Magazine of Civil Engineering. 2019. 89(5). Pp. 16–25
Инженерно-строительный журнал. 2019. № 5(89). С. 16–25

Magazine of Civil Engineering

journal homepage: http://engstroy.spbstu.ru/

ISSN
2071-0305

DOI: 10.18720/MCE.89.2

Clay-cement-concrete diaphragm — justifying calculation for new-built constructions

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Keywords: embankment dam, clay-cement concrete diaphragm, bored-secant piles, strain-stress state, soil/structure interaction, numerical modeling, cut-of wall, strength

Abstract. Due to the observed improvement of machines and mechanisms and the process equipment thereof used during the construction of clay-cement concrete slurry walls by means of bored-secant piles, the author proposes to extend the range of considered designs of impervious elements of embankment dams by adding modifications with an arch diaphragm and an inclined diaphragm. Performed surveys and comparisons with the traditional design (vertical wall) allowed to identify the main trends of the influence of using the effect of clay-cement concrete diaphragms inclination and the arch effect on the change in the strain-stress state of the embankment dam — diaphragm system. Consideration of the clay-cement concrete diaphragm designs proposed by the author in designing embankment dams will allow extending the range of possible application of this technical solution. It was established that there is a possibility to optimize the existing technical solutions for the clay-cement concrete diaphragm embankment dams if they are designed with due consideration of not only the assignment of clay-cement concrete strength and strain-stress properties, but also taking into account the change in configuration of the diaphragm itself.

1. Introduction

The distinguishing features of hydraulic power facilities defined by high investment costs of construction have justified the need for research aimed at finding the new and improving the existing technical and process solutions for the construction of hydraulic power facilities, ensuring application of modern machines and mechanisms and use of new materials.

One of the ways to reduce the time for a dam construction is to replace the classic impervious element, for example, an asphalt-concrete one, with a clay-cement-concrete cut-off wall constructed by means of using bored-secant piles.

Paragraph [1–5] contains data on hydraulic engineering structures with thin impervious elements of various designs built around the globe, including those built using clay-cement concrete; the same paragraph also specifies the peculiarities of operation of such structures.

Surveys and works related to the above-mentioned field have also been carried out in Russia. Paragraph [6–10] contains a description and analysis of the Russian experience of building an impervious element for embankment dams represented by clay-cement-concrete diaphragms in the course of design, reparation and construction of hydraulic structures.

In Russia, this technical solution was first applied in 2017 during the construction of the Nizhne-Bureyskaya HPP located in Amurskaya Oblast. The structures of the Nizhne-Bureyskaya HPP waterfront include: the spillway, the HPP building, the left-bank embankment dam with the length of 400.0 m and maximum height of 38.0 m. The embankment dam features an impervious element, which is a thin clay-cement-concrete diaphragm created after the erection of the embankment dam body to the design elevations during one construction season.

Orishchuk, R.N. Clay-cement-concrete diaphragm – justifying calculation for new-built constructions. Magazine of Civil Engineering. 2019. 89(5). Pp. 16–25. DOI: 10.18720/MCE.89.2.

Орищук Р.Н. Глиноцементобетонная диафрагма, расчётное обоснование новых конструкций // Инженерно-строительный журнал. 2019. № 5(89). С. 16–25. DOI: 10.18720/MCE.89.2.

This solution was applied at hydraulic power facilities with such height parameters and productive head pressures for the first time in the world (Figure 1).

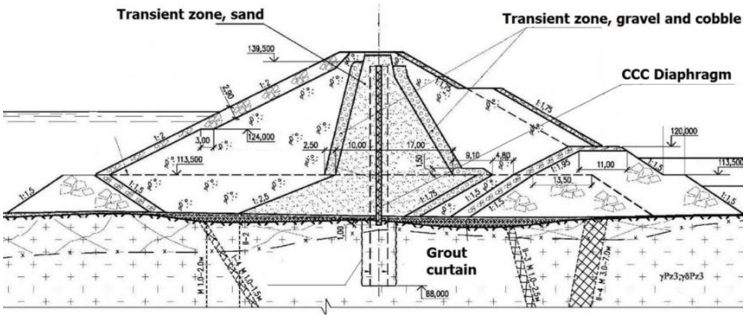


Figure 1. Cross section of Nizhne-Bureyskaya HPP embankment dam.

The experience of construction and operation of the Nizhne-Bureyskaya HPP embankment dam has demonstrated high efficiency of the proposed technical solution. With a comparable cost of construction of an embankment dam with an option involving core erection using local cohesive soils, the implemented technical solution allowed to reduce the dam construction time from 22 to 14 months. The scientific and technical justification of reliability and safety of such impervious elements and the development of design and process solutions was performed by the JSC “Vedeneev VNIIG” and JSC “Lenhydroproject”.

Previously at the Gotsatlinskaya HPP located in the Republic of Dagestan (Russian Federation), during the preliminary design stage a solution involving the installation of an impervious clay-cement concrete diaphragm using the bored-secant piles method was considered as one of the possible technical solutions for the installation of an impervious element in the embankment dam body (Figure 2).

