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PIPELINE RELIABILITY LEVEL FOR THE DIFFERENT COLLAPSIBLE STRATA

Probabilistic analysis of the loessial collapsible soil deformation modulus in the water saturated for two areas of pipeline laying in the Poltava and Kherson region were performed. Respective distributing laws and statistics were obtained. With help of Ansys finite element simulation was performed in the form of the Monte-Carlo method. Pipeline deformation in the loessial collapsible strata local soaking area was modeled; internal operating pressure and temperature difference were considered. Pipeline failure probability by longitudinal stresses parameter in the fine sand soil was obtained, random functions stochastic apparatus was used. Pipeline failure probability by longitudinal stresses parameter with similar geometric parameters and internal operating pressure simulation results were compared with the base composed by fine sand and loessial collapsible strata 7 and 13 meters.

Keywords: *buried main pipeline, loessial collapsible strata, longitudinal stresses, reliability level.*

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ІМОВІРНІСТЬ БЕЗВІДМОВНОЇ РОБОТИ ТРУБОПРОВОДУ ДЛЯ РІЗНОЇ ПОТУЖНОСТІ ПРОСАДОЧНОЇ ТОВЩІ

Виконано імовірнісний аналіз модулю деформації лесового просадочного ґрунту у водонасиченому стані для двох ділянок прокладання трубопроводу Полтавської області та Херсонщини. Отримано відповідні закони розподілу та статистики. За допомогою методу Монте-Карло, у формі методу скінченних елементів, проведено імовірнісне моделювання трубопроводу на ділянці локального замочування масиву лесового ґрунту із врахуванням внутрішнього робочого тиску і температурного перепаду. За допомогою імовірнісного апарату випадкових функцій отримано значення надійності трубопроводу прокладеного у мілкому однорідному піску. Порівняно результати моделювання трубопроводу з однаковими геометричними параметрами та внутрішнім робочим тиском для основи складеної мілким піском та просадочною товщою різної потужності 6,2 та 13 м. для трубопроводу Отримано значення імовірності безвідмовної роботи трубопроводу за параметром поздовжніх напружень.

Ключові слова: *підземний магістральний трубопровід, лесова просадочна товща, поздовжні напруження, імовірність безвідмовної роботи.*

Introduction. Main pipeline linear part MPLP soil basis differential settlements lead to additional longitudinal stresses in the pipeline walls, destruction of anti-corrosion coating and reduce pipeline durability [1 – 6]. In addition, MPLP large deflection may cause formation of gas hydrates in places of «local hollows» that confirms necessity of the different settlements regulation.

Large values of the MPLP differential settlements are typical for pipeline laying in non-standard soil conditions. Non-standard soil conditions are such conditions when there are pipeline layer designed in areas with the following characteristic features [1, 3, 7]: swamp or flooded areas, areas with underground cavities of various nature (mining and mine construction zones, areas with karst cavities, etc.), thawing permafrost areas, landslide territories, seismic zones.

For Ukraine loessial collapsible soils are very common problem, because such soil occupy 65 – 70% of the territory. Such problem is especially urgent for the southern region, where loessial layer reaches 45…50 m, and the value of the soil collapse from its own weight may occur 1…2 m [8 – 10].

Analysis of recent sources of research and publications. MPLP differential deformations in swelling clays investigation show that pipeline, with dimensions 1220 × 22 mm, has longitudinal stress σ_{l} = 165 MPa, for soil movements 310 mm on the wave longitude about 50 m [2]. In area of thawing permafrost on the wavelength of 38 m soil local deformations is 158 mm. In those conditions pipeline, with dimensions 1220 × 32 mm, has longitudinal stress about σ_{l} = 100 MPa [1]. It should be noted that both of the researches were made basing on the hypothesis of equivalence between soil differential settlements and pipeline deformations [1, 2].

Deterministic calculations for the similar soil conditions typical in Ukraine – loessial collapsible soil showed quite close results [11]. It should be mentioned, that for soil it is used linear model with soil deformational modulus in the natural and water saturated state. For example, in the loessial collapsible 9 m strata settlements which are determined by the engineering technique, S_{slg} = 266 mm pipeline, with external diameter 1000 mm, have follow deformations and longitudinal stresses. Results are presented for different type of contact between soil and pipeline. Bonded contact was chosen as most relevant.

Table 1 – Soil settlements, pipeline deformations and longitudinal stresses

Soaked area length, L, m	Pipeline wall thickness, *t*, mm	Measured Value	FEM Simulation		
			Bonded	Frictional	Contact is absent
50-65 m (water spreading from top to down)	10	S_{slg}, мм	285	285	290
		S_{sl}^{pipe}, мм	284	421	422
		$\sigma_{dif}^{max(min)}$, МПа	+169 -195	+142 -147	+155 -143
	15	S_{slg}, мм	285	285	285
		S_{sl}^{pipe}, мм	285	411	417
		$\sigma_{dif}^{max(min)}$, МПа	+138 -166	+126 -133	+137 -135
	20	S_{slg}, мм	292	285	285
		S_{sl}^{pipe}, мм	288	296	411
		$\sigma_{dif}^{max(min)}$, МПа	+129 -145	+121 -121	+128 -127

Highlighting of unsolved parts of the problem. Pipeline strength in a nonstandard soil conditions is investigated. The next step in improving calculation methodic is to determine pipeline reliability level [4, 12] on longitudinal stresses parameter σ_l. There are four main input random variables RV, which define pipeline reliability by longitudinal stresses parameter: pipeline steel yield strength $\tilde{\sigma}_y$, internal operating pressure value $\tilde{P}$, temperature difference $\Delta\tilde{t}$, uneven settlement value, which almost fully determinate value of the bending stresses $\tilde{\sigma}_{dif}$. Stochastic parameters of the first three factors are investigated. According to geotechnical problems of Ukraine, loessial collapsible soil deformational modulus in the water saturated state and its stochastic parameters are the most interesting parameter for us. Soil local collapsible settlements from its own weight $S_{s\ell g}$ and respective bending stresses σ_{dif} could be obtained with help of Ansys probabilistic simulation.

Purpose of the work is to determine relevant distribution and statistics for the loessial collapsible soil deformational modulus in the water saturated state. Obtain pipeline longitudinal stresses and respective failure probability.

