Effects of Bedding Types on the Behavior of Large Diameter GRP Flexible Sewer Pipes

Dr. Adnan Falih Ali
Professor
College of Engineering, University of Baghdad
Email: af_bas1@yahoo.com

Raad Abdulkhudhur Sehaib
Assistant Lecturer
Engineering of Building and Construction,
University of Technology
Email: raad_1972_sehaib@yahoo.com

ABSTRACT

Flexible pipes, such as GRP pipes, serve as effective underground infrastructure especially as sewer pipeline. This study is an attempt for understanding the effects of bedding types on the behavior of large diameter GRP flexible sewer pipes using three dimensional finite element approaches. Theoretical and numerical analyses were performed using both BS EN 1295-1 approach and finite element method (ABAQUS software). The effects of different parameters are studied such as, depth of backfill, bedding compaction, and backfill compaction. Due to compaction, an increase in the bedding compaction modulus (E'_1) results in a reduction of both stresses and displacements of the pipe, especially, for well compacted backfill. An increase of (E'_1) from 14MPa to 30MPa results in a reduction in stresses 40% and about 25% in displacements. Maximum reductions in stresses were found to be about 25% only while the reduction in displacement was found to be less than 10%. As backfill material compaction modulus (E'_2) is increased from 14MPa to 40MPa, a maximum reduction in stresses within the pipe was found to be not less than 60% while the displacement reduces up to 65%.

Key words: Flexible Pipes; GRP Pipes, Bedding Compaction, Backfill Compaction, ABAQUS

تاثيرات أنواع طبقة الفرش على تصرف أنابيب المجاري المرنة ذات الأقطار الكبيرة من نوعGRP

د. عدنان فالح علي
استاذ
قسم الهندسة المدنية*كلية الهندسة*/جامعة بغداد

رعد عبدالخضر سحيب
مدرس مساعد
قسم هندسة البناء والانشاءات-الجامعة التكنولوجية

الخلاصة

تعتبرالأنابيب المرنة كأنابيب GRP المطمورة من خطوط انابيب البنى التحتية الفعالة وخصوصا" في خطوط أنابيب المجاري.هذه الدراسة محاولة لفهم تأثيرات أنواع الفرش على سلوك أنابيب المجاري المرنة ذات الأقطار الكبيرة من نوع GRP باستخدام نظرية العناصر المحددة ثلاثية الأبعاد. حيث أجريت التحليلات النظرية والعددية باستخدام كل من (BS EN 1295-1) وطريقةالعناصرالمحدودة ثلاثيةالأبعاد بأستخدام (برنامجABAQUS). تم دراسة تأثيرعدة متغيرات مثلا":عمق مادة الدفن ، رص مادة الفرش تحت الأنبوب ورص مادة الدفن. بسبب الزيادة في حدل مادة الفرش (E'_1) فانه ينتج انخفاض في كل من الأجهادات والتشوهات في الانبوب، وخصوصا" عندما تكون تربة الدفن محدولة جيدا". زيادة (E'_1) من14MPa الى 30MPa ينتج اكبر انخفاض في الاجهادات ب40% وحوالي 25% في التشوهات. اكبر انخفاض في الاجهادات حوالي 25% فقط بينما الانخفاض في التشوهات اقل من 10%. عندما رص مادة الدفن(E'_2) يزداد من 14MPa الى 40MPa فان اكبر انخفاض في الاجهادات خلال الانبوب يكون اكبر من 60% بينما التشوهات تقل باكبر من 65%.

الكلمات الرئيسية: الانابيب المرنة،انابيب GRP، رص مادة الفرش، رص مادة الدفن ، برنامج ABAQUS

1. INTRODUCTION

Buried pipes for sewer systems are usually subjected to external forces caused by backfill and additional surcharge due to traffic loading. Accordingly, stresses within the pipe walls will be developed, those stresses are assumed to be depending on the type of backfill, depth of backfill and the bedding type in additional to pipe diameter. The present paper presents a theoretical investigation of the behavior of large diameter sewer pipes made of (GRP) when buried at different depths, moreover, the study presents the effect of bedding type on the developed stresses, strains and displacements of the pipe walls using finite elements analysis implemented in the ready software ABAQUS.

2. OBJECTIVES

The main objectives of the current work are:

(a) To provide a comparative analysis of flexible sewer pipes taking into account variation of the following factors,

- Depths of the pipes variation relative to the pipe diameter.
- Properties of the soil used to backfill above the pipe.

(b) To study the effect of bedding type on the behavior of flexible sewer pipes

(c) To present numerical case studies by implementing the finite element procedure so as to provide a more accurate behavior of the flexible pipe and to compare the results with the available procedure currently in use to assess the pipe behavior.

3. ANALYTICAL APPROACH of (BS EN 1295-1)

An analytical method is recommended in UK by **[BS EN 1295-1**], and is summarized in the following steps:

3.1 Soil Modulus

Soil modulus is the parameter of the most influence on the structural calculation, as soil stiffness will generally be significantly greater than the pipe stiffness. Spangler modulus values have been determined from empirical measurements and are indicated in **Tables 1** for the native soil**.** The soil modulus adjustment factor (C_L), is used to take into account the influence of native soil properties on the overall soil modulus (E'), and can be calculated by using Eq.(1) as shown below: **["Design and Installation Manual of Ridgidrain, Ridgisewer and Polysewer"].**

$$\boldsymbol{C_L} = \frac{\mathbf{0.985+(0.544}\boldsymbol{B_d/B_c})}{[\mathbf{1.985-0.456}(\boldsymbol{B_d/B_c})](\boldsymbol{E'_2/E'_3})-[\mathbf{1}-(\boldsymbol{B_d/B_c})]} \tag{1}$$

$$E' = E'_2 \times C_L \tag{2}$$

3.2 Vertical Soil Pressure (P_e)

The vertical dead load applied to the pipe system is typically restricted to the soil pressure generated by the pipe backfill material. The load is taken as the pressure imposed by the prism of soil directly overlying the pipe. No allowance is made within the available standards for the effect of shear between the backfill material and the trench walls. Where the density of the backfill material is not available, (value of 19.6kN/m^3) may be assumed for design purposes.

$$P_e = \boldsymbol{\gamma} \times H \tag{3}$$

3.3 Surcharge Pressure (P_s)

The imposed pressure from vehicle traffic is largely dependent on the depth of cover above the pipe. Surcharge loads are calculated using Boussinesq's theory which is plotted in **Fig.1**

3.4 Deflection Lag Factor (D_L)

An empirical factor is used to account for relaxation, or creep, of the pipe/soil system and other general long-term settlement effects. A conservative design approach is taken by assuming no beneficial effect is derived from frictional forces between the trench walls and backfill material, in addition to the use of a long-term pipe stiffness parameter. Values generally range from **1.0** to **1.5**, dependant on the type of pipe surround used and its level of compaction. A well installed gravity flow pipe, utilising a single sized granular bed and surround, a value of **1.0** is typically taken for the deflection lag factor.

3.5 Deflection Coefficient (K_X)

A bedding factor is used to represent the extent of lateral support provided by the pipe bedding. For pipes receiving support over the full **180°** lower half of the pipe a value of **0.083** should be used, whereas bedding providing only a line load support, a value of **0.100** would be more appropriate.

3.6 Pipe Deformation

The deformation of flexible pipes under load results in the ovalization of the pipe (a reduction in the vertical diameter and an increase in the horizontal diameter). As the horizontal diameter of the pipe increases, it derives support from the sidefill and trench wall. This passive earth pressure increases as the pipe deforms further until the pipe-soil system comes into equilibrium.
Ovalization can be calculated using Eq. (4) as shown below:

$$\frac{\Delta}{D} = \frac{K_x[(D_L P_e)+P_s]}{(8EI/D^3)+(0.061E')} \tag{4}$$

3.7 Buckling Resistance of Buried Pipeline

The buckling resistance of buried, flexible non-pressurized pipelines is a combination of the pipes inherent buckling resistance and support afforded by the pipe surround. The critical buckling pressure of a buried pipe is substantially greater than that for unrestrained pipes subject to external loading. Bending stress can be calculated by using Eq. (5) as shown below:

$$\sigma_{bs} = E\, D_f\left(\frac{\Delta}{D}\right)\left(\frac{t}{D}\right) \tag{5}$$

4. FINITE ELEMENT MODEL

Numerical applications using Finite Element Analyses are carried out to assess the behavior of buried pipes in trench installations. In the numerical analyses, effects of pipe material, height of fill above the pipe, soil properties are investigated. In the current study, effects of bedding types on the behavior of large diameter GRP flexible sewer pipes are studied by using FE. The FE analyses were carried out using ABAQUS**, [Hibbitt, Abaqus Manual,(2009)],** program in addition to the analysis based on the traditional procedure used for structural design of buried pipelines which is used under various conditions of loading **[BSI. 1295-1] ,British Standard,1998.**

Each of the above mentioned parameters was varied within an acceptable practical range and the corresponding results of stresses and deformations have been calculated numerically to explain the global response, as follows:

- Pipe diameter is equal to (3 m).
- Trench width is equal to (4 m).
- Depths of the pipes are varied such that the soil depth above the pipe equals to:
  - Pipe outside diameter (m).
  - Pipe outside diameter +1.5 m.
  - Pipe outside diameter +3 m.
- Properties of the soil surrounding the pipe and the bedding material were varied such that:
  - Bedding Soil Modulus, **E'$_1$**, of bedding material to have values of 14, 20 and 30MN/m^2.
  - Embedment Soil Modulus, **E'$_2$**, of backfill material to have values of 14, 30 and 40 MN/m^2.
  - Native Soil Modulus, **E'$_3$**, to have values of 14, 20 and 30MN/m^2.

