Surveillance of the banks of reservoirs on the Drava River in Slovenia after extensive floods

Surveillance des rives de réservoirs sur la rivière Drava en Slovénie après de graves inondations

Pavel Žvanut*[1]

[1]Slovenian National Building and Civil Engineering Institute, Ljubljana, Slovenia

Abstract. The Slovenian section of the Drava River is 133 km long, and over this distance it has a descent of 148 m. Eight HPPs are located on this section (six directly in the river course, whereas the other two in derivation channels of the river). Ten concrete gravity dams, with a structural height between 17 and 54 m, created eight reservoirs. In addition to their main use for electricity generation, reservoirs are also used for floods mitigation, irrigation, industrial water use and recreation. At the beginning of November 2012, extremely high flows of the Drava River, which exceeded 100-year flood, caused floods in the middle and lower reaches of the river. Extraordinary visual geotechnical inspections of the banks, in order to determine any instability of them, were carried out immediately after this event. Numerous landslides and landslips were identified, as well as damage to nearby buildings, but also damage and threat to transport infrastructure. Damaged banks of reservoirs and damaged infrastructure were instantly rehabilitated. In the future, it is necessary to perform regular and extraordinary surveillance of the banks of reservoirs, drawing attention to damage that needs immediate rehabilitation, thus preventing the occurrence of eventual disastrous consequences.

Résumé. Le tronçon slovène de la rivière Drava est long de 133 km, et sur cette distance, il présente une descente de 148m. Huit centrales hydroélectriques sont situées sur cette section (six directement sur le cours de la rivière, deux autres sur les canaux de dérivation). Dix barrages-poids en béton, d'une hauteur structurelle comprise entre 17 et 54 m, ont créé huit réservoirs. En plus de leur utilisation principale pour la production d'électricité, les réservoirs sont utilisés pour l'atténuation des inondations, l'irrigation, l'utilisation industrielle de l'eau et les loisirs. Début novembre 2012, les débits extrêmement élevés de la Drava, qui ont dépassé la crue centennale, ont provoqué des inondations dans les cours moyens et inférieurs de la rivière. Afin de déterminer toute instabilité des berges, des inspections géotechniques visuelles extraordinaires ont été réalisées immédiatement

* Corresponding author: pavel.zvanut@zag.si

après cet événement. De nombreux glissements de terrain ont été identifiés, ainsi que des dommages aux bâtiments voisins, mais aussi des dommages et menaces aux infrastructures de transport. Les berges des réservoirs et des infrastructures endommagés ont été instantanément réhabilitées. À l'avenir, il est nécessaire d'effectuer une surveillance régulière et extraordinaire des berges des réservoirs, en attirant l'attention sur les dommages qui nécessitent une réhabilitation immédiate, prévenant ainsi l'apparition d'éventuelles conséquences désastreuses.

1 Introduction

There are more than forty large dam structures in Slovenia, both concrete and embankment dams, which are intended for water retention for various purposes; mainly electricity generation, as well as floods mitigation, irrigation, industrial water use and recreation. There are also some historical dams and the dams which are used for other commercial purposes (Fig. 1) [1].

Most water reservoirs in Slovenia are used for several purposes. For example, on the three largest rivers in Slovenia - the Drava River, the Sava River and the Soča River - there are twenty-one (21) reservoirs with actual priority use for electricity generation, but they are also used for other purposes such as flood protection, irrigation, industrial water use and recreation [2].

