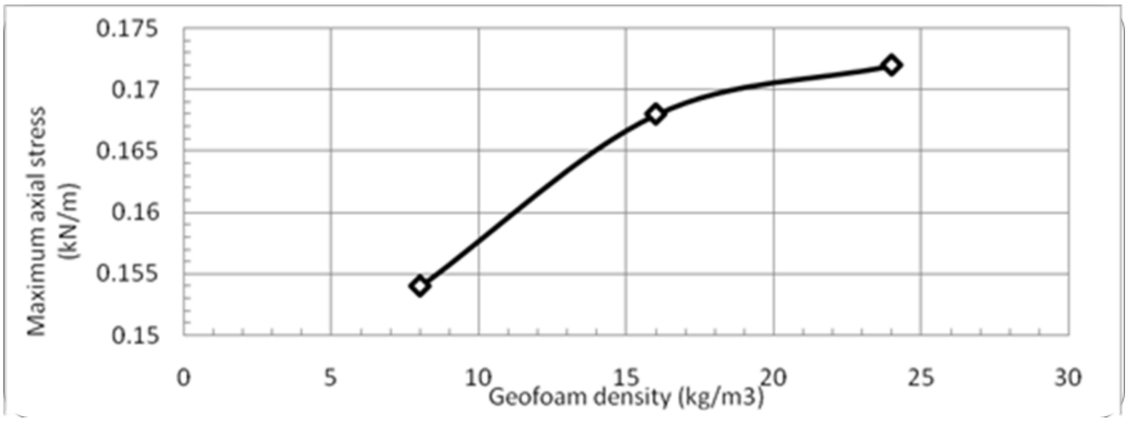
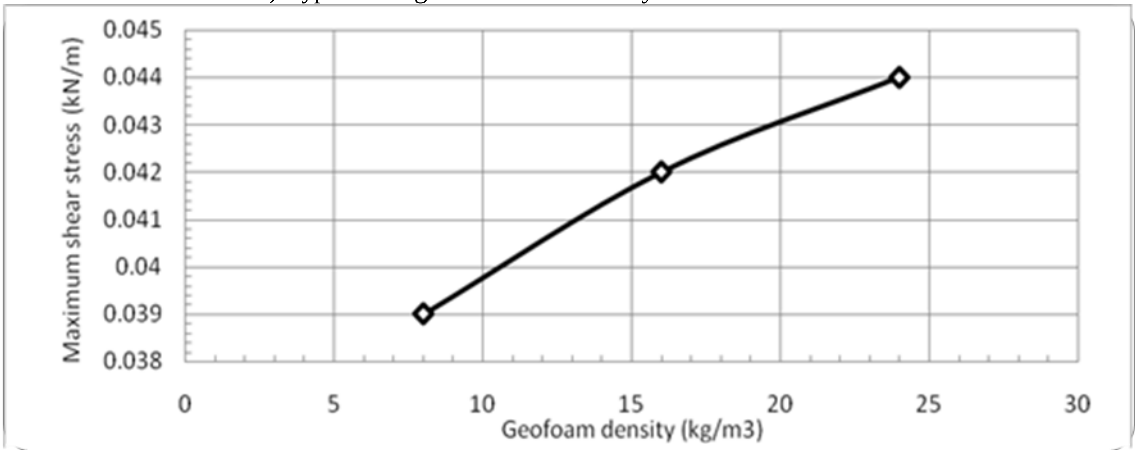
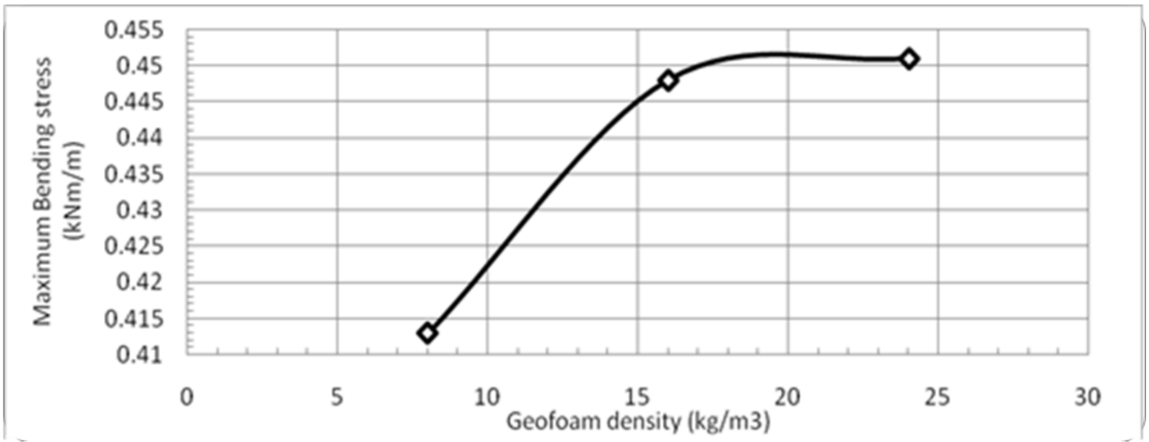


