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Protecting buried pipelines using different shapes of geofoam blocks

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Abstract

Purpose. This research presents experimental modeling and numerical analysis on reducing stress and protecting buried pipelines using three arrangements techniques of expanded polystyrene (EPS) geofoam blocks: embankment, EPS block embracing the upper part of the pipe and EPS blocks as two posts and a beam.

Methods. An experimental model consisted of steel tank with boundaries dimensions depending on the diameter of the pipe located at the center of it. The backfill on the pipe was made from sand and embedded EPS blocks with two techniques: EPS block embracing the upper part of the pipe and EPS blocks form two posts and a beam. Series of experiments were carried out using static loading on rigid steel plate to measure the pipe deformations and strains, as well as backfill surface displacement. The numerical analysis was used to simulate the experimental model using the finite element software program PLAXIS-3D.

Findings. The results reveal that the most effective method which prevents stress on the buried flexible pipe was EPS post and beam system followed by EPS embracing the upper part of the pipe. The results obtained from the numerical analysis and the experiment demonstrate the same trend. The parametric study shows that EPS post and beam blocks model has higher surface displacement than embracing the upper part of the pipe model, which is more effective in case of high rigidity of the pipe.

Originality. Reducing stress on buried pipes using different geofoam shapes to find which one is the optimum method.

Practical implications. Two configurations of EPS geofoam blocks – EPS block embracing the upper part of the pipe and EPS blocks post and beam system - ensure successful stress reduction and protect buried pipes.

Keywords: *buried pipelines, EPS blocks, embankment, experimental setup, numerical analysis*

1. Introduction

Underground utilities such as conduits and buried pipelines systems are used for transmitting or distributing urban commodities. Underground utilities are expected to resist stresses from dead and live loads on pipes. The buried structures problems caused by stresses are ring bending, axial stress, radial deformation and longitudinal bending. These problems may lead to leaks or breaks in a pipe network [1]. The expanded polystyrene (EPS) geofoam was used as a lightweight construction material as early as in 1972 for the roadway project in Norway, while in the USA foam blocks were first used in 1980s.

Because of such advantages of EPS as its light weight, low cost, thermal resistance, vibration damping and compressible properties, it has been used in different technologies in many countries during last decades. Geofoam is also used to solve many important engineering problems associated with settlement, bearing capacity of weak layers, and slope stability [2]-[6]. Kim et al. (2010) [7] presents the experimental research into the optimal geometry of an EPS block which resulted in the vertical pressure decrease by about 31%-36%. In case of horizontal pressure, reduction was 37% for double layers of EPS and 5% for a single layer of EPS, respectively. Thus, the results may be different depending on the width of EPS, while double layers of EPS provide better solution for reducing the earth load on a pipe. Ahmed et al. (2013) [8] studied the interaction between the earth pressure acting on the backfill and the wall of a rigid PVC pipe subjected to cyclic and static loading conditions. The results demonstrated that the embedded EPS 15 geofoam block reduced the earth pressure on the rigid pipe.

Hussein (2015) [9] found that EPS block located over the pipe brings about a significant reduction in the measured stress especially, at the crown and invert locations. Bartlett et al. (2015) [5] illustrated different systems of EPS geofoam used for protecting buried pipelines through or under roadway and railway: imperfect ditch, slot-trench cover system with EPS block, EPS embankment system, and finally post and beam EPS system. The authors tried to utilize a post and beam method in a project to protect pipes from moving. They used two EPS blocks on both sides of the pipe as posts and a

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capping EPS block (beam) was placed on top of the two posts. The results show that the maximum vertical stress in the two posts is about 60 kPa, while the maximum vertical stress in the beam is about 20 kPa, which is acceptable for stress of EPS 29. Tarek et al. (2018) [10] studies the effect of four techniques with EPS geofoam on reduction of the earth pressure on flexible buried pipes using the experimental and numerical models. The following geofoam techniques were used: EPS embracing the upper part of the pipe and EPS forming post and beam with the head void.

The results show that the best two models are EPS block post and beam and EPS block embracing the upper part of the pipe part. Abdollahi and Tafreshi (2018) [11] studied the embedded EPS post and beam model in reinforced and unreinforced backfill soil. The results show that a denser EPS block reduces the beam deflection and soil surface settlement. The EPS density has no major effect on the beam stress. Bahr et al. (2019) [12] used experimental model tests to study the stress reduction techniques of EPS geofoam and deformation of buried pipes and the soil backfill behavior under static loading. The most effective low-cost methods with embedded EPS blocks were with sand. According to Meguid et al. (2020) [13], their results confirmed that the EPS blocks within the backfill material enhance the response of the shallow buried pipes subjected to repeated loading. This research investigates reduction of the stress and deformation of unplasticized polyvinyl chloride (UPVC) buried pipes using two methods of embedded geofoam blocks by performing a series of experimental model tests under static surface loading. The experimental results are compared with the finite element software program PLAXIS-3D of the same model.

2. Materials and methods

2.1. Materials

2.1.1. Sand

Sand used in this research was passed onto sieve No. 4 (4.76 mm). The graph in Figure 1 illustrates the sand particle distribution by size, while Table 1 shows the properties of the used sand.

