*Studia Geotechnica et Mechanica, Vol. XXXV, No. 1, 2013* DOI: 10.2478/sgem-2013-0011

# HORIZONTAL DRAINS AS EFFECTIVE MEASURE FOR LANDSLIDE REMEDIATION

MILOSLAV KOPECKÝ, MARTIN ONDRÁŠIK, DARINA ANTOLOVÁ

Faculty of Civil Engineering, Department of Geotechnics, Slovak University of Technology,
Radlinského 11, 813 68 Bratislava, Slovakia.
E-mail: miloslav.kopecky@stuba.sk, martin.ondrasik@stuba.sk

**Abstract:** Decrease of groundwater table level or decrease of buoyancy effects of groundwater is one of the most important landslide remediation measures. In Slovakia as well as in the world the horizontal drainage boreholes are often used for the landslide remediation. The article describes 40 years' experience with use of the horizontal drainage boreholes in Slovakia, particularly in terms of their effectiveness and long-term functionality.

## 1. INTRODUCTION

Among the most common methods used for subsurface drainage of landslide slopes is realization of horizontal drainage boreholes (HDB). The advantage of this method lies in its quick effectiveness and relatively low cost.

According to the archive documents the HDB were used for the first time in 1939 in California [1]. In the former Czechoslovakia HDB were put into practice by Prof. V. Mencl and the first landslide remediation using HDB in Slovakia was carried out on landslide in Harmanec in 1965 [2]. The boom in the deployment of HDB occurred in Slovakia between 1973 and 1980. For example, in the vicinity of the town of Handlova there were at that time realized HDB with a total length of 23.5 km [3].

Today in Slovakia the horizontal drainage boreholes are used in more massive scale for stabilization of slopes and tunnel portals in the extensive highway constructions.

## 2. CONSTRUCTION OF HORIZONTAL DRAINAGE BOREHOLES

### 2.1. CONSTRUCION IN SLOVAKIA

The horizontal boreholes are drilled mainly with spiral drills, less with a rolling drills. The borehole is then permanently equipped with steel casing of profile mostly 89 or 108 mm. In Slovakia, there is mainly used a method of gradual pressing of fully perforated casings (Fig. 1E), which are then used as a permanent casting. Starting guide tubes (length 6–30 m), consisting of full steel pipes (∅ 152–171 mm) are mounted in a concrete discharge objects. HDB vary in length, averaging 110 meters, maximum length was up to 260 m, the inclination varies from 0 to 20° (mostly 2–3°).

In some landslides, where the drilling technique could not be used, the drainage pipes (length about 20 m and ∅11 cm) were driven into the landslide body with the use of pressurized water (water jet).

### 2.2. CONSTRUCTIONS IN THE WORLD

In other countries the horizontal borehole is usually equipped with the casting after the drilling. Hollow drilling pipes are used as the temporary casting. The advantage of this technology is that based on the geological environment detected it is possible to use either the most suitable perforations of the permanent casting or a filter instead of perforations. As the permanent casting exclusively plastic tubes are used. The advantage of plastic tubes is their high chemical resistance, on the other hand, they have a low strength in the case of a landslide activity

The diameter of the drilling pipes is from 120 to 150 mm and the diameter of plastic tubes is mostly from 60 to 100 mm. The bottom part of the tubes is usually without perforations to prevent re-infiltration of the drained water into the surrounding environment. This may be important especially in parts of the HDB located above the groundwater table. In Slovakia, the re-infiltration of the drained water into the surrounding environment was observed when fully perforated tubes were used. The most common perforation used on the plastic tubes is a slot perforation (Fig. 1A).

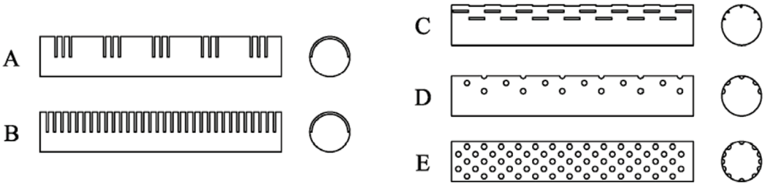

Fig. 1. Examples of perforations used on steel or plastic tubes

A current trend is implementation of casting with wider perforation protected with coating from geotextile. Only rarely laminated or stainless steel filters are used. The question of their necessity is still open. According to the experience the HDB operate mostly reliably even without filters. This is probably due to the gradual establishment of a natural filter in their surroundings.