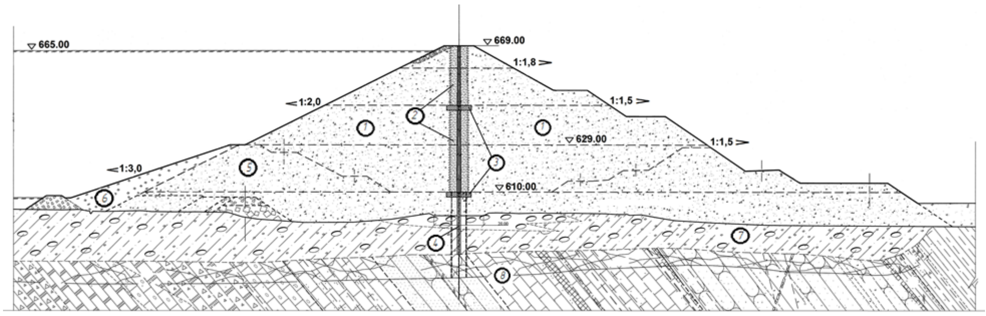


Figure 2. Design cross section of Gotsatlinskaya HPP embankment dam: 1 — downstream and upstream shells; 2 — stages (layers) of diaphragm construction; 3 — joint of connection between diaphragm layers and foundation (foreshaft); 4 — impervious element; 5 — upstream cofferdam; 6 — impervious screen; 7 — alluvial base; 8 — bedrock base.

The set of calculations performed in ABAQUS 2016 specialized software aimed at justification of the possibility of constructing a clay-cement-concrete diaphragm embankment dam by means of bored-secant piles method using the Gotsatlinskaya HPP as an example has shown that the calculated diaphragm compressive stresses are close to the maximum allowed values for clay-cement concrete and amount approximately to 1.65–1.80 MPa. In addition to that, calculations revealed extensive areas of diaphragm tensile stresses confined to the side abutments with maximum tensile stresses in the crest part of the dam equal to 0.33 MPa (0.21 MPa [11] along the board).

Tensile stresses significantly reduce the reliability of WTE operation, especially for the clay-cement concrete diaphragm constructed by means of bored-secant piles which is characterized by vertical split seams presence; movement along such seams can lead to their opening and blowout piping, both along the seams and in contact with the side abutments. Due to the lack of scientific and technical justification of the possibility of reliable clay-cement-concrete diaphragms operation at the start of the dam body backfill (2012–2013) and taking into account the high seismic activity of the hydraulic power station area, a decision was taken to abandon the clay-cement-concrete diaphragms design in favor of the classical option involving an impervious element made of asphalt concrete.

At present, considering the accumulated practical experience gained during Nizhne-Bureyskaya HPP construction as well as the performed set of research works aimed at finding solutions to ensure reliable operation of this type of impervious element, it can be stated that its widespread use is justified (if the relevant justification is available) in the design of an embankment dam with the height of up to 100 m. It should be noted that the equipment that has appeared in the arsenal of construction companies (inclined drilling machines) as well as the accumulated practical experience could significantly extend the range of designs available with this type of an impervious element, including construction of diaphragms in the form of arches or erection of flat diaphragms at predetermined slope angles [12].

No solutions similar to the one proposed by the author exist anywhere else in the world. The survey results contained in this article may allow for using them both for structures elaboration at the design stage and for construction of embankment dams not only in Russia but also when implementing hydraulic engineering projects worldwide.

Based on the necessity of ensuring the required embankment dams reliability and safety level with the proposed impervious element type and the reduction of tensile stresses risk in the diaphragm body, the author has carried out a set of calculations in order to assess the change in the strain-stress state of the diaphragm when its configuration is changed.

This survey was aimed at analyzing the influence of changes in the configuration of the clay-cement-concrete diaphragm of an embankment dam on its strain-stress state.

The following tasks were set and then solved in order to achieve this goal:

1. To elaborate a numerical model of an embankment dam (taking as an example the Gotsatlinskaya HPP embankment dam site) based on the ABAQUS 2016 finite-element software package;

2. To elaborate a plan for calculation experiments and perform the relative calculations regarding the two possible technical solutions aiming at establishing the conditions for a more favorable strain-stress state of clay-cement-concrete diaphragms: the option with an arch outline diaphragm and the other option with an inclined diaphragm.

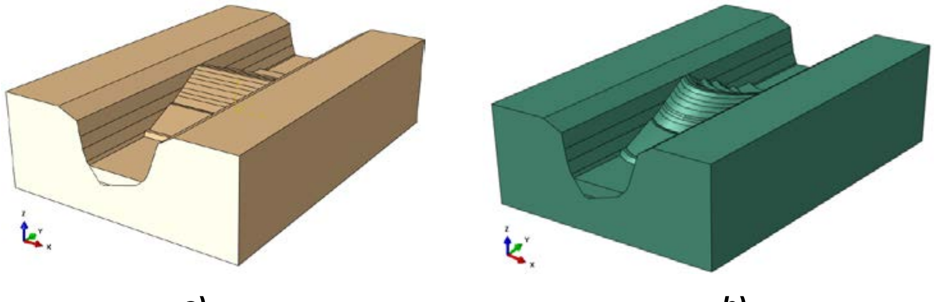
3. To compare the results of the strain-stress state calculations performed with the results of previous calculations of the strain-stress state of an embankment dam having a traditional vertical clay-cement-concrete diaphragm regarding the values of horizontal displacement, maximum settlement, tensile stress and compressive stress.

2. Methods

The author has elaborated a numerical model of an embankment dam (taking as an example the Gotsatlinskaya HPP embankment dam site) based on the ABAQUS 2016 finite-element software package; all the embankment dam material properties and clay-cement concrete properties were assumed to be identical in order to allow for a correct comparison of calculation results. The diameter of the bored-secant piles of the clay-cement-concrete diaphragm was assumed as 1.2 m for all options.

