Mobile Derivational Micro-HPP for Reserve Water Supply and Standby Power Service of Recreation Facilities and Harbour Installations of Russky Island

Mobilna derivacijska hidroelektrana za opskrbu rezerve vode i energije za rekreacijske sadržaje i instalacije u marini na Ruskom otoku

Denis Vladimirovih Kasharin
e-mail: dendvk1@mail.ru

Tatiana Petrovna Kasharina
e-mail: kasharina_tp@mail.ru

Mihail Aleksandrovih Godin
e-mail: godin_m_a@mail.ru

DOI 10.17818/NM/2015/4.5
UDK 627(57)
Preliminary communication / *Prethodno priopćenje*
Paper accepted / *Rukopis primljen:* 7. 4. 2015.

Summary

The article considers the problems of justification of derivational micro-HPP usage for reserve water supply and standby power service of harbour installations for Russky Island. The first part of the article describes the justification of the power supply necessity for recreation facilities and yachting harbour installations (marinas) on Russky Island, including the prospect of their further development and new construction activities. The second part of the article considers the justification of innovative technologies usage of mobile derivational micro-HPP for recreation facilities and harbour installations power supply. The third part of the article deals with the principal design parameters for calculation of composite mobile diversion conduit and its cable-stayed system schemes which are used to fix the diversion conduit in light of wind effects. The forth part of the article shows the simulation modeling of the diversion conduit.

KEY WORDS

Russky island
mobile diversion microHPP
derivational water pipeline
composite materials
stress-strain state of a soft shell
numerical simulation

Sažetak

U članku se prozmatraju problemi opravdanosti derivacijske uporabe mikrohidroelektrane za opskrbu rezerve vode i energije u lučkim postrojenjima na Ruskom otoku. U prvom dijelu članka opisuje se opravdanost potrebe napajanja za rekreacijske sadržaje i za postrojenja u marinama na Ruskom otoku, uključujući mogućnost njihovog daljnjeg razvoja i nove izgradnje. Drugi dio članka se bavi opravdanošću uporabe inovativne tehnologije u mobilnim derivacijskim hidroelektranama za rekreacijske sadržaje i napajanje postrojenja u marinama. Treći dio članka bavi se glavnim projektnim parametrima za izračun kompozitne mobilne cijevi za preusmjeravanje i njezinog sustava sa zategama kojim se koristi za fiksiranje cijevi za preusmjeravanje u slučaju pojave vjetra. Četvrti dio prikazuje simulaciju izrade cijevi za preusmjeravanje.

KLJUČNE RIJEČI

Ruski otok
mobilna diverzija
mikro hidroelektrana
derivacijski vodeni cjevovod
kompozitni materijali
stanje naprezanja mekane ovojnice
numerička simulacija

PART 1 / *Prvi dio*

Russky Island, situated in the Sea of Japan, had formerly been military-oriented, but due to the decision dealing with the organization of a tourist-recreational zone on its territory and construction of infrastructural facilities, after the Asia-Pacific Economic Cooperation organization summit (APEC), has vast prospects for the development of civil infrastructure, its reserve water and power supply (Fig. 1) [1,2,3].

Hence the topical question is the problem of water and power supply provision of recreation facilities and harbour installations for small-sized crafts.

Currently the basic power supply of the island with energy reservation is provided by Vladivostok's cable-based network and by the three mini-TPP: "Northern", "Central" and "Aquarium". However, it covers only some part of the island – the Sapyorny Peninsula. On this peninsula there are such objects as: the Far Eastern Federal University's campus, a health care centre, a fire station, a police station, an independent water supply system with desalination plans and a wastewater treatment facility. Due to the possibility of harbour installation building in the bays of the northern and northeast parts of the island – "Unnamed", "Ajax" and "Paris" in order to provide the cargo transshipment, almost all the available powers will be required for their energy supply (Fig 1.) [2,3].