Collapsible soil stochastic characteristics estimation. Engineering data of the geotechnical researches in the Kherson city – Object #1, and Poltava region – Object #2 (fig. 1) are taken as statistical material. Should be noted, that area of the Object #2 is right on the pipeline route, samples were taken during the pipeline isolation repair.

Figure 1 – Loess soil sampling during the pipeline isolation repair works

Statistical data of the Object #1 were taken from 10 bore pits, with 13 m depth. Soil samplings were conducted over 1 meter [9] in rings, with further uniaxial compression test. During the research four geological elements were allocated: Strata-1 – vegetation layer (Loamy black soil, loose, solid); Strata-2 – loess loam, brownish-yellow, carbonate, light silty, in natural state solid in the saturated state fluid, macroporous, collapsible; Strata-3 – sandy loess loam, yellow, carbonate, silty, in natural state solid in the saturated state fluid, macroporous, collapsible; Strata-4 – loess loam, yellow-brown, brown, carbonate, heavy silty, in natural state solid in the saturated state fluid. Strata-5 – noncolapsible loam. During the geotechnical investigations groundwater level wasn't found.

General sampling of the Object #1 physical and mechanical soil properties was 128 elements: where Strata-2 – 52, Strata-3 – 48, Strata-4 – 28. Soil layers thickness were assigned as following: Strata-1 – 0.6 m, Strata-2 – 4.6 m, Strata-3 – 4.9 m, Strata-4 – 2.9 m, total 13 m (fig. 2. a). Underlying Strata-5 – 2 m. Physical and mechanical properties of the array are shown in the table. 2.

Object #2 statistical was taken from the bore pit from the 2,3 m depth. Three soil layers were singled: Strata-1 – vegetation layer (Loamy black soil, loose, solid); Strata-2 – sandy loam, light-brown, silty, in natural state solid in the saturated state fluid, macroporous collapsible; Strata-3 – loam grey heavy silty solid noncollapsible. General sampling of the Object #2 mechanical soil properties was 24 elements. During the geotechnical investigations groundwater level wasn't found. Soil layers thickness were assigned as follow: Strata-1 – 1.1 m, Strata-2 – 6.2 m, Strata-3 – 2 m, total 9 m (fig. 2. b). Physical and mechanical properties of the array are shown in the table. 3.

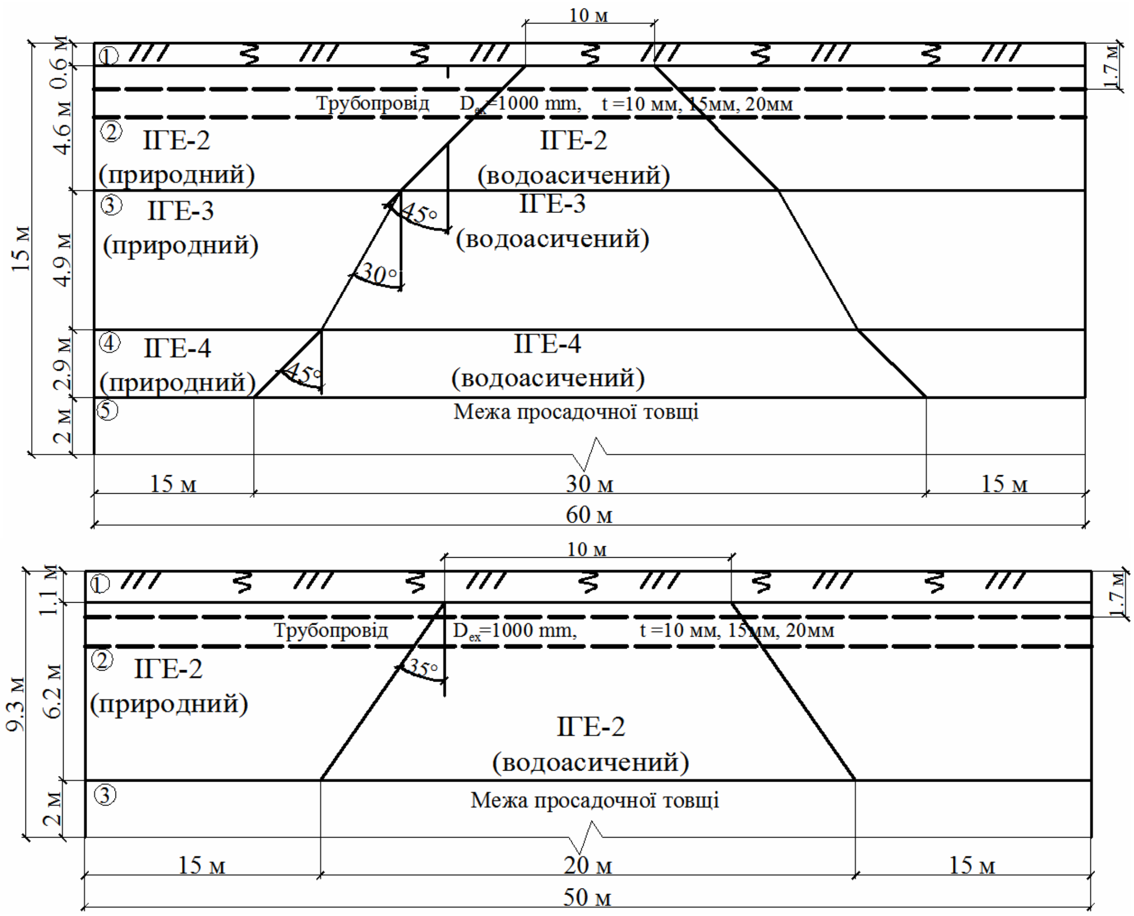


Figure 2 – Design model of the system «MPLP – loessial soil» local soaking: a - soil conditions Object #1; b - Object #1