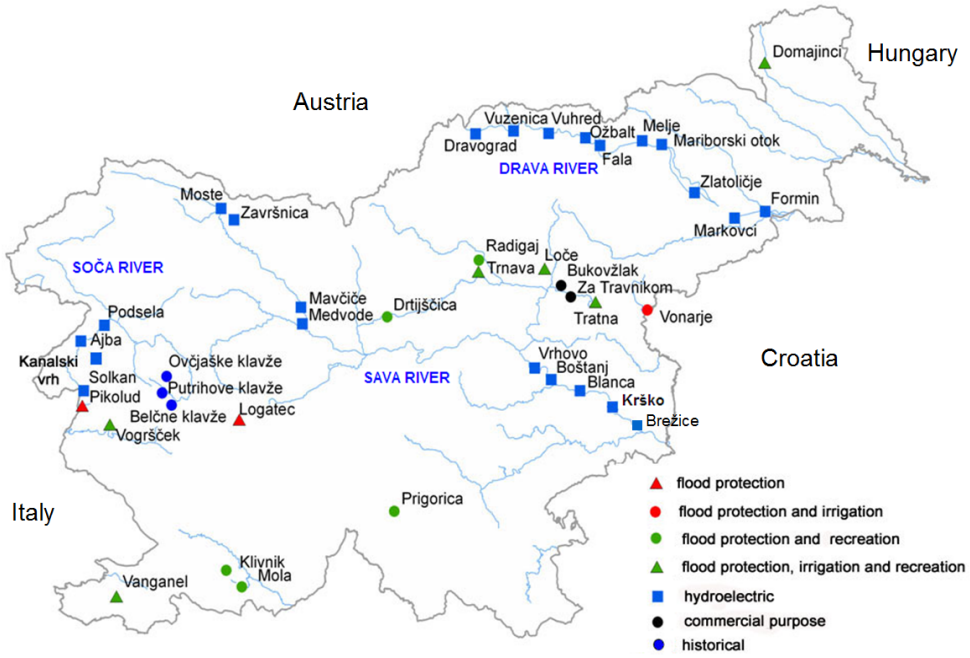

Fig. 1. The locations of large dams in Slovenia (Source: www.slocold.si).

2 Water reservoirs on the Drava River in Slovenia

The Drava River flows through southern central Europe and is approximately 725 km long. It is a tributary of the Danube River. The source of the river lies near the Austrian-Italian border in the northern Italy at 1450 m a.s.l. It flows through Italy (very short section), Austria, Slovenia and Croatia, concluding its journey at Osijek, where it flows into the Danube River. Along its course, the Drava River connects the Alpine and Pannonian biogeographical regions (see Fig. 2) [3].

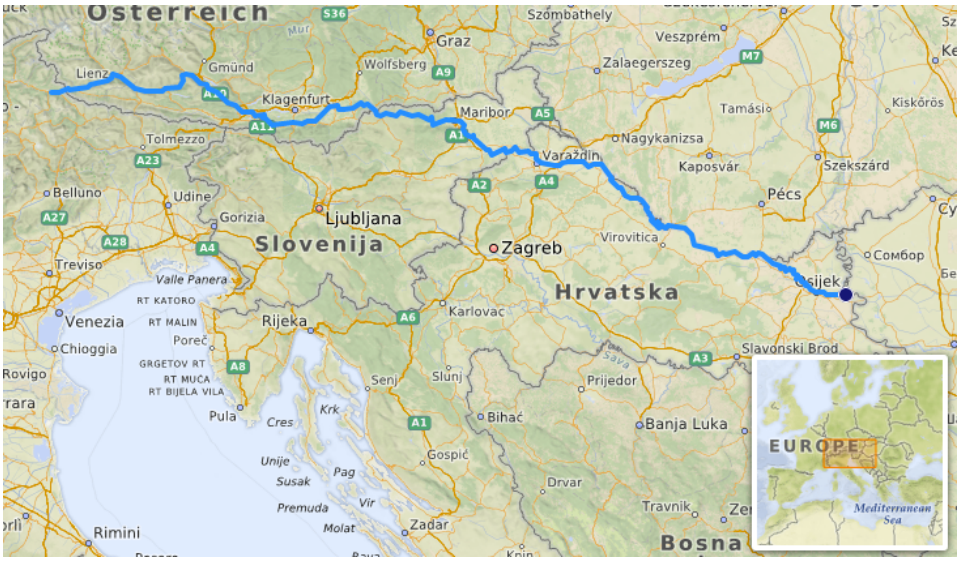

Fig. 2. Course of the Drava River (Source: https://en.wikipedia.org/wiki/Drava).

The Slovenian section of the Drava River is 133 km long, and over this distance it has a descent of 148 m. Because of the high rate of flow and also the relatively steep gradient, eight HPPs are located on this section of the Drava River. Six HPPs (Dravograd, Vuzenica, Vuhred, Ožbalt, Fala and Mariborski otok) are located directly in the river course, whereas the other two HPPs (Zlatoličje and Formin) are situated in derivation channels of the river (see Fig. 3). Between the years 1918 and 1978 ten concrete gravity dams were built. Their structural heights vary between 17 and 54 m. The dams created eight multipurpose reservoirs. In addition to their priority use for electricity generation, the reservoirs are also used for floods mitigation, irrigation, industrial water use and recreation [4-5].

