LANDSLIDE RISK MANAGEMENT IN THE COASTAL ZONE OF THE KUIBYSHEV RESERVOIR DUE THE DESIGN OF HIGH-SPEED LINE "MOSCOW-KAZAN"

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High-speed railway "Moscow-Kazan" by the draft crosses the Volga (Kuibyshev reservoir) in Chuvashia region 500 m below the village of New Kushnikovo. The crossing plot is a right-bank landslide slope with a stepped surface. Its height is 80 m; the slope steepness -15-16º. The authors should assess the risk of landslides and recommend anti-landslide measures to ensure the safety of the future bridge. For this landslide factors have been analyzed, slope stability assessment has been performed and recommendations have been suggested. The role of the following factors have been analyzed: 1) hydrologic - erosion and abrasion reservoir and runoff role; 2) lithologyc (the presence of Urzhum and Northern Dvina horizons of plastically deformable rocks, displacement areas); 3) hydrogeological (the role of perched, ground and interstratal water); 4) geomorphological (presence of the elemental composition of sliding systems and their structure in the relief); 5) exogeodynamic (cycles and stages of landslide systems development, mechanisms and relationship between landslide tiers of different generations and blocks contained in tiers). As a result 6-7 computational models at each of the three engineering-geological sections were made. The stability was evaluated by the method "of the leaning slope". It is proved that the slope is in a very stable state and requires the following measures: 1) unloading (truncation) of active heads blocks of landslide tiers) and the edge of the plateau, 2) regulation of the surface and groundwater flow, 3) concrete dam, if necessary.

Key words: risk of landslides, slope stability, hydrologic, lithologyc hydrogeological, geomorphological and exogeodynamic factors of landslides risk, anti-landslides measures.

I. INTRODUCTION

High-speed Railway (HSR-2) "Moscow-Kazan-Yekaterinburg", which is planning to start building in 2017, will create the necessary incentives for the development of the economies of many subjects of the Russian Federation (Moscow, Vladimir, Nizhny Novgorod region, Chuvashia, Tatarstan, and others). By the project HSR-2 will cross the Volga in the Kuibyshev Reservoir area. The length of the bridge will be more than 4.5 km. As the intersection is considered land in Mariinsky Posad district on the territory of the Chuvash Republic. This site is located on the right elevated landslide bank of the river Volga to 1.5 km above the recreation center "Belye kamny" or 500 meters below the village of New Kushnikovo. It is highly relevant the definition of sustainability the section of the route HSR-2 under the conditions of existence of landslide risk on the coast and the development of recommendations to improve its resistance to the required variables from the normative documents [6,7].

The research task was to assess the overall and local stability of the river Volga valley slopes between the marks 120 m (edge of the plateau) and 52 m (Shoreline, Kuibyshev reservoir, Volga riverbed) in the zone of HSR-2 location; determine the stability of the edge of the plateau on total length by 25 m at the site of the road crossing the Volga River valley; evaluate the role of erosion and abrasion processes on the Kuibyshev reservoir coast in the general stability of the slope and its parts; clarify hydrogeological features of the array and their role in the overall and local stability of slope.

II. MATERIALS AND METHODS OF RESEARCH

To solve the problems it was necessary to evaluate the hydrological conditions of the reservoir; analysis of hydrogeological and geomorphological conditions of the coastal zone by performing the engineering and geological survey (EGS); prepare a consolidated geological section of fundamental bases of the array on materials the reference wells and outcrop studies; study of structure of the old landslide system (blocks, tiers, stories) in the strip passing BCM-2, connections between elements of the landslide system (blocks in tiers, between tiers of different generations, their subordination in stories) in accordance with the methodological workings [1-5,7-10]; identifying the main factors and causes of landslides, with particular attention to the role of the Volga in the management of sustainability the considered slope and landslide processes within it in the past and at present.

Three geological and geomorphological profile of the landslide slope were drawn up according to the EGS, materials mining and drilling works of the "Giprostroymost" Institute and route observations. Then, based on them were made the structural and kinematic calculation models. On the profiles shown retrospectively various positions of landslide bodies in the area of the considering Volga hillside: in its past (before the landslide) and present (after a landslide) states. The normative and calculated physical and mechanical properties of the soil-rock array were justified according to laboratory tests of soils by methods of a triaxial compression, "stamp on stamp", and the retroactive accounting. Separately shear characteristics of soil displacement zone were justified. Calculations of stability were performed on drawn up structurally-kinematic models for retrospective, current and forecast models by the best method "of the leaning slope".

