Determination of Design Parameters in Large Size Reinforced Polyethylene Pipes

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ABSTRACT

In this paper, large size polyethylene (PE) pipes (1000 mm in diameter), buried underground, are analyzed to determine the effect of both internal and external pressure on their mechanical behaviour. The effect of surrounding soil and temperature change caused during pipe installation and operation is also included. To determine the real cause of failure (which occurs during operation), two types of reinforcement have been considered. The first model deals with a pipe reinforced by external PE rings (core tube) and in the second, a corrugated layer is used as a reinforcement. The failure cause in each case has been analyzed and the relationship between pipe thickness, maximum pipe stress, temperature drop, internal pressure, pipe depth, and elasticity of foundation has been investigated to set a design basis for any further applications.

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Key Words:
polyethylene;
core tube;
corrugated;
elastic foundation.

INTRODUCTION

At present, water supply and sewerage systems are among leading industries throughout the world [1]. In each type of usage, such as supplying water to villages and urban areas, agricultural, or sewerage disposal, there is a need for certain standards and design characteristics which has to be met. Since world population is widely increasing, then a need for expanding towns and cities has been resulted into a noticeable growth in pipe production. Among these, pipes made from poly-

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meric material have increased in a large scale, due to their excellent resistance to environmental effects, corrosion, and lower costs of production and maintenance [2]. There is no doubt that polymers have lower strength than metals. Therefore, for those polymeric pipes buried underground, reinforcement must be considerd to increase the ring stiffness, as well as strength, to withstand any imposed internal and/or external pressure. One way of reaching this goal is to impose either external rings around the pipe periphery or by attaching a wavy (corrugated) layer on the outside wall.

For a proper selection of buried pipes, many parameters such as soil properties, and its pressure on the pipe must be carefully examined.

Soil Properties

According to the existing standards, soil properties used underneath, around, and above the pipe, must be carefully selected [3,4]. In order to determine the proper dimensions of the trench path, as shown in Figure 1, one must carefully study soil composition and its integrity, in which the pipe lies. Since soil density is directly proportional to its strength, then its effect becomes an important parameter in designing underground pipes.

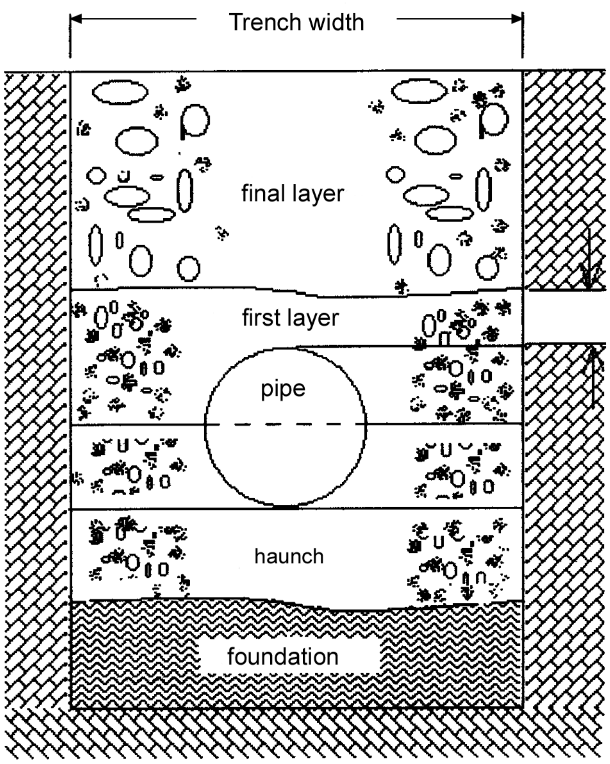


Figure 1. Standard set up of a buried pipe.

