doi: 10.5862/MCE.65.4

Calculation of optimized methods of the river underwater pipeline backfill with the use of APMWinMachine 9.7

Расчет оптимизированных способов засыпки речного подводного трубопровода с использованием APMWinMachine 9.7

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Key words: river underwater pipeline; the way of backfill; backfill with cofferdams; installation of temporal loads; the calculation of optimized methods

Ключевые слова: подводный трубопровод; способ засыпки; засыпка перемычками; установка временных пригрузов; расчет оптимизированных способов

Abstract. Nowadays, the standard techniques of backing the ballasted pipeline laid in a bottom trench are used: sequential deposition of soil by suction dredges along the slurry pipeline, soil discharge by self-dumping barges, soil unloading from a barge by the grapple, soil pumping from barges. The disadvantage of these methods is that backfill is done in consecutive stages, and soil, falling into water increases water specific weight to the pulp specific weight. As a result, the buoyancy force increases and, when backfill is accomplished, the pipeline is raised above the design reference mark. The aim of the research is to optimize the existing methods of pipelines backfill, which will prevent or reduce the rise of the pipeline from the design position during its backfill. The optimized methods of the submerged pipelines backfill, which use temporal metal and reinforced concrete loads or backfill by cofferdams, have been calculated with the help of APMWinMachine software. The results of the model calculation by the method of finite elements show the effectiveness of the proposed methods of the submerged pipeline backfill.

Аннотация. Сегодня засыпка уложенного в подводную траншею забалластированного трубопровода производится стандартными способами: последовательное рефулирование грунта земснарядами по пульпопроводу, сброс грунта саморазгружающимися шаландами, сброс грунта из барж путем выгрузки его грейфером, перекачивание грунта из барж. Недостатком данных методов засыпки подводного трубопровода является то, что засыпка ведется последовательно, а грунт, попадая в воду, вызывает увеличение удельного веса воды до удельного веса пульпы. Вследствие этого возрастает выталкивающая сила, под действием которой трубопровод поднимается, и после завершения засыпки оказывается выше проектной отметки. Целью работы является оптимизация существующих способов засыпки подводных трубопроводов, которая предотвратит или снизит выход трубопровода из проектного положения при его засыпке. С помощью пакета инженерных программ APMWinMachine рассмотрены и рассчитаны оптимизированные способы засыпки подводных трубопроводов, которые заключаются в использовании временных металлических или железобетонных пригрузов или засыпке трубопровода перемычками. Результаты расчетов моделей методом конечных элементов показывают эффективность предложенных способов засыпки.

Introduction

In the pipe conduit construction of submerged crossing, the problem of subaqueous pipelines escapement from the design position during the construction is commonly encountered, and, particularly, during the backfill of the trench ballasted pipelines laid in the bottom. This problem is commonly encountered in subsea pipelines construction by the trench method implemented by the public corporations such as joint stock company Podvodtruboprovodstroy (submerged crossing across the river Ob on the oil pipeline Surgut-Perm, submerged crossing across the river Ishim on the gas pipeline Ostrogozhsk-Belousovo, and others), public corporation “Mezhregiontruboprovodstroy” (submerged crossing across the river Volga on oil pipeline Druzhba-2, gas pipeline Yamal-Europe across the Baidarata Bay) and others.

By the trench method, the standard techniques of backing of the trench ballasted pipeline laid in the bottom are used: sequential deposition of soil by suction dredges along the slurry pipeline, soil discharge by self-dumping barges, unloading of soil from barge by grapple, soil pumping over from barges [1–14].

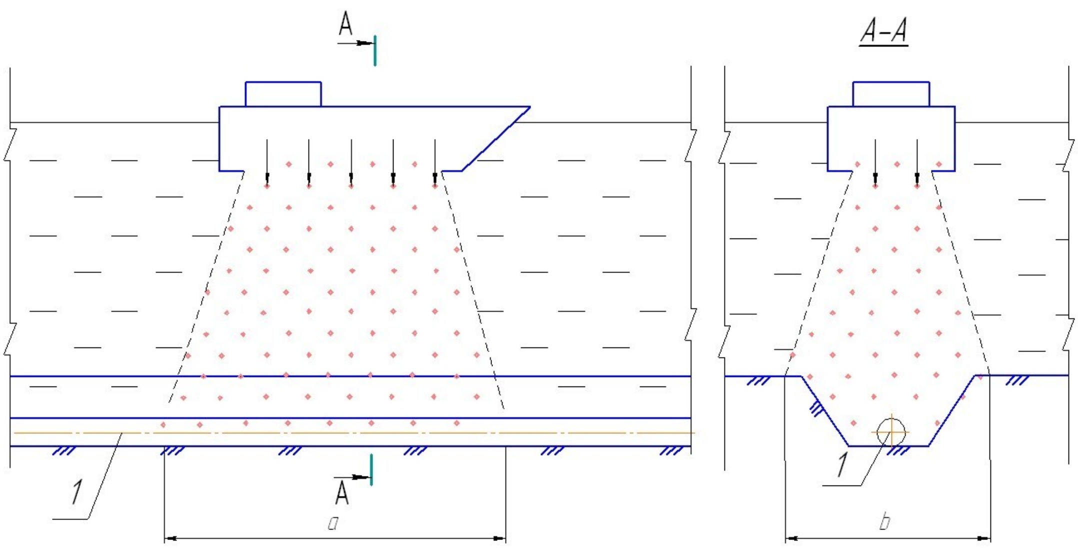
The imperfection of these methods of subaqueous pipeline backfill (especially by the method of soil discharge by self-dumping barges) is that backfill is is done in consecutive stages, but soil, falling into water induces the increase of water specific weight from 1100 kg/m^3 to the pulp specific weight of 1400 kg/m^3. As a result, the buoyancy force (under this force the pipeline elevates Archimedean force) increases and when backfill is accomplished, the pipeline is raised above the design reference mark. This is also a widely-spread problem during backfill pipeline outstretches, for instance, in marine pipelines [15–20].

Consequently, the task is to optimize the existing methods of backfill pipelines outstretches, in order to prevent or reduce the escapement of subsea pipelines from the design position during its backfill.

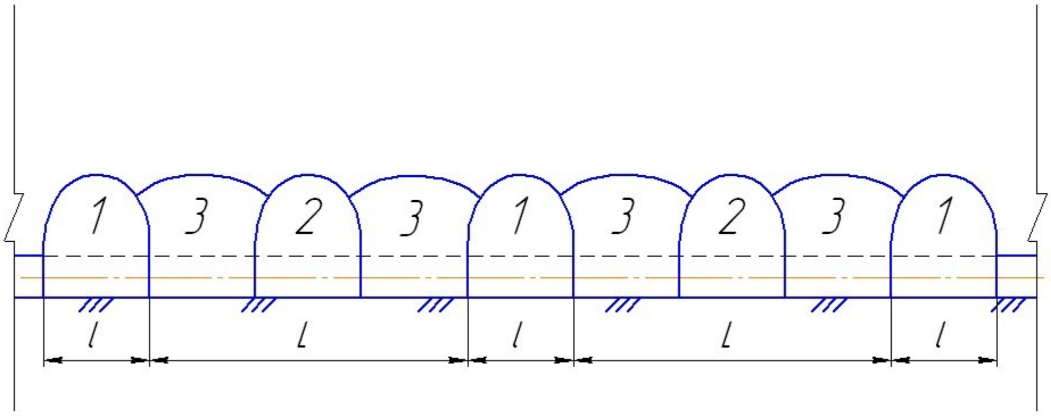
Methods

To prevent the escapement of submerged pipelines from the design position during its backfill with soil due to the increase of water special weight, and, as a result, increase of buoyancy force (Archimedean force), which influences the pipeline, the following method of backfill process rationalization of subaqueous pipe conduit is proposed [21]. The standard backfill methods of subsea pipe conduit are implemented sequentially, i.e. backfill is started from one spot and is led along the pipeline continuously. That is why water density increases because of soil balanced in water, the buoyancy force increases too, and the pipeline rises higher than the design position. There is also a flux availability which enables spreading suspended soil in the water along the developed bottom trench, hereupon the operating zone of this elevated Archimedean force increases. As a result, backfill is to be produced with extent “l” of cofferdams and “L” distance between them, and their proportions will be defined with the software APMWinMachine [22].

The backfill of subaqueous pipeline with self-dumping barges is proposed in Picture 1, during which the zone with length “a” and width “b” is developed. In this zone the specific water weight can reach 1400 kg/m^3. The order of a submerged pipeline backfill with cofferdams by the optimized method is proposed in Picture 2.



Picture 1. The scheme of pipeline backfill with imported soil from self-dumping barges

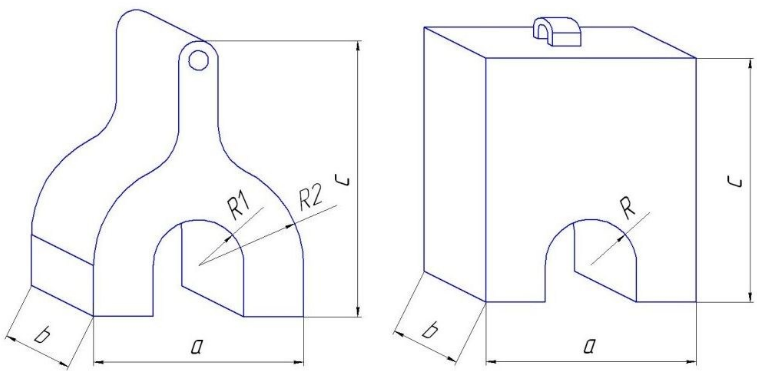


Picture 2. The order of submerged pipeline backfill with cofferdams.

