Study of natural gas pipeline behaviour

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Abstract:
In order to prevent incidents due to uncontrolled gas leakage and explosion/fires were devastating look at the factors that determine the safety in operation of gas networks made of polyethylene. Sustainability and safety in operation, lines of distribution networks and installations for use in natural gas represents a complex issue with implications for economic, social and environmental. Underground natural gas pipes are subjected to a series of prompts both static and dynamic which could lead to damage. The complexity of the problems stemming from the diversity of stress factors acting on the related pipelines supply natural gas. In this context, the authors analyse the behaviour of pipelines under the effect of the stresses to which they are subject by using finite element modelling.

Key words: gas, gas networks, urban grids, polyethylene.

1. Introduction
Polymeric materials today are used widely in industry pipelines. Polyethylene pipes are widely adopted in many countries for distribution networks for natural gas. PEHD pipes offer many benefits compared to metal pipes. The advantages of these pipes include lightweight, flexibility, high ductility, weldability and low-cost installation.
Use pipes buried natural gas represents a common solution. Mechanical behaviour of underground pipes is influenced directly by the different properties of material filling and the surrounding soil. The higher the fill material and rigidity of the structure around the pipe is higher so its resistance to external requests.
Underground pipelines requests include the weight of the soil above the pipe, additional tasks due to internal and external actions-the pressure in the pipeline, hydrostatic pressure-and request traffic. For an underground pipe support material is sand where it buried pipeline excavated rocks, respectively.[4],[5]
The state of tension induced in a pipe buried by the applied loads was first determined by Marston [3]. Later, Spangler used linear elasticity and experimental studies to propose the Iowa formula [8]. Watkins and Anderson (2000) have developed more formulas to calculate the modulus of soil elasticity around a buried pipe that gives better results than Sprangler’s formula [11]. Using the finite element method (FEA) allows the investigation of soil-pipe interaction of buried pipes. In this respect under article considering the cumulative effect of factors that influence the behaviour of underground pipes from HDPE with actual conditions and track technology.

2. Design of piping
Design of piping buried natural gas is based on the principle of soil-pipe interaction. Thus, the pipe and the surrounding field influence each other's physical and mechanical performance. Tensions induced in polyethylene gas pipelines are due to a combination of permanent and dynamic internal or external loads due to traffic. Internal strength comes from gas pressure.
The permanent static load acting on the underground pipeline is determined by the weight of the overhead filling, which can be composed of the weight of the sand, the soil, and the road clothing (if the pipe is located in the road)
Pressure on the traffic pipe depends on vehicle weight, tire pressure and size, drag speed, and other factors. It is assumed that the maximum load applied to the outside of the pipe is equal to the load above it. In fact, the load applied to an underground pipe may be significantly lower than the one mentioned above because the shear resistance transfers part of the external load to the side walls of the trench. Typically, pipeline design uses the calculated NP116-2005 load according to Figure 1.

3. Buried pipeline Modelling

Modelling the tensions of pipe buried is used algorithm [7],[9]:

1. Declaration of the initial conditions:
   Type and diameter of pipeline; depth of laying; the type and size of the trench; Nature of the land; traffic type; hydrostatic level

2. Establishment of model of soil-pipe interaction

3. Determination of loads:
   Soil, water, traffic, total

4. To specify the characteristics of the material and the criteria limit

5. Calculation of stresses and deformations of pipe walls

6. Sizing-checking the thickness of walls

By way of example, a case study for determining the stress and deformation state in a PE 100-SDR11 high density polyethylene pipe having a D = 63x3.6 mm and the physico-mechanical characteristics shown in Table 1 is presented below.

The pipeline is laid according to ANRE-2018 Technical Regulations, in clay soil, in a vertical wall excavation, on a compacted sand bed with physical-mechanical characteristics determined in the Rocky Mechanics Laboratory at U.P., presented in Table 2.

### Table 1 Elastic properties of PE100 pipes

| Static force reference N/m²x10⁶ | The modulus of elasticity to traction at 23°C N/m²x10⁶ | Minimum required resistance N/m²x10⁶ | Long-term hydrostatic strength at 20°C N/m²x10⁶ | Poisson's coefficient |
|-------------------------------|-----------------------------------------------|----------------------------------|---------------------------------------------|----------------------|
| 10÷11.19 | 900÷1100 | 10 | 8 | 0,35 |

The additional traffic load was 544,780 N / m². It was considered to be an average traffic on a street road.[3],[4],[5],[6]

### Table 2 Properties of compacted sand

| Specific weight Kg/cm³ | Angle of inner friction grad | The modulus of elasticity N/m²x10⁶ | Poisson's coefficient |
|------------------------|-----------------------------|----------------------------------|----------------------|
| 1900-2000              | 25-35                       | 60                               | 0,2-0,3              |