At the same time a major part of Russky Island, separated

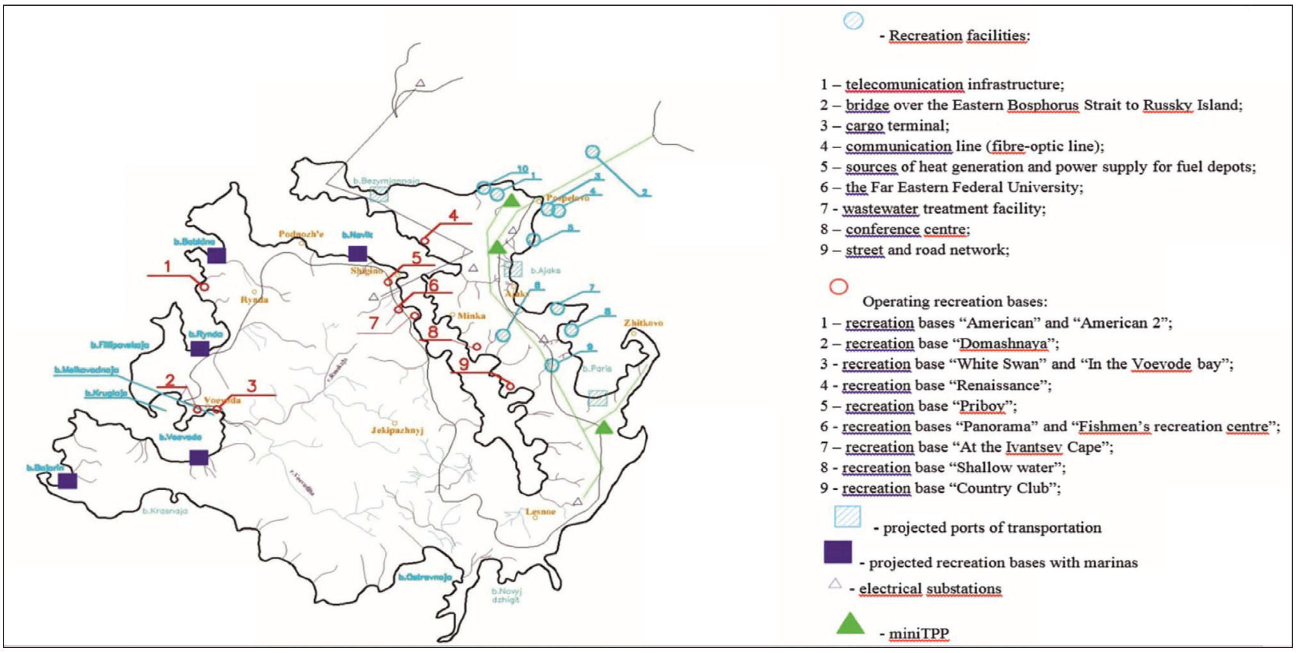


Figure 1 Location of civil infrastructure facilities on Russky Island

Slika 1. Lokacija civilnih infrastrukturnih sadržaja na Ruskom otoku

by the Novik bay, has no reliable water and power supply or other utilities. Only 3 of 11 operating bases are situated on the Sapyorny Peninsula. Almost all the bases have berthing structures and grant a lease for small-sized water transport. The number of tourists varies from 35 to 140 people with a total population of 600 people. Water supply is achieved either by means of underground sources or by means of imported water. Each base and berthing structure must have a water supply system, which provides from 0,0001 to 0,0003 cum/cm, and dedicated capacity form 20 to 100 kW.

According to a study of Stratievsky O.B., Guremin O.B. and others, the bays on the west part of the island are the most important for the tourist-recreational zone. They include: the Novik bay, the Babkina bay, the Rynda bay, the Philippovsky bay, the Voevode bay, the Boyarin bay. Their waters are not deep (about 2,8 m), well protected against southeast monsoon winds prevailing during the summer time and have developed gravel beaches and valuable recreational and bio-reproducing offshore areas. It's valuable to use such bays as New Djigit and Ostrovnaya that are well protected against wind and have beach zones. Together their recreational capacity may be about 5000 people [5].

In order to widen the recreation zone and to provide recreation with the minimum negative ecological effect on the environment it's necessary to build well-furnished camp cities and recreation bases that have their pontoon berthing structures or joint use marinas in the prospective to provide small-sized promenade boat traffic, yachting, different kinds of powerboating sports and etc. Marinas must provide the following services: moorage in the water, shore storage, sanitary complex services (lavatory, shower, laundry); collection of wastes and bilge water from yachts and powerboats; filling up with provisions and stores, fuels, water; light repair services for small-sized crafts; reception of guests' yachts; options (yacht charter, marine practice for young people, professional sport and amateur competitions and others) [5, 6].

Due to the planned increase of tourist attractions on the island it's necessary to foresee sources of water and power supply having the minimum negative ecological effect on the environment, maneuverable (smoothing unequal daily electrical energy use, uprising of peak loads), providing with decentralized power supply with the minimum costs of their building. Hydroelectric power plants meet these requirements most closely. Further, let us consider the justification of hydroelectric power plants constructions, adapted to natural and climatic conditions of Russky island.