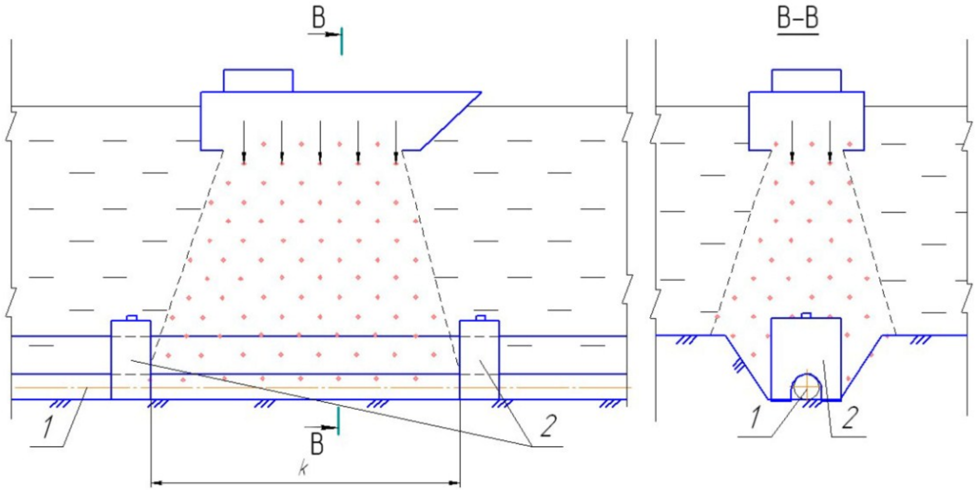
The optimized method of underwater pipeline backfill consists of the following stages. The pipeline “I” laid in a subaqueous trench is filled with cofferdams according to the order, presented in the Picture 2, with an extent “l” and distance “L” between them, the value of which is obtained by the rated way. The restraint of the cofferdam extent (approximately 10–30 meters) accommodates the absence of the floating-up capability of the pipeline in the starting period of backfill, and cofferdams themselves (number 1) do not enable the pipeline to float in the following zones (№ 2–№ 3) further on between the cofferdams (1, 2, 3 – is the sequence of the earth cofferdam backfill along the pipeline).

There is also another variant of the optimized method of a submerged pipeline backfill which is in the temporary plant of reinforced concrete and metal loads 2 on the ballasted pipeline “I” with the distance “k” between them during the execution of works as presented in Pictures 3 and 4. After the completion of works during the pipeline backfill, reinforced concrete or metal loads 2 are demounted, which means that they are of a reusable type, ipso facto, the rise in the cost of the backfill construction is negligible. The proportion of metal and concrete loads (a, b, c, R, R1, R2) and also the distance “k” between them are defined by calculations in accordance with the theory of strength of materials [23] or with the assistance of different engineering programs for the determination of bending deflections and strained conditions by the method of finite elements, for example ANSYS or APMWinMachine [22].

Moreover, it is necessary to note that the given data will be different for certain conditions, which are defined by both the pipeline data (diameter, wall thickness, the behavior of pipe metal, location of the pipeline) and characteristics of the environment (type of backfill soil, alteration of specific water weight during the backfill soil), etc. During the estimation some assumptions are allowed. As far as coffering is estimated by reliability and stability of the pipeline position against the pipeline floating-up and all coffering is directed to withstand the resistance to the forces acting on the pipeline (buoyancy force, hydrodynamic action on water flow and so on), so the data referring to this influence is not considered and negative buoyancy of the pipeline compared to the effects under the standard conditions (during the backfill) goes into the pipeline stability position stock. That is why estimation is calculated for the part of buoyancy force, which occurs because of the alteration of specific water weight during the backfill soil.



Picture 3. The variants of reinforced concrete or metal loads, used in the optimized method of submerged pipeline backfill.



Picture 4. The arrangement scheme of reinforced concrete and metal loads during the optimized method of submerged pipeline backfill.

Results and Discussion

Let is calculate the parameters of the optimized backfill methods of riverside underwater transitions with an analytical approach and then, verify the accuracy of the calculation with the help of software engineering program APMWinMachine 9.7.

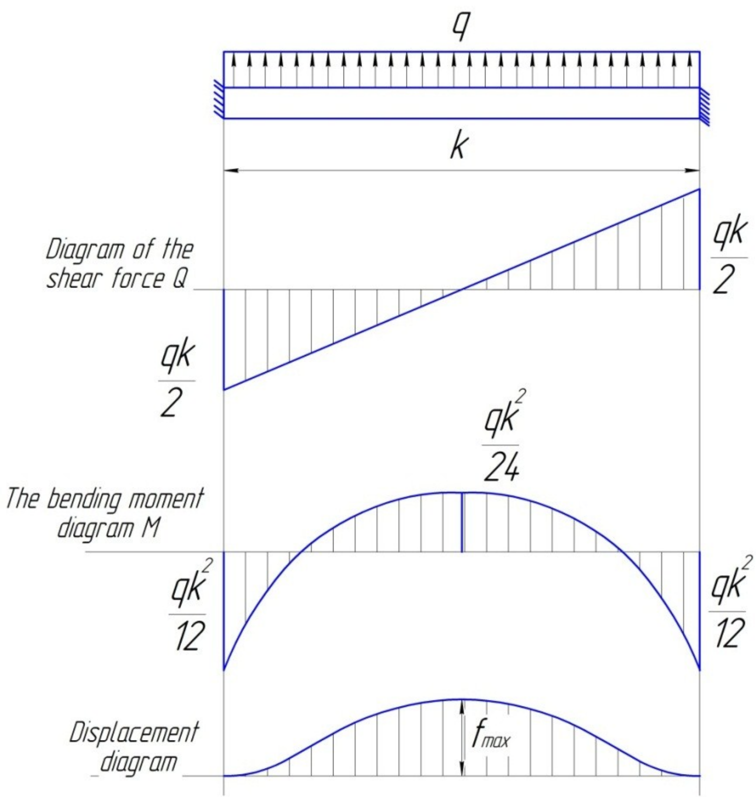
The initial data for calculation:

- the view of pumped-over product – gas;
- category of pipeline – I;
- the area of laying – Leningradsky District;
- the external diameter of the pipeline – 1020 mm;
- nominal pipeline thickness – 14 mm;
- the pressure in the pipeline – 6.3 Pa;
- fettling thickness – 30 mm;
- fettling tightness – 600 kg/m^3;
- isolation thickness – 5 mm;
- backfill soil –silty;
- specific weight of soil – 18 kN/m;
- soil adherence – 2 kPa;
- single cast iron annular loads of mass – 1100 kg, 1130 pieces;
- pulp specific weight – 1400 kg/m^3.

The calculation of the parameters of optimized backfill methods with the use of metal and ferric-concrete cantledges

According to [10], the acceptable deviation of pipeline axis from design position on the pipeline underwater transition is 100 mm.

The pipeline calculation is conducted according to the model of transversal-loaded beam fixed from both sides with anchorages as it is indicated in Picture 5. Shearing force diagrams Q are shown in Picture 5, as well as bending moment M and transition diagrams.



Picture 5. Design diagram and shearing force diagrams, bending moment and transition diagrams.

The distributed load "q" affects the entire area of underwater pipeline "k" and is directed upwards. The maximum bending moment emerges at the feet (ferroconcrete and metal cantledges) and is $M_{max} = M_f = \frac{qk^2}{12}$. In the "k" midspan the bending moment is equal to $\mathrm{M_m} = \frac{\mathrm{qk}^2}{24}$.

The maximum bending deflection is in the midspan and is defined by the formula (1):

$$f_{max} = \frac{1}{384} \cdot \frac{qk^4}{EI}, \tag{1}$$

where q – distributed load, affecting underwater pipeline as a result of its soil backfill and increase of specific water density with the soil on the quantity $\Delta\rho_w$ and estimated by formula (2), N/m:

$$q = n_p \frac{\pi D_l^2}{4} \Delta\rho_w g, \tag{2}$$

where n_p – the index of reliability of loading that equals 1,1 [11];

D_l – the external diameter of isolated lined pipeline, m;

$\Delta\rho_w$ – the alteration of water density during the pipeline backfill, submerged in the water with different soils (it is measured with the help of engineering research and by the natural experimental research), in their absence it is assumed for the most unfavorable cases as equal to $\Delta\rho_w = 300\ kg/m^3$);

g – acceleration of gravity m/s^2;

E – modulus of elasticity of pipe material, MPa;

I – axial moment of pipe inertia, m^4:

$$I = \frac{\pi}{64}(D_e^4 - D_i^4), \tag{3}$$

k – opening, m.

Hereby, knowing all the necessary parameters, it is possible to estimate potential plugged bay that is the distance between temporary metal and ferroconcrete cantledges by formula (4):

$$k = \sqrt[4]{\frac{384 f_{max} EI}{q}}, \tag{4}$$

where f_{max} – the maximum bending deflection is in the midspan, acceptable deviation of pipeline axis from design position, $f_{max} = 100\text{мм}$.

Let is derive a formula for weighing (and in the series of dimensional measurement) cantledge:

1) each cantledge accommodates stability only in the half of the bay, that is k/2. The buoyancy force, affecting the pipeline section of k/2 length, determined by expansion of water density with the soil on the quantity $\Delta\rho_w$, is determined by formula (5):

$$F_{A.p} = q\frac{k}{2} = n_p \frac{\pi D_l^2}{4} \Delta\rho_w g \frac{k}{2}. \tag{5}$$

2) Consequently, the present buoyancy force is necessary to be pressed by usage of cantledge. The cantledge is affected by water buoyancy force with soil and it equals

$$F_{A.c} = n_p V_c \rho_{w.s}, \tag{6}$$

where V_c – the volume of cantledge is determined by formula,m^3 (7):

$$V_c = \frac{m_c}{\rho_c}, \tag{7}$$

where $\mathrm{m_c}$ – accumulation of cantledge, kg;

ρ_c – density of the cantledge material (steel, cast iron or ferroconcrete), kg/m^3.