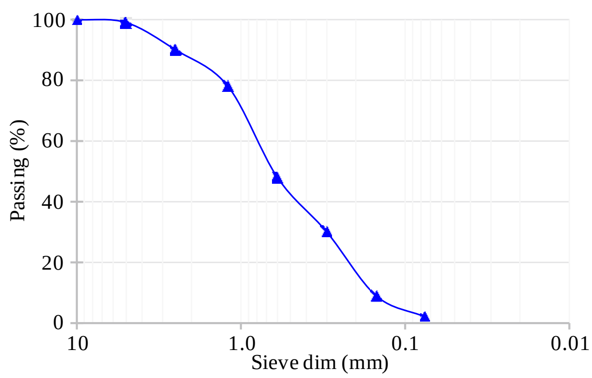

Figure 1. Distribution of sand particles by size

2.1.2. EPS foam

The properties of EPS 20 geofoam blocks are listed in Table 1. The direct shear box test of EPS blocks was carried out according to ASTM 5321 [14], and the unconfined compression test [15], [16] confirmed that the EPS geofoam satisfies ASTM 6817 [17].

Table 1. Properties of materials

Property	Sand	EPS 20	UPVC pipe
Unit weight (kN/m^3)	15.5	0.197	14
Modulus of elasticity, E (kN/m^2)	11000	5000	2×10^6
Specific gravity, Gs	2.69	–	–
Internal friction angle, φ°	32	9	–
Cohesion, C (kN/m^2)	1	22	–
Axial Rigidity, EA (kN/m)	–	–	4590
Flexural rigidity, EI (kN·m^2/m)	–	–	5.5
Poisson's ratio, v	0.30	0.15	0.4

Figures 2 and 3 show the mechanical properties of EPS geofoam.

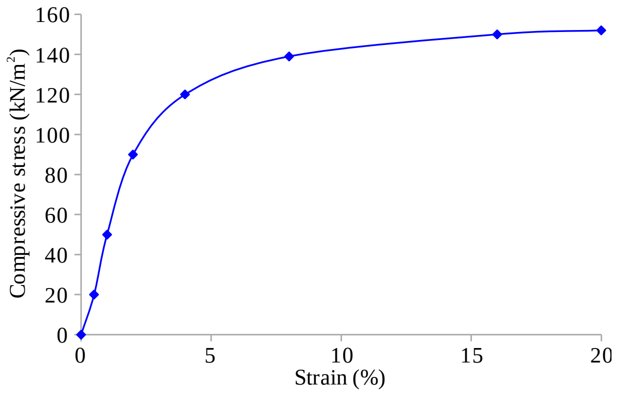

Figure 2. Stress- strain relationship of EPS geofoam blocks

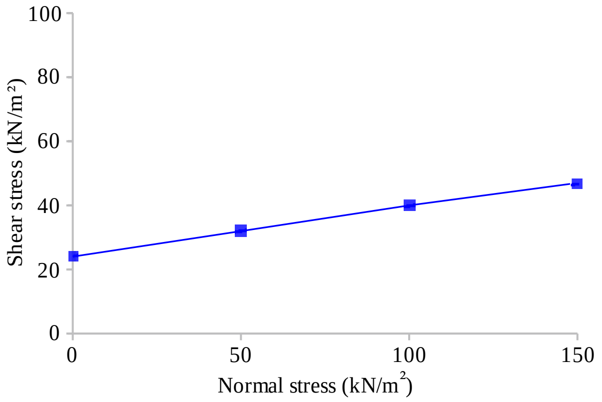

Figure 3. Shear strength of EPS from Direct Shear Box

2.1.3. Pipe

The UPVC pipe used in the experiments is 110 mm diameter and 600 mm long, with thickness of 4 mm. Specification of the UPVC pipe according to the manufacturer is shown in Table 1.

2.2. Loading frame and steel tank

A steel tank 1380×1000×300 mm wide with 10 mm plexiglass face was fixed with loading frame 1400 mm long × 1200 mm height as shown in Figure 4.

The boundaries of the steel tank were: 2.6 D (D – the pipe diameter) from the surface level to the pipe crown, and 2.8 D from the base of the tank to the pipe invert, while the tank side was at 5.5 D from circumference of the pipe [18]. The tank has a hole in the front and rear side for the pipe to go through, and a rubber membrane put at both ends of the pipe (front and rear sides) to prevent sand leakage during loading.

Figure 4. The loading frame and steel tank in case of EPS embankment

A load frame was used to transfer the load from hydraulic jack to load cell placed above a soft steel plate 500×280×30 mm that transmits the load uniformly to the sand, EPS geofoam block and finally to the buried pipe. Dial gauges were put inside the pipe, and electrical strain rosettes were placed on the outer surface to measure the pipe deformations and strain. The strain gauges were placed on the crown and half-length the springline connected to the data logger.

2.3. Methods

2.3.1. Sand model

Three compacted layers of air-dried sand with each layer thickness of about 100 mm were placed in the tank from the base to the lower level of the pipe. The UPVC pipe was placed in the position crossing the tank space through a hole, and a rubber membrane was inserted around the pipe bonded with walls by silicon. The sand was poured and compacted around the pipe from the invert to the crown. The final layer of sand was added to the completely covered pipe reaching the height of 310mm above the pipe crown.

2.3.2. EPS block embracing the upper part of the pipe

After filling the tank with a lower layer of sand, a layer of EPS geofoam block with dimensions 330×165 mm (3*D*×1.5*D*) was added. The EPS block was tailored as a curved shape by using cure cylinder from one side to embrace the upper pipe directly. After levelling the geofoam block, compacted sand was used to fill the tank to reach the height 310 mm over the pipe crown, as shown in Figure 5a.

2.3.3. EPS blocks post and beam

The empty tank was filled with sand bed layer till the lower level of UPVC pipe; the new pipe was put, two posts from EPS geofoam with dimensions 150 mm height × 100 mm width were placed at both sides of the pipe and then an EPS beam block with dimensions 330×100 mm was put on the foam block leveled horizontally. The sand was used to fill the tank to reach the height 300 mm over the pipe crown, as shown in Figure 5b.