Pipe Flexibility

For the above reasons, several types of materials are being used in pipe industry, where each type must satisfy certain conditions such as, strength, rigidity, elasticity, and durability, etc. Hence, one can categorize pipes into two groups, rigid and flexible. A pipe is considered to be flexible if it can sustain a load and show flexibility as much as 2% of its initial diameter without any drastic failure. Other than that, the pipe is considered to be rigid [5].

In flexible types, such as thin wall cast iron or polyethylene pipes, the radial deflection or buckling of the wall becomes an important factor in pipe design or selection. In rigid pipes, the stresses induced by the external and/or internal loading become the dominant factor for their usage. For polyethylene material, relationship between the stresses and strains can be considered to be linearly elastic if the induced displacement is less than 10% of the original length [6,7]. This assumption is applied to each model in this research, and its validity is justified throughout the results.

Design Theory

Any model or design theory that can best predict the failure of an object, will be suitable for simulation of stresses produced by the loading. As mentioned earlier, in flexible pipes such as steel or polyethylene, controlling displacement, stresses and buckling are the important factors that must be considered throughout the design process [8]. One of the most frequently used equations in the design of plain polyethylene pipes (no reinforcement), is the Sprangler-Iowa [9] formula. This formula is used in a variety of ways, but it is generally presented as:

$$\Delta x = \delta (KWR^3)/(EI + 0.06\,E'R^3) \qquad (1)$$

where, E′ depends on the soil type. For buried pipes, this value increases with the soil density and/or the pipe depth.

A simplified state of the above formula is that in which one replaces the amount of EI with the pipe's rigidity. This formula can be written as [4]:

$$\Delta x = \left\{KWR^3/[D^3PS/(53.77) + (0.061E'R^3)]\right\} \qquad (2)$$

Minimum values of pipe rigidity are presented in ASTM and AASHTO standards [5].

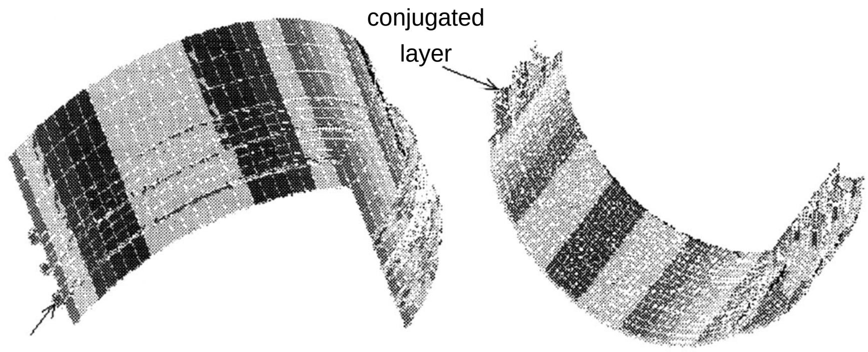


Figure 2. Models of reinforced pipes, (a)- reinforced by core tubes, and (b)- reinforced by a corrugated layer.

Wall Buckling

Buckling phenomena can influence any flexible pipe design, wherein pressure is exerted externally either by the soil, hydrostatic pressure, or any relative vacuum. High flexibility will result into lower resistance against buckling. In buckling formula, it is assumed that the external pressure is exerted uniformly along the wall circumference at the outside wall. According to ASSHTO standard, the suggested formula for critical load differs slightly from the assumption above and it is given by [5].

$$P_{cr}= 9.24(R/A_p)(C_w E' EI/0.149R^3)^{0.5} \qquad (3)$$

Modelling of Polyethylene Pipes

Due to lack of information available on reinforced polyethylene pipes with large diameters, it is required to determine the stress propagation and any other design factors, to set a ground basis for any future application of such pipes. It should be emphasized that the current modelling is based on a size that is mostly available in Iran s market. Although these pipes are not designed to take any internal pressure, they are subjected to a hammer shock, at no will, during the first minutes of operation. For this reason, to prevent excessive loading of the pipe, the critical values of the following parameters must be clarified.

a) Maximum deflection in the pipe.
b) Maximum stresses in the pipe.
c) Minimum thickness required to bear the load imposed on the pipe.

