Vol.(5),No.(2),(2017),21-29
MUTHANNA JOURNAL OF ENGINEERING AND TECHNOLOGY (MJET)
مجلة المثنى للهندسة والتكنولوجيا
Journal homepage:www.muthjet.com
Print ISSN:2572-0317, Online ISSN:2572-0325

Parametric Studies of Reducing Applied Stress on Buried Pvc Pipes Using Finite Element

Basim Jabbar Abbas*

Civil Engineering, College of Engineering, Al-Muthanna University

ARTICLE INFO

Received: 17/7/2017

Accepted: 3/10/2017

Keywords

PVC pipe, Geogrids, Loose sand, Dense sand, vertical crown deflection, Embedding ratio.

ABSTRACT

The buried pipes are used for many purposes as drainage and water supply in addition many other projects such as oil pipelines and transferring the rivers water. The used pipes are made from various materials and different diameters which are mostly subjected to moving stresss and overburden pressures. The present study is focused on possibility of reducing the effect of applied stress on the buried PVC pipes into the loose and dense conditions of sand soil by reducing the settlement of using geogrids and thin layer of concrete. The response of the pipes was studied with and without treatment. In this study, finite element analyses were used to evaluate the behaviour of 500 mm PVC pipe buried in sand soil. The effects of many variable parameters as embedment ratio of pipes, density of soil and geogrids locations were investigated. Twenty-two models were conducted using Plaxis 3D program. Dimensions of the numerical models were (1 × 2 × 3)m. Accumulated incremental stresss were applied on the surface of soil with 500 mm in width and along the length of pipe. For each model, the relationship between the surface pressure and the corresponding pipe crown deflection was investigated. In view of the results, it can be concluded that the embedment ratio of pipes, density of sand and utilizing the geogrids are fundamental parameters that influence the buried pipes. Also the results demonstrate that replacing the top soil with dense and reinforcing it by geogrid layer gives greater protection for pipes.

دراسة العوامل المؤثرة لتقليل الاجهادات المسلطة على الانابيب البلاستيكية المدفونة باستخدام العناصر المحددة

الخلاصة

إنّ الأنابيبَ المدفونةَ تسعمل للعديد مِنْ الأغراضِ كتصريف وإمداد المياه بالإضافةً إلى العديد مِنْ التطبيقاتِ الأخرى مثل خطوطِ الأنابيب النفطِ وتُحوّلُ مياه الأنهارَ. إنّ الأنابيبَ المستعملةَ تصنع مِنْ الموادِ المختلفةِ وبأقطارِ متنوعة والتي يسلط عليها غالبا أحمالِ المتحركة واحمال الضغوطَ الناتجة من وزن التربة. هذه الدراسةِ ركزت على إمكانيةِ تَخفيض تأثيرِ الحملِ التطبيقيِ على أنابيبِ البلاستيكية المدفونة في التربة الرملِية الرخوة والكثيفة بواسطة تَخفيض الهطول الحاصل باستعمال طبقة من geogrids . قياس الازاحة العمودية للانابيب تم دراستها قبل وبعد المعالجةِ. في هذه الدراسةِ، التحليلات باستخدام العناصرِ المحدودةِ لتَقييم سلوكِ أنابيب بلاستيكية بقطر 500 مليمترِ مدَفنَونة في تربةِ رملِية. تأثيرات العديد مِنْ العناصرِ المتغيّرةِ مثل عمق دفن الأنابيبِ، كثافة التربةِ ومواقعِ geogrids قد تم دراستها. اثنان وعشرون نموذج من العناصرِ المحدودةِ أجرتْ بالاستعمال برنامج Plaxis ثلاثي الابعاد. أبعاد النماذجِ العدديةِ كَانتْ (1 × 2 × 3) م. الأحمال التزايدية المتراكمة تم تسليطها على سطحِ التربةِ بعرض 500 مليمترِ وعلى طول الإنبوبِ. لكُلّ نموذج، العلاقة بين الضغطِ التطبيقيِ والازاحة العموديةِ للانبوب تم تسجيلها. من النَتائِج الحاصلة، من الممكن أَنْ يُستَنتجَ ان نسبةَ الدفن للأنابيبِ، كثافة الرملِ واستعمال geogrids من العَناصر الرئيسيةَ التي تُؤثّرُ على الأنابيبِ المدفونةِ.كذلك اظهرت النَتائِجَ بأنّ إعادة الدفن بالرملِ الكثيفِ والتسليح باستخدام geogrids تعطي حماية فعالة للانابيب.

الكلمات المفتاحية

انبوب بلاستك، الجيوكرد، الرمل الرخو، الرمل الكثيف، الانحراف العمودي للانبوب، نسبة الدفن للانبوب.

---

*Corresponding author.
E-mail addresses: basm.gabar@mu.edu.iq

DOI:10.52113/3/eng/mjet/2017-05-02/21-29

Introduction:

Infrastructure and Pipes lines are important reference for modern life. The mainly benefits of buried pipes are for water supply and main drainage besides many other purposes such as energy transportation and natural resources such as oil, liquefied gas and the coal slurries The flexible pipes are design to control deflection or elastic buckling in the pipes (Rajkumar and Ilamparuthi, **2009**). The safety of buried pipes which are consider one of the most important urban facilities depends usually on the safe design and performance of these buried structures under different stressing conditions. This is easy to be done if their real behaviour is well understood and their design is considered (Tafreshi and Khalaj, 2008).

