Behavior and Modeling of Some Underground Utilities Using Geofoam Technologies

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Abstract: This paper investigates the effect of using expanded polystyrene EPS geofoam techniques on reducing the vertical and horizontal stresses acting on flexible buried pipes based on an experimental study and numerical analysis. An experimental model with center flexible pipe resting on sand, the overburden is either in the form of pure sand or EPS geofoam blocks and sand applied with EPS different techniques. A series of experiments were carried out to measure the pipe deformation using a static surface loading. The numerical analysis was carried out to simulate the experimental model using the finite element software programs PLAXIS-3D. The results showed that, the EPS geofoam block reduces the buried pipe deflections and strains by a percentage depending on block density and applied technique, and the most effective methods are EPS encasement block with a head void method and EPS block embraces the upper pipe part. The numerical results from PLAXIS-3D and the experimental measured data are compatible with same trend, with more results based on parametric study.
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Keywords Buried pipes; Expanded polystyrene EPS; Experimental Model; Numerical Analysis.

1. Introduction

Underground Utility are infrastructures such as: buried pipelines and conduit systems which used for transmitting or distributing water supply, waste water, natural gas and oil, electricity, heat, lights, storm drains and other similar commodities. Buried pipes are manufactured from different materials in various shapes and sizes (Ilamparuthi and Rajkumar, 2009). The main constructed types of buried pipes and conduits are ditches and projecting conduits that divided into positive, negative and imperfect ditch projecting conduits. Pipes may be flexible or rigid. Underground utilities are expected to withstand the induced stresses from live and dead loads, earth pressure and internal pressure. All these stresses cause problems such as radial deformation, ring bending, axial extension or compression and longitudinal bending moment, these problems may lead to leakage or broken of pipe network (Ng, 1994).

The Expanded Polystyrene (EPS) geofoam was used as lightweight construction material from 1972 at Oslo, Norway for the roadway project. It was used as foam blocks in the U.S.A in 1980s. Japanese constructed their first lightweight fill project in 1985, after a few years geofoam usage in Japan comprised approximately 50 percent of the worldwide used as a lightweight fill (NCHRP, 2004).

Yoshizaka and Sakanoue, (2004) investigated the reduction of soil pipe interaction due to two kinds of lightweight back-fill material EPS (Expanded Polystyrene) and EGW (Expanded Glass Waste) on buried pipe. The results showed that, lightweight back-fill had 56% and 34% reduction in the lateral soil-pipe forces, respectively, on the soil-pipe interaction in the case that the cover-depth is 0.9 m.

Bartlett et al., (2015) summarized different cover systems of EPS geofoam to protect infrastructures that traverse through or under roadway and railway from deformations or ruptures. The cover systems are embankment, imperfect ditch method, slot-trench cover system with EPS block placed in slot and finally post and beam EPS system. The results showed that, EPS geofoam blocks lightweight cover systems protect buried steel pipes from faulting or permanent ground deformation.

This research will assess the stresses and deformations of flexible buried UPVC pipe and the behavior of soil back-fill around it, under static loading conditions by performing a series of laboratory experimental model tests. Different techniques using EPS geofoam with different densities as partially lightweight back-fill material was evaluated to reduce stress on buried pipes, and minimize its deformations. The experimental results for all cases are comparing with finite element software program 'PLAXIS-3D' for the same model and parametric study.

2. Model Experimental Work and Applied Techniques

The loading frame with steel tank dimensions are 1400 mm long x 300 mm width x1200 mm height, UPVC pipe was placed in position crossing the tank faces as shown in Figure (1).

Five series of tests were carried out to investigate the different overburden geofoam techniques, the setup of these were carried as follows:

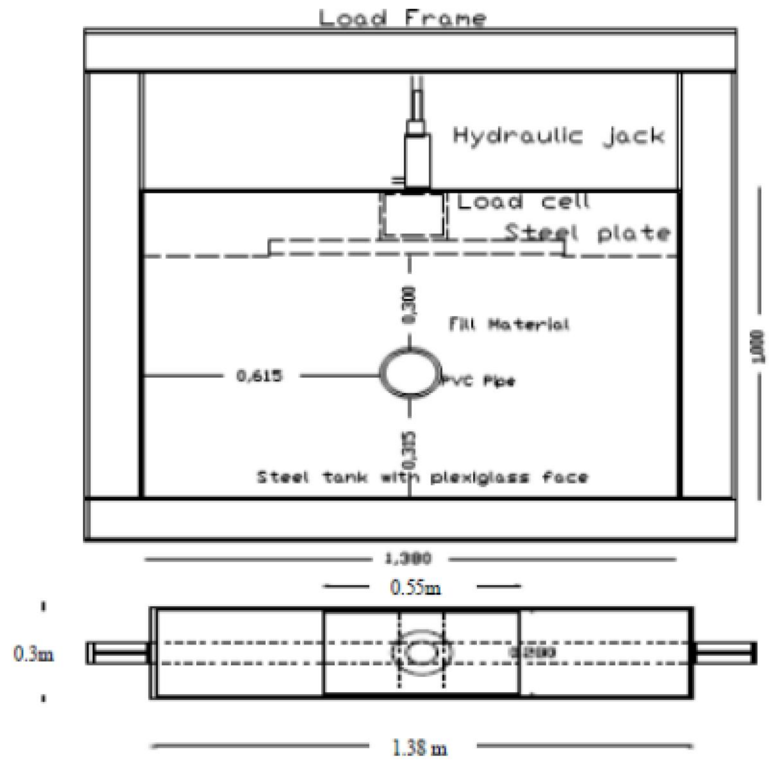


Figure 1. The loading frame and steel tank

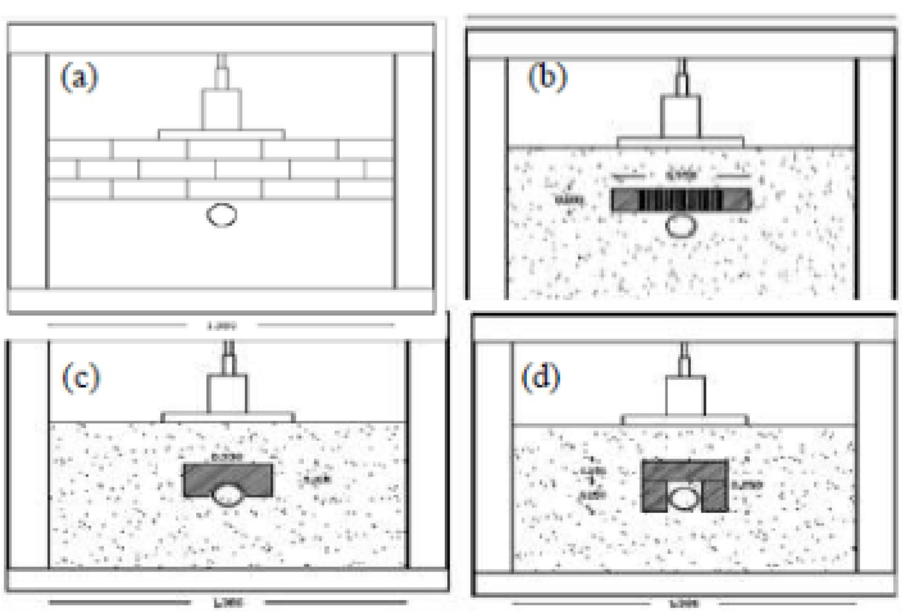


Figure 2. The experimental model (a) Embankment (b) Imperfect ditch method (c) Embraces upper pipe (d) Encasement pipe

(a) Pure sand overburden method: In this test UPVC pipe was placed in position crossing the tank faces, and the sand was placed in three lifts and compacted around the pipe from the invert to the crown, to reach the height of 300mm above the crown. Thin colored layer of sand was put at the top of the overburden layer, and black line was drawn on the outside of the fiber glass to monitor the deformation of the sand lifts.

(b) Embankment method: The overburden layer was formed from EPS geofoam blocks to reach the height of 300 mm over the pipe crown as shown in Figure (2a).

(c) Imperfect ditch method: In this technique EPS block was used as an imperfect ditch overburden model. The sand was poured on the pipe and compacted to reach 20mm height over pipe. A layer of EPS geofoam block was placed over sand with dimensions of 550mm×100mm, then compacted sand fill was put to reach the height 300mm over pipe crown, as shown in Figure (2b).

(d) Embraces upper pipe method: the overburden layer of EPS geofoam block with dimensions of 330mm×165mm was put on the pipe, the EPS block was tailored as curved shape to fit the pipe diameter from one side to embraces upper part of the pipe directly, and then the block level was adjusted. The sand fills the model to reach the 300mm height over pipe crown, as shown in Figure (2c).

(e) Encasement pipe method: Embedded EPS encasement block as overburden model was prepared by placing two posts from EPS geofoam with dimensions of 165mm height×100 width at both sides of the pipe, and then EPS beam block with dimensions 330mm×165mm was put the foam block leveled horizontally. The sand was poured in the model and compacted to reach the 300mm height as shown in Figure (2d).

3. Numerical Analysis

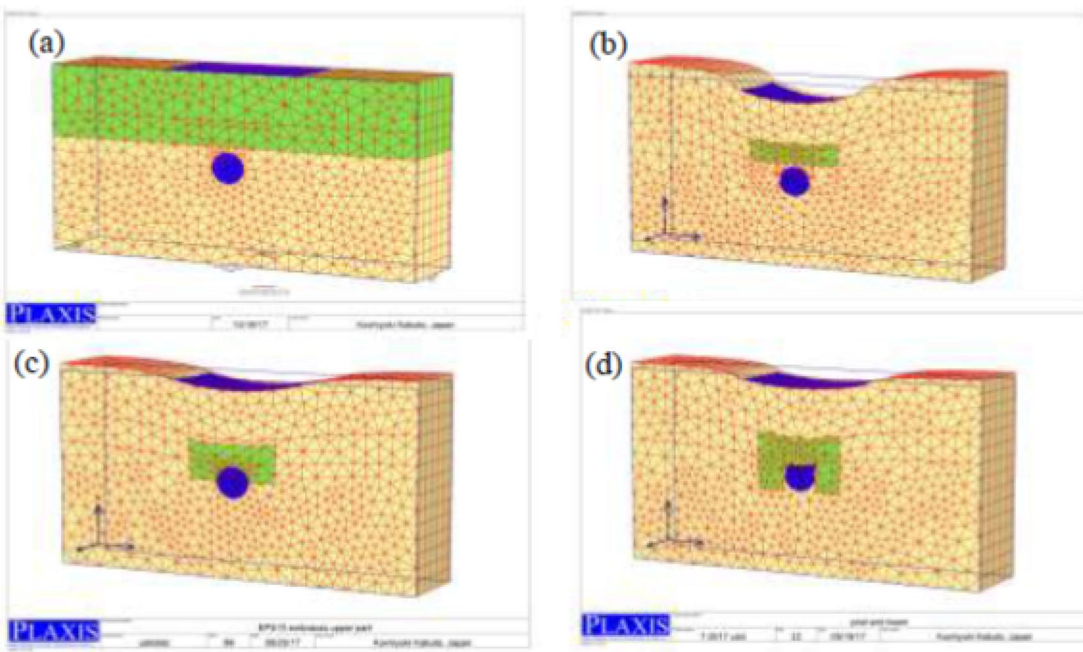


Figure 3. Numerical model in case of EPS block (a) Embankment (b) Imperfect ditch method (c) Embraces upper pipe (d) Encasement pipe.