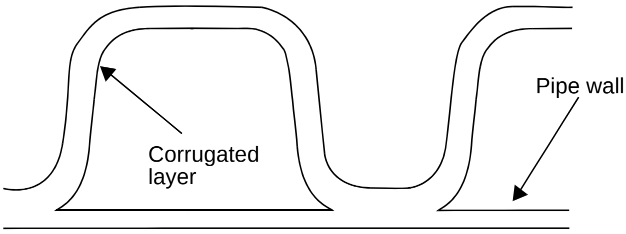
Undoubtedly, in pipe design, if the above parameters are not carefully selected (or studied), failure will result in weak areas or areas, where stress concentration is highest. In this paper, the effects of several parameters such as pipe depth and thickness, temperature drop, and inside pressure, are studied on the stresses induced in the pipe. Furthermore, a trial is made to explain the real cause of failure for such pipes in the field.

To reach this goal, modelling is accomplished in a few steps, where in each case the effect of a new parameter is included to optimize the model which will best suit the physical situation. These steps are as follow:
(a) Modelling of a plain polyethylene buried pipe and comparing the results with those obtained from eqn (2) to justify the assumptions made throughtout the modelling.
(b) Modelling of a reinforced pipe (either by core tubes or by a corrugated layer) as shown in Figure 2. Modelling is accomplished for a case where the pipe is buried one meter below the ground surface.
(c) Modification of the model in (b) to include the effect of the pipe joints and soil's elasticity.
(d) Application of the internal pressure, burial depth, and temperature drop (between the two working times of installation and operation).

In order to study pipe s failure, Von Mises stress is chosen to be the limiting stress. The magnitude of this stress is given by:

$$S = \left[\frac{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2}{2} \right] \qquad (4)$$

To prevent failure, it is assumed that Von Mises



Mould dimensions	inch	mm	Pipe dimensions	inch	mm
Number of corrugations	1.5		Pitch		
Mould block length	8.00	203.2	Profile height	5.200	132.08
Pitch	5.333	135.47	Inside dia.	2.924	74.28
Corrugation height	2.464	62.58	Outside dia.	39.370	1000.00
Inside dia.	41.450	1052.84	Crest width	45.219	1145.55
Outside dia.	46.376	1178.00	Trough width	3.130	79.51
Sidewall angle	6.0		Crest wall thickness	1.565	39.75
Crest width	3.210	81.54	Trough wall thickness	0.265	6.80
Trough width	1.605	40.77	Sidewall thickness	0.433	11.00
Crest fillet rad.	0.905	23.00	Pipe lineer thickness	0.350	8.90
Trough fillet rad.	0.591	15.00	Cold plug dia.	0.236	6.00
			Comper. Double wall thickness	40.380	1025.64
Pipe shrinkage (%)	2.5			0.835	13.60
Liner compression factor	0.800		Pipe properties	Units os noted	
Density [lb/ft^3. g/cm^3]	59.933	0.96			

Figure 3. A cross section of the pipe and its corrugated layer.

stress must be smaller than the yield stress. That is,

$$S<\sigma y \tag{5}$$

For polyethylene pipes, a magnitude of 8 MPa is used for yield stress throughout this analysis.

RESULTS AND DISCUSSION

NISA Software has been used to determine the induced stresses caused by the external and/or internal loading. This program is a well known engineering software that is widely used to solve both structural and fluid problems. To model a problem, a wide number of elements are available which would enable the designer to model his problem properly. The software is capable of analyzing both linear and non-linear problems. Time dependent problems, fluid, and heat transfer problems, can be solved as well. Modeling is performed using DISPLAY III module where, upon successful application of the load and boundary conditions to the model, a NISA file can be created. Running this file through proper module (which depends on the type of analysis), would lead into results which could be observed by reading proper post files.

