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Identifying the Trouble Zone above Buried Conduits and Stress Reduction Using Compressible Inclusion

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ABSTRACT. In the recent years, the Kingdom of Saudi Arabia started some huge projects in the field of infrastructure development through all the Kingdom regions. Reinforced concrete pipes are considered to be a good and economic choice for sewage pipes since they are less expensive, locally produced, and environmentally safe. The use of reinforced concrete pipes is not limited to the sewage systems, but they are also used in water and oil transfer as well as in storm water drainage systems and utility tunnels throughout the Kingdom cities. The current paper aims to identify the trouble zone above buried conduits to be careful during installation pipes or construct buildings on these zones and to investigate how to improve the performance of rigid conduits under heavy overburden soil loads using EPS-Polystyrene around it and compared the geometry of trouble zone above pipe with different diameters of pipes and modulus of elasticity of inclusion. The results of the study show the improvement in the performance of reinforced concrete pipes under high overburden pressure by reducing the vertical stress above buried pipes around 95% when using a thin layer of EPS-geofoam around pipes due to the development of arch action above the pipe. Also, the trouble zone is determined for different diameters of pipes to protect buildings that will be constructed from settlement.

Keywords**:** Buried conduits, Stress reduction, EPS geofoam, Trouble zone, FLAC.

List of Symbols

Do: Outer diameter of pipe (m);
H: Height of fill up to pipe (m);
PL: Prism Load;
VAF: Vertical Arching Factor;
W: Soil unit weight (N/m^3).

1. **Introduction**

In the recent years, engineers started to use new materials for the sewage pipes such as plastic, reinforced concrete, and fiberglass. Reinforced concrete (RC) pipes are considered an economic and environmentally safe alternative when engineers think of installing utility pipe lines for sewage and water projects. Compared with other types such as steel, composite, or plastic pipes, concrete pipes are built using locally produced, less expensive, and less harmful to environment materials. The serious problem of increasing usage of concrete pipes is their ability to resist high overburden pressure when burying them at high embedment depth underground surface and their effects on constructed buildings.

There are two types of pipes can be used for transfer fluids under the ground surface, rigid and flexible pipe [1]. Rigid pipes are generally limited by thrust in the pipe wall and cracking in the pipe like reinforced concrete, plain concrete and clay pipes. Flexible pipes are generally limited by deflection, buckling, and yielding in the pipe wall like metal and plastic pipes [1]. EPS is the abbreviation for Expanded Poly Styrene. Expanded polystyrene, EPS-Geofoam is a lightweight material that has been used in engineering applications around the world since at least the 1950s [2].

Researchers measured the deformation and the vertical and horizontal earth pressure on buried concrete pipes using hydraulic pressure cells [4]. Hydraulic earth pressure measuring cells can installed next to pipe in both sides and above pipe below and above compressible layer with measured distance [4]. For installations with granular backfill material, the long-term measured vertical pressure above the pipe ranged from 23% to 25% of the overburden pressure and about 45% for the one with cohesive soil backfill [4]. Also, the type of soil used in the embankment construction affects the performance of induced arching because the field with granular fill reduced the vertical pressure over the culvert more than the one with silty-clay embankment [4]. The results also show that the deformation of EPS compressible layer is greater in cohesive fill than in granular fill [4].

The final compression of the EPS geofoam compressible layer at the end of embankment construction ranged from 27 % to 32 % of concrete pipes with granular fill and 50 % for cast-in-situ box culvert with cohesive fill [4]. So, the induced trench installation method is successful in reducing the vertical loads on the buried pipes and culverts and it depends on the selection of backfill material with higher stiffness like granular fill material [4]. Table (1) shows a list of physical model studies on induced trench for different researchers from 1979 to 2016 [5, 10 and 11].

2. Objectives

The research aims to achieve the following objectives:

1. Identifying the geometry of trouble zone above buried pipes with different diameters of pipes surrounded with inclusion that graded from flexible to rigid materials.
2. Investigation of the reduction of the vertical stress on buried conduits and improving the stress state by installing a compressible inclusion around it.

3. Methodology

In order to achieve the research objectives, the addressed problems have been analyzed by using different numerical models (Mohr, Elastic and null model) of FLAC 8.0 (finite difference analysis software). FLAC is a 2-D explicit finite difference program used for engineering mechanics computation [6]. This program used for engineering problems to simulate the behavior of structures built of soil, rock, concrete or other materials [6]. FLAC also contains many special features like interface elements, plane stress, plane strain, groundwater and consolidation and structural element models [9]. Furthermore, the FLAC will also calculate the shear strain which is the ratio of the change in deformation to its original length perpendicular to the axes of the member due to shear stress of soil which is further dependent on shear stress and shear modulus. It also contains a database for materials and its properties that will use in a model [9]. Analytical verification for numerical results has been done using equations to calculate a vertical stress above buried pipe.