A lot of studies were performed in order to investigate the response of buried pipes either analytically (using elastic theory) or numerically (using finite element or difference techniques) as Abel and Mark (1973), Rajkumar and Ilamparuthi (2008), Bildik et al. (2012), Kouretzis et al (2016) and Fattah et al. (2016). However in last years some of experimental works in the area of buried pipes have received attention from the researchers

In the present markets many new materials were used in manufacturing the pipes such as plastic resins where there are three major specimens of plastic pipes were marked in applications of water-industry such as Polyethylene (PE), Polyvinyle chlonde (PVC), and Fibre-reinforced plastic (FRP).

The thermoplastic material (PVC) is stronger than polyethylene material (PE), so thermoplastic material allowing using thin wall sections and reduces the weight and cost. The plastic pipes is more popular due to the real modification in technologies of the manufacturing and there are more advantages of using it than using the concrete and ductile iron pipes such as weight, the cost, the efficiency and the long term chemical stability (Rajkumar and Ilamparuthi, 2008).

A geosynthetic is defined as “a planar product manufactured from polymeric material used with soil, rock, earth, or other geotechnical engineering related material as an integral part of a man-made project, structure or system” (ASTM D 4439-11, 2011).

The principal benefits of using the geosynthetic are to improve some characteristics of the soils as the hydraulic, the mechanical and physical properties. In the present days, the geosynthetics are being utilized for many purposes in addition to geotechnical engineering. In construction applications the used geosynthetics are often geofoam, geotextile, geomembrane, geogrid, geonet, geocomposites and geocell. For geotechnical engineering, the geosynthetics have been successfully used in several applications of civil engineering including roadways, railroads, airports, retaining structures (Marto et al., 2013). Hosseini et al (2002) studied experimentally the behavior of buried pipes under cyclic stressing conditions. They developed a model is capable of simulating and monitoring flexible pipes under different conditions. Thus, the study explained that leaving the uncompact soils surrounding buried pipes may result in serious damages to pipes during earthquake stressings. The abovementioned depth (equal 2D) can be recommended as the minimum required depths for safe design and performance of buried pipes in dense soils.

Tafreshi and Khalaj (2008) developed laboratory model including polyethylene pipes have small diameter and high-density, the pipes were buried in reinforced sand and subjected to repeated stresss simulating the vehicle stresss. In all tests, the maximum amplitude of applied pressure was 5.5 kg/cm^2. The deformation of the pipe at eight points on the circumference of the tested pipes was recorded to measure the radial deformations of the pipe. The results showed that the percent vertical diameter change (ΔD) and settlement of soil surface (SSS) can be reduced up to 56% and 65% for ΔD and SSS, respectively, by using geogrid reinforcement, and increase the safety of embedded pipes. Also, the efficiency of reinforcement was decreased by increasing the number of reinforcement, the relative density of soil and the embedded depth of the pipe.

The numerically simulation of the buried pipe problem by finite elements method using the newest version of PLAXIS-3D software was modified by Fattah et al in 2016. It was found that the results of vertical crown deflection for the model without geogrid obtained from PLAXIS-3D are higher than those obtained by two-dimensional plane strain by about 21.4% while this percent becomes 12.1 for the model with geogrid, but in general, both have the same trend.

Nirmala R. et al (2016) conducted a study is to determine of the deformations of flexible UPVC pipes under loose soil conditions using experimental investigation and theoretical studies and suggest the effective ways to reduce the deflections of buried UPVC pipes using geo reinforcing materials. The testing of UPVC pipes was done using a soil box facility for different soil covers with and without geogrids for incremental stressing using hydraulic jack under loose soil conditions. The test results indicate that diametric strain in pipe increases with decrease in soil cover and the use of geogrids to reduce the diametric strain is effective at shallow depths and their effectiveness decreases with increase in soil cover.

The power of using the finite element method is that once the model is set up, many cases can be analyzed and the sensitivity of assumptions can be tested. Furthermore, a finite element analysis can be performed for many buried pipe applications that are difficult to analyze using conventional analysis procedures. There are three-dimensional finite element analysis programs available, but generally they do not have the proper constitutive relationship for modeling soil and do not provide interface elements that allow slip between the soil and the pipe. In these cases, it may be necessary to compare three-dimensional solutions for conditions that can be modeled numerically with that provided from the real experimental results.

The objective of the present study is to investigate the improvement the soil considering settlement reduction. The problems are conventionally analyzed through three-dimensional plane strain for sand soil improved using either geo-grid reinforcement layers or thin layer of concrete are placed above the pipe to reduce stress transfer.