Table (1) Properties of Materials

Property	Sand	EPS 15	EPS 30	UPVC pipe
Unit Weight (kN/m^3)	15.5	0.147	0.289	13.98
Modulus of elasticity E (kN/m^2)	11000	3000	8000	2.75×10^6
Specific gravity G_S	2.69	-	-	-
Shear parameters	Φ=32°	Φ=7°	Φ=10°	-
Poisson’s ratio ν	0.30	0.07	0.2	0.4
EA (kN/m)	-	-	-	4590
EI (kNm^2/m)	-	-	-	6.05

In this study the experimental models were simulated and verified using finite element software program PLAXIS-3D as shown in Figure (3). The dimensions of the numerical model are the same dimensions of the experimental model 1380mm long, 1000mm height and 300mm wide. The pipe dimensions were 110 mm in diameter and 4 mm wall thickness represented as six circular segment elements as plate. The model identified as a plane strain of 15-node elements then it was generated in third dimension, sand was undrained using Mohr-Columbe plasticity model and EPS was Linear Elastic model. This research predicts surface displacement, crown and spring line deformation to be compared with experimental results from surface stress for level up to180 kN/m^2. The results of five experimental models were previously published in paper by (Bahr et al., 2017). Figure (3) shows the models in Plaxis-3D; table1 summarizes the material properties of EPS geofoam and sand.

4. Verification of Proposed Numerical Model

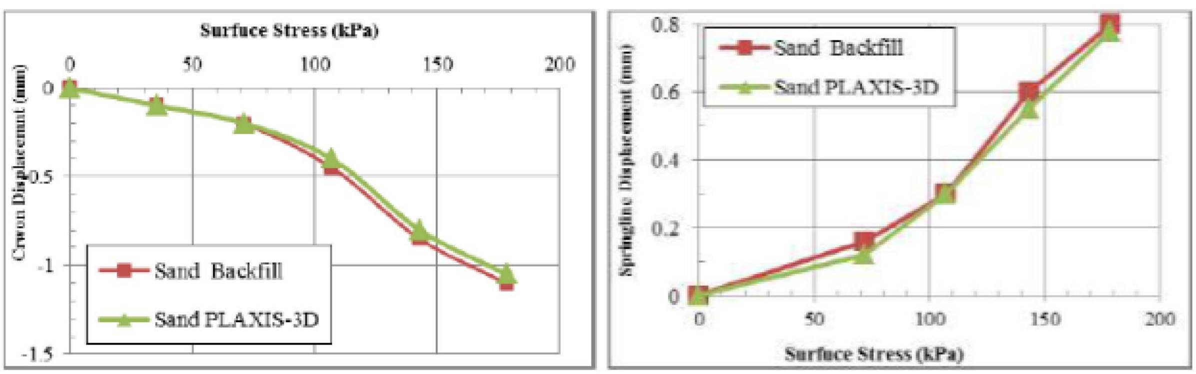
The four EPS geofoam models were previously studied using experimental physical model (Bahr et al., 2017), the experimental results showed that, the most effective models which reduce the stresses on flexible pipe were EPS encasement pipe with head void model and then EPS block embraces the upper pipe model.

4.1 Sand Back-fill Model

Figure (4-a, b) show the deformation of the pipe crown (vertical) and spring line (horizontal) as results in case of sand back-fill, the predicted numerical results are in fair agreement with the measured experimental data. The crown curves has linear behavior when the surface stress for stress level up to 71.5kPa, then the behavior changed to be nonlinear at maximum surface stress180kPa. The spring line curves have linear behavior for surface stress level up to 143kPa, then changes to be nonlinear trend.

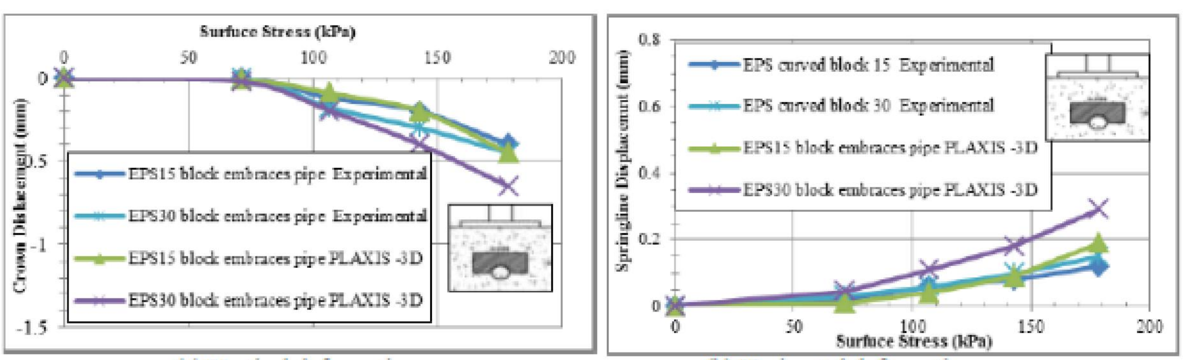
4.2. Embedded EPS Block Embraces the Upper Part of the Pipe

Figures (5-a, b) show the pipe crown (vertical) and spring line (horizontal) deformations in case of EPS block embraces pipe method. The results indicate that, for both EPS 15 and EPS30, the crown and spring line deformations to be linear up to stress level of 71.5 kN/m^2, after which the deformations becomes nonlinear with higher rate.



(a) Vertical deformation (b) Horizontal deformation

Figure 4. Deformation of UPVC buried pipe in case of sand back-fill model



(a) Vertical deformation (b) Horizontal deformation

Figure 5. Deformation of UPVC buried pipe in case of embedded EPS block embraces the Pipe upper part model.

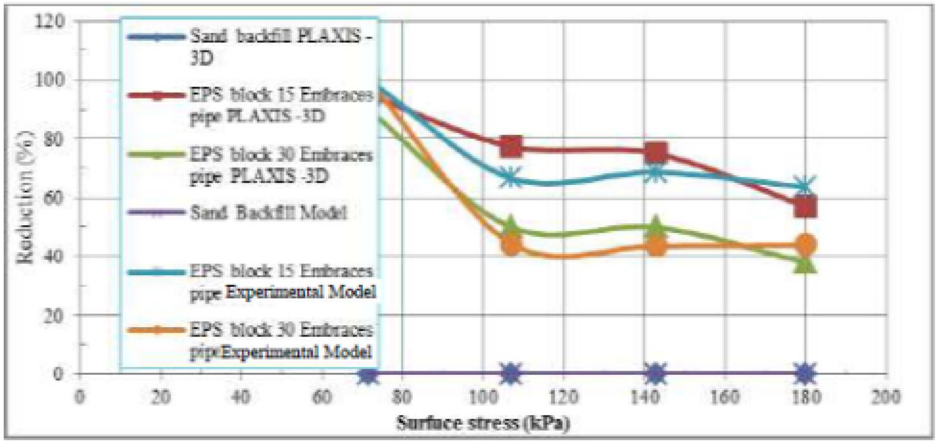


Figure 6-a. Percentage reduction in crown deformation of UPVC buried pipe in case of embedded EPS block embraces the pipe upper part the pipe model