The three-dimensional finite element models of pipe-soil interaction were performed by using, ABAQUS, version 6.10-1, computer program. The finite element method is one of the most popular numerical methods used for obtaining an approximate solution for complex problems in various fields of engineering.

The flexible sewer pipeline model including five steps following:

4.1 Types of Loads on a Pipeline

The design and analysis of buried flexible pipelines are carried out for the total loads, comprising the effects of the dead load exerted by soil and the live load caused by traffic.

Both, dead and live loads acting directly on the pipeline are assumed vertical and of static nature acting on the pipeline.

4.1.1 Dead Load

The weight of soil, which is generally called dead load, is calculated using ABAQUS program. ABAQUS calculates the loading using the acceleration magnitude that one may enter in the gravity load definition and the density is specified in the material definition.

$$\textit{Unit weight (kN/m}^3\textit{) = Mass density (kg/m}^3\textit{)} \times \textit{Gravity load (9.81m/sec}^2\textit{)} \qquad (6)$$

The dead load on the buried pipeline is normally substantially greater than the live load because the effects of live load, usually due to traffic, diminish rapidly with depth of soil above the pipe.

4.1.2 Live Load

The pressure exerted on pipelines by concentrated surface surcharges, such as vehicle wheels, construction vehicles, or track railway, are generally called live load.

HS Loadings

The HS loadings are illustrated in **Fig.2**. They consist of a tractor truck with semi-trailer or of the corresponding lane loading. The HS loadings are designated by the letters HS followed by a number indicating the gross weight in tons of the tractor truck. The variable axle spacing has been introduced in order that the spacing of axles may approximate more closely the tractor trailers now in use. The variable spacing also provides a more satisfactory loading for continuous spans, in that heavy axle loads may be so placed on adjoining spans as to produce maximum negative moment, **[The American Association of State Highway and Transportation Officials, (2002)].**

Traffic load is represented as a rectangle area over the surface backfill as shown in **Fig.3** in ABAQUS program.

4.2 Material Properties

4.2.1 Soil Properties

There exist several types of soils: clay, sand, rock, undistributed granular soils, placed granular soils and compacted backfill ground around buried pipelines placed in an excavated trench.

In this study, the soil is divided into two types: bedding and backfill soils. The types of soil and their mechanical properties are shown in **Table 2**

4.2.2 Pipeline Properties

Large diameter fiberglass reinforced plastic (GRP) pipelines which are used for trunk sewer construction or sewer networks are assumed to possess the properties shown in **Table 3**.

4.3 Models of the Soil and the Pipeline

In this study, the finite element models of the pipeline and the soils are established using the package ABAQUS to carry out the analysis of flexible buried pipelines. In the ABAQUS program, the soil model is defined as a three-dimensional (3D) deformable solid body and elastic characterised, which is divided into two types: bedding and backfill soils as shown in **Fig.4**.

On the other hand the pipeline is simulated as a three-dimensional (3D) deformable shell model as shown in **Fig.5**.

4.4 Surfaces of the Soil and the Pipeline

Definition surfaces of the soil and pipeline to generate contact interaction between the parts of the model. The limits of each type are shown in **Fig.6** and **Fig.7**.

4.5 Assembly of Pipeline and Soil

A physical model is typically created by assembling various components. The assembly interface in ABAQUS allows analysts to create a finite element mesh using an organizational scheme that parallels the physical assembly. In ABAQUS, the components that are assembled together are called part instances. An assembly is a collection of positioned part instances of soil and pipeline as shown in **Fig.8**. An analysis is conducted by defining boundary conditions, constraints, interactions, and a loading history for the assembly.

4.6 Interaction between the Soil and a Pipeline

In ABAQUS, the types of constraints include tie, rigid body, display body, coupling, MPC (Multi- Point Constraint), shell-to-solid coupling, embedded region and equation. A tie constraint ties two separate surfaces together so that there is no relative motion between them.

One constraint (called tie) is adopted for simplicity to connect bedding top surface and backfill bottom surface, backfill surface and pipeline top surface as well as bedding surface and pipeline bottom surface, which are fully bonded to each other as shown **Fig.9**.

4.7 Boundary Conditions

In a 3D-finite element model related to soil and pipeline, two boundary conditions of 3D- finite element soil model need to be considered; bottom surface and four side surfaces of 3D-finite element soil model whereas 3D-finite element pipeline model, boundary conditions need to be considered at two end surfaces of a pipeline and circumferential pipeline surface which comes into contact with soil.

4.7.1 Boundary Condition of Soil's 3D-Finite Element Model

First, the four side surfaces (left, right, front, and back) of the 3D-finite element soil model are supposed to be on rollers as shown in **Fig.10** since these surfaces for left, right, front, and back restrain only the horizontal movement (i.e. u = w = 0).. Additionally, the bottom surface of the 3D-FE soil model is proposed to be completely fixed (i.e. u = v = w = 0) in order to restrain horizontal (i.e. u = w = 0) and vertical movement (i.e. v= 0). This is because the bottom boundary is selected at the known location of a bedrock surface, **Rao, (1999)**.

4.7.2 Boundary Condition of Pipeline's 3D-Finite Element Model

Boundary condition of proposed of 3D-finite element pipeline model is shown in **Fig.11**; Two end surfaces of the pipeline and surrounding the pipeline surface come into contact with soil.

4.8 Element Types

Under the comprehensive consideration of buried pipelines, the 3D reduced integration continuum brick element with twenty nodes with a second-order (or quadratic) interpolation, C3D20R was selected for the (bedding and backfill) soils as shown in **Fig.12**.

The (3D) reduced shell continuum element with eight nodes with a second-order (or quadratic) interpolation, S8R was selected for the pipeline as shown in **Fig.13**.

The second-order elements are more effective than the first-order elements because the second-order elements can deal with bending dominant problems which cannot be solved by the first-order elements, **Lee, (2010)**.

4.9 Defining Loads

In ABAQUS, self-weights of both soil and pipelines are represented as gravity loads, while the traffic load is represented as a pressure load over the surface backfill as shown in **Fig.14**.

4.10 Meshing both Soil and Pipeline Model

The mesh module contains tools that allow ABAQUS/CAE to generate a finite element mesh on created models. Various levels of automation and control are available so that a mesh is produced. The mesh is the step related to dividing the models into lots of small parts. These divided 3D small meshed elements in models play an important role to offer suitable results in accordance with the chosen number of elements and the type of element as shown in **Fig.15**.

4.11 Creating an Analysis Job

Once all of the tasks involved in defining the model are finished, it is necessary to use job module for analysing the created model. The job module allows ABAQUS/CAE to interactively submit a job for analysis and monitor its progress.

4.12 Displacement of a Buried Pipeline

The pipeline can deform like an oval shape along the whole length under the subsiding soil involved in short-term serviceability issue. A typical deformation of a pipeline under static loads is shown in **Fig.16**.

4.13 Stresses in GRP Pipelines

The maximum longitudinal stress has been computed from the general elastic static analysis. The static loads, which are simulated vertically, caused the pipeline to be deformed into an oval shape and allowed the maximum longitudinal stress of a buried pipeline to occur at both the crest and the invert of a pipeline as shown in **Fig.17**.

It is possible to conclude that the generated maximum stress of a pipeline at both crest and invert of the pipeline makes the flexible pipeline to buckle at these positions of the pipeline. This means that if there is not enough strength of a pipeline for resisting static loads, the buckling will be generated at both the crest and the invert of a pipeline and the flexible pipeline will totally collapse when stresses reaches a critical buckling level.

5. NUMERICAL RESULTS AND DISCUSSIONS OF CASE STUDIES

Using the procedure adopted in the previous section, parametric studies are carried out and presented in the current section, and these parametric studies take into consideration variation of several parameters as follows:

5.1 Effect of Bedding and Backfill

Under various bedding and backfill conditions, when examining the analysis results given in **Fig. 18** to **19** it can be noted that:

1. Bedding compaction was found to be of important influence on both stresses and displacements of the pipe irrespective of pipe diameter as predicted by the (FE) approach. It was also found that increasing bedding compaction (E'_1) results in a reduction of both stresses and displacements of the pipe, especially, for well compacted backfill. This behavior is attributed to the tendency of rigid behavior of the pipe, the underneath, and surrounding materials. An increase of (E'_1) from 14MPa to 30MPa results in a maximum reduction in stresses by 40% and to about 25% in displacements.
2. If the backfill material (E'_2) is loose, bedding compaction was found to be effective mainly in cases of shallow pipes where the stresses still reduce with compaction but the displacements were found to be less affected. Maximum reductions in stresses were found to be about 25% only while the reduction in displacement was found to be less than 10%.