III. RESULTS OF THE RESEARCH

Viewed plot widths up to 320 m along the shore of the Volga and an average length of 240 m and a height of 68 meters is an old landslide system which presented by landslide tiers of 2 generations associated by method of conjugation. Slope array is composed of terrigenous-carbonate strata the Urzhum tier of middle Permian and it submitted by alternation of reddish-brown clay with variegated marl and light gray limestone, sometimes - with varying degrees of weathering silt and siltstone.

Engineering and geological conditions that has been determined the stability of slopes. Taking into account the specificity of the geological structure of area (irregular alternation of a wide variety of terrigenous and carbonate rocks layers), in the office processing of materials it was decided to allocate not separated traditional varieties of Tatarian stage rocks of the Permian system in the sections (clay, silt, limestone, etc.) but rock strata presented by various combinations of these varieties with the consolidated physical and mechanical properties (IGE).

Stratum 1 (IGE-1). Clay is a reddish-brown, light, with weakly calcareous portions, with interlayers of siltstone and marl (in the range of 5.6-5.9 m and 6.9-7.4 m respectively); to a depth of 2.0 m - hardly plastic, below - mainly semi-solid consistency. Thickness of the stratum is 10.5 m, the lower mark - 111.3 m. It is a local aquitard (AT-1). By the weathering crust is timed perched water, which is unloaded within the main failure wall and provocative earth flows.

Stratum 2 (IGE -2). Marl (55%) is interbedded with limestone (45%): clayey marl is fractured, with nests of silt. Fractured limestone is destroyed to the state of broken stone and flour, it is slightly cavernous, with aquifer (AF-1). Thickness of the stratum is 3.7 m, the lower mark - 107.6 m.

Stratum 3 (IGE-3). The clay is light, dense and solid, slightly fractured, marly and with a few layers and nests of silt. It is with rock debris of limestone and siltstone at the bottom. Thickness of the stratum is 6.2 m, the lower mark - 101.4 m. It is a local aquitard (AT-2) for the AF-1.

Stratum 4 (IGE-4). Limestone is white, destroyed to rubble state, mainly clay, with interlayers of strong limestone, slightly cavernous, at the base – with gravel marl. It is aquifer (AF-2). Thickness of the stratum is 10.5 m, the lower mark - 90.9 m.

Stratum 5 (IGE-5). Clays (60%) are interlayered with marl (40%): clay is reddish-brown, light, hard, fractured, sites by sites is like mudstone, with lenses and interlayers of silt solid. Marl is hard, fractured, with an admixture of silt. Thickness of the stratum is 13.8 m, the lower mark - 77.1 m. It is a local aquitard (AT-3) for the AF-2.

Stratum 6 (IGE-6). Limestone (71%) is grayish-white and white, strong, cavernous, with interlayers of marl, silt, interbedded with thick, solid, slightly calcareous clay. It is aquifer (AF-3). Thickness of the stratum is 17.1 m, the lower mark - 60.0 m.

Stratum 7 (IGE-7). It is limestone (70%) with interlayers of marl (30%). Limestone is light gray, strong, cavernous, fractured, sometimes destroyed to the state of broken stone and flour. A layer is aquiferous (AF-4). Marl is light pink, thick, solid and slightly fractured, with nests of silt. Thickness of the stratum is 10.7 m, the lower mark of 49.3 m.

Stratum 8 (IGE-8). It is limestone (70%) and marl (30%) with interlayers of siltstone and mudstone. The rocks crushed to rubble state. Marl is multicolored, solid, fractured, clayey with lenses and layers of argillite (0.4-0.7 m), very strong, fractured, calcareous. A layer is aquiferous (AF-5). Thickness of the stratum is 10.5 m, the lower mark - 38.4 m.