Properties of Sandy Soil

In this study, the linear elastic-perfectly plastic Mohr-Coulomb criteria were used to represent the materials of the general soil profile and the sand. To simulate the model of sand soil, five input parameters were required: Young's modulus (E) as the basic stiffness parameter, Poisson’s ratio (υ), internal friction angle (φ), cohesion (c) and dilatancy angle (ψ). There was no need to enter ground water condition in the analyses because the soil layer in this study was dry. The physical and chemical parameters of soil used in this investigation are shown in Tables 1.

Properties of geogrid layers

The geogrid is consisting of bars in some size to form sections with constant dimensions which are usually intersecting at right angles. The Grids are similar to fabric of welded wire except that the grid rods in one line do not lie on top of the rods in the orthogonal direction (Rajkumar and Ilamparuthi 2008).

The strength of the geogrids is ranged between 20 and 250 kN/m, and they are being utilized in reinforced slopes and road constructions. The Geogrids can be parted according to the stiffness into two groups:

1- Stiff geogrids, mostly high density polyethylene (HDPE) with a monolithic mesh structure. 2- Flexible geogrids, mostly polyethylene terephthalate (PET) with poly vinyl chloride (PVC) or acrylic coating with mechanically connected longitudinal and transverse elements (Voskamp, 2003).

Table 1 Physical properties of the soil.

Parameter	**Name**	**loose**	**Dense**	**Unite**
Material model	Model	Mohr-Coulomb	Mohr-Coulomb	-
Type of material behavior	Drainage type	Drained	Drained	-
Unit weight of soil above phreatic level	$\gamma_{unsat.}$	15.8	17	kN/m^3
Unit weight of soil below phreatic level	$\gamma_{sat.}$	15.8	17	kN/m^3
Young’ modulus (constant)	E	9000	19000	kN/m^2
Poisson’s ratio	ν	0.3	0.3	-
Cohesion (constant)	c_{ref}	3	5	kN/m^2
Friction angle	Ø	31	42	-
Dilatancy angle	Ψ	1	12	-

The used geogrid in this research was Tensar geogrid (SS2). It was manufactured by the British Company Netlon ltd. The mechanical properties of Tensar SS2 including the weight (mass), Young’s modulus, Shear modulus, Thickness, and Poisson’s ratio are summarized in Table 2.

Table 2: The mechanical properties of Tensar SS2 geogrids After (Sheer Ali, 2015)

Parameter	**Name**	**Value**	**Unite**
Thickness	d	0.0015	m
Weight	γ	7.4	kN/m^3
Young’s modulus	E	0.99	GPa
Shear modulus	G	1.4×10^5	kN/m^2
Poisson’s ratio	ν	0.4	-

The PLAXIS 3D Version 2013 program allows for orthotropic as well as anisotropic materials behavior in geogrid elements, which is defined by the following parameters:

$$N_1 = EA_1\varepsilon_1 \quad (1)$$

$$N_2 = EA_2\varepsilon_2 \quad (2)$$

In the case of orthotropic behavior $EA_1 = EA_2$ in the general three dimensional case (PLAXIS 3 D manual, 2013).

Where:
N_1= Maximum tensile force in 1- Direction.
N_2= Maximum tensile force in 2- Direction.
E= Young's modulus for geogrid.
A= Section area for geogrid.
ε_1 and ε_2= the strain in 1 and 2 direction.

So, from the provided information which is shown in table 2 the axial stiffness at 5% axil strain will be 74 kN/m.

Properties of PVC Pipes and Modeling

In the numerical study a PVC pipe of D = 500 mm diameter and thickness 12.3 mm was selected. To simulate a pipe in PLAXIS 3D, a cylinder with required parameters were drawn in the specified depth with diameter = 500 mm. To create a cylinder, a specified radius, height and accuracy at a location (x, y, z) in a specified direction which described by a vector were depended. The wall of cylinder was simulated as 3D plate elements which are defined by the thickness, d, Young's modulus, E, and Poisson's ratio, ν, as well as the material unit weight, γ.
The physical properties of the pipe were partly taken from manufacturers of the pipe and are summarized in Table 3.

Table 3: The physical properties of PVC pipe After (Nirmala. R et al, 2016).

Parameter	Symbol Name	Value	Unite
Thickness	d	0.0123	m
Unite Weight	ɣ	15	kN/m^3
Young's modulus	E	2750	MPa
Poisson's ratio	ν	0.4	-

Finite Elements Modeling and Boundry Conditions

Finite element (FE) methods have been used in most geotechnical engineering to appraise complex problems. 3D modeling can simulate field conditions properly while traditional analysis is time consuming and complicated, in addition using the laboratory models need more effort and budget. The finite element software of PLAXIS 3D foundation version 2013, developed by the Delf technical university, is selected in this paper.
In this study, the depth and width of the models are selected as sufficient so that it simulate real behaviour in the field. The models consist of soil volume 1 × 2 m plan area and 3m in depth. The used pipe in the analysis has diameter 500 mm and wall thickness 12.3 mm and the positive interfaces were added around the pipes to consider soil-pipe interaction. Option of the standard boundary is selected in the program, where this boundary option considers the movement of top surface to be free in all directions. When considering the model boundary in yz-plane, displacements in the x directions are limited to zero where displacements in the y and z directions are free. The bottom boundary is fixed in all directions. The mesh was medium generation, utilized as the global coarseness of model and the software automatically refines the critical areas in the model.