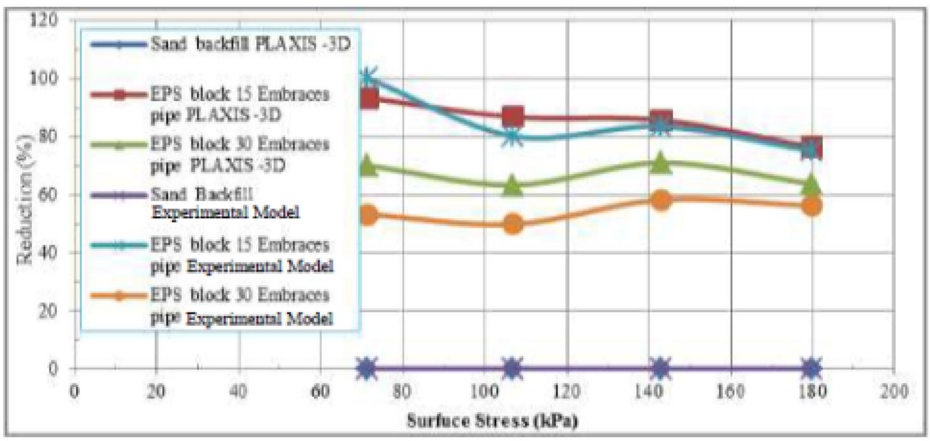


Figure 6-b. Percentage reduction in spring line deformation of UPVC buried pipe in case of EPS block embraces the pipe upper part the pipe model

The effectiveness of embedded EPS block embraces the upper part of the pipe to reduce the vertical (crown) and Horizontal (spring line) deformations are presented in Fig (6-a & b). The numerically predicted reduction was evaluated based on the experimentally measured data as listed in Table (2).

Table (2) Numerical prediction of percentage reduction and experimentally measured deformations for embedded EPS block embraces the upper part of the pipe

Foam	**Stress (kPa)**	**Vertical (Crown)**			**Horizontal (Spring line)**		
		71.5	**143**	**180**	**71.5**	**143**	**180**
EPS 15	Experimental	100	70	65	100	83	75
	Numerical	100	75	56	93	83	74
	Compatibility	100	107	86	93	100	98.7
EPS 30	Experimental	100	45	44	58	59	55
	Numerical	90	50	38	67	69	62
	Compatibility	90	111	86	115	115	112

The comparison of Table (2) indicates that, the numerically predicted percentage reduction in crown and spring line deformations are nearly close to measured results by about 86%-115%.

4.3. Embedded EPS Encasement Blocks Model

The numerically predicted pipe vertical and horizontal deformations compared with the experimentally results are plotted in Figure (7). It can be observed that, the crown and spring line deformations with EPS 15 or EPS30 to be in linear relationship up to stress level of 71.50 kN/m^2, after which the deformations becomes nonlinear with higher rate.

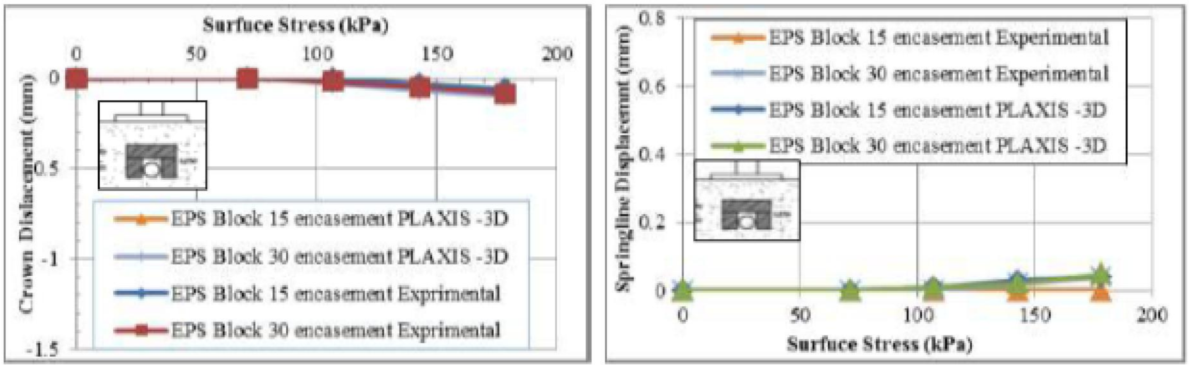


Figure7. Deformation of UPVC buried pipe in case of embedded EPS encasement blocks model.

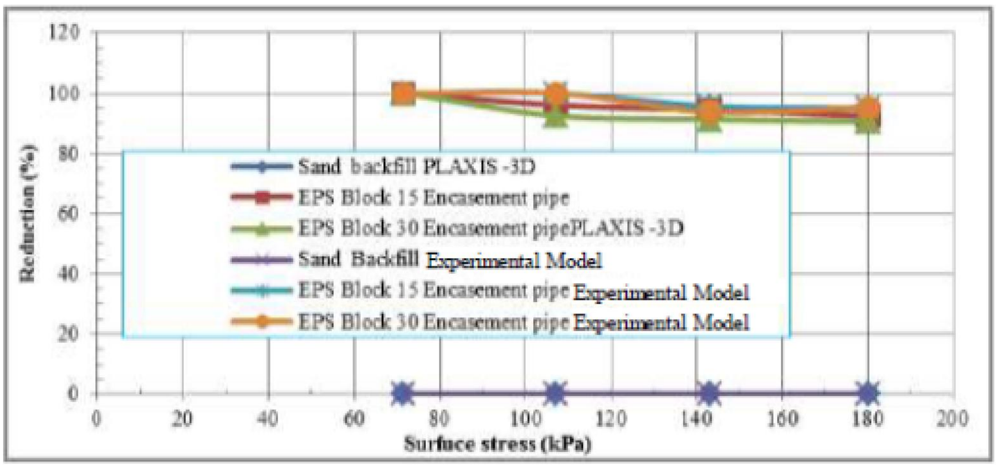


Figure 8-a. Percentage reduction in crown deformation of UPVC buried pipe in case of embedded EPS block embraces the pipe upper part the pipe model