PART 2 / *Drugi dio*

The climate of the island is characterized by steady monsoon winds and has the highest rainfall intensity in summer. In autumn the weather is warm, there is little or no rainfall, sunny days predominate. Severe frosts and winds can be observed (from 6 to 15 m per sec and faster) in winter [7, 8]. According to the orohydrographic characteristics, the central part of the island is mountainous. Its highest mountains are: Russkaya (291m); Glavnaya (279); Centralnaya (251m). The outskirts and coastline of the island represent a range of bluff rocky areas and beaches with lagoons and isolated lakes. Hydrographic networks include 24 brooks and the minor river Russkaya belonging to the Far East type. Its slope is 160 m. The water catchment area is 18 sq m, width – 4 m, mid depth – up to 1 m, length – 10 km and annual river flow – 0,23 cum/cm. During high tides the water downstream becomes brackish due to seawater penetration from the Voevode bay with a salt content of 32%. All streams are covered with ice from November-December to March-April.

Summer is the most comfortable period for water sports, the temperature of the seawater is about 22-25 °C. Autumn is preferable for yachting and water transport. Total duration of the recreation period is 155 days [8].

Due to the fact that the majority of existing and planned recreation areas (including tourist camps, berthing structures and marinas) belong to low energy intensity consumers (from

20 to 100 kW) with the highest amount of water and energy consumption in the summer-autumn period and which are located near minor mountain rivers estuaries, it appears optimum to use diversion HPP.

Since existing "hose" derivational micro-HPP constructions provide power up to 16 kW, they don't guarantee sufficient reliability during their exploitation because of hose wrenches and damages, and in the process of traditional diversion HPP erection it is necessary to build protective constructions. Laying diversion conduits with use of heavy construction equipment causes deforestation along their line and a significant negative effect on the environment, it is necessary to develop an engineering solution for seasonally operated diversion microHPP.

It is thought that a water-storage scheme will be the most optimum because it is suggested to use microHPP data under the conditions of large daily inequality of water and power supply for low energy intensity objects. According to the scheme, water dumping (some volume of water) is carried out from a river into an upstream pool, then, water dumping is carried out into a downstream pool which functions as a clean-water reservoir.

Since it is assumed the use of these micro-HPP under conditions of considerable daily unsteadiness, if water and energy supply purposed for the facilities of low energy intensity, the most optimal will be scheme of Pumped-Storage Electric Power Plant. In accordance with this scheme in turbine mode, it is made diversion of part of the water from the river, which is directed into the upper reservoir, after that it passes through the derivational water pipeline and the turbines; it is removed into the lower reservoir, which may serve as a reservoir of clean water. In the hours of low power consumption micro-HPP works in pumping mode, pumping water from the lower reservoir to the upper reservoir, accumulating energy to cover peak loads.

Currently, we have developed a new technical solutions for mobile derivational micro-HPP in complete with the composite derivational water pipeline made of composite materials (Fig. 2) [9].