## 3. POSSIBILITIES OF UTILIZATION OF THE HORIZONTAL DRAINAG BOREHOLES IN LANDSLIDE AREAS

The basis for the use of HDB is understanding of the geological and hydrogeological conditions, particularly of area recharging the landslide with groundwater. Especially it is very important to determine how the landslide mass is recharged by groundwater. There is a considerable difference between the solution of drainage of landslide recharged by ordinary rainfall infiltration and by groundwater originating from larger hydrogeological structures.

Horizontal boreholes are realized either from the surface or in the case of deeper slip surfaces from shafts with a wide diameter. In the case of Handlova landslide these shafts had a diameter of 6 m and a depth of 6–10 m (Fig. 2). This configuration allowed drainage of the landslide slip surface area to the HDB almost on its entire length. Drainage of water accumulated in such shafts is also provided by horizontal boreholes connecting shafts with suitable recipient.

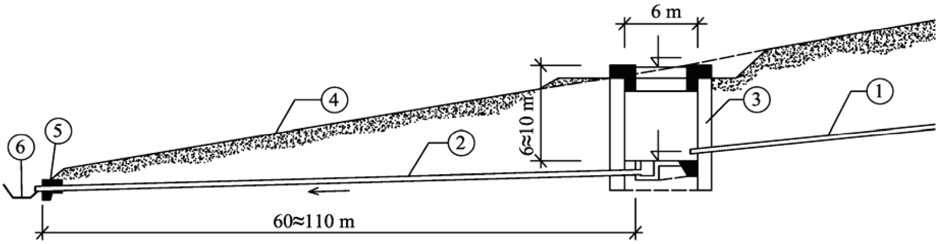

Fig. 2. Scheme of horizontal drainage boreholes realized from a shaft (after Flimmel [4]):
1 – fan of horizontal drainage boreholes, 2 – borehole draining the shaft, 3 – shaft made of drilled piles,
4 – terrain surface, 5 – concrete discharge object, 6 – recipient channel

The horizontal boreholes are often used also for drainage of groundwater flowing out of other drainage object – underground gravel walls. In both cases it is wise to make the horizontal borehole prior to shaft or wall.

HDB are suitable as remediation measure especially for drainage of significantly watered layers of lager thickness and mutually interconnected. HDB efficiency is the best if the horizons are captured, especially in the upper parts of the slope where the effect of the water hydrostatic pressure reduction contributes most to the slope stability. They are effective also for drainage of groundwater gathered on a dilatational slip surface of landslides.

On the other hand, it is not suitable to use HDB in thick layers of fine-grained (pelitic) rocks with low permeability. Lot of horizontal boreholes are necessary to install in such case, because the areal coverage of one HDB in such material is very small. Great care must be taken when using HDB for remediation of deep landslides not only in pelitic, but also in strongly weathered and broken semi-hard rocks.

Due to the effective drainage of large landslide slopes there is always an increase of the effective normal stress on the slip surface, which can lead either to contractant behavior of rocks and soils with development of their significant supple strain related also to the increase of pore pressures in a wide slip zone, or to a decrease of their shear strength, or even to significant subsidence of the overlying layers.

Design of longer HDB (longer than 50 m) must respect also the fact that passing through softer rock declines (by 4–8°) and passing through harder clastic rocks the vertical alignment inclines (by 2–4°). Lateral deviation of the borehole is in turn consistent with the direction of rotation of the drilling tool.

Use of the HDB was very interesting at the site V. Čausa [5]. When draining landslide by electroosmosis method the horizontal boreholes were involved as cathode and served to drain the accumulated water. Anode system consisting of a network of vertical steel rods was placed along the horizontal boreholes. By the time the dry horizontal drainage boreholes due to electroosmosis started to discharge the groundwater.

## 4. EFFECTIVENESS OF HORIZONTAL DRAINAGE BOREHOLES

The most effective are mainly the HDB located in pressurized aquifers rich in water. According to Brandl [6], if such layer is not in a slope, it is considered a success when 20 to 30% of all HDB encountered groundwater in the slope. Nakamura [7] stated that according to his experience it is around 45%.

The largest discharge from HDB is achieved during drilling (max. 300 $\text{l.min}^{-1}$), or shortly after, and then the discharge has declining trend (Fig. 3). The initial large discharge is mostly because of static groundwater reserves. Water from rainfalls is not a sufficient source to recharge larger dynamic resources. HDB discharge more water from the landslide than a volume of inflowing groundwater is recharging it. The further decrease of the discharge with time is also caused by the slow clogging of the casting perforations (Section 6).