Table 2 – Physical and mechanical properties of Object #1 loessial basis

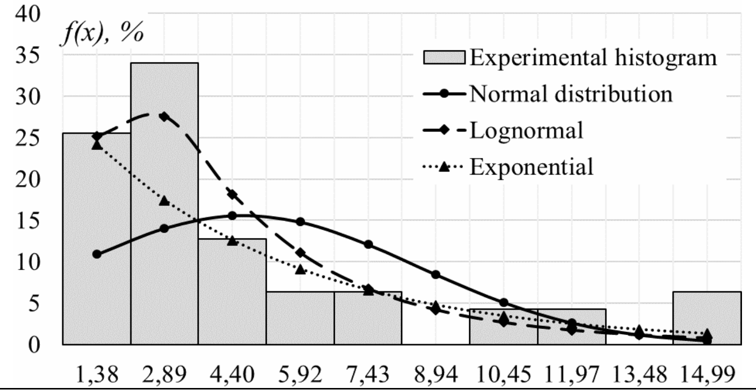
Soil properties		Numerical values				
		Strata 1	Strata 2	Strata 3	Strata 4	Strata 5
Strata thickness, h, m		0,6	4,6	4,9	2,9	2,0
Soil density, ρ, kg/m^3		1500	1568	1568	1627	1860
Saturated soil density, ρ_{sat}, kg/m^3		1840	1885	1797	1848	-
Void ratio, *e*		-	0,91	0,94	0,86	-
Relative collapsibility, ε_{sl}, %, for pressure, P, MPa	0,05	-	1,1	1,0	1,0	-
	0,10	-	2,2	2,0	1,9	-
	0,20	-	4,8	4,5	4,3	-
	0,25	-	6,0	5,4	5,1	-
Deformation modulus, E_s, MPa (respective pressure range)	natural conditon	6	12,4	13,2	14	15
	water saturated state		4,7	3,3	2,72	-
Poisson ratio soil, *μ*	natural conditon	0,31	0,33	0,33	0,32	0,31
	water saturated state	-	0,35	0,35	0,34	-

Table 3 - Physical and mechanical properties of Object #2 loessial basis

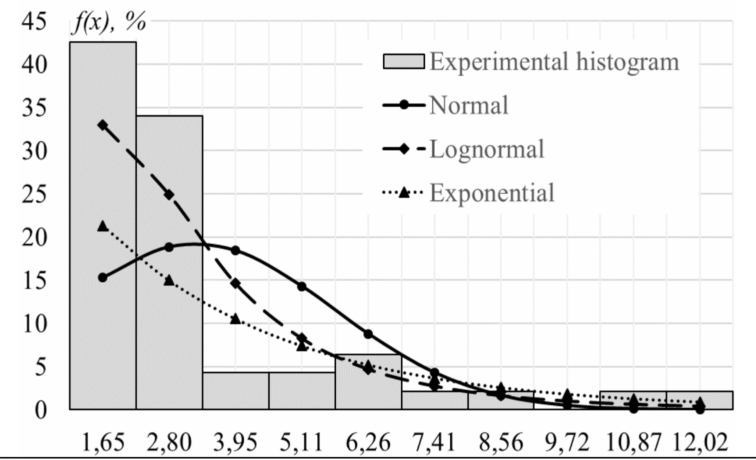
Soil properties		Numerical values		
		Strata 1	Strata 2	Strata 3
Strata thickness, h, m		1,1	6,2	2,0
Soil density, ρ, kg/m^3		1500	1495	1860
Saturated soil density, ρ_{sat}, kg/m^3		1840	1840	-
Void ratio, *e*		-	1,08	-
Relative collapsibility, ε_{sl}, %, for pressure, P, MPa	0,05	-	1,3	-
	0,10	-	3,0	-
	0,15	-	4,2	-
	0,20	-	5,6	-
Deformation modulus, E_s, MPa	natural conditon	6	12	14
	water saturated state		2,8	
Poisson ratio soil, *μ*	natural conditon	0,31	0,33	0,31
	water saturated state	-	0,35	-

Each soil strata was tested for the uniaxial compression with different pressure intervals for Object #1 (σ = 0,05…0,1; 0,1…0,2; 0,2…0,25 MPa) and for the Object #2 (σ = 0,05…0,1; 0,1…0,15; 0,15…0,2 MPa). It is necessary because soil deformation modulus is variable for each pressure interval [13] and to get most correct results during FEM it is set its value based on actual pressure range (fig. 2 a, b). In the scope of the current paper there only graphs are included used for the following probabilistic simulation (fig. 3).

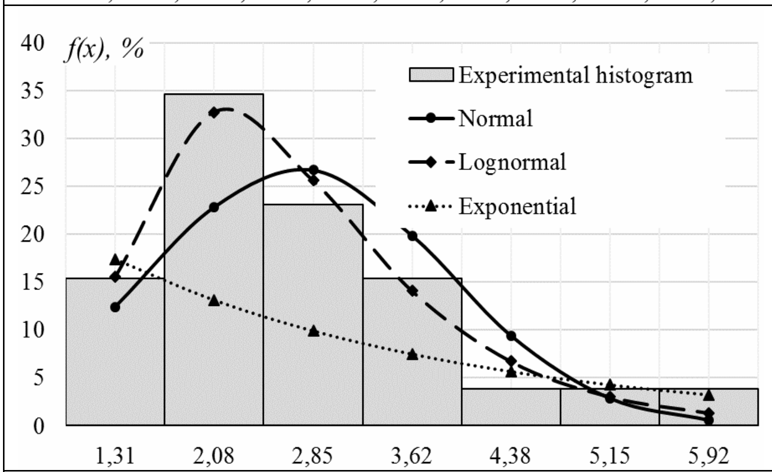
Figure 3 – Water saturated soil deformation modulus E_{SAT}, MPa



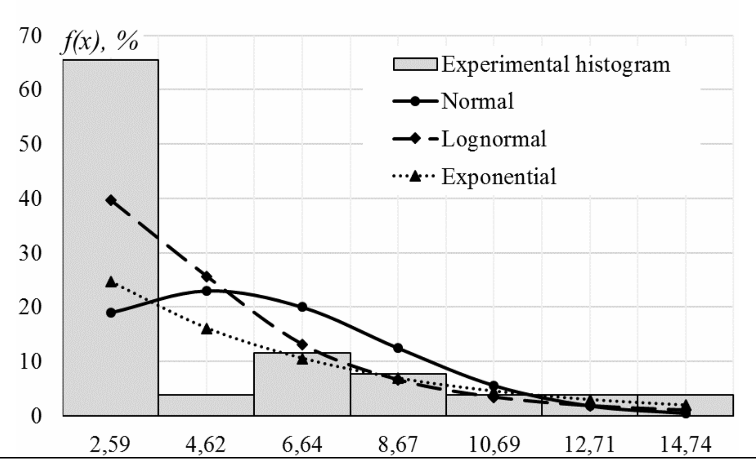
Object #1 Strata-2 for the pressure range 0,05 - 0,1 MPa