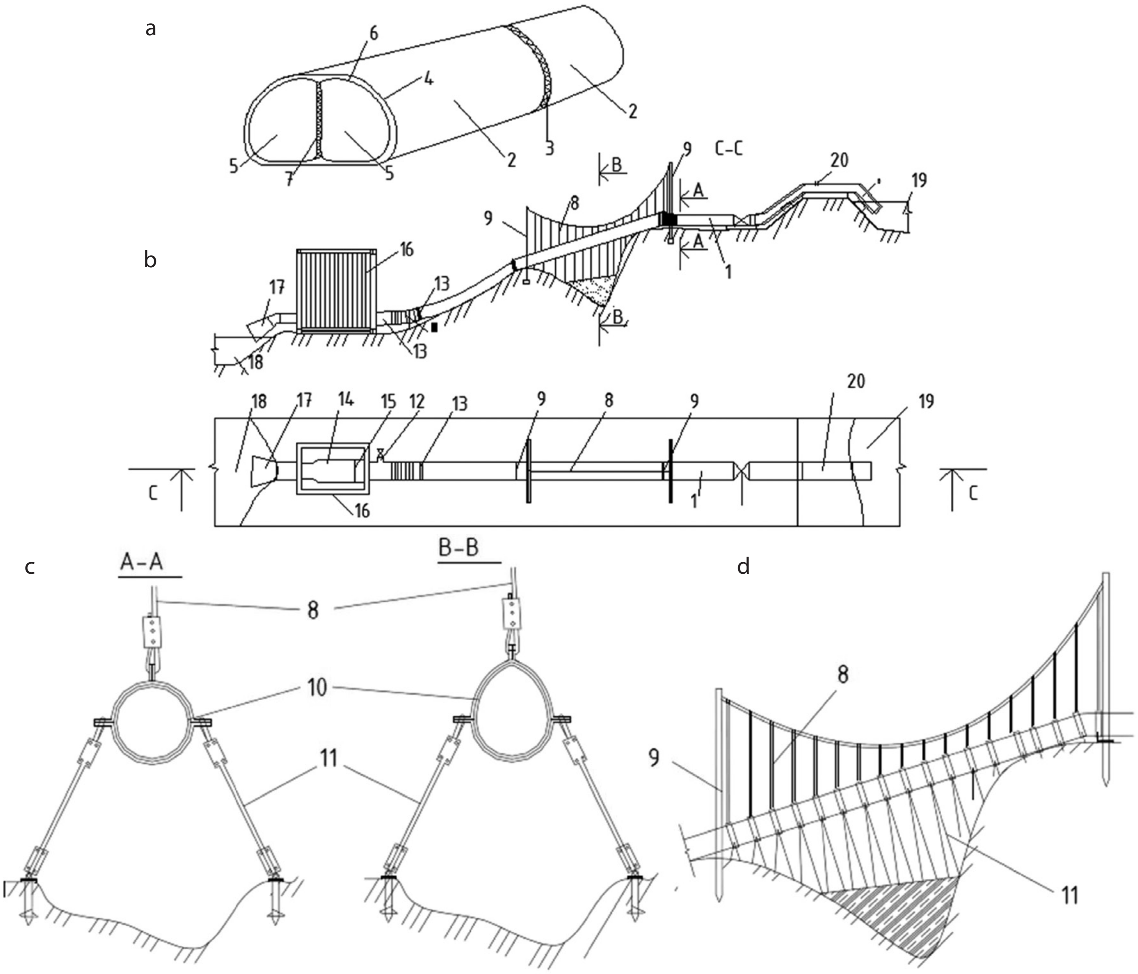


Figure 2 Mobile derivational micro-HPP with a composite derivational water pipeline made of composite materials.

Slika 2. Mobilna derivacijska mikro hidroelektrana s kompozitnim derivacijskim vodenim cjevovodom izrađenim od kompozitnih materijala:

a - section of the derivational water pipeline; b - business plan and cross-section of the mobile derivational micro-HPP; c, d - fastening of water pipeline by means of guy-roped system;

1 - soft double chamber water pipeline; 2 - water supply sections; 3 - flexible connections; 4 - outer shell; 5 - inner shells; 6 composite coating (nano) materials; 7 - flexible connections; 8 - guy-roped system; 9- supports; 10- pipe shell; 11 - stay roosts; 12 - additional tension brace; 13 - diversion of water for water supply; 14 -compensator; 15 - hydroelectric unit; 16 - device for damping hydraulic shock and technical condition monitoring; 17 - building; 18 - diffuser; 19 - the lower reservoir; 20 - siphon water intake.

Operation of the mobile derivational micro-HPP passes as follows (Figure 2b). Water from a small water course enters the upper reservoir 19, then through the siphon water intake 20 it flows by gravity into a soft dual-chamber water pipeline consisting of water supplying section 2 (Figure 2a), while at the expense of the inner shells 5 and cross connections 7 it is occurred damping of transverse circulation, also the inner coating 6 protects them from abrasive wear. And the inner shell 5 is protected by outer shell 4.

When crossing of uneven terrain and landslides by route water pipeline, it is necessary to install cable system 8 and the flexible single shelled pipeline made of stronger material further reinforced with pipe shells. The dynamic effect of the wind on its lateral surface is perceived by additional stay ropes 11 (Fig. 2, c, d). When the height of water is more than 100 m, it is provided hard water pipeline made of glass fibers impregnated with binding substances based on unsaturated polyester resin, followed by curing and reinforced with bandage. In the case of water hammer when there is emergency changing of the flow rate, it is necessary to use of hydraulic shock damping device. After the energy utilization when passing through hydroelectric set 14, the stream is released through a diffuser 17 in the lower reservoir 18. Let us make comparative analysis of the use of soft single-chamber or double-chamber pipelines used as an upper part of the derivational water pipeline and the justification for the calculated positions to determine their parameters.