Fig. 3. HDB discharge during drilling and two months after

Efficacy of the HDB is many times incorrectly evaluated according to discharge rate. However, the amount of water flowing out of the HDB is not as important as the reduction of the buoyancy effects of groundwater in the slope. To get this change in a low permeable hydrogeological environment it is enough to drain a small amount of ground water, or just drops. However, if in high permeable layers HDB give lots of water, it is not necessarily effective in terms of slope stability if the inflow into landslide is larger than the HDB discharge.

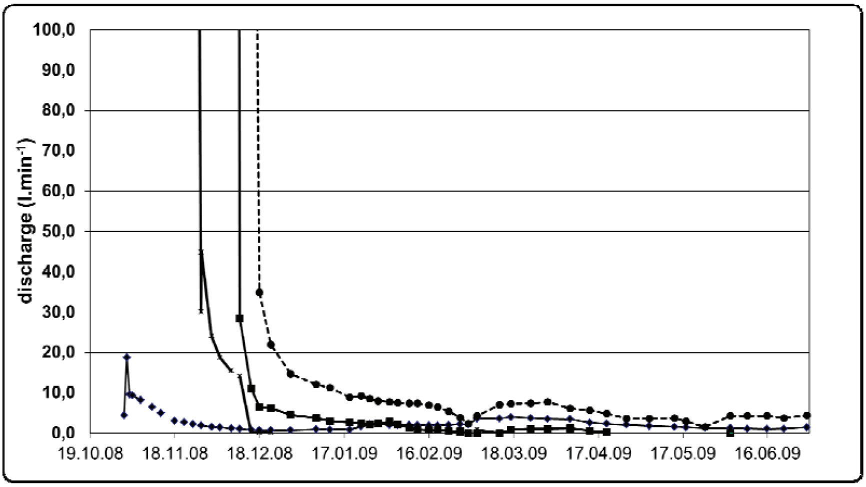

Fig. 4. Declining trend of HDB discharge in Považská Bystrica

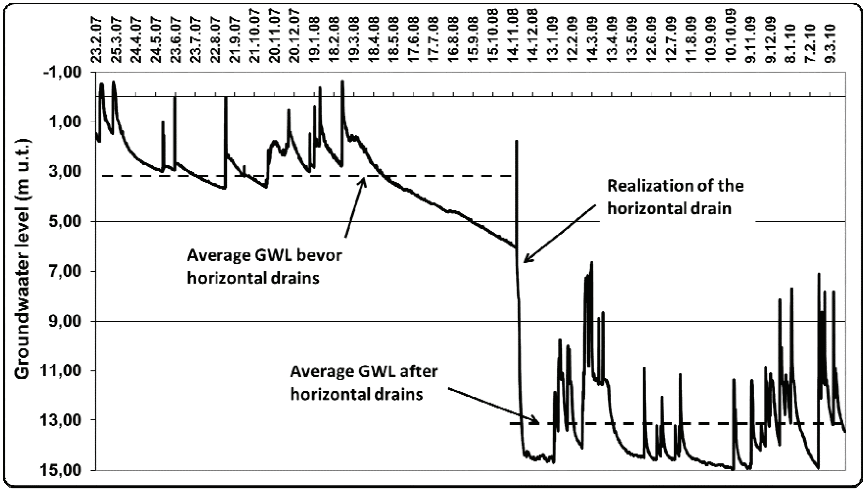

Fig. 5. Example of a decrease of GWT in observation well after the HDB realization

The aforementioned criteria of HDB efficiency by discharge rate fluctuation are considered only as indicative. Actual impact of HDB on an increase of landslide area stability can be evaluated indirectly, in particular by changes in hydraulic potential and its gradient, changes in pore pressure or, in the simplest case, changes of groundwater tables (Fig. 5). The direct effect can be evaluated by various methods of movement measurements at the surface or in the body of a landslide.

In Fig. 5, there is an example of groundwater table (GWT) decrease measured in observation well with a continuous sensor which was set to one hour reading period (locality highway rest area in Považská Bystrica). The average decrease of GWT in observation wells after realization of HDB was almost 10 m, which resulted in a slowdown, respectively stopping of the landslide motion as proved by measurements in the nearby inclinometer. The overall decrease of GWT in the landslide area under the highway rest area after realization of 41 HDB with total length of 3 572 m was 10 to 12 m in comparison to original state of GWT [8 and 9].

Some authors have investigated the effectiveness of HDB in relation to the way they are distributed. However, it is not relevant whether the horizontal boreholes are located in a fan like shape, or are situated in a slope parallel to each other.