2.3.4. EPS blocks embankment

After removing the layer of sand with pipe reaching the lower level of the steel tank, a bed of sand was prepared from the base of the model tank to the lower level of the pipe, the new pipe was inserted and placed over the sand bed, then geofoam blocks with dimensions of 300×300×100 mm were arranged as overburden layer with the depth of 300 mm, as shown in Figure 5c.

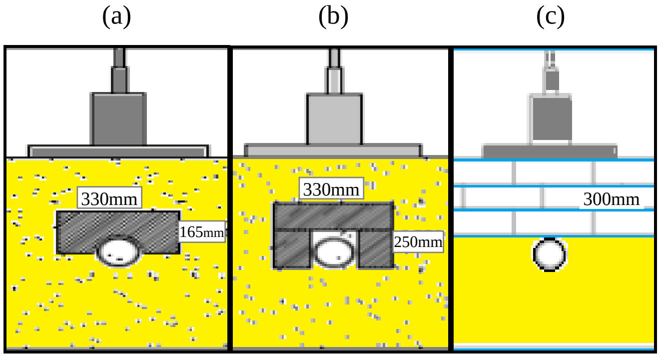

Figure 5. EPS blocks arrangement (a) embracing the upper part of the pipe; the post and the beam (b); embankment (c)

2.4. Numerical analysis model

The numerical model was used to simulate and verify the experimental model results using finite element program PLAXIS-3D. The model identified the plane strain with 15-node elements. The materials were defined as undrained using elasto-plastic Mohr-Coulomb model. The pipe was represented by six circular segment elements of a plate. This simulation predicts surface settlement of the steel plate, crown and springline deformation. For the purpose of verification, the simulation results have been compared with experimental results, for the case of surface stress 180 kN/m^2.

3. Results and discussion

3.1. Experimental results

Figure 6 shows the vertical displacement of steel plate on the surface, for the case of EPS geofoam models compared with sand backfill. The results presented in Figure 5 indicate that the minimum surface displacement occurs in the case of EPS embracing the upper part of the pipe with 13% reduction. In the case of EPS blocks' post and beam arrangement, the maximum surface displacement exceeds sand displacement by about 6%.

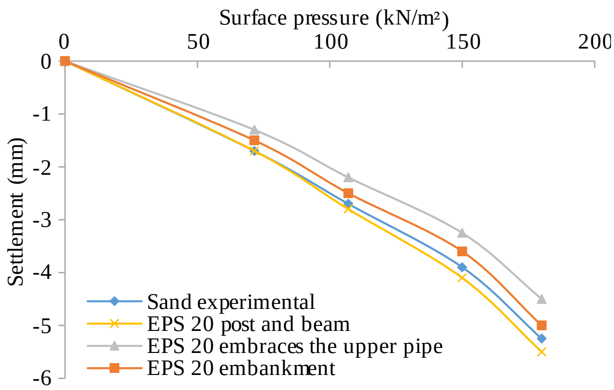

Figure 6. Surface displacement of backfill models

The data presented in Figure 7 illustrate the pipe crown displacement curve for the case of different shapes of EPS blocks.

The crown deformation curves of EPS embracing the upper part of the pipe appear after surface stress 71.5 kPa with linear behavior until maximum surface stress. The vertical reduction percentages of the pipe are 100, 66, 63 and 55% at surface stresses 71.5, 107, 143 and 180 kPa, respectively. The maximum crown deformation is 0.5 mm.

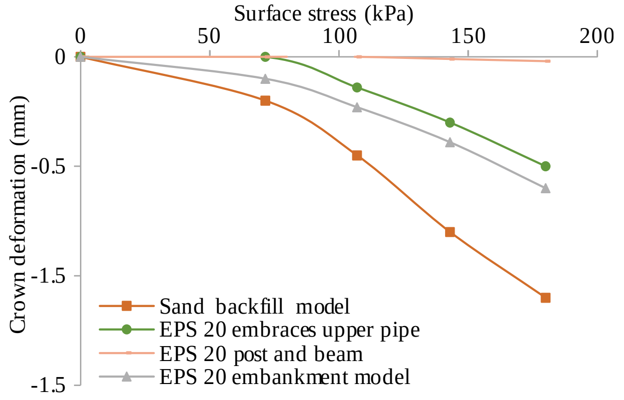

Figure 7. Crown deformations of UPVC buried pipe in case of EPS blocks embracing the pipe upper part model

While, in case of EPS 20 post and beam blocks model, the crown displacement behavior started after surface stress 107 kPa with linear behavior until it reached the value of the maximum surface stress 180 kPa. Under the surface stresses 71.5 and 180 kPa, the reductions in pipe vertical deformation due to the use of EPS 20 are about 100 and 95% respectively. The results of the EPS embankment model indicated that the crown displacement is proportional to the surface stress, and this linear relationship gives a reduction in the pipe deformation about 55% corresponding to 180 kPa.

The springline displacement curve of the pipe is confirmed in Figure 8, showing that the springline curve of EPS embracing the upper part of the pipe starts after 71.5 kPa with linear behavior until the maximum surface displacement 180 kPa, at the maximum stress the springline displacement being 0.28 mm.