Object #1 Strata-3 for the pressure range 0,1 - 0,2 MPa



Object #1 Strata-4 for the pressure range 0,2 - 0,25 MPa



Object #2 Strata-2 for the pressure range 0,1 - 0,2 MPa

Table 4 – Normal, lognormal, exponential distributions, statistics for water saturated loessial collapsible soil in water saturated state E_{sat}

Stochastic parameters	$M1$	$M2$	$M3$	$M4$	$\overline{X}$	$\widehat{X}$	μ_3	μ_4	$\hat{X}$	ν, %	A_x	E_x	Distr.	Pearson criteria $\chi^2_{досл.}$ $(\chi^2_{табл.})$
Object #1 Strata-2 – loess loam, brownish-yellow, carbonate, light silty, in natural state solid in the saturated state fluid, macroporous, collapsible														
E_{sat}, MPa, σ = 0,05…0,1 MPa	1,17	7,89	49,29	349,8	4,66 (1,28)	14,93 (0,52)	85,86	349,8	3,9 (0,72)	0,83	1,49	1,18	Norm.	31,4(14,1)
													Log.	7,1(14,1)
													Exp.	11,6(15,5)
Object #1 Strata-3 – sandy loess loam, yellow, carbonate, silty, in natural state solid in the saturated state fluid, macroporous, collapsible														
E_{sat}, MPa, σ = 0,1…0,2 MPa	1,40	6,29	39,58	288,4	3,27 (0,96)	5,75 (0,43)	28,48	228,0	2,40 (0,66)	0,73	2,07	3,89	Norm.	53,2(14,1)
													Log.	9,9(14,1)
													Exp.	25,3(15,5)
Object #1 Strata-4 – loess loam, yellow-brown, brown, carbonate, heavy silty, in natural state solid in the saturated state fluid														
Deformation modulus E_{sat}, MPa, pressure range σ = 0,2…0,25 MPa	0,84	2,92	9,61	39,85	2,72 (0,92)	1,29 (0,16)	1,53	6,34	1,13 (0,4)	0,42	1,03	0,76	Norm.	8,4(14,1)
													Log.	1,8(14,1)
													Exp.	16,5(15,5)
Object #2 Strata-2 – sandy loam, light-brown, silty, in natural state solid in the saturated state fluid, macroporous collapsible;														
Deformation modulus E_{sat}, MPa, pressure range σ = 0,1…0,15 MPa	1,58	5,5	24,8	129,0	2,79 (0,9)	2,19 (0,25)	4,19	19,21	1,48 (0,50)	0,53	1,28	0,97	Norm.	7,7(9,5)
													Log.	1,5(9,5)
													Exp.	9,1(11,1)

Note: M1 – M4 – moments of 1-4 orders; $\overline{X}$ – mathematical expectation; $\widehat{X}$ – dispersion; μ3 –central point of the third order; μ4 – central point of the fourth order; σ – standard; v – variation ratio; A – asymmetry; E – kurtosis.
In brackets values of key statistics for the lognormal distribution are shown.

It was learned experience of the previous soil stochastic researches [13], therefore normal, lognormal and exponential distributions to approximate experimental data are used. Typical histograms and distributions curves for the water saturated loessial collapsible soil in water saturated state E_{sat}, are presented on the fig. 3, respective statistics in the table 4.

Pearson criterion χ^2 were chosen as criterion to estimate current distribution implementation possibility. Statistical analysis of the table 4. show, that lognormal distribution is the most relevant to approximate experimental data of the loessial collapsible soil deformational modulus in the water saturated state E_{sat}. as lognormal distribution is relevant for all mentioned sampling, and respective Pearson criterion value is the smallest comparatively with other distributions table 4.

Above mentioned data confirm previous conclusions which prove that lognormal distribution is the most relevant for soil deformational modulus approximation, but it also essentially new because collapsible soils instead of homogeneous sand embankments are investigated [13].

Probabilistic simulation. Current normative documents in the MPLP design and construction make big focus on the hoop stresses ant operating pressure, in the same time longitudinal stresses from the soil differential settlements are almost ignored [14].

It is reasonable with help of FEM and direct mathematical simulation to compare failure probability of the similar pipeline in the different soil conditions. There is observed pipeline in the homogenous fine sands, and loessial collapsible strata with thickness 13 m Kherson city area (fig. 2 a) – Object #1 and 7 m Poltava region – Object #2 (fig. 2 b). Geometrical parameters of the MPLP, load deterministic and stochastic values for all variants is in the table 5.

For the first variant soil strata without special properties are investigated, therefore it is reasonable to implement direct mathematical simulation. Pipeline as beam on the elastic base fits best. The further step is implementation of the pipeline differential equation stochastic solution in the form of the random functions (RF).

For correct simulation parameters of the correlation function $k_x(\xi)$of the soil conditions variability along the length of the pipeline (1, 2) and respective spectrum density $S_r(\omega)$of this functions should be considered. It should be noted that, those parameters for correct simulations were included in the table 5.

Table 5 – Input parameters to determine pipeline failure probability

Parameter		Designation	Value
External diameter		D_{ex} , m	1,020
Pipeline wall thickness		t , m	0,0096
MO pipeline steel strength		$\overline{\sigma_y}$, kN/cm^2	49
Standard of the pipeline steel strength		$\hat{\sigma}_y$, kN/cm^2	4,9
The length of section		L, m	6036
MO of the soil backfill		$\overline{q}_1$, kN/m	32,1
Pipe and isolation weight		$\sum \overline{q}_{2-4}$, kN/m	3,17
MO of the linear coefficient of elastic foundations		$\overline{c}_{yo}$, kN/m^2	1347
Correlation function parameters of the soil conditions variability along the pipeline length	$k_x(\xi) = e^{-\alpha\xi}$	α , m^{-1}	0,046
	$k_x(\xi) = e^{-\alpha\lvert\xi\rvert} \cos \beta\xi$	α , m^{-1} θ, m^{-1}	0,023 0,911
Temperature difference MO		$\overline{\Delta t}$, ^{0}C	23,4
Temperature difference standard		$\Delta\hat{t}$, ^{0}C	1,74
Operating pressure MO [12]		$\overline{p}$, kN/cm^2	0,456
Operating pressure standard [12]		$\hat{p}$, kN/cm^2	0,0314
Heterogeneity coefficient		β	1

