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UNSTABLE SLOPES ON RIGHT-SIDE END OF THE DAM BODY OF LIPTOVSKÁ MARA WATER RESERVOIR**

1. Introduction

Water reservoir (WR) Liptovská Mara (fig. 1) with its volume of water (180 mln. m³) is the largest WR in Slovakia. It was put in operation in 1975.

Fig. 1. Localization of the water reservoir Liptovská Mara in a map of Slovakia

On the right–side of the dam body of WR Liptovská Mara there are located two landslides. On the water–side bank it is Veľkomarský landslide and on the downstream face of the dam it is Malý Valčianský landslide (fig. 2).

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Both landslides were developed in the area consisting of unfolded Paleogene flysch strata. The area of Veľkomarský landslide extends with length 900 m, width 550 m and the maximum thickness of the sliding material in the accumulation zone of the landslide exceeds 30 m [3]. The whole landslide is composed of several partial landslides of various ages. The supposed volume of the sliding mass exceeds 5 mln. m³ [1].

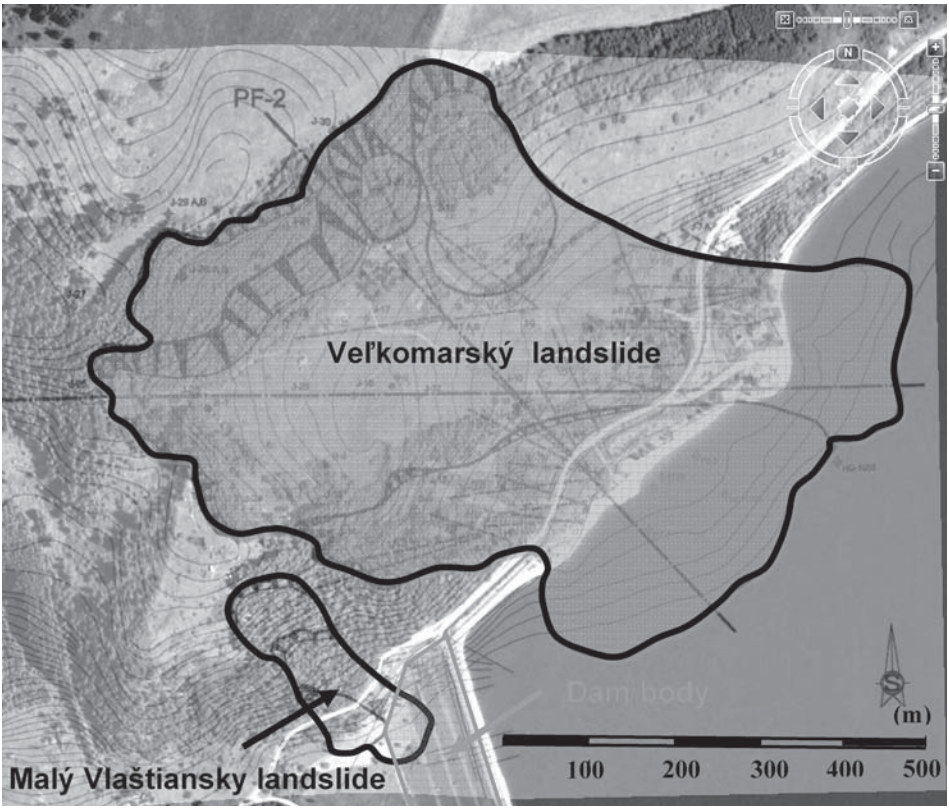

Fig. 2. Localization of the dam profile between Veľkomarský and Malý Vlaštiansky landslides, (satellite photo by Google Earth)

The Malý Vlaštiansky landslide is sited in close vicinity of the dam body, even part of its accumulation zone is located under drainage and stabilization foot slope of the downstream face of the dam body. The length of the landslide is approximately 320 m, width about 100 m. The landslide thickness ranges from 5 to 12 m.

The stability calculation of Veľkomarsky landslide performed prior to the WR construction had appointed to low stability of the slope. The calculation result meant concern about significant instability of the landslide after finishing the dam construction due to water buoyancy acting on the accumulation zone of the landslide.

To improve the Veľkomarsky landslide stability after finishing the construction of the WR the following remediation measures were taken (fig. 4):

— building of stabilization anti–abrasion embankments consisting of gravel and sand on the landslide toe (in 1974–75) — the thickness of the embankments was 7 m (volume 700 000 m³),
— realization of horizontal drainage wells (HDW), (4 stages in 1974–77),
— creating a system of surface drainage gutters (in 1976–1978).

2. Recent activities on the landslides

The activity of the Malý Vlaštiansky landslide is recently not monitored. Basing only on the field examination we suppose that the landslide accumulation zone, which is loaded by the embankment and partly also by the dam body, is stable and only upper part of the landslide can show some signs of activity.

Although on the Veľkomarský landslide there is geodetic network, however the results of the measurements of position changes of the fixed observation points on the landslide cannot be used for qualified assessment of the activity of the landslide (movement of „solid" points). For overview of activities of Veľkomarský landslide therefore changes of altitude of geodetic points are used only.