3.1 Numerical Model

The numerical analysis has been done by using FLAC finite difference analysis program. The simulations of different models are done for a concrete pipe under the ground surface 20m deep that surrounded with 20cm thickness of cover material (Figure (1)) that tested with different modulus of elasticity from flexible to rigid material.

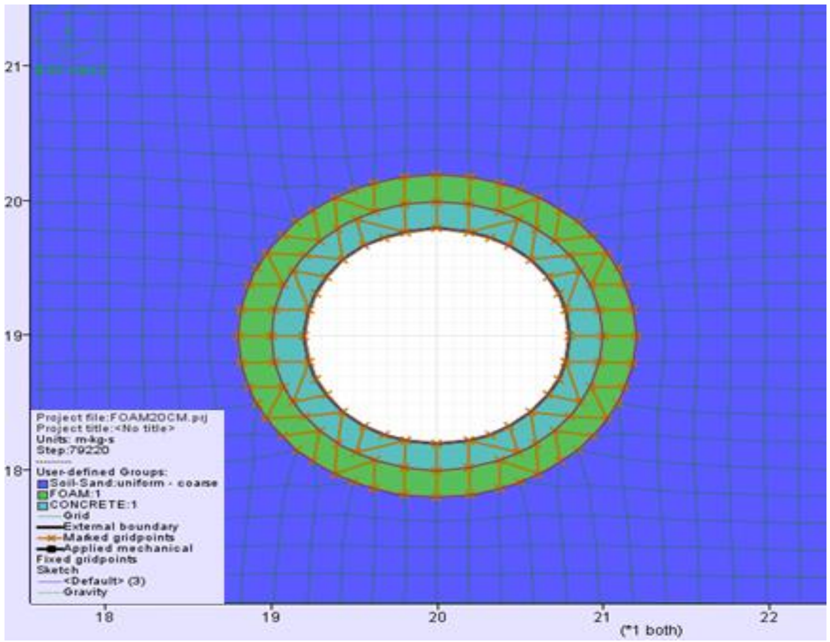

Fig. (1). Numerical model of concrete pipe

These models' simulations will help to understand how the stress on the pipe will reduce by distribution of the loads around pipe with arch action method because there is a compressible layer around it. Furthermore, from strain border above pipe, the disturbance zone geometry can be determined. Dimensions used in these simulations are 40m x 40m and its divided into grids with 200 X 200 elements which that each element is 20cm x 20cm. Tables (2 and 3) shows the properties of materials from database of FLAC that used to prepare a model.

3.1.1 Loading and Boundary Conditions:

This model ran with a dead load of backfill soil without adding any external loads with the following boundary conditions:

i. Fix X axis at i = 1 and i = 201 (Prevent movement at right and left sides).
ii. Fix Y axis at j = 1 (Prevent movement at the bottom).

3.1.2 Results and Discussion

Figure (2) shows a vertical section for a geometry of trouble zone above concrete buried pipe surrounded with inclusion. Figure (3) from FLAC software brief the shear strain increment that indicates the trouble zone above buried pipe and show the top and bottom widths of this zone by coloring the strain line and its geometry near the shape cone.

