Landslides as hazard for Moscow cultural heritage

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Abstract Blocked landslides are widespread in Moscow. The displacement of such landslides connects with Upper Jurassic clays. As a rule, these landslides have huge web depth. This depends on the possibility of huge damage. The last one obstructs stabilizing measures. Landslides have regressive (inside slope) development and durable (tens and hundreds of years) periods of slow deformations (1-30 centimeter per year). Such deformations give place to short periods of activation with displacements of some meters and more.

In Moscow activation of such landslides threatens to cultural heritage, site which also a part of UNESCO. Landslide slope on Vorobievy Mountains where are Troicy Zhivonachalnoj temple, Andreevskij monastery, Muchenicy Tatiany temple under MSU is considered in depth.

Keywords
Landslides, slope stability, hazard, cultural heritage.

Introduction

Blocked landslides are widespread in Moscow. The displacement of such landslides connects with Upper Jurassic clays. Firstly, Pavlov A.V (1869-1947) near the Vorobievy Mountains explored them in 1908. It connected with the slope deformation close to east edge of Vorobievka village. The Viewing point situates there nowadays. Landslide occurred opposite pressure pond according to the M.V. Churinov data. This landslide carried the part of the slope along 250 m and destroyed the substructure of yacht club. Engineering investigations were carried in 1920 at the Vorobievy Mountains. It connected with International Red Stadium design and construction (1920-1925). The investigations in 1930 include deep drilling for design «hydro accumulating» power station, highway stream crossing, embankments and descents. Since 1960 and later on B.M. Danshin, M.V. Churinov, I.S. Rogozin, F.V. Kotlov, V.V. Kuntzel, K.A. Gulakjan, E.P. Emelianova, M.N. Paretzkaja, G.P. Postoev, S.D. Pigarina studied other landslides of Moscow: Fili, Kolomentskoe, Choroshevo and others. These specialists had different point of views about the landslides age, there activation factors, slump basis. This was due to lack of knowledge about landslide slopes and complete methods of stability assessment.

Deep blocked slopes detects in Moscow river valley on 12 sites (Shukino, Serebryanyj forest, Horoshevo-1, Fili-Kuntcevo, Nizhnie Mnevniki, Horoshevo-2, Poklonnaya Mountain, Vorobievy Mountains, Kolomenskoe, Moskvorechie, Chagino, Kapotnya) and in Shodnia river valley on 3 sites (Shodnia, Tushino, Kurkino) (fig.1).

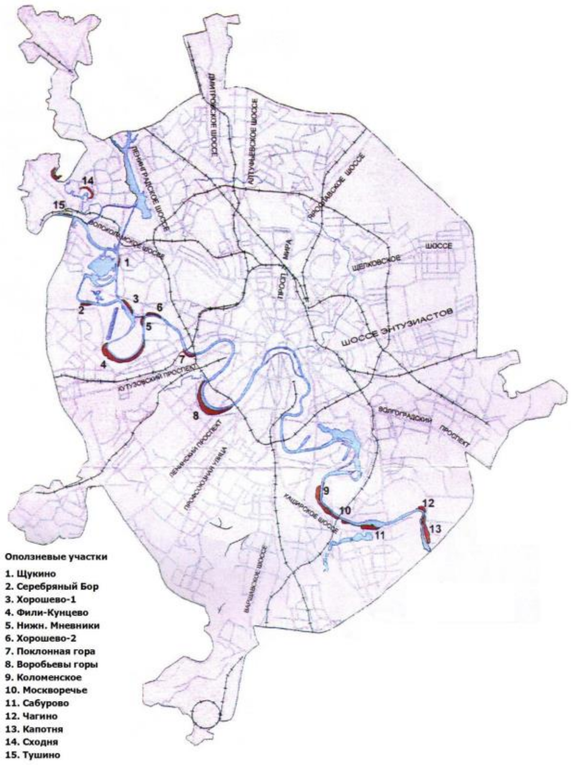

Figure 1. The areas of deep blocked landslides development in Moscow [9]

Slopes with deep landslides has specific relief: high abrupt slope (over landslide ledge) – in upper part; terrace with hilly and chine relief – in the middle and lower part. The spread of sliding area is various (from 0,5 to 3,0-3,5 km). The width (the length along landslide direction) is about 100-380 m. Planform is frontal, rarely it is circus. The volume of separate sliding blocks are about some hundred thousand m3. The volume of sliding body single circus is 5-7 mln. m3. Landslides characterizes by regressive (inside slope) growth and durable (tens and hundreds of years) periods of slow deformations which changes by periods of its activation with offset value about some meters and more [12].