The study consists of three stages, the first one deal with the vertical crown deflection of pipe under various surfaces stresses without treatment in loose and dense sand. To reduce the effect of surface stress on the pipe and increase the performance of it, the geogrid are used in the second stage. The third stage included replacing the top loose sand with well compacted dense sand.
All models are created as that constructed in the field for all stage.

Finite Elements Modeling without treatment

The finite element models of untreated sand soil were fabricated for loose and dense sand conditions. The pipe was located beneath the natural ground level at variable depth depending on the embedding ratio (H/D), the embedding ratio (H/D) ranged from 1 to 4 as shown in Fig. 1. The applied surface stress was modeled by creating plain surface on ground level in width equal to the diameter of the pipe (500 mm). Therefore, the effect of surcharge stress is investigated using finite element methods by applying accumulated increment stresses. About 5000 soil elements with 15 triangular nodes were taken to generate the mesh of the soil and footing. The vertical crown deflections of the pipe were recorded under using progressive surface stresss until reaching to failure stress. The finite elements of untreated sand soil models are shown in Fig. 2, 3 and 4.

Technique of gogrid reinforcement

The second case is the modeling of reinforced soil by layer of Tenser SS2 geogrid above the pipe. The geogrid layer was placed into the sand at width equal to 1 m (2D) along the length of model. The vertical distance from ground level to geogrid layer (h) was considered variable depending on (h/D) ratio which starts from 0.5 to 2 as shown in fig. 5. So, the effect of geogrid location is investigated using finite element methods. To activate the soil-geogrids interaction, positive interfaces were added above the geogrids layers. Depending on the materials properties which shown in table 1 and materials properties of geogrid shown in table 2, the model of 5000 node triangular elements for improved soil with one layer of geogrid is presented in Figs. 4 and 5.

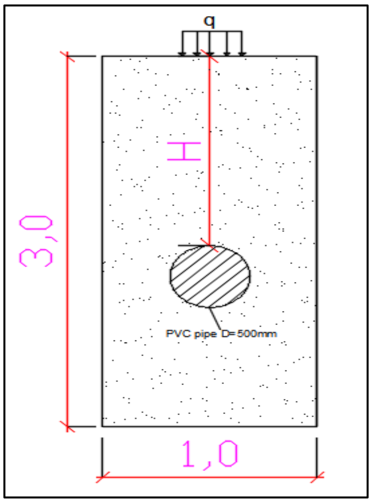

Figure 1: Geometric model of soil-pipe without treatment

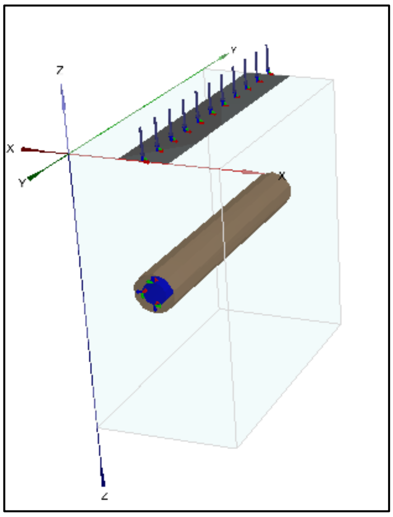

Figure 2: Input geometry of the untreated model for H/D =3

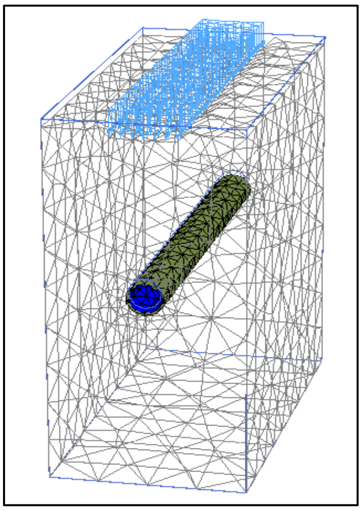

Figure 3: Mesh view of the untreated model in PLAXIS 3D

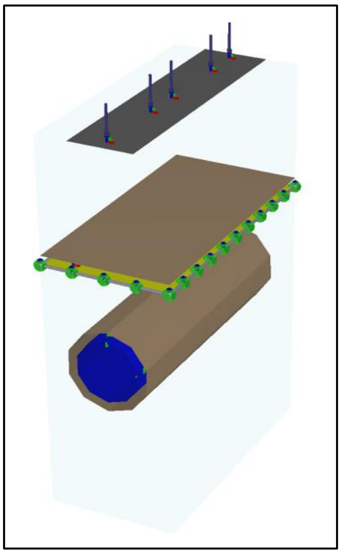

Figure 4: General view with Geogrid

Validity of Numerical works

The numerical models of the present work have been validated by comparing some of the present results with that published by other workers. The results of the present work are plotted in the relationship between the applied stresses with corresponding vertical crown deflection of pipes and then compared with other publisher such as Rajkumar and Ilamaruthi's study (2008) and Bildik et al (2012). The second comparison was using the vertical stress from the PLAXIS analyses with that obtained from Newark's analytical equation (1935). Newmark (1935) developed an equation to calculate the vertical stresses occurring beneath stress below a flexible strip stress as shown in Fig. 7 depending on the following:

$$\Delta\sigma = \frac{q}{\pi}[\beta + \sin\beta\cos(\beta + 2\delta)] \qquad (3)$$

