BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iași
Volumul 68 (72), Numărul 3, 2022
Secţia
CONSTRUCŢII. ARHITECTURĂ
DOI: 10.2478/bipca-2022-0025

BEHAVIORAL ANALYSIS OF HIGH-DENSITY POLYETHYLENE GAS DISTRIBUTION PIPES UNDER LOAD

BY

LUDOVIC CĂLCÎI*, **LADISLAU RADERMACHER and ANDREI BURLACU**

“Gheorghe Asachi” Technical University of Iasi-Romania, Faculty of Civil Engineering and Installations, 59A Prof. D. Mangeron Blvd., 700050, Iasi, Romania

Received: July 19, 2023
Accepted for publication: September 20, 2023

Abstract. With a view to sustainable development, the safe supply of natural gas necessary for food preparation and home heating is a priority issue.

The natural gas industry is a competitive market that requires high-performing assets that can be translated into high operational availability, production efficiency, reliability, and maintainability of all assets.

The quality of natural gas supply systems is the basic indicator of the economical energy industry. Reliability being, along with other technical and economic indicators, is a component of quality, it must be in the attention of all the factors that determine the good running of the company.

Following the technological developments in the field of plastics, in the last decades, the pipes made of polyethylene are more and more frequently used in the realization of the natural gas distribution systems.

The use of high-density polyethylene pipes is due to the fact that the service life, corrosion resistance, flexibility, and resistance to dynamic stress are superior to steel pipes.

However, this material also has some disadvantages.

---

*Corresponding author; *e-mail*: ludovic-dorel.calcii@student.tuiasi.ro

High-density polyethylene pipe is easily affected by ultraviolet light. In addition, the mechanical strength of high-density polyethylene pipe is lower than that of steel.

Due to the increase in the number of vehicles in urban areas and the degradation of asphalt on roads, the rate of damage to polyethylene pipes has increased rapidly.

In view of the problems encountered in the operation of high-density polyethylene pipes installed underground in the roadway, an analysis of these problems is necessary.

This type of analysis is based on the assumption that pavements are subjected to static loads and that paving materials, supports, and pipes are linearly elastic materials. In reality, the pavements are subjected to both static and dynamic loads, the asphalt mixtures are viscoelastic materials, and the clays have plasticity. So, for simplicity, static loads are applied on a road section with properties of linear elastic material.

The paper deals, by numerical methods (finite element method), with the deformation modulus and the stress state of high-density polyethylene pipes subjected to the loads resulting from the movement of vehicles on an asphalt road.

This paper examined the application of QuickField software on an asphalt pavement at different vehicle positions and the responses of high-density polyethylene pipes to these loads.

These analyzes help to position high-density polyethylene pipes in the roadway directly from the design.

Keywords: methane, pipeline, traffic load, high-density polyethylene, accident consequence.

1. Introduction

Due to the growing number of vehicles in urban areas and the degradation of asphalt on roads, the damage rate of polyethylene pipes has increased rapidly.

This type of analysis is based on the assumption that pavements are subjected to static loads and that paving materials, support and pipe are linearly elastic materials. In reality the pavements are subjected to both static and dynamic loads, asphalt mixtures are viscoelastic materials, and clays have plasticity. So for simplification, static loads are applied on a road section with properties of linear elastic material.

2. Geometric model

Conventionally flexible pavements consist of layers, wear surface, base and subbase on a stable structure in which the pipe is laid. The working model is according to Fig. 1, which represents a street section according to the dimensions in Fig. 1. The pipe is laid at a depth of 0.9 meters from the ground surface, according to (Order nr. 89/2018).

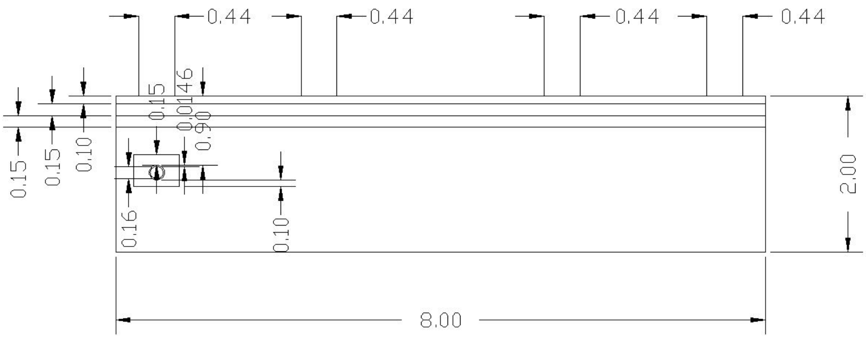

Fig.1 − The dimensions of the model.