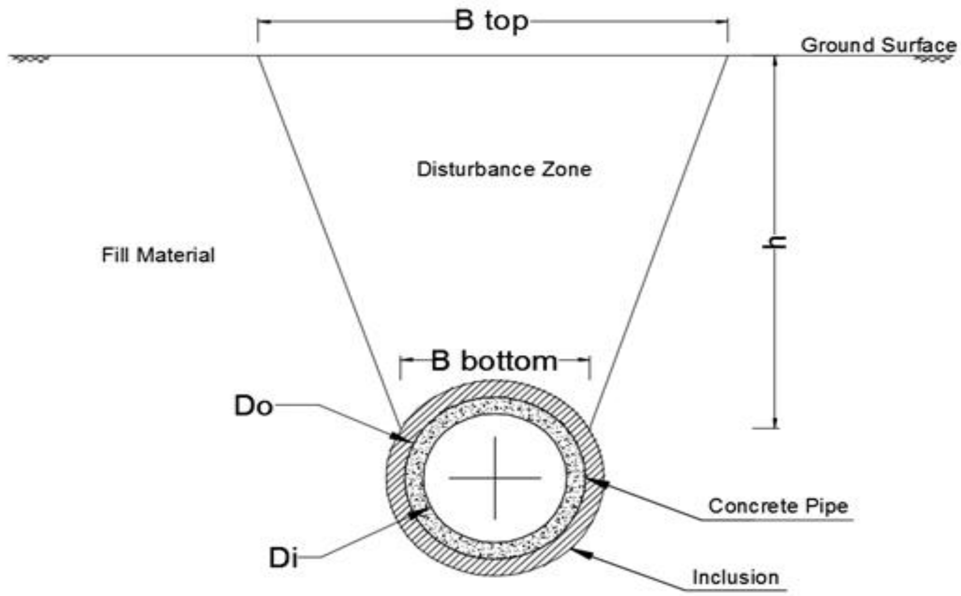

Fig. (2). Vertical section for disturbance zone

Simulations have been done 12 times with models named (Mohr, Null and Elastic) (Figure (2)) for different diameters of concrete pipes with ranged modulus of elasticity of cover material from 25 KPa to 25 GPa. Figure (4) shows the curve between diameter of pipe and the bottom width of disturbance zone directly above pipe for each modulus of elasticity of inclusion material. We can notice that the bottom width is directly proportional to the diameter of pipe in the case of flexible pipe and inversely proportional in the case of rigid pipe. Figure (5) shows the curve between diameter of pipe and the top width of trouble zone above pipe near the surface of ground for each modulus of elasticity of inclusion material. Moreover, the Figure (5) highlight the information that the top width is directly proportional to the diameter of pipe in the case of flexible and rigid pipe.

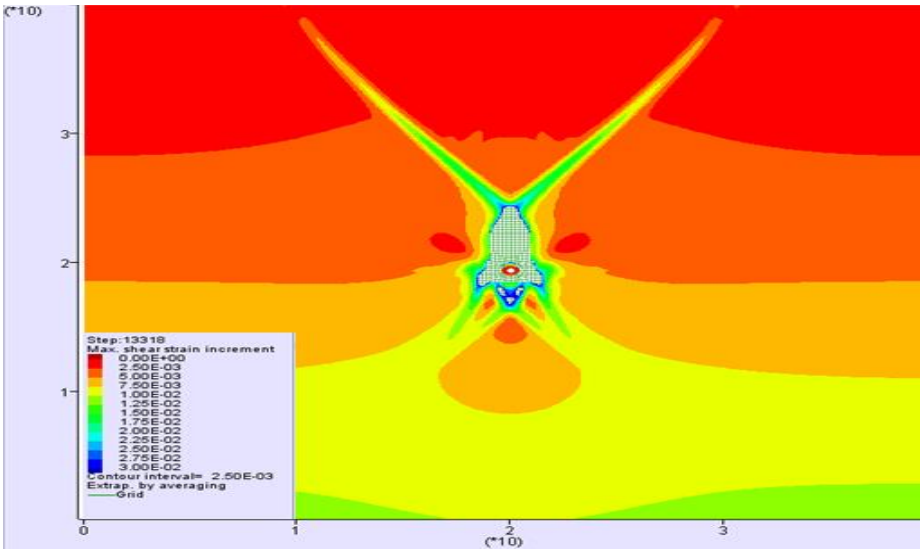

Fig. (3). Shear Strain Increment from FLAC for flexible inclusion (E=25KPa)

