Constructing development and integrated coastal zone management in the conditions of the landslide slopes of Cheboksary water reservoir (Volga River)

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Constructing development and integrated coastal zone management in the conditions of the landslide slopes of Cheboksary water reservoir (Volga River)

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Abstract. Uncontrolled construction and insufficient accounting of engineering-geological and hydro-geological conditions of the coastal zone, intensified technogenic impact on sloping surfaces and active urbanization led to the emergence of serious problems and emergency situations on the coasts of many Volga reservoirs, including the Cheboksary reservoir, within Cheboksary urban district and adjacent territories of Chuvashia. This article is devoted to substantiation of the possibility of rational construction development of landslide slopes of the Cheboksary water reservoir.

1. Introduction

The Volga River has a length of 127 km within the Chuvash Republic. The lower part of the Cheboksary reservoir and the upper section of the Kuibyshev reservoir are located here. Cheboksary hydroelectric power station (HPP) was built last in the cascade of the Volga hydrosystems. The hydraulic power plant is located in the zone where the water supply of the Kuibyshev reservoir is running low. Start of the first hydroelectric complex unit occurred in 1980. The first unit of the hydrosystem was commissioned in 1980. In the flood of 1981 the reservoir was filled to the level of 63 m. The reservoir has been operating at this level for 36 years. Forecasts for changes in the natural environment, including shores in the design and construction of the Cheboksary HPP were performed in terms of a water level mark of 68 m. As a result, all the forecast values for re-forming the coasts, siltation of the bottom and water pollution proved to be untenable. At the same time, the increased anthropogenic press on the slopes within the Cheboksary agglomeration leads to a decrease in the stability of the coasts which can cause dangerous abrasion and landslide processes. In addition to the intensive construction of residential buildings, industrial, recreational, agricultural and other facilities, excavation work on the right bank of the reservoir is actively being carried out (laying of electrical and telephone cables, repairing of heating mains and conduits, etc.).

As a result, the groundwater regime is violated, which can also contribute to landslide. Already in 1973, during the construction of the pit of the Cheboksary hydropower plant, the landslide covered the southern shore of the pit and part of the indigenous slope of the Volga. The volume of the landslide mass of the soil was about 200 thousand m³. The water drainage system, power line and road were temporarily disrupted. 65 new landslides were counted at the beginning of operation of the Cheboksary hydroelectric power station in 1981 from the village of VasilSursk to the dam of the Cheboksary HPP. JSC "RusHydro", in charge of the operation of the Cheboksary water reservoir, has created a water protection zone for the preservation of coastal landscapes (at a distance of 1-3 km from the water edge). However, in violation,
during the years of operation of the hydroelectric power station, dachas, garages and recreation centers were built here.

2. Material and methods

Landslide process is one of the most dangerous natural processes and many works in foreign and domestic scientific literature have been devoted to its study. They define the landslide process, development factors, classification and consider the mechanism of the process [1, 2, 3, 4, 5]. In conditions of shortage of land resources, people actively develop and build up lands with landslide slopes. In connection with this, applied engineering and geological scientific developments on risk reduction in landslide conditions become very relevant [6, 7, 8, 9]. Among the factors of development of landslide processes is the factor of creating reservoirs on the banks of rivers. So, the coastal zone becomes a zone of increased risk in economic development which requires the creation of an integrated management system. In the world practice there is such a management system for oceanic coasts [10, 11]. Obviously, the need has come for such documents for the coasts of reservoirs.

The main factors of landslide formation on the slopes of the Cheboksary water reservoir, in our opinion, are: 1) structural features of rocks of the sedimentary cover of the Russian plate (subhorizontal occurrence, their fracturing); 2) lithological structure of rocks (terragenous, predominantly clayey, poorly argillized rocks of the Upper Permian Paleozoic, covert deluvial formations of river valleys, buried beams and ravines that extend to the reservoir; 3) the geomorphological features of the northern part of the Volga Upland (the mark of the Miocene alignment surface is about 210-215 m, and the main basis of erosion of Chuvashia is the Volga River with marked elevations of 53 m at the Kuibyshev Reservoir to 63 m in Cheboksary), erosion and landslide types of slopes with their limiting morphometric parameters (height and steepness); 4) climatic and hydrological conditions of the temperate zone, differently manifested on the slopes of different genetic types and exposures; 5) hydrogeological conditions of the slopes to the depth of the erosion cut, which are the consequence of their geological structure, drainage conditions, relief and climate. Hydrogeological and hydrological factors affect the stress field in the massif, the shear characteristics of soils, control the role of hydrodynamic and hydrostatic pressures on the stability of slopes. Our observations confirm the ever increasing role of human economic activity in landslide formation.