The dimensions of the finite element mesh (FEM) must be small enough to allow detailed analysis of the pipe section. The small mesh size increases the number of discretization elements, as a result, the memory and computation time increase. For this reason, discretization increases outside the pipeline. In our case the modeling was done with QuickField Student 6.4 software.

The boundary conditions for the finite element model have a significant significance on the model response. At the edge of the road, the adjacent ground also has two forces, vertical friction and passive pressure. The boundary conditions representing these forces were not included in the analysis. Thus, the model is considered embedded in the edge and in depth.

3. Properties of materials

As can be seen in Fig. 1, we have 3 layers of infrastructure, a basic layer of sand in which the pipe and the pipe are laid. The elastic properties are shown in Table 1 (Faheem, 2014), (PEHD - Valrom Industrie), (Căpraru C., 2016), (Radermacher L., 2018), (Radermacher L., 2019).

Table 1
Elastic properties

Material	Thickness mm	Modulus of elasticity E N/m ^{2}	Density ρ kN/m ^{3}	Poisson's ratio
Asphalt	100	$2.1 * 10^9$	20	0.45
Layer 1 Crushed stone	150	$1 * 10^8$	20	0.35
Layer 2 Crushed stone	15	$5 * 10^7$	18	0.30
Clay		$742 * 10^5$	15.7	0.30
Sand		$2 * 10^7$	17	0.30
HDPE	14.6 (D=160mm)	$1 * 10^9$	9.39	0.25

4. Static charging

This section presents the static charging condition. The maximum applied load taking into account (Shave J., 2011), (Khademi-Zahedi, 2019), (BS 9295:2010), (Ahmad M., 2017) is 115kN per axle and 57.5kN per wheel, respectively Fig. 2.

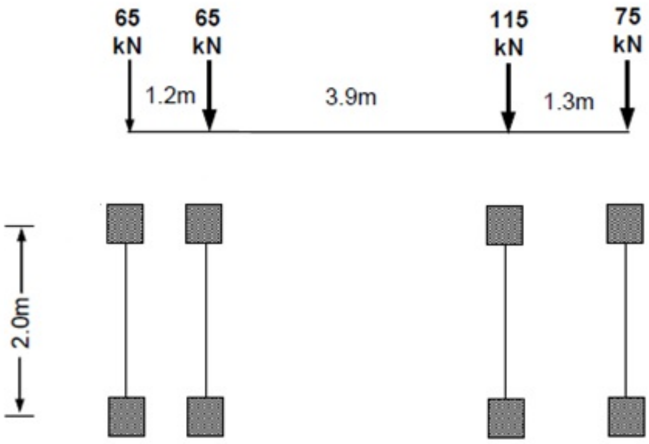

Fig. 2 – How to load the road in normal conditions.

To determine the force actuation surface, we start from the assumption that (Zaghloul, 1993), (Aguilar-Martínez J., 2015), (Gholam A., 2014), (Ahmad M., 2017) the length of the contact area or the footprint of the tire is a rectangular area with semi-round ends, as shown in Fig. 3.

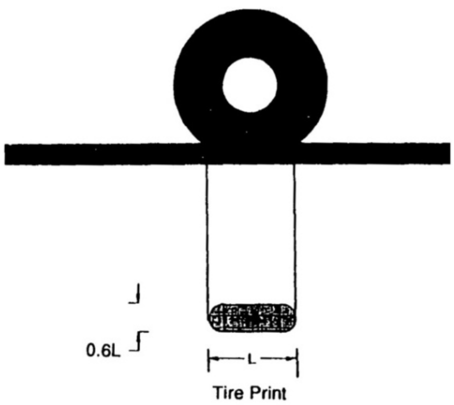

Fig. 3 – Footprint of the tire.

The area of the contact surface (of the wheel footprint) is based on the relationship:

$$A=0.5227\cdot L^2 mm^2 \quad (1)$$

It is considered that when inflating with an optimal pressure, a tire runs quickly and smoothly, molding and ensuring at the same time the adhesion with the road and has the maximum surface according to the Fig. 4.

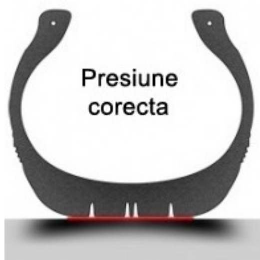

Fig. 4 – Tire maximum surface.

Taking into account the presented fingerprint areas for tires in Romania can be found in table 2.