PART 3 / *Treći dio*

In determining the initial cross-section parameters of the single-shelled soft water pipeline, which has supporting on horizontal plane over all its length, we take into account only the internal hydrostatic pressure. The shape of its cross section is described by two Euler elastics - the upper and lower module elliptic integrals which are located in the following range $1 < k^2 < 2$ (Figure 3).

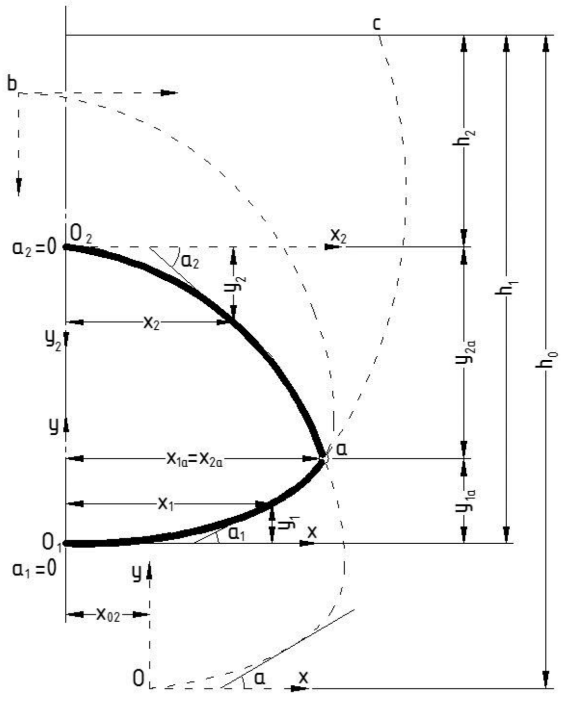


Figure 3 Layout drawing of cross-section of the water pipeline shell made of elastics.

Slika 3. Plan presjeka ovojnice vodenog cjevovoda izrađene od elestičnih traka

The upper elastic can move relatively the lower one so, that the starting point of the lower elastic (α = 0) and the upper endpoint ($\alpha = \pi$) are on the same vertical. Further, when making composition from the lower elastic its initial section is remained. The initial position of the coordinate axes for the initial section remains. For upper elastic it is appointed a new coordinate system, the beginning of which goes to the border of the lower elastic [8, 10].

Parametric equations of upper elastic will have the following form:

$$y_1 = h_1\left[1-\sqrt{1-k_1^2\sin^2\varphi}\right]; \tag{1}$$

$$x_1 = h_1\left[\mathrm{E}(\varphi,k_1)-\left(1-k_1^2/2\right)\mathrm{F}(\varphi,k_1)\right], \tag{2}$$

where x_1 and y_1 - the coordinates of the lower thread, m; h_1 - distance of the farthest point of the lower thread to the surface of the filling, m; E_1 (φ; k_1) and E2 (φ; k_1) - elliptic integrals of the first and second kind, respectively; k_1 - elliptic integral module (module elastics); N_1 - The upper thread tension, *kN / m* φ - angle $\varphi = \alpha_1 / 2$; α_1 - the angle between the tangent to the thread, and the abscissa degrees.

The values of x_1, y_1, α_1, φ the reference points:

$$y_{1a} = h_1[1-\sqrt{1-k_1^2\sin^2\varphi_{a1}}];$$
$$x_{1a} = h_1\left[\mathrm{E}(\varphi_{a1},k_1)-\left(1-k_1^2/2\right)\mathrm{F}(\varphi_{a1},k_1)\right];$$

where $\varphi_{a1} = \alpha_{1a}/2$

When making outlines of the lower thread by equations (4.19), (4.20), the parameter φ needs to receive values in the range $0 \le \varphi \le \varphi_{a1}$.

When $k_1 \le 1$ form of the lower thread will represent elastic of the second kind, while $k_1 > 1$ - elastics of the first kind.

For the upper thread, we accept the coordinate system $x_2O_2y_2$. Parametric equations of upper elastic will look like:

$$y_2 = h_2\left[\sqrt{\left(1-k_2^2\sin^2\varphi\right)/\left(1-k_2^2\right)}-1\right]; \tag{3}$$

$$x_2 = h_2\left\{\left(1-k_2^2/2\right)\left[\mathrm{F}(\pi/2,k_2)-\mathrm{F}(\varphi,k_2)\right]-\left[\mathrm{E}(\pi/2,k_2)-\mathrm{E}(\varphi,k_2)\right]\right\}\Big/\sqrt{1-k_2^2} \tag{4}$$

where x_2 and y_2 - coordinates of the point of the upper thread, m; h_2 - the distance the most remote point of the upper thread, m; $k_2^2 = 4\overline{N_2}/h_2^2 + 4\overline{N_2}$, E_1 (*φ; k*) and E_2 (*φ; k*) - elliptic integrals of the first and second kind, respectively; k_2 - module of elliptic integral (module of elastic); $\overline{N_2}$ - The upper thread tension, *kN /m*; α_2 - the angle between the tangent to the thread and axis x_2 degrees $\varphi_{a2} = (\pi - a_{2a})/2$;.