The combination of slope and wave geodynamic processes and lithology became the leading factors in the formation of landslide-dangerous engineering and geological conditions on the slopes of the Cheboksary water reservoir. Lithology is represented by interstratification of clayey strata with sandy-marly complexes of the Permian Paleozoic system. The abrasion of the Volga coasts is complicated by slope processes, and abrasion-landslide, abrasion-landslide, abrasion-scree, abrasion-accumulative types of reservoir banks are formed. The most widespread are landslides in places where the banks are composed of rocks of the Tatarian stage of Perm. As a result, landslide blocks successively displacing, capture significant parts of the slopes and lead to the formation of a stepped relief. In the Upper Permian rocks with relative heights of 30-50 m and steepness of the slopes 15-30°, types of landslides-block are formed. According to the degree of manifestation of landslide processes they belong to the II and III categories of danger. The dimensions of the displaced landslide blocks reach sizes 50-70 at 40-60 m. The heights of the walls of separation are up to 20-30 m. The length of the wall of detachment in front landslides reaches 130-170 m. Landslides form well-defined semicircles, frontal terraces and have such characteristic: separation walls, tongue parts and shafts of bulging. With the slope steepness of 20° mudflows-flows began to form due to the creation of the reservoir. In general, on the Volga right bank are landslides classified according to the displacement mechanism by types: extrusion, slip, flow and special. Based on the methodology of S.I. Bolisov and others, with our additions [12], the coasts of the Cheboksary reservoir were typified and their present state was determined with subsequent evaluation of the geological and geomorphological safety of the studied territory. The definition of complex geomorphological safety of the coastal zone of the Cheboksary reservoir included an analysis of engineering-geological conditions, intensity of terrain fragmentation, landscape differentiation, presence of dangerous exogenous processes, etc. The calculation of the coefficients of geological and
geomorphological safety of the territory showed that the abrasion-landslide type of the coast is characterized by indicators from 15.2 to 17.3; Erosion type of coast - 17.4; Protected - 17.2-18.8; Abrasion-screeshaped type - 15.8-17.3; Abrasion-accumulative and Accumulative type - 17.9-19.8. This gives grounds to refer them to the groups of banks with low and medium stability.

Depending on the engineering and geological conditions on the coast of the Cheboksary and Kuibyshev reservoirs, the following areas suitable for construction and economic use can be identified: 1) Sustainable and suitable for widespread development, represented by water dividing areas on the right bank of the Volga, accumulative surfaces of the left bank and flat river over-flooded terraces and deluvial slopes in the indigenous and Quaternary sediments. They can be suitable for agriculture. Possible problems here are: the issues of water supply, steep slopes and the level of groundwater. 2) Conditionally stable, economic development of which is difficult because of their relief. These are coastal slopes that have reached the equilibrium state without landslides and scree, slopes of valleys of large beams and tributaries. Possible uses are as gardens and meadows. Construction will require anti-landslide and anti-erosion measures here. 3) Unsuitable areas affected by landslide deformations.

As technogenic protection of the pre-river zone of the Cheboksary reservoir can be recommended: 1) Usage of polymeric materials to strengthen the beach surface from sand and pebbles. A negative factor is the weak resistance against wave action. In addition, the polymer coating will worsen the ecological situation of the coastal zone since in the river part of the beach this crust will be covered with microalgae mucus as well as boulder-stone blind in water. 2) Stone outline. Stone-block or tetra-pits are used; however this will completely remove the shore from the recreational nature management. This method was implemented directly at the structures of the Cheboksary hydroelectric complex. 3) Construction of interrupted breakwaters. On the relatively shallow left bank of the Cheboksary reservoir, this method of protection can give good results but on the deep right coasts, which are just prone to landslide deformations, this method is of little effect. And the construction of intermittent breakwaters on a steep landslide underwater slope is problematic. 4) Protection of the coast by groynes. With the deep underwater slope of the landslide type, the application of this option is also problematic. 5) Concrete counter-bank. It is the most effective method for socially significant territories implemented by Cheboksary, Novocheboksarsk, Sosnovka sites, etc.

In each case, the criteria for selecting the most effective technogenic protection of the Cheboksary water reservoir banks are: 1) the lower cost of the structure; 2) less material consumption; 3) higher degree of quenching of wave energy; 4) the best ecological properties.