The effectiveness of horizontal boreholes is also evaluated by mathematical modeling. Models are often very simplified in the boundary conditions and internal geological settings, which does not reflect real settings of the highly inhomogeneous landslide. HDB are likely to be considered as exploratory for some time and their design will have empirical character mainly.

In the design of HDB, it is important to know what their range in the geological environment is. According to experience in Slovakia [10] in clay and sandy-clay landslide sediments the observed lateral drainage range was maximum from 7 to 10 m, in loam-rocky debris the range is 15 m and in clay-pebble landslide sediments the range is up to 25–30 m.

## 5. EVALUATION OF FUNCTIONALITY OF HDB IN THE LANDSLIDE AREAS IN SLOVAKIA

For the evaluation, we have reviewed available data from the HDB which was over 30 years old. That set consists of 435 horizontal drainage boreholes realized in Slovakia. The basic data for the boreholes were:

- length of HDB,
- HDB inclination,
- discharge rate during drilling,
- discharge rate after drilling – initial discharge,
- diameter of perforated casting,
- year of installation.

The values mentioned for all HDB are statistically summarized in Table 1.

Table 1

Basic statistical data for HDB under investigation

| | Minimum | Maximum | Average | Modus | Median |
|---|---|---|---|---|---|
| Length of borehole (m) | 20 | 210 | 110.2 | 150 | 110 |
| Borehole inclination (°) | 0 | 20 | 3.32 | 3 | 2.22 |
| Discharge during drilling ($l.min^{-1}$) | 0 | 600 | 22.3 | 3 | 4 |
| Discharge after drilling ($l.min^{-1}$) | 0 | 600 | 20.3 | 6 | 4 |
| Diameter of perforated casting (mm) | 60 | 112 | – | 108 | 108 |
| Year of drilling | 1967 | 1984 | – | 1976 | 1977 |

A visual inspection of the HDB mentioned showed that 59% of all boreholes were still functional. As functional, such HDB were considered which drained any quantity of groundwater from landslides. These included also HDB dropping or visibly wet at least. The aim of the evaluation was to assess whether any of the available information has significant impact on preserving functionality of the HDB up to now.

**a) Discharge rate of functional HDB**

In Fig. 6, a division of HDB according to their initial discharge rate is illustrated.

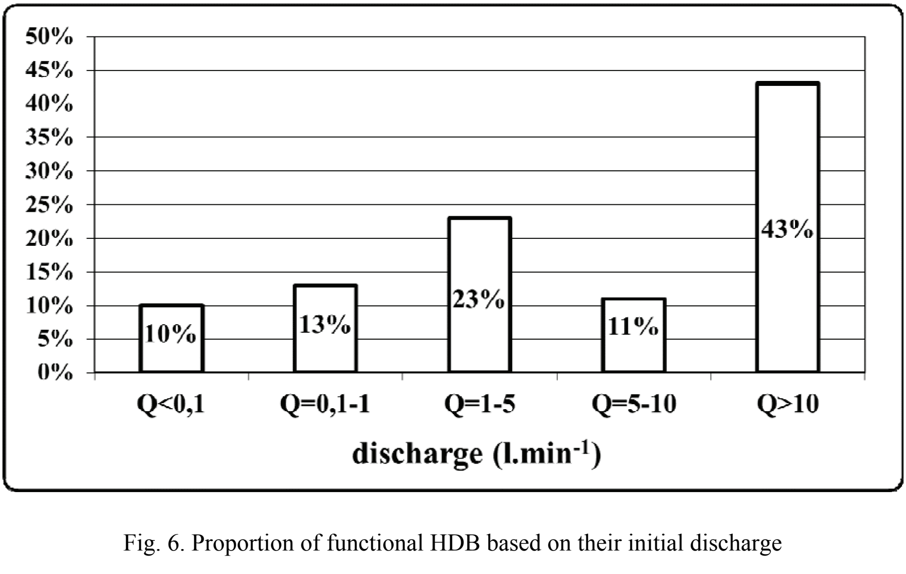

Fig. 6. Proportion of functional HDB based on their initial discharge

The figure shows that up to 43% of the horizontal boreholes had initial discharge rate greater than 10 $l.min^{-1}$. On the other hand, only 10% of the HDB had discharge less than 0.1 $l.min^{-1}$.

**b) Inclination of functional HDB**

Distribution of boreholes according to the inclination is illustrated in Fig. 7.