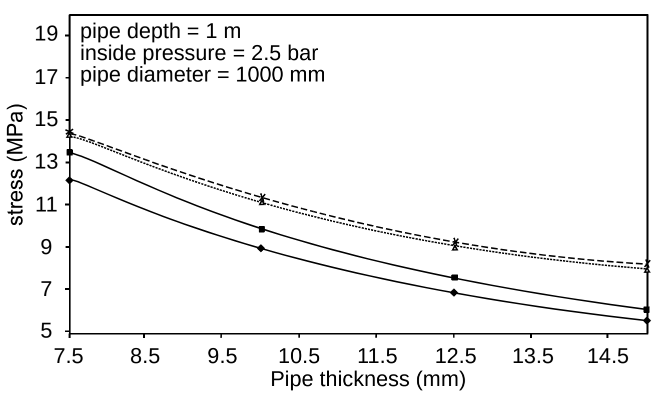
Using this software, the analysis is performed on polyethylene pipes with a diameter of 1000 mm and a modulus of elasticity E = 937 MPa [9]. The soil that buries the pipes is considered to be clay with a proctor density of 90-95%. For a reinforced pipe with core tubes, a distance of 73 mm is used between any two successive rings (which are located on the outside wall). To analyze the pipe with a corrugated layer, the same dimensions reported by the pipe manufacturer were used (Figure 3). The internal pressure was assigned to be 2.5 bar (250 kPa). This is the highest water pressure (due to hammer shock) reported by Sugar and Cane Company at the first minutes of operation. This company is one of the major users and suppliers of such products.

In order to verify the integrity of the model as well as its initial assumptions, the deflection results for a simple pipe (with no stiffener rings), were obtained and compared to those associated with eqn (2). The precentage difference was found to be less than 2%. Moreover, for a reinforced pipe, the maximum radial displacement under an internal pressure of 2.5 bar, at ΔT = 60 C, and a depth of 1000 mm, was measured to be almost 4 mm. This value is very small compared to a diameter of 1000 mm. This result, along with the former, verifies the accuracy of the model and the initial assumption made on its elastic behaviour.

Since pipes are exposed to direct sunshine for a period of time before they are buried, they would warm up. Hence, the temperature difference between the two working times of installation and operation could be as high as 60 C. This would impose additional stresses in the pipe due to a drop in temperature.

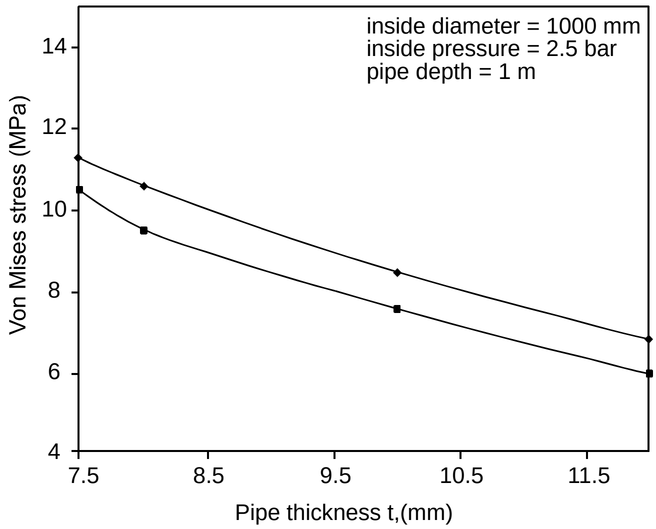
Close examination of the post file results indicated that the location of maximum stesses was next to the second core tube adjacent to a pipe joint.