As for the complex of anti-landslide measures (ALM), the following types of preventive measures have been proposed by builders and designers for many years: 1) Mechanical retention of landslide masses. 2) Cutting, unloading and terracing of the slopes. 3) Regulation and filling of beams, ravines. 4) Installation of networks of upland drainage. 5) Drainage of groundwater. 6) Agroforestry. All of them are implemented in one or another way in the practice of construction in Chuvashia.

Land-use planning to reduce losses from landslides includes active and passive methods, used both individually and in combination: 1) Active methods: transfer or modification of existing buildings; protection of existing buildings. 2) Passive methods: restriction of new construction; building regulation.

In the practice of prospecting for the construction in the areas of dangerous slope processes the relevance of the engineering-geological approach is beyond doubt. The essence of the engineering-geological approach is reduced to the following stages [13]: 1) Geological and geomorphological survey and compilation of engineering geological maps and sections based on survey data. 2) Compilation of correct calculated structural and functional models from the materials of this survey and sections both in the present state of the slope and, if necessary, in the past. 3) Selection of the optimal design formula and optimal design parameters for the stability of landslide slopes. 4) The calculation of the stability of landslide systems, at first based on laboratory data of the shear strength of soils. And then, if necessary, performing reverse calculations to clarify the shear strength of the soil of the bedrock (peak strength) and landslide accumulations after displacement (residual strength). 5) According to the data obtained, the stability forecast for the edge of a plateau not covered by a landslide. As a result, in the calculation schemes, the role and significance of each element and component will be taken into account in the
functioning of the entire landslide geomorphosystem, in mechanisms and intensity of the manifestation of landslide deformations. Correct structural-functional models of landslide systems will reflect the mechanisms and structure of real landslides of the objects under study, which are more objective compared to simplified test models such as the circular cylindrical model of plane displacement, etc. These real models are compiled according to certain principles taking into account the genetic types of slopes, the types of landslides by the displacement mechanism, modern concepts of the structure and component-elemental composition of landslide systems. That is, the hierarchy of the landslide geomorphic system will be taken into account: types of landslide blocks, types of landslide tiers and landslide floors [13].

Monitoring of dangerous exogenous processes on the coast of the Cheboksary reservoir has been carried out since 1980 by various design and survey organizations ("RusHydro", "Engineering Shore Protection", "ChuvashTISIZ" and JSC "Institute Chuvashgiprovdokhoz"), as well as by scientists from the Chuvash State University. Observable sites are assigned to I and II significance categories. Geodetic measurements are carried out on profiles with frames. To protect valuable economic facilities on dangerous shores, concrete slopes and surge suppressors, artificial beaches, drainage systems and other engineering protection facilities have been created in the city Cheboksary, Novocheboksarsk, in the Yadrinskaya and Sosnovsky agricultural lowlands.

However, there are numerous new data on landslide phenomena of recent years that arose both under the influence of the Cheboksary hydropower plant regime and intensive urban construction (figure 1).

One of the examples of construction on landslide slopes is the rapidly commissioned microdistrict VI "Center" in Cheboksary on the left bank of the river Cheboksarka (authors of the project for the construction of the microdistrict VI in the central part of the Cheboksary city – Ltd "Architectural Bureau "Classic", architect N.A. Rozhkova, designer M.A. Kitaev).

The conducted field studies made it possible to distinguish here three engineering geological (IG) areas:
1) Arrays of type A – leveling surfaces or plateaus (the upper tier of the relief), characterized by the greatest stability.2) Arrays of type B – slopes of various genetic types (middle tier of relief) characterized by medium and high degree of danger. 3) Arrays of type B – floodplain and bottom of beams (the lower tier of relief) characterized by an average and low degree of danger. The boundaries between the arrays A and
B are determined by the walls of the landslide system failures, the edges of the erosion slopes, and between the B and B - the rear seam of the floodplain of the river Cheboksarka [14].