The main reason of landslides origin was washout of the Moscow river high bank. Since 1770 6 floods with amplitude of water about 7,5 – 8,8 m were found on Moscow river. This means that water table treatment happened every 20-30 years. Since 1937 the river controlled by hydraulic structure. However, spring water level rise in 1955-1960 on Moscow river was 2-2,5 m. This caused the retreat of slope crest at a speed of 0,3-0,5 m/year.

More than half a century (in 1965), V.V. Kuntzel Has published a paper "About the age of deep landslides in Moscow and near Moscow areas connected with Jurassic clayey deposits [7]. Conclusions from this article are widely used in fields of the development history and structure of sliding slopes in Moscow. The article has two main points:

– vast majority of "ancient" landslides (huge sliding blocks) viewed on slopes have been taking shape along last 2000-3000 years;

– the duration of completely sliding cycle is 300-350 years (calculated on the Vorobievy Mountains example).

Figure 2. Hilly and depression relief at the base of slope in the Kolomenskoe near the Useknoveniya Glavy Ioanna Predtechi church. The relief is a result of the original sliding stages split

Moscow landslides activity assessment

Further, the illustration of slopes history development in Moscow with blocked landslides is given. Due to bank caving with the adequate height (more then 17-25 m above river level in low level) and upper Jurassic clayey deposits at the basement, the primary shear landslides forms with displacement surface close to circular cylindrical shape. Progressive erosion of sliding bodies front parts causes the slow "after main" displacement with the descent of their top parts. It induces changes in tense conditions of the virgin rock mass neighbouring part. If the top part of throwing back surface is in some position, so tense changes will be enough to break the balance of neighboring slope part. The last one also unplugs because of shear and detruncating along the surface close to circular cylindrical shape at descending part. This zone develops along shear surface of original block at the other part. Then the process is going to be cycle and develop in the way of "plateau". Sliding displacements also occur in detached blocks (in their front part, which is close to slump basis).

The main number of blocks and maximum length (along displacement direction) of sliding massive occurs on the highest slopes. Horizontal displacements of sliding massive are relatively low. The sub rotary displacements prevail with concomitant erosion as body end as upper part of "top" blocks. Changes in tense condition lead to stability disturbance of other blocks. They occur because of discharging horizontal tension. The last one happens thru low horizontal displacements and descent of top parts the previous blocks. It decreases vertical tensions on displacement surface.

The influence of low horizontal displacements on tense in massive may be illustrated by following example. Maximum value of riser the ditch bottom with the depth about 15-20 m in the generalized soil conditions is not higher than 20 cm. That means that it is 1-1,3% from width of excavated soils.

Usually soils is excavated fully from the trench. It may be raised (move upward) on 20 cm to complete the same result. This lead to full tension discharge (obviously, the transfer of lateral tension should be excluded). Therefore, the summary horizontal displacement about 1 - 3 m is enough to form 5 huge sliding blocks.

That way occur the conditions to renew creep flow in sliding massif. The slope becomes to be in limiting state while reaching the critical value. The catalyst of the main displacement with occurrence of new blocks were extremal floods on rivers. The last one lead to the growth of pore pressure in the displacement zone (especially on the top landslide submerged area).

Rapid flood recession leaveы behind the pore pressure dissipation in clayey soils. It also lead to sharp growth of hydraulic grades in sliding tongue massif. It increased the hydrodynamic pressure.

The tiny sub block forms when the influence of near slope crest discharge. This happens because minor displacement of sliding body tongue part could not reach deeply in the massif behind slope edge.

Maybe because of this the real displacement surface is going in massif near the slope edge, not in the depth.

In the result of bed deeping in Moscow river watercourse the additional nugatory technogenic influence on the stability occurs. In 1980 and 1981, washing the river watercourse was made. It may lead to the effect occurrence, which is similar to streambed erosion.

The massif displacement speed on sliding areas in Moscow are less than in 1960-1970 years. On some areas (Karamishevskaya embankment, Serebryanyj pine forest, Vorobievy Mountains and others) for the last 10-15 years, new surface manifestation occurs (in the form of tension joint). This could imply that the process is going to the other stage.