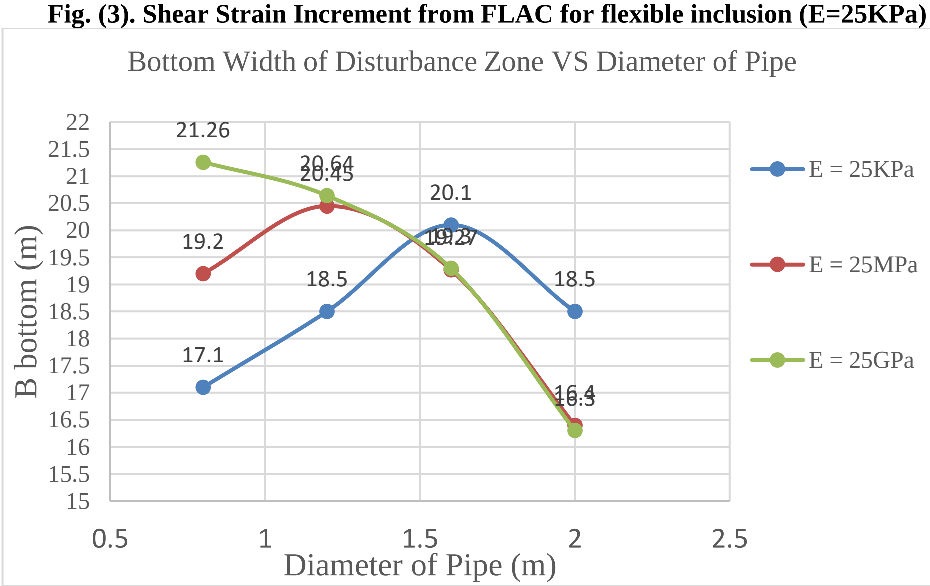

Fig. (4). Curve between diameter of pipe and bottom width of disturbance zone

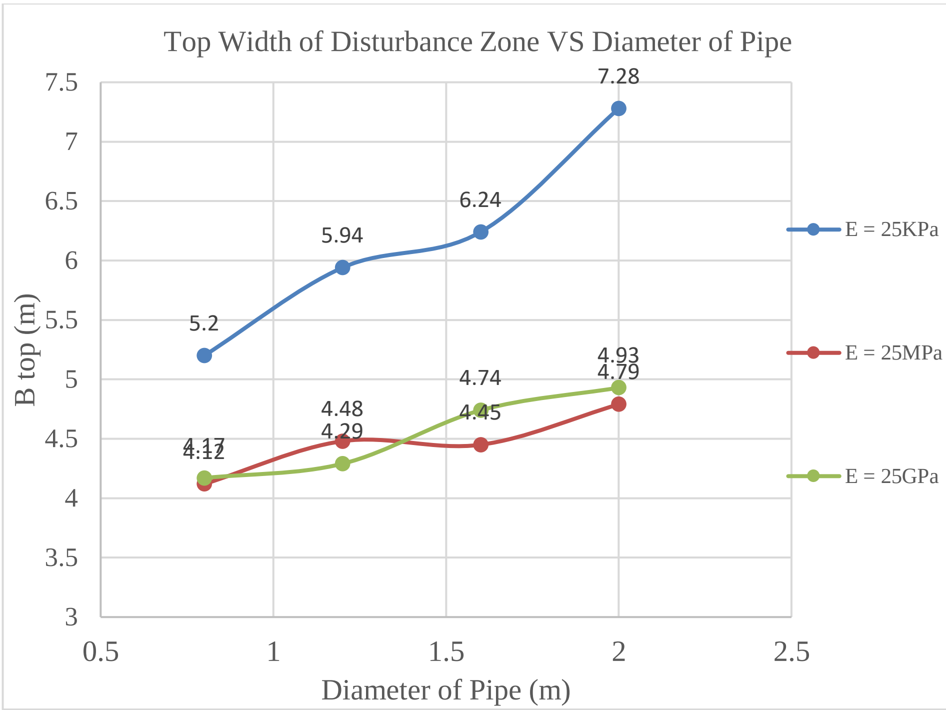

Fig. (5). Curve between diameter of pipe and top width of disturbance zone

Figures (6 and 7) from FLAC simulation reveal the difference in values of vertical stress between flexible and rigid inclusion around pipe and how the flexible inclusion reduces the stress around 95%. Figure (8) which shows the curve between diameter of pipe and the vertical stress (Syy) above pipe near the surface of inclusion material for each modulus of elasticity, the vertical stress above flexible material reduced about 95% from rigid material is noticed.

Figures (9 and 10) which shows the vertical displacement of simulation from FLAC and the curve between diameter of pipe and the vertical displacement (Y-disp) above pipe near the surface of inclusion material for each modulus of elasticity, the flexible material causes more vertical displacement than rigid material.

3.2 Analytical Verification of a Numerical Results

Analytical verification has been done for all models that have modulus of elasticity for inclusion material same as soil modulus E = 25MPa using prism load equation for trench method [9].

$Syy = VAF * PL$ (N/m^2)

$PL = w\ (H + \frac{Do(4-\pi)}{8})$ (N/m^2)

VAF = 1.4 for the type of trench.