The ground in which the pipe was buried is the dense, yellow-earthed clay with the elastic parameters shown in Table 3.
Table 3 Elastic Properties of Initial Roof Roofs (Unperturbed Rock)

| Specific weight Kg/m³ | The modulus of elasticity, N/m² x 10⁶ | Poisson's coefficient |
|-----------------------|----------------------------------------|----------------------|
| 2000-2250             | 240                                    | 0.35                 |

To model the pipeline behaviour, use the QuickField™ Student Edition 6.3.2.2098 SP2 program. The stress distribution analysis is based on the Maximum Shaping Energy Rating Criterion (von Mises criterion). Von Mises criterion (stored energy of deformation):

$$\sigma_{Mi} = \frac{1}{2} \sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2}$$

where $\sigma_1$, $\sigma_2$ and $\sigma_3$ denote the principal stresses in descending order.

The discretization of the model for applying the finite element method was done according to the scheme in figure 2.

Figure 1. Schematic presentation of the model a) and dimensions model for finite element analysis b)
The model was analysed comparatively in three application assumptions, corresponding to successive phases of execution:

a) Inserting the pipe into a sand layer, compacted to a height of 15 cm above the upper generator, the load is given by the weight of the sand, \( P = \gamma_{\text{sand}} h_{\text{sand}} \) N/m²;

b) Completing the soil filler filling, compacted to the initial state \( P = \gamma_{\text{sand}} h_{\text{sand}} + \gamma_{\text{rock}} h_{\text{rock}} \) N/m²;

c) Loading of the filling with additional traffic load.

The state of tension and deformations are presented in tabular and graphical form in the figures 3, 4, 5 and the tables 4, 5, 6.

**Case 1.** Applying the model presented for the compacted sand situation, we obtain the outcomes of the von Mises stress state and the deformation according to Figure 3 and Table 4.
Table 4 Mises distribution of the stress and deformation of the pipeline, compacted sand

| Position | L (cm) | x (cm) | y (cm) | d (cm) | \(\sigma_{\text{Mi}}\) (N/m²) |
|----------|-------|-------|-------|-------|------------------|
| 0        | 0     | 70.536| 12.869| 0.132252| 2145230          |
| 1        | 0.922703| 70.731| 13.7706| 0.13467| 2472910        |
| 2        | 1.84541| 71.143| 14.5791| 0.138632| 1692440         |
| 3        | 2.7681 | 71.761| 15.2481| 0.144104| 939449          |
| 4        | 3.69081| 72.575| 15.6495| 0.149479| 478791          |
| 5        | 4.61352| 73.478| 15.7839| 0.151687| 491391          |
| 6        | 5.53622| 74.377| 15.648| 0.149477| 591255          |
| 7        | 6.45892| 75.178| 15.2179| 0.144048| 878318          |
| 8        | 7.38162| 75.833| 14.5771| 0.138019| 1624550         |
| 9        | 8.30432| 76.249| 11.9587| 0.128963| 2294360         |
| 10       | 9.22703| 76.431| 12.8625| 0.131675| 2069350         |
| 11       | 10.1497| 76.249| 11.9587| 0.128963| 2294360         |
| 12       | 11.0724| 75.851| 11.1314| 0.124487| 1591040         |
| 13       | 11.9951| 75.204| 10.4872| 0.118621| 899783          |
| 14       | 12.9178| 74.378| 10.0885| 0.113583| 585162          |
| 15       | 13.8405| 73.469| 9.9449| 0.111704| 579640          |
| 16       | 14.7632| 72.559| 10.098| 0.113917| 599382          |
| 17       | 15.6859| 71.776| 10.5416| 0.118886| 1039430         |
| 18       | 16.6086| 71.119| 11.1734| 0.124789| 1690310         |
| 19       | 17.5313| 70.706| 11.9892| 0.129488| 2385600         |

Case 2. Taking into account that the sand is compacted and the rock is compacted to the initial state, obtain the results of the von Mises tension and the deformation state in Figure 4 and Table 5.