Data of regime observations for surface points and inclination supervisions also show notable differences in deformations:

– the displacement of sliding blocks is observed along the existing displacement zone on Kolomensky area of Chertanovsky manifold and on Choroshevo-1.

Instrumental observations for deep landslide growth on the stage of main displacement (Choroshevo-1 area) shows that the duration of first 2 stages (destruction of base rocks and displacement speed increasing) lasts for 8 months. Maximum displacement speeds are 35 mm/day.

Since 1985 until 2005 frame, which is near the landslide top, has went down on 476 mm and moved out of position to the river on 580 mm. The frame on the quay wall growth up to 226 mm and moved out of position to the river on 2032 mm [3]. It was observed near Chertanovsky manifold in Kolomensky area.

Distortion and changing the massif form prevails on Vorobievy Mountains.

Holy Trinity temple in Choroshevo

White Stone Holy Trinity temple stands on the high bank of the Moscow River for more than four centuries. It is one of the jewels of Russian architecture of XVI century (fig. 3).

It was constructed between 1596 and 1597 years and was finished when Boris Fedorovich Godunov has mounted the throne.

Piskarevski chronicler wrote about the temple erection: «In days of pious king and grand prince Fedor Ivanovich of all Russia… the stone temple in the village Choroshevo under the petition of boyar Boris Fedorovich Godunov» [10].

Figure 3. Holy Trinity temple in Choroshevo

The first mention about the sliding processes near the Holy Trinity temple in Choroshevo occurs since 18 century. In 1771 “landing slip near the Moscow river happened”.

In 1877, a new threat of landing slip near the temple perturbed parishioners.

Choroshevo “undergo to inevitable and imminent danger of collapse and fall into the river” (according to “extra” internal memorandum of Moscow, district clerk from October 18, 1877). A special and imminent danger threatens the church and the house occupied by the parish board. Several cracks formed at the beginning of October in the coastal to the Moscow river area. The highest fracture situated on the mountain, which now has a length of more than 100 fathoms. This fracture begins in the middle of the church fence (near the fence, behind the house of the volost board), and then across the yard and garden of the merchant Egorova (two links of the fence already collapsed). Behind the garden of Egorova, the upper crack, descending downhill, will connect with another mountain crevice. The last one starts in the same place against the church, goes straight along the entire mountain in the space of half a mile and ends at the end of the rural buildings, where the bank of the river begins. The huge mass of earth, outlined by the upper crevice, connects with another crack. It quickly began to settle down and disappear without a trace, as if filling up an invisible underground void. More than 5 fathoms is from the Church to the edge of the collapse. The water keys began punching in Choroshevo closer to Konyushennaya Sloboda, between the right and left sides of the buildings. It was not happen before. If no measures takes, the destruction of buildings in the left side of the village Choroshevo will accelerate [1].

The church community returned to the issue of reinforcement the bank of the Moscow River that threatens to collapse. It happens in the year of the 300th anniversary of the Romanov dynasty, in a petition dated February 1913.

Holy Trinity temple (our historical holy) situates at the high bank (about 30 fathoms) of the Moscow River. This bank gradually creeping. It will cause inevitable falling to the church. In this case, the church situated more than 20-30 fathoms from the bank will be standing at the 3-5 fathoms from the abrupt coastal cliff.

Thirty years ago, there was a landslide near the coast and it cracked the church wall. Just one minor landslide and the church will inevitably fall. The parishioners and the rector of the church organize measures to eliminate the inevitable church falling. These measures include tree plantations, fences formation and do not bring good results because all of them were showered and destroyed during spring floods. Our parish, for their poverty, could not organize more capital measures. That’s why with the fear and a broken heart, every spring, we are awaiting the destruction of the dear shrines” [2].

A.V. Pavlov, the professor of Russian University of Transport was the consulter. He told about the great threat to the temple. For this reason, it is necessary to force the bank or to luff the temple to the safe place [15].