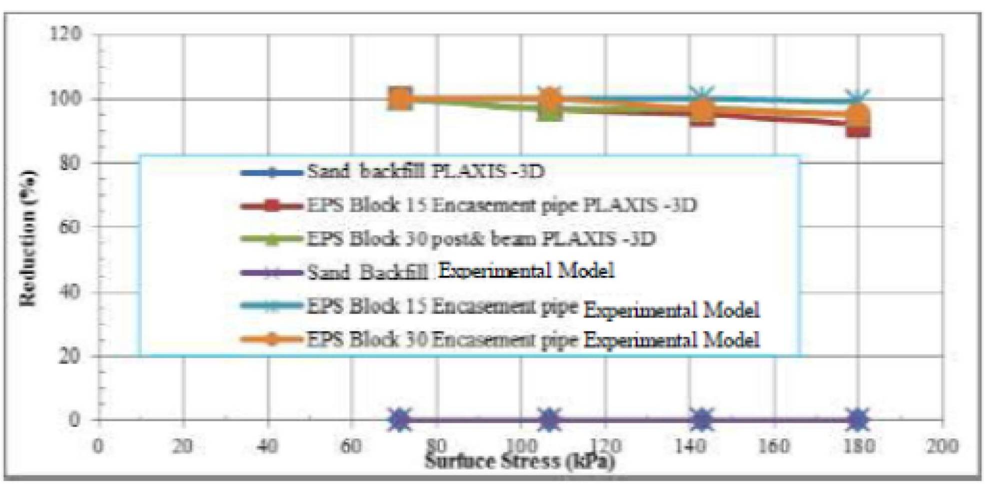


Figure 8-b. Percentage reduction in spring line deformation of UPVC buried pipe in case of embedded EPS block embraces the pipe upper part the pipe model

The effectiveness of Embedded EPS Encasement Blocks method to reduce the pipe crown and spring line deformations with EPS 15 and EPS30 under various applied surface loading are presented in Fig (8-a & b). The numerically predicted reduction was evaluated based on the experimentally measured data as listed in Table (3).

Table (3) Numerical prediction of Percentage reduction and experimentally measured deformations for embedded EPS encasement blocks model

Foam	**Stress (kPa)**	**Vertical (Crown)**			**Horizontal (Spring line)**		
		71.5	**143**	**180**	**71.5**	**143**	**180**
EPS 15	Experimental	100	100	95	100	100	99
	Numerical	100	96	92	100	97	92
	Compatibility	100	96	97	100	97	94
EPS 30	Experimental	100	100	95	100	97	95
	Numerical	100	93	90	100	97	95
	Compatibility	100	93	95	100	100	100

Table (3) indicates that, in case of embedded EPS encasement blocks, the numerically predicted percentage reduction in crown and spring line are nearly close to measured experimental results by about 93%-100%.

5. Parametric Study

The proposed numerical model was applied to investigate the deformations of PVC and steel pipe 600 mm (24”) diameter crossed the road, with different overburden depths corresponding to pipe diameter (H/D), and EPS geofoam with various densities. The intensity of maximum live load from road traffic was estimated to be 180kN/m^2. The model identified as a plane strain with 15-node elements and it was generated in third direction. The materials were defined as undrained using Elasto-plastic Mohr–Coulomb model and EPS was Linear Elastic model.

Table 4. Properties of materials

Property	**Sand**	**Concrete**	**EPS 15**	**EPS 22**	**EPS 30**	**PVC Pipe 600 mm (24")**	**Steel Pipe 600 mm (24")**	**PVC Pipe 300 mm (12")**
Unit Weight (kN/m^3)	17.5	22	0.147	0.218	0.289	14	75	14
Modulus of elasticity E (kN/m^2)	20000	22000	3000	5500	8000	-	-	-
Specific gravity G_S	2.75	-	-	-	-	-	-	-
Relative density (D_r)	0.4	-	-	-	-	-	-	-
Shear parameters	-	-	-	-	-	-	-	-
Poisson’s ratio ν	0.25	0.2	0.07	0.15	0.2	0.37	0.3	0.37
EA (kN/m)	-	-	-	-	-	0.864×10^5	37×10^5	0.986×10^5
EI (kNm^2/m)	-	-	-	-	-	3730	1.7×10^5	1216

5.1. Effect of Different Overburden Models on 600mm Steel and PVC Pipe

Figure (9) shows the surface deformation results in case of embedded EPS block embraces pipe with different EPS densities and overburden depth. The results show the surface deflection curves have the high deflections at shallow depth of H/D= 0.5, then to decreases with the increase of overburden depths. The surface displacement of EPS encasement blocks model is more than EPS embraces upper part of pipe.

Figures (10) indicated that, the shows comparison of crown (vertical) deformation results in case of EPS block embraces pipe and EPS encasement pipe with various overburden depths and EPS densities. The results indicate that, the crown deflection curves have high deflection at shallow depth of H/D= 0.5, then the displacement to decrease with the increase of overburden depth. The EPS encasement blocks model with different EPS densities had no effect on pipe at crown.

Figures (11) illustrated that, the shows comparison of spring line (horizontal) deformation results in case of EPS block embraces pipe and EPS encasement pipe with relative various overburden depths and EPS densities. The results illustrated that, the spring line deflection curves have high deflection at shallow depth of H/D=0.5, then the displacement to decrease with the increase of overburden depth. The

EPS encasement blocks model with different EPS densities had no effect on pipe at spring line.