Consequently,

$$F_{A.c} = n_p \frac{m_c}{\rho_c} \rho_{w.s}. \tag{8}$$

The weight of cantledge in the air is determined by formula (9):

$$P_c = m_c g. \tag{9}$$

With the assumption that all forces affecting the cantledge must at least balance each other, we compose the equation of static balance of all the forces (10, 11):

$$P_c - F_{A.p} - F_{A.c} = 0, \tag{10}$$

$$m_c g - n_p \frac{\pi D_l^2}{4} \Delta\rho_w g \frac{k}{2} - n_p \frac{m_c}{\rho_c} \rho_{w.s} = 0. \tag{11}$$

From here the mass of cantledge is derived m_c:

$$m_c - n_p \frac{\pi D_l^2}{4} \Delta\rho_w \frac{k}{2} - n_p \frac{m_c}{\rho_c} \rho_{w.s} = 0, \tag{12}$$

$$m_c \left(1 - n_p \frac{\rho_{w.s}}{\rho_c}\right) - n_p \frac{\pi D_l^2}{4} \Delta\rho_w \frac{k}{2} = 0, \tag{13}$$

$$m_c = \frac{n_p \frac{\pi D_l^2}{4} \Delta\rho_w \frac{k}{2}}{1 - n_p \frac{\rho_{w.s}}{\rho_c}}. \tag{14}$$

Let us calculate the parameters for a specific pipeline with the initial data.

The distributed load, affecting underwater pipeline is calculated as follows:

$$q = n_p \frac{\pi D_l^2}{4} \Delta\rho_w g = 1.1 \cdot \frac{\pi \cdot 1.09^2}{4} \cdot 300 \cdot 9.81 = 3020.8\ N/m.$$

The distance between temporary metal and ferroconcrete cantledge is as follows:

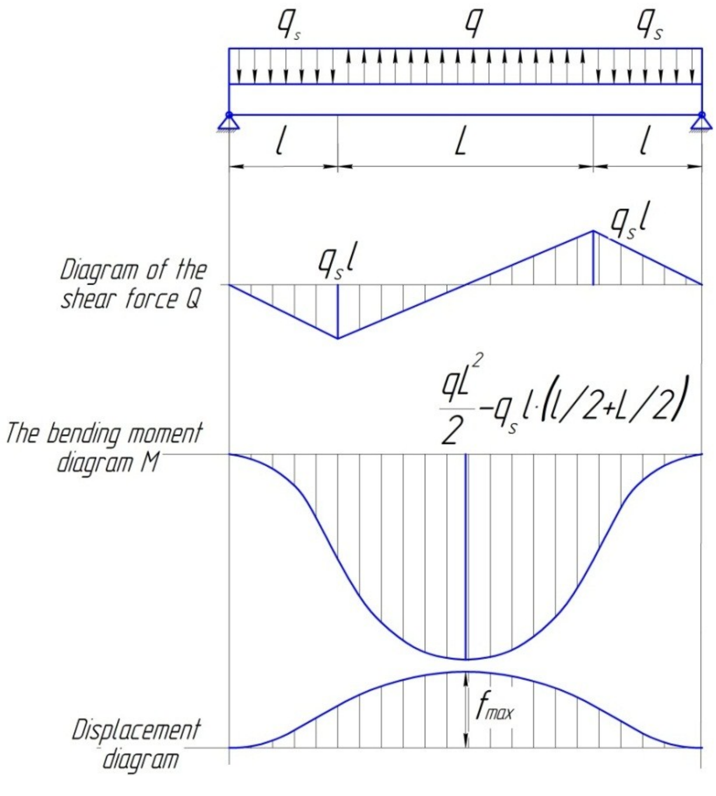
$$k = \sqrt[4]{\frac{384 f_{max} EI}{q}} = \sqrt[4]{\frac{384 \cdot 0.1 \cdot 2.06 \cdot 10^{11} \cdot 559843 \cdot 10^{-8}}{3020.8}} = 61.88\ m.$$

The mass of the cantledge for cast iron with a density is equal to $\rho_c = 7000\ kg/m^3$:

$$m_c = \frac{n_p \frac{\pi D_l^2}{4} \Delta\rho_w \frac{k}{2}}{1 - n_p \frac{\rho_{w.s}}{\rho_c}} = \frac{1.1 \cdot \frac{\pi \cdot 1.09^2}{4} \cdot 300 \cdot \frac{61.88}{2}}{1 - 1.1 \cdot \frac{1400}{7000}} = 12214.3\ kg.$$

The calculation of parameters of optimized backfill methods with the use of earth cofferdams

The pipeline calculation is conducted according to the model of transversal-loaded beam fixed from both sides with joints as it is indicated in Picture 6. Shearing force diagrams Q are shown in Picture 6, as well as bending moment M and transition diagrams.



Picture 6. Design diagram and shearing force diagrams, bending moment and transition diagrams

For the pipeline to be left in the design position during the backfill, the equation 15 is necessary:

$$2q_s l = qL, \tag{15}$$

where q_s – distributed load from the soil activity (with the record of buoyancy force affecting it), N/m:

$$q_s = (\gamma_s - \gamma_w) D_l h_0, \tag{16}$$

where γ_s – specific weight of soil in the air, N/m^3;

γ_w – specific weight of water is assumed equal to $\gamma_w = 11000 \frac{N}{m^3}$;

h_0 – pipeline laying depth from the bottom of the basin to the top of the generating line, m.

Hereby, the support reactions equal zero (but in the reality they do not equal zero and they are up-directed, which is explained by negative buoyancy at the expense of reliability coefficient on the loads).

The distributed load "q" affects the entire area of underwater pipeline "L" and is directed upwards. The distributed load acts at the footings on the areas "l".

The maximum bending moment emerges in the midspan and is defined by formula 17:

$$M_{max} = \frac{qL^2}{2} - q_s l\left(\frac{l}{2} + \frac{L}{2}\right). \quad (17)$$

The maximum bending deflection is in the midspan. In the case of bending in the midspan, let us use the universal equations of methods of the initial parameters 18, 19:

$$\theta = \theta_0 + \frac{1}{EI}\left[\sum m_i\,(z-a_i) + \sum F_i \frac{(z-b_i)^2}{2} + \sum q_i \frac{(z-c_i)^3}{6}\right]; \quad (18)$$

$$y = y_0 + \theta_0 z + \frac{1}{EI}\left[\sum m_i \frac{(z-a_i)^2}{2} + \sum F_i \frac{(z-b_i)^3}{6} + \sum q_i \frac{(z-c_i)^4}{24}\right]. \quad (19)$$

In our case the universal equations of the method of initial parameters are presented in formulas 20, 21:

$$\theta = \theta_0 + \frac{1}{EI}\left[q_s \frac{z^3}{6} - (q+q_s)\frac{(z-l)^3}{6} + (q+2q_s)\frac{(z-l-L)^3}{6}\right]; \quad (20)$$

$$y = y_0 + \theta_0 z + \frac{1}{EI}\left[q_s \frac{z^4}{24} - (q+q_s)\frac{(z-l)^4}{24} + (q+2q_s)\frac{(z-l-L)^4}{24}\right]. \quad (21)$$

The boundary conditions are as follows:

1) For z=0y=0=>y_0=0 in the usage of (20);

2) For z=2l+Ly=0=> in the usage (21):

$$0 = \theta_0(2l+L) + \frac{1}{EI}\left[q_s \frac{(2l+L)^4}{24} - (q+q_s)\frac{(l+L)^4}{24} + (q+2q_s)\frac{l^4}{24}\right];$$

$$\theta_0 = \frac{1}{EI(2l+L)}\left[(q+q_s)\frac{(l+L)^4}{24} - q_s\frac{(2l+L)^4}{24} - (q+2q_s)\frac{l^4}{24}\right].$$

Consequently, in the midspan for z = l+L/2 the deflection is determined by formula 22 as follows:

$$y = \frac{1}{EI(2l+L)}\left[(q+q_s)\frac{(l+L)^4}{24} - q_s\frac{(2l+L)^4}{24} - (q+2q_s)\frac{l^4}{24}\right]\left(l+\frac{L}{2}\right) + \\ + \frac{1}{EI}\left[q_s\frac{\left(l+\frac{L}{2}\right)^4}{24} - (q+q_s)\frac{(L/2)^4}{24}\right]. \quad (22)$$

As it is seen from (22), the deflection depends on the pipeline material characteristics (E), cross-section of pipeline (I) distributed loads (q, q_s) and also distances (l, L). Among the data there are 2 unknown values, to be defined. Proceeding from 15, "L" can be derived from "l" by formula 23:

$$L = \frac{2q_s l}{q}. \quad (23)$$

Considering formula (23) and knowing that the maximum bending deflection in the midspan is $y = f_{max} = 100mm$, let us substitute it in (22) and get the formula 24:

$$f_{\max}=\frac{1}{\mathrm{E}\cdot\mathrm{I}\cdot\left(2l+\frac{2\mathrm{q}_s\cdot l}{\mathrm{q}}\right)}\cdot\left[(\mathrm{q}+\mathrm{q}_s)\cdot\frac{\left(l+\frac{2\mathrm{q}_s\cdot l}{\mathrm{q}}\right)^4}{24}-\mathrm{q}_s\cdot\frac{\left(2l+\frac{2\mathrm{q}_s\cdot l}{\mathrm{q}}\right)^4}{24}-(\mathrm{q}+2\mathrm{q}_s)\cdot\frac{l^4}{24}\right]\times$$

$$\times\left(l+\frac{\frac{2\mathrm{q}_s\cdot l}{\mathrm{q}}}{2}\right)+\frac{1}{\mathrm{E}\cdot\mathrm{I}}\cdot\left[\mathrm{q}_s\cdot\frac{\left(l+\frac{\mathrm{q}_s\cdot l}{\mathrm{q}}\right)^4}{24}+\mathrm{q}_s\cdot\frac{\left(\frac{\mathrm{q}_s\cdot l}{\mathrm{q}}\right)^4}{24}\right]. \quad (24)$$

Hereby, knowing all the necessary parameters, we can define "l" and then "L".

Let us calculate the parameters for a specific pipeline with the initial data.