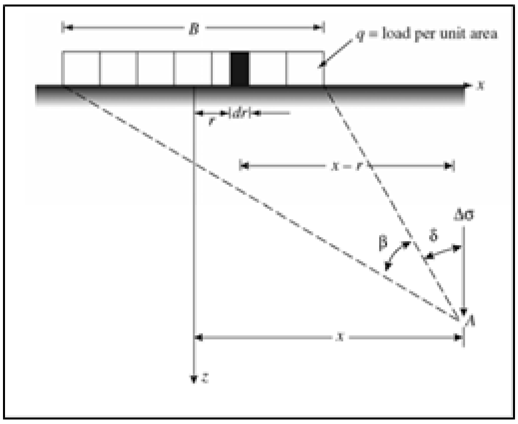

Figure 5: Determination of vertical stress below a flexible strip stress (after Newmark 1935).

Figures 6 and 7 illustrate a relation between applied surface stress and the vertical total stress for loose and dense sand at embedding ratio (H/D) = 3. The behaviour of vertical total stress on pipe with applied surface stresss from the PLAXIS analyses showed generally similar behavior with Newmark's analytical theory. There is some deviation between the FEM results and analytical methods. The results obtained from FEM are significantly smaller than that obtained from analytical methods.

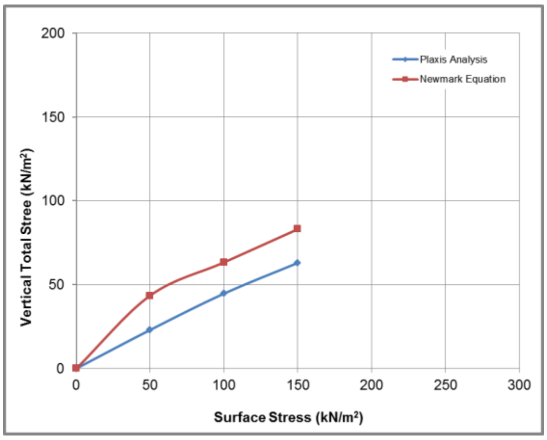

Figure 6: Finite element and analytical vertical total stress comparison for loose sand at embedding ratio (H/D) =3

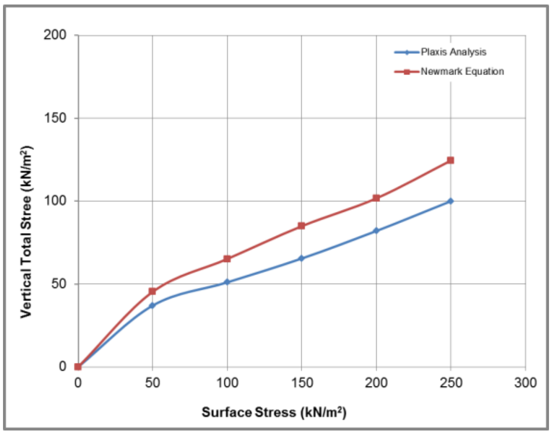

Figure 7: Finite element & analytical vertical total stress comparison for dense sand at embedding ratio (H/D) =3

The Results and Discussion

The main aim of this study is to find out many factors which effected on the behavior of embedded PVC pipe in sandy soil. The investigated factors are surcharge stress, density of sand, and the location on embedded PVC pipe. In addition the effect of using geogrid with its location was investigated.

1. Embedment Ratio Factor

The factor of embedment ratio against surcharge stress is investigated using finite element methods. The vertical crown deflection of the pipe under various surface stresss was measured. Figures 8 and 9 illustrate crown deflections for pipe versus surface stress with various embedding ratios (H/D) for loose and dense sand soil.

Computer simulations show that the pipe behavior mainly depending on intensity of surcharge surface stress. The results show that crown deflection of the embedded pipe increase linearly with increasing the surcharge stress in loose and dense sand conditions. The results also explain that pipe crown deflections decrease with increase the embedment ratios in loose and dense sand conditions. It is observed that for same surface stress, decreasing the backfill increase the crown deflection for pipe. This due to small backfill causes direct transmitting the stress to the pipe. Bildik et al (2012) explained that pipe displacements increase linear with increase in surcharge stress and the backfill cover gave more protection to the pipe. Rajkumar and Ilamparuthi (2008) concluded that increasing the backfill cover affords greater protection to the pipe and the stiffness of the pipe-soil system increases with increase the cover height.