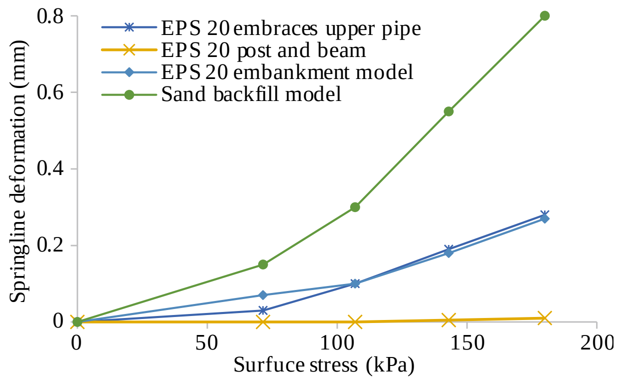

Figure 8. Springline deformations of UPVC buried pipe in case of EPS blocks embracing the pipe upper part model

The horizontal reduction percentages of the pipe are 80, 67, 69 and 67% corresponding to surface stresses 71.5, 107, 143 and 180 kPa. On the other hand, the springline displacement of EPS post and beam blocks starts after the surface stress 107 kPa, then it reaches 0.05 mm at the maximum surface stress 180 kPa with linear behavior, the reductions in the pipe horizontal deformation are about 100 and 99% under surface stresses 71.5 and 180 kPa, respectively. Finally, the springline displacement results of the EPS embankment model demonstrated that the pipe deformation is linearly proportional to the surface stress, while the reductions in the pipe horizontal deformation are about 54 and 67% under surface stresses 71.5 and 180 kPa, respectively.

The crown and the springline diametric strain of the buried pipe, for the case of different EPS backfill models compared with sand backfill is confirmed in Figure 9.

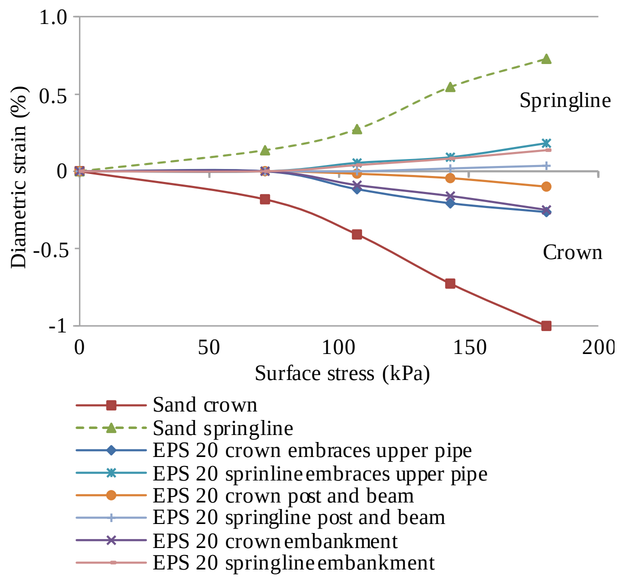

Figure 9. Diametric strain of UPVC buried pipe

The results shown in Figure 9 indicate that the EPS 20 block embracing the upper part of the pipe model ensures the strain reduction by about 75% at the maximum surface stress. However, in the case of post and beam blocks the strain is reduced by about 99%, corresponding to the maximum surface stress. The crown reduction of EPS embankment is about 67%. On the other hand, the effectiveness of different EPS models for reducing the springline diametric strain compared with sand backfill varies. In case of EPS embracing the upper part of the pipe part model using EPS 20, the strain is reduced by about 67%. However, with EPS 20 post and beam blocks arrangement, the springline strain is reduced by about 99%. The springline strain reduction of EPS embankment is about 67%.

3.2. Numerical verification results

The results presented in Figure 10 show the pipe crown deformation of sand backfill experimentally and numerically, the numerical results being in agreement with the experimental results.

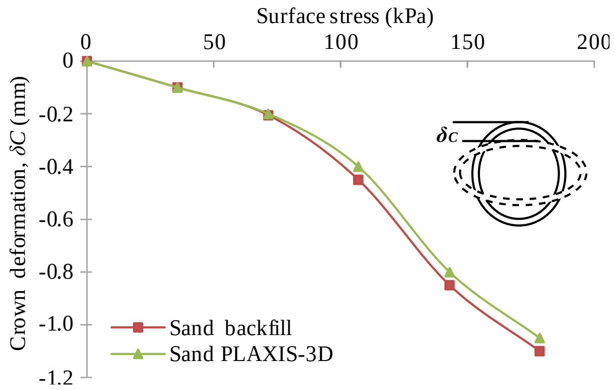

Figure 10. Vertical deformation of UPVC pipe in the sand model

The crown curves behave linearly at the surface stress up to 71.5 kPa, and their behavior becomes nonlinear at the maximum surface stress 180 kPa, the resulting deformation being about 1.05 and 1.1 mm for the numerical and experimental study, respectively.

Figure 11 illustrated the experimental and numerical results the pipe springline deformation due to sand backfill, the numerical results having the same trend as the measured experimental results.

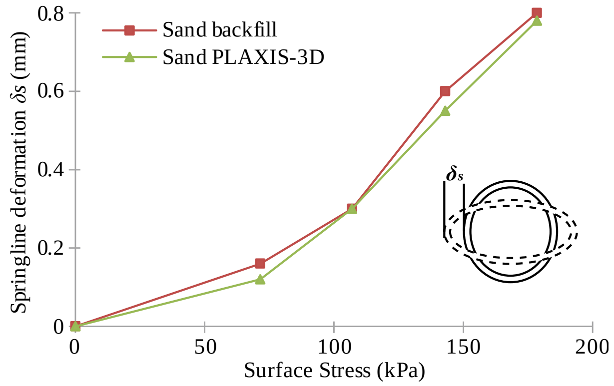

Figure 11. Horizontal deformation of UPVC pipe in case of sand model

The springline numerical result at the maximum surface stress 180 kPa is about 0.78 mm while the experimental result is 0.8 mm. These values are lower than maximum deformations of the flexible pipe.

Figure 12 presents the experimental and numerical crown deformation results of different EPS block models.