For D$_o$ = 0.8m

$PL = 1600 * 9.81(20 + \frac{0.8\ (4-\pi)}{8}) = 3.1526 * 10^5$ N/m^2

$Syy = 1.4 * 3.1526 * 10^5 = \mathbf{4.4136 * 10^5}$ **N/m^2**

From FLAC simulation the magnitude of Syy at the same point (i=101, j=100) that calculated with equation:

$Syy = \mathbf{4.656 * 10^5}$ **N/m^2**

For D$_o$ = 1.2m

$PL = 1600 * 9.81(20 + \frac{1.2\ (4-\pi)}{8}) = 3.1594 * 10^5$ N/m^2

$Syy = 1.4 * 3.1594 * 10^5 = \mathbf{4.4231 * 10^5}$ **N/m^2**

From FLAC simulation the magnitude of Syy at the same point (i=101, j=100) that calculated with equation:

$Syy = \mathbf{5.341 * 10^5}$ **N/m^2**

For D$_o$ = 1.6m

$PL = 1600 * 9.81(20 + \frac{1.6\ (4-\pi)}{8}) = 3.1661 * 10^5$ N/m^2

$Syy = 1.4 * 3.1594 * 10^5 = \mathbf{4.4325 * 10^5}$ **N/m^2**

From FLAC simulation the magnitude of Syy at the same point (i=101, j=100) that calculated with equation:

$Syy = \underline{\mathbf{5.274 * 10^5\ N/m^2}}$

For D_o = 2m

$PL = 1600 * 9.81(20 + \frac{2\,(4-\pi)}{8}) = 3.1728 * 10^5\ N/m^2$

$Syy = 1.4 * 3.1728 * 10^5 = \underline{\mathbf{4.4419 * 10^5\ N/m^2}}$

From FLAC simulation the magnitude of Syy at the same point (i=101, j=100) that calculated with equation:

$Syy = \underline{\mathbf{5.881 * 10^5\ N/m^2}}$

Table (4) shows the values of vertical stress for all models that get from FLAC software and from equation.

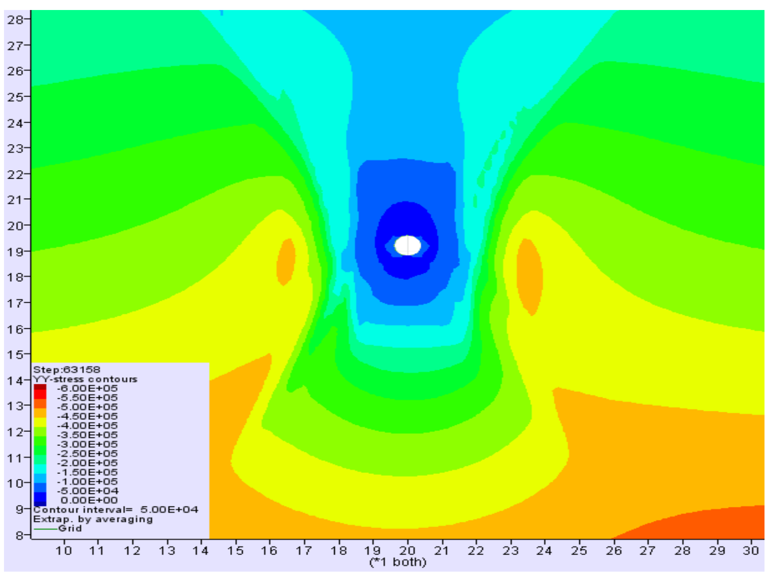

Fig. (6). Vertical stress (Syy) from FLAC for flexible inclusion (E=25KPa)