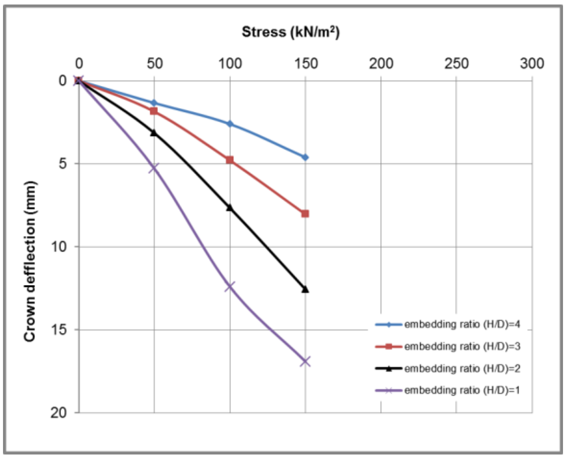

Figure 8: Pipe crown deflections versus surface stress behavior for loose sand.

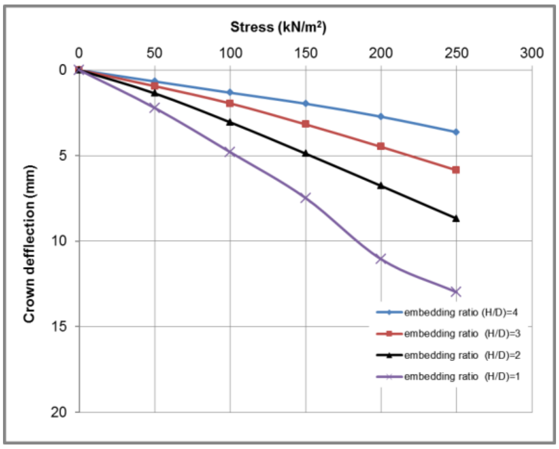

Figure 9: Pipe crown deflections versus surface stress behavior for dense sand.

2. Density of Sand Factor

Two surface stresss were used to investigate effect factor of the densities for sand. The depended densities in this comparison are loose and dense condition. Figures 10 and 11 explain crown deflections for PVC pipe with various embedding ratios (H/D) under two surface stresses of 100 kN/m^2 and 150 kN/m^2 respectively.

The study shows that pipe displacement is evidently influenced by the density of sand. The relations between embedment ratios with crown deflections are approximately linear. At surface stress of 100 kN/m^2, the percentage difference of crown deflection between dense and loose sand condition is 61.32 % and 49 % for H/D = 1 and 4 respectively. At surface stress of 150 kN/m^2, the percentage difference of crown deflection between dense and loose sand condition is 55.77 % and 57.33 % for H/D = 1 and 4 respectively.

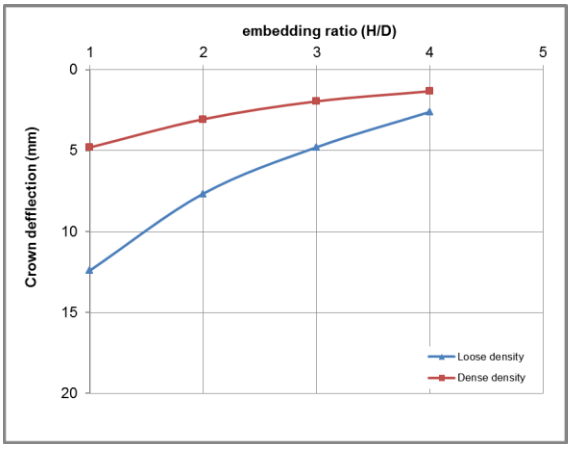

Figure 10: Pipe crown deflections versus embedding ratios (H/D) at surface stress =100 kN/m^2.

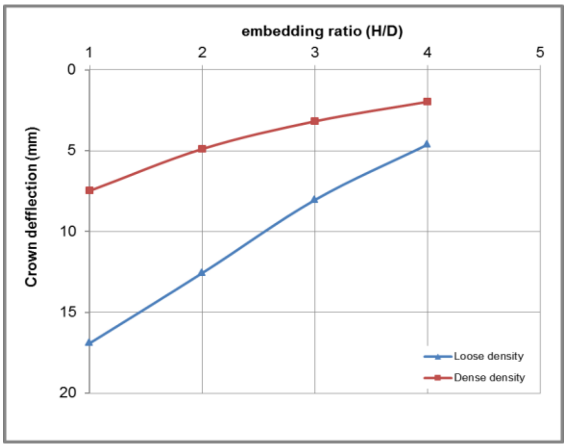

Figure 11: Pipe crown deflections versus mbedding ratios (H/D) at surface stress =150 kN/m^2.

3. The Effect of Geogrids

The vertical crown deflection against surcharge stress for buried pipes reinforced by layer of geogrid is investigated using finite element methods. The ratios (h/D) which are distances from ground level to geogrid layer on the diameter of pipe were starting from 0.5 to 2. The loose and dense densities were used and the embedding ratio (H/D) was fixed to 3. Figures 12 and 13 illustrate crown deflections for pipe versus surface pressure with various (h/D) ratios for loose and dense sand soil.

The results explain that the transmitted stress above the pipe crown evidently had been decreased in the case of soil had been reinforced by geogrid. Due to presence of the geogrid the pipe crown deflections were reduced for loose and dense sand.

Figure 14 explains crown deflections for PVC pipe with various (h/D) under two surface stress of 150 kN/m^2 and embedding ratio (H/D) =3.