A model of a dam with an inclined flat clay-cement-concrete diaphragm with a vertical deviation of 15° towards the tail race is shown in Figure 3a. A simulation model of an embankment dam with a vertical arch clay-cement-concrete diaphragm is shown in Figure 3b. The dam body is represented by a part of an arch-shaped shell with the radial section coinciding with the dam cross section. In this case, the clay-cement-concrete diaphragm is an arch integrated into the side abutments with a horizontal curve radius of 90 m.

The following materials were used in the numerical simulation: [12–18].



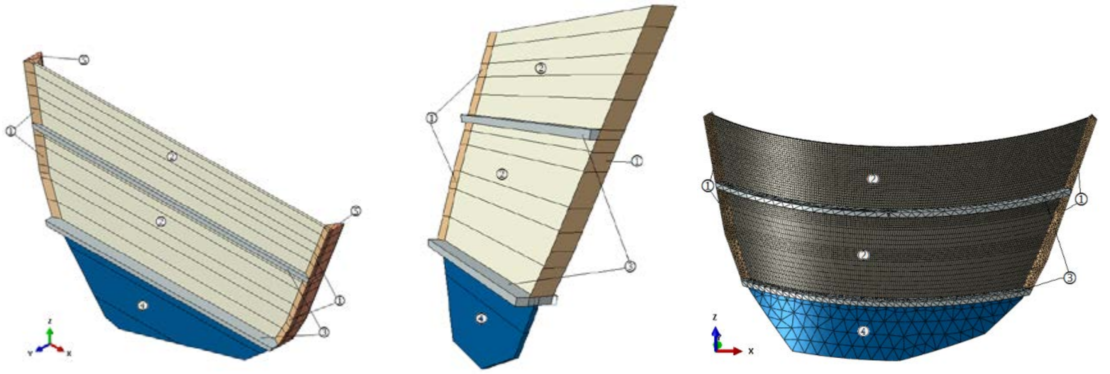
a) ***b)***

Figure 3. Overall view of «Gotsatlinskaya HPP — foundation system» three-dimensional model: *a)* a flat vertical or inclined diaphragm dam; *b)* an arch diaphragm dam.

A three-dimensional model of the studied impervious elements is shown in Figure 4.

Calculation experiments planning was performed with consideration of such factors as compliance with the absolutely identical boundary conditions in order to ensure the possibility of comparing the obtained results and with two options considered according to the conditions for filling the reservoir and the possibilities of establishing the conditions for a more favorable strain-stress state of clay-cement-concrete diaphragms for the proposed options with an arch outline diaphragm and the other option with an inclined diaphragm.

Two reservoir filling cases were considered for the options of a soil embankment with various clay-cement-concrete diaphragms:



a) Vertical *b) Inclined* *c) Arch*

Figure 4. Three-dimensional model of dam non-soil impervious elements:
1 — CCC cushions; 2 — diaphragm layers; 3 — foreshaft; 4 — cut-off wall; 5 — rock abutment.

First option includes filling the reservoir in two steps:

A) After the construction of the upstream cofferdam and the cut-off wall, the water level in the reservoir rises from the elevation of 602.0 to 628.0;

B) After the construction is complete, the water in the reservoir rises from the elevation of 628.0 to the elevation of 665.0, which corresponds to the normal flood control storage level.

Second option includes filling the reservoir in three steps:

A) After the construction of the upstream cofferdam and the cut-off wall, the water level in the reservoir rises from the elevation of 602.0 to 628.0;

B) After the installation of the first diaphragm layer, the reservoir is filled from the elevation of 628.0 to the intermediate elevation of 643.0;

C) After the construction is complete, the level rises from the elevation of 643.0 to the flood control storage level of 665.0.

The consolidated plan developed for calculating strain-stress state of the options is presented in Table 1.

Table 1. Plan of Options for Calculating Strain-Stress State of Gotsatlinskaya HPP Embankment Dam Site with a Flat Vertical, Flat Inclined and Arch Clay-Cement-Concrete Diaphragm.

Number of layers	Number of filling stages	Clay-cement-concrete diaphragm design		
		Flat vertical	Flat inclined	Arch vertical
One layer of bored-secant clay-cement-concrete piles	3	+	–	–
Two layers of bored-secant clay-cement-concrete piles	2	+	+	+
	3	+	+	+

3. Results and Discussion

The results have been compared with the results of calculations for the vertical clay-cement-concrete diaphragm previously performed by the author and presented in [11].The following parameters describing the clay-cement-concrete diaphragm working conditions for all the options considered have been compared: values of horizontal displacement, maximum settlement, tensile stress and compressive stress.

The results of diaphragm displacement calculation for the considered configurations for the two-layer diaphragm options with 2 and 3 stages of reservoir filling are given in Table 2.

Table 2. Displacement Calculation Results for an Embankment Dam with a Flat Vertical, Flat Inclined and Arch Vertical clay-cement-concrete diaphragm.

Number of layers	Reservoir filling mode	Clay-cement-concrete diaphragm design	Maximum diaphragm displacement towards tail race, cm	Percentage of area of clay-cement-concrete diaphragm displacement towards tail race, (by more than 20 cm) from total area, %	Deviation of crest part towards the headrace, cm
Two layers	2 stages	Flat vertical	33	22	8
		Flat inclined	25	15	5
		Arch vertical	25	20	9
Two layers	3 stages	Flat vertical	32	18	4
		Flat inclined	22	5	1
		Arch vertical	22	15	4

When analyzing the obtained results, it can be noted that the maximum horizontal displacements for the proposed alternative configurations almost coincide and fall within the range of 22–25 cm, the highest values of the maximum displacement correspond to the vertical diaphragm option while these displacements are essentially independent from the phasing of reservoir filling and equal 32–33 cm.