Geomorphological features. The surface of the plateau is inclined at a 4-5 degree angle to the Volga; runoff promotes erosion dismemberment of the plateau edge and wall disruption, gully formation, drainage of the slope array. Low-water mark level of the Volga (reservoir) is 52.0 m, in flood 55.3 m and before filling of the reservoir is about 49.0 m. The Volga bed is separated from the shore by ridge of islands, so the processes of the bottom and side erosion are almost stopped; indications of abrasion processes are not noticeable. Old landslide 2-3-stepping slope consists of a number of genetically interrelated elements: lower denudation plateau – is a disruption wall of 1st order 2nd generation old landslide, old landslide terrace of the same generation, landslide scarp and landslide terrace of the 1st generation, landslide block of planar displacement (PD), the front block of thrusting-bulging, coastal erosion-talus scarp (ancient cliff), towpath. The average slope steepness is 15,5degree on its edge to the shoreline of the Volga riverbed. Total slope length is 220 m and a height of 68-70 m.

These genetic elements are described in more detail below:

1. **Denudation plateaus** almost without cover formations, inclined at an angle about 4-5^{o} to the Volga River. His part adjacent to the brow is complicated by a variety of gullies and ravines with constant streams in the bottoms. It is covered by deciduous forests with occasional oaks older than 150-200 years. Brow plateau jagged, with the circus shaped ledges. They are tops of small landslides, earth flows. Marks surface is 120-122 m and it increase in the SW direction.

2. **Old landslide failure wall** of the 1st order, 2nd generation of 20-22 m in height (between markers 95 and 102 m) and steepness 20-25^{o} is complicated by five ravines and many small landslides in the ravine and in the slope. It is under planning denudation by runoff and sliding saturated soils, it is turf-covered by forest of various age (from 20-30 to 60-70 years) and has no signs of violation of general stability.

3. **Old landslide terrace** (2nd generation) up to 40 m and a width of 100 m, is complicated by branched ravines 1 and 2, diverging to the failure wall and converging at the front edge of the terrace. Ravines adjacent to the brow of denudation slopes, that testify ravines ancient age. Therefore, landslide terraces are even older. The right side of the terrace with a mark of 97-100 m surface and steepness of to 5º is best preserved then left steeper (up to 7°) apart. The rear terrace seam pit №3 opened crushed landslide soils. The front edge of the terrace sharply cut by scarp, the fourth element of the slope. This terrace is the edge of the plateau, dropped nearly 20 m along a circular surface (radius of about 160-170 m).

4. **Landslide scarp** height 5-8 m (the height increases in a northerly direction) is the front face of the block 2nd generation, or a fragment of a failure wall slip landslide 1st generation without evidence of tongue units (thrusting, bulging, etc.). The ledge is cut of ravines, gullies on both sides, but behind ravines it going again in both directions in no less vivid form, despite the significant planning. These gullies are much younger then quite deep landslides.

5. **Landslide terrace** length of 35-40 m is the surface of the head rotation block of landslide tier 1st generation. The front edge of the block is in the compression zone and on the border with the planar displacement block is complicated by the shaft and the extrusion bumps.

6. **Landslide block** of up to 40-45 m is a fragment of the primary slope of the Volga river displaced in the 1st tier almost on a plane surface. Block is almost structural, with no signs of plastic deformation. At the front edge there are dome-shaped uplifts - plastic compression signs (by type of "barrel") in the area of tongue block.

7. **Front thrusting-bulging block** with a surface having a reverse gradient. There are signs of squeezing and uplift on the day surface of the block.

8. **Coastal erosion and talus ledge or ancient cliff** with no signs of avalanches and landslides. Slope is stabilities, turf-covered, up to 12-15 m between the average marks of 70 and 56 m.

9. **Shoreline,** at elevation 56-52 m is presented by bedrock outcrops and boulders fall apart (colluvium) of limestone and dolomite is between the low-water (52-53 m) and high water (56-57 m) level, width up to 10 m without signs of coastal erosion. This is the front part of the landslide system with thrusting signs of interbedded marl, limestone and partly of clay strata.

These relief items are mainly landslide origin operating in the overall system, interconnected genetically and determine the overall and local forecast stability of the whole array and its parts.

According to geomorphological data, only the top two steps are failure walls of independent two landslide generations of the 1st order, formed after each other and interconnected by interfacing way - upper block dives under the head unit of the lower tier, causing its deformation, formation of extrusion shaft in junction of rotation and plane displacement blocks of the lower tier and others.

