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BEHAVIOUR OF THE BACKFILLED RIGHT BANK OF THE MAVČIČE DAM

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1. INTRODUCTION

The Mavčiče concrete gravity dam, part of the corresponding hydro-power plant, was built on the Sava River, in central Slovenia (see Fig. 1), in 1986. It has a maximum structural height of 38.5 m, and the dam crest has a length of 149 m. The concrete dam structure consists of an erection bay, a machine hall, and two spillways, followed by an embankment dam (see Fig. 2). The total capacity of both spillways, which are closed by radial gates with flaps, is 3,200 m^3/s. The reservoir, which contains 10.7 hm^3 of water, has a length of 7.0 km and the surface area of 1.0 km^2, whereas the catchment area of the reservoir is 1,480 km^2 [1, 2].

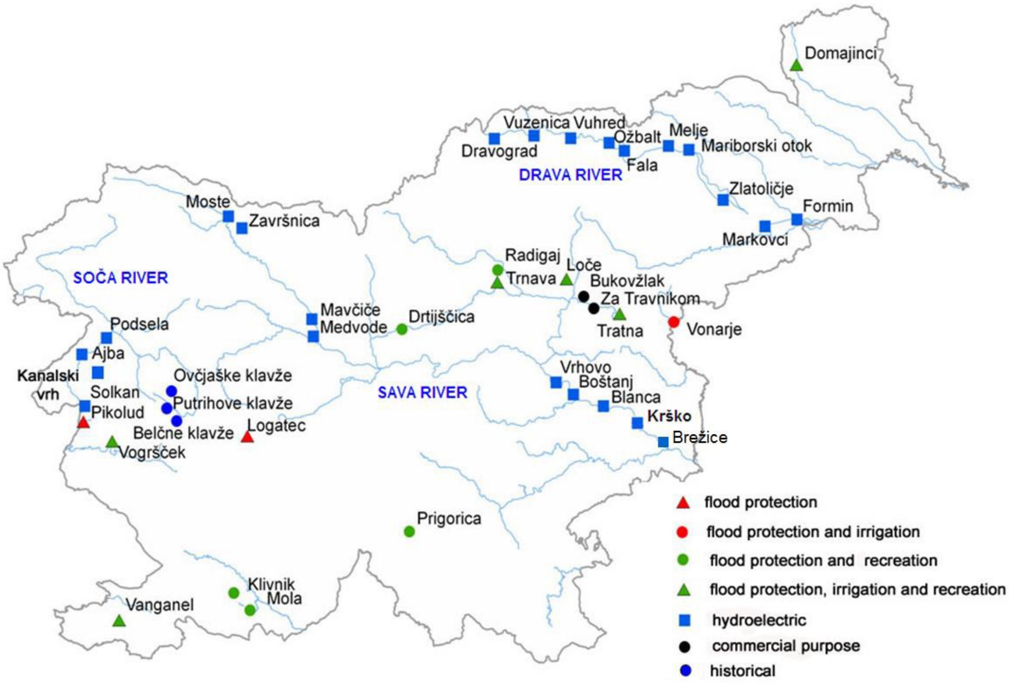

Fig.1
The locations of large dams in Slovenia

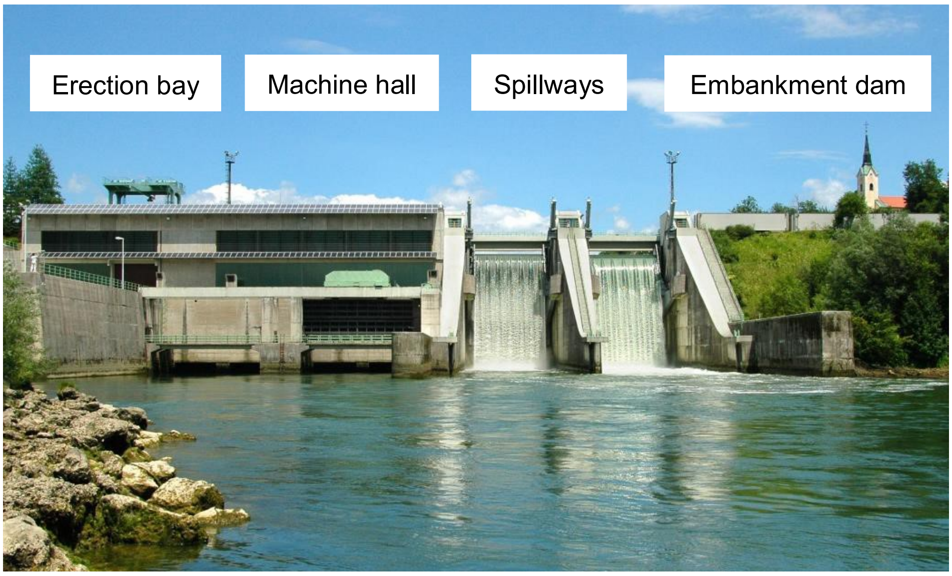

Fig. 2
View of the Mavčiče Dam

2. FOUNDATION OF THE DAM

Most of the Mavčiče Dam is founded on permeable Quaternary conglomerate bedrock, so that a cut-off grout curtain had to be constructed to a depth of up to 60 m below the ground surface, i.e. up to 296 - 302 m above sea level, where a layer of impermeable Oligocene marine clay occurs. The foundation of the machine hall is, for instance, at the altitude of 309.50 m. However, the erection bay, which is located on the right bank of the dam, is founded on a layer of gravel backfill, up to about 25 m thick, which lies on top of the conglomerate bedrock. The upper courtyard, which is located behind the erection bay, has an altitude of 348.00 m, whereas the lower courtyard, which lies in front of the erection bay, is located 10.75 m lower, i.e. at the altitude of 337.25 m [3]. The foundation of the right portion of the dam is presented in Fig. 3.

