Proceedings of the 20th International Conference on Soil Mechanics and Geotechnical Engineering– Rahman and Jaksa (Eds)

Settlements of an erection bay of the Mavčiče Dam founded on a backfill

Tassements d'une travée de montage du barrage de Mavčiče fondée sur un remblai

Pavel Žvanut
Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia, pavel.zvanut@zag.si

ABSTRACT: The Mavčiče concrete gravity dam was built on the Sava River, in Slovenia, in 1986. It is 38.5 m high, whereas the dam crest is 149 m long. 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 Quaternary conglomerate bedrock, while the erection bay is founded on a layer of gravel backfill, up to 25 m thick, which lies on the bedrock. Measurements showed increasing settlements of the erection bay (22 mm in 12 years). Due to differential settlements, the crane rails which connect the erection bay to the machine hall became non-functional and needed height corrections. The investigations showed that the settlements were the consequence of the secondary consolidation of the backfill, and probably also of the scouring of fine material from it. Rehabilitation works were performed in 1999-2000 and since then the measurements showed smaller settlements (9 mm in 20 years); however, due to operation of the crane rails the settlement process must be stopped by additional grouting of the permeable zones.

RÉSUMÉ: Le barrage-poids en béton de Mavčiče a été construit sur la rivière de Sava en Slovénie, en 1986. Il est 38,5 m haut, tandis que la crête du barrage a 149 m de longueur. La structure du barrage se compose d'une travée de montage, d'une salle des machines et de deux évacuateurs de crue, suivis d'un barrage en remblai. La majeure partie du barrage est fondée sur un fond rocheux du lit du conglomérat quaternaire, tandis que la travée de montage est fondée sur une couche de remblai de gravier, jusqu'à 25 m d'épaisseur, qui repose sur le fond rocheux du lit. Les mesures ont montré des tassements progressifs de la travée de montage (22 mm en 12 ans). En raison des tassements différentiels, les rails de la grue qui relient la travée de montage à la salle des machines sont devenus non fonctionnels et nécessitaient des corrections de hauteur. Les investigations ont montré que les tassements étaient la conséquence de la consolidation secondaire du remblai et probablement aussi d'un affouillement des matériaux fins de celui-ci. Des travaux de réhabilitation ont été effectués en 1999-2000 et depuis lors, les mesures ont montré des tassements plus petits (9 mm en 20 ans); néanmoins, en raison du fonctionnement des rails de la grue, le processus de tassement doit être arrêté par injection supplémentaire des zones perméables.

KEYWORDS: concrete dam, dam monitoring, differential settlements, internal erosion, rehabilitation works.

1 INTRODUCTION.

The Mavčiče concrete gravity dam was built on the Sava River, in central Slovenia (see Figure 1), in 1986. It is 38.5 m high, whereas 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 (see Figure 2). The total capacity of both spillways is 3200 m^3/s. The reservoir behind the dam contains 10.7 hm^3 of water and has a length of 7.0 km (SEL 2021; SLOCOLD 2021).

Figure 1. Locations of large dams in Slovenia.

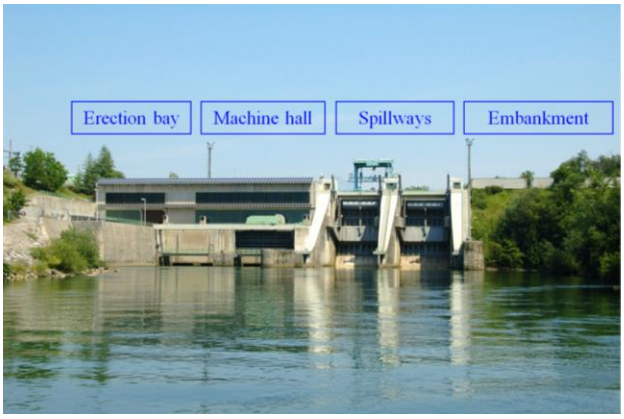

Figure 2. Front view of the Mavčiče Dam.

2 DAM FOUNDATION

Since most of the discussed dam is founded on permeable Quaternary conglomerate bedrock, 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 machine hall is founded on conglomerate bedrock at the altitude of 309.50 m, whereas the erection bay, which is located next to it, is founded on a layer of gravel backfill, up to 25 m thick, which lies on top of the bedrock. The lower courtyard, which is located in front of the erection bay, has an altitude of 337.25 m, whereas the upper courtyard, which lies behind the erection bay, is located 10.75 m higher, i.e. at the altitude of 348.00 m (Brinšek 1989).