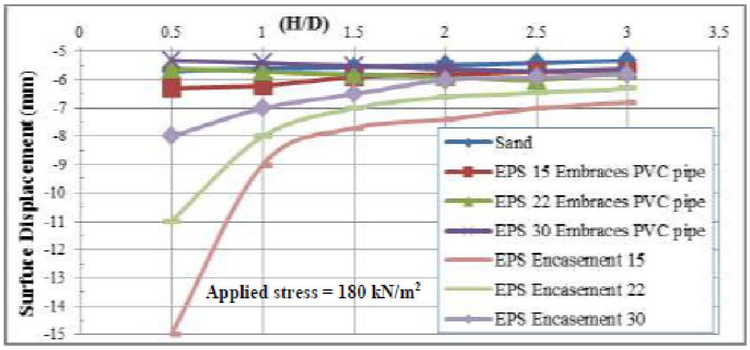


Figure (9) Surface displacement in case of embedded EPS block Encasement and Embraces upper PVC and Steel pipe model with relative EPS densities and (H/D).

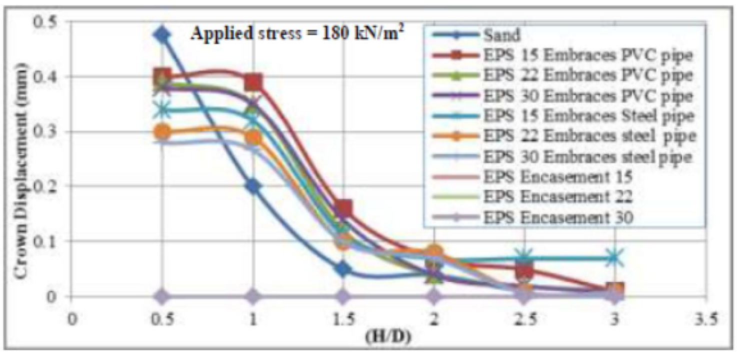


Figure 10. Crown displacement in case of embedded EPS block Encasement and Embraces upper PVC and Steel pipe model with relative EPS densities and (H/D).

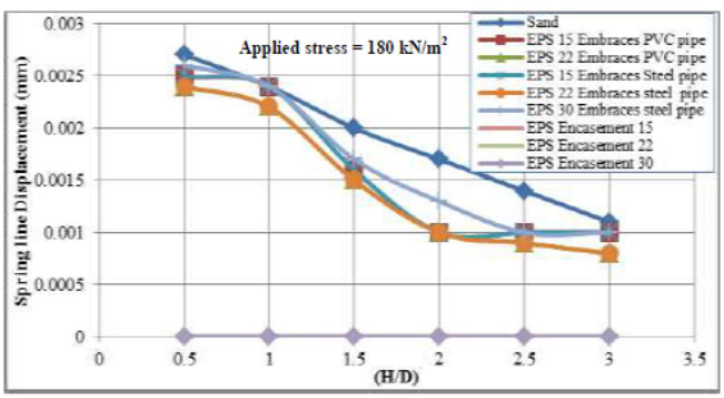


Figure 11. Spring line displacement in case of embedded EPS block Encasement and Embraces upper PVC and Steel pipe model with relative EPS densities and (H/D).

5.2. Density of EPS and Pipe Diameter

5.2.1 Expanded Polystyrene Geofoam (EPS) 15

Figure (12) shows the surface deformation results in case of embedded EPS 15 block embraces pipe with different pipe diameter and overburden depth. The results show the surface deflection curves have high deflection at shallow depth 0.3m then the displacement decrease with increase of overburden depth. In case of EPS embraces upper pipe the surface displacement had the same trend and value of sand. The surface displacement of EPS encasement blocks model is more than EPS embraces upper part of pipe.

Figures (13) indicated that, the comparison of crown (vertical) deformation results in case of EPS 15 block embraces pipe and EPS encasement pipe with various overburden depths and pipe diameter. The results indicate that, the crown deflection curves have high deflection at shallow depth of 0.3m, then the displacement to decrease with the increase of overburden depth, small diameter has large displacement. The EPS encasement blocks model with different EPS densities had no effect on pipe at crown.

Figures (14) illustrated that, the comparison of spring line (horizontal) deformation results in case of EPS 15 block embraces pipe and EPS encasement pipe with relative various overburden depths and pipe diameter. The results illustrated that, the spring line deflection curves have high deflection at shallow depth of 0.3m, then the displacement to decrease with the increase of overburden depth, small diameter has large displacement. The EPS encasement blocks model with different EPS densities had no effect on pipe at spring line.

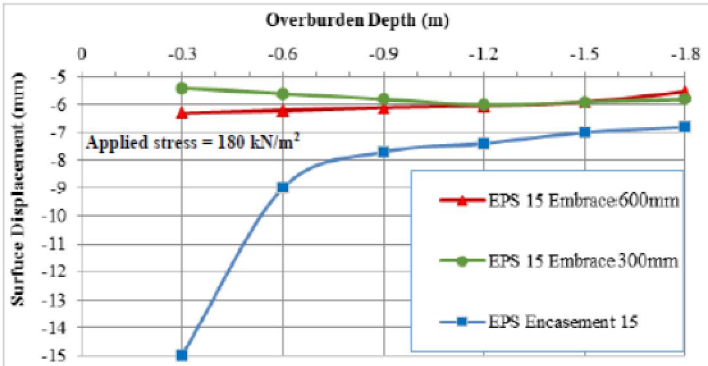


Figure 12. Surface displacement in case of EPS 15 models on 600 mm (24") and 300 mm (12") pipes

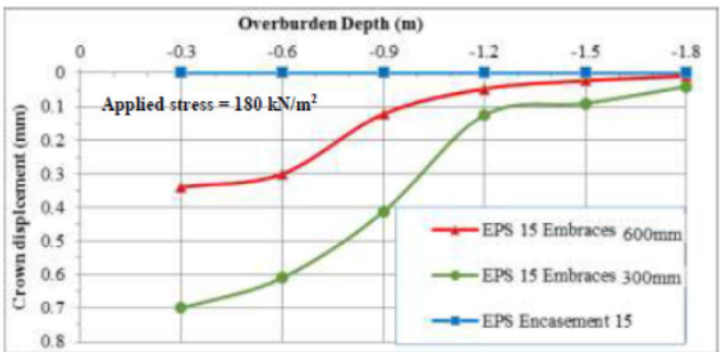


Figure 13. Crown displacement in case of EPS 15 models on 600 mm (24") and 300 mm (12") pipes