Table 1
Areas for tires in Romania

Tire width L_a mm	Fingerprint length $L= L_{at}/0.6$ mm	L^2 mm^2	Fingerprint area A mm^2	A m^2	Pressure P N/m^2	p kPa
155	258.33	66736.11	34882.97	0.0349	1648369.04	1648.37
165	275.00	75625.00	39529.19	0.0395	1454621.35	1454.62
175	291.67	85069.44	44465.80	0.0445	1293128.69	1293.13
185	308.33	95069.44	49692.80	0.0497	1157109.31	1157.11
195	325.00	105625.00	55210.19	0.0552	1041474.46	1041.47
205	341.67	116736.11	61017.97	0.0610	942345.42	942.35
215	358.33	128402.78	67116.13	0.0671	856723.98	856.72
225	375.00	140625.00	73504.69	0.0735	782263.04	782.26
235	391.67	153402.78	80183.63	0.0802	717103.96	717.10
245	408.33	166736.11	87152.97	0.0872	659759.54	659.76
255	425.00	180625.00	94412.69	0.0944	609028.32	609.03
265	441.67	195069.44	101962.80	0.1020	563931.17	563.93

As the small width tires are not for the maximum load, further analysis will take into account the 165 mm wide tire subjected to a pressure of 563.93kPa. It is considered that the car is parked so the loads are maximum.

5. Analyze

In the first stage it is considered that only one wheel acts. The result is in Fig. 5.

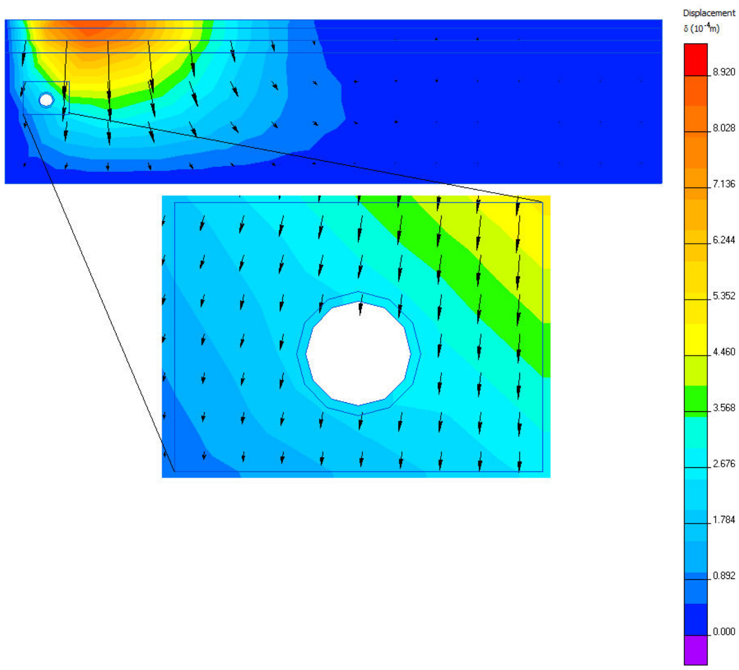

Fig. 5 – First stage result.

In the second stage both wheels of the car are considered.

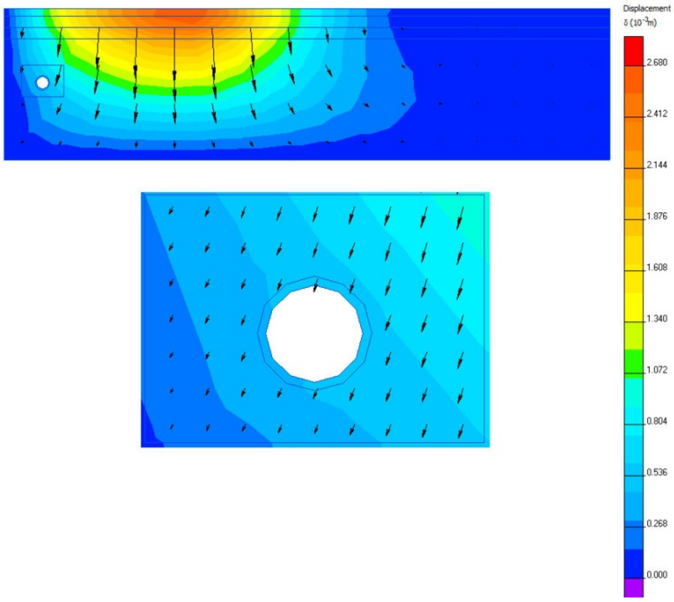

Fig. 6 – Second stage result.

In the third stage, the existence of a stationary car on the second lane is taken into account.