3. The procedure suggested by the (BSI) were found to lead to results which are close to those predicted by the (FE) in the following cases
    - Well and very well compacted bedding ($E'_1 \geq 20$ MPa)
    - Relatively narrow trenches as compared to the pipe diameters
    - Well compacted backfill surrounding pipes of relatively small diameters
    - However, displacements of the pipes as predicted by the FE approach were found to be close to those predicted by the BSI approach in cases of well compacted bedding and backfill for pipes of medium and small diameters.

This behavior is related to the increase in angle of repose of the backfill materials which results almost in a solid medium behavior which is assumed by both the FE and the BSI procedure.

5.2 Effect of Depth of Backfill

From **Fig.20** and **Fig.21**,the maximum longitudinal stress of GRP pipe increases with depth increasing for bedding soil modulus (E'_1) 14, 20 and 30MPa and for backfill soil modulus (E'_2) 14, 30 and 40MPa. Also The maximum vertical displacement of GRP pipe increases with depth increasing for bedding soil modulus (E'_1) 14, 20 and 30MPa and for backfill soil modulus (E'_2) 14, 30 and 40MPa.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. The stresses and deformations within the pipe walls increase with pipe depth below the ground surface, however, the rate of increase in stresses and deformations becomes less as the depth exceeds 2 times the diameter due to the increase in the arch action.
2. The stresses within the pipe were found to maintain constant values or slightly decrease with the increase of trench width.

3. In cases of loose bedding materials, displacements within the pipe were found to reduce with the increase of trench width, especially in cases of deep pipes.

6.2 Recommendations

1. A study on the flexible sewer pipes in underground water should be made.
2. Effects of seismic load on buried pipeline are another topic for future study.

REFERENCES

- Hibbitt, Karlsson and Sorenson, 2009, *Abaqus Theory Manual*, Version, Inc., INC
- Design and Installation Manual of Ridgidrain, Ridgisewer and Polysewer. Available at,(www. Polypipe Civils.co.uk.).
- The American Association of State Highway and Transportation Officials, (2002).
- AWWA (American Water Works Association), 2005,*"Fiberglass Pipe Design",* M45, Second Edition
- British Standard, 1998," *Structural design of buried pipelines under various conditions of loading*", BS EN 1295-1
- Lee, H., 2010," *Finite element analysis of a buried pipeline*", M.Sc. Thesis, University of Manchester, School of Mechanical, Aerospace, and Civil Engineering
- RAO, S. S., 1999, "*The Finite Element Method in Engineering*", Boston, Butterworth-Heinemann.

NOMENCLATURE

C_L: Soil Modulus Adjustment Factor
D: Mean Diameter of Pipe
D_f : Strain Factor
D_L: Deflection Lag Factor
E': Average Values of Modulus of Soil Reaction
E'_1: Bedding Soil Modulus
E'_2: Embedment Soil Modulus (Backfill)
E'_3: Native Soil Modulus
K_X: Deflection Coefficient (Bedding Constant)
P_e: Vertical Soil Pressure, kN/m^2
P_S: Surcharge Pressure, kN/m^2
S22**:** Maximum Longitudinal Stress, N/m^2
t: Thickness of the Pipe Wall, mm
U: Vertical Displacement

Δ: Pipe Deflection
γ: Unit Weight of Soil, kN/m^3.
σ_{bs} : Bending Stress in Pipe Wall
AB**AQUS/CAE:** Complete Abaqus Environment
AWWA: American Water Works Association

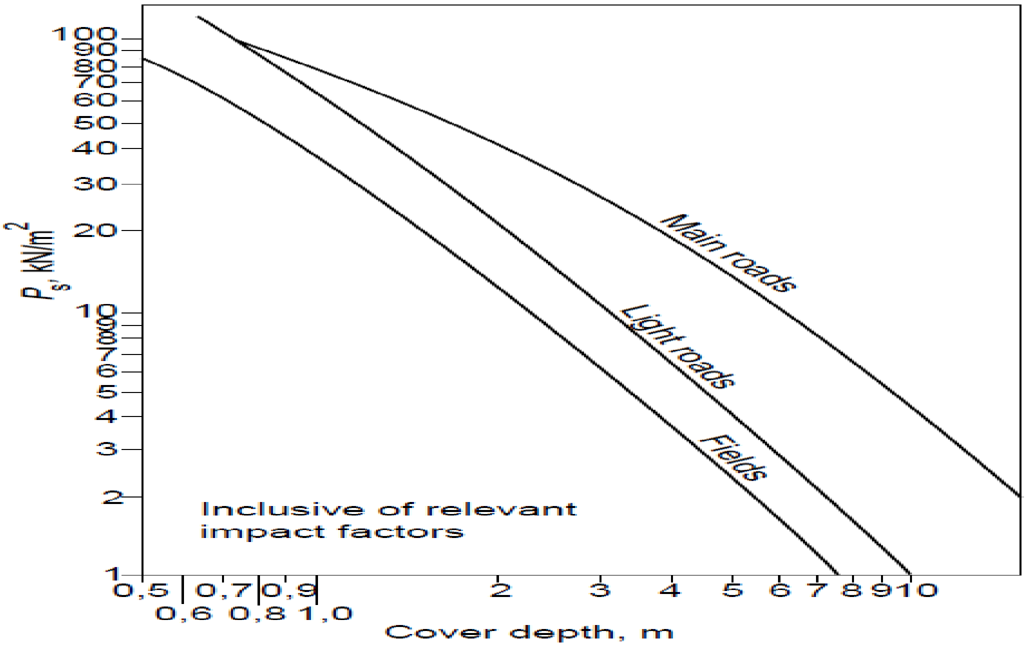


Figure1. Surcharge pressure P_s due to vehicle wheels, British standard, (1998).

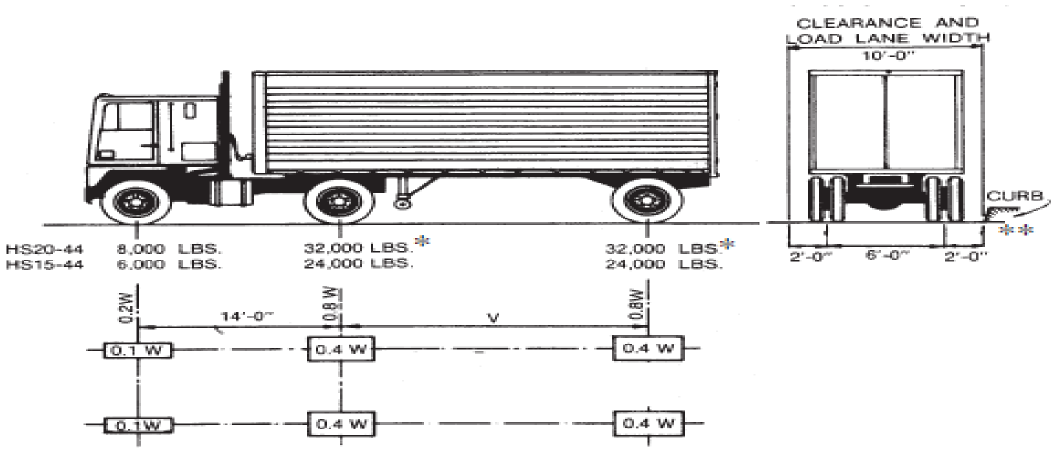
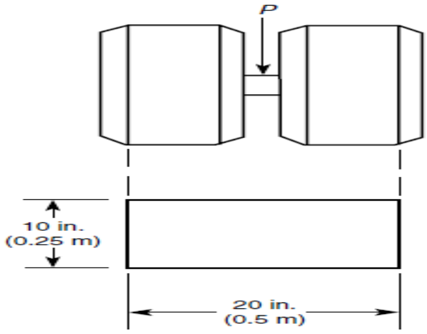


Figure2. Standard HS trucks, the American Association of State Highway and Transportation Officials, (2002).