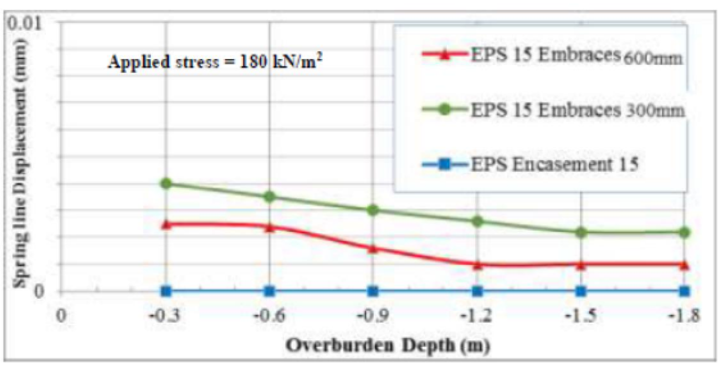


Figure 14. Spring line displacement in case of EPS 15 models 600 mm (24") and 300 mm (12") pipes

5.3.2 Expanded Polystyrene Geofoam (EPS) 22

Figure (15) shows the surface deformation results in case of embedded EPS 22 block embraces pipe with different pipe diameter and overburden depth. The results show the surface deflection curves have high deflection at shallow depth 0.3m, then the displacement decrease with increase of overburden depth. In case of EPS embraces upper pipe the surface displacement had the same trend and value of sand.

The surface displacement of EPS encasement blocks model is more than EPS embraces upper part of pipe.

Figures (16) indicated that, the shows comparison of crown (vertical) deformation results in case of EPS 22 block embraces pipe and EPS encasement pipe with various overburden depths and pipe diameter. The results indicate that, the crown deflection curves have high deflection at shallow depth of 0.3m, then the displacement to decrease with the increase of overburden depth, small diameter has large displacement in sand. The EPS encasement blocks model with different EPS densities had no effect on pipe at crown.

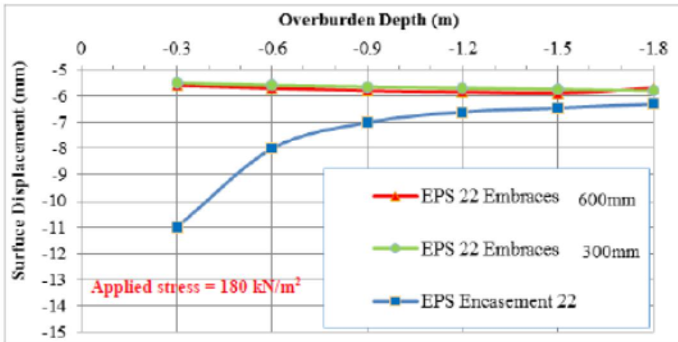


Figure 15. Surface displacement subjected to surface stress 180 kN/m^2 in case of EPS 22 models on 600 mm (24") and 300 mm (12") pipes

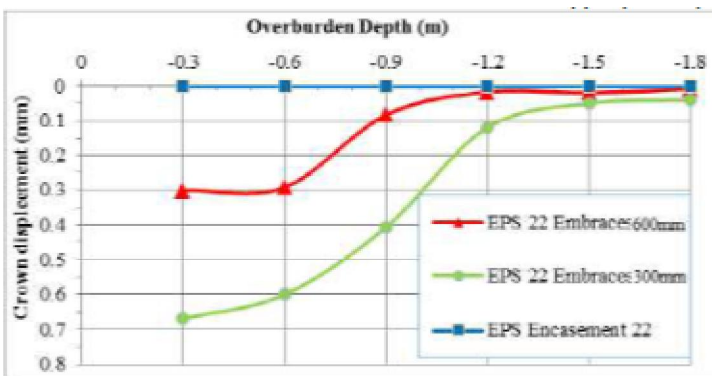


Figure 16. Crown displacement subjected to surface stress 180 kN/m^2 in case of EPS 22 models on 600 mm (24") and 300 mm (12") pipes

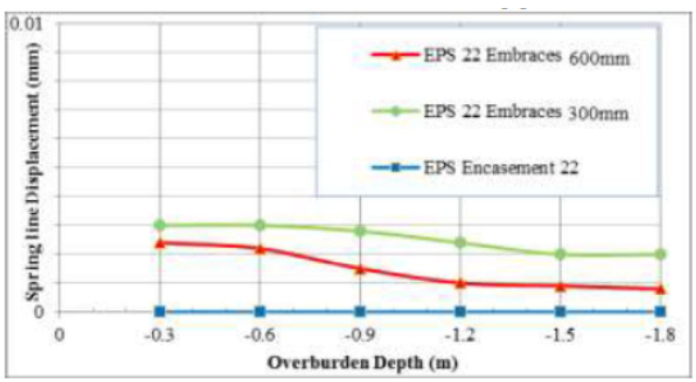


Figure17. Spring line displacement subjected to surface stress 180 kN/m^2 in case of EPS 22 models 600 mm (24") and 300 mm (12") pipes

Figures (17) illustrated that, the shows comparison of spring line (horizontal) deformation results in case of EPS 22 block embraces pipe and EPS encasement pipe with relative various overburden depths and pipe diameter. The results illustrated that, the spring line deflection curves have high deflection at shallow depth of 0.3m, then the displacement to decrease with the increase of overburden depth, small diameter has large displacement. The EPS encasement blocks model with different EPS densities had no effect on pipe at spring line.

5.3.3 Expanded Polystyrene Geofoam (EPS) 30

Figure (18) shows the surface deformation results in case of embedded EPS 30 block embraces pipe with different pipe diameter and overburden depth. The results show the surface deflection curves have high deflection at shallow depth 0.3m, then the displacement decrease with increase of overburden depth. In case of EPS embraces upper pipe the surface displacement had the same trend and value of sand. The surface displacement of EPS encasement blocks model is more than EPS embraces upper part of pipe.