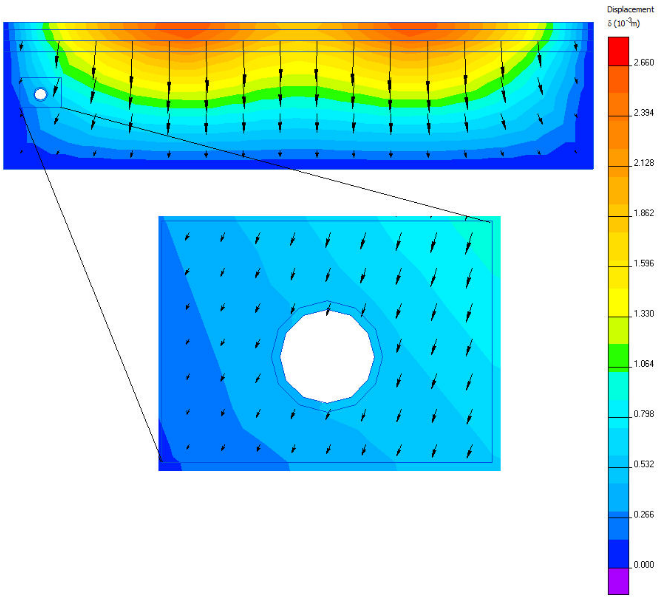

Fig. 7 – Third stage result.

If a series of points are chosen on the contour of the pipe on the median axis for the analysis of the pipe deformation, the diagram is obtained:

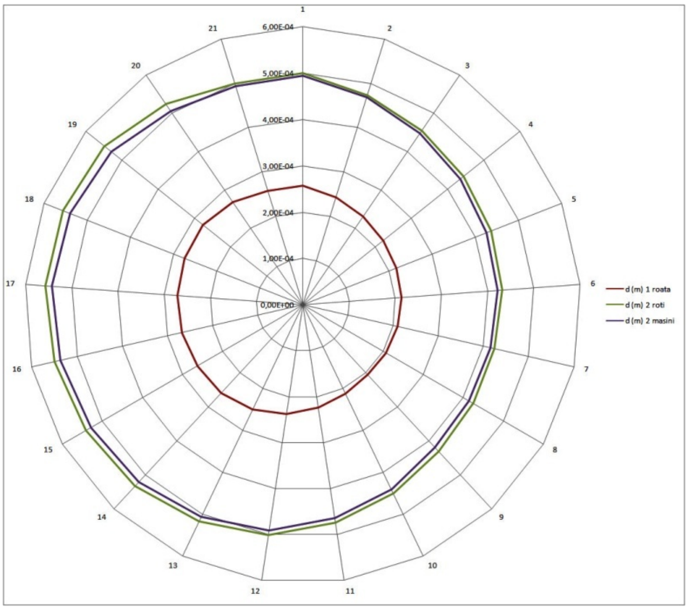

Fig. 8 – Pipe deformation diagram.

6. Conclusions

Deformation of the HDPE pipeline line increases with increasing traffic loads and road material properties.

If only the action of a single wheel is taken into account, the results are flawed because the influence of the entire weight of the car is not taken into account.

From the analysis of the obtained results, it was observed that the maximum deformation takes place if the car is parked on the pipe.

If there are two adjacent cars, the effects are canceled so that the deformation of the pipe is less than in the case of a single car.

These analyzes help to position the HDPE pipes in the roadway directly from the design.

The model can be improved by taking into account the viscoelastic behavior of the asphalt and the Mohr Coulomb breaking criterion for the road support layer. For sand it is recommended to use the Drucker – Prager breaking criterion. Polyethylene can be considered linear elastic.

REFERENCES

*** *Ordinului nr. 89/2018 pentru aprobarea Normelor tehnice pentru proiectarea, execuţia şi exploatarea sistemelor de alimentare cu gaze naturale.*

Faheem, Hamdy & Hassan, Ahmed, *2d plaxis finite element modeling of asphalt-concrete pavement reinforced with geogrid*, Journal of Engineering Sciences, 42, 1336-1348, (2014).

*** Carte tehnica pentru ţevi şi fitinguri PEHD - Valrom Industrie.

Căpraru C., Pistrol J., Kopf F., Adam D., *Modelarea numerică a compactării pământurilor cu role oscilatoare*, XIII-a Conferinţă Naţională de Geotehnică și Fundații – Cluj-Napoca, (2016).

Radermacher L., Bors A.-M., Lingvay D., Nicula (Butoi) N. O., Voina A., Marin D., *Sustainable and safe in exploitation of gas networks. Part1. Stress factors of plastic pipelines*, Electrotehnica, Electronica, Automatica (EEA), 66 (4), 66-72, (2018).