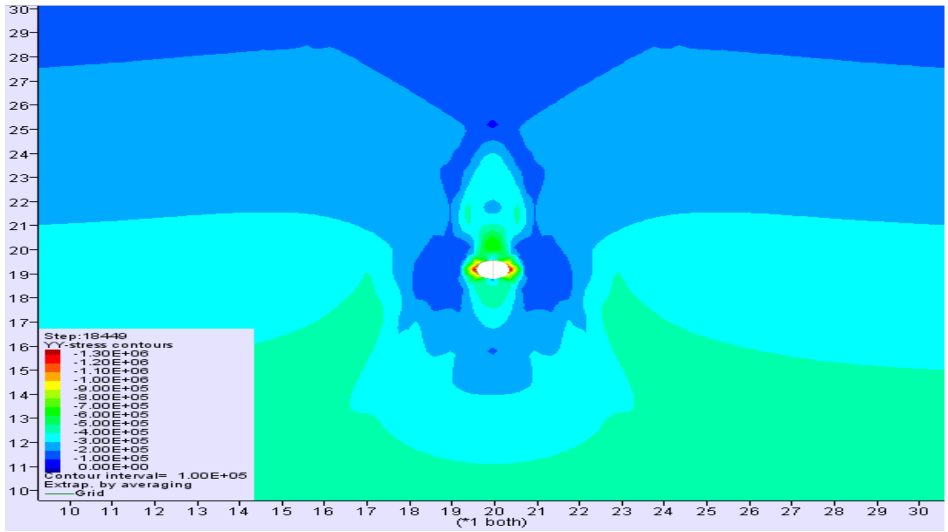

Fig. (7). Vertical stress (Syy) from FLAC for rigid inclusion (E=25GPa)

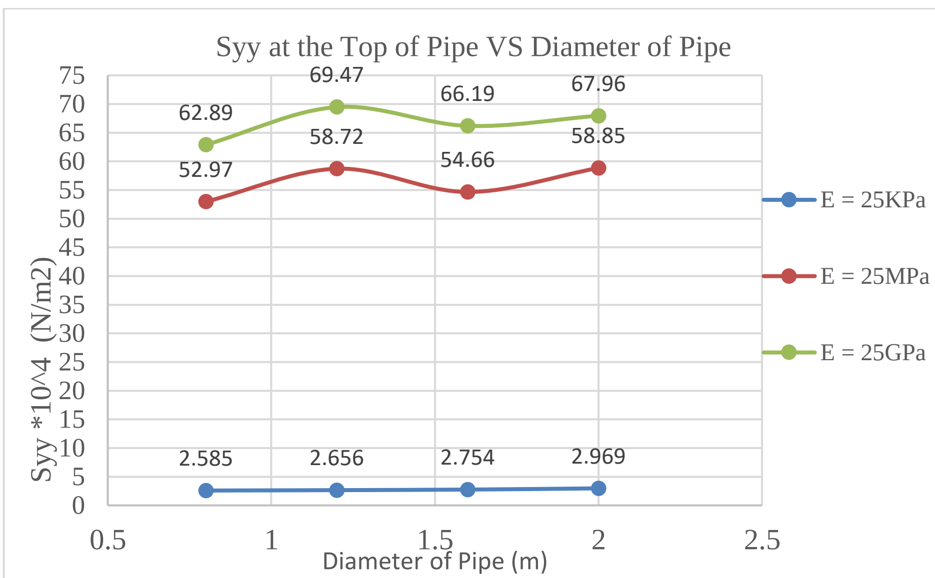

Fig. (8). Curve between diameter of pipe and vertical stress above pipe surface

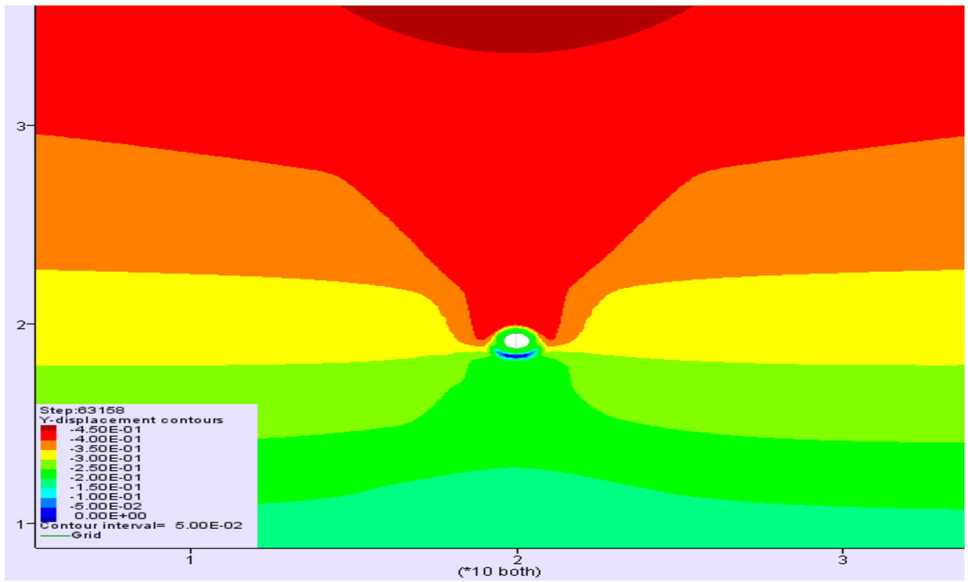

Fig. (9). Vertical displacement (Y-disp) from FLAC for flexible inclusion (E=25KPa)