Figure 3 shows the foundation of the right part of the Mavčiče Dam.

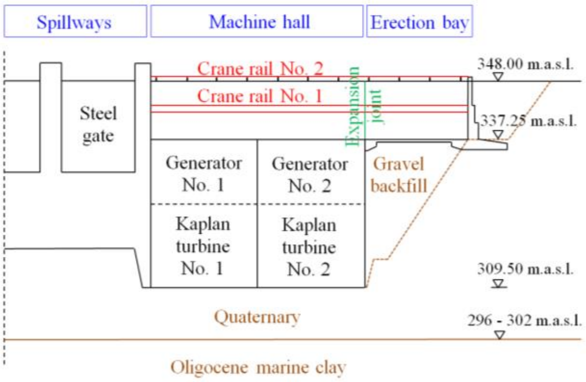

Figure 3. Foundation of the right part of the dam.

3 DAM MONITORING SYSTEM

Monitoring system of the Mavčiče Dam behaviour includes: deformation measurements (vertical, horizontal and relative displacements; see Figure 4), visual inspections (geotechnical, structural), groundwater measurements (piezometric levels, uplift pressures, temperatures, specific electrical conductivities) and measurements of external loads on the dam (water level of the reservoir, air temperature, ground acceleration).

Long-term monitoring of the behaviour of the dam started at the time of the dam's completion, in 1986, and covered all necessary types of measurements and visual inspections (Štrucl et al. 1987).

In the years 1999 to 2000, an upgraded system for monitoring the detailed behaviour of the right part of the dam was established, which covered additional twenty-six geodetic points for measurements of vertical displacements (Batagelj 2001). Eighteen of these geodetic points (marked by 1 to 10 and by A to H) are located in the upper courtyard, and the other eight geodetic points (marked by 11 to 18) are located in the lower courtyard (see Figure 4).

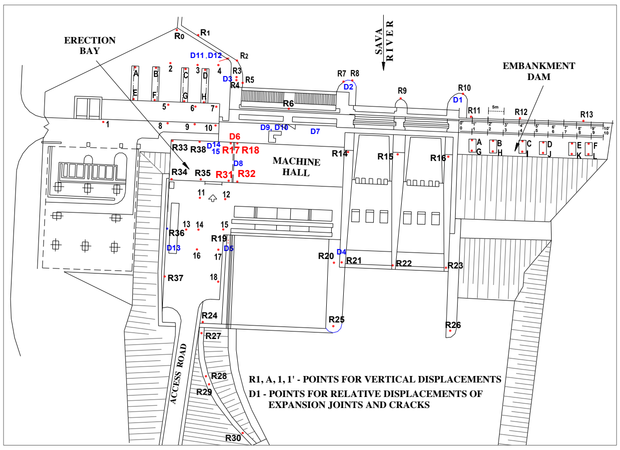

Figure 4. Monitoring system for deformation measurements.

4 RESULTS OF DAM MONITORING AND NECESSARY MEASURES

The results of measurements and visual inspections performed so far generally did not show any unexpected behaviour of the dam structure. However, this did not apply to the area of the erection bay located at the top of the backfilled right part of the dam, where the results of geodetic measurements of vertical displacements showed a significant increase in settlements. As a result of these settlements, differential settlements with respect to the adjacent machine hall occurred. By 1999, i.e. over a period of 12 years, these differential settlements had increased to 22 mm (see Figure 5). These results were confirmed by measuring the relative displacements of expansion joint (marked by D6), located between the machine hall and the erection by (see Figure 6) (Žvanut & Brinšek 2018).

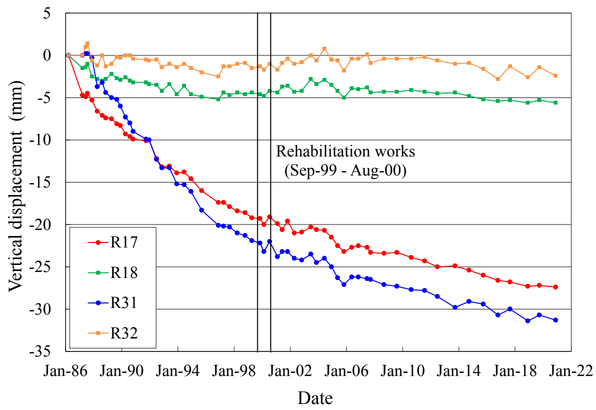

Figure 5. Measured settlements next to the expansion joint between the machine hall and the erection bay.