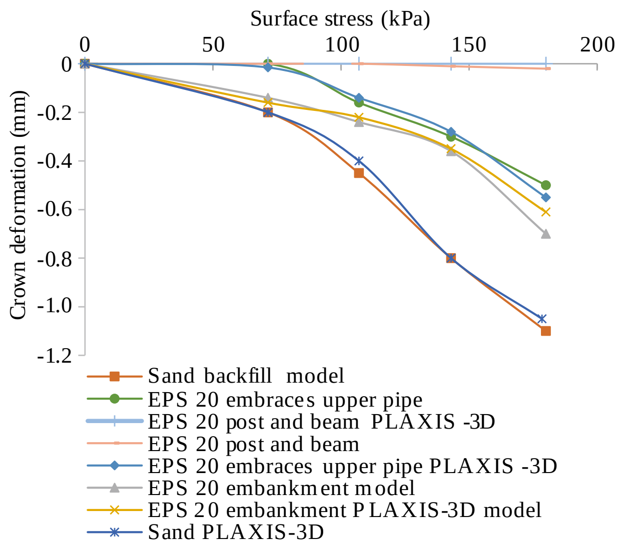

Figure 12. Crown deformation of UPVC buried pipe

The results show that in case of EPS block post and beam model, the crown deflection curve of experimental and numerical results starts after 143 kN/m^2 with linear behaviour near zero. The crown deformation curves of EPS embracing the upper part of the pipe model start after the surface stress reaches 71.5 kPa, then the behavior becomes nonlinear until the deformation reaches 0.5 mm at the maximum surface stress 180 kPa, with experimental and numerical results confirming the same trend. On the other hand, the EPS embankment deformation is linearly proportional to the surface stress until it reaches 0.33 mm at 143 kPa, then, at the maximum surface stress, it is 0.65 mm. The numerical results illustrate the same behaviour with 12% deviation.

The results shown in Figure 13 reflect the comparison between numerical and experimental values of springline curves.

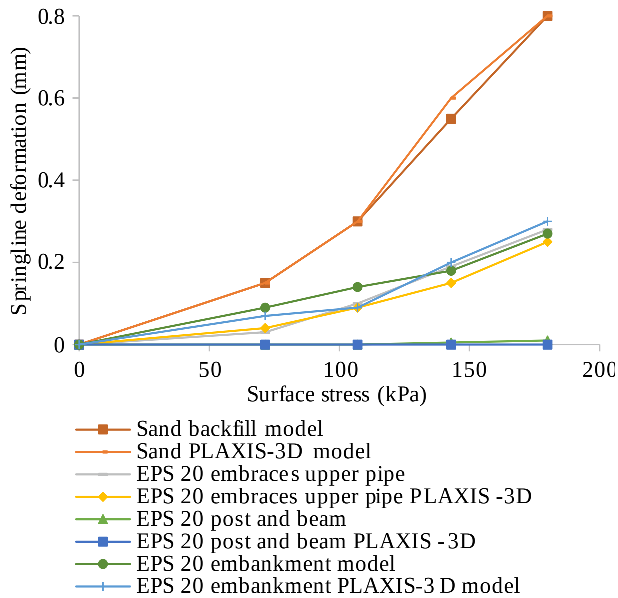

Figure 13. Springline deformation of the UPVC buried pipe

The numerical results obtained for the EPS block embracing the upper part of the pipe linearly started at the surface stress of 71.5 kPa, then they became nonlinear, with experimental and numerical curves demonstrating the same behaviour with deviations. On the other hand, in case of EPS post and beam, the linear behavior caused by the surface stress is observed at the values near to zero. The numerical results in case of the EPS embankment model agree with experimental results, describing the same behaviour. The experimental and the numerical displacement values at the maximum stress of 180 kPa are 0.28 and 0.30 mm of deformation, respectively. The lower values were obtained in the case of post and beam model because the embedded EPS beam distributes the stress to the two posts on both sides of the pipe, and, consequently, the pipe is not affected by the stress. On the other hand, EPS embracing the upper part of the pipe absorbed the stress and transferred it to the both sides as well as the upper part of the pipe, thus the resulting deformation was more than in the post and beam model.

Table 2 indicates that the difference between the numerical and experimental reduction percentages of EPS embracing the upper part of the pipe at the crown and the springline deformations is about 0-10%.

Table 2. Deviation of the numerical reduction percentage from the experimental results in the EPS embracing the upper part of the pipe model

Stress, kN/m^2	Vertical (crown)			Horizontal (springline)		
	71.5	143	180	71.5	143	180
Experimental, %	100	63	55	75	69	65
Numerical, %	100	65	50	80	75	60
Deviation, %	0	3	10	7	9	8

The reduction percentages for both numerical and experimental studies are nearly the same at low surface stress, while this compatibility decreases with increase in the surface displacement. This happens because EPS compresses and absorbs stress until the allowable limit, then it transfers the stress to both sides as well as the pipe. According to Table 3, in the case of embedded EPS post and beam blocks, the numerical results are 93-100% close to the measured experimental results. The reduction percentages of both numerical and experimental results are nearly the same.

Table 3. Deviation of the numerical reduction percentage from the experimental results in the EPS post and beam model

Stress, kN/m^2	Vertical (crown)			Horizontal (springline)		
	71.5	143	180	71.5	143	180
Experimental, %	100	100	99	75	69	65
Numerical, %	100	100	100	80	75	60
Deviation, %	0	0	1	7	9	8

Table 4 indicates that in the EPS embankment model, numerical results are 87-93% close to the measured experimental results. The reduction percentages of both numerical and experimental studies are nearly the same at low surface stress, while this compatibility is proportional to the surface displacement.