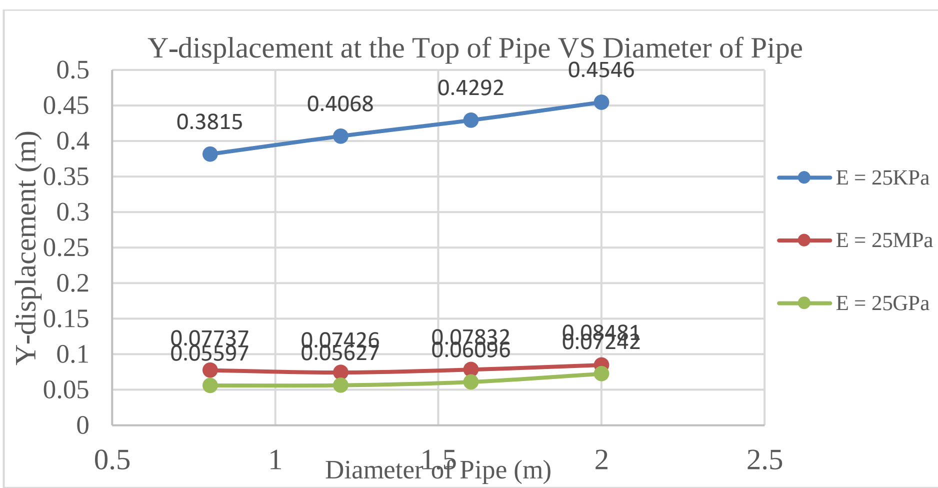

Fig. (10). Curve between diameter of pipe and vertical displacement above pipe surface

4. Conclusion

Numerical studies of circular rigid buried pipe 20m deep underground surface with the use of inclusion material surrounded it with different modulus of elasticity have been performed by using a finite difference program (FLAC 8.0), the following conclusions are made.

i. A bottom width of trouble zone that is directly above buried pipe is directly proportional to the diameter of pipe in the case of flexible pipe and inversely proportional in the case of rigid pipe.
ii. A top width of trouble zone that is near to the ground surface is directly proportional to the diameter of pipe in both cases flexible and rigid pipe but the case of flexible has higher values compared to rigid one.
iii. When a vertical stress (S_{yy}) above surface of pipe compared between flexible and rigid material around pipe, it is reduced by 95% with the case of flexible pipe because the compressible inclusion distributes loads around pipe with arch action method.
iv. The flexible material causes more vertical displacement (Y-displacement) than rigid material above buried pipe.

5. Recommendations

Based on research findings/conclusions, the future researchers must determine the trouble zone, vertical stress and vertical displacement above buried pipes by changing the properties of fill material like (type of soil, water content and density) and inclusion like (density, thickness of inclusion and distance from conduits).

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7. References

[1] Yoo, C.H., Kang, J. "Soil-Structure Interaction for Deeply Buried Corrugated PVC and Steel Pipes." Auburn University, (May 2007).

[2] Elragi, A.F. "Selected Engineering Properties and Applications of EPS Geofoam." State University of New York, NY, USA, (2000).

[3] Steven, F. B, Bret, N.L., Jan,V. "Methods of Protecting Buried Pipelines and Culverts in Transportation Infrastructure Using EPS Geofoam." Geotextiles and Geomembranes journal, (October 2015), 43 (5), pp. 450-461.

[4] Vaslestad, J, Sayed, M.S., Johansen, T.H., Wiman, L. “Load Reduction and Arching on Buried Rigid Culverts Using EPS Geofoam, Design Method and Instrumented Field Tests.” Norwegian Public Roads Administration, (2011).

[5] Turan. A, El Naggar, M.H., Dundas, D. “Investigation of Induced Trench Method Using a Full-Scale Test Embankment.” Geotech Geo Eng, (March 2013).

[7] American Concrete Pipe Association. “Concrete Pipe Design Manual.” Chapter 4, (2011), pp. 45-53.

[8] Steven, F, Bret, N, “Protection of Pipelines and Buried Structures Using EPS Geofoam”, Paper, University of Utah, (May 2014).

[9] FLAC (Fast Lagrangian Analysis of Continua v8.0.449) PDF manuals.

[10] Kim, H, Choi, B, and Kim, J, “Reduction of Earth Pressure on Buried Pipes by EPS Geofoam Inclusions", Geotechnical Testing Journal, Vol. 33, No. 4, (2010).

