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STUDY ON THE BEHAVIOUR OF HIGH-DENSITY POLYETHYLENE (HDPE) PIPES BURIED, ON THE EXPLOSION'S EFFECT

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Abstract. *Abstract. The behaviour of buried pipes made of HDPE (high density polyethylene) due to an explosion refers to finding a safe distance at which the pipe does not suffer plastic deformations. To solve this problem in this paper, the response of HDPE (high density polyethylene) pipes buried to an explosion due to sabotage or terrorism is analysed by numerical modelling.*

Keywords: TNT explosive, JWL parameters, buried pipeline, gas, FEM

1. Introduction

Due to increased energy's consumption and global changes, natural gas still has an important role in energy production.

In each country, the main method of the natural gas's transportation is through underground pipes. Natural gas pipelines could be destroyed by explosions that can threaten the safety of structures and people.

Used for the distribution of water, gas, etc., the underground pipes in HDPE are considered among the most important elements of the installations.

Existing studies, concerning the explosion reaction of underground pipes, refer to the search for the safety distance in the event of an explosion in which the tube does not undergo plastic deformation

The study of buried pipes that can be destroyed by earthquakes or explosions has been studied by Newmark [1] and M. Mokhtari. et al. [2], M. Hajiazizi et al. [3], O, Adibi et al. [4]

Esparza et al. [5] developed an explosion analysis method to obtain simple methods necessary to determine the maximum stresses and pressures in underground steel pipes. The methods of Esparza et al. [5] applies to the design of pipes that can be subjected to explosions. However, the scale of these problems should be solved by numerical methods [2].

An analysis using numerical modelling of explosions applied to buried structures is presented in [6].

2. Finite element modelling

In the present article, the mechanical behaviour of the HDPE buried pipe is analysed numerically using the finite element method. To this end, a complete 3D model with finite elements was developed using a combined Eulerian-Lagrangian method.

Different models are used to model the behaviour of the used materials (HDPE, soil, explosive, air). These models are briefly explained below.

2.1. The material model for HDPE

The behavioural-modelling of HDPE activity is treated by different authors in [7-15], resulting in various constitutive equations. Starting from those presented in [2] and [16] and through laboratory experiments, the characteristic curve of the HDPE material was obtained (Figure 1) by using HDPE's properties presented in Table 1. The data experimentally obtained were used to model the behaviour of the HDPE pipeline.

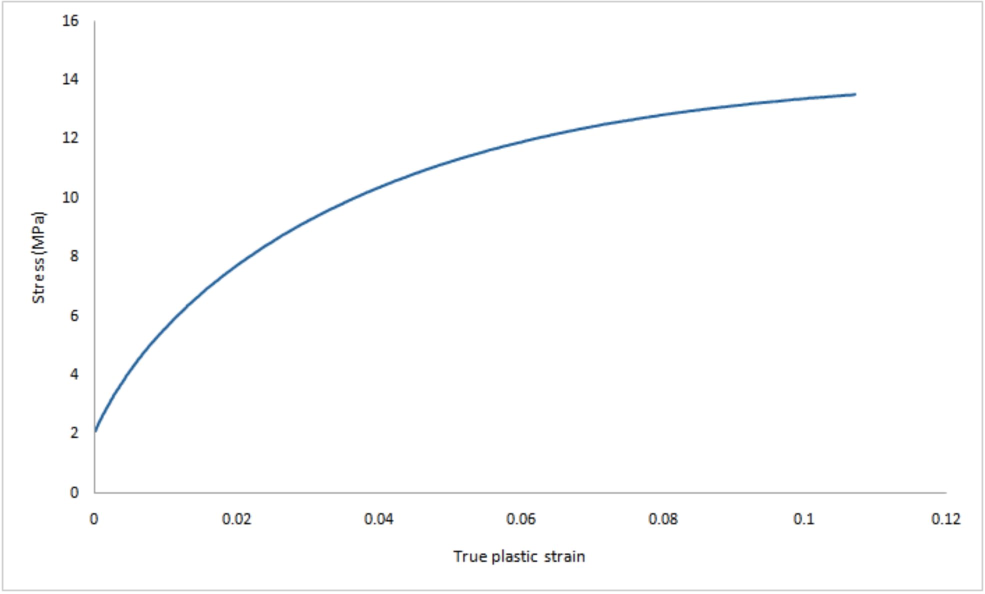


Fig. 1 - The characteristic curve of the HDPE pipeline

Table 1

Properties HDPE

Density [kg/m^3]	Young's Modulus [MPa]	Poisson's ratio
9230	700	0.3

2.2. Modelling of soil behaviour

The tube is placed in clay with the parameters presented in Table 2.