Table 4. Deviation of the numerical reduction percentage from the experimental results in EPS embankment model

Stress, kN/m^2	Vertical (crown)			Horizontal (springline)		
	71.5	143	180	71.5	143	180
Experimental, %	60	62	55	57	67	67
Numerical, %	54	56	56	66	72	64
Deviation, %	11	10	12	13	7	7

4. Parametric study

The 3D numerical analysis model is performed by using finite element software program PLAXIS-3D (Version 2.1). The model analyzes the effect of two EPS geofoam configurations – EPS embracing the upper part of the pipe model and EPS post and beam model – on reducing the stress on the buried pipe with real scale dimensions. This model considers the steel pipe (600 mm) and polyvinyl chloride (PVC) pipes of two diameters – 600 mm (24″) and 300 mm (12″), in terms of variant parameters: different overburden depths in respect to the pipe diameter (*H*/*D*) and relative density of EPS geofoam, with the maximum intensity of the live load from the road traffic estimated to be 200 kN/m^2. The model identified a plane strain with 15-node elements. The mate-rials were taken as undrained using elasto-plastic Mohr-Coulomb model as demonstrated in Figure 14.

(a) (b)

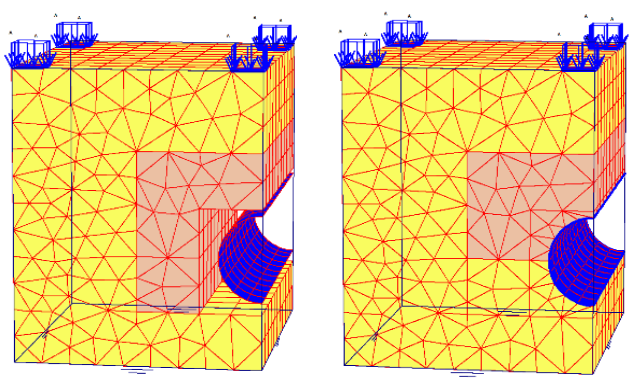

Figure 14. Numerical analysis with the 3D model for (a) post and beam and (b) block embracing the upper part of the pipe configurations

Table 5 shows the properties of materials.

Table 5. Properties of materials used in the parametric study

Properties	Sand	EPS 20	PVC pipe 300 mm	PVC pipe 600 mm	Steel pipe 600 mm
Unit weight (kN/m^3)	17.5	0.198	14	14	–
E (kN/m^2)	20000	5000	–	–	–
Specific gravity, G_S	2.69	–	–	–	–
Shear parameters	$\Phi = 42°$ $C = 1$ kPa	$\Phi = 9°$ $C = 20$ kPa	–	–	–
Poisson's ratio, ν	0.25	0.15	0.37	0.37	0.3
EA (kN/m)	–	–	0.986×10^5	0.864×10^5	279×10^5
EI (kN·m^2/m)	–	–	1216	3730	13.6×10^5

4.1. Effect of pipe material

Figure 15 presents the comparison of surface displacement values in terms of relative EPS densities for the cases of embedded EPS block embracing the upper part of the pipe and post and beam model with different (*H*/*D*).

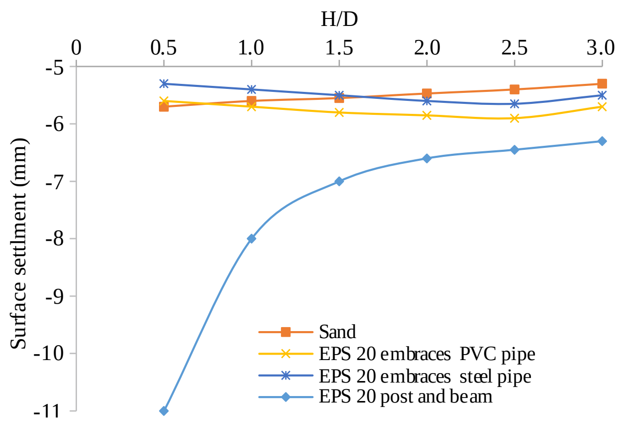

Figure 15. Surface displacement of EPS models and relative H/D

The results show that all curves of the surface displacement have maximum deflection at the beginning when *H*/*D* equal 0.5, then the displacements decrease with the increase of *H*/*D* showing nonlinear behavior until reaching the maximum *H*/*D*. In the case of EPS embracing the upper part of the PVC pipe, the surface displacement has the same trend and value as that of the sand. The EPS post and beam blocks model corresponds to the maximum surface displacement for both PVC and steel pipes.

Figure 16 presents the crown deformation values of both PVC and steel pipes for the cases of EPS block embracing the pipe and EPS post and beam configuration with relative *H*/*D*.

All crown displacement curves start with high values of crown displacement which correspond to shallow depth, and further they reach the minimum level of displacement at the maximum *H*/*D*. The EPS post and beam blocks model eliminates the crown deformation. Figure 17 illustrates the springline deformations of PVC and steel pipes in terms of different EPS block models with relative *H*/*D*.

The results show that the springline displacement curves are inversely proportional to *H*/*D*. The EPS post and beam blocks model eliminates the springline deformations.

