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Evaluation of Stresses in Buried Pipelines in the Underground Crossing Area

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Abstract

According to EN 13480-6: 2004, the stresses that can develop in the walls of the pipes, buried pipes used in the distribution of natural gas, are produced by: the inner pressure of gas being transported, temperature, the weight of the soil, traffic loads.

This paper presents the results obtained in the case of a Φ2″ pipe using the standard method and the finite element method (FEM). Also studied were the cases in which the ground beneath the pipe was added to certain areas so that the pipe no longer gets in touch with the soil along its length. For these cases we have determined the maximum uploads of the Φ2″ pipe which this can support in an under crossing area.

Key words: *gas pipes, traffic loads, FEM*

Introduction

According to EN 13480-6: 2004 [1], the stresses that can develop in the walls of the pipes, buried pipes used in the distribution of natural gas, are produced by: the inner pressure of gas being transported, temperature, the weight of the soil, traffic loads.

In the paper [2] has been presented the calculation of the stresses due to backfill and loads due to live loads induced in gas pipes in the underground crossing area in accordance with [1].

Using these formulas, for a pipe Φ2″ with outside diameter D_0 = 60.3 mm and wall thickness s = 3.2 mm, depth H_t = 0.8 m in a trench width L_t = 0.6 m, in a loamy soil with γ_t = 1800 daN/m^3, $k\mu = k\mu'$ = 0.152 resulted a force of weight of the soil F_1 = 7.103 N/mm.

With regard to live loads produced by vehicles, if one considers the pipeline passing over a vehicle with total weight of 30 tf, and that it is distributed on the front axle is 40% and 60% on the rear axle, then concentrated load acting on the pipe is $F_c = 30\cdot0.6/2$ = 9 tf = 90 kN. Using the methodology presented in [1] shows the force of the pipe request F_7 = 3.11 N/mm.

Consequently the maximum stress that develops in the pipe produced by the weight of the soil above and the traffic is [1]: $\sigma_{\max}^{F_1+F_2}$ = 10.2 MPa.

Analytical Design

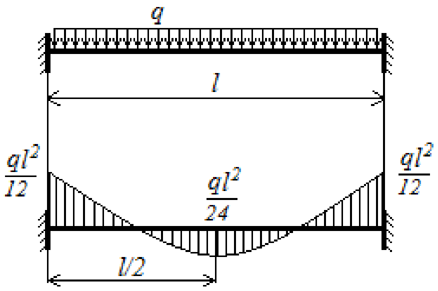


Fig. 1. The model of pipe.

The value of these stresses may be higher if the soil under the pipe was compression to certain areas so that the pipe no longer gets in touch with the soil along its length. For this case was imagined a situation in which the pipe is with fixed ends and is loaded by a distributed force q due by the weight of the soil F_1 and the traffic loads F_7 (fig. 1).

Maximum bending moment is:

$$M_{\max}^{q} = \frac{ql^2}{12}. \tag{1}$$

For pipe Φ2″ with outside diameter D_0 = 60.3 mm and wall thickness s = 3.2 mm was determined the allowable bending moment a L290NB steel and a safety factor of 0.7.

$$M_a = 0.7 R_e \cdot W = 0.7 \cdot 290 \cdot 7783.82 = 1588 \text{ Nm}. \tag{2}$$

For $q = F_1$ = 7.103 N/mm, of equality $M_{\max}^{q} = M_a$ result the maximum length of length of pipe witch is not in contact with soil: $l_{\max}^{F_1}$ = 1.638 m. If $q = F_1 + F_7$ then $l_{\max}^{F_1+F_7}$ = 1.366 m.

Numerical Analysis

A case closer to reality can be a pipe which, for a certain length of it is in contact with soils with different characteristics, so that may occur a situation equivalent to that in Figure 2, where, on a certain length, the pipe on a soil less stiff.