It is also apparent when comparing the area of the diaphragm sections with displacements exceeding 20 cm that movements are mostly specific to the option with a flat inclined diaphragm which are 0.7 times less than those of the classical vertical diaphragm option in the case of 2-stage filling and 3.6 times less in the case of 3-stage filling. The change in the reservoir filling mode produces the maximum positive effect on the option with a flat inclined diaphragm as the area of the maximum displacement zone reduces by exactly 3.0 times. This pattern is also observed in horizontal displacements of tilting towards the headrace of the clay-cement-concrete diaphragm crest part.

All the considered configuration options in the setting of almost equal maximum horizontal displacements are generally in more favorable conditions characterized by a smaller overall displacement of the whole diaphragm body and a lesser tilt towards the headrace in case of a three-stage filling as compared to the two-stage filling mode. The change in the filling mode has the most significant effect on the inclined diaphragm option that, for the case being considered, has the smallest areas of maximum horizontal displacements.

The results of maximum settlement calculations for all the clay-cement-concrete diaphragm configurations considered are given in Table 3.

Table 3. Maximum Settlement Calculation Results for an Embankment Dam with a Flat Vertical, Flat Inclined and Arch Vertical Clay-Cement-Concrete Diaphragm.

Number of layers	Reservoir filling mode	Clay-cement-concrete diaphragm design	Maximum diaphragm settlement values, cm
Two layers	2 stages	Flat vertical	45
		Flat inclined	36
		Arch vertical	42
Two layers	3 stages	Flat vertical	40
		Flat inclined	30
		Arch vertical	32

Table 3 shows that for all the clay-cement-concrete diaphragm configuration options and reservoir filling modes in 2 and 3 stages the spread in maximum settlement values is relatively small and ranges from 30 to 45 cm. At the same time, for all considered stages of reservoir filling, the inclined diaphragm option shows minimum settlement with values 0.75–0.80 times less than the classical option with a vertical diaphragm.

In general, it can be noted that the more favorable case having the lowest values of the maximum vertical settlement is the one with a three-stage reservoir filling characterized by a decrease in their values by (11–24) % in relation to the two-stage filling; same is noted for the maximum horizontal displacements. In general, the settlement has a value of approximately (0.5–0.7) % of the dam height and are permissible.

The analysis of the results of strain-stress state calculation for different options of the clay-cement-concrete diaphragm configurations with tensile stresses considered is given in Table 4. The resulting values are also compared in terms of various design cases of reservoir filling – filling in 2 and 3 stages. The table contains maximum tensile stress values for the side abutments of the embankment dam first and second layers and in the upper crest belt.

Table 4. Results of Calculations of Tensile Areas of an Embankment Dam Design with a Flat Vertical, Flat Inclined and Arch Vertical Clay-Cement-Concrete Diaphragm.

Number of layers	**Reservoir filling mode**	**Design** clay-cement-concrete diaphragms	**Maximum tensile stresses, MPa**	**Tensile stresses in side abutments (b is strip width)**		**Tensile stresses of the upper crest belt (b is strip width)**
				1st layer	**2st layer**	
Two layers	2 stages	Flat vertical	0.33	Up to 0.2 MPa at b ≤ 2–3 m	Up to 0.2–0.3 MPa at b ≤ 3–5 m	Up to 0.15 MPa at b ≤ 3–4 m
		Flat inclined	0.33	Up to 0.2 MPa at b ≤ 2 m	Up to 0.2–0.3 MPa at b ≤ 1–3 m	Up to 0.06 MPa at b ≤ 4–6 m
		Arch vertical	0.33	Very low	Up to 0.15 MPa at b ≤ 1–3 m	Up to 0.03 MPa at b ≤ 2–3 m
Two layers	3 stages	Flat vertical	0.30	Up to 0.15 MPa at b ≤ 3 m	Up to 0.24 MPa at b ≤ 2 m	Up to 0.06 MPa at b ≤ 2 m
		Flat inclined	0.20	Very low	Up to 0.15 MPa at b ≤ 1 m	Very low
		Arch vertical	0.27	Very low	Up to 0.12 MPa at b ≤ 0.5 m	Up to 0.03 MPa at b ≤ 1–1.5 m

The resulting stress values for the considered clay-cement-concrete diaphragm configurations shall be compared according to the ones previously determined for clay-cement-concrete [11]. The adopted Mohr-Coulomb yield criteria, $\mathrm{tg}\,\varphi = 0.78$ and $c = 0.32$ MPa, correspond to the ultimate tensile strength $R_t = 0.31$ MPa and the ultimate compressive strength $R_c = 1.35$ MPa. These values conform to the average values of the clay-cement-concrete strength characteristics for the formulae previously applied and studied.

It should be noted that the maximum tensile stresses for these design cases are within the range of 0.33–0.20 MPa, and their upper value exceeds the maximum allowable values for clay-cement-concrete. At the same time, these maximum stresses occur in the local crest zone of the dam confined to the side abutments above the flood control storage level elevations and, accordingly, in general do not have any significant effect on the reliability of its operation.

The calculation option with reservoir filling in 2 stages is characterized by the maximum tensile stresses. When the pattern of reservoir filing is changed, a significant decrease is observed in tensile stresses for the arch and inclined diaphragm configurations by 0.8 and 0.6 times, respectively, while for the flat vertical diaphragm this decrease is not so significant.