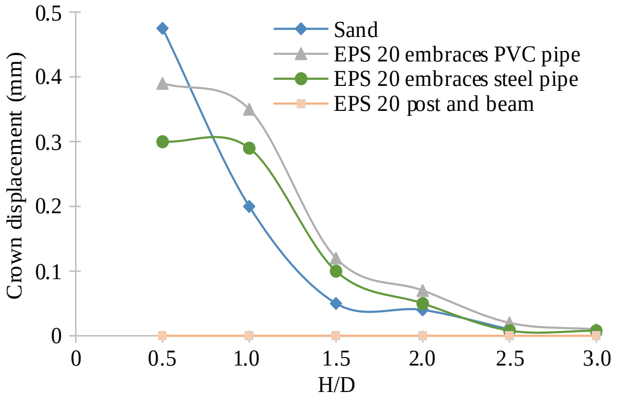

Figure 16. Crown deformation of different EPS models and relative H/D

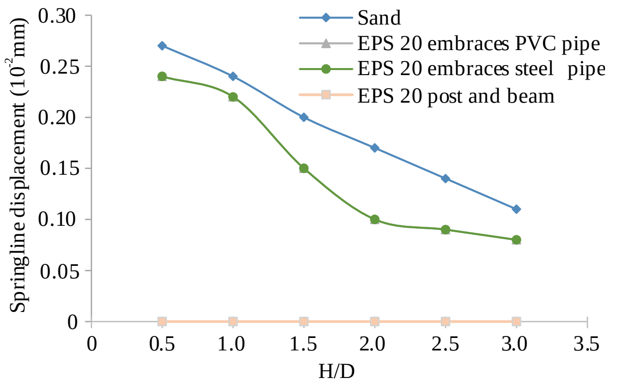

Figure 17. Springline expansion of EPS models and relative H/D

4.2. Effect of pipe diameter

Figure 18 illustrates the surface displacement results of EPS 20 for the cases of an embedded EPS block embracing the upper part of the pipe and post and beam models with pipes of 600 and 300 mm diameter and different overburden depths. The *H/D* is calculated for the large diameter pipe (600 mm).

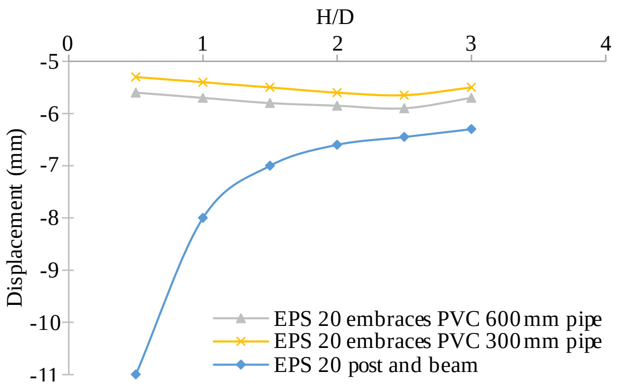

Figure 18. Surface displacement in the case of EPS 20 models with 600 and 300 mm dia pipes

The results show that the maximum surface displacement corresponds to the shallow depth of 300 mm, then it decreases gradually to the minimum at the depth of 1800 mm. The EPS embracing model yields good results, while the EPS post and beam model demostrates a higher surface displacement for both diameters especially at shallow depths without any effect on the pipe.

Figure 19 describes the crown deformation occurring due to different overburden models of EPS 20. The results showed that the crown displacement curves have maximum deflection at shallow depth of 300 mm (*H*/*D* = 0.3), then the displacement decreases with the increase in overburden depth until it reaches 1800 mm (*H*/*D* = 3). The small pipe diameter corresponds to a larger displacement, the EPS embracing configuration reduces the deformations, while EPS post and beam pattern prevents the crown deformation for all depths.

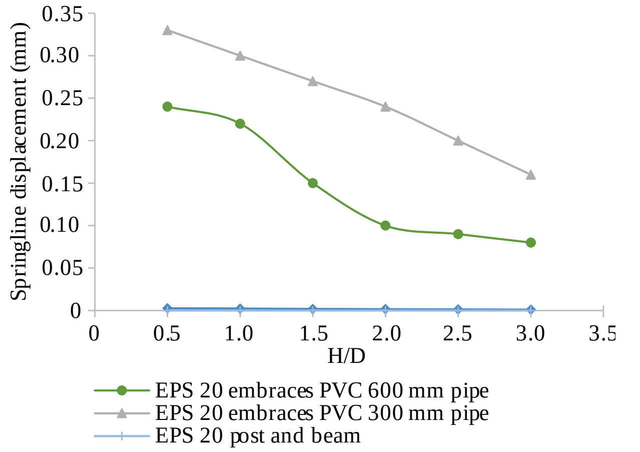

Figure 19. Crown displacement in the case of EPS 20 models with 600 and 300 mm dia pipes

The springline deformation of the PVC pipes of two diameters related to different EPS models and overburden depths is presented in Figure 20.

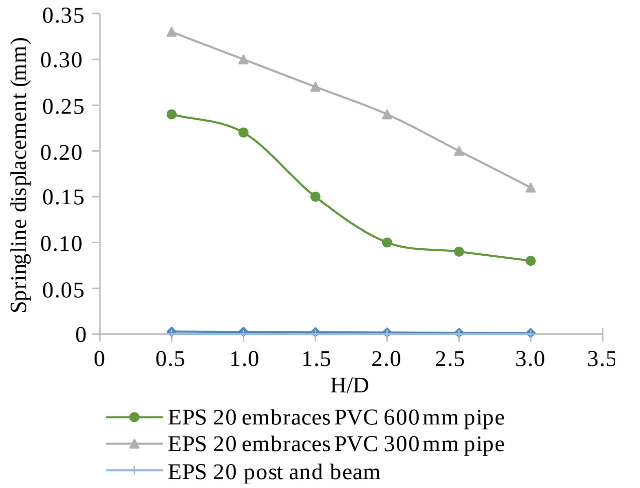

Figure 20. Springline expansion in the case of EPS 20 models with 600 and 300 mm dia pipes

5. Conclusions

This research focuses on the effect of EPS geofoam installation on reducing the earth pressure distribution over buried pipes. Different EPS geofoam backfill techniques were used: EPS block embracing the upper part of the pipe and EPS post and beam configuration with head void. These techniques use EPS geofoam as cover or as a trench backfill system. A large-scale setup model was designed to set up the backfill of 300 mm high in a rigid box. The surface stress was applied onto a steel plate until it reached the PVC pipe that had horizontal and vertical dial gauges as well as strain gauges, the density of EPS geofoam block being 20 kg/m^3. The research allowed to draw the following conclusions.