The distributed load, affecting the underwater pipeline is as follows:

$$q=n_p\frac{\pi D_l^2}{4}\Delta\rho_w g=1.1\cdot\frac{\pi\cdot 1.09^2}{4}\cdot 170\cdot 9.81=1711.8\ N/m.$$

The distributed load from the soil activity (with the record of buoyancy force affecting it) is follows:

$$q_s=(\gamma_s-\gamma_w)D_l h_0=(18000-11000)\cdot 1.09\cdot 1=7630\frac{N}{m}.$$

For $f_{\max}=100mm, l=7.76mm, L=\frac{2q_s l}{q}=\frac{2\cdot 7630\cdot 7.76}{1711.8}=69.177m,$

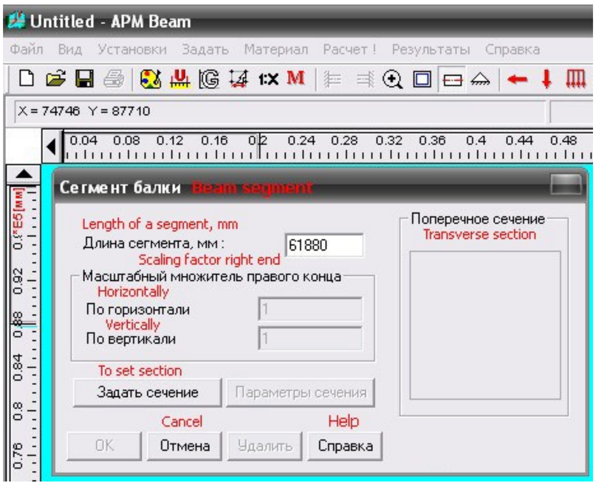
for $f=10mm, l=4.36mm, L=\frac{2q_s l}{q}=\frac{2\cdot 7630\cdot 4.36}{1711.8}=38.868m.$

Let us verify the accuracy of the calculation with the help of software engineering program APMWinMachine 9.7.To calculate the parameters of the optimized method of underwater pipeline backfill with the use of reinforced concrete and metal loads, the program APMBeam is used, which can be applied for the calculation and design of braced construction elements by the method of finite elements and also for the calculation of the following parameters:

1) reactions in pillow blocks and restraints;
2) allocation of bending moments and bending corners;
3) allocation of twisting moments and twisting corners;
4) allocation of radial and axial forces;
5) allocation of movements and tensions.

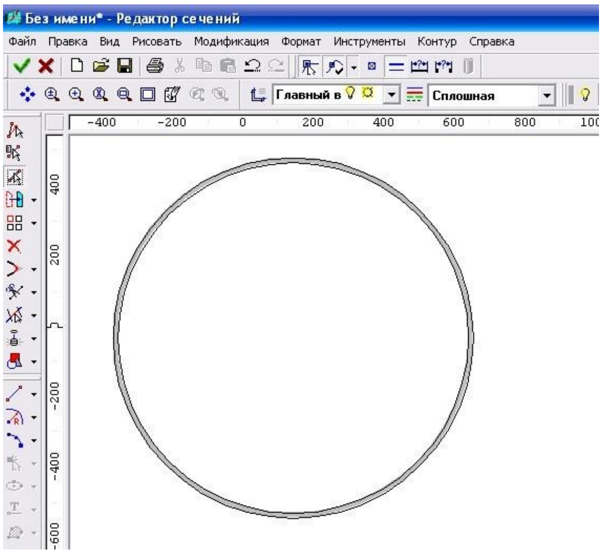
All calculation should be divided into steps.

1) The created segment and given length (Picture 7):



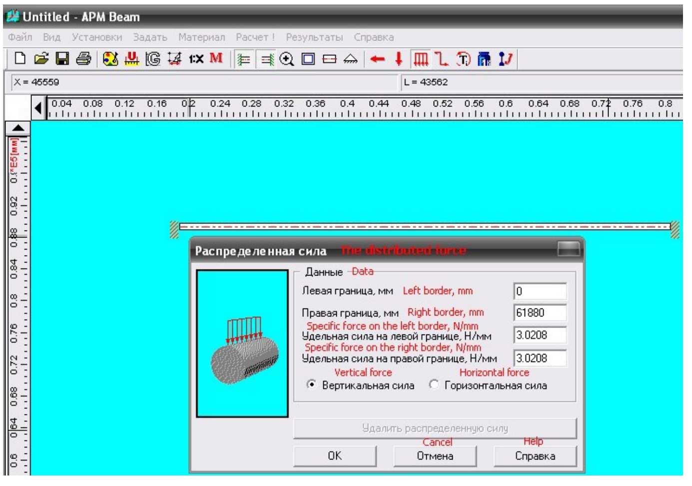
Picture 7. The creation of a segment

2) Set of the section (Picture 8):



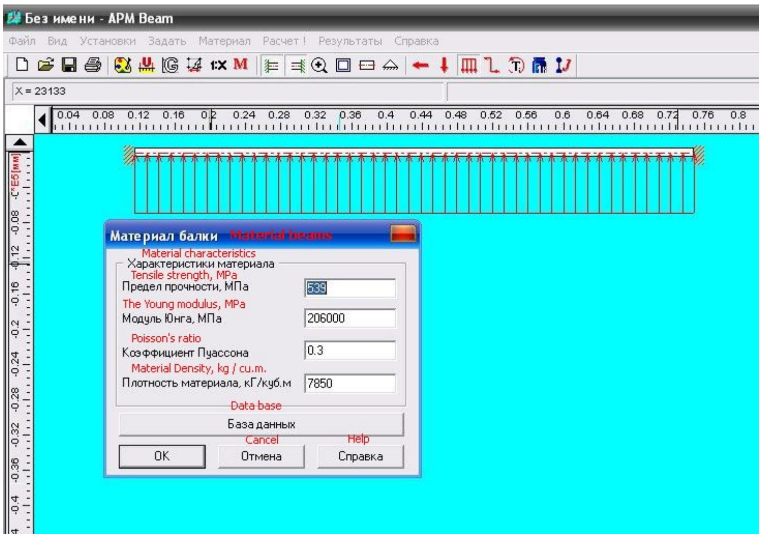
Picture 8. The creation of section

3) Setting of the pillow blocks and restraints and assigned loading q (Picture 9):



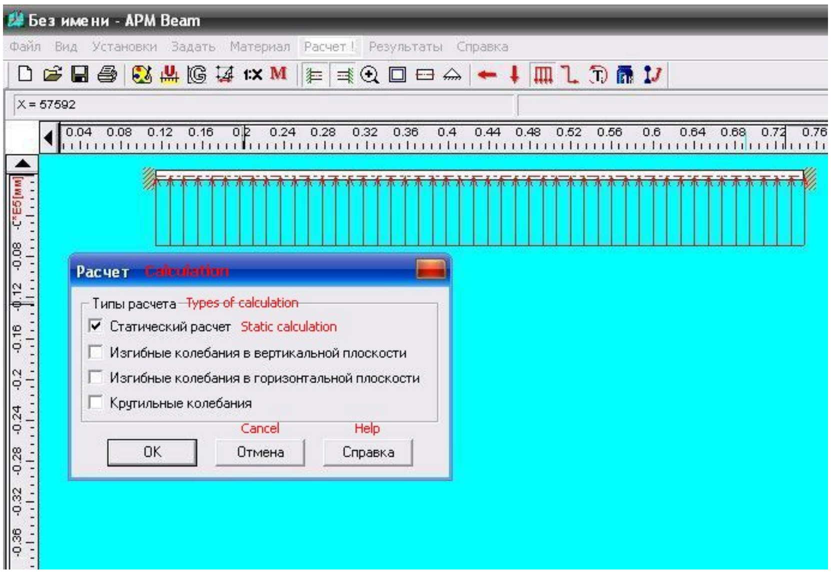
Picture 9. Assigning of pillow blocks and loading

4) Assignment of the material (Picture 10):



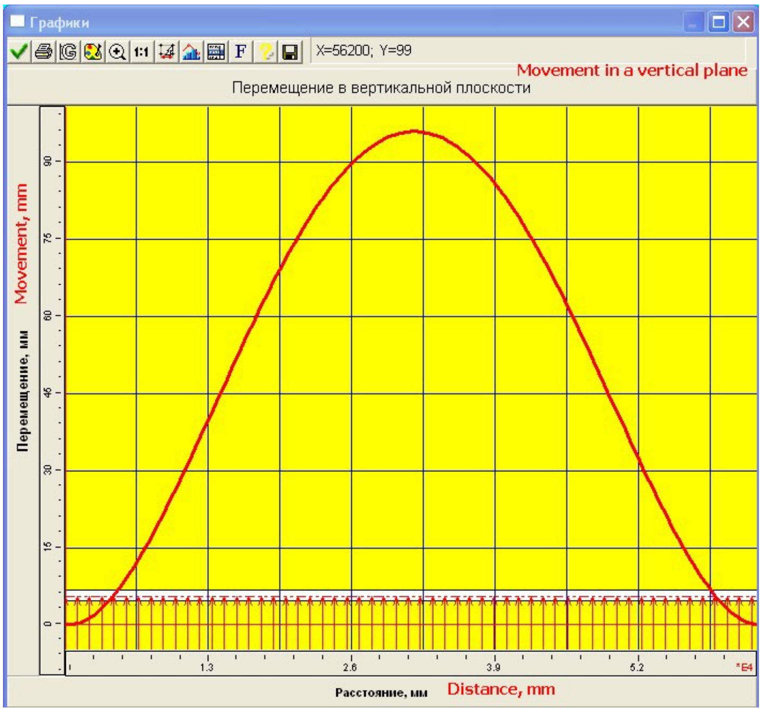
Picture 10. Assignment of material.