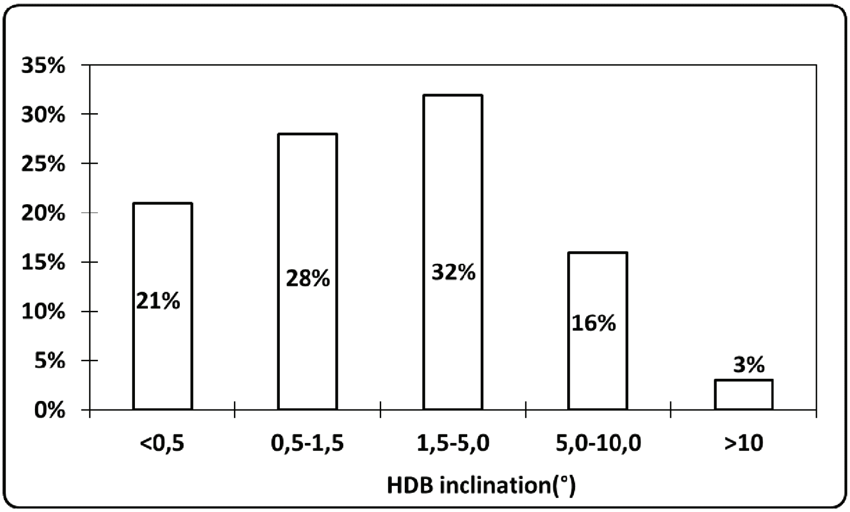

Fig. 7. Proportion of functional HDB based on their inclination

81% of functional HDB has inclination up to 5° and only 3% of HDB has inclination over 10°.

**c) Length of functional HDB**

Almost 80% of all horizontal boreholes have a length greater than 100 m. The number of HDB with a length from 100 to 150 m is approximately equal to the number of HDB longer than 150 m. The relationship between the length of the borehole and the initial discharge rate was not confirmed.

**d) Age of functional HDB**

The functional boreholes evaluated are minimum 29 years old, with 64% of boreholes being more than 35 years old.

In the conclusion of this Section we can say that there was observed only one factor that affects the functionality of HDB. It is the initial discharge rate of HDB (Fig. 6), because up to 43% of HDB functioning today had initial discharge rate greater than 10 $\mathrm{l.min}^{-1}$ and 54% greater than 5 $\mathrm{l.min}^{-1}$.

A small inclination of a borehole may not have effect on HDB functionality, because up to 49% of today functioning boreholes have inclination up to 1.5°.

## 6. TYPES AND CAUSES OF CLOGGING OF HDB BOREHOLES AND MEASURES FOR ITS PREVENTION

Based on our monitoring of current quality of HDB (including inspection with camera) the causes of clogging can be divided into 3 groups:

A. Inside of the casting:
- casting is cut off (broken) due to movement on slip surface and the borehole is filled with soil sediments,
- sediments are entering the casting at the inner end of the borehole,
- sediments are deposited due to sudden changes of discharge,
- algae or rust produced in the borehole can slow the flow of water and thus increase deposition of sediments,
- precipitants from water are depositing in casting.

B. At casting perforation and in the borehole vicinity:
- corrosion of the steel casting,
- filter is clogged with iron oxides contained in water,
- calcium is precipitated on the part of the filter,
- filter is clogged with fine particles of sediment,
- plant roots grow through the borehole near its proximity to terrain.

C. At HDB mouth:
- precipitation of $CaCO_3$ deposits,
- coarse and fine sediment particles,
- freezing of water.

According to our observations during the HDB inspection the cause of drainage capacity decrease of the HDB may be also corrosion of casting with filter, mechanical clogging with fine sludge, chemical and biochemical clogging with iron oxides, $CaCO_3$ precipitation or overgrowth of borehole head with algae and moss or even with plant roots. However, usually the cause is a combination of the phenomena mentioned.

These phenomena are most intense near the mouth of HDB, where there is a rapid exchange of air and frequent temperature changes. Thus we would recommend that the mouth of HDB should possibly lay under water (e.g., reservoirs). Overlapping of HDB mouth by 1.5 m thick gravel earthfill is appropriate also as protection against frost action [11]. During several freezing days at low discharge rate of HDB (up to 8 $\mathrm{l.min^{-1}}$) the water freezes at borehole mouth and plugs it, which causes accumulation of water inside the horizontal borehole and threatens the stability of a slope. It should be noted, however, that the freezing of water is also affected by its temperature and mineralization.

## 7. METHODS FOR PURIFICATION OF HDB

One of the localities where the HDB are in operation for almost 40 years is the landslide near Liptovská Mara dam. The landslide area is about 900 × 550 m where 28 HDB were made with a total length of 3800 m (Fig. 8).