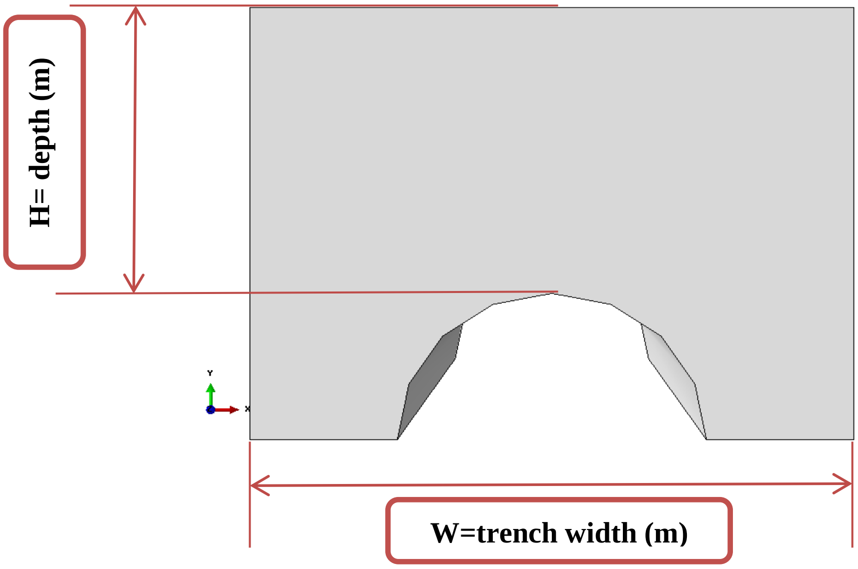
Where:

P: wheel load magnitude

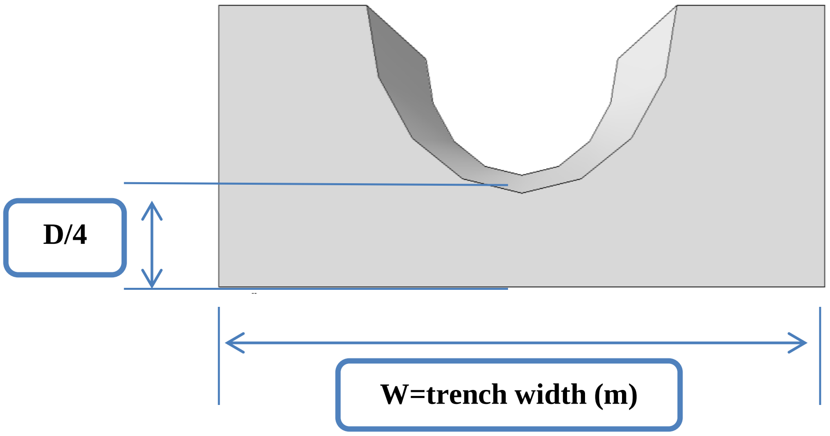
P= 72k N for AASHTO HS-20

$$\text{Pressure load} = \frac{Traffic\ load}{Area\ of\ tire\ imprint} = \frac{72\ \text{kN}}{(0.5\times0.25)m^2} = 576\,\frac{\text{kN}}{m^2}$$

Figure3. Representation of tire imprint of HS-20 live load over the surface backfill, AWWA-M45, (2005)