5) Choice of “Calculation” insert and assignment of “Static calculation” (Picture 11):



Picture 11. The start of calculation

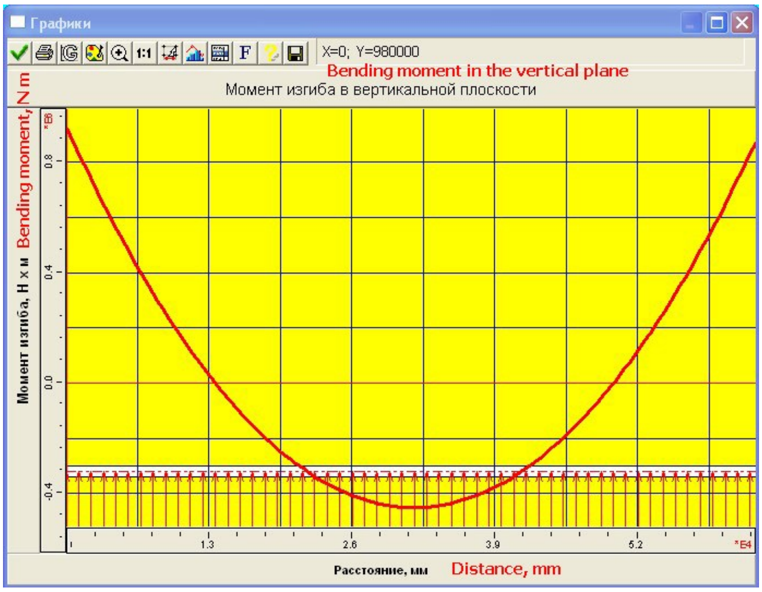
6) Choose the insert “Results” – “Graphical charts”. In the open window choose “Movements” – “Vert.” and analyze results (Picture 12):



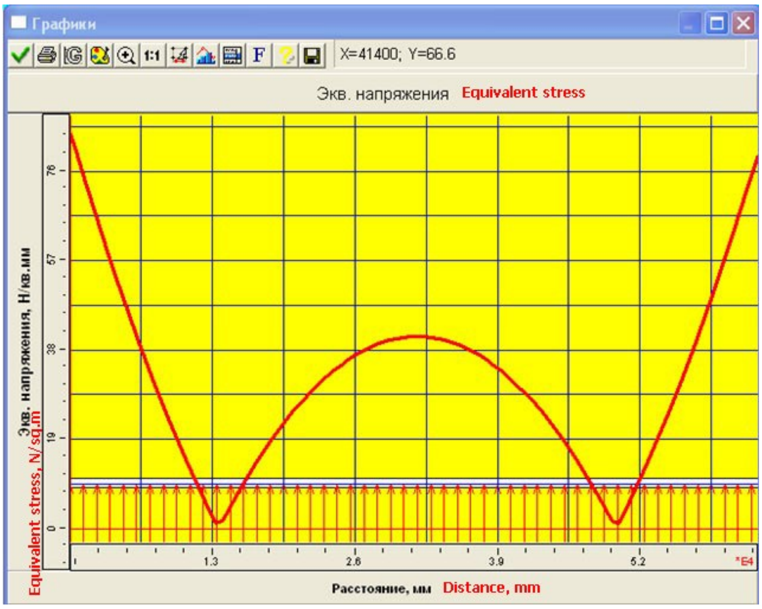
Picture 12. Graphical Chart of vertical movements

In the graphical chart you can see that bearable vertical movements of the pipeline are 98 mm, which is acceptable and is approximately equal to rates of 100 mm. Therefore, the analytical calculations are correctly fulfilled [24–26].

Also, we can demonstrate other graphical charts of the obtained calculation: graphical charts of bending moments, tensions, which are chosen in the same window as a graphical chart of vertical movements (Pictures 13, 14).



Picture 13. The graphical chart of the bending moment



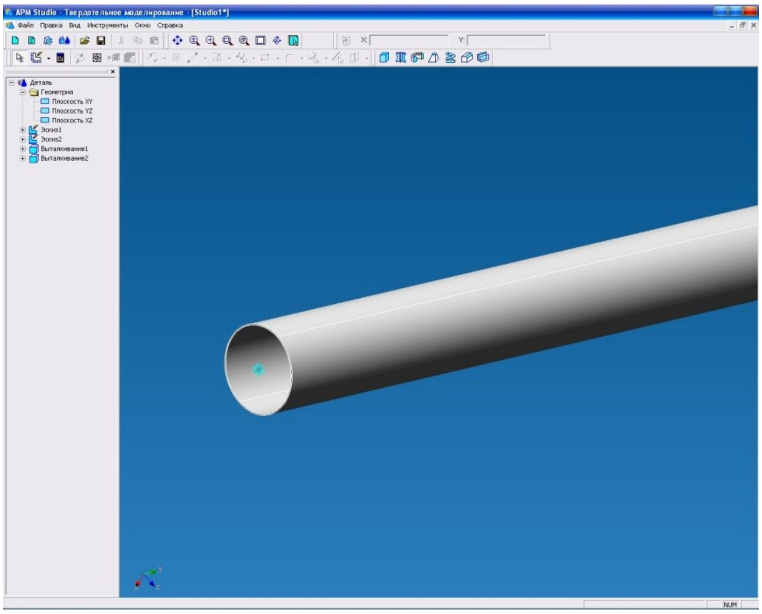
Picture 14. The tension graphical chart

From the tension graphical charts, we can see that maximum stress occurs at the ends of the zone (in the zone of loads mounting) and are approximately equal to 84 MP, which notably lowers the point of steel fluidity equal to 390 MPa. Therefore, the toughness is provided.

Let us calculate the given example in the APM Structure3D program, which is designed for the calculation and design of spatial constructions and also the calculation of solid state models by the method of finite elements.

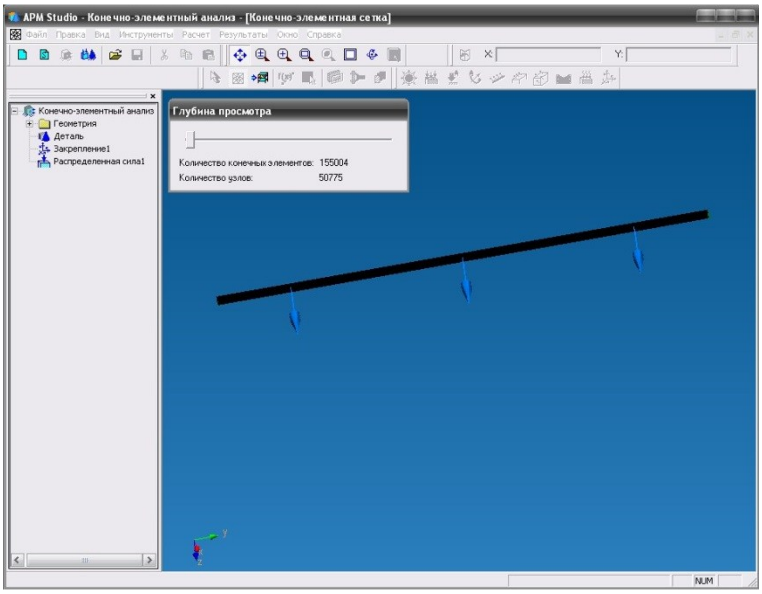
All the process of the calculation is divided into steps:

1) Create a solid state model of the pipeline zone with the set-up parameters from initial data and the length k = 61.88 m (Picture 15);



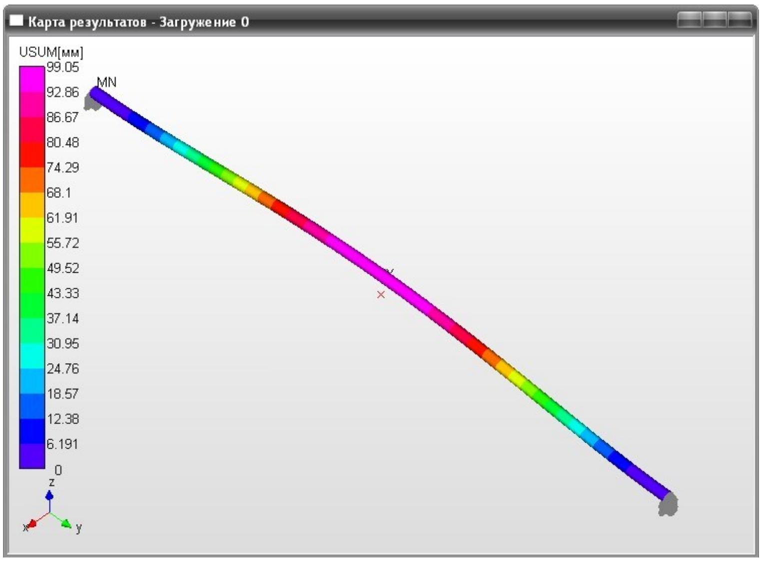
Picture 15. The creation of solid state pipeline model

2) Choose the function “The finite-elemental analysis”, where you can create a pillow block (restraints at the ends of pipeline) and specific weight q, which disrupts it into a finite-element mesh (Picture 16);



Picture 16. The creation of finite-element mesh

3) Move the given finite-element mesh into APMStructure3D, set up material and choose the insert “Calculation”–“Static calculation”, and after that the calculation the map of movements and tensions (Pictures 17, 18) is obtained.



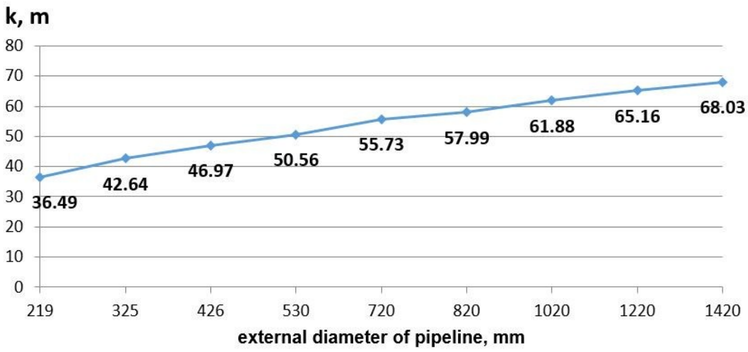
Picture 17. The displacement map

Picture 18. The tension map

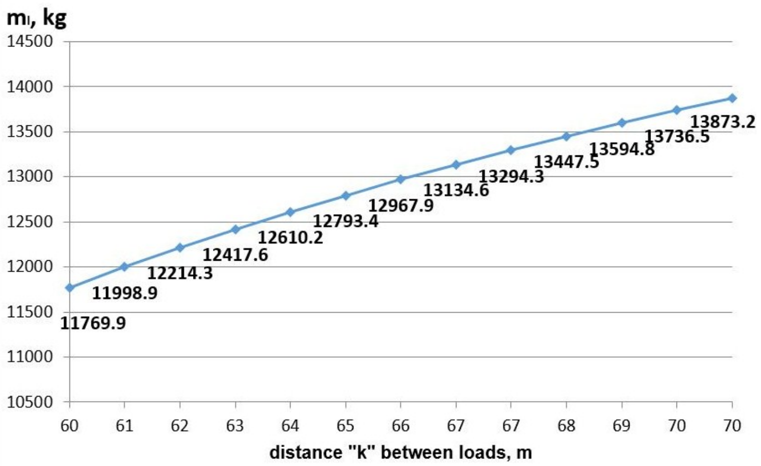
From the tension graphical charts, we can see that bearable tensions occur at the ends of the zone (in the zone of loads mounting), the stress rate reaches 79.54 MPa which is approximately equal to calculated tensions in the program APMBeam. Also, the stress rate reaches 99.05 mm, which is also acceptable and is approximately equally calculated.