Even when HDB fulfill their function and at maximum level of groundwater table they serve as a safety overflow. From the long term point of view (since 1974) it is possible to observe gradual decrease of the total amount of water discharging from the landslide (Fig. 9).

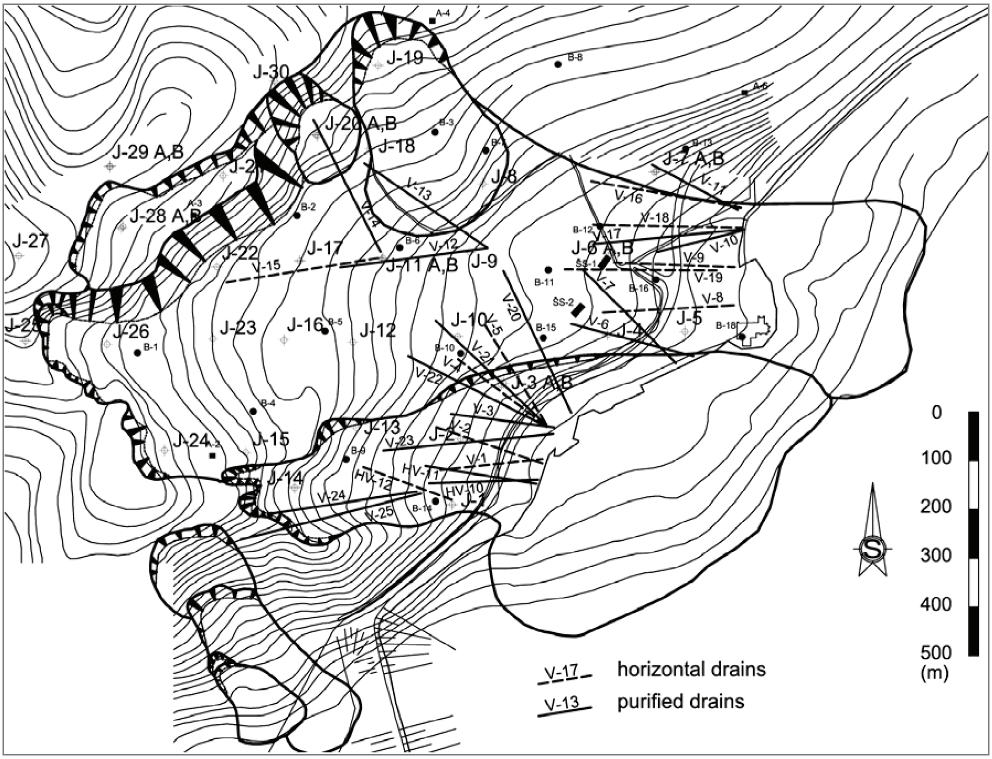

Fig. 8. Distribution of HDB on the landslide Liptovská Mara

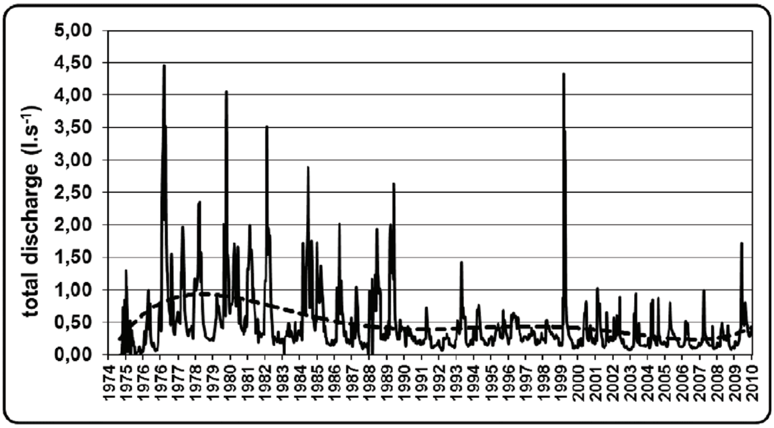

Fig. 9. Decreasing trend of the total discharge from HDB at the landslide Liptovská Mara

Cleaning and reactivation of HDB in Slovakia is performed as follows. First, a spiral drill clears HDP from deposits and incrustations. Then a pressurized water jet is inserted into the HDB, with water jet velocity of 30 m.s$^{-1}$. The borehole is cleaned up when clear water flows from the mouth of the borehole.