$$k_x(\xi) = e^{-\alpha\xi} \;=>\; S_r(\omega) = \frac{\alpha\beta_0^2\overline{q}^2}{\pi}\left[\frac{1}{\omega^2+\alpha^2}\right], \tag{2}$$

$$k_x(\xi) = e^{-\alpha|\xi|}\cos\beta\xi \;=>\; S_r(\omega) = \frac{\alpha\beta_0^2\overline{q}^2}{\pi}\left[\frac{1}{(\omega-\theta)^2+\alpha^2}+\frac{1}{(\omega+\theta)^2+\alpha^2}\right], \tag{3}$$

where β_0 – heterogeneity coefficient that characterizes the variation of the total load on the pipeline;

α, θ – correlation function parameters;

ξ – shift between cross sections of the process, 1 m.

The relationship among soil condition heterogeneity RF and pipeline curvature RF [2]

$$S_\chi(\omega)=\frac{S_r(\omega)\omega^4}{(EI\cdot\omega^4+\bar{c}_{yo})^2}\,, \tag{4}$$

where $\bar{c}_{y0}$ – MO of the linear coefficient of elastic foundations.

Standard of the bending moment $\hat{M}$ RF $\tilde{M}(x)$ calculating with help of pipe bending stiffness the bending EI and pipeline curvature $\bar{\chi}^2$

$$\hat{M}=EI\cdot\left[\int_0^\infty S_\chi(\omega)d\omega\right]^{1/2}\,. \tag{5}$$

Pipeline reliability function is follow

$$P(L)=1-Q(L)=P[\sup_{0\le x\le L}\left|\sum\sigma_{позд}\right|<R_y]\,, \tag{6}$$

where $\sup\limits_{0\le x\le L}\left|\sum\sigma_{позд}\right|$ – an upper limit of the function $\left|\sum\sigma_{позд}\right|$ at the interval $0\le x\le L$, a $Q(L)$ – pipeline failure probability on the interval L.

Pipeline bearing capacity has normal distribution therefore whole function will have such distribution and failure probability will have form (6) [2, 5]

$$Q(L)=\exp[0{,}5(\gamma_0^2-\beta^2)]\,, \tag{7}$$

where γ_0 – characteristic maximum of RF $\sum\tilde{\sigma}_{позд}(x)$; β – safety characteristic.

According to [4]

$$\gamma_0=\sqrt{2\,ln\left[\omega_\chi L\Big/\pi\cdot\beta_\chi\right]}\,, \tag{8}$$

where $\omega_{\omega\chi}$ – effective frequency of a RF. It characterize MPLP axis curvature and total longitudinal stresses variability; $\beta_{\omega\chi}$ – RF broad badness ratio $\sum\tilde{\sigma}_{позд}(x)$ [4].

$$\omega_{\omega\chi}=\left[\int_0^\infty S_\chi(\omega)\omega^2 d\omega\Big/\int_0^\infty S_\chi(\omega)d\omega\right]^{1/2}\,, \tag{9}$$

$$\beta_{\omega\chi}=\left[\int_0^\infty S_\chi(\omega)\omega^4 d\omega\int_0^\infty S_\chi(\omega)d\omega\right]^{1/2}\Big/\int_0^\infty S_\chi(\omega)\omega^2 d\omega. \tag{10}$$

Longitudinal stresses $\tilde{Y}$ RF MO $\bar{Y}$ and safety characteristic β

$$\bar{Y}=\bar{\sigma}_y-\frac{\bar{N}_{\Delta t}-\bar{N}_p}{F}\,,\quad \beta=\frac{\bar{\sigma}_y-\dfrac{\bar{N}_{\Delta t}-\bar{N}_p}{F}}{\sqrt{\hat{\sigma}_y^2+\dfrac{1}{F^2}\hat{N}_{\Delta t}^2+\dfrac{1}{F^2}\hat{N}_p^2+\dfrac{1}{W^2}\cdot\hat{M}^2}} \tag{11}$$

According to [15] the most responsible objects, which failure leads to the biggest consequences class CC3, it must have failure probability lover then $1\cdot 10^{-6}$. Corrected values of the correlation functions (1) and (2) allow to obtain following results from table 6, which shows that bending stresses doesn’t exceed 15 MPa and MPLP failure probability is much higher than needed values. These data show that in the homogeneous soils without special properties differential settlements are unimportant.

Table 6 – Modelling results of the MPLP longitudinal stresses failure probability

Parameter	Designation	CF 1	CF 2
Bending moment Standard	$\hat{M}$, kNm	58,6	44,6
Longitudinal (tensile) strength MO	$\overline{N}$, kN	3970	3970
Longitudinal (tensile) strength Standard	$\hat{N}$, kN	929	929
Safety characteristic	β	7,07	7,13
RF effective frequency	$\omega_{\omega\chi}$, m^{-1}	0,21	0,707
RF broad badness ratio	$\beta_{\omega\chi}$	1,708	1,244
Characteristic maximum of RF	γ_0	3,305	2,49
MPLP failure probability	$Q(t)$	**3,3·10^{-9}**	**1,0·10^{-8}**

Similar pipeline in the soil conditions fig. 2. a and 2 b is considered. There are collapsible strata 13 m and 7 m respectively. Deterministic characteristics of the soil strata are presented in the table 2 and 3. Stochastic parameters of the soil basis are shown in the table 4. Stochastic parameters of the operating pressure and temperature difference are in the table 5. In general, design scheme can be shown as in the fig. 4. Soil deformations and respective longitudinal stresses for loads MO values are shown on fig. 4 b, c.

With help of Ansys [16] probabilistic modelling in the Monte-Carlo simulation (fig. 5) form distributions and statistics for the soil deformations and pipeline stresses could be obtained. Modeling is performed for MPLP with wall thickness 10 mm for both soil collapsible strata (fig. 6), and for the wall thickness for which pipeline has normative failure probability – $1\cdot10^{-6}$, table 7.