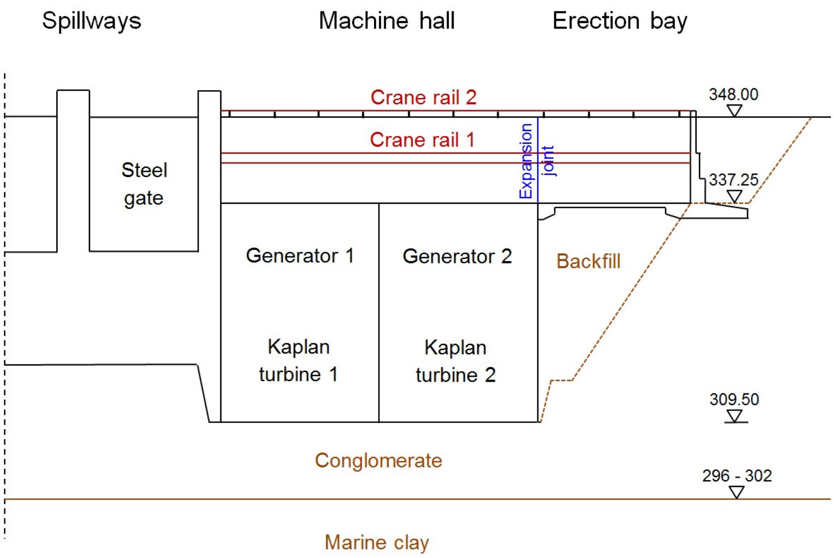

Fig. 3
The foundation of the right portion of the Mavčiče Dam

3. MONITORING SYSTEM OF THE DAM

Long-term manual technical monitoring of the behaviour of the dam began in 1986, at the time of the dam's completion, and included all necessary types of measurements and inspections. In 1999 to 2000 the supplemented monitoring system of the detailed behaviour of the right bank of the dam was established, which included twenty-six points for the vertical displacement measurements. Eighteen of these points (indicated by 1 to 10 and by A to H) were located in the upper courtyard, whereas the other eight points (indicated by 11 to 18) lies in the lower courtyard (see Fig. 4).

Because of the need for more accurate determination of the state of the dam, an automatic measurements of several parameters, mainly hydrostatic and partly hydrodynamic, began in 2003. In 2005 an automated monitoring system for determining the dynamic response of the dam to strong earthquakes, i.e. when the peak ground acceleration exceeds 0.05 g, was established (see Table 1).

Monitoring system of the Mavčiče Dam behaviour includes: deformation measurements (vertical, horizontal and relative displacements, see Fig. 4), visual inspections (structural, geotechnical), groundwater measurements (piezometric levels, uplift pressures, temperatures, specific electrical conductivities) and measurements of external loads on the dam. The latter are carried out in the reservoir, in the stilling basin, in the dam itself (including the inspection gallery and the crest of the dam), as well as on the ground surface about 150 m downstream from the dam [4, 5]. Automatic parameters are shown in Table 2.