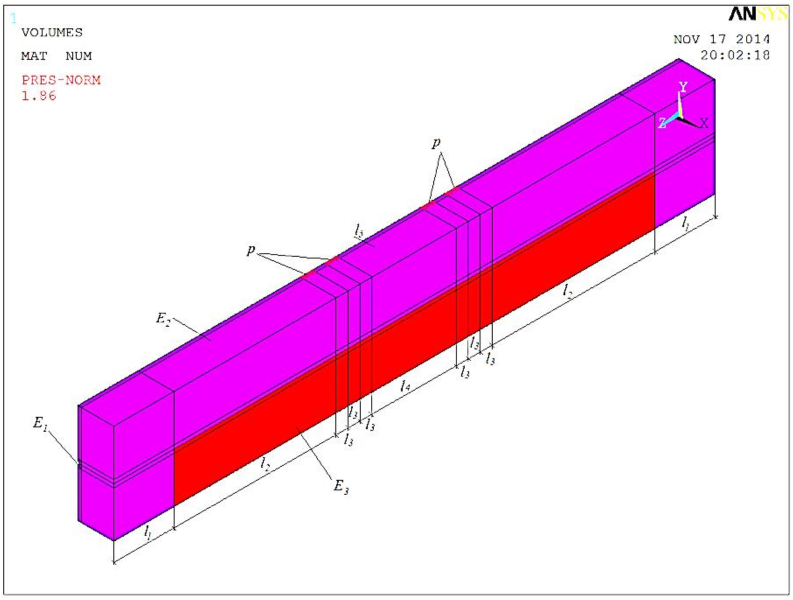


Fig. 2. The FEM model of pipe.

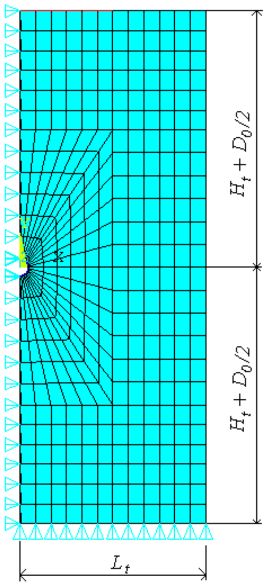


Fig. 3. The mesh.

For this case, to determine the stresses use the finite element method (FEM). Using the symmetry, we achieved a geometric pattern shown in Figure 2. The three modules of elasticity E_1, E_2, and E_3 are: E_1 – modules of elasticity of pipe material; E_2 – modules of elasticity of soil with greater rigidity; E_3 – modules of elasticity of soil with less rigidity.

Geometric model was meshed with SOLID45 finite element. The model links, in Figure 3, and uploads, in Figure 2, is show.

Using this model runs performed in the ANSYS program with the following features:

- dimensions: $l_1 = 1$ m; $l_2 = 2{,}7$ m; $l_3 = 0.2$ m; $l_4 = 1.4$ m; $l_5 = 0.0603$ m;
- pipe features: $D_0 = 60.3$mm; $s = 3.2$mm; $\rho_1 = 7850$kg/m^3; $E_1 = 210000$ MPa; $v = 0.3$;
- soil features: density $\rho_2 = \rho_3 = 2000$ kg/m^3; $E_2 = 50 \ldots 200$ MPa; $E_3 = 5 \ldots 20$ MPa; $v_1 = v_2 = 0.25$.

It was considered the weight of the soil and traffic loads. The loading due by the 30 tf vehicle has been transposed by the pressure p model calculated with relation (see fig. 2).

$$p = \frac{18 \cdot 10^4}{4 \cdot 200 \cdot (2 \cdot 60.3)} = 1.8656 \text{ MPa}. \tag{3}$$

The values of stresses obtained that developed in the wall of the pipe, different assumptions and different values of E_2 and E_3 modules are presented in Table 1. In Figures 4 and 5 are presented the maps of the stresses.

Table 1.

Soil features	Axial maximum stress σ_{max}, MPa
$E_2 = 200$ MPa	10.547
$E_2 = 200$ MPa; $E_3 = 5$ MPa	13.365

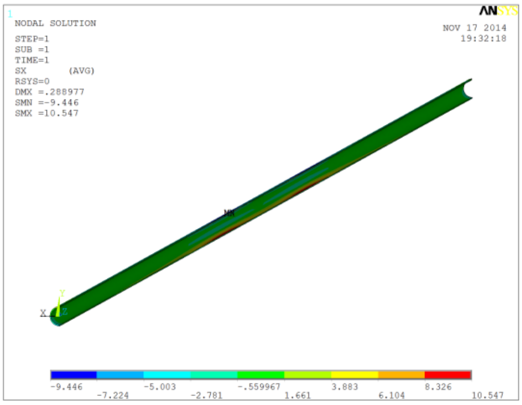


Fig. 4. Axial stresses σ_{ax}, MPa, for $E_2 = E_3 = 200$ MPa.