The coordinates of the reference point:

$$y_{2a} = h_2\left[\sqrt{\left(1-k_2^2\sin^2\varphi_{a2}/1-k_2^2\right)}-1\right];$$

$$x_{2a} = h_2\left\{\left(1-k_2^2/2\right)\left[\mathrm{F}(\pi/2,k_2)-\mathrm{F}(\varphi_{a2},k_2)\right]-\left[\mathrm{E}(\pi/2,k_2)-\mathrm{E}(\varphi_{a2},k_2)\right]\right\}\Big/\sqrt{1-k_2^2}\,.$$

Taking into account the geometric meaning of the parameters, it is easy to notice that in the general case, when the cross-section at the reference point is broken, $\varphi_{a2} \neq \varphi_{a1}$.

The sectional shape of the shell is determined by the set of equations (1) - (4). The conjugation conditions of two threads should be added to these equations, i.e., the boundary conditions at the reference point:

$$y_{1a} + y_{2a} = h_1 - h_2 \ ;$$
$$x_{1a} = x_{2a}$$

In the absence of fracture at the reference point, i.e., in the case of the smooth contour of the cross-section, another boundary condition should be added to these two:

$$\alpha_{1a} + \alpha_{2a} = \pi \ \text{ or}$$
$$\varphi_{a1} = \varphi_{a2} = \varphi$$

Of those already considered values, being included in the task, first of all it is necessary to emphasize as a major and subject to determination are the following: modules k_1 and k_2, values of parameters φ_{a1} and φ_{a2} (or, respectively, values of the angles α_{1a} and α_{2a}), the distances h_1 and h_2, the coordinates of the reference point x_{1a} , y_{1a}, x_{2a} y_{2a}. Cross-sectional area of the shell bounded by the two threads (by the axis of the wall), in the case of a smooth contour, is determined by the formula:

$$\omega = \left[k_1^2 h_1^2 - k_2^2 h_2^2 / \left(1 - k_2^2\right) \right] \sin 2\varphi_a / 2$$

Useful cross-sectional area, taking into account the fact, that the wall thickness is small compared to the size of the cross section, it is permissible to determine the approximate formula:

$$\omega_c = \omega - S_1 \delta_1 - S_2 \delta_2$$

where S_1 and S_2 - length of the upper and lower thread, respectively, m; δ_1 - the distance from the lower thread to the inner surface of the shell, m; δ_2 - distance from the top thread to the inner surface of the shell, m.

Axial perimeter of the shell's cross-section is determined by the formula:

$$S = k_1^2 h_1 \,\mathrm{F}(\varphi_a, k_1) + k_2^2 h_2 \left[\mathrm{F}(\pi/2, k_2) - \mathrm{F}(\varphi_a, k_2) \right] \Big/ \sqrt{1 - k_2^2} \quad (6)$$

Using equations (1) - (4) and (5), (6) in the range of internal pressures from 9.81 to 490.5 kPa, which corresponds to a pressure change in the water pipeline of the derivational HPP at heights of 2 to 50 m there were obtained transversal contours of single-chamber (Figure 4a) and outer shells of two-chamber (Figure 4b).

These transversal contours were used for numerical simulation of hydraulic conditions of one- and two-chamber soft water pipelines.

PART 4 / *Četvrti dio*

To determine the comparative analysis of the hydraulic conditions of the single-shelled and the two-shelled water pipelines, as well as their stress-strain state there was completed the numerical simulation program Ansys 15.0.

The models represent the sections of water pipeline of 30 m length 30m on the surface, fixed in the upper part of the siphon water intake in the perimeter of cross-section having a coefficient of friction between the shell and the surface - 0.3 and the inclination angle to the horizontal plane – 30o.

The simplest case of steady motion, when the pressure is in the range of 1.5 to 3 m in the initial section of water pipe-line, was under consideration.