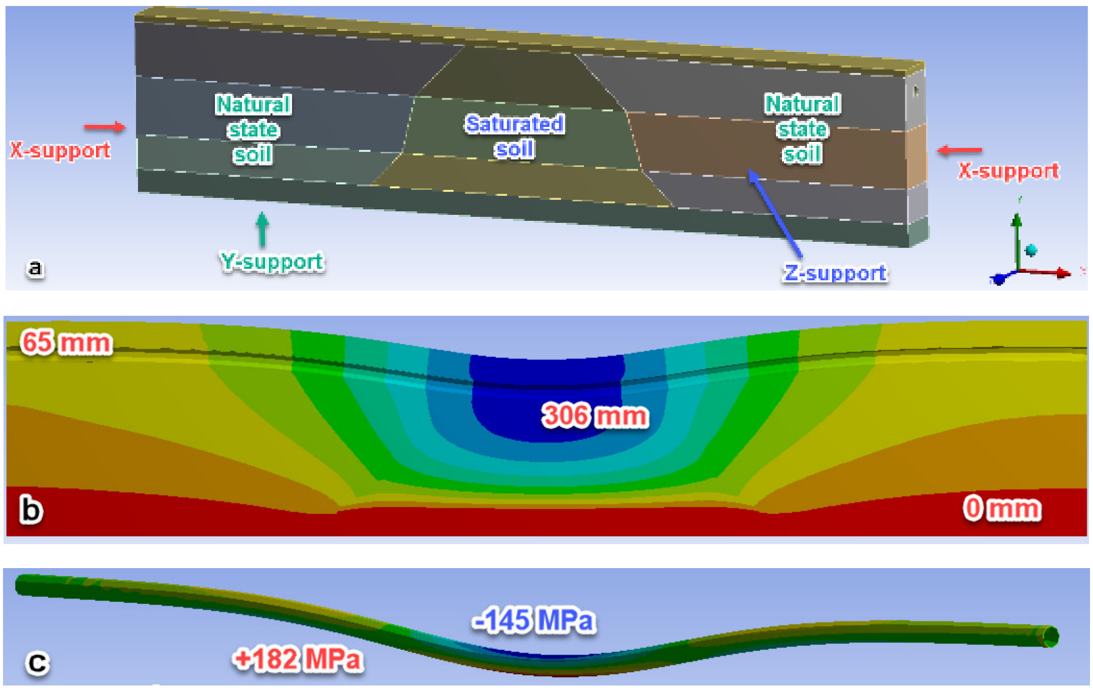


Figure 5 – FEM simulation with loads and influences MO values for the Object #1 soil conditions MPLP wall thickness t = 38 mm

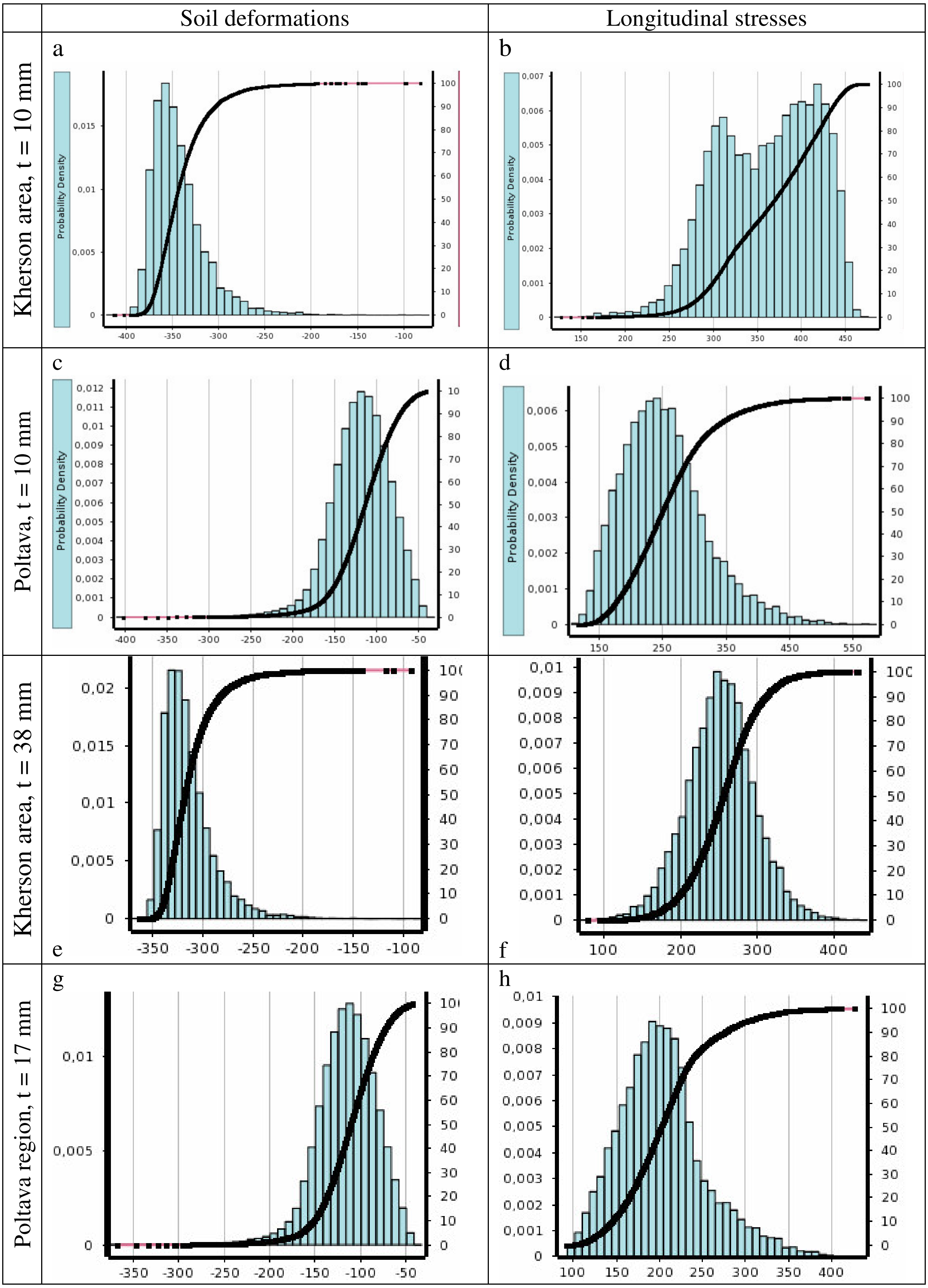


Figure 6 – FEM simulation results for different soil condition and MPLP different wall thickness