The variation in maximum Von Mises and hoop stresses are shown as a funtion of thickness in Figure 4. Using this figure, one can notice that for a wall thick-



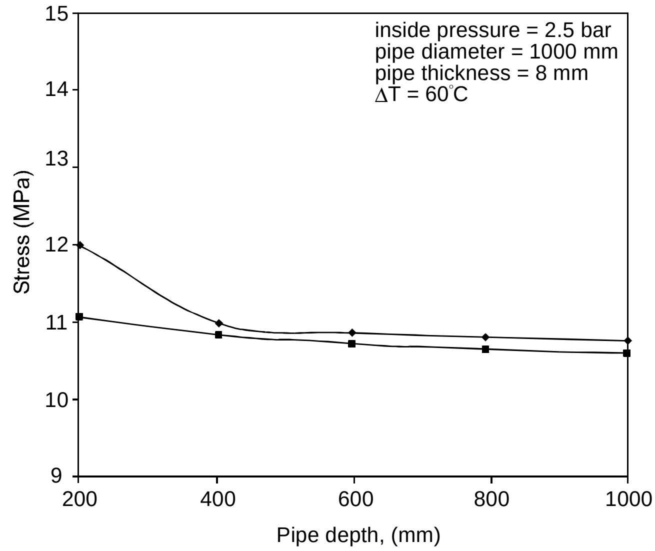
(—◆—) Von Mises stress for pipes reinforced by core tube; (—■—) maximum hoop stress for pipes with core tubes; (—▲—) Von Mises stress in plain pipes; (—✕—) maximum hoop stress in plain pipes.

Figure 4. Variation in maximum pipe stresses vs. pipe thickness.



(—◆—) Von Mises stress in pipes with core tube; (—■—) Von Mises stress in corrugated pipes.

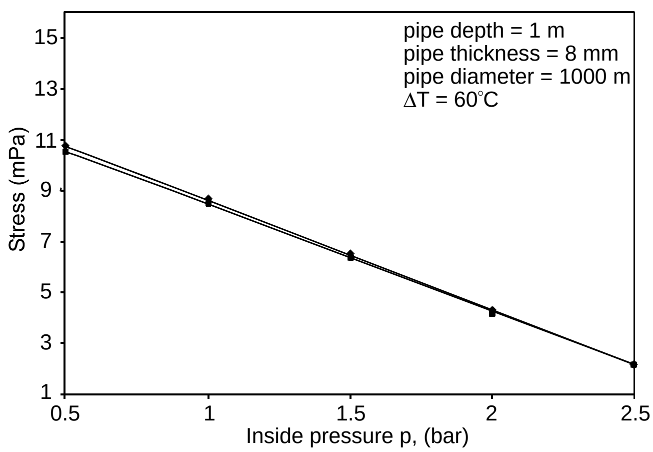
Figure 5. Variation in maximum Von Mises stresses vs. pipe thickness.



(—◆—) Maximum hoop stress in pipes with core tube; (—■—) maximum Von Mises in pipes with core tubes.

Figure 7. Variation in maximum pipe stresses vs. pipe depth.

ness of 8 mm, the maximum hoops stress is 13.3 MPa, where the maximum Von Mises stress happens to be 12.2 MPa. Comparison of these two stresses with that of yield stress (8 MPa), indicates that if the pipe is buried 1 m below the ground surface, at an internal pressure of 2.5 bar, it can not withstand the induced stresses, and hence, failure (in terms of bursting) might happen. This has been actually the case, where bursting failure has been reported in the farm, at the same location where the model has predicted. In order to compare the effect of reinforcement on the pipe stresses, similar results (for a plain pipe), have been superimposed on the same figure. According to the results, the reinforcement rings have greatly improved the mechanical behaviour of the pipe. Also, for load conditions indicated on this figure, in order to prevent failure, the wall thickness must be at least 12 mm to prevent any excessive stress greater than that associated with the yield point.