As the initial cross-sections, there were taken shapes of single-shelled and two-shelled water pipelines variable regarding length depending on the pipeline's internal overpressure (Figure 4).

The starting material of water pipeline was isotropic reinforced with aramid fibers, PVC. It had the following characteristics: thickness 0.004 m; density 750 kg / m3; Poisson's ratio: 0.45; Young's modulus: E = 1,7×109 Pa, tensile strength 14 MPa.

After creation of a 3-D model in the module of Static Structural of environment ANSYS Workbench, the form data were tested under static condition. To simulate, the contact between the shell and the base, there was set up using target surface, which was a base for the contact surface, presenting a shell. Since the shell is not fixed, the boundary condition is effected by restriction of movements of the base in all directions [11].

The results of the comparison of the received data on the analytical dependences and the results of numerical simulations were satisfactory, since the deviation from the horizontal vertical projection of cross-section of a shell for the single-shelled water pipeline was less than 8%, and less than 12% for two shelled water pipeline.

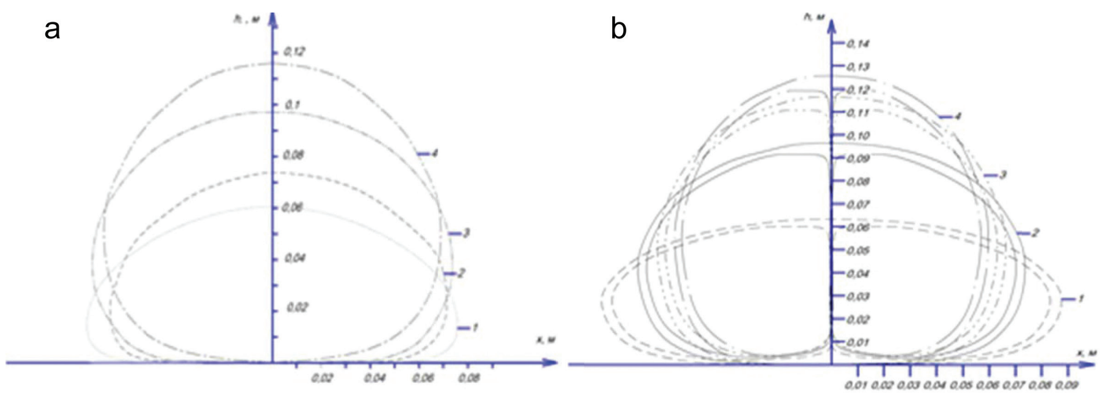
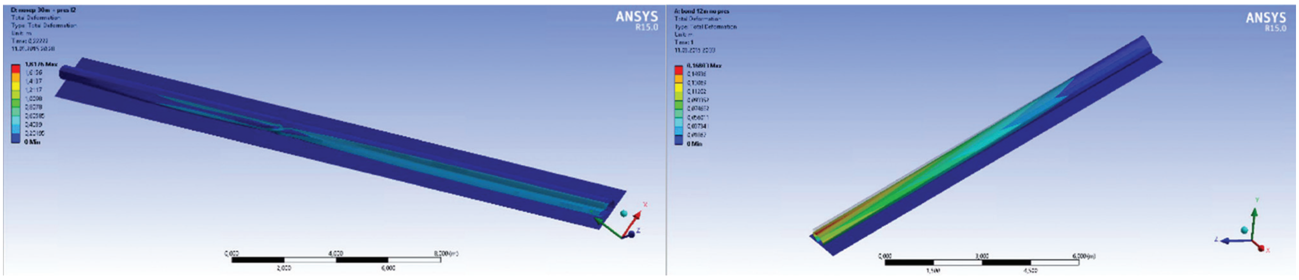


Figure 4 Change in the stress-strain state of a soft shell with perimeter L = 0,4 m, depending on the internal overpressure in the shell (1- 10 кPa, 2-50 кPa, 3-100 кPa, 4-400 кPa): a - for single-chamber shell; b - for two-chamber shell.

Slika 4. Promjena u stanju naprezanja meke ovojnice opsega L = 0,4 m, ovisno o unutarnjem nadtlaku u ovojnici (1- 10 кPa, 2-50 кPa, 3-100 кPa, 4-400 кPa)



a b

Figure 5 Numerical simulation of the section of derivational water pipeline of 30 m length and a slope surface along its route 30º
Slika 5. Numerička simulacija dijela derivacijskog vodenog cjevovoda duljine 30 m i površina nagiba od 30º
a, b - respectively single-shelled and two-shelled water pipeline.