Table 7 – MPLP FEM simulation results

Parameter			Designation	Value	Distribution
Kherson Region, **Estimated** wall thickness ***t = 10 mm***	Deformation in the middle of the soil array	MO	$\overline{S}_{mid}$, mm	340	Normal
		Standard	$\hat{S}_{mid}$, mm	29,0	
	Deformation at the bound of the soil array	MO	$\overline{S}_{bound}$, mm	67	Normal
		Standard	$\hat{S}_{bound}$, mm	1,6=>0	
	Pipeline total longitudinal stresses, σ_l	MO	$\overline{\sigma}_y$, MPa	363,9	Normal
		Standard	$\hat{\sigma}_y$, MPa	56,9	
	Safety characteristic		β	2,39	
	MPLP failure probability		$Q(\beta)$	$8{,}2 \cdot 10^{-3}$	
Poltava Region, **Estimated** wall thickness ***t = 10 mm***	Deformation in the middle of the soil array	MO	$\overline{S}_{mid}$, mm	115,9	Normal
		Standard	$\hat{S}_{mid}$, mm	35,0	
	Deformation at the bound of the soil array	MO	$\overline{S}_{bound}$, mm	39	Normal
		Standard	$\hat{S}_{bound}$, mm	1,1=>0	
	Pipeline total longitudinal stresses, σ_l	MO	$\overline{\sigma}_y$, MPa	258,2	Normal
		Standard	$\hat{\sigma}_y$, MPa	67,1	
	Safety characteristic		β	3,70	
	MPLP failure probability		$Q(\beta)$	$4{,}4 \cdot 10^{-4}$	
	Designation		Value	Distribution	
Kherson Region, **Estimated** wall thickness ***t = 30 mm***	Deformation in the middle of the soil array	MO	$\overline{S}_{mid}$, mm	311,0	Normal
		Standard	$\hat{S}_{mid}$, mm	24,8	
	Deformation at the bound of the soil array	MO	$\overline{S}_{bound}$, mm	59	Normal
		Standard	$\hat{S}_{bound}$, mm	1,1=>0	
	Pipeline total longitudinal stresses, σ_l	MO	$\overline{\sigma}_y$, MPa	2	Normal
		Standard	$\hat{\sigma}_y$, MPa	24,6	
	Safety characteristic		β	4,73	
	MPLP failure probability		$Q(\beta)$	$1{,}0 \cdot 10^{-6}$	
Poltava Region, **Estimated** wall thickness ***t = 17 mm***	Deformation in the middle of the soil array	MO	$\overline{S}_{mid}$, mm	110,0	Normal
		Standard	$\hat{S}_{mid}$, mm	33,2	
	Deformation at the bound of the soil array	MO	$\overline{S}_{bound}$, mm	39	Normal
		Standard	$\hat{S}_{bound}$, mm	1,1=>0	
	Pipeline total longitudinal stresses, σ_l	MO	$\overline{\sigma}_y$, MPa	207,7	Normal
		Standard	$\hat{\sigma}_y$, MPa	50,8	
	Safety characteristic		β	4,87	
	MPLP failure probability		$Q(\beta)$	$5{,}5 \cdot 10^{-7}$	

Conclusions. Lognormal distribution fits best for the probabilistic representation of the loessial collapsible soil deformation modulus in the water saturated state. The smallest values instead normal and exponential laws were confirmed by Pearson criterion. Pipeline with geometrical parameters $1020 \times 9{,}6$ (10) mm, similar internal pressure $\overline{p} = 4{,}56 MPa$, and temperature difference $\overline{\Delta t} = 23{,}4^o C$, has follow longitudinal stresses parameter failure probability for the different soil conditions: homogenous fine sand – $3{,}3 \cdot 10^{-9}$ – $1{,}0 \cdot 10^{-8}$ (according to the correlation function), soil collapsible strata is about 6,2 m – $4{,}4 \cdot 10^{-4}$, soil collapsible strata is about 13 m – $8{,}2 \cdot 10^{-3}$. So, for soil basis without special properties it was obtained very low failure probability, instead for the non-standard (loessial) soil conditions having unacceptable failure probability value. Also high variation ratio for the soil deformations in the array middle and pipeline stresses could be observed, which is explained by very high soil deformation modulus variation ration and lognormal distribution. The latest make impact on the character of the output functions distribution.

Mentioned design model with FEM simulation allows designing pipelines with pre-calculated reliability level. For considered soil conditions normative failure probability reached for the wall thickness 30 and 17 mm for Kherson and Poltava region.