Analyzing the results of all 3 calculations, we can draw the conclusion about the right choice of the calculation methods and accuracy of the obtained results for the concrete pipeline.

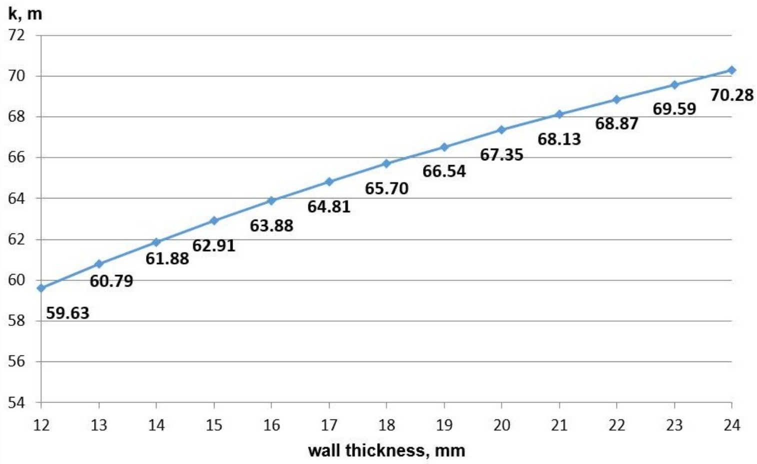
Then we can fulfil calculations by these methods for different cases. They will vary in diameter, in the pipeline wall thickness and the type of backfill soil. The final results will be the distance between metal and reinforced concrete loads “k” and the mass of this load (we will use the cast iron with density as the load material) (Pictures19–24).



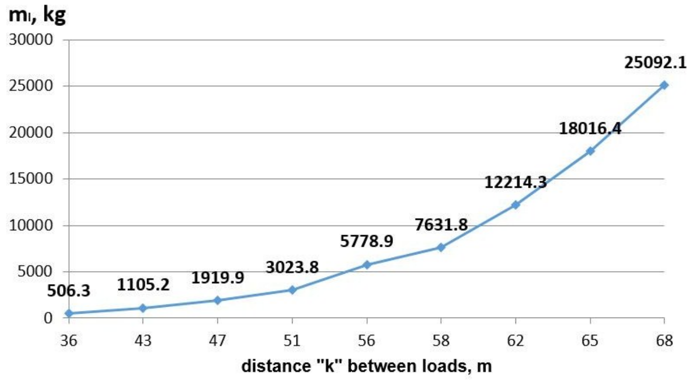
Picture 19. The diagram of distance "k" between the loads versus pipeline wall thickness with diameter 1020 mm, with the change of water density of 300 kg/m^3 and pulp specific weight of 1400 kg/m^3



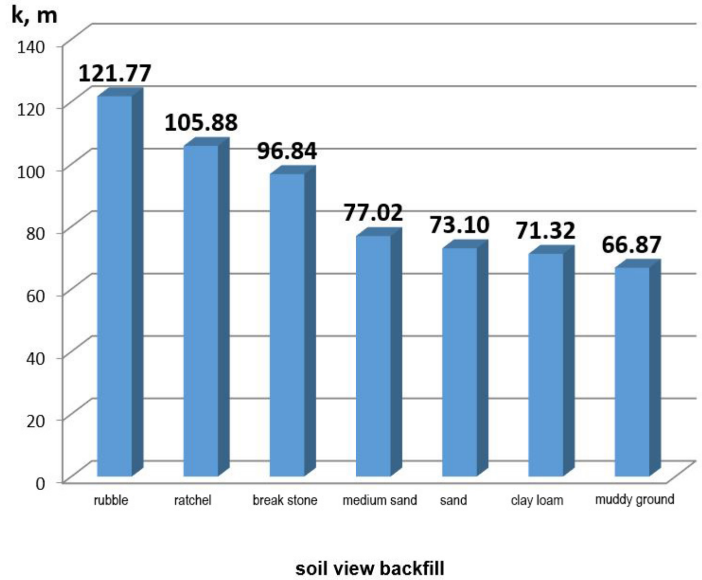
Picture 20. The diagram of load mass versus distance "k" between them for the given pipeline with diameter 1020 mm with the relevant walls thickness, with the change of water density of 300 kg/m^3 and pulp specific weight of 1400 kg/m^3



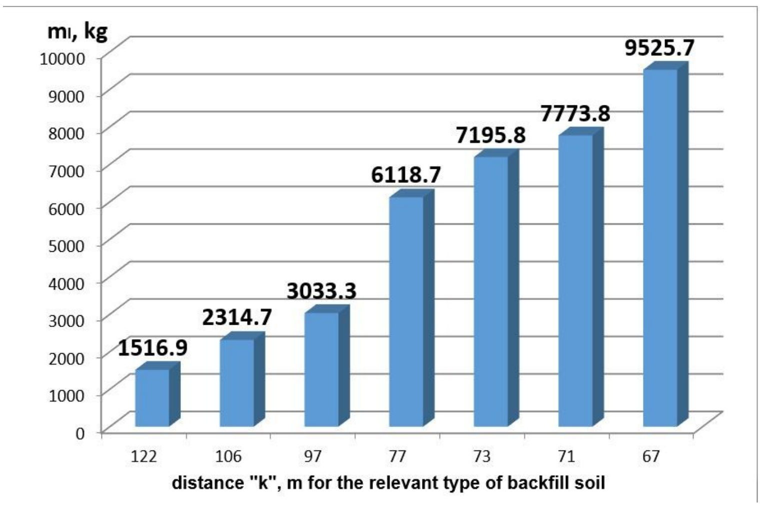
Picture 21. The diagram of the distance between loads "k" versus external diameter of the pipeline for the pipelines with the wall thickness of 14 mm, with the change of water density of 300 kg/m^3 and pulp specific weight of 1400 kg/m^3



Picture 22. The diagram of load mass versus distance k between them for the given pipelines of different diameters with the wall thickness 14 mm, with the change of water density of 300 kg/m3 and pulp specific weight of 1400 kg/m3



Picture 23. The diagram of the distance between loads "k" versus soil view backfill for the pipeline with outboard diameter 1020 mm, wall thickness 14 mm, with different values of change of density of water andpulp specific weight



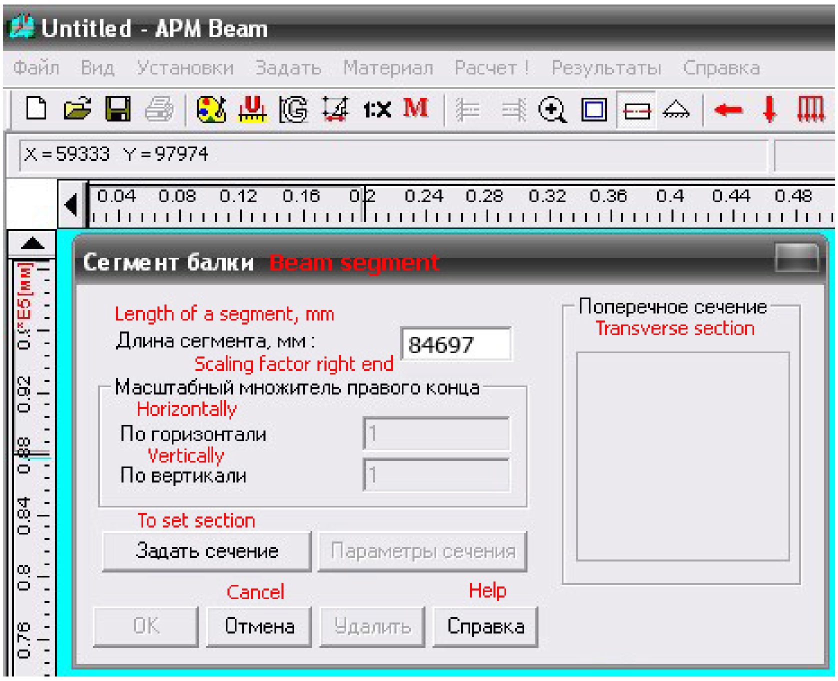
Picture 24. The diagram of load mass versus distance "k" between them for the pipeline with the outboard diameter 1020 mm, wall thickness 14 mm with the backfill of relevant soil sorts

Now we examine the parameters of the optimized way of backfill subaqueous pipeline with the cofferdams for analogous initial data.

We begin the calculation with the help of software engineering programs APMWinMachine 9.7, particularly in APM Beam.