Arrays of type A are almost entirely built up, genetically and structurally rather monotonous and are an object of engineering protection for the building of slopes. Between these tiers of relief are high-altitude slips landslide systems, subject to local sliding deformations, even with their temporary trimming for construction purposes. The building properties of ancient and long-slope slopes (type B) are determined by the structure and mechanism of these landslides, i.e. on which functional components of landslide geomorphic systems the designed buildings are located, and how the pattern of distribution of loads on the slope and the regime of underground and surface waters in connection with vertical planning and other design solutions will change. The structure of the entire slope polygon is complicated by the fact that the elements of landslides oriented almost along the strike of the Cheboksary valley are overlaid with an age-old buried and modern ravine-girder net, significantly complicating the construction properties of the landfill. Therefore, knowing the confinement of the project object to those or other elements of the landslide system, it is possible to predict in advance the character of its influence on the stability of the slope. The accumulative floodplain of the Cheboksarka River (type B), bounding by its rear seam the considered slope site, is for it a counterbank, a basis of erosion and a place for the accumulation of ravine prowl. As a result, recommendations were made on the construction conditions taking into account the identified and projected hazardous processes. Calculations of slope stability in the natural state taking into account the designed buildings as well as vertical planning and engineering preparation of the territory, communications and roads are performed. However, a local landslide in the playground area of the kindergarten (position 26) caused deformations in May 2014, which suspended the commissioning of the facility for 8 months. In addition, the formation of a deep landslide by cutting the slope with a foundation pit to position 24 began. There was a threat of landslides within position 25 due to over-wetting of the soil grounds. In an emergency order measures were taken to reduce the groundwater level to 5 m [14].

The presence of an object of unfinished hydraulic engineering construction – the Cheboksary HPP and the reservoir of the same name is the most important problem of economic development of the Middle Volga region. Therefore, the problem of functioning of the bank protection structures of the Cheboksary water reservoir remains the most urgent task of construction and territorial development. At the same time, the designer and the customer meet with a number of difficult problems due to imperfections in the regulatory framework at all stages of implementation of bank protection facilities.

First, these projects are relatively "obsolete" due to current changes of natural processes. Over time, planned and high-altitude deformations of the coastal slope occur, leading to the need for adjustments to the design estimates, the repetition of approval procedures and the passing of expertise. As a result of multi-stage (preparation of outgoing documentation, numerous approval and expertise of project, preparation for construction), the construction is delayed. And by the time the building permit is received, the project needs to be corrected. Therefore, it is necessary to simplify and speed up the procedure for approving state expertise of "Design and estimate documentation" (DED) for the construction of shore protection facilities. And then immediately proceed to the implementation of the facilities on the readiness of the DED for their construction.

Further, artificial beaches, etc. refer to deformable structures. And the regulatory requirements for the rules of their operation are imperfect. Therefore, it is advisable to take decisions on the need to develop a special section on the operation of these structures as part of the DED for the construction of deformable structures, section, including the need to monitor facilities, with the development of a program and separate estimates for its implementation, as well as additional workloads and accordingly estimates for annual repairs and even restoration of similar facilities.

Thirdly, the unique feature of anti-landslide and bank protection structures of reservoirs is the only or a small number of variants of their spatial location. However, in reality, the most optimal land plots under anti-landslide and bank protection structures have already been allocated to other facilities and without servitude compliance. This is especially true for water protection zones (WPZ). Therefore, when providing land plots in the WPZ, it is important to legislatively fix the obligatory introduction of an
easement in the title documents or the right to withdraw the land plots needed for the landslide and bank protection structures.

Russian legislation on the one hand has many regulatory mechanisms for the protection and use of natural resources in the coastal zone. But in the Russian legislation there are no uniform statutes on integrated management of coastal zones, various elements of it regulate federal laws in the field of environmental management and environmental protection: Urban Planning Code, Land Code, Water Code, Forest Code; Federal laws: "On Environmental Protection", "On Subsoil", "On Ecological Expertise", "On Sanitary and Epidemiological Well-Being of the Population", "On Specially Protected Natural Territories", etc. As a result, a superficial opinion is formed that full-fledged environmental protection in the coastal zone is carried out. However, the narrowly sectoral character of legal norms is not very much combined with the integrated approach necessary to manage coastal and landslide risks. Territorial planning carried out within the framework of the Urban Development Code could be a good tool for sustainable development in coastal zones. The weak side is that the management of each of the elements of the natural environment is carried out by separate departments that are not formally subordinate to local government bodies. As a result, decisions on integrated environmental protection in the framework of territorial planning schemes are ignored. The solution of problems should go with attraction of experts in the field of architecture and construction, territorial planning, environmental protection. Representatives of public environmental and hail protection organizations, local self-government bodies, enthusiasts of water sports and tourism, etc. should participate in the development of proposals. The search of the way of of coastal territory development in which the balance of interests of the population and investors is observed under condition of unconditional preservation of valuable objects of natural and cultural heritage remains the most urgent task.