(a) Backfill soil



(b)Bedding soil

Figure4. Soil model in ABAQUS program

Figure5. Pipeline model in ABAQUS program

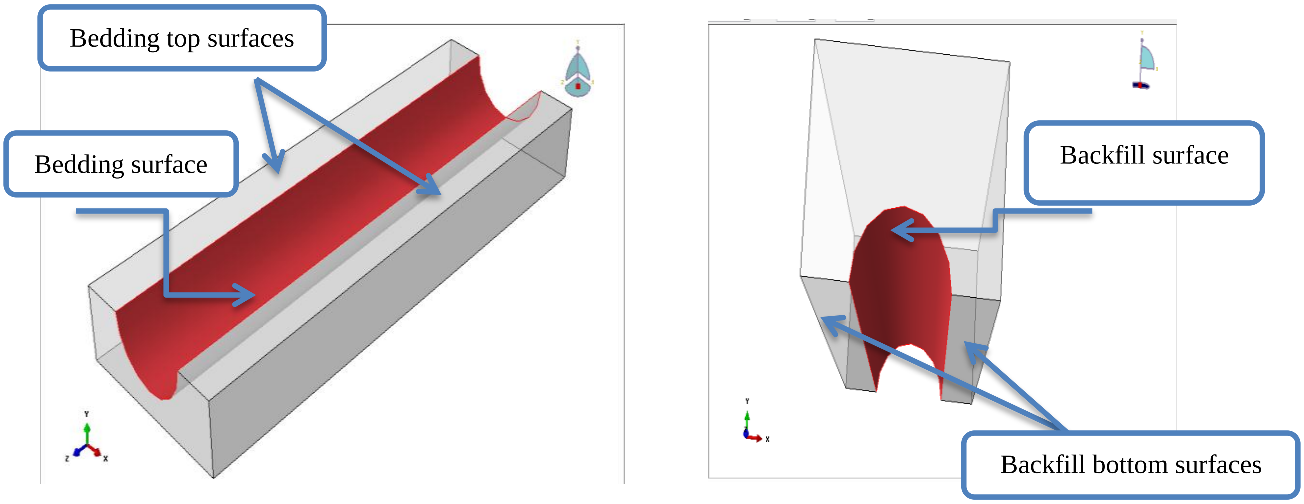


Figure6. Limits of bedding and backfill soils

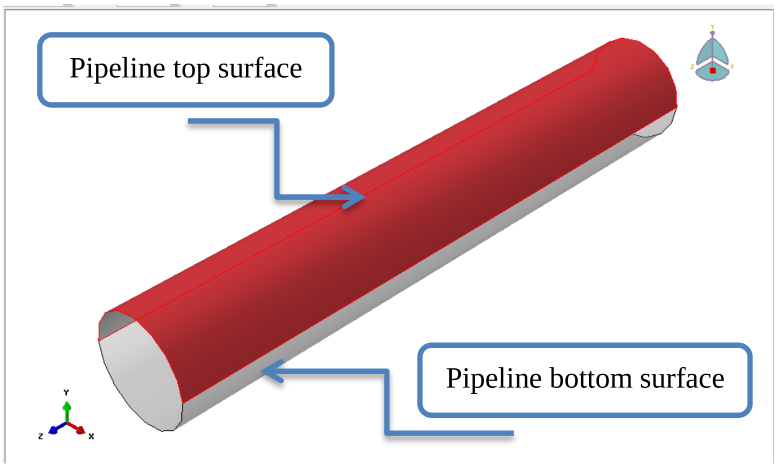


Figure7. Surfaces of a pipeline

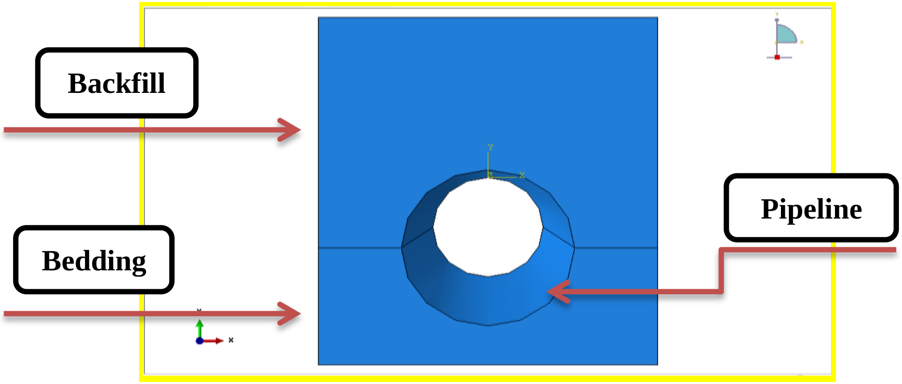


Figure8. Assembly of pipeline and soil

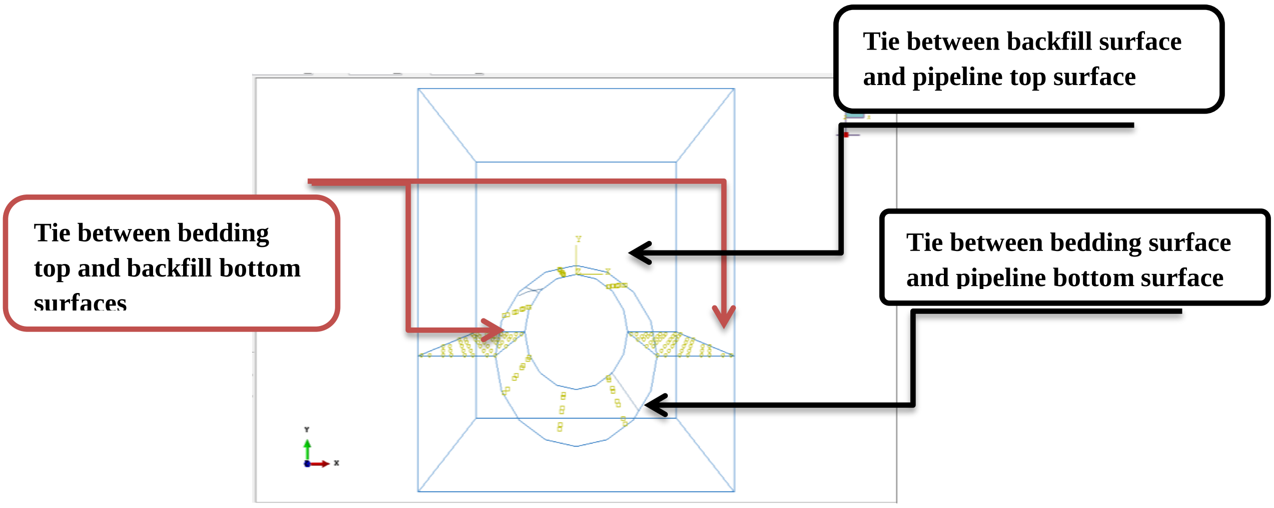


Figure9. Interaction between the soil and a pipeline

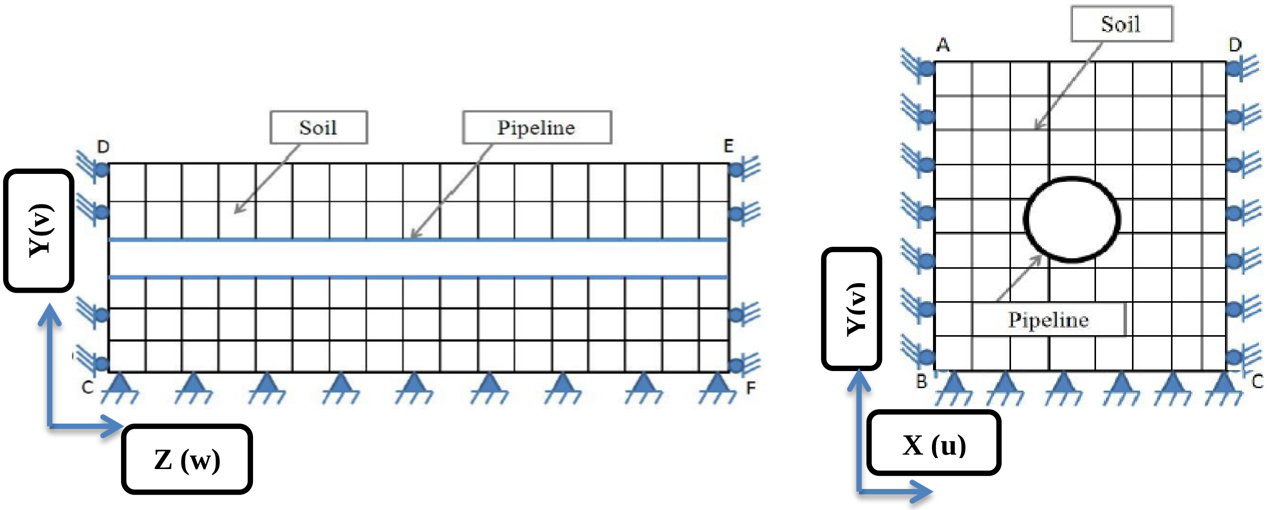


Figure10. Boundary conditions of the 3D-finite element of soil model, **Lee, 2010.**

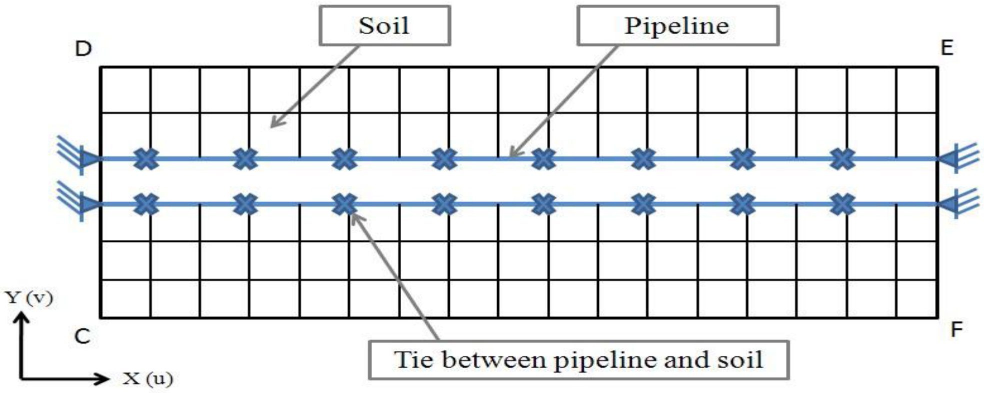


Figure11. Roller boundaries for two end surfaces of pipeline**, Lee, 2010**

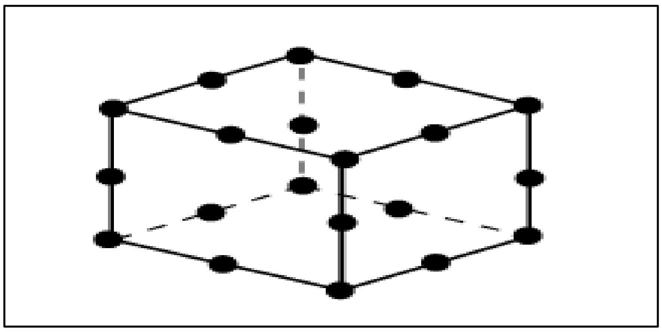


Figure12. Quadratic element (20-node brick, C3D20R), **Abaqus Theory Manual, 2009**

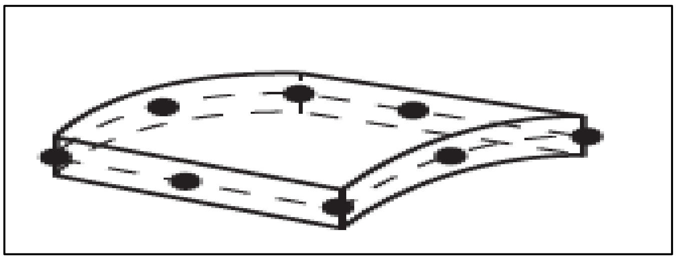


Figure13. Shell element (8-node shell, S8R), **Abaqus Theory Manual, 2009**

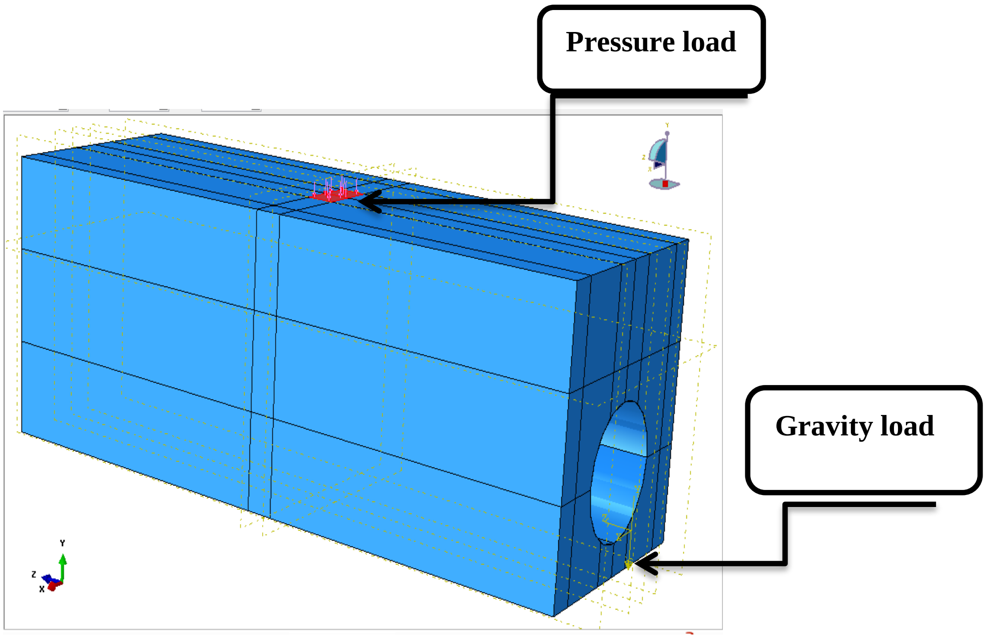
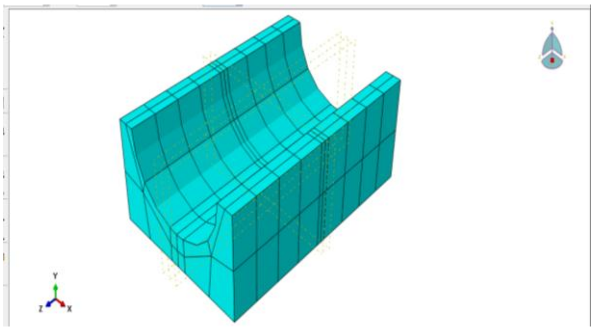
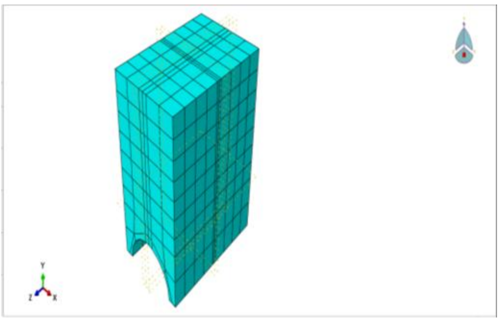