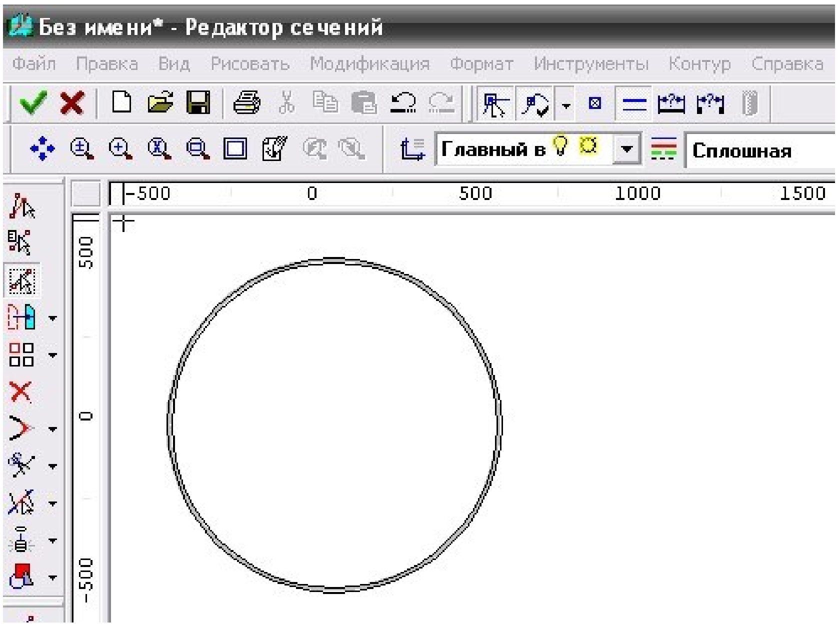
We divide all the calculation into the following steps:

1) Create segment with the given length ($2l + L = 2 * 7.76 + 69.177 = 84.697\ m$) (Picture 25);



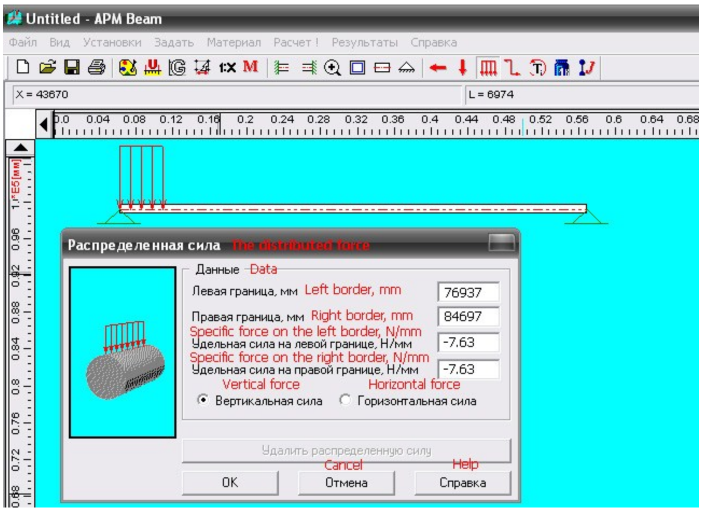
Picture 25. The creation of segment

2) Setting of the section (Picture 26);



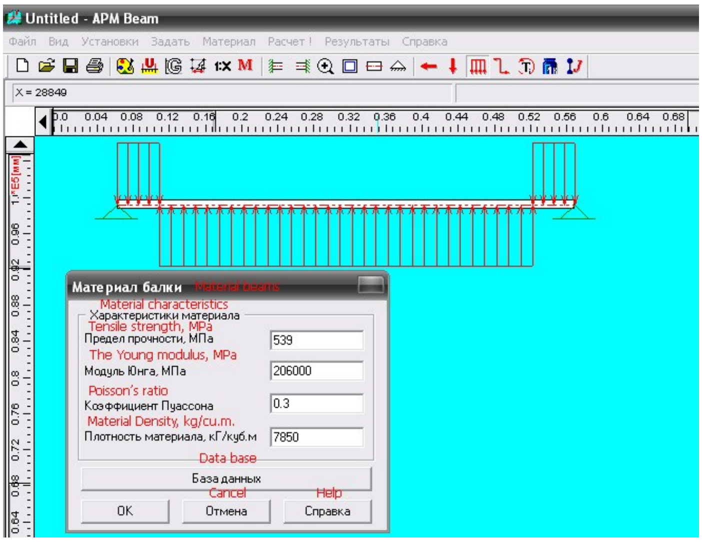
Picture 26. The creation of section

3) Setting of pillow blocks and restraints and assigned loading (Picture 27);



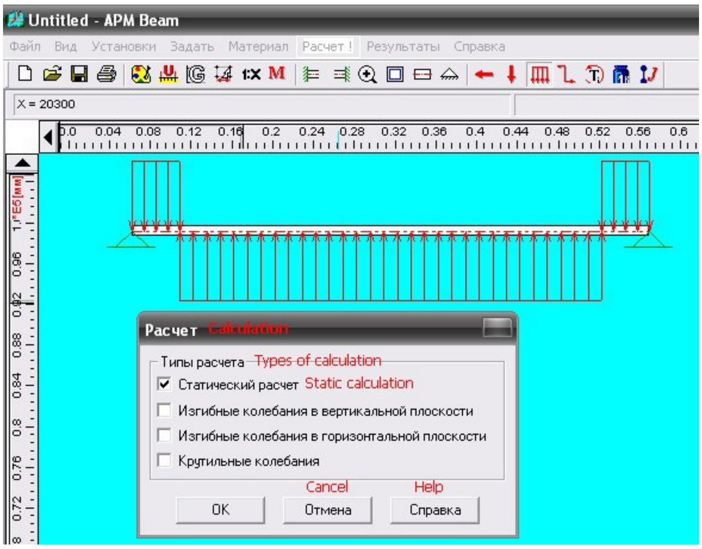
Picture 27. Assigning of pillow blocks and loading

4) Assignment of the material (Picture 28);



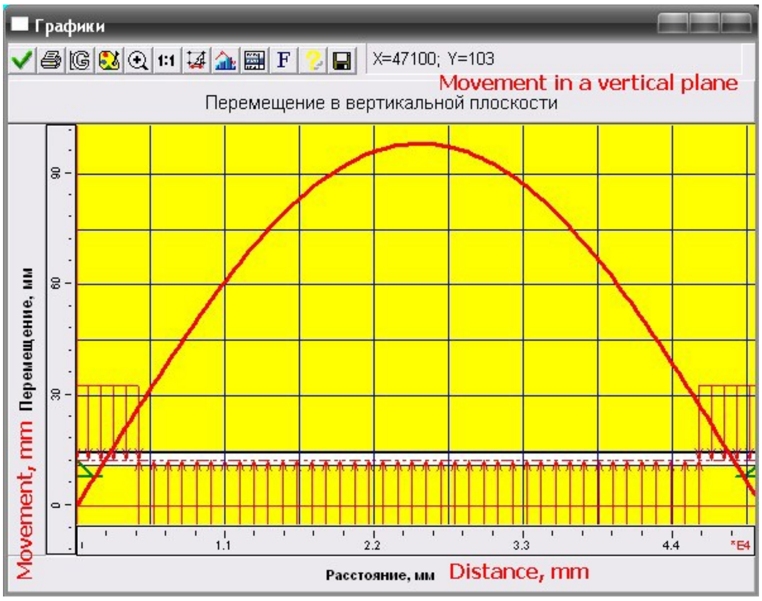
Picture 28. Assignment of material

5) Choice of "Calculation" insert and assignment of "Static calculation" (Picture 29);



Picture 29. The start of the calculation

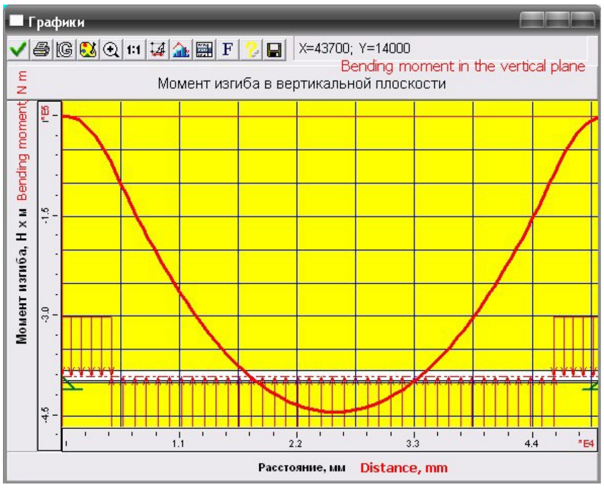
6) Choose the insert “Results”–“Graphical charts”. In the open window choose “Movements”–“Vert.” and analyze results (Picture 30).



Picture 30. Graphical Chart of vertical movements

In the graphical chart you can see that bearable vertical movements of the pipeline are equal to 98 mm, which is acceptable and is approximately equal to rates 100 mm. Therefore, the analytical calculations are correctly fulfilled.

We can also demonstrate other graphical charts of the obtained calculation results: graphical charts of bending moments, tensions, which are chosen in the same window as a graphical chart of vertical movements (Pictures 31, 32).



Picture 31. The graphical chart of bending moment

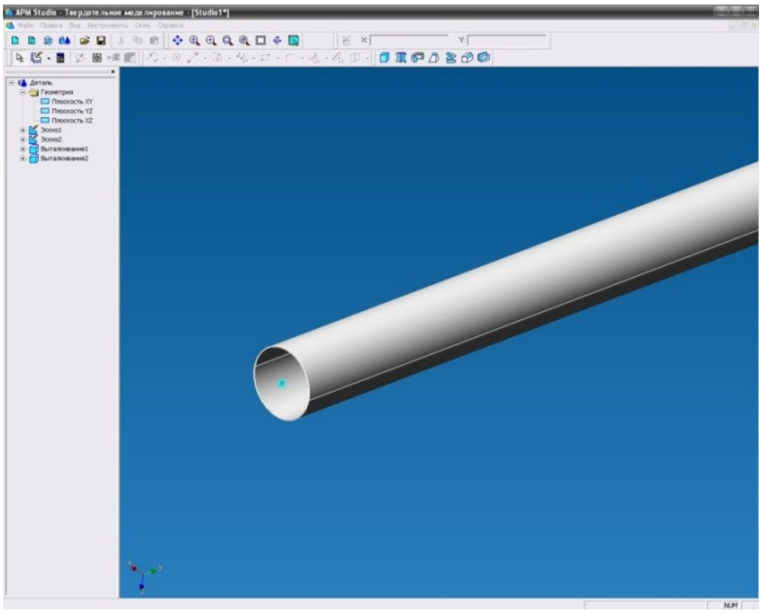
Picture32. The tension graphical chart

From the tension graphical charts, we can see that bearable tensions occur at the midspan zone and they are approximately equal to 40.3 MPa, which notably lowers the point of steel fluidity equal to 390 MPa. Therefore, the toughness is provided.

Let us calculate the given example in the program APM Structure3D.