It should be noted that the values of side abutments tensile stresses for the flat vertical diaphragm option (in the second layer) are close to the maximum allowable ones for all considered stages of reservoir filling. For the rest of the considered options, the tensile stress values in case of the 3-stage reservoir filling do not exceed 0.15 MPa, which ensures reliable diaphragm operation.

Tensile stresses in the upper crest belt for all the cases considered are small and do not exceed the allowable values.

Minimum tensile stresses in side abutments have been obtained for the arch configuration diaphragm with the option of 3-stage reservoir filling.

Table 5 contains the strain-stress state calculation results for a clay-cement-concrete diaphragm determining the compressive stresses. The table shows the values of maximum compressive stresses in clay-cement-concrete diaphragm sides and body for the first and second layers and in various reservoir filling modes.

Table 5. Compressive Stress Calculation Results for an Embankment Dam with a Flat Vertical, Flat Inclined and Arch Vertical Clay-Cement-Concrete Diaphragm.

Number of layers	**Reservoir filling mode**	**Design** clay-cement-concrete diaphragms	**Maximum compressive stresses, MPa**			
			Layer 1		**Layer 2**	
			Side	**Body**	**Side**	**Body**
Two layers	2 stages	Flat vertical	1.65	1.1	0.6	0.3
		Flat inclined	1.67	1.0	0.4	0.4
		Arch vertical	1.85	1.1	0.8	0.4
Two layers	3 stages	Flat vertical	1.65	1.0	0.5	0.3
		Flat inclined	1.26	0.9	0.3	0.4
		Arch vertical	1.71	0.9	0.6	0.5

The maximum compressive stresses are confined to the first layer side abutments and fall within the range between 1.26 MPa and 1.85 MPa. The bigger values are as follows: 1.65 MPa for the flat vertical design, 1.67 MPa for the flat inclined design and 1.85 MPa for the arch vertical design corresponding to the option of 2-stage reservoir filling. The resulting calculated valuesof compressive stresses in the side abutments for all considered cases exceed or are close to the maximum allowable values for the adopted ultimate compression strength of clay-cement-concrete $R_c = 1.35$ MPa. At the same time, these stresses are confined to narrow areas with a width not exceeding 0.5–1.0 m and, probably, they will require only some adjustment of the applied clay-cement-concrete composition in order to ensure that the maximum allowable values of clay-cement-concrete compressive strength are not exceeded. This statement is particularly true in relation to the inclined flat diaphragm option where a more favorable pattern of compressive stresses distribution is observed.

Maximum compressive stresses of the first layer of the clay-cement-concrete diaphragm body for all configurations, regardless of the phasing of reservoir filling, have little difference and are about 1.0 MPa. For the second layer of all the considered clay-cement-concrete diaphragm structures, the compressive stress values are 2.0–2.5 times smaller.

In general, it can be noted that the calculated maximum compressive stresses in all considered clay-cement-concrete diaphragm designs (flat vertical, flat inclined, arch vertical) mostly do not exceed the maximum allowable values of clay-cement-concrete compressive strength. The exception is the narrow areas of increased compressive stresses resulting from the calculations of these diaphragms, which are located in the first layer along the line of side abutment on the tail race end. However, these areas do not pose any danger to the structure since they do not extend into the depth of the diaphragm, but are localized in the outer layer with the thickness of not more than 1.0 m.

The complex numerical simulation performed allowed to identify the main trends of the influence of using the effect of the clay-cement-concrete diaphragm inclination and the influence of the arch effect on the strain-stress state of an embankment dam with a clay-cement-concrete diaphragm.

Based on the results of the analysis of the three-dimensional model performed using the example of the Gotsatlinskaya HPP embankment dam with a clay-cement-concrete diaphragm, an extremely complex strain-stress state pattern was obtained describing the connections of the strain-stress state both with the design features of the diaphragm itself and the embankment dam installation procedure, and with reservoir filling mode, that is, creating the pressure head of the structure.

It has been determined that settlement and displacements causing dangerous tensile stresses that may lead to clay-cement-concrete diaphragm cracking occur in the following sections:

– in the upper clay-cement-concrete diaphragm belt, however, they do not spread deep inside the impervious element and are localized within the first 2–3 m from the clay-cement-concrete diaphragm crest. They may potentially lead to the opening of a rhythmic sub-vertical joint system;

– in the side abutments, observed along the entire abutment length, potentially forming sub-vertical displacement cracks, with the nature of the deformations and the presence of clay-cement-concrete cushions in the abutments to the rock sides and concrete abutments considered, without crack opening;

– in contact with the foundation, observed along the entire length of the abutment to the foundation, potentially forming sub-horizontal displacement cracks, with the nature of deformations and the presence of foreshaft in the foundation abutment considered, without crack opening;

– in the lower third of the central clay-cement-concrete diaphragm part due to the nature of displacement towards the tail race under water pressure, an area of maximum deformations is formed in the clay-cement-concrete diaphragm, with the potential possibility of opening of a radial sub-horizontal and sub-vertical cracks.

To ensure reliable functioning of a clay-cement-concrete diaphragm during the entire period of the embankment dam operation, special attention should be paid to these areas when designing protective or remedial measures during supervision at construction and operation stages; at the same time, in the design special attention should be paid to the issues of reservoir filling mode assignment, and actual compliance therewith should be ensured. It is necessary to ensure the required quality of construction and installation works, availability of construction and technical supervision over construction works. The research results also confirm the potential possibility of cracks opening in the clay-cement-concrete diaphragm body for all considered configurations, which confirms the relevance of development of a clay-cement-concrete diaphragm design with an obligatory mending layer in the transition zone from the headrace side [19–21].