Regular observations took place since 1975 and lasts until now. Until 2006 some minor mudslides occurred. They were 1-2 m along brow slope in length. High accuracy observations lasts since 1977 until 1984. They were taken place in 300 m down the river from Holy Trinity church. The highest average of frame displacement (86-91 mm) were near the river and decreased deep into the slope. They were 45-46 mm close

to the top of the slope. Noticeable signs of deep deformations were not noticed [8, 9].
The main landslide displacement occuries in 2006. The length of wall disruption was 300 m, the height was 0,5-1,0 m, which then increased to 3 m. Wall disruption situated in 5 m from one of the cottages and 15 m from the church. It threatens to their safety (fig. 4-5).

Figure. 4. Wall disruption of sliding sub block and the widest part of slipping down the under rim part at the territory of Holy Trinity temple (12.10.06), sliding area Choroshevo-1

Figure 5 Sliding fracture of lower sliding blocks opposite the temple

In October 2006 observation network occurred. It include soils deformation frames and stamps (over than 50 signals). Lately there occurred bore halls (inclinometric, tensor, metric, and others) which were used for observations. There were also clinometers organized on load-carrying structure of cottages and church. Observations on soil frames conducted at a frequency of twice a week, and then every two weeks (since May 2007) [13].

Instrumental observations shows that planned displacement of sliding terrace was more than dissenting block. The frame situated at the base of the slope displaced on 84 mm. The displacement was on the central trunk. Other frames situated on dissenting block displaced on 57-68 mm. [6]. The fracture which separates block from delyapsiya unfold on 0,7-1,1 m in a year [14].
Activation of sliding process Matches with the construction of Zhivopisnyj Bridge, with driving of piles for temporary support in southwest area of Choroshevo alignment. At the end of 2007, the displacement speeds decreased to 2 mm in a month. However in January 7, 2008 after opening the traffic along the bridge the speeds increased by four, reached 2 mm in a week [14]. Therefore, the main reason of sliding process activation are tecnogenic loads.

Quantity slope stability assessment

There are many stability assessment methods at present. The preferred method of calculations depends from the type of sliding process and mechanism of sliding masses possible displacement. [4].

The class of limit equilibrium method (Spenser) and finite elements method (FEM) were used along the estimates. These methods applies for heterogeneous slopes.

Engineering and geological models were created for stability estimation. The results of the performed study of engineering and geological conditions of the investigated territory were the base for model construction. They allowed establishing boundaries between engineering and geological elements that differs in their physical and mechanical characteristics. The model of Coulomb-Mohr soil destruction was the main along calculations. [5].
The results of slope stability assessment with the definition of stability factor (Sf) are on the fig. 6 (Spenser method).

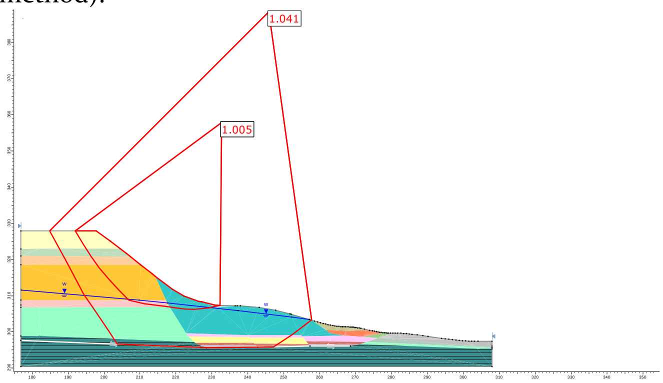

Figure 6 Geomechanical scheme with the results of slope stability estimation

In the result of sliding slope stability modeling by FEM the similar results received (fig. 7).

3D stability assessment realized for evaluation of the extent development the sliding process (by the limit equilibrium method (Spenser) (fig. 8).

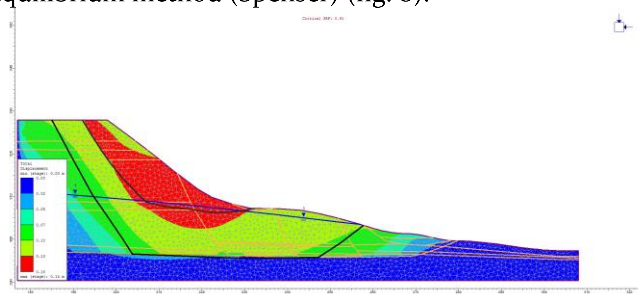

Figure 7. The estimation result by FEM method (Fs – 0.91). Black lines are the sliding surfaces estimated by Spenser method