Radermacher L., Mateescu T., *Study of natural gas pipeline behaviour*, IOP Conf. Ser.: Mater. Sci. Eng. (2019).

Shave J., Christie T., Denton S., Kidd A., *Development of traffic surcharge models for highway structures*, Bridge Design to Eurocodes, SN - 978-0-7277-5746-3, ICE Publishing, (2011).

Khademi-Zahedi, Shishesaz M., *Application of a finite element method to stress distribution in buried patch repaired polyethylene gas pipes*, Underground Space, 4 (1), 48-58, (2019).

*** *BS 9295:2010, Guide to the structural design of buried pipelines.*

Zaghloul, Sameh M, White, Thomas, *Use of a Three-Dimensional, Dynamic Finite Element Program for Analysis of Flexible Pavement*, Transportation Research Record, Issue Number: 1388, (1993).

Aguilar-Martínez J., Alvarez-Icaza L., *Analysis of tire-road contact area in a control oriented test bed for dynamic friction models*, Journal of Applied Research and Technology, 13(4). (2015).

Gholam Ali Shafabakhsh, Mohsen Talebsafa, Mana Motamedi, Saber Kie Badroodi, *Analytical evaluation of load movement on flexible pavement and selection of optimum neural network algorithm*, KSCE Journal of Civil Engineering (0000) 00(0):1-9, (2014).

Ahmad M., Abu Abdo, *Effects of dual versus super single truck tire on flexible pavement performance; a mechanistic approach*, ARPN Journal of Engineering and Applied Sciences, 12 (13), (2017).

ANALIZA MODULUI DE DEFORMARE A CONDUCTELOR DE GAZE NATURALE REALIZATE DIN POLIETILENA DE INALTA DENSITATE PEHD AMPLASATE IN CAROSABIL

În vederea dezvoltării durabile, furnizarea în siguranță a gazelor naturale necesare pentru prepararea alimentelor și încălzirea locuinței este o problemă prioritară.

Industria gazelor naturale este o piață competitivă care necesită active de înaltă performanță care pot fi traduse în disponibilitate operațională ridicată, eficiență a producției, fiabilitate și mentenanță a tuturor activelor.

Calitatea sistemelor de alimentare cu gaze naturale este indicatorul de bază al industriei energetice economice. Fiabilitatea fiind, alături de alţi indicatori tehnici şi economici, este o componentă a calităţii, ea trebuie să fie în atentia tuturor factorilor care determină buna funcţionare a societăţilor de distribuţie.

Ca urmare a evoluţiilor tehnologice din domeniul materialelor plastice, în ultimele decenii, conductele din polietilenă sunt din ce în ce mai des folosite în realizarea sistemelor de distribuţie a gazelor naturale.

Utilizarea conductelor de polietilenă de înaltă densitate se datorează faptului că durata de viață, rezistența la coroziune, flexibilitatea și rezistența la stres dinamic sunt superioare conductelor de oțel.

Cu toate acestea, acest material are și unele dezavantaje.

Conducta din polietilenă de înaltă densitate este ușor afectată de lumina ultravioletă. În plus, rezistența mecanică a conductei de polietilenă de înaltă densitate este mai mică decât cea a oțelului.

Datorită creșterii numărului de vehicule în mediul urban și degradării asfaltului pe drumuri, rata deteriorării conductelor de polietilenă a crescut rapid.

Având în vedere problemele întâmpinate în exploatarea conductelor de polietilenă de înaltă densitate instalate în subteran în carosabil, este necesară o analiză a acestor probleme.

Acest tip de analiză se bazează pe ipoteza că pavajele sunt supuse la sarcini statice și că materialele de pavaj, suporturile și conductele sunt materiale elastice liniare.

În realitate, pavajele sunt supuse atât la sarcini statice, cât și dinamice, mixturile asfaltice sunt materiale vâscoelastice, iar argilele au plasticitate, deci, pentru simplitate, sarcinile statice sunt aplicate pe o secțiune de drum cu proprietăți ale materialului elastic liniar.

Lucrarea tratează, prin metode numerice (metoda elementelor finite), modulul de deformare și starea de solicitare a conductelor de polietilenă de înaltă densitate supuse sarcinilor rezultate din deplasarea vehiculelor pe un drum asfaltat.

Această lucrare a examinat aplicarea software-ului quickfield pe un pavaj de asfalt la diferite poziții ale vehiculului și răspunsurile conductelor de polietilenă de înaltă densitate la aceste sarcini.

Aceste analize ajută la poziționarea conductelor de polietilenă de înaltă densitate în carosabil direct de la proiectare.