Figure14. Representation of loads on assembly of soil and pipeline models



(a) Bedding Model



(b) Backfill Model

(c) Pipeline Model **(d) Assembly Model**

Figure15. Meshing of soil and pipeline

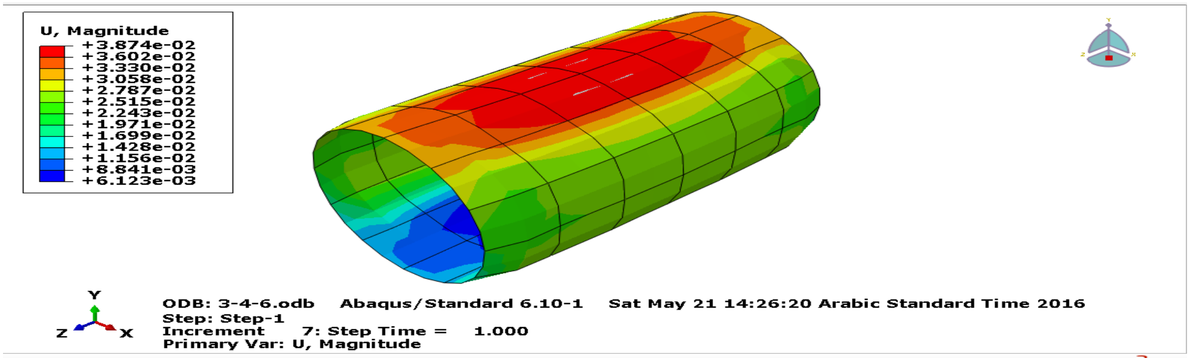


Figure16. Deformations of GRP pipelines

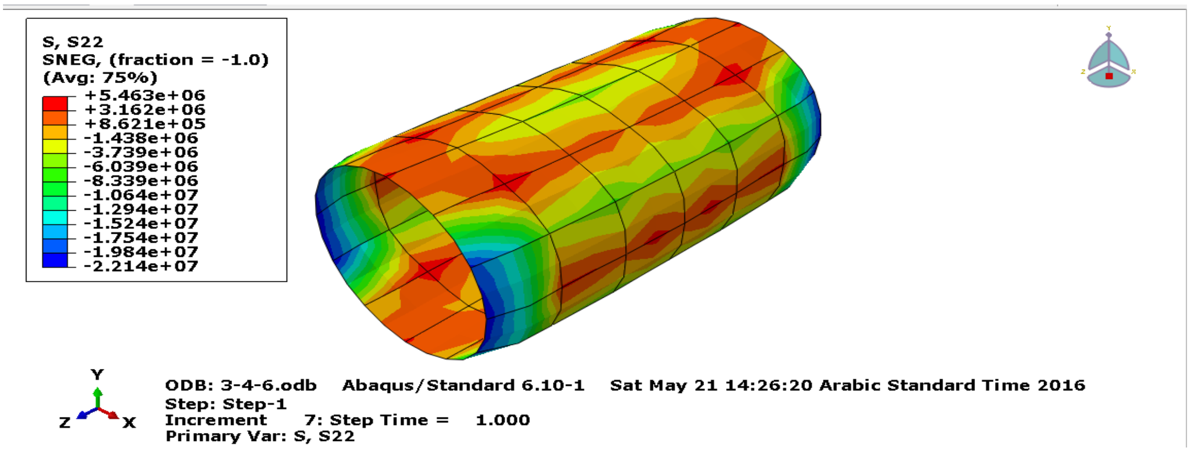
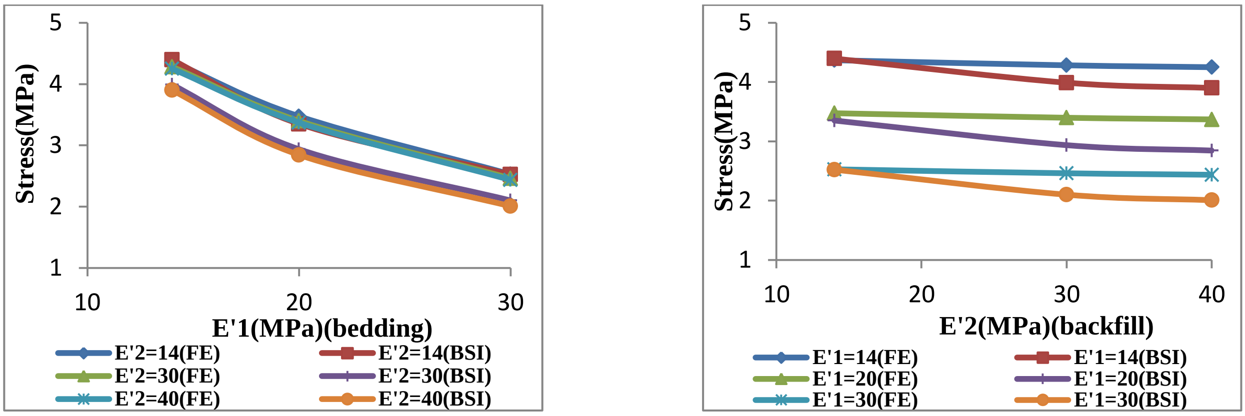
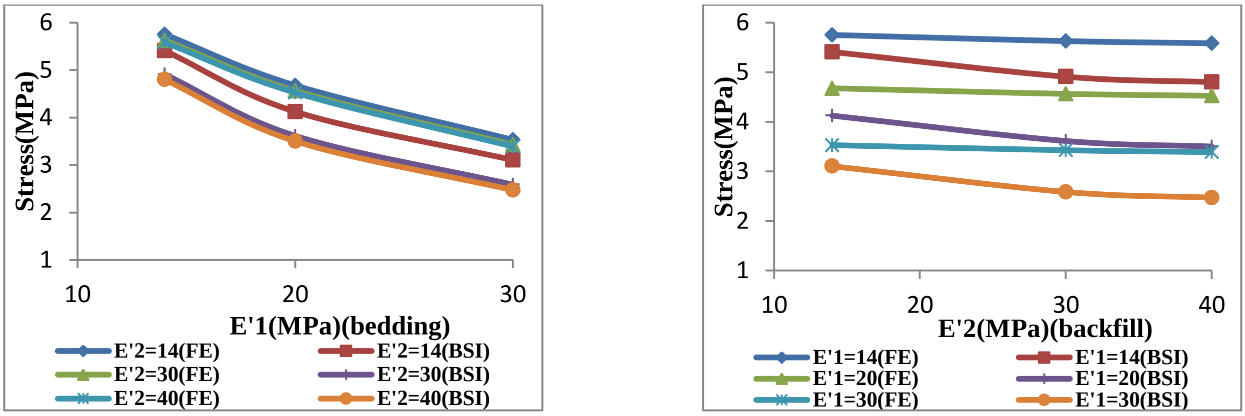