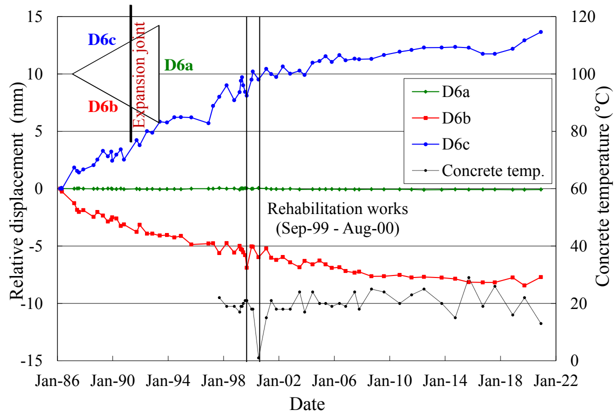

Figure 6. Relative displacement of the discussed expansion joint D6.

Due to the resulting differential settlements, the crane rail which is located along the crest of the dam, as well as the crane rail which connects the machine hall to the erection bay, became non-functional, and needed height corrections (see Figure 7). The results of geotechnical investigations, by drilling three investigation boreholes (one in the upper courtyard area and two in the erection bay area) in 1993, and additional six such boreholes (four drilled in the upper courtyard area and another two drilled in the lower courtyard area) in 1996, showed that the settlements were the consequence of the secondary consolidation of the backfill, and probably also of the scouring of fine material from the backfill.

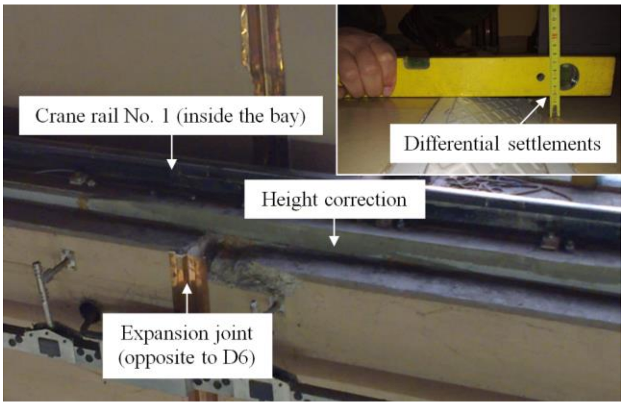

Figure 7. Performed height corrections of the crane line No. 1, located inside the erection bay.

For this reason, between September 1999 and August 2000, rehabilitation works of the backfill and the substratum of the erection bay at the right part of the dam were carried out (see Figures 8 and 9) using grouted boreholes, which extended into a depth of 50 m below the ground surface or from 1 to 2 m into the impermeable base. The distance between the individual boreholes amounted to 1.25 m. The permeation grouting was carried out using a combination of water reactive polyurethane and a mixture of cement and bentonite (Isakovič et al. 2002).

Geodetic measurements of vertical displacements carried out since then have shown that the settlement rate of the erection bay has slowed down slightly (by November 2020, i.e. over the last 20 years, the settlements had increased by up to 9 mm, see Figure 5); however, from the point of view of the operation of the two crane rails the settlement process must be stopped.

Since the end of rehabilitation works in 2000, the results of latest geodetic measurements of vertical displacements performed in 2020, at eight points in the lower courtyard area, showed settlements up to 9 mm, which is similar as in the case of the erection bay area. Since 2000, the settlements at ten points in the upper courtyard area did not reach 9 mm until 2020, while at the remaining eight points in the same courtyard the settlements locally reached even up to 35 mm (Žvanut et al. 2021).

Figure 8. Performed rehabilitation works at the right part of the dam.