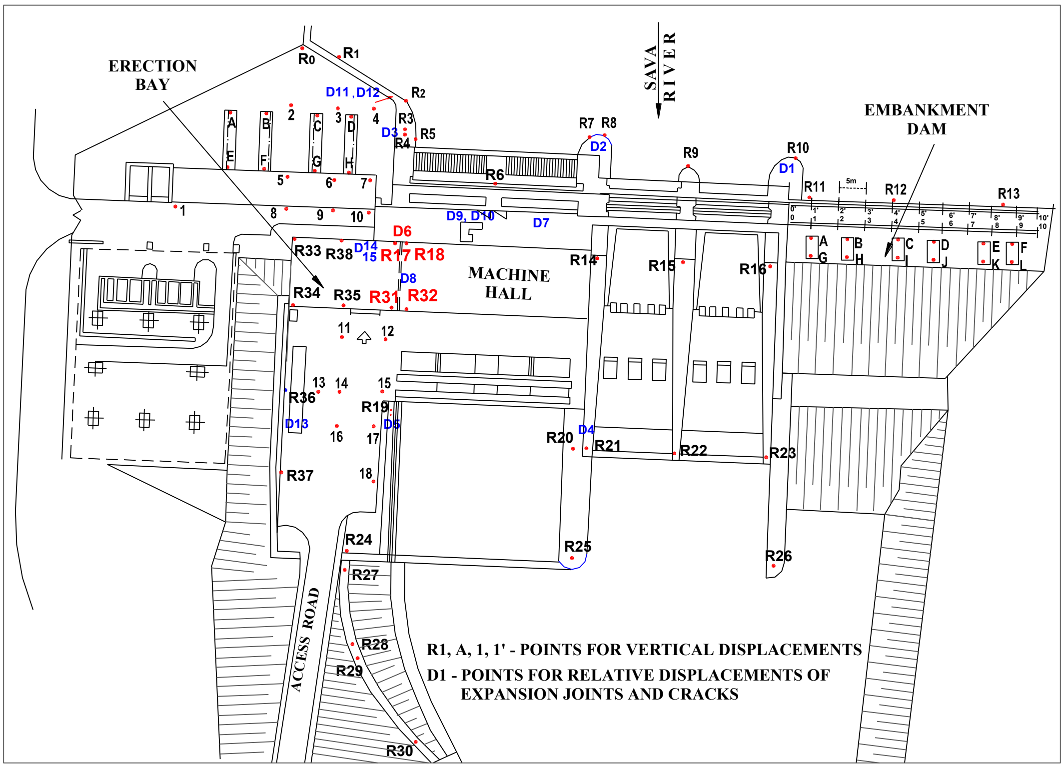

Fig. 4
The monitoring system for measurements of vertical and relative displacements

Table 1
The establishment of the technical monitoring system

Year	Established monitoring activity
1986	Manual measurements and visual inspections
1999 - 2000	Additional deformation measurements (right bank)
2003	Automated measurements (hydrostatic, partly hydrodynamic)
2005	Automated measurements (dynamic - strong earthquakes)

Table 2
Automatic measuring parameters for monitoring the behaviour of the dam

Type	Location	No.	Measuring parameter
Deformation	Expansion joint	1	Displacement (x, y, z)
Groundwater	Uplift pressure caps	4	Uplift pressure
	Side piezometer	6	Piezometric level, temperature, specific electrical conductivity
External loads	Reservoir and stilling basin	1	Water level, temperature, specific electrical conductivity
	Crest of the dam	1	Air temperature, acceleration
	Inspection gallery	1	Air temperature, acceleration
	Dam structure	1	Concrete temperature
	150 m downstream	1	Acceleration

4. RESULTS OF MONITORING, INVESTIGATIONS AND ACTIONS

In general, the results of measurements and visual inspections did not show any abnormalities. However, this was not the case for the erection bay located on the top of the backfilled right bank of the dam, where the results of measurements of vertical displacements showed increasing settlements [6]. By 1999, i.e. over a period of 12 years, these settlements had increased to 22 mm (see Fig. 5). These results were confirmed by measuring the relative displacements of expansion joint D6, located between the erection bay and the machine hall (see Fig. 6).