Analysis of hydro-geological characteristics of the array detected the following. The survey data and the drilling confirmed the presence here of only two aquifers (AF): 1st type of perched water - on the edge of the plateau (118-115 marks) and 2nd AF interstratal type - lower marks 77-79 m in the fundamental array on plateau, and the landslide slope. Power both AF are atmospheric, infiltration and by overflowing through fractures from the upper to the lower horizon.

Hydro-geological conditions were taken into account in the calculations and as a weighting factor and as a factor of the hydrodynamic pressure in the portion of the array, which is located in full water saturation zone, between the constant level of groundwater and surface displacement. This role can be played in an array aquifer marked surface of 77.0 m or less, which has been adopted in the calculation models of the boundary between the zones of aeration and water saturation. Upper AF with of perched water regime discharged from the upper edge of the failure wall, is now not play a significant role in the stability of deep landslides, but provokes small, localized landslides,earth flows within the failure walls, and on the sides of the ravine. This horizon will play a significant role in the future of landslide deformation deep recess beads, and it should be intercepted by trapping drains before excavation construction.

Hydrological conditions arisen in connection of adjacent of the landslide failure wall (element 2) to denudation slightly tilted to the Volga bed plateau (item 1), which is a forest covered large catchment area, and in connection with the regime of the reservoir. Rain and melt water with draining perched water contribute to gully erosion, soak diluvial-eluvial formations and their displacement.

For the calculation of stability factor and landslide pressure were used averaged strength characteristics of the selected eight geological-lithological varieties of strata from terrigenous carbonate rocks of Permian Urzhum middle tier (P_{2ur}), described above and forming the Volga valley fundamental coastal slope. Normative and calculated values of strength and deformation characteristics of soil fundamental bases strata (IGE) of the slope array at $\alpha = 0.95$ identified for described above eight strata and were obtained by statistical processing of the soil testing laboratory (Institute "Giprostroymost") in wells №№1 and 2. To determine the prognostic slope stability data values were corrected by the inverse calculation. In general, to assess the sustainability old landslide slope highlighted two additional IGE with the parameters of the shear strength of the soil displacement zone, getting by inverse calculations: EGE-9 - the bedrock of natural occurence, not deformed by landslides before, with the parameters total peak strength, in which there was a separation of sliding blocks (tiers) first, and then the second generation of the native array and began their movement; GTE-10 - landslide formation with parameters residual strength of soil displacement zone in which the movement has stopped of landslide bodies (masses) mentioned above.

These parameters are obtained by back-calculation models based on three geological and geomorphological profiles and reflect the position of supposedly real landslide bodies in the form of blocks and their combinations (tiers) of two generations as it is now, and in the past, in their before landslides (peak) and post landslides (residual value) states. These figures correspond to the strength limit state of old landslides slope under the worst combination of natural factors of sustainability - groundwater, geomorphological, hydrogeological and hydrological. They are recommended by us to calculate anti-landslide measures to bring the stability of the slope array in conjunction with the planned road and bridge to the required regulatory documents of value (eg, the Cs is not less than 1.33). Reflecting the worst natural conditions, the calculation model does not include technological load and the designed object impact.

Dangerous geological and engineering-geological phenomena and processes. Two landslide tiers (upper and lower) is well manifested in geomorphological profile, with two failure walls, with two head blocks with rotation features (the reverse slope of the surface, drainage basins at the rear seam), with mounds of extrusion on the border of the head and medium blocks and signs of bulging in the front of the lower tier. These and many other features clearly indicate that there was formed a deep multi-block sliding landslide (cutoff).

According to the description, landslide tiers of two generations are connected by the interfacing way (upper more younger tier dives under the first). They have undergone to considerable slope denudation. The head failure wall, as the area of the upper unloading AF of perched water type, is moistened at the edge. It is much planned with the participation of local flow landslides, including solifluction type.

Existing data indicate about the involvement of landslides 1st order to the group of slip landslides with head rotation-dumping blocks and tongues within the riverbed. The underwater tongues part was, perhaps longer. However, to determine the eroded by the Volga part of landslide accumulations is now impossible.

Landslide slopes and landslide pressures stability calculations. For the forecast the stability of our slope used practice has tested the geological similarity method (analogies), based on a comparative analysis of all the relevant factors of the geological array environment, combined with the structural and functional analysis of existing landslides, compiling calculation models that simulate the state of the slope at moments "to displacement" and "after displacement" landslide.