In late March 2006, the abrupt warming and rapid melting of very thick snow cover led to infiltration of water from the melted snow and to increase of groundwater levels in the sliding slope to maximum ever observed during the entire observation period. These high groundwater levels were synchronously with changes of elevation of the survey points. A significant decrease was recorded on points from B–1 to B–6, which are located in the head of the landslide area (from 6.9 to 12.2 mm — 9.8 mm in average! Fig. 3), and what indirectly points to a partial activation of the landslide area.

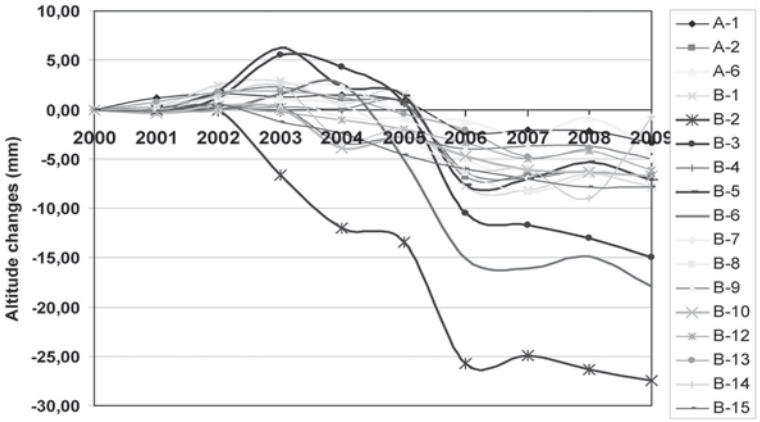

Fig. 3. Cumulative curves of altitude changes (mm) of fixed observation points during years 2000–2009

Fig. 4. Scheme of existing monitoring points and remediation measures on Veľkomarský and Malý Vlaštiansky landslides [2]
1 — earth dam, 2 — Vah river fluvial sediments, 3 — deluvial sediments, 4 — Paleogene strata, 5 — landslide bodies, 6 — water level, 7 — part of the Veľkomarský landslide under the water of the reservoir, 8 — surface drainage gutters, 9 — horizontal drainage wells, 10 — gravel walls, 11 — fixed geodetic points, 12 — geodetic observation points, 13 — observation well

3. Status of the current monitoring network on the landslides

The monitoring network (fig. 4) of both landslides was built 35 years ago. On the Veľkomarsky landslide in 1974–1975 there were built sites for observation of ground water levels (observation wells — 30 pcs). As remedial measures also 28 horizontal drainage wells with the total length of 3 800 m were built in 4 stages.

The groundwater level and discharge rate of HDW are monitored once per 14 days. In the period 2003–2010 16 observation wells were equipped with automatic piezometers (ŠGÚDŠ and TBD). Monitoring is carried out in order to assess the effectiveness of the remediation measures. For tracking of movements of the landslide a network of geodetic control points, consisting of 6 fixed points and 17 observation points was built in the landslide area. The geodetic measurements are performed once a year.

On Malý Vlačtiansky landslide the groundwater level is monitored in 13 observation wells and discharge rate in 8 HDW with frequency once per 7 days. Geodetic points are not built on this landslide. After 35 years of operation the monitoring elements are in different condition. Since installation several observation wells have been destroyed or become dysfunctional in terms of clogging by fine slurry in the bottom of the well.

With regard to long term monitoring of the HDW discharge, it is possible to observe decrease of the total volume of the water being removed from the landslide (fig. 5).

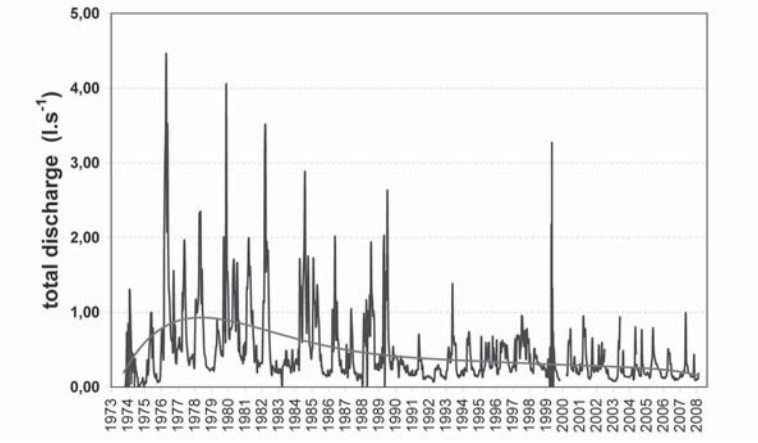

Fig. 5. Downward trend of the total discharge from all HDW on Veľkomarský landslide

However, this overall groundwater level decline does not have to play a role in reducing of local slope stability, unless due to decrease in water discharge from HDW the groundwater level is not increased in the nearby observation wells. The negative impact of the discharge decline in HDW from V–12 to V–15 located in the landslide head area is quite obvious. In this area, in observation wells J–16, J–17 (fig. 6), J–18, J–11B, J–11A the groundwater level is increasing for long time period, in the case of J–11A the groundwater freely flows out the well as

from artesian well. People from TBD made inspection in the horizontal drainage wells with use of camera. The largest throughput was observed only up to 30 m (in 2 wells). In most cases the camera got only a few meters away from the HDW mouth. The inspection results have pointed out that the broken HDWs should be either cleaned or replaced by new HDWs.