Then, for the flow of water using module Fluid CFX based on the same geometric model there were calculated speed and the hydrodynamic pressure on the wall of the single-shelled and two-shelled water pipeline. They were then re-applied as external loads on the module to determine the Static Structural deformations, including those associated with the transverse torsion of the water pipeline.

Examples of the results of research of single- and two-shelled water pipeline with the same perimeters on the outer shell of 0.4 m are shown in Figure 5.

As seen in Figure 5 at a distance of 12 m, it happens twisting of flexible single-shell water pipeline (Figure 5a), which will requires when it is applied, extra fixtures in inaccessible mountains. At the same time two-shelled water pipeline as seen in (Figure 5, b) does not curl and the deformation is within the limits of elastic. In this regard, despite the greater amount of material, safe operation of the waterway, will be provided and the length of the sections can be increased

The work is carried out by the authors in the framework of the agreement № 14.579.21.0029 for a grant from 06.05.2014. The theme: "Development of technical solutions and construction technologies of mobile derivational micro-HPP for seasonal "water - and energy supply" on the instructions of the Ministry of Education and Science of the Russian Federation Federal Program "Research and development on priority directions of scientific-technological complex of Russia for 2014 - 2020 years". Unique identifier of Applied Scientific Research (project) RFMEFI57914X0029.

ABSTRACTS / *Sažeci*

Based on the analysis of natural and climatic characteristics and development prospects of Russky Island, there were detected the need for additional supply of water and seasonal activities for the touristic - recreational facilities, including port facilities.

There was proved the application of new technical solutions regarding use of the mobile derivational micro-HPP for seasonal water-supply of facilities and recreational infrastructure of the Russky Island with reduced ecological environmental impact.

Achieved justifying calculations of sections for the derivational water pipeline with soft shells, defined by their parameters for a range of pressures 9,81 … 490,5 кPa. Numerical simulation in Ansys 15.0 of program module Static Structural showed them sufficient convergence with the results of analytical formulas (1) - (4) with static analysis The maximum deviation was equal to 12%, which is acceptable in the case of large deformations. In the future, depending on the data it will be used for pre-calculation of the two-shelled soft water pipe configuration.

The results of numerical modeling of the hydraulic conditions of one- and two-chambered shells made in the program Ansys 15.0 allow to make a conclusion that on the areas with a length of more than 30 m and an inclination of 30º on the line of the pipeline, twisting of single-shelled water pipeline occurs, so more optimal is to use two-shelled construction, which will provide higher reliability of operation of the derivational water pipeline.

REFERENCES / *Literatura*

1. Maslennikov B. G. Peter the Great Bay. Vladivostok: the Far Eastern Book publisher, 1956. – 76 p.
2. Decree of the Government of Russia No. 201 of 31 of March 2010 "On the development of a tourist-recreation special economic zone on the territory of Ryssky Island, Vladivostok urban district, Primorsky Krai"
3. http://apec.primorsky.ru/
4. Mostovaya O. Megawatts for a Russian. 'Electric power. Transmission and distribution' No. 4 (13), «Kabel» Book publisher – Moscow – 30-33pp. http://old.eepr.ru/2012/08/24/chitajte-v-chetvyortom-nomere-zhurnala-elektroenergiya-peredacha-i-raspredelenie-za-2012-god
5. Guremina N.V. Enviromental state and prospects for the recreation development of Russky Island in the Peter the Great bay (the Sea of Japan)// data of the first interregional conference 'Modern problems of regional development" – Birobidzhan: book publisher: IRPIA EB RAS, 2006 – 18-20pp.
6. http://www.pandia.ru/text/77/151/5874.php
7. Moshenko A.V. Geographic position and hydrological regime of the Peter the Great bay//Regional portal "Primorsky Krai, Russia" (http://www.fegi.ru/PRIMORYE/SEA/gidro.htm). 2002
8. Kasharin D. V., Kasharina T. P., Godin P. A., Godin M. A. Use of pipelines fabricated from composite materials for mobile diversion hydroelectric power plants//Power Technology and Engineering. 2015. T. 48. № 6. C. 448-452.
9. The application for the invention RU MPK E02B9/02 №2015106761. Integral mobile diversion conduit and method of construction. date of filing 26.02.2015
10. Kasharin D.V. Protective engineerring structures of composite materials in hydroeconomic construction: monograph]/ Novocherkassk YuRGTU, 2012, 343 p.
11. ANSYS mechanical APDL guide structural analysis. - ANSYS, Inc., 2012. – C. 841-1110.