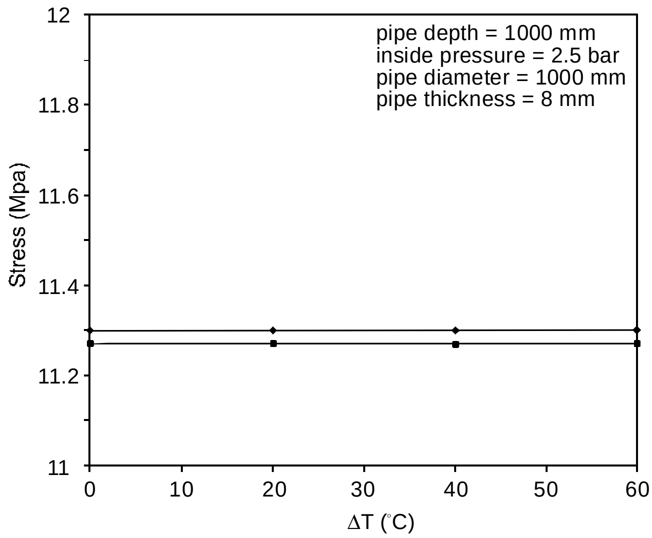
(—◆—) Maximum hoop stress in pipes with core tube; (—■—) maximum Von Mises in pipes with core tubes.

Figure 6. Variation in maximum pipe stresses vs. inside pressure.

The results obtained on a pipe reinforced by external rings and those reinforced by a corrugated layer, are shown in Figure 5. As noticed, under the same loading conditions, the Von Mises stresses in a pipe reinforced by a corrugated layer are less than those of a pipe reinforced by core tubes. Therefore, a corrugated pipe with a diameter of 1000 mm can sustain the load easier compared to a pipe of similar diameter reinforced by core tubes. This result has also been experienced in agricultural fields where under the same loading conditions, failure (due to excessive stress) has only resulted into bursting of those pipes reinforced by core tubes.

The relationship between maximum pipe stresses vs. the internal pressure and burial depth are shown in Figures 6 and 7. According to Figure 6, with a reduction in the internal pressure, both Von Mises and hoop stresses are reduced linearly.

According to Figure 7, with the presence of an internal pressure equal to 2.5 bar, an increase in depth beyond 40 cm has almost no effect on stresses pro-



(—◆—) Maximum hoop stress in pipes with core tube; (—■—) maximum Von Mises in pipes with core tubes.

Figure 8. Variation in max stresses vs. temperature drop in the pipe.

duced in the pipe (the results are for ΔT= 60 C). As indicated on both figures, the wall thickness is assumed to be 8 mm. As mentioned earlier, for a pipe of 1000 mm in diameter, this thickness has a vast usage in Iran s agricultural industry.

Figure 8 shows the relationship between the temperature drop and the induced stresses in the pipe. As one can realize, the relationship is almost flat and hence, in presence of an internal pressure equal to 2.5 bar, the change in stresses due to a drop in temperature is negligible compared to the cases produced by the internal pressure.

CONCLUSION

According to the results, for polyethylene pipes of 1000 mm in diameter, when buried one meter below the ground surface, one can conclude the following:

- Under an internal pressure of 2.5 bar, selection of a wall thickness equal to 8 mm will result into excessive stress in the pipe (when reinforced through core tubes), and hence, failure (even in terms of bursting) might occur.

- Compared to a plain pipe, reinforcing the outside wall through a corrugated layer, will result into a reduction of stresses as well as an increase in buckling strength.

- For the same loading conditions, the stresses produced in a reinforced pipe through a corrugated layer is less than those produced in a similar pipe stiffened by core tubes (Figure 5).

- The maximum hoop and Von Mises stresses will drop linearly as the internal pressure in pipe is decreased (Figure 6).

- The induced stresses due to soil pressure (height of the soil above the pipe) are much less than those produced by internal pressure (Figure 7).

- The stresses produced from a drop in temperature (equal to 60 C) are much less than those created by an internal pressure of 2.5 bar (Figure 8).

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