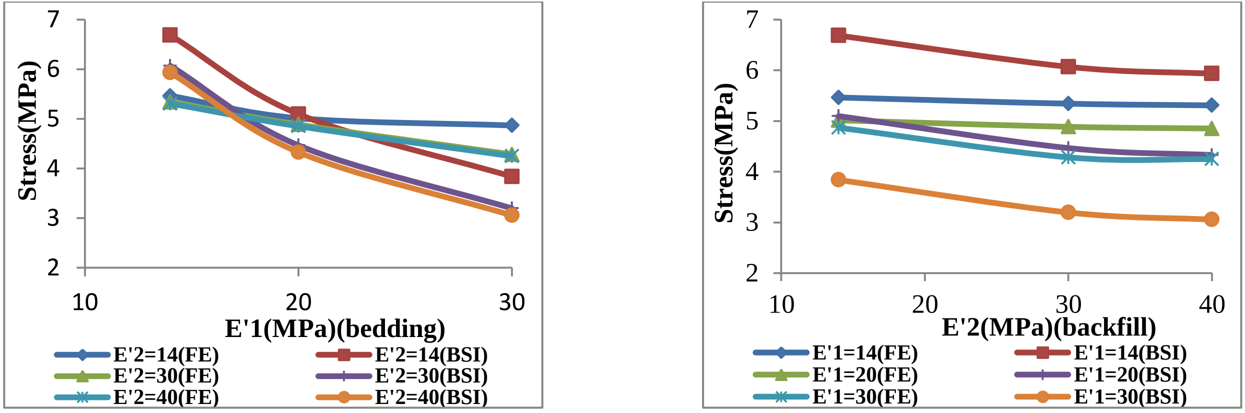
Figure17. Stresses in GRP pipelines



Diameter=3m, trench width=4m, depth=3m

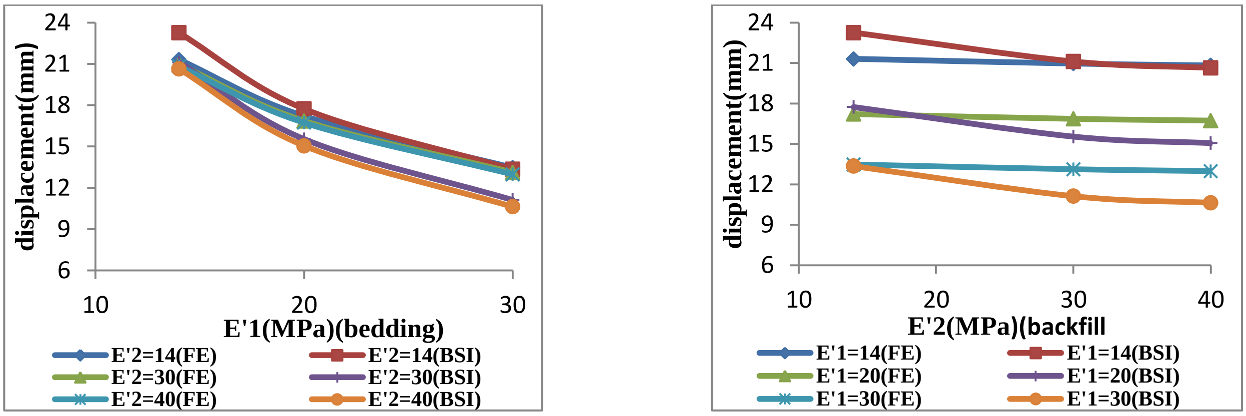


Diameter=3m, trench width=4m, depth=4.5m

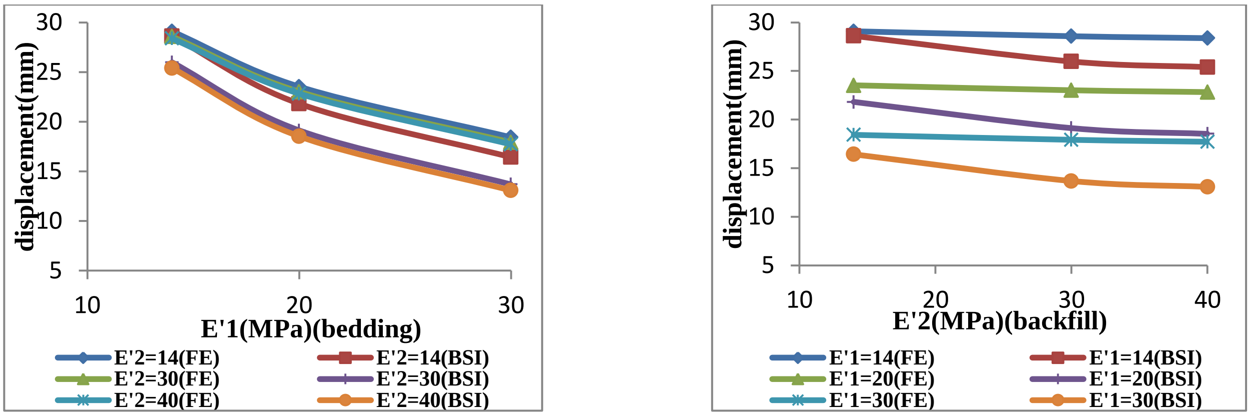


Diameter=3m, trench width=4m, depth=6m

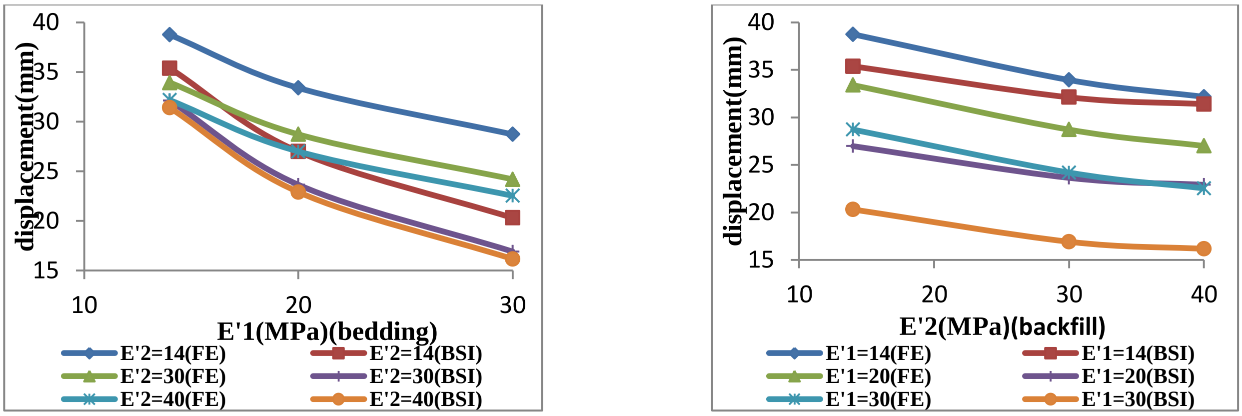
Figure18. Maximum longitudinal stress in GRP pipe of (3.0m) diameter placed in different types of soil (Bedding and Backfill).



Diameter=3m, trench width=4m, depth=3m

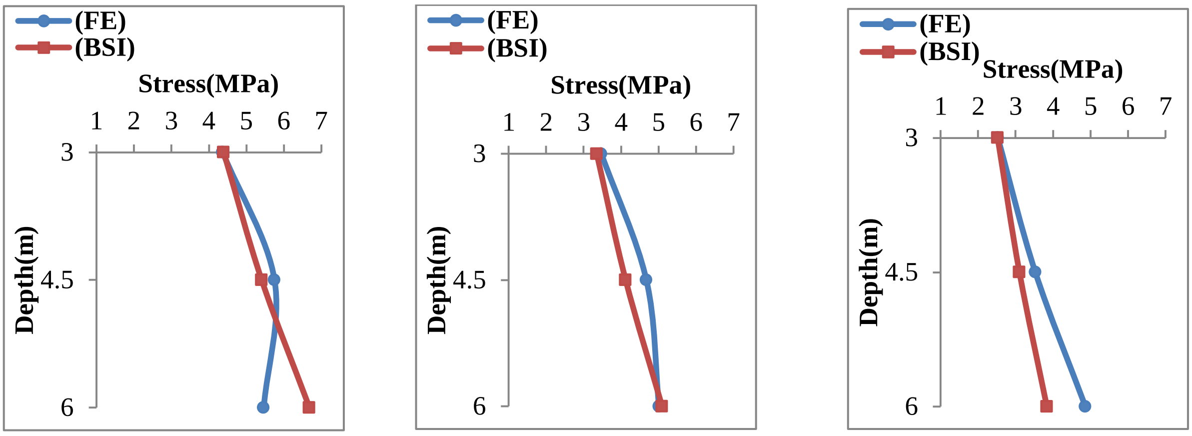


Diameter=3m, trench width=4m, depth=4.5m



Diameter=3m, trench width=4m, depth=6m

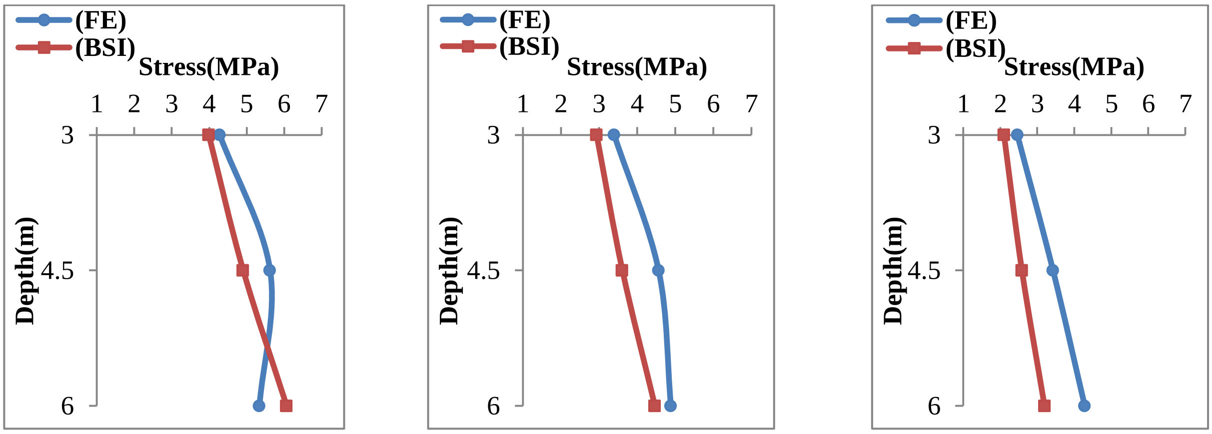
Figure19. Maximum vertical displacement in GRP pipe of (3.0m) diameter placed in different types of soil (Bedding and Backfill).