The performed numerical simulation and detailed analysis of the strain-stress state calculation results for different configurations of a two-layer clay-cement-concrete diaphragm (with the specified foundation properties), dam body and clay-cement-concrete have revealed that for the inclined flat diaphragm option the minimum horizontal displacements and vertical settlement were obtained; the strain-stress state pattern is more favorable as well. This option can be recommended for further elaboration and preparation of justification materials for the application thereof as an impervious element in an embankment dam with a height exceeding 70 meters, for which using the classical option with a vertical clay-cement-concrete diaphragm is already significantly difficult.

When designing an embankment dam with a clay-cement-concrete diaphragm in the future, it is generally reasonable to account for technical and process possibilities of erecting diaphragms both with the effect of inclination and the arch effect, and to consider these options taking into account the identified trends in the influence of these effects on the strain-stress state of an embankment dam with a clay-cement-concrete diaphragm.

An important condition ensuring the following reliable and safe operation of an embankment dam with this type of impervious element is the development of the process flow-charts for dam construction providing exhaustive information on the process flow of work performance and controlled parameters within the construction arrangement design.

4. Conclusions

1. For purposes of analyzing the influence of changes in the clay-cement-concrete diaphragm configuration of an embankment dam on its strain-stress state a numerical model of an embankment dam (taking as an example the Gotsatlinskaya HPP embankment dam site) based on the ABAQUS 2016 finite-element software package has been elaborated;

2. A plan for calculation experiments has been elaborated and mathematic simulation has been performed in relation to the technical solutions aiming at establishing the conditions for a more favorable strain-

stress state of clay-cement-concrete diaphragms proposed by the author: the option with an arch outline diaphragm and the other option with an inclined diaphragm.

3. The results of the strain-stress state calculations performed have been analyzed and compared with the results of previous calculations of the strain-stress state that showed the main trends of the influence of clay-cement-concrete diaphragm configurations as compared to a traditional vertical clay-cement-concrete diaphragm regarding the values of horizontal displacement, maximum settlement, tensile stress and compressive stress.