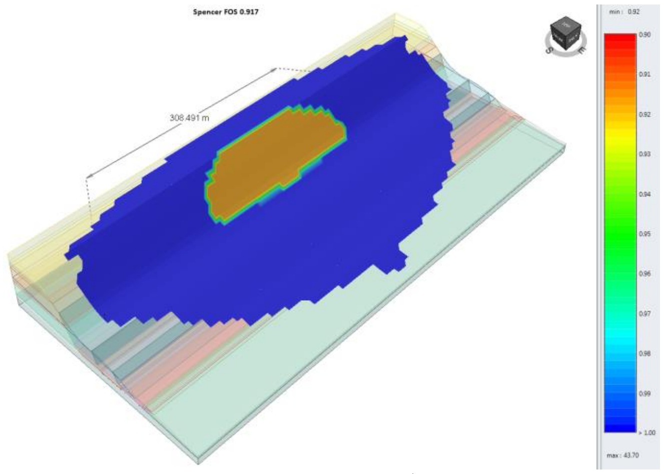

Figure 8. 3D slope stability assessment (by the limit equilibrium method (Spenser)

Estimated results about the landslide width (308 m) are well coordinate with the field data along engineering and geological investigations (300 m).

Conclusion

The analysis of data allows making a conclusion that there are two possible variants of sliding deformations.
According to the first variant the secondary landslide forms on the slope (Fs-1.005). Such scenario was proved along the geophysical investigations (fig. 9).

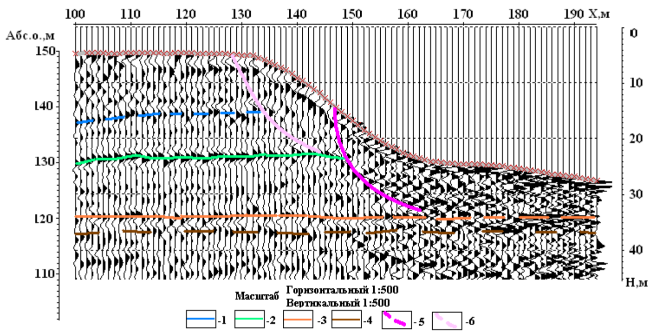

Figure 9. Deep seismogeological profile. 1 – the roof of the Cretaceous (?) deposits, 2 – the roof of the Volgian sediments; 3 – the roof of the Oxford clays; 4 – the roof of the Callovian clays; 5 - existing surface displacement; 6 – potential surface displacement

According to seismological profile, the block of secondary landslide forms on the sliding slope.

In concordance with the second variant, a new sliding block forms on the slope (Fs -1.04). Its sliding surface arranged to Upper Jurassic clays of Oxford stage. This variant was proved along inclinometric observations (fig.10).
Therefore, along the activation of sliding process there may be both variants when the process develops systematically. The secondary landslide formed on the first stage. Its activation on the second stage induced the new block formation with to Upper Jurassic clays of Oxford stage sliding surface. Maximum deformations were on the first stage. Second stage characterizes by long duration of sliding process.

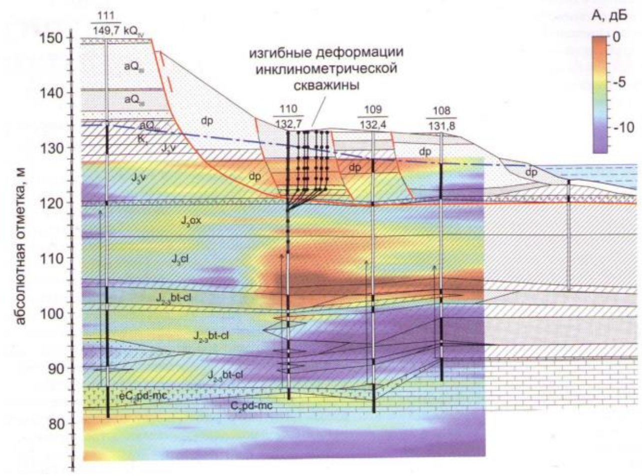

Figure 10. Geophysical profile and the results of inclinometric observations at the territory of Choroshevo-1. A – Amplitude of microseismic oscillation [16]

Correct ideas about the mechanism of landslide processes allow to predict them effectively and avoiding erroneous decisions on landslide protection.
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