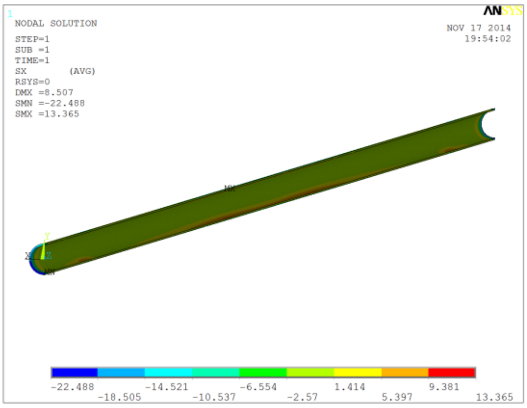


Fig. 5. Axial stresses σ_{ax}, MPa, for $E_2 = 200$ MPa, $E_3 = 5$ MPa.

In weld area the stress increase because of geometric discontinuities. If it is considered a pipe length $2l$ with fixed ends and loaded by the force F exactly half its length (see fig. 6), then the vertical displacement of section 2 shall be determined by the relationship:

$$v_2 = \frac{Fl^3}{24EI} \tag{4}$$

where E is the modulus of elasticity of the pipe material, I – moment of inertia of axial section pipe.

Bending moment in 2 sections is:

$$M_2 = \frac{Fl}{4} \tag{5}$$

Taking into account the relation (4) maximum stress according to the displacement is:

$$\sigma_2 = \frac{M_2}{W} = \frac{6v_2 EI}{l^2 W} = \frac{3v_2 D_0 E}{l^2}\,. \tag{6}$$

Using FEM is bound and applied pipe shape as shown in Figure 6. Thus it is considered a pipe length 2*l*, diameter D_0 and thickness s (fig. 7). Using the symmetry results the model in Figure 8.

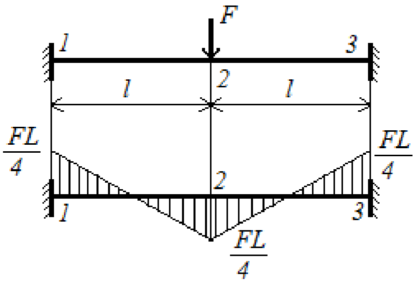


Fig. 6. The equivalent welded pipe

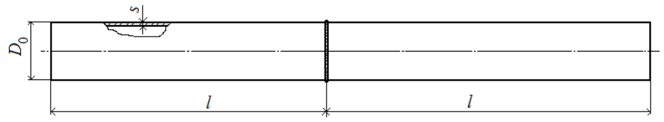


Fig. 7. The model of welded pipe

In order to achieve the physical model, geometric model was meshed in 3D finite elements, type SOLID18. All nodes in the vertical plane of symmetry, perpendicular to the axis of the pipe, they print a displacement $\Delta Y = v_2$.

Concentration factor of the stresses in the weld area shall be determined by the relationship:

$$C_{it} = \frac{\sigma_{\max}^{MEF}}{\sigma_2} \tag{7}$$

where $\sigma_{\max}^{MEF}$ represents the maximum stress in the weld zone obtained using MEF, which corresponding to v_2 displacement.

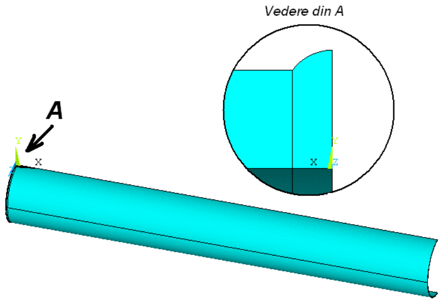
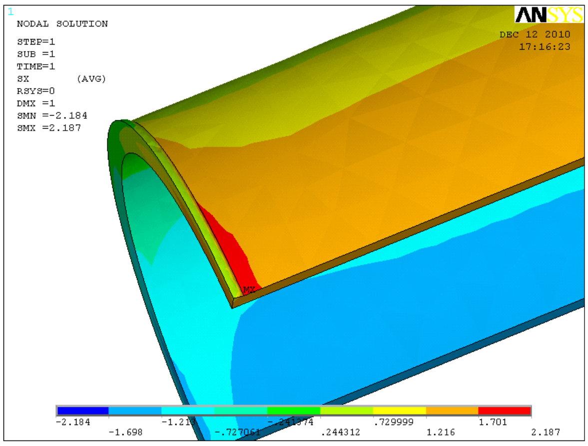