References

1. Radchenko, V.G., Lopatina, M.G., Nikolaichuk, Ye.V., Radchenko, S.V. Opyt vozvedeniya protivofiltracionnyh ustrojstv iz gruntocementnyh smesej [Experience in construction of water seals from soil-cement mixtures]. Gidrotekhnicheskoe Stroitel'stvo. 2012. No. 6. Pp. 46–54. (rus)
2. Fedoseyev, V.I., Shishov, I.N., Pekhtin, V.A., Krivonogova, N.F., Kagan, A.A. Protivofiltracionnye zavesy gidrotekhnicheskih sooruzhenij na mnogoletnej merzlote [Grout curtains of hydraulic structures on permafrost]. Experience in Design and Work Performance In 2 volumes. Saint Petersburg: JSC «Vedeneev VNIIG». 2009. Vol. 2. Pp. 303–316. (rus)
3. Argal, E.S., Korolev, V.M. On some properties of claycement concrete and features of cutoff wall in dam body. Gidrotekhnicheskoe Stroitel'stvo. 2019. No. 5. Pp. 10–19.
4. ICOLD. Soil-cement for embankment dams. Bulletin № 54. 1986.
5. Lorenz, W., List, F. Application of the trench diaphragm method in constructing the impervious core of dams consisting in part of low-grade fill material. 12-th ICOLD Congress. 1976. Q. 44, R. 6. Mexico. Pp. 93–104.
6. Orishchuk, R.N. Problemy proektirovaniya, stroitelstva i ekspluatacii glinocementobetonnyh diafragm gruntovyh plotin, vozvodimyh metodom burosekushchihsya svaj [Design, construction and operation issues of clay-cement-concrete diaphragms of soil dams mounted by means of bored-secant piles]. Izvestia of B.E. Vedeneev VNIIG, JSC. 2018. Vol. 287. Pp. 3–13. (rus)
7. Radzinskiy, A.V., Rasskazov, L.N., Sainov, M.P. Plotina stometrovoy vysoty s glinotsementobetonnoy diafragmoy po tipu «stena v grunte» [Clay-cement Concrete Diaphragm of the Type «Slurry Wall» in the 100 Meter High Dam]. Vestnik MGSU [Proceedings of Moscow State University of Civil Engineering]. 2014. No. 9. Pp. 106–115. DOI 10.22227/1997-0935.2014.9.106-115 (rus)
8. Miltsin, V.L., Orishchuk, R.N., Solskiy, S.V. Rekomendacii po proektirovaniyu, raschetam i vozvedeniyu protivofiltracionnogo elementa iz glinocementobetonnyh burosekushchihsya svaj [Recommendations on design, calculations and erection of a watertight element from clay-cement-concrete bored-secant piles]. Company Standard. – STP 310.02.NT-2017. St. Petersburg: B.E. Vedeneev VNIIG, JSC, 2017. 117 p. (rus)
9. Sainov, M.P., Soroka, V.B. Ultra-high rockfill dam with combination of the reinforced concrete face and clay-cement diaphragm. Magazine of Civil Engineering. 2018. 81(5). Pp. 135–148. DOI 10.18720/MCE.81.14
10. Borzunov, V.V., Denisov, G.V., Kadushkina, E.A., Nikolaeva, E.A., Fedorov, A.V. Experience in design and construction of the Nizhne-Bureyskaya HPP embankment dam using a bored-secant piles diaphragm as an impervious element. Gidrotekhnicheskoe Stroitel'stvo. 2019. No. 6. Pp. 2–11.
11. Prokopovich, V.S., Velichko, A.S., Orischuk, R.N. Napryazhenno-deformirovannoye sostoyaniye zemlyanoy plotiny s glinotsementobetonnoy diafragmoy na primere zemlyanoy plotiny Gotsatlinskoy GES [Analysis of stress-strain state of embankment dam with CCCD]. Izvestia of B.E. Vedeneev VNIIG, JSC. 2016. Vol. 282. Pp. 87–98. (rus)
12. Orishchuk, R.N. Novye konstrukcii gruntovyh plotin s glinocementobetonnymi diafragmami [New designs of soil dams with clay-cement-concrete diaphragms]. Izvestia of B.E. Vedeneev VNIIG, JSC. 2019. Vol. 292. Pp. 21–30. (rus)
13. Kang, F.E.I., Han-Long, L. Secondary development of ABAQUS and its application to static and dynamic analyses of earth-rockfill dam. Rock and Soil Mechanics. 2010. Vol. 31. No. 3. Pp. 881–890.
14. Rasskazov, L.N., Radzinsky, A.V., Sainov, M.P. Plotiny s glinotsementobetonnoy diafragmoy: napryazhenno-deformirovannoye sostoyaniye i prochnost [Dams with clay-cement concrete diaphragm stress-strain state and strength]. Gidrotekhnicheskoe Stroitel'stvo. 2014. No. 9. Pp. 37–44. (rus)
15. Rekomendacii po raschetu napryazhenno-deformirovannogo sostoyaniya i ustojchivosti vysokih plotin iz gruntovyh materialov pri staticheskih i sejsmicheskih vozdejstviyah P 824-85 [Recommendations on calculation of the strain-stress state and stability of high dams of soil materials under static and seismic influences P 824-85]. Moscow: Hydroproject. 1985. Pp. 112. (rus)
16. Sainov, M.P. Osobennosti chislennogo modelirovaniya napryazhenno-deformirovannogo sostoyaniya gruntovykh plotin s tonkimi zhestkimi protivofi l'tratsionnymi elementami [Numerical Modeling of the Stress-Strain State of Earth Dams That Have Thin Rigid Seepage Control Elements]. Vestnik MGSU [Proceedings of Moscow State University of Civil Engineering]. 2012. No. 10. Pp. 102–108. DOI 10.22227/1997-0935.2012.10.102-108. (rus)
17. Sainov, M.P. Priblizhjonnyj prognoz prochnosti protivofil'tracionnoj steny v osnovanii plotiny [Approximate prognosis of the strength of the anti-seepage wall at the base of the dam]. Nauchnoe obozrenie. 2017. No. 4. Pp. 34–38. (rus)
18. Luo, Z.J., Zhang, Y.Y., Wu, Y.X. Finite element numerical simulation of three-dimensional seepage control for deep foundation pit dewatering. Journal of Hydrodynamics. 2008. Vol. 20. No. 5. Pp. 596–602. DOI 10.1016/S1001-6058(08)60100-6
19. Solsky, S.V., Orischuk, R.N., Lopatina, M.G., Orlova, N.L. Issledovaniye samozalechivaniya treshchin v glinotsementnobetonnykh diafragmakh (na primere zemlyanoy plotiny Gotsatlinskoy GES). [Study of crack self-healing in clay-cement concrete diaphragms (using the example of Gotsatlinskaya HPP)]. Izvestia of B.E. Vedeneev VNIIG, JSC. 2017. Vol. 283. Pp. 19–29. (rus)
20. Solskyi, S.V., Orischuk, R.N., Orlova, N.L. Model of crack self-healing in clay-cement concrete diaphragm of embankment dam. Budowle piętrzące eksploatacja i monitoring. Warszawa: Instytut Meteorologi I Gospodarki Wodnej. Panstwowy Institut Badawczy. 2017. Pp. 341–349
21. Solskiy, S.V., Lopatina, M.G., Bolshakova, O.A. Vodonepronicaemoe sopryazhenie betonnoj oblicovki bortovogo primykaniya s glinocementnymi blokami [Watertight sidewall of concrete encasement of side abutment with clay-cement blocks]. Patent RF, No. 127088, 2013. (rus)

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Инженерно-строительный журнал

ISSN
2071-0305

сайт журнала: http://engstroy.spbstu.ru/

DOI: 10.18720/MCE.89.2

Глиноцементобетонная диафрагма, расчётное обоснование новых конструкций

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Ключевые слова: грунтовая плотина, глиноцентобетонная диафрагма, буросекущиеся сваи, напряженно-деформированное состояние.

Аннотация. В связи с совершенствованием машин и механизмов, технического оснащения и технологических приемов, применяющихся при производстве работ по устройству гиноцементобетонных «стен в грунте» методом буросекущихся свай, автор предлагает расширить диапазон рассматриваемых конструкций противофильтрационного элемента грунтовых плотин, добавив к ним модификации с арочной и наклонной диафрагмой. Проведенные исследования позволили выявить основные тенденции влияния использования эффекта наклона глиноцементобетонных диафрагм и арочного эффекта на изменение напряженно-деформированного состояния системы грунтовая плотина — диафрагма в сравнении с традиционной конструкцией (вертикальная стена). Учёт предложенных автором конструкций глиноцементобетонных диафрагм при проектировании грунтовых плотин позволит расширить диапазон возможного применения данного технического решения. Установлено, что имеется возможность оптимизации существующих технических решений грунтовых плотин с глиноцементобетонной диафрагмой при их проектировании с учётом не только назначения прочностных и деформативных характеристик глиноцементобетона, но и с учётом изменения конфигурации самой диафрагмы.