The results of investigations, by drilling three research boreholes (one in the upper courtyard and two in the erection bay) in 1993, and another six such boreholes (four drilled in the upper courtyard and another two drilled in the lower courtyard) in 1996, indicated that the settlements were the consequence of the secondary consolidation of the backfill, and probable also due to scouring of fine material from the backfill. Due to the resulting differential settlements, the crane rail which connects the erection bay to the machine hall, as well as the crane rail which is located along the crest of the dam, became non-functional, and needed height corrections (see Fig. 7). For this reason rehabilitation works of the backfill and of the substratum of the right bank of the dam were performed between September 1999 and August 2000, using 50 m long grouted boreholes (see Fig. 8). This grouting was performed using a combination of water reactive polyurethane and a cement-bentonite mixture [7]. Measurements performed since than have shown that the settlement rate of the erection bay has slowed down slightly (by 2017, i.e. over the last 17 years, the settlements had increased by up to 8 mm, see Fig. 5), but from the point of view of the operation of the two crane rails the settlement process needed to be stopped.

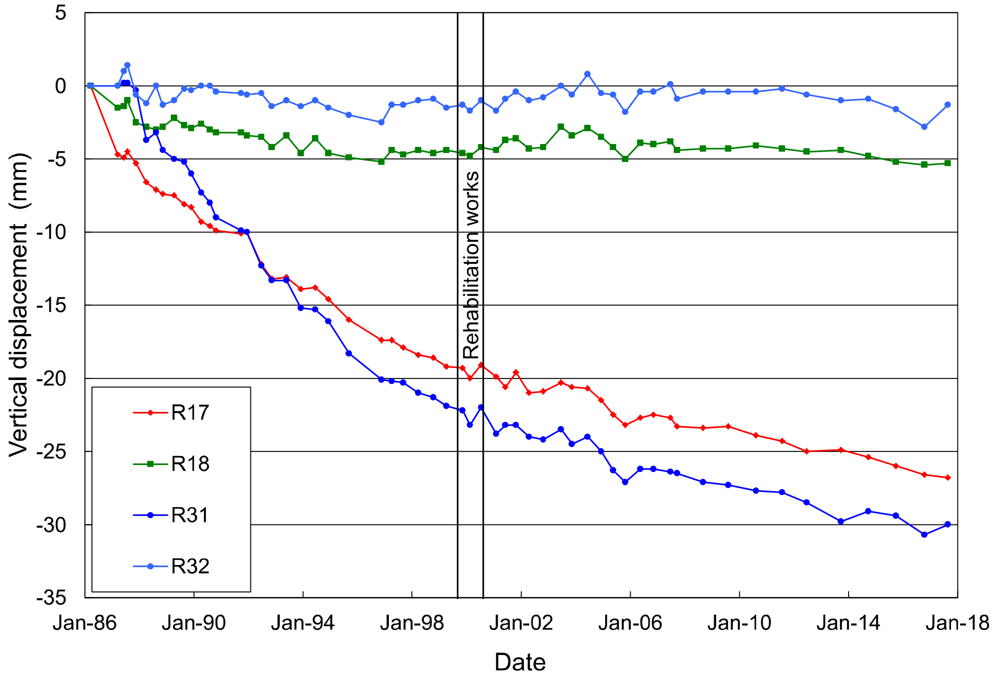

Fig. 5
Vertical displacements of the erection bay

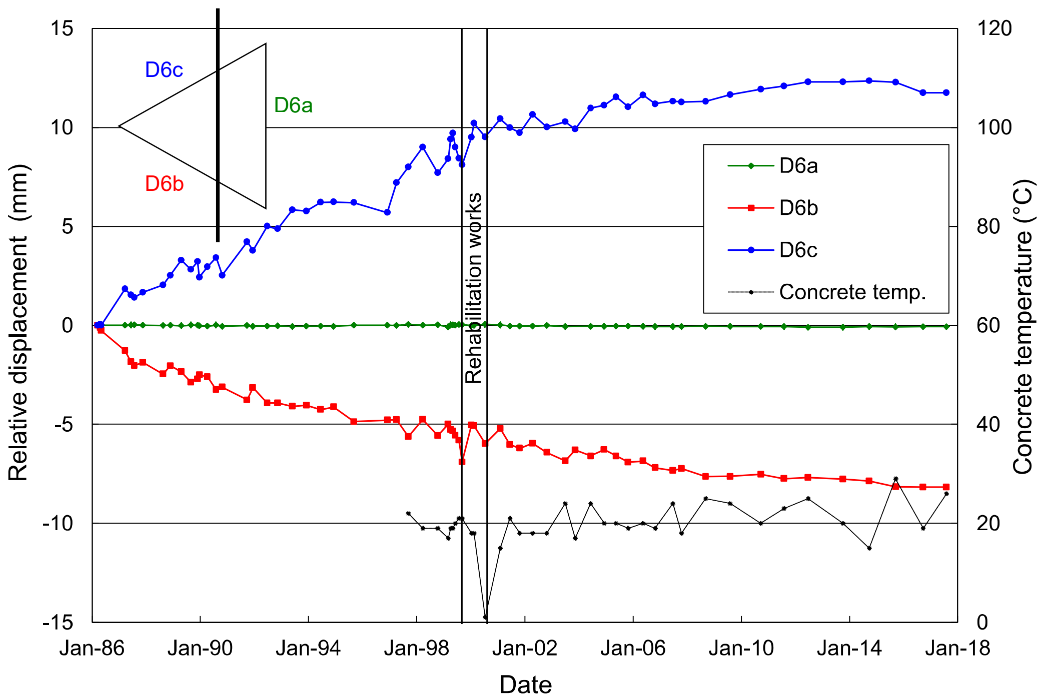

Fig. 6
Relative displacement of expansion joint D6

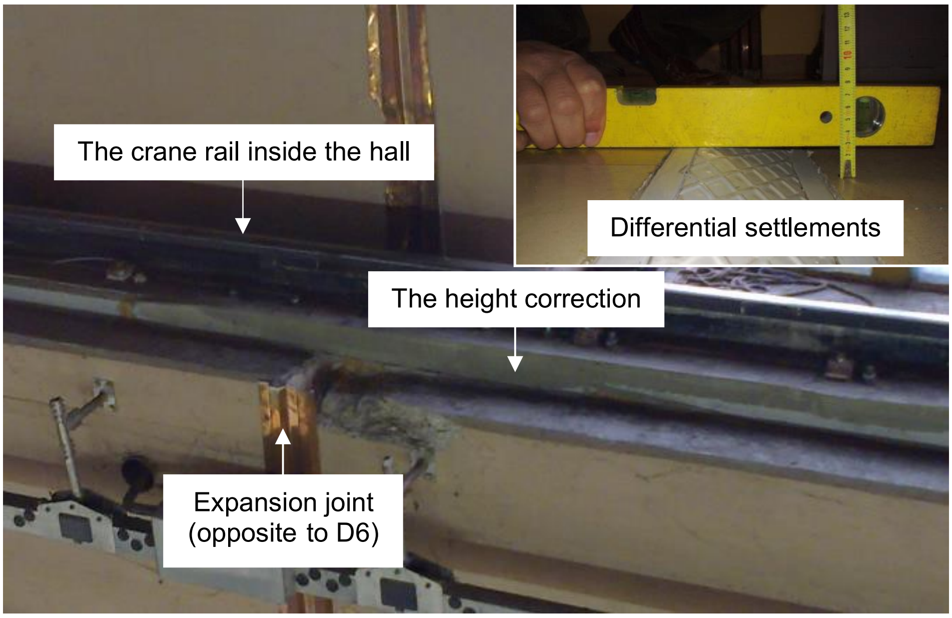

Fig. 7
Height corrections of the crane line inside the erection bay

Fig. 8
Rehabilitation works at the right bank of the dam

The results of the vertical displacement measurements at eight points in the lower courtyard, since the end of rehabilitation works in 2000, showed settlements up to 8 mm, which is similar as in the case of the erection bay. Since 2000, the settlements at ten points in the upper courtyard did not reach 8 mm, whereas at the remaining eight points the settlements reached locally even up to 32 mm.

Additional investigations, involving the drilling of two research boreholes in the upper courtyard, 28.0 m and 30.0 m in depth, as well as appropriate field tests (soil and rock classification, groundwater level, standard penetration test) and laboratory tests (particle size distribution curve, water permeability coefficient) carried out on 21 samples, were performed between November 2015 and March 2016. According to the results of these most recent investigations, the newer settlements were the consequence of additional scouring of fine material from the backfill [8].