Table 2

Properties for the soil model

Share modulus [MPa]	Density [kg/m^3]	Friction angle [°]	Young's Modulus [MPa]	Poisson's ratio	Cohesion [MPa]
240	2200	24	50	0.3	1

According to [17] the behaviour of the soil influences the propagation of seismic waves in the soil. In this context, the breaking criterion used for the soil is Mohr-Coulomb.

2.3. Modelling of TNT (trinitrotoluene) equivalent

The Jones-Wilkins-Lee (JWL) equation which describes the pressure generated by the explosion of explosive chemicals explosive and has is written as follows [2,18-22]:

$$P = A\left(1-\frac{\omega}{R_1 \cdot \upsilon}\right)\cdot e^{-R_1 \cdot \upsilon} + B\left(1-\frac{\omega}{R_2 \cdot \upsilon}\right)\cdot e^{-R_2 \cdot \upsilon} + \frac{\omega}{\upsilon}\cdot E \tag{1}$$

where v = the specific volume
E = the specific energy.

v=ρ_e/ρ is defined by using ρ_e =density of the explosive (solid part) and ρ =density of the detonation products. The A, B, R1, R2, ω constants values (for many common explosives) were determined by dynamic experiments [2]. The parameters of the Jones-Wilkins-Lee equation for TNT (Trinitrotoluene) are given in Table 3:

Table 3

Jones-Wilkins-Lee parameters for TNT (Trinitrotoluene) [2, 24]

Parameter	Value	Parameter	Value
ρ_0 [kg/m^3]	1630	B [GPa]	3747
E [kJ/m^3]	6000000	R_1	4.15
C_d [m/s]	6930	R_2	0.9
A [GPa]	373.8	ω	0.35
TNT equivalent [kg] [25]	10		

The ideal gas state equation (in a simplest forms) is used to simulate air [2]:

$$p_h = (\gamma - 1)\cdot \rho \cdot e \tag{2}$$

where p_h = the hydrostatic pressure;
ρ = the density;
e = the specific internal energy;
γ = the adiabatic exponent (Table 4):

Table 4
Air

Parameter	Value
γ	1.4
ρ_0, kg/m^3	1.225
T_o, K	288.2

3. Dimensions, discretization, and general settings

Table 5
Dimensions for the HDPE pipeline [26]

Parameter	Value
Type	PE100 SDR 11
External diameter, mm	630
Wall thickness, mm	37.4

According to the presentation and builds, the model in shown in Figure 2. The dimensions are beaten by a parametric analysis, consequently, its dimensions do not influence the results. The model is based on the planes symmetry x, y = 0 [2].

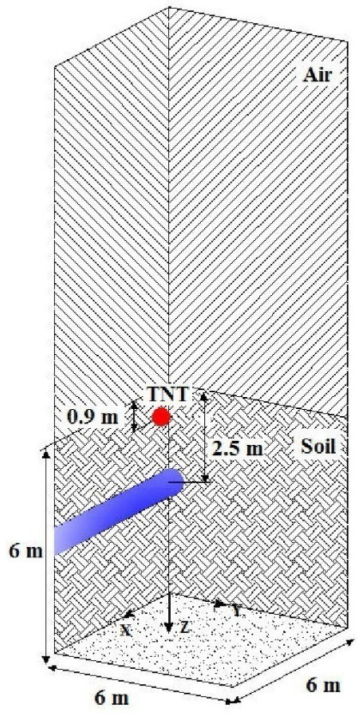


Fig. 2 - The full coupled model

To allow free movement and minimize the reflection of explosion waves, the boundary conditions in the Eulerian environment are unlimited.

The dimensions in Figure 2 are designed so as not to affect the results of the analysis [2]. The pipeline, TNT (trinitrotoluene), air and soil material are modelled from the Lagrangian domain. In critical regions (below the location of the explosive charge) modelling is done with small discretization elements and larger elements in remote regions, this is due to the use of the limited node version of the ABAQUS program (student version) [23].

4. Results, discussions and conclusions

The explosion effect' simulation has been performed following two steps:

1. Before the explosion stage (only the weight of the ground exerted on the model has been considered);
2. The detonation's stage.

The contact between the surrounding ground and the HDPE pipe's exterior is based on the General Contact algorithm. This model of algorithm allows any free movement of the ground pipe.

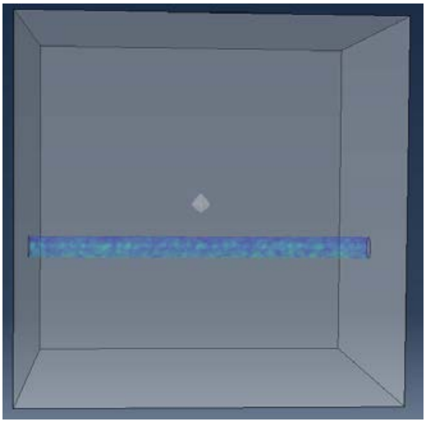
The study of the explosion's effect takes place immediately below the place of the explosive charge where its influence is maximum. The effect of the explosion on the ground surrounding the pipeline before and after the explosion is ignored. In the proposed model, the detonation occurs near the pipe (fig. 3a), so that its effect affects the pipe, the explosive charge of TNT was placed at about 1 m depth and the pipe is buried at 2.5 m depth.