a) Typical e-log for Geofoam density with Maximum axial stress



b) Typical e-log curve for Geofoam density with Maximum shear stress



c) Typical e-log curve for Geofoam density with Maximum Bending Stress

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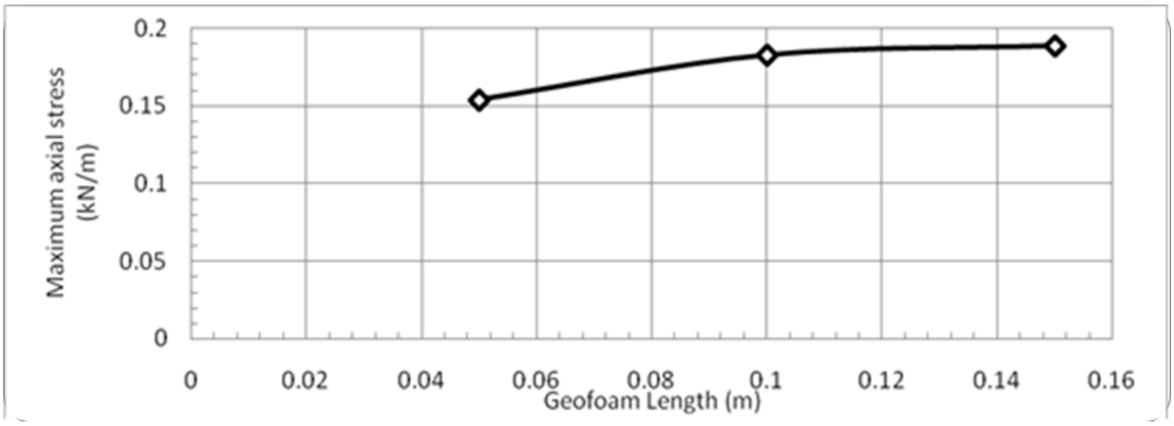
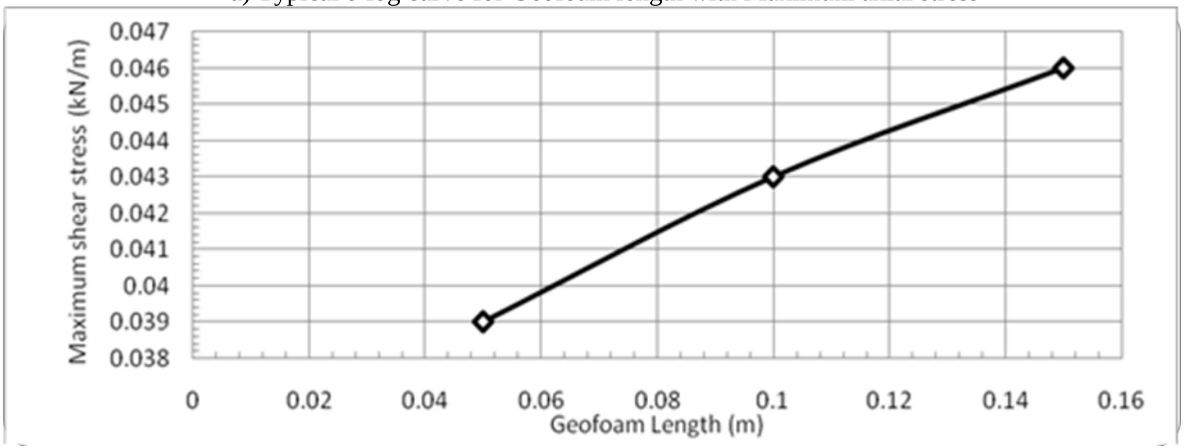
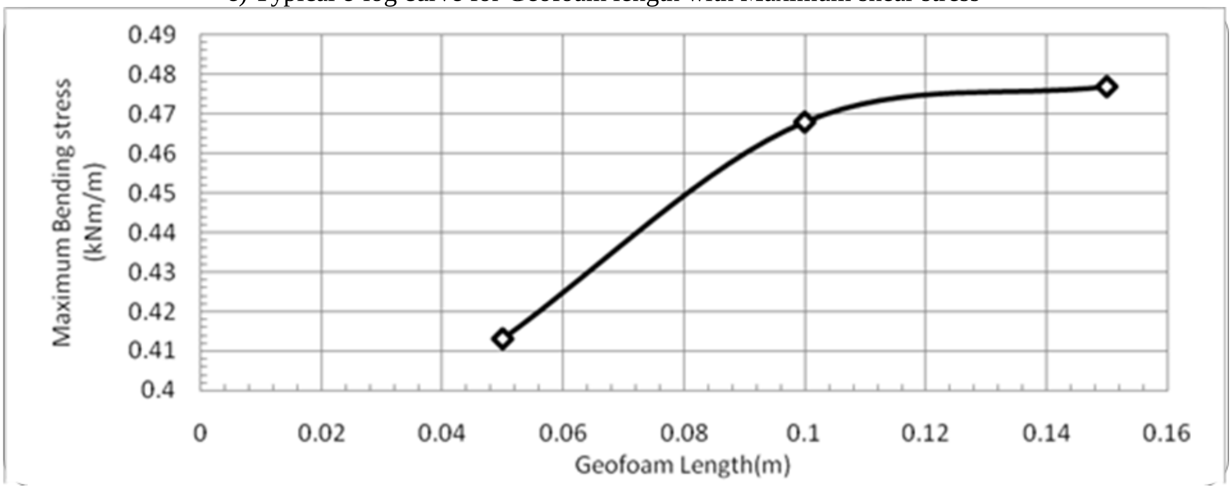