Diameter=3m, trench width=4m, E’2=14, E’1=14

Diameter=3m, trench width=4m, E’2=14, E’1=20

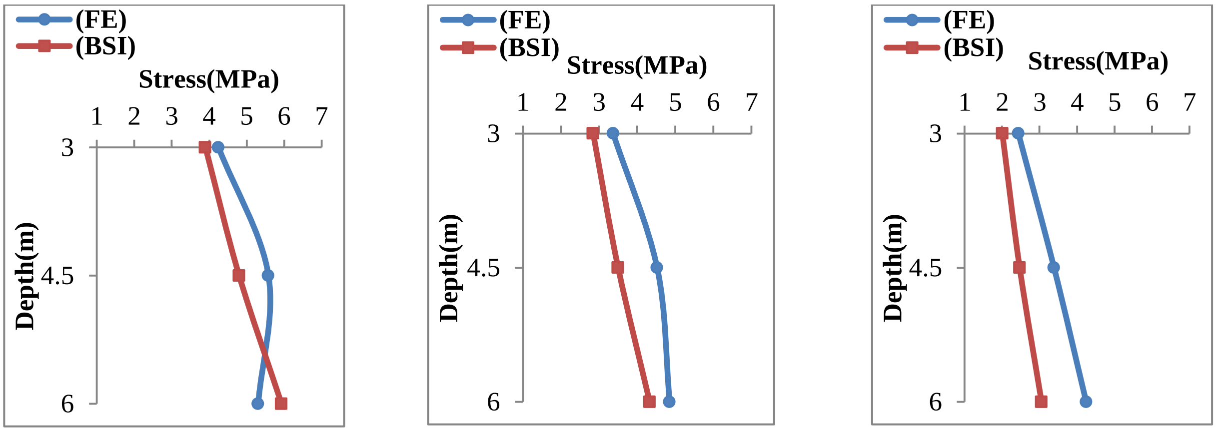
Diameter=3m, trench width=4m, E’2=14, E’1=30



Diameter=3m, trench width=4m, E’2=30, E’1=14

Diameter=3m, trench width=4m, E’2=30, E’1=20

Diameter=3m, trench width=4m, E’2=30, E’1=30

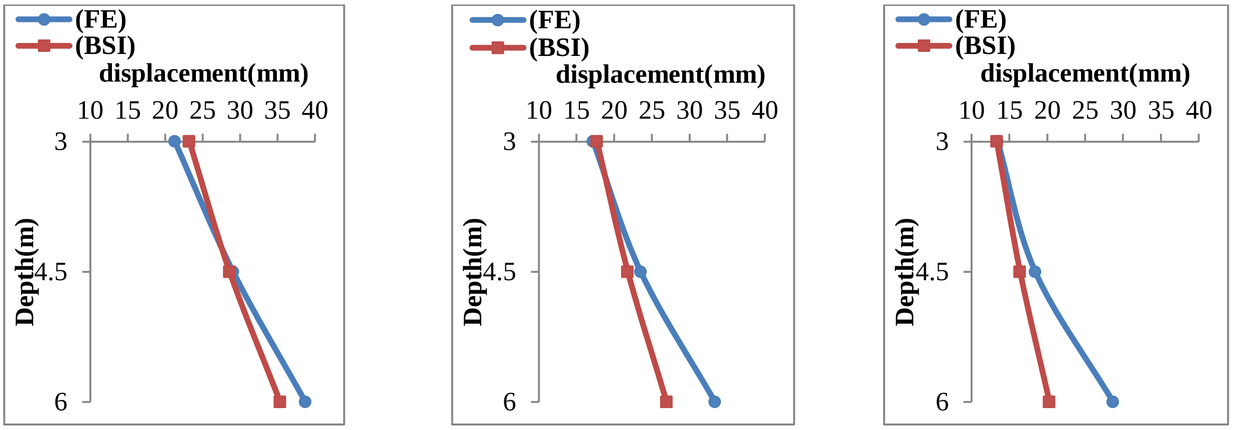


Diameter=3m, trench width=4m, E’2=40, E’1=14

Diameter=3m, trench width=4m, E’2=40, E’1=20

Diameter=3m, trench width=4m, E’2=40, E’1=30

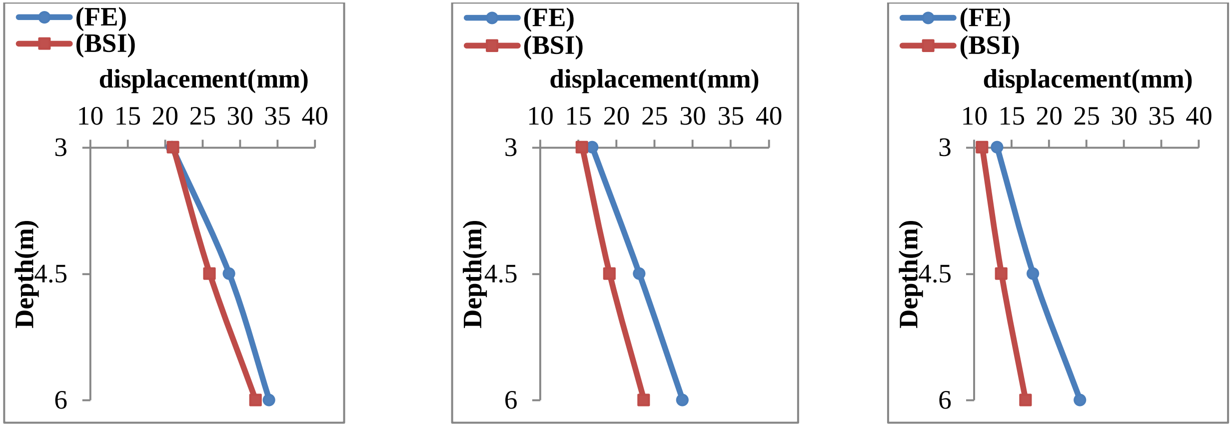
Figure20. The variation of maximum longitudinal stress within the GRP pipe wall versus depth of backfilling above pipe



Diameter=3m, trench width=4m, E’2=14, E’1=14

Diameter=3m, trench width=4m, E’2=14, E’1=20

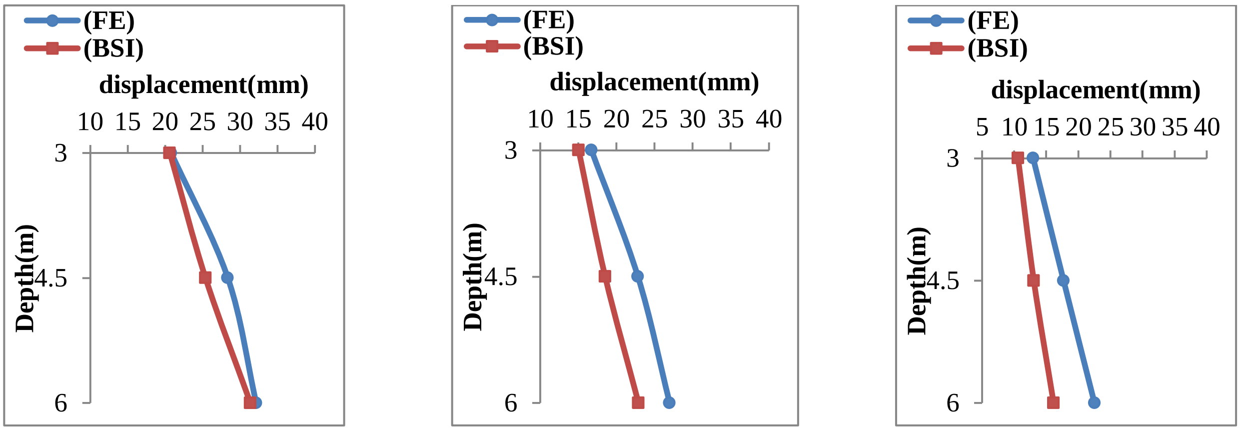
Diameter=3m, trench width=4m, E’2=14, E’1=30



Diameter=3m, trench width=4m, E’2=30, E’1=14

Diameter=3m, trench width=4m, E’2=30, E’1=20

Diameter=3m, trench width=4m, E’2=30, E’1=30



Diameter=3m, trench width=4m, E’2=40, E’1=14

Diameter=3m, trench width=4m, E’2=40, E’1=20

Diameter=3m, trench width=4m, E’2=40, E’1=30

Figure21. The variation of maximum vertical displacement (deformation) within the GRP pipe wall versus depth of backfilling above pipe

Table1. Guide values of Spangler modulus for native soils (E'_3), **(BS EN 1295-1), 1998**

Soil type	**Spangler modulus for soils in various conditions (MN/m^2)**				
	Very dense	**Dense**	**medium dense**	**Loose**	**Very loose**
Gravel	Over 40	15to 40	9 to 15	5 to 9	3 to 5
Sand	15 to 20	9 to 15	4 to 9	2 to 4	1 to 2
Clayey, silty sand	10 to15	6 to 10	2.5 to 6	1.5 to 2.5	0.5 to 1.5
Clay	Very hard	11 to 14			
	Hard	10 to 11			
	Very stiff	6 to 10			
	Stiff	4 to 6			
	Firm	3 to 4			
	Soft	1.5 to 3			
	Very soft	0 to 1.5			

Table2. Properties of bedding and backfill soils used in the study

Term	**Bedding**	**Backfill**
Density (kg/m^3)	1950	1950
Young’s modulus (MPa)	14	14
	14	30
	14	40
	20	14
	20	30
	20	40
	30	14
	30	30
	30	40
Poisson’s ratio	0.3	0.3

Table3. Material properties of GRP pipeline**, BS 5480, (1977)**

Term	**value**
Mass density (kg/m^3)	1850
Stiffness (N/m^2)	5000
Young’s modulus (MPa)	($stiffness*D^3$)/I
Poisson’s ratio	0.3