5. CONCLUSIONS

In the years following the Mavčiče Dam completion in 1986, the results of measurements of vertical displacements showed increasing settlements of the erection bay at the right bank of the dam, and therefore the differential settlements according to the adjacent machine hall, which resulted to uselessness of both crane rails, which needed height corrections. After investigations, involving the drilling of research boreholes, as well as appropriate field and laboratory tests in 1993 and 1996, the rehabilitation works of the backfill and the substratum of the right bank of the dam were performed in 1999 and 2000. Since even after the rehabilitation works, the settlements of the erection bay continued to increase, additional investigations, involving the drilling of two research boreholes as well as suitable tests (soil and rock classification, groundwater level, standard penetration test, particle size distribution and water permeability coefficient) were carried out in 2015 and 2016. The results of these investigations showed that the settlements measured in the recent years were the outcome of the additional internal erosion of the backfill.

In order to achieve a final solution to the problem of the subsidence of the erection bay, additional rehabilitation works of the backfill and substratum of the right bank of the dam, by grouting the permeable zones, would be needed in order to stop both the scouring of fine material from the backfill, as well as any internal erosion of the cavernous conglomerate at the base of the backfill. The latter concerns the long-term stability of the right bank of the dam with potentially serious results.

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SUMMARY

The Mavčiče concrete gravity dam, part of the corresponding hydro-power plant, was built on the Sava River, in Slovenia, in 1986. It has a maximum structural height of 38.5 m, and the dam crest has a length of 149 m. The dam structure consists of an erection bay, a machine hall, and two spillways, followed by an embankment dam. Most of the dam is founded on permeable Quaternary conglomerate bedrock, so that a cut-off grout curtain had to be constructed to a depth of up to 60 m below the ground surface, where a layer of impermeable Oligocene marine clay occurs. However, the erection bay, which is located on the right bank of the dam, is founded on a layer of gravel backfill, up to about 25 m thick, which lies on top of the conglomerate bedrock.

Long-term manual technical monitoring of the behaviour of the dam began in 1986, and an automated monitoring system was established between 2003 and 2005. In general, the results of measurements and visual inspections did not show any abnormalities. However, this was not the case for the erection bay located on the top of the backfilled right bank of the dam, where the results of measurements of vertical displacements showed increasing settlements. By 1999, i.e. over a period of 12 years, these settlements had increased to 22 mm.

The results of investigations, by drilling three research boreholes in 1993, and another six such boreholes in 1996, indicated that the settlements were the consequence of the secondary consolidation of the backfill, and probable also due to scouring of fine material from the backfill. Due to the resulting differential settlements, the crane rail which connects the erection bay to the machine hall, as well as the crane rail which is located along the crest of the dam, became non-functional, and needed height corrections. For this reason rehabilitation works of the backfill and of the substratum of the right bank of the dam were performed between September 1999 and August 2000, using 50 m long grouted boreholes. This grouting was performed using a combination of water reactive polyurethane and a cement-bentonite mixture. Measurements performed since than have shown that the settlement rate has slowed down slightly (by 2017, i.e. over the last 17 years, the settlements had increased by up to 8 mm), but from the point of view of the operation of the two crane rails the settlement process needed to be stopped. Additional investigations, involving the drilling of two research boreholes, as well as appropriate laboratory and field measurements, were performed between November 2015 and March 2016. According to the results of these most recent investigations, the newer settlements were the consequence of additional scouring of fine material from the backfill.

In order to achieve a final solution to the problem of the subsidence of the erection bay, additional rehabilitation works of the backfill and substratum of the right bank of the dam, by grouting the permeable zones, would be needed in order to stop both the scouring of fine material from the backfill, as well as any internal erosion of the cavernous conglomerate at the base of the backfill. The latter concerns the long-term stability of the right bank of the dam with potentially serious results.

KEY-WORDS

gravity dam, concrete dam, Mavčiče Dam, behaviour, monitoring, automated monitoring, deformation measurement, groundwater, inspection, piezometer, uplift, water level, seepage, settlement, geotechnical investigation, internal erosion, rehabilitation.

MOTS-CLES

barrage-poids, barrage en béton, Barrage Mavčiče, comportement, auscultation, auscultation automatique, mesure de déformation, eau souterraine, visite, piézomètre, sous-pression, niveau hydraulique, infiltration, tassement, geotechnique, erosion interne, rehabilitation.