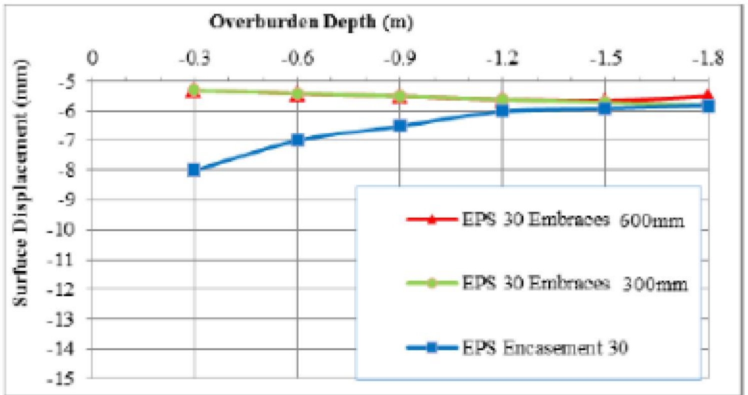


Figure18. Surface displacement subjected to surface stress 180 kN/m^2 in case of EPS30 models on 600 mm

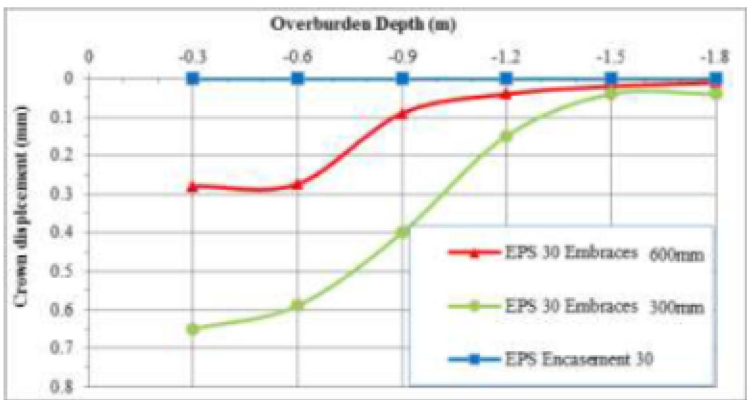


Figure19. Crown displacement subjected to surface stress 180kN/m^2 in case of EPS 30 models on 600 mm (24") and 300 mm (12") pipes.

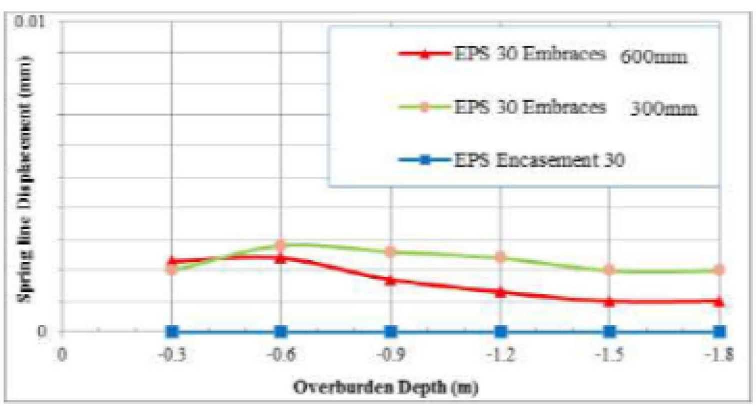


Figure 20. Spring line displacement subjected to surface stress 180kN/m^2 in case of EPS 30 models on 600 mm (24") and 300 mm (12") pipes.

Figures (19) shows comparison of crown (vertical) deformation results in case of EPS 30 block embraces pipe and EPS encasement pipe with various overburden depths and pipe diameter. The results indicate that, the crown deflection curves have high deflection at shallow depth of 0.3m, then the displacement to decrease with the increase of overburden depth, small diameter has large displacement. The EPS encasement blocks model with different EPS densities had no effect on pipe at crown. Figures (20) shows comparison of spring line (horizontal) deformation results in case of EPS 30 block embraces pipe and EPS encasement pipe with relative various overburden depths and pipe diameter. The results illustrated that, the spring line deflection curves have high deflection at shallow depth of 0.3m, then the displacement to decrease with the increase of overburden depth, small diameter has large displacement. The EPS encasement blocks model with different EPS densities had no effect on pipe at spring line.

6. Coclusions

This paper evaluates the effect of installing EPS geofoam on reducing the earth pressure distribution over buried pipes. Different EPS geofoam back-fill techniques were used such as: Embankment, Imperfect ditch, EPS block embraces the pipe and EPS encasement pipe with head void, these techniques of EPS geofoam defined as cover or as trench back-fill system. A large-scale setup model was designed to put the minimum height of back-fill in rigid box over flexible pipe and the surface pressure was applied over the steel plate, the pipe has horizontal and vertical dial gauges and two strain gauges, the density of EPS geofoam block were 15 and 30 kg/m^3. The results drawn from the experimental and numerical analysis are as following:

1. The different methods of EPS Geofoam EPS30 and EPS15 were access to reduce the earth pressure on flexible buried pipes depending on back-fill model and EP density.

2. The EPS30 geofoam embankment method reduces the vertical and horizontal deformations by about 36% and 57%, respectively. The EPS15 embankment method reduced the vertical and horizontal deformations by about 46 and 70 %, respectively.

3. The imperfect ditch method from EPS30 reduces the vertical and horizontal deformations by about 0 and 37%, respectively. EPS15 reduces the vertical deformations by about and horizontal deformations by about 50 and 60%, respectively.

4. The EPS block embraces the pipe method reduce the vertical and horizontal deformations by about 45 and 55 % for EPS 30, respectively and by about 65 and 75%, respectively for EPS15. The numerical deformation results 38% at crown and 62% at spring line for EPS 30 and 57% at crown and 74% at spring line for EPS15.

5. The EPS block encasement pipe with head void method reduces the vertical and horizontal deformations by about 95% and 95% for EPS30 and by about 95 and 99% for EPS15, respectively. The numerical deformation results 90% at crown and 95% at spring line for EPS 30 and 92% at crown and 92% at spring line for EPS15respectively.

8. The EPS 30 is more effective in case of surface displacement than EPS15 because of the EPS30 is of low compressibility.

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