![Figure 4](image-url)  
**Figure 4.** Distribution of Mises stress state in the pipe wall, compacted sand and rock is compacted to the initial state
Table 5 Mises distribution of the stress and deformation of the pipeline, compacted sand and rock is compacted to the initial state

| Position | L (cm) | x (cm) | y (cm) | d (cm) | \( \sigma_{Mi} \) (N/m²) |
|----------|--------|--------|--------|--------|-------------------------|
| 0        | 0      | 70.536 | 12.869 | 0.043506 | 2067090                 |
| 1        | 0.922703 | 70.731 | 13.7706 | 0.04554 | 2082700                 |
| 2        | 1.84541 | 71.143 | 14.5791 | 0.047912 | 1604080                 |
| 3        | 2.7681 | 71.761 | 15.2481 | 0.050597 | 1108400                 |
| 4        | 3.69081 | 72.575 | 15.6495 | 0.052983 | 626235                  |
| 5        | 4.61352 | 73.478 | 15.7839 | 0.054069 | 476723                  |
| 6        | 5.53622 | 74.377 | 15.648 | 0.053407 | 584594                  |
| 7        | 7.38162 | 75.833 | 14.5771 | 0.048551 | 1479970                 |
| 8        | 8.30432 | 76.245 | 13.7607 | 0.046117 | 1979060                 |
| 9        | 9.22703 | 76.431 | 12.8625 | 0.044044 | 2113500                 |
| 10       | 10.1497 | 76.249 | 11.9587 | 0.042061 | 2144120                 |
| 11       | 11.0724 | 75.851 | 11.1314 | 0.039317 | 1673850                 |
| 12       | 11.9951 | 75.204 | 10.4872 | 0.036512 | 1182160                 |
| 13       | 12.9178 | 74.378 | 10.0885 | 0.034059 | 797620                  |
| 14       | 13.8405 | 73.469 | 9.9449 | 0.03278 | 575054                  |
| 15       | 14.7632 | 72.559 | 10.098 | 0.033325 | 622721                  |
| 16       | 15.6859 | 71.776 | 10.5416 | 0.035554 | 1131770                 |
| 17       | 16.6086 | 71.119 | 11.1734 | 0.038389 | 1677500                 |
| 18       | 17.5313 | 70.706 | 11.9892 | 0.041134 | 2129900                 |

Case 3. Since the sand is compacted, the rock is compacted to the initial state and taking into account the additional load, obtain the results of the von Mises tension and the deformation state of Figure 5, 6 and Table 6.

Table 6 The distribution of the Mises stress state and deformation to the pipe wall when the excavated land is brought to the initial state.

| Position | L (cm) | x (cm) | y (cm) | d (cm) | \( \sigma_{Mi} \) (N/m²) |
|----------|--------|--------|--------|--------|-------------------------|
| 0        | 0      | 70.536 | 12.869 | 0.019843 | 1032660                 |
| 1        | 0.922703 | 70.731 | 13.7706 | 0.020737 | 1063340                 |
| 2        | 1.84541 | 71.143 | 14.5791 | 0.022002 | 928282                  |
| 3        | 2.7681 | 71.761 | 15.2481 | 0.023594 | 642287                  |
| 4        | 3.69081 | 72.575 | 15.6495 | 0.025135 | 319510                  |
| 5        | 4.61352 | 73.478 | 15.7839 | 0.026152 | 222424                  |
| 6        | 5.53622 | 74.377 | 15.648 | 0.026066 | 137695                  |
| 7        | 6.45892 | 75.178 | 15.2179 | 0.024943 | 338752                  |
| 8        | 7.38162 | 75.833 | 14.5771 | 0.023307 | 675131                  |
| 9        | 8.30432 | 76.245 | 13.7607 | 0.021819 | 965484                  |
| 10       | 9.22703 | 76.431 | 12.8625 | 0.020662 | 1141200                 |
| 11       | 10.1497 | 76.249 | 11.9587 | 0.019747 | 1176960                 |
| 12       | 11.0724 | 75.851 | 11.1314 | 0.018378 | 838585                  |
Figure 5. The distribution of the Mises stress state a) and deformation b) to the pipe wall when the excavated land is brought to the initial state.
Conclusions
Polyethylene pipe systems have a significant and growing market share for low, medium and medium pressure piping systems for the transport of combustible gases.
The results of the finite element analysis indicate that the maximum values of the Von Mises tension appear on the inner surface of the tube.
The condition of stress and deformation decreases due to the increase in the crest of the sand and decreases with the increase of the compaction of the soil above the sand.
The results show that the mechanical properties of PE100 can be strongly influenced by the actual load conditions.
If the maximum value of Von Mises in the buried pipeline exceeds the allowable value for the material used in high density polyethylene pipes, shown in Table 1, the tube is damaged and must be replaced. [13],[1].
To avoid these problems, polyethylene pipes can be protected in rigid protective tubes that can take over the loads to which the pipe is subjected.
For all underground pipelines, account must be taken first of all of the need to properly compact the filler materials.
The results show that the mechanical properties of PE100 can be greatly affected by the load conditions used in the model. [2]
To complete the study, we propose to extend the analysis for other categories of stresses, types of pipe materials and diameters.
The pressure exerted on the pipeline due to a vehicle on the active surface (mainly the loads due to the wheels of trucks or trains) depends on vehicle weight, tire pressure and size, vehicle speed, and other factors.

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