The influence of the explosion begins just below the explosive charge (i.e. point A in Figure 4). As time passes from the moment of explosion to its completion, the tension and deformation of the pipe increase, the damage of the pipe (maximum voltage) moves from point A to point B (i.e. point B in Figure 4), along pipeline. The place where the explosion's effect (i.e. the state of tension and disorientation is maximum) is at point B.

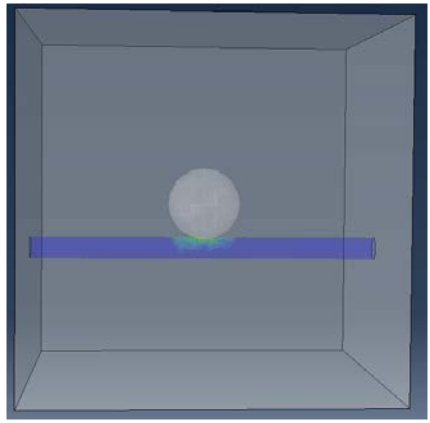
From the analysis of the results in Figure 3 it is observed that the explosion deforms the HDPE pipe over the resistance limit. It is concluded that significant amounts of TNT equivalent can cause significant damage to natural gas pipelines. The crater dimensions for underground explosions coincide with those found in the literature [25].

The results of these studies can help design buried HDPE pipes to avoid damage in the event of an explosion near a natural gas pipeline.

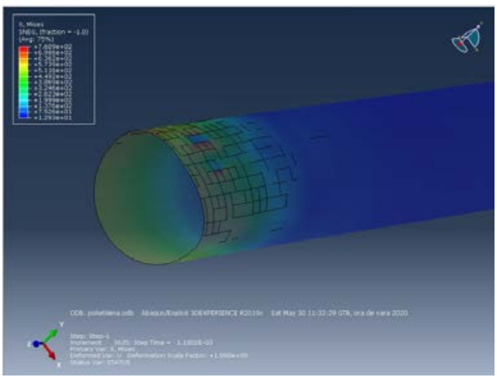
The study can be developed for different gas pressures in the pipeline, the behaviour of HDPE pipes with steel ones can be analysed [2].



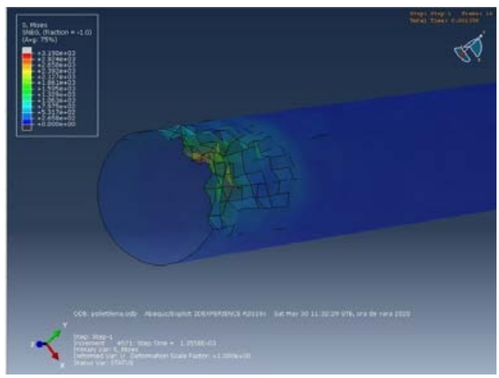
a)



b)



c)



d)

Fig. 3 - State of tension in the pipe due to the explosion
a) time 0.0, c) time 1.1×10^{-3}, b) & d) time 1.35×10^{-3}s

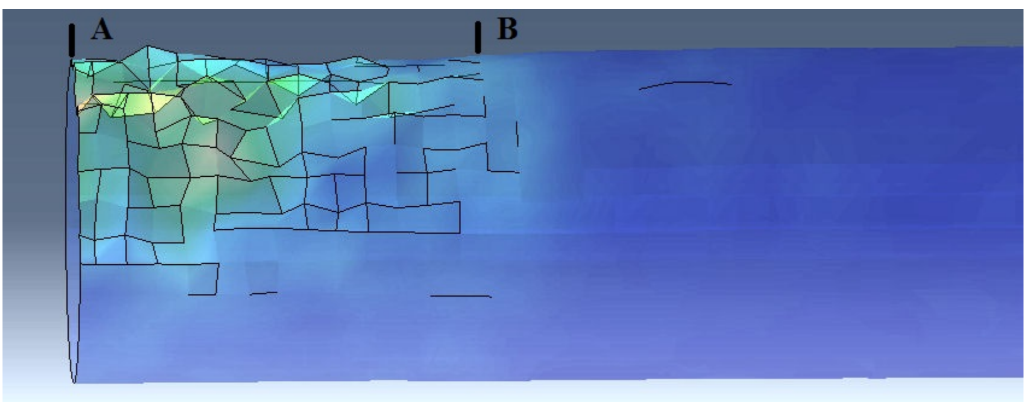


Fig. 4 - State of tension in the pipe due to the explosion, at time 1.35×10^{-3}s

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