The cleaning of Liptovská Mara landslide was performed as described above in several stages. In the first stage, in the summer 1995 nine HDB were cleaned up. These were the HDB that showed long-term low discharge rate.

After 15 years in operation the cleaning confirmed to be very successful in three horizontal boreholes V-7 (Fig. 10), V-23 and HV-10. Significant result of the cleaning was observed also in the HDB HV-11. The result of cleaning effectiveness on the other HDB could not be unambiguously determined.

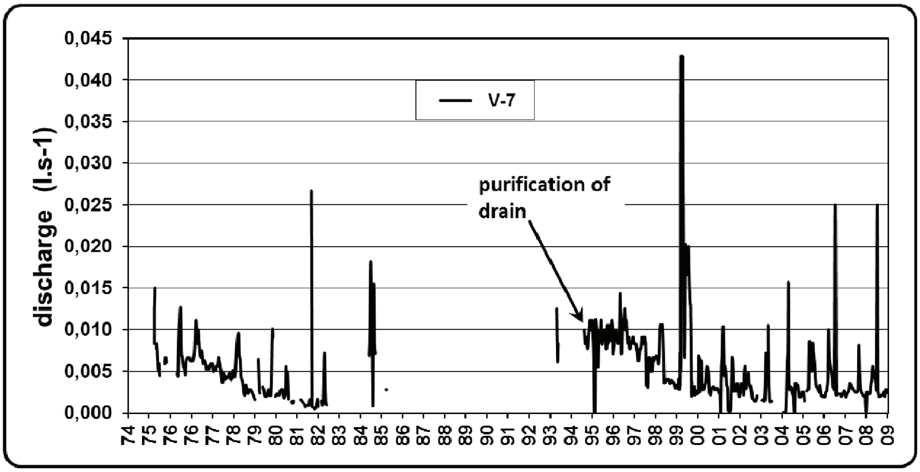

Fig. 10. Recovery of discharge on HDB V-7 after its cleaning in 1995

The global decrease of the total discharge rate from all HDB (Fig. 9) may not play a role in reducing the local slope stability if due to discharge rate decrease no increase of GWT level is observed in nearby observation wells.

However, there is obviously a negative effect of the decrease of discharge rate in HDB from V-12 to V-15 situated in the main crown area of the landslide (Fig. 8), where there is a long term increase of GWT in observation wells J-16, J-17 (Fig. 11), J-18 J-11B as well as J-11 – where groundwater is flowing out from a vertical borehole head as from artesian well [12].

Based on the above information decision to perform another cleaning of HDB was made in 2011. Results of the process of purification of HDB on Liptovská Mara landslide are given in Table 2.

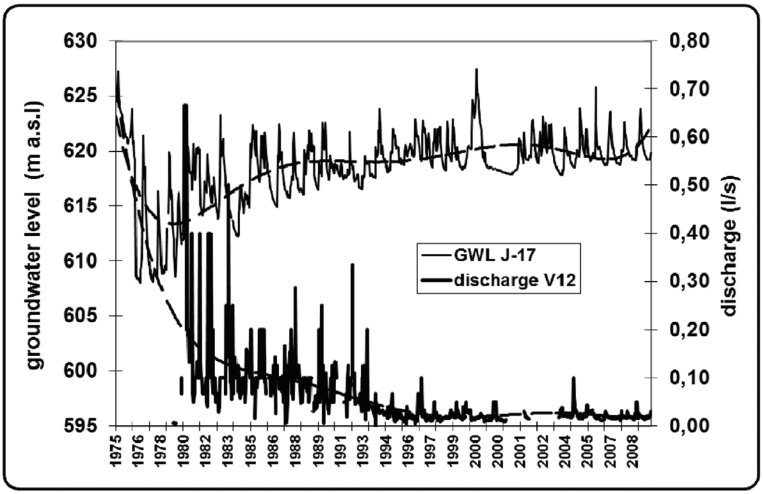

Fig. 11. A decrease of functionality of HDB V-12 and GWT rise in observation well J-17