Calculation models (up to 5-7 models on each of the three engineering-geological sections), compiled by the historical and geological and palaeogeomorphological analysis the landslide survey materials taking into account the experience of performing such works since 1985 in many regions of the former USSR. They reflect the 4 stages of evolution of the slope during the Late Pleistocene and Holocene: 1) the initial erosion-talus stage (the "before the displacement" state of the slope); 2-3) then the steps of forming two landslide tiers with its failure walls, head and other blocks including front (state "after displacement"); 4) the final stage of the modern denudation - smoothing the landslide system elements (planning of the failure walls, filling cracks and turfing surface, formation of gullies, etc.). We are put in the basis of the structural and kinematic analysis of the models an established correlation between the elements of landslides and their presence in relief (diagnostic signs) in the form of landslide terraces with different slopes surfaces, shafts and extrusion hillocks between the blocks, fragments the primary surface of the slope, and others.

On the basis of the above information on the structure of the slope array geological environment, the structure and mechanisms of landslides was compiled calculation models for a unified methodological works [2, 3-5, 7-9], was made direct and inverse calculations to verify the conformity of laboratory parameters strength of soil actual values, was updated the peak and residual strength of soil displacement zone needed to assess the current state of landslide slopes and their sustainability, taking into account the construction of the railway.

Calculations of the section 1-1 (model M-1.1 - M 1.7) corresponds to the sliding slopes state, showed that laboratory values of strength slope stability is much higher than the limit equilibrium (C_s is about 1.0) and can not be used to assess the natural stability of old landslide slope and to development recommendations to ensure it reliable stability together with the projected railway. Getting back calculations generalized strength characteristics of soil strata, forming the root array (peak strength of the soils of GTE-9) and landslide formations (residual strength indicators soils of GTE-10) are for this purpose more reliable indicators of strength in comparison with laboratory data, as they are satisfy the condition of limit equilibrium. According to figures obtained by the residual strength of the estimate of overall stability of the old landslide slope (calculation model M.1-5, C_s = 1.09), and in terms of the peak and residual strength - to assess the possibility of separation from the edge of the plateau of the new block (calculation model M.1-6, C_s = 1.12). These calculations confirm the presence of the considered slopes in their current state of a certain reserve of stability, but they also point to the need to take certain measures to bring their resistance to the required values. This C_s is provided a holding force in 2105.0 at a shear force of 1922.0 tons to bring C_s to 1.33 is necessary to increase the holding force on the 451.0 tonnes (project landslide pressure), and to bring the C_s to 1.25 – is need 298.0 t. In the considered method of assessing the sustainability of optimum stability can be ensured even at C_s about 1.15.

Analogous calculations are made on other sections. Consequently, the old landslides are in a very stable state within sections 1-1 and 2-2 and in sustainable state in the profile of 3-3. To attainment the state of the area the slope within the profile 1-1 to C_s = 1.25 is required to increase the retaining force by 298 tons per meter, while the C_s= 1.33 - need to increase the holding force up to 450 tons per meter.

The following measures are recommended in their period of operation to ensure reliable stability of the slopes: 1) regulation of surface runoff within the plateau and diversion them outside the site; 2) interception the perched water by prey drains; 3) filling 1 and 2 gullies but with preserving their draining role; 4) truncation of soil from the 2-tier head block to designing marks of the projected road; 5) the design of the recess must be considered the possibility of formation of local landslides on board, similar to those observed within the main failure walls [11-14].

IV. CONCLUSION

The stability calculations of 3 profiles includes at 6-7 models have shown that the system is in a very stable state (C_s = 1.05-1.07). This parameter should be at least 1.3 taking into account building codes for the normal operation. The erosion and abrasion Volga role in landslide deformation is insignificant, as the mainstream of the Volga in study site is closest to the left bank and a bay was formed at the right bank and was separated by a chain of islands from the mainstream. The authors recommend to improve slope stability (C_s 1.3) to carry out anti-landslide events. They should include the vertical planning of the slope (truncation of the head active landslide blocks that lead to unloading head parts of landslide tiers), regulation of surface runoff and groundwater interception of the top AF and loading the front of the landslide by concrete dam (if necessary).

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