Литература

1. Радченко В.Г., Лопатина М.Г., Николайчук Е.В., Радченко С.В. Опыт возведения противофильтрационных устройств из грунтоцементных смесей // Гидротехническое строительство. 2012. № 6. С. 46–54.
2. Федосеев В.И., Шишов И.Н., Пехтин В.А., Кривоногова Н.Ф., Каган А.А. Противофильтрационные завесы гидротехнических сооружений на многолетней мерзлоте // Опыт проектирования и производства работ. В 2 т. Т. 2. СПб.: ВНИИГ им. Б.Е. Веденеева, 2009. С. 303–316.
3. Аргал Э.С., Королев В.М. О некоторых свойствах глиноцементобетона и особенностях работы стены в грунте в теле плотины // Гидротехническое строительство. 2019. № 5. С. 10–19.
4. ICOLD. Soil-cement for embankment dams // Bulletin № 54. 1986.
5. Lorenz W., List F. Application of the trench diaphragm method in constructing the impervious core of dams consisting in part of low-grade fill material // 12-th ICOLD Congress. 1976. Q. 44, R. 6, Mexico. Pp. 93–104.
6. Орищук Р.Н. Проблемы проектирования, строительства и эксплуатации глиноцементобетонных диафрагм грунтовых плотин, возводимых методом буросекущихся свай // Известия ВНИИГ им. Б.Е. Веденеева. 2018. Т. 287. С. 3–13.
7. Радзинский А.В., Рассказов Л.Н., Саинов М.П. Плотина стометровой высоты с глиноцементобетонной диафрагмой по типу «стена в грунте» // Вестник МГСУ. 2014. № 9. С. 106–115. DOI 10.22227/1997-0935.2014.9.106-115
8. Мильцин В.Л., Орищук Р.Н., Сольский С.В. Рекомендации по проектированию, расчетам и возведению противофильтрационного элемента из глиноцементобетонных буросекущихся свай // Стандарт предприятия. – СТП 310.02.НТ-2017. СПб. изд. АО «ВНИИГ им. Б.Е. Веденеева», 2017. 117 с.
9. Саинов М.П., Сорока В.Б. Сверхвысокая каменно-набросная плотина с комбинацией железобетонного экрана и глиноцементобетонной диафрагмы // Инженерно-строительный журнал. 2018. № 5(81). С. 135–148. DOI 10.18720/MCE.81.14
10. Борзунов В.В., Денисов Г.В., Кадушкина Е.А., Николаева Е.А., Федоров А.В. Опыт проектирования и строительства грунтовой плотины Нижне-Бурейской ГЭС с применением в качестве противофильтрационного устройства диафрагмы из буросекущихся свай // Гидротехническое строительство. 2019. № 6. С. 2–11.
11. Прокопович В.С., Величко А.С., Орищук Р.Н. Напряженно-деформационное состояние земляной плотины с глиноцентобетонной диафрагмой (на примере земляной плотины Гоцатлинской ГЭС) // Известия ВНИИГ им. Б.Е. Веденеева. 2016. Т. 282. С. 87–98.
12. Орищук Р.Н. Новые конструкции грунтовых плотин с глиноцементобетонными диафрагмами // Известия ВНИИГ им. Б.Е. Веденеева. 2019. Т. 292. С. 21–30.
13. Kang F.E.I., Han-Long L. Secondary development of ABAQUS and its application to static and dynamic analyses of earth-rockfill dam // Rock and Soil Mechanics. 2010. No. 3.
14. Рассказов Л.Н., Радзинский А.В., Саинов М.П. Плотины с глиноцементобетонной диафрагмой. Напряженно-деформированное состояние и прочность // Гидротехническое строительство. 2014. № 9. С. 37–44.

15. Рекомендации по расчету напряженно-деформированного состояния и устойчивости высоких плотин из грунтовых материалов при статических и сейсмических воздействиях. П 824-85. М.: Гидропроект, 1985. 112 с.
16. Саинов М.П. Особенности численного моделирования напряженно-деформированного состояния грунтовых плотин с тонкими противофильтрационными элементами // Вестник МГСУ. 2012. № 10. С. 102–108. DOI 10.22227/1997-0935.2012.10.102-108
17. Саинов М.П. Приближённый прогноз прочности противофильтрационной стены в основании плотины // Научное обозрение. 2017. № 4. С. 34–38.
18. Luo Z.J., Zhang Y.Y., Wu Y.X. Finite element numerical simulation of three-dimensional seepage control for deep foundation pit dewatering // Journal of Hydrodynamics. 2008. Vol. 20. No. 5. Pp. 596–602. DOI 10.1016/S1001-6058(08)60100-6
19. Сольский С.В., Орищук Р.Н., Лопатина М.Г., Орлова Н.Л. Исследование самозалечивания трещин в глиноцементнобетонных диафрагмах (на примере земляной плотины Гоцатлинской ГЭС) // Известия ВНИИГ им. Б.Е. Веденеева. 2017. Т. 283. С. 19–29.
20. Solskyi S.V., Orischuk R.N., Orlova N.L. Model of crack self-healing in clay-cement concrete diaphragm of embankment dam // Budowle piętrzące eksploatacja i monitoring. Warszawa: Instytut Meteorologi I Gospodarki Wodnej. Panstwowy Institut Badawczy. 2017. Pp. 341–349
21. Сольский С.В., Лопатина М.Г., Большакова О.А., Водонепроницаемое сопряжение бетонной облицовки бортового примыкания с глиноцементными блоками. Патент РФ № 127088, 2013.

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