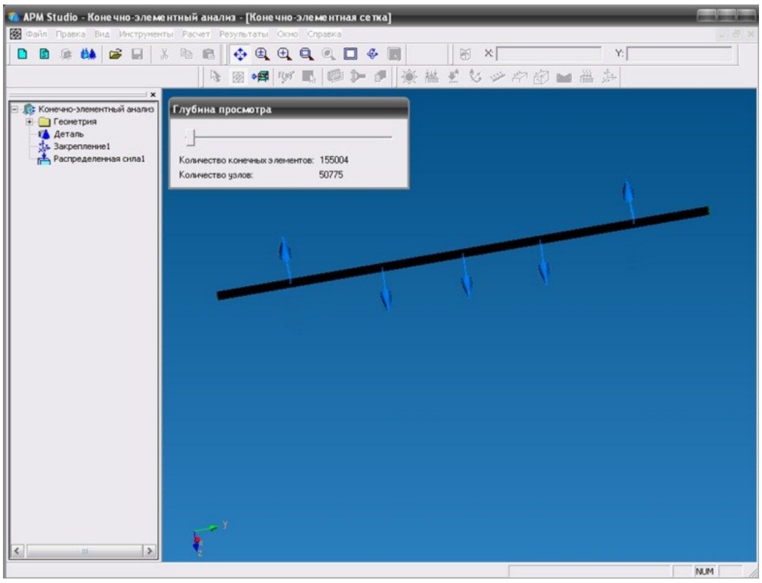
The calculation process is divided into the following steps:

1) Create a solid state model of pipeline zone with the set-up parameters from initial data and the length 84.697 m (Picture 33);



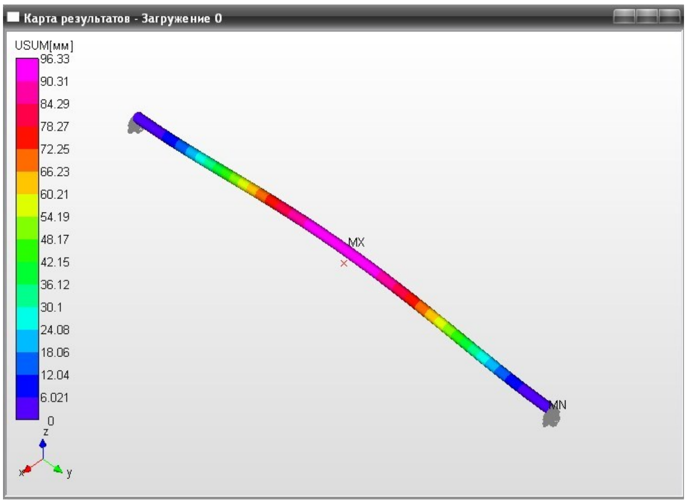
Picture 33. The creation of solid state pipeline model

2) Choose function “The finite-elemental analysis”, where you can create pillow blocks (restraints at the ends of pipeline) and specific weight, which sdisrupt it into finite-element mesh (Picture 34);

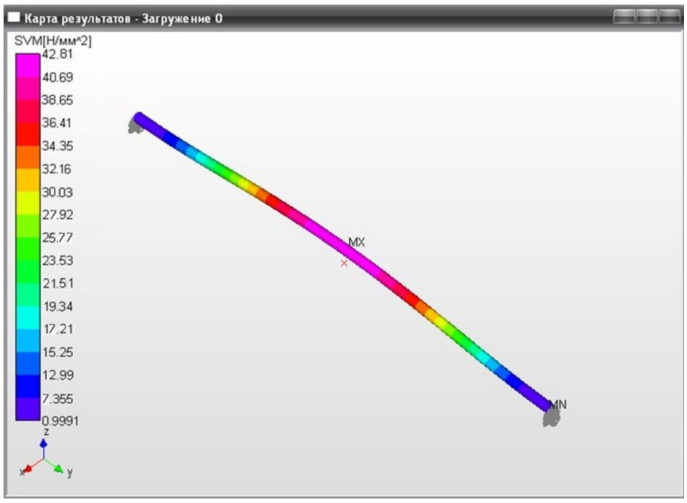


Picture 34. The creation of finite-element mesh

3) Move the given finite-element mesh into APM Structure3D, set up material and choose the insert “Calculation”–“Static calculation”, after the calculation the map of movements and tensions (Pictures 35, 36) is obtained.



Picture 35. The displacement map

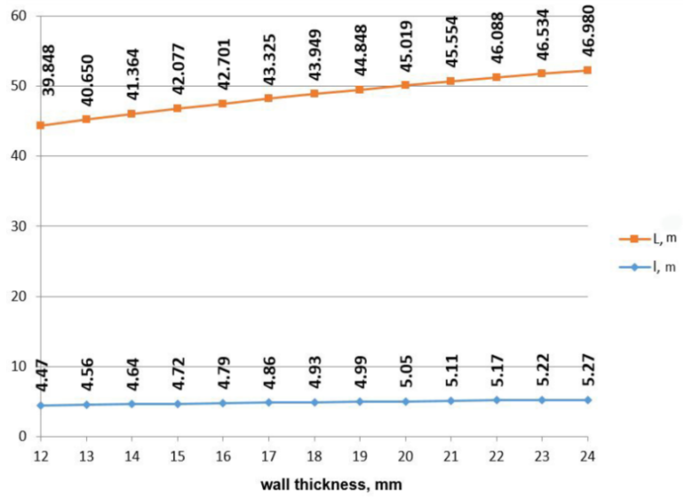


Picture 36. The tension map

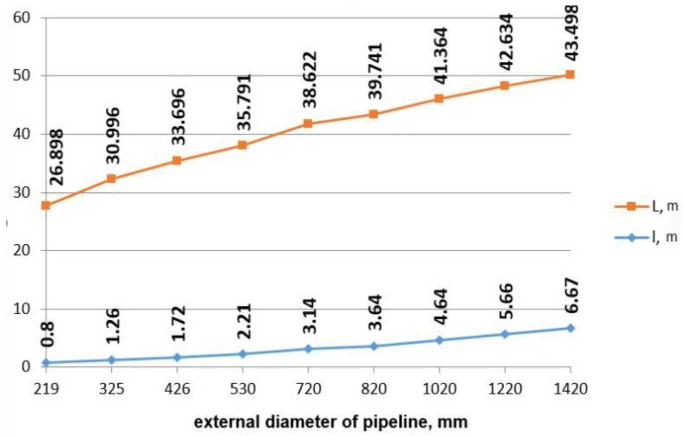
From the tension graphical charts, we can see that bearable tensions occur at the ends of the zone (in the zone of loads mounting), the stress rate reaches 42.81 MPa which is approximately equal to calculated tensions in the program APMBeam. Also, the stress rate reaches 96.33 mm, which is also acceptable and approximately equally calculated.

Analyzing the results of all three calculations, we can draw the conclusion about the right choice of the calculation methods and accuracy of the obtained results for the concrete pipeline.

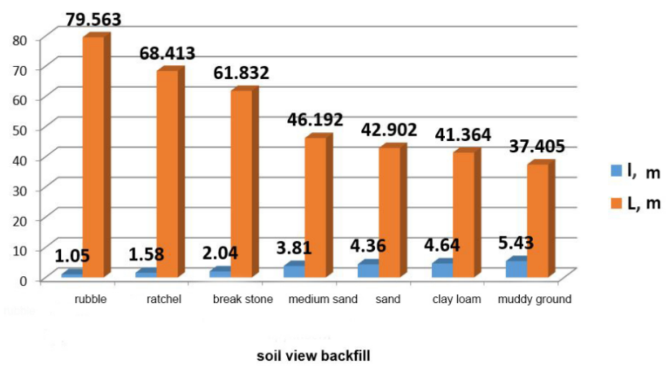
Then we can fulfill calculations by these methods for different cases. They will vary in diameter, in the pipeline wall thickness, also the type of backfill soil. The final results will be the distances “l” and “L” (Pictures 37–39).



Picture 37. The diagram of distance "l" and "L" versus pipeline wall thickness with diameter 1020 mm, with the change of water density of 170 kg/m3 and pulp specific weight of 1270 kg/m3, soil – loamy soil.



Picture 38. Diagram of distance "l" and "L" versus external diameter of the pipeline for pipelines with wall thickness 14 mm, with the change of water density of 170 kg/m3 and pulp specific weight of 1270 kg/m3, soil – loamy soil.



Picture 39. Diagram of distance "l" and "L" versus soil sort backfill for the pipeline with the outboard diameter of 1020 mm, wall thickness 14 mm, with different values of change of water density of and pulp specific weight

On the diagrams, presented in pictures 37–39, it can be seen that the results are significant for "l" from 0.8 to 6.67 m and for "L" from 26.898 to 79.563 m. These results can be explained by the dependence of these values from many parameters, not only inherent to backfill soil, but also to pipeline characteristics. But, despite that, these methods of backfill of subaqueous pipeline are very effective, because, according to all calculations, they provide the design position of subaqueous pipeline after backfill fulfillment. Moreover, the expenses for metal or reinforced loads, for their mounting and demounting, connected with backfill technology of underwater pipeline backfill by cofferdams, are still much smaller due to the method of execution of works, dredging works, etc.

So far, the similar calculation of existing methods of backfill has not been conducted yet, which proves the innovativeness of the proposed ways of underwater pipeline backfill [27]. However, the method is paid much attention to in such works as [28–42] due to operating reliability of submarine pipelines depending on the methods of construction. The causes of the accidents in underwater pipelines due to imperfection of the construction methods are also examined.

Conclusions

1. The article examines the existing methods of submerged pipelines backfill, and determines their deficiencies. .The optimized methods of backfill which were patented are proposed in the article.

2. All optimized methods of backfill have been designed with the help of software engineering programs APM WinMachine 9.7, particularly in APM Beam, APM Studio and APM Structure3D programs. The results of the model calculation by the method of finite elements prove the effectiveness of the proposed methods of submerged pipeline backfill.

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Kozhaeva K.V. Calculation of optimized methods of the river underwater pipeline backfill with the use of APMWinMachine 9.7. *Magazine of Civil Engineering*. 2016. No. 5. Pp. 42–66. doi: 10.5862/MCE.65.4