[11] Witthoeft, A, Kim, H, “Numerical Investigation of Earth Pressure Reduction on Buried Pipes Using EPS Geofoam Compressible Inclusions”, Geosynthetics International Journal, Vol. 23, Issue 4, July (2016).

Table (1). Physical Model Studies

Title	Structure	Remarks
Floyd & Clark (1979) [5]	Box culvert	No results are reported due to problems related to instrumentation
Valested (1993) [5]	Box culvert	37 % reduction of the vertical stresses relative to the overburden stresses on top of the box and no pressures on the sides and bottom are reported
Okabayashi (1994) [5]	Box culvert	Recommended optimized size and location of compressible EPS geofoam layer
Bourque (2002) [5]	Twin box culvert	Studied the effect of culvert spacing and compressible material geometry
MacLeod (2003) [5]	Box culvert	80 % reduction in vertical stress relative to the overburden stresses on top of the culvert and a small increase in the lateral stresses
Mcaffee and Valsangkar (2005) [5]	Single box and pipe culvert	64–76 % reduction in vertical stress relative to the overburden stresses on top of the culvert and larger lateral stresses relative to vertical stresses
Parker (2008) [5]	Single pipe culvert	76 % reduction in vertical stress relative to the overburden stresses on top of the culvert and a small increase in the lateral stresses
Hobi Kim (2010) [10]	Buried pipe	73% reduction in vertical pressure acting on the pipe and 60% on horizontal earth pressure
Witthoeft & Kim (2016) [11]	Buried pipe	EPS inclusions are effective in reducing the earth pressure acting on the pipe due to positive arching action

Table (2). Properties of Materials That Used in A Model from FLAC Database

	Mass Density (Kg/m^3)	Elastic Modulus (Pa)	Poisson's Ratio (unit less)	Thickness (m)
Inclusion Material	20	25 E3 – 25 E9	0.25	0.2
Concrete Pipe	2200	5 E10	0.25	0.2

Table 3. Backfill Soil Properties

	Type of Soil	Mass Density (Kg/m^3)	Cohesion (c)	Angle of Friction (º)	Elastic Modulus (Pa)	Poisson's Ratio (unitless)
Soil	Uniform Coarse Sand	1600	0	34	25 E6	0.25

Table 4. Values of Vertical Stress

Diameter of Pipe (m)	S_{yy} from FLAC (N/m^2)	S_{yy} from Equation (N/m^2)
0.8	$4.656*10^5$	$4.4136*10^5$
1.2	$5.341*10^5$	$4.4231*10^5$
1.6	$5.274*10^5$	$4.4325*10^5$
2.0	$5.881*10^5$	$4.4419*10^5$

تحديد منطقة الاضطراب فوق القنوات المدفونة وتخفيف الاجهادات باستخدام طبقات قابلة للانضغاط

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ملخص البحث.في السنوات الأخيرة ، بدأت المملكة العربية السعودية بعض المشاريع الضخمة في مجال تطوير البنية التحتية في جميع مناطق المملكة. تعتبر الأنابيب الخرسانية المسلحة خيارًا جيدًا واقتصاديًا لأنابيب الصرف الصحي لأنها أقل تكلفة وتنتج محليًا وآمنة بيئيًا. لا يقتصر استخدام الأنابيب الخرسانية المسلحة على أنظمة الصرف الصحي ، ولكنها تستخدم أيضًا في نقل المياه والنفط وكذلك في أنظمة تصريف مياه الأمطار والأنفاق العامة في جميع مدن المملكة.

تهدف هذه الورقة العلمية إلى تحديد منطقة الاضطراب فوق القنوات المدفونة لأخذ الحذر أثناء تركيب الأنابيب أو بناء المباني في هذه المناطق والتحقيق في كيفية تحسين أداء القنوات الصلبة تحت أحمال التربة الثقيلة المحملة باستخدام طبقات البوليسترين حولها بأقطار مختلفة من الأنابيب ومعامل مرونة يتدرج من الصلب الى المرن. أظهرت نتائج الدراسة التحسن في أداء الأنابيب الخرسانية المسلحة تحت الضغط العالي عن طريق تقليل الضغط الرأسي فوقها حوالي ٩٥ ٪ عند استخدام طبقة رقيقة من البوليسترين حول الأنابيب بسبب توزيع الاحمال حول المواسير. أيضا، يتم تحديد منطقة الاضطراب لأقطار مختلفة من الأنابيب لحماية المباني التي سيتم بناؤها من الهبوط