On the Malý Vlaštiansky landslide there was observed long lasting increase of groundwater level in 5 observation wells. The measurements of the HDW discharge rate were not available, but their inspection by survey camera proved their reduced functionality (blocked perforation).

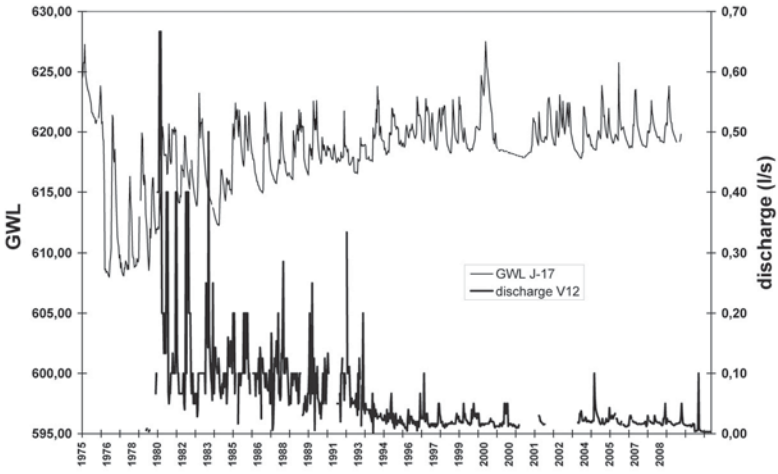

Fig. 6. Decrease of effectiveness of HDW V-12 and gradual increase of GWL in borehole J-17

4. Proposal of building and maintenance of the monitoring network for the landslides

The proposal of the complex monitoring of the landslides on the right-side of the dam body of WR Liptovská Mara was designed such a way that its result was:

— determination of the landslide recent activity,
— forecasting the future development of the stability,
— setting the critical values for need of realization additional remediation measures.

4.1. Veľkomarský landslide

The proposed measures were split in to 3 stages — table 1. Emphasis is placed especially on the building of inclinometer boreholes and reconstruction of geodetic network, because stability (or better dynamics) of any slope can be judged the best way by combination of geodetic measurements of the surface movement with inclinometric measurements of movement under the surface. It will be also necessary to clean the existing HDW. If such measures proves ineffective, it will be necessary to proceed with a construction of new HDW.

TABLE 1
Proposed measures on the Veľkomarský landslide in 3. stages

Stage		Proposed measures	Purpose and output of the measures
1.	Specifying and obtaining additional information on landslide area		
	a)	Geodetic survey of existing monitoring elements and important elements of the landslide areas	Creating a representative model of slope deformations + positioning of the network elements
	b)	Geophysical measurements — 4 profiles with total length 2380 m	Determination of surface and depth extent of the landslide area + precising the location of new inclinometers
2.	Building of new elements of the monitoring network		
	a)	building inclinometer boreholes — total 7 pc — 200 m	Observation of movements in depths of the massif. Determination of residual shear strength parameters of soils from samples taken during the drilling.
	b)	building new piezometers — total 4 pc — 100 m	Measurement of GWL in the vicinity of inclinometer boreholes + installation of automatic piezometers.d
	c)	new geodetic points — 5 pc	Measurement of surface movements of landslide the area — movement of blocks in the upper part of the landslide area.
3.	Reconstruction of the current monitoring network elements		
	a)	geodetic points — rebuilding all 22 pc	Rebuild geodetic points in their original places and adjusting their surroundings for measurements by methods of Very accurate leveling and GPS.
	b)	piezometer — reconstruction of approximately 11 pcs — 265 m	Reconstruction of the broken wells
	c)	horizontal drainage wells — about 2000 m	Cleaning those HDW which show long-term decline in discharge rate and those in which there is a rise of GWL (fig. 5) In the case of inefficient cleaning new HDW will be necessary to build.

4.2. Malý Vlaštiansky landslide

Works will consist of geodetic survey and implementation of one geophysical profile to create a representative model of the landslide. As new elements of the monitoring network we propose to build one inclinometer borehole and five geodetic points. Also it will be necessary to clean the existing HDW, or in case of ineffectiveness of such measures, it will be necessary to make new HDW.

5. Conclusion

Even during the renovation and reconstruction of new elements of the monitoring network it is necessary to continue with monitoring measurements on both landslides. However, gradually it is necessary to upgrade the system to automatic data acquisition in order to determine the threshold conditions for the possible activation of the landslides. Only then it will be possible to implement necessary measures in time and to provide a safe operation of the WR Liptovská Mara.

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