References

1. *Котляревский В. А. Расчет деформаций трубопроводов в ореолах оттаивания адаптацией нормативных требований / В. А. Котляревский // Электронный журнал «Нефтегазовое дело». – 2013. – № 3. – С. 206 – 216.*
   Kotlyarevskiy V. A. Raschet deformatsiy truboprovodov v oreolah ottaivaniya adaptatsiey normativnyh trebovaniy / V. A. Kotlyarevskiy // Elektronnyy zhurnal «Neftegazovoe delo». – 2013. – № 3. – S. 206 – 216.
   http://ogbus.ru/authors/KotlyarevskyVA/KotlyarevskyVA_1.pdf
2. *Ларионов Ю. В. Оценка напряженно-деформированного состояния трубопровода на участках пучения грунта / Ю. В. Ларионов, Д. Ю. Грязнев, С. Н. Чужинов // Электронный журнал«Нефтегазовое дело». – 2012. – № 6. – С. 107 – 120.*
   Larionov Yu. V. Otsenka napryazhenno-deformirovannogo sostoyaniya truboprovoda na uchastkah pucheniya grunta / Yu. V. Larionov, D. Yu. Gryaznev, S. N. Chuzhinov // Elektronnyy zhurnal «Neftegazovoe delo». – 2012. – № 6. – S. 107 – 120.
   http://ogbus.ru/authors/LarionovYuV/LarionovYuV_1.pdf
3. *Расчет и обеспечение прочности трубопроводов в сложных инженерно-геологических условиях / А. М. Шаммазов, Р. М. Зарипов, В. А. Чичелов и др. – М. : Интер, 2005. – 706 с.*
   Raschet i obespechenie prochnosti truboprovodov v slozhnyh inzhenerno-geologicheskih usloviyah / A. M. Shammazov, R. M. Zaripov, V. A. Chichelov i dr. – M. : Inter, 2005. – 706 s.
   ISBN 5-98761-006-0.
4. *Palmer A. Settlement of a pipeline on thawing permafrost / A. Palmer // Journal of the Transportation Engineering Division, Vol. 98, No. 3. – 1972. – P. 477 – 491.*
5. *ASME B31.8-2003. Gas transmission and distribution piping system New York: American Society of Mechanical Engineers. 2003. – 168 p.*
6. *EN 1993-4-3 (2007) (English): Eurocode 3: Design of steel structures - Part 4-3: Pipelines [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]. – 44 p.*
7. *Pichugin S. Verification of the pipeline deformational model in non-standard soil conditions / S. Pichugin, V. Rozhko, P. Vynnykov // Збірник наукових праць. Серія: Галузеве машино-будування, будівництво. – Полтава, ПолтНТУ , 2016. – Вип. 1 (46). – С. 153 – 163.*
   Pichugin S. Verification of the pipeline deformational model in non-standard soil conditions / S. Pichugin, V. Rozhko, P. Vynnykov // Zbirnik naukovih prats. Seriya: Galuzeve mashino-buduvannya, budivnitstvo. – Poltava, PoltNTU , 2016. – Vip. 1 (46). – S. 153 – 163.
   http://znp.pntu.edu.ua/files/archive/ua/46_2016/19.pdf

8. *Interaction of the artificial bases with Collapsing Soils / V. Shokarev, V. Shapoval, A. Tregub, V. Grechko, A. Shokarev, A. Serdyuk, G. Rozenvasser, M. Kornienko, E. Petrenko, N. Zotsenko, Y. Vynnykov // Geotechnical Engineering in Urban Environments. – Proc. of the 14th European Conf. on Soil Mechanics and Geotechnical Engineering (Madrid, 24 – 27 September 2007). – Millpress Science Publishers Rotterdam, 2007. – P. 481 – 486.*
9. *Хрустева Ж. В. Строительные свойства лессовых грунтов района г. Херсона : автореф. дис. на здобуття наук. ступеня кандидата техн. наук : спец.: 05.23.02 – основания и фундаменты, подземные сооружения / Ж. В. Хрустева. – К., – 1966. – 15 с.*
   Hrusteva Zh. V. Stroitelnye svoystva lessovyh gruntov rayona g. Hersona : avtoref. dis. na zdobuttya nauk. stupenya kandidata tehn. nauk : spets.: 05.23.02 – osnovaniya i fundamenty, podzemnye sooruzheniya / Zh. V. Hrusteva. – K., – 1966. – 15 s.
10. *Крутов В. И. Проектирование и устройство оснований и фундаментов на просадочных грунтах / В. И. Крутов, А. С. Ковалев, В. А. Ковалев. – М. : , 2013. – 544 с.*
   Krutov V. I. Proektirovanie i ustroystvo osnovaniy i fundamentov na prosadochnyh gruntah / V. I. Krutov, A. S. Kovalev, V. A. Kovalev. – M. : ASV, 2013. – 544 s.
11. *Пічугін С. Ф. Розрахунок рівня надійності лінійної частини підземних магістральних трубопроводів / С. Ф. Пічугін, О. Є. Зима, П. Ю. Винников // Збірник наукових праць. Серія: Галузеве машинобудування, будівництво. – П. , ПолтНТУ, 2014. – Вип. 1 (40). – С. 109 – 119.*
   Pichugin S. F. Rozrahunok rivnya nadiynosti liniynoyi chastini pidzemnih magistralnih truboprovodiv / S. F. Pichugin, O. E. Zima, P. Yu. Vinnikov // Zbirnik naukovih prats. Seriya: Galuzeve mashinobuduvannya, budivnitstvo.– P., PoltNTU, 2014. – Vip. 1 (40). – S. 109 – 119.
12. *Зима О. Є. Надійність сталевої конструкції магістрального трубопроводу: автореф. дис. на здобуття наук. ступеня кандидата техн. наук : спец.: 05.23.01 – будівельні конструкції, будівлі та споруди / О. Є. Зима – Полтава, 2014. – 22 с.*
   Zima O. E. Nadiynist stalevoyi konstruktsiyi magistralnogo truboprovodu: avtoref. dis. na zdobuttya nauk. stupenya kandidata tehn. nauk : spets.: 05.23.01 – budivelni konstruktsiyi, budivli ta sporudi / O. E. Zima – Poltava, 2014. – 22 s.
13. *Zotsenko M. Evaluation of Failure Probability of Soil Cushions / M. Zotsenko, Y. Vynnykov, M. Kharchenko // Geotechnical Safety and Risk: Proc. of the 3rd International Symposium on Geotechnical Safety and Risk (ISGSR 2011). – Germany: Munich. – 2011. – P. 249 – 257.*
14. *СНиП 2.05.06-85. Магистральные трубопроводы. – М. : ЦИТП Госстроя СССР, 1988. – 52 с.*
   SNiP 2.05.06-85. Magistralnye truboprovody. – M. : TsITP Gosstroya SSSR, 1988. – 52 s.
15. *ДБН В.1.2-14-2009 Загальні принципи забезпечення надійності та конструктивної безпеки будівель, споруд, будівельних конструкцій та основ. – К. : Мінрегіонбуд,2009. – 29 с.*
   DBN V.1.2-14-2009 Zagalni printsipi zabezpechennya nadiynosti ta konstruktivnoyi bezpeki budivel, sporud, budivelnih konstruktsiy ta osnov. – K.: Minregionbud, 2009. – 29 s.
16. *Бруяка В. А. Инженерный анализ в Ansys Workbench. Часть 2 / В. А. Бруяка, В. Г. Фокин, Я. В. Кураева. – Самара, Самар. гос. техн. ун-т, 2013. – 149 с.*
   Bruyaka V. A. Inzhenernyy analiz v Ansys Workbench. Chast 2 / V. A. Bruyaka, V. G. Fokin, Ya. V. Kuraeva. – Samara, Samar. gos. tehn. un-t, 2013. – 149 s.

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