Table 2

Results of purification process of HDB on Liptovská Mara landslide

| | HDB lable | Original depth (m) | Purified depth (m) | Discharge prior to purification ($l.min^{-1}$) | Discharge after the purification ($l.min^{-1}$) |
|---|---|---|---|---|---|
| HDB cleaning in 1995 | V-6 | 125 | 124 | dry | 0.65 |
| | V-7 | 125 | 127 | dry | 13.04 |
| | V-11 | 97.5 | 149 | 1,42 | 1.83 |
| | V-17 | 150 | 152 | dry | 1.9 |
| | V-24 | 150 | 56 | dry | 0.42 |
| | V-25 | 150 | 84 | dry | dry |
| | HV-10 | 112 | 123 | dry | 5.55 |
| | HV-11 | 120 | 125 | 0.32 | 0.54 |
| | V-23 | 150 | 150 | – | – |
| | **total** | **1179.5** | **1090** | **1.74** | **23.93** |
| HDB cleaning in 2011 | V-3 | 130 | 132 | – | – |
| | V-12 | 210 | 161 | 0.045 | 0.054 |
| | V-13 | 150 | 145 | 0.125 | 0.172 |
| | V-14 | 150 | 150 | 0.025 | 0.125 |
| | V-20 | 150 | 148 | – | – |
| | V-21 | 150 | 96 | – | – |
| | V-22 | 150 | 145 | – | – |
| | V-23 | 150 | 122 | 0.76 | 9.38 |
| | **total** | **1240** | **1099** | **0.955** | **9.731** |

Nearly 60% of the total length of HDB was overall cleaned up. And as can be seen from both cleaning stages, immediately after cleaning the discharge rate was increased about 12 times. The final efficiency of the HDB cleaning will be verified in the future by monitoring the discharge rate of HDB and groundwater table level.

## 8. CONCLUSION

As was shown in the present article, in Slovakia the use of HDB is an effective tool for drainage and subsequent stabilization of landslides. The HDB can be effective even after 40 years in operation, however it is necessary to provide their maintenance, especially regarding the part near their mouth. Restoring or improving the functionality of HDB can be performed by a relatively undemanding cleaning, as we have shown on the example of Liptovská Mara landslide.

*This research was funded by the grants No. 1/0944/11 VEGA Agency.*

## REFERENCIES

[1] SMITH T.W., STAFFORD G.V., *California experience with horizontal drains for landslide correction and prevention*, presented at the Annual Convention A.S.C.E. New York City, New York, October 24–28, 1955, 17 pages.

[2] NEMČOK A., *Zosuvy v slovenských Karpatoch*, Bratislava, Veda, 1982, 306 pages.

[3] ČERTÍK P., FLIMMEL I., SPUSTA P., *Skúsenosti zo sanačných prác v Handlovskej kotline*, Konferencia Výskum, prieskum a sanácia zosuvných území na Slovensku, Nitrianske Rudno, 1996.

[4] FLIMMEL I., *Horizontal drainage borings and cast-in-situ pille walls as stabilization treatment of landslides in sedimentary rocks*, Bulletin of the Int. Assn. of Engineering Geology, Issue Number: 16, 1977, 168–170.

[5] VILUMSEN A., ARVENSIS M., *Elektroosmóza – perspektívna metóda sanácie zosuvov*, Konferencia Výskum, prieskum a sanácia zosuvných území na Slovensku, Nitrianske Rudno, 2–4 Oktober 1996, Vyd. IRIS, Bratislava 1996.

[6] BRANDL H., *Geotechnische Massnahmen zur Sicherung von Rutschhängen*, 8 Christian Veder – Koloquium, TU, Graz, 1993, 39 pages.

[7] NAKAMURA H., *Landslide control works by horizontal drainage works*, Landslides, Proc. 5th symposium, Vol. 2, Lausanne, 1988, 965–970.

[8] KOPECKÝ M., *Posúdenie vplyvu realizácie horizontálnych odvodňovacích vrtov na hydrogeologické pomery a na stabilitu zosuvných svahov pod odpočívadlom*, Katedra Geotechniky, SvF STU Bratislava, 2010.

[9] KOPECKÝ M., GRÓF V., ONDRÁŠIK M., HRIC S., *Monitoring zosuvných svahov pod odpočívadlom pre D1 v Považskej Bystrici*, In zborník: 9, Medzinárodná Geotechnická Konferencia, STU Bratislava, 2009, 229–234.

[10] FUSSGÄNGER E., MALGOT J. et al., *Metódy výskumu a prieskumu svahových deformácií – čiastková výskumná úloha*, IGHP, Žilina, 1982.

[11] ZÁRUBA Q., MENCL V., *Sesuvy a zabezpečovaní svahů*, Druhé přepracované a doplněné vydání, Academia, Praha, 1987.

[12] KOPECKÝ M., ANTOLOVÁ D., *Návrh komplexného monitoringu na Veľkomarskom a Malom Vlaštianskom zosuve*, Záverečná správa, Katedra Geotechniky SvF STU, Bratislava, 2010, 38 pages.