d) Typical e-log curve for Geofoam length with Maximum axial stress



e) Typical e-log curve for Geofoam length with Maximum shear stress



f) Typical e-log curve for Geofoam length with Maximum bending stress

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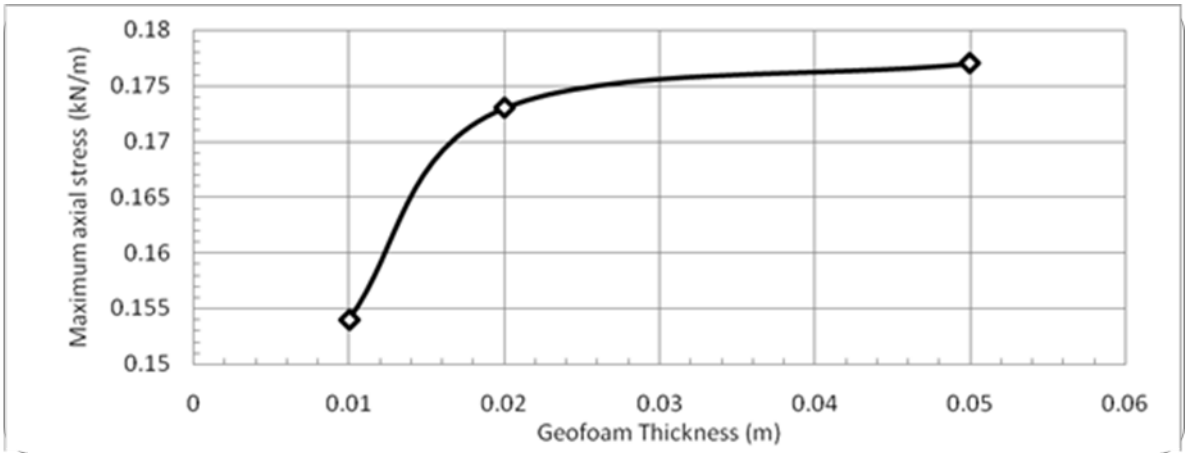
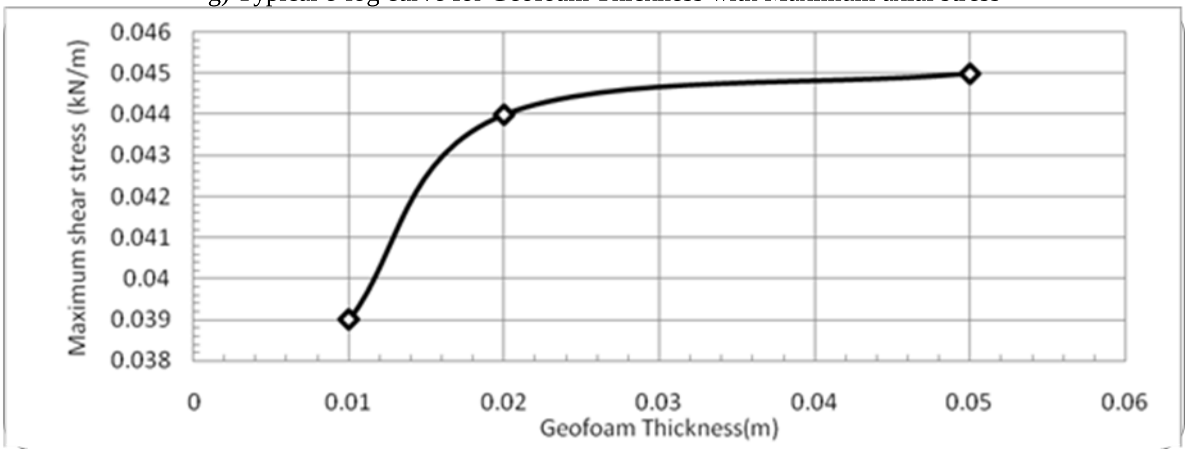
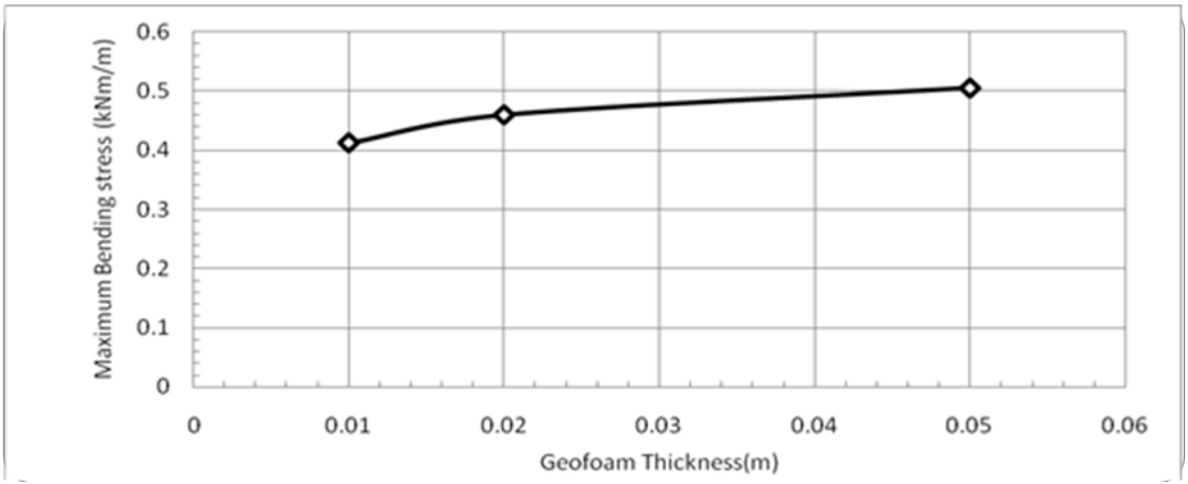


g) Typical e-log curve for Geofoam Thickness with Maximum axial stress



h) Typical e-log curve for Geofoam Thickness with Maximum shear stress



i) Typical e-log curve for Geofoam Thickness with Maximum bending stress

Fig 3 Influence of geofoam thickness, length & density on the load transfer

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V. CONCLUSION

1. Geofoam as a compressible inclusion placed below described displacement of the strip footing provides significant reduction in transferred load on the buried cast iron pipe.
2. The load on buried pipe reduces as the density of the geofoam inclusion decrease. So, the load transferred could be made minimum by decreasing density of the geofoam inclusion. With increase in width of the geofoam load reduction increase.

LIMITATIONS

1. The superstructure may be disturbed because of low density of a geofoam with greater thickness.

2. Load transfer mechanism may also be the function of pipe material type and surrounding soil, so a detailed parametric study using these variable is needed to perform to arrive up to suitable implementation of geofoam in the field applications of pressure reduction.

RESULTS AND DISCUSSION

Influence of geofoam thickness, geofoam length and geofoam density; Deformation in the vertical direction was calculated from image analysis for all the model tests performed in the present study. It was observed that the deformations in the pipe are inversely proportional to the thickness & length of the geofoam and directly proportional to the density of the geofoam. Figure 3 shows the variation of vertical deformation occurred in pipe with respect to the thickness of the geofoam maximum reduction in load transferred of up to 33.33% was observed in case of low-density geofoam (EPS8) having a maximum thickness of geofoam 50mm.table 3 summarizes the results obtained from the series of the model tests performed in this study.

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