From the figure it is clear that increasing the depths of geogrids (h/d) decreases the transmitted stress and then decreases the pipe crown deflections for loose and dense sand. Reinforcing the soil above the PVC pipe which is buried in shallow depth is appropriate solution to reduce the crown deflection.

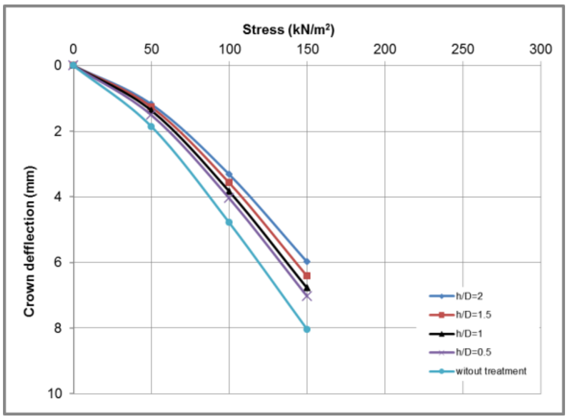

Figure 12: Pipe crown deflections versus surface stress for loose sand reinforced with geogrid (H/D=3).

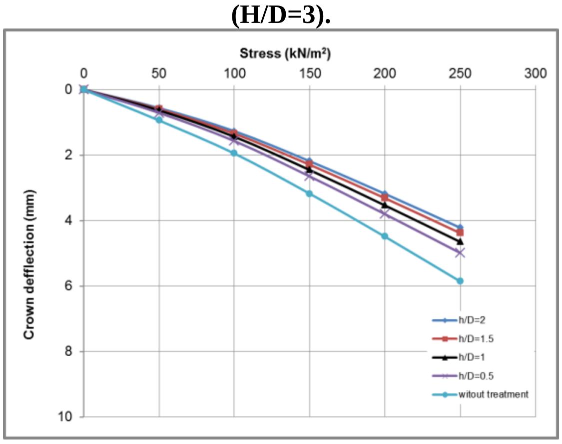

Figure 13: Pipe crown deflections versus surface stress for dense sand reinforced with geogrid (H/D=3).

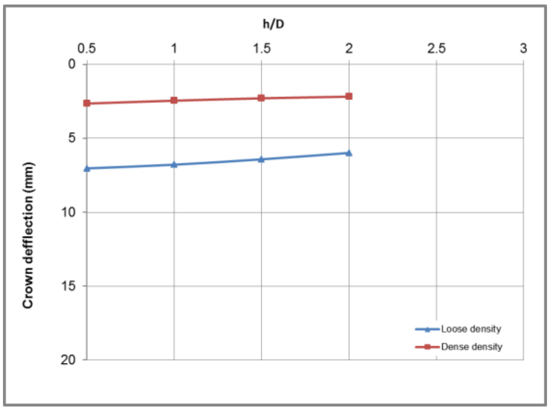

Figure 14: Pipe crown deflections versus (h/D) at surface stress =150 kN/m^2 and (H/D =3).

4. Comparison between the improvement methods

The appropriate method to improve the loose backfill above the buried PVC pipe was investigated. To conduct comparison between the three improvement techniques on loose sand, the embedding ratio (H/D =3) was chosen. The first improvement technique was using geogrid layer at h/D = 2. The second improvement technique was replacing the loose top soil above the pipe with dense sand. The third improvement technique was replacing the loose top soil with dense sand and reinforcing it by geogrid layer at h/D=2. Figure (15) explains the three improvement techniques represented by crown deflections of PVC pipe versus various surface stresss for loose sand in embedding ratio (H/D) =3. The results show that improvement using geogrid only in loose backfill decreases the crown deflection to 25.5% at surface stress = 150 kN/m^2. Replacing the top backfill with dense sand decreases the crown deflection to 48.7% at surface stress = 150 kN/m^2. Replacing the top backfill with dense sand and reinforcing it by geogrid at h/D=2 decreases the crown deflection to 59.4%. So replacing the top soil with dense and reinforcing it by geogrid layer gives greater protection for pipes.

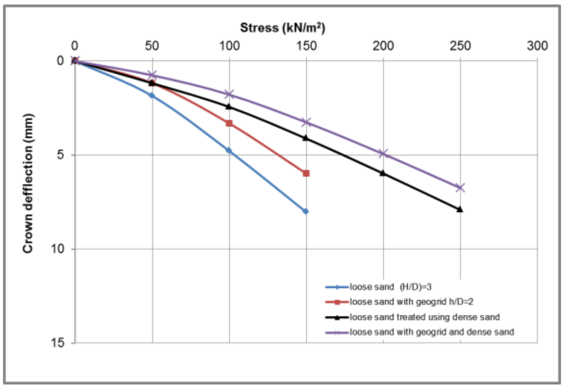

Figure 15: Pipe crown deflections versus surface stress of loose sand for three improvement techniques in embedding ratio (H/D) =3.

The Conclusions.

A series of numerical analysis were carried out to evaluate the crown deflections of buried pipes in sand soil. The improvement using geogrid layer and top sand replacement techniques were investigated. Some parameters which affect crown deflections of buried pipes were studied. Based on the obtained results of the present work, the following conclusions can be drawn:

1- The results show that the pipe behavior mainly depending on intensity of surface stress. The crown deflection of the embedded pipe increases linearly with increasing the surcharge stress in loose and dense sand conditions.