The results show that application of EPS 20 Geofoam helps to reduce the deformations and strains of buried pipes with percentage depending on EPS block shape. These methods are also instrumental in protecting buried pipes.

EPS embracing the upper part of the pipe corresponds to the minimum surface displacement, which is 13% less than sand displacement. On the other hand, the maximum surface displacement was observed in the EPS blocks post and beam model, which exceeds sand displacement by about 6%.

The EPS block embracing the pipe model at 180 kPa has reduction percentage of about 55% at the crown and 65% at the springline. This model reduces deformations by compressing and absorbing the stress, and then transferring it to the earth at both sides and the pipe plate.

The EPS block post and beam pattern with head void model reduces most of the stress because of the beam absorbing part of the stress and transferring it onto the two posts, which causes reductions at the crown and the springline by about 100% at the maximum surface stress.

The numerical percentage of EPS block embracing the upper part of the pipe model is 50% at the crown. While the springline reduction is about 60%. On the other hand, the EPS block post and beam pattern with head void model reduces about 100% of the crown and the springline stress.

The numerically predicted percentage of crown and springline reduction is close to the measured experimental results by about 13%. The parametric study shows that the most effective and economical method is EPS block embracing the upper part of the pipe model in the conditions of large diameter, high rigidity of the pipe, because this technique can transfer small amount of stress onto the pipe.

Steel pipe is subjected to lower deformations than PVC pipe in the case of EPS embracing the upper part of the pipe.

EPS post and beam pattern with shallow depths prevents the pipe deformations given the surface displacement is high.

The most effective method which reduces stresses over the buried flexible pipe is an EPS post and beam pattern with head void model, followed by the EPS block embracing the upper part of the pipe model. But here we should take into account that EPS post and beam model is more expensive than EPS embracing the upper part of the pipe model.

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Захист підземних трубопроводів за допомогою блоків геопіни різної конфігурації

Д. Хассан

Мета. Чисельний аналіз напружень та розробка захисту підземних трубопроводів за допомогою пінополістирольних (ППС) блоків з геопіни.

Методика. В експериментальній моделі використовувався сталевий контейнер, розміри якого відповідали діаметру труби, що знаходиться в його центрі. Трубу засипали піском і розташовували ППС блоки двома способами: навколо верхньої труби і у вигляді каркаса з двох стійок та балки. У ході декількох експериментів жорсткий сталевий лист піддавався статичному навантаженню для вимірювання деформацій і напружень труби, а також зміщення поверхні засипки. Експериментальна модель була побудована в результаті чисельного аналізу методом кінцевих елементів за допомогою програми PLAXIS-3D.

Результати. Дослідження показало, що найефективніший спосіб запобігання деформації гнучкої підземної труби полягає у створенні стійко-балочної ППС системи і далі установки ППС блоків навколо верхньої труби. Результати чисельного аналізу та експериментів свідчать про одну й ту ж тенденцію. Параметричне дослідження показало. що в стійко-балочній ППС моделі величина зміщення поверхні вище, ніж в моделі ППС шкаралупи навколо верхньої труби, що набагато ефективніше для захисту труби з високим ступенем жорсткості.

Наукова новизна. Виявлено зниження величини навантаження на підземні труби за рахунок використання ППС блоків різної конфігурації, що дозволило визначити оптимальний метод захисту труб.

Практична значимість. Запропоновано два способи застосування ППС блоків геопіни: стійко-балочна ППС система та установка ППС блоків навколо верхньої труби. Їх комбінація дозволяє забезпечити захист підземних труб і зменшити їх деформацію.

Ключові слова: *підземні труби, ППС блок, насип, експериментальна модель, чисельний аналіз*

Защита подземных трубопроводов при помощи блоков геопены различной конфигурации

Д. Хассан

Цель. Численный анализ напряжений и разработка защиты подземных трубопроводов при помощи пенополистирольных (ППС) блоков из геопены.

Методика. В экспериментальной модели использовался стальной контейнер, размеры которого соответствовали диаметру трубы, находящейся в его центре. Трубу засыпали песком и располагали ППС блоки двумя способами: вокруг верхней трубы и в виде каркаса из двух стоек и балки. В ходе нескольких экспериментов жесткий стальной лист подвергался статической нагрузке для измерения деформаций и напряжений трубы, а также смещения поверхности засыпки. Экспериментальная модель была построена в результате численного анализа методом конечных элементов с помощью программы PLAXIS-3D.

Результаты. Исследование показало, что самый эффективный способ предотвращения деформации гибкой подземной трубы состоит в создании стоечно-балочной ППС системы и затем установки ППС блоков вокруг верхней трубы. Результаты численного анализа и экспериментов свидетельствуют об одной и той же тенденции. Параметрическое исследование показало. что в стоечно-балочной ППС модели величина смещения поверхности выше, чем в модели ППС скорлупы вокруг верхней трубы, что гораздо эффективнее для защиты трубы с высокой степенью жесткости.

Научная новизна. Выявлено снижение величины нагрузки на подземные трубы за счет использования ППС блоков различной конфигурации, что позволило определить оптимальный метод защиты труб.

Практическая значимость. Предложены два способа применения ППС блоков геопены: стоечно-балочная ППС система и установка ППС блоков вокруг верхней трубы. Их комбинация позволяет обеспечить защиту подземных труб и уменьшить их деформацию.

Ключевые слова: *подземные трубы, ППС блок, насыпь, экспериментальная модель, численный анализ*