Fig. 8. The FE model of welded pipe



```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
SX       (AVG)
RSYS=0
DMX =1
SMN =-2.184
SMX =2.187
```

Fig. 9. The stresses map

For pipe Φ2″ with outside diameter D_0 = 60.3 mm and wall thickness s = 3.2 mm was made the finite element model. The welding seam had geometric characteristics: width $l_C = 0.8s$ and the height $h_C = 0{,}.2s$. In Figure 9 is presented map of stresses in the weld area for l = 5 m and $v_2 = \Delta Y$ = 1 mm. Using the appropriate pipe considered and the maximum stress value obtained through MEF $\sigma_{\max}^{MEF}$ = 2.187 MPa we can calculate the concentration factor of the stresses in the weld area:

$$C_{it} = \frac{\sigma_{\max}^{MEF}}{\sigma_2} = \frac{2.187}{1.52} = 1.44 \tag{8}$$

Conclusions

Evaluation of stresses in buried pipelines for a proper track is governed by [1] for both the load due by the weight of the soil and traffic loads.

Are the situations when, due to natural phenomena, the pipeline is no longer in contact, throughout its length with the soil of the settlement.

For these situations the paper presents methods to assess the stresses in wall of pipes.

Thus, we evaluated the maximum length that a pipe does not rest on the bed of the allowable stress in the wall of the pipe. For the analysis of Φ2″ pipe resulted a maximum length $l_{\max}^{F_1}$ = 1.638 m for the load due by the weight of the soil and $l_{\max}^{F_1+F_7}$ = 1.366 m for the load due by the weight of the soil and traffic loads.

Another situation examined was a pipe that string on land of different thicknesses. In this case, to assess the stresses, it has resorted to MEF.

The results have highlighted two aspects:

- If the pipe is string on homogeneous soil, the maximum stress developed in the wall of the pipe due by the weight of the soil is very similar to the stress calculated for the same request, the situation with the relationships specified in [1]: $\sigma_{\max}^{F_1+F_2}$ = 10.2 MPa towards $\sigma_{\max}^{MEF}$ = 10.5 MPa;
- If the pipe length of 3.9 m on a soil that has a module of elasticity of 40 times lower than the soil at the ends of the length considered, the maximum stress has an increase of about 27% from 10.5 MPa at 13.4 MPa.

An increase in the maximum stress occurs in areas of joint of pipes. For increase of stresses assessment at the base of the weld used MEF. For the pipeline studied Φ2″ the factor of amplification of the stresses was 1.44.

The aspects analyzed in this paper can be used in particular in the case of assessment of reasons for crack of buried pipes used in the distribution of natural gas, especially in the underground crossing area but may require the design and conditions such as avoiding placement merge areas of pipes in underground areas of road or rail.

References

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2. Rîpeanu, R.G., Metea, V., Pupăzescu, Al. – Studies regarding soil induced stresses in buried steel gas pipes, *Tribological Journal BULTRIB*, Papers from the *Conference BULTRIB '12* under the hosting of the *International Scientific Conference FIT 2012*, Sofia, October 18-20, 2012.

Evaluarea tensiunilor în conductele îngropate în zona subtraversărilor

Rezumat

În lucrare sunt prezentate rezultatele privind calculul tensiunilor produse de greutatea pământului şi de sarcinile mobile în zona de subtraversare a unei căi rutiere pentru o conductă Φ2″ din oţel, utilizată la distribuţia gazelor naturale. Calculul tensiunilor s-a efectuat atât prin metoda din standard cât şi prin metoda elementelor finite (MEF). De asemenea s-au studiat cazurile în care pământul de sub conductă s-a tasat pe anumite zone astfel încât ţeava conductei nu mai ia contact cu pământul pe toată lungimea. Pentru aceste cazuri s-au determinat încărcările maxime pe care conducta Φ2″ analizată le poate suporta în zona unei subtraversări.