Consideration of the social factor in the coastal zone, the prospects for the development of the territory and the escalating environmental problems are a task of great importance. The coasts of the reservoirs are the most important element in the economic development of the regions of the Volga region. Preventing or minimizing the negative consequences of coastal and landslide development is an important part of coastal zone management. Thus, the removal of sandy material for construction needs on the left bank of the Cheboksary reservoir can lead to a shortage of long-shore deposits and the replacement of the accumulative regime for abrasion, which will undoubtedly affect the formation of beaches and the functioning of the left-bank recreational zone. The problem of managing territorial development in the coastal zone is to find and maintain a dynamic balance between the processes of economic development and the processes that form the ecological state of the environment.

The next problem is the training of personnel with synthetic knowledge in the field of technical and natural sciences, hydraulic engineering, geotechnics, engineering geology and applied geomorphology. Previously, the departments on coastal protection in the design institutes were organized and successfully operated("Giprocommunstroy", "PNIIIS" in Moscow, the "Hydroproject" and systems of "Giprovodkhoz" in a number of the Volga cities). The construction of anti-landslide and bank protection structures was carried out by highly professional construction organizations, trusts, qualified personnel, appropriate equipment. At present, in this activity there are people who do not have the necessary experience, the quality of their work is doubtful. Anti-landslide protection and bank protection in their projects are reduced to the erection of retaining walls, wave walls and reinforced concrete buns without adequate drainage and other ALM. Over the past two decades a large number of design and production organizations have emerged that clearly having low professionalism and little knowledge of coastal and slope processes and the impact of erected bank protection structures on them. It is necessary to increase the requirements for qualification of workers in this field, in the likeness of tightening the requirements for cadastral engineers in the field of land management and cadastral activity by the Ministry of Economic Development in 2016.

This explains the complex approach in the scientific substantiation of the landslide risk management strategy in the coastal zone of the Volga reservoirs and in adjacent sloping areas. At the same time, the
diversity of social, technical and natural factors must be taken into account. The complex scientific justification for anti-landslide and coastal protection measures should be based on reliable modern methods that allow assessing the effect of erected structures on the natural course of coastal and slope processes, on the ecology of the adjacent reservoir and the coastal section and also take into account social consequences. Recently much attention has been paid to the mathematical modelling of geocontrol. However, without minimizing the importance of mathematical modelling, it should be noted that this method gives good results when applied as an accompanying one. Mathematical models should not be blindly copied; they should take into account regional engineering and geological features of slope, landslide and abrasion processes. So, underestimation of the features of the geodynamics of the coastal zone in any area of design leads to emergency consequences, as discussed above, and to financial costs. As a rule, only after the project's shortcomings are identified as a result of emergencies, developers are turning to scientists. A preventive scientific justification for protecting the coasts is necessary. For this purpose, in the universities, in the training of civil engineers, geotechnicians and designers focused on professional activities in the coastal zones it is necessary to introduce the teaching of the relevant disciplines of the variable cycle. It should be understood that there are no universal solutions in the field of landslide risk management, there are only basic methods of solution.

3. Results and discussion
Underestimation of the complex engineering and geological situation in the coastal zone of the Cheboksary water reservoir in urban development leads to a rise in the cost of creating various national economic objects. Often the construction process has to be suspended in connection with activating landslide deformations, which confirms the extreme need for thorough engineering and geological surveys at the design stages. Landslide-hazardous engineering and geological conditions on the slopes of the Cheboksary reservoir are caused by a combination of slope and wave geodynamic processes and lithology, represented by interlacing clay differences with sandy-marly complexes of the Permian Paleozoic system. Our observations confirm the growing role of human economic activity in landsliding. The variety of natural factors acting in the coastal zone, their influence on the constructed hydrotechnical and other capital structures and the feedback account predetermined high requirements for competent specialists in the complex interaction of knowledge in geotechnics and hydraulic engineering, design and construction of structures in the coastal zone and applied natural scientific disciplines. When resolving controversial issues of coastal nature management, it is necessary to adhere to the principles of decision-making on economic, social and environmental tasks at the state, regional and local levels in the light of the interests of both present and future generations of citizens; integrated approach to management of coastal and landslide risks; involvement in the discussion of wide circles of the public in the decision-making processes and in monitoring the management of landslide risks on the coasts of the Cheboksary and other Volga reservoirs.

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