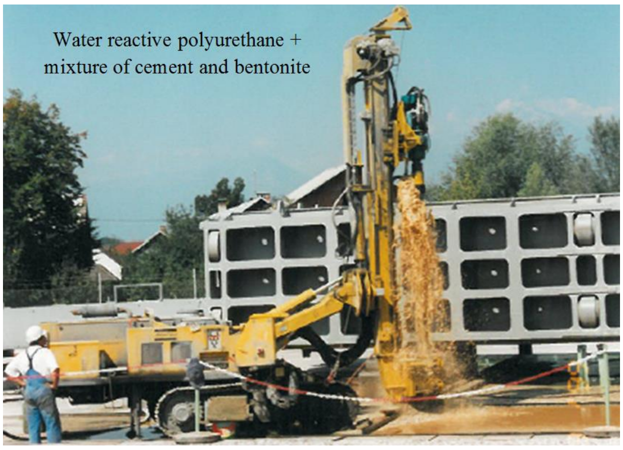

Figure 9. Performed rehabilitation works at the Mavčiče Dam.

Further geotechnical investigations, which were carried out between November 2015 and March 2016, involved the drilling of two additional investigation boreholes in the upper courtyard area, 28.0 m and 30.0 m in depth, as well as adequate field tests (i.e. standard penetration test, soil and rock classification, groundwater level) and laboratory tests (i.e. water permeability coefficient, particle size distribution curve) performed on 21 samples. According to the results of these latest investigations, the newer settlements were the consequence of additional scouring of fine material from the layer of gravel backfill and also regrouping of fine fractions to deeper levels (Prokop et al. 2016).

5 CONCLUSIONS

During long-term monitoring of the behaviour of the Mavčiče Dam, the results of geodetic measurements of vertical displacements showed increasing settlements of the erection bay at the right part of the dam, and therefore the differential settlements relative to the adjacent machine hall, which resulted to uselessness of both crane rails, which needed height corrections. After extensive geotechnical investigations, which included the drilling of investigation boreholes and appropriate field and laboratory tests in 1993 and 1996, the rehabilitation works of the backfill and the substratum of the erection bay of the right bank of the dam were carried out in 1999 and 2000. As the settlements of the erection bay continued to increase even after rehabilitation works, further geotechnical investigations, which involved the drilling of two additional investigation boreholes as well as adequate field and laboratory tests (standard penetration test, soil and rock classification, groundwater level, water permeability coefficient and particle size distribution) were performed in 2015 and 2016. The results of these latest geotechnical investigations showed that the settlements measured in the recent years were the consequence of the additional internal erosion of the gravel backfill.

The final solution to the problem of the subsidence of the erection bay would be achieved by additional rehabilitation works of the backfill and substratum of the erection bay of the right part of the dam, by grouting the permeable zones, 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 gravel backfill, which has also been found in recent investigations. The latter refers to the long-term stability of the right side of the dam, which could have potentially serious consequences (i.e. the subsidence of the cavernous conglomerate, which would cause instability of this part of the Mavčiče Dam).

6 REFERENCES

Batagelj J. 2001. Upgrading of the geodetic monitoring system of the right part of the Mavčiče Dam. *Report No. P 900/00-680-1/01*, ZAG Ljubljana, Slovenia.

Brinšek R. 1989. Project task for the establishment of an automatic monitoring system of the Mavčiče Dam. *Report No. 2-778/89*, ZRMK Ljubljana, Slovenia.

Isakovič S. et al. 2002. Rehabilitation of Mavčiče Dam at Sava River in Slovenia with extra sealing. *Proc. Int. Cong. on conservation and rehabilitation of dams*, Madrid, Spain, 803-809.

Prokop B. et al. 2016. The control exploration drilling on the right bank of the Mavčiče Dam. *Report No. 8-04-2016*, Proksam Ltd, Vrhnika, Slovenia, 16 p.

SEL. 2021. *Hydroelectric Power Generation Company Ltd website*, Slovenia, https://www.sel.si/.

SLOCOLD. 2021. *Slovenian National Committee on Large Dams website*, Slovenia, http://www.slocold.si/.

Štrucl V. et al. 1987. Establishment of the technical monitoring system of the Mavčiče Dam. *Report No. 2-710/86*, ZRMK Ljubljana, Slovenia.

Žvanut P. and Brinšek R. 2018. Behaviour of the backfilled right bank of the Mavčiče Dam. *Proc. ICOLD Int. Symp.: Hydro Engineering*, Vienna, Austria, 820-830.

Žvanut P. et al. 2021. Technical monitoring of the Mavčiče Dam. *Annual reports 1998-2020*, ZAG Ljubljana, Slovenia.