2- The relations between embedment ratios with crown deflections are approximately linear. The pipe crown deflections decrease with increase the embedment ratios in loose and dense sand conditions. It is observed that for same surface stress, decreasing the backfill increase the crown deflection for pipe.

3- The behaviour of vertical total stress on pipe with applied surface stresss from the PLAXIS analyses showed generally similar behavior with Newmark’s analytical theory. There is some deviation between the FEM results and analytical methods. The results obtained from FEM are significantly smaller than that obtained from analytical methods.

4- The pipe crown deflections are evidently influenced by the density of sand. At same surface stress, the pipe crown deflections decreased more than 50% when the pipe is buried in dense sand.

5- The results explain that the transmitted stress above the pipe crown evidently had been decreased in the case of soil had been reinforced by geogrid. Due to presence of the geogrid the pipe crown deflections were reduced for loose and dense sand. Increasing the depths of geogrids (h/d) decreases the transmitted stress and then decreases the pipe crown deflections for loose and dense sand.

6- Replacing the top backfill with dense sand decreases the crown deflection in acceptable percentage. This percentage increases when replacing the top backfill with dense sand and reinforcing it by geogrid. So replacing the top soil with dense and reinforcing it by geogrid layer gives greater protection for pipes.

References

1. Rajkumar R. and Ilamparuthi K. 2009, "Structural Performance of Buried Flexible Plastic Pipe-An Experimental Study " International Journal on Design and Manufacturing Technologies, Spain, Vol.3, No.1, PP. 77-82.
2. Tafreshi Moghaddas, S. N., Khalaj, O., 2008, "Laboratory Tests of Small-Diameter HDPE Pipes Buried in Reinforced Sand under Repeated-Stress," Geotextiles and Geomembranes, 26, PP. 145–163.
3. Abel, J.F. and Mark, R. 1973, "Stresses Around Flexible, Elliptic Pipe". Journal Soil Mechanics and Foundation Div., Proc. ASCE, Vol. 99, No. SM7.
4. Rajkumar, R. , Ilamparuthi, K., 2008, "Experimental Study on the Behaviour of Buried Flexible Plastic Pipe", Electronic Journal of Geotechnical Engineering EJGE, Vol. 13, PP. 1-10.
5. Bildik, S., Laman, M. and Suleiman, M.T., 2012, "Parametric Studies of Buried Pipes Using Finite Element Analysis, 3rd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering", Near East University, Nicosia, North Cyprus.
6. Kouretzis, George P., Karamitros, Dimitrios K. and Sloan, Scott W., 2016," Analysis of buried pipelines subjected to ground surface settlement and heave, Canadian Geotechnical" Journal, Vol.52No.8,pp. 1058-1071,.
7. Fattah, M.T., Zbar, B.S. and Al-Kalali, H. M., 2016, "Three-Dimensional Finite Element Simulation of the Buried Pipe Problem in Geogrid Reinforced Soil", Journal of Engineering, No. 5 Vol..
8. American Society for Testing and Materials (ASTM D4439-11), 2011, Standard Test Methods for Standard Terminology for Geosynthetics.
9. Marto A., Oghabi, M. and Eisazadeh, A., 2013, "the Effect of Geogrid Reinforcement on Bearing Capacity Properties of Soil under Static Stress; A Review", Electronic Journal of Geotechnical Engineering EJGE, Vol. 18, Bund. J, pp. 1881-1898.
10. Hosseini, M. M., S.M. and Moghddas Tafreshi, S. N., 2002, "Soil-Structure Interaction of buried Pipes under Cyclic Stressing Conditions", International Journal of Engineering, Vol. 15, No. 2, pp. 117-124.
11. Nirmala R., Rajkumar R., Akkineni S.T. and Vignesh B. K., 2016," Experimental and Theoretical Studies on Plasticized Poly Vinyl Chloride (UPVC) Pipe Buried in Cohesionless Backfill", International Journal of Advanced Engineering Technology, Vol. VII/No. III/.PP..122-125.
12. Voskamp W. (2003) “Performance Properties of Geogrids” Reinforced Soil Engineering, Advances in Research and Practice, 4th edition, vol. 1. Library of Congress Cataloging: Publisher’s, PP. 32-48.
13. Sheer Ali, Tawfek 2015, “Geogrid Reinforced Earth versus Piles for The Foundations of Interchange Bridges”, PhD thesis, Civil Engineering Dept., College of Engineering, Al-Nahrain University, Baghdad, Iraq.
14. PLAXIS 3D Manual, 2013, Materials Models Manua, Delt University ot Technology & PLAXIS bv, Netherlands.
15. Newmark, N.M., Simplified Computation of Vertical Pressures in Elastic Foundations, University of Illinois Engineering, Experiment Station, Circular No. 24, Illinois, 1935.
16. Das, B., 2011, "Principals of Foundation Engineerin", Seven edition, Library of Congress Control Number: 2010922634, USA.