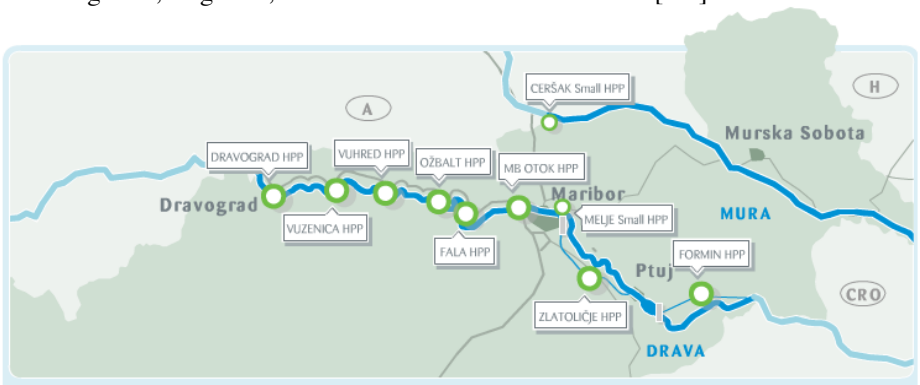

Fig. 3. Location of the HPPs on the Slovenian section of the Drava River (Source: DEM archive).

3 Extreme event – Extensive floods in November 2012

After a very long drought, which lasted in Slovenia from autumn 2011 to autumn 2012, the first abundant precipitation in the country occurred at the end of October 2012. The next abundant precipitation, which appeared in Slovenia a week later, on 4th and 5th November 2012 (see Fig. 4), caused that - due to the pre-saturation of the soil with water and also due to the melting snow that fell in late October - the flows of most rivers began to increase rapidly. The consequences of this extreme event were the floods of many rivers in Slovenia (see Fig. 5) [6-8].

The worst floods were caused by the Drava River (in the middle and lower reaches of the river; see Fig. 6), which - also due to the extremely increased inflow from Austria on 5th November in the morning - rose sharply and reached record flows. The extremely high flows of the Drava River (i.e. more than 2600 m^3/s at the Dravograd Dam, whereas at the border with Croatia the flow was even estimated at about 3000 m^3/s; see Fig. 7) greatly exceeded the flow of the Drava River just before this event, which was about 500 m^3/s at the Dravograd Dam, and also exceeded 100-year return period of flood event (see Fig. 8) [9-11].

It was found out that the damage caused by the extensive floods on 4th and 5th November 2012 was the largest recorded damage due to natural disasters in the history of independent Slovenia.

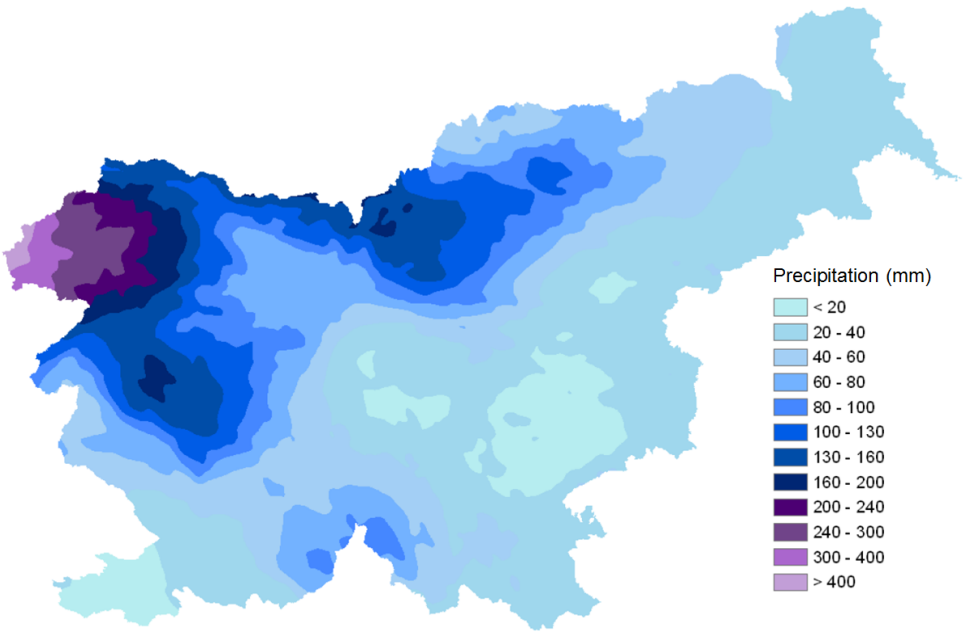

Fig. 4. Spatial distribution of 48-hour precipitation (between 4th November 2012 in the morning and 6th November 2012 in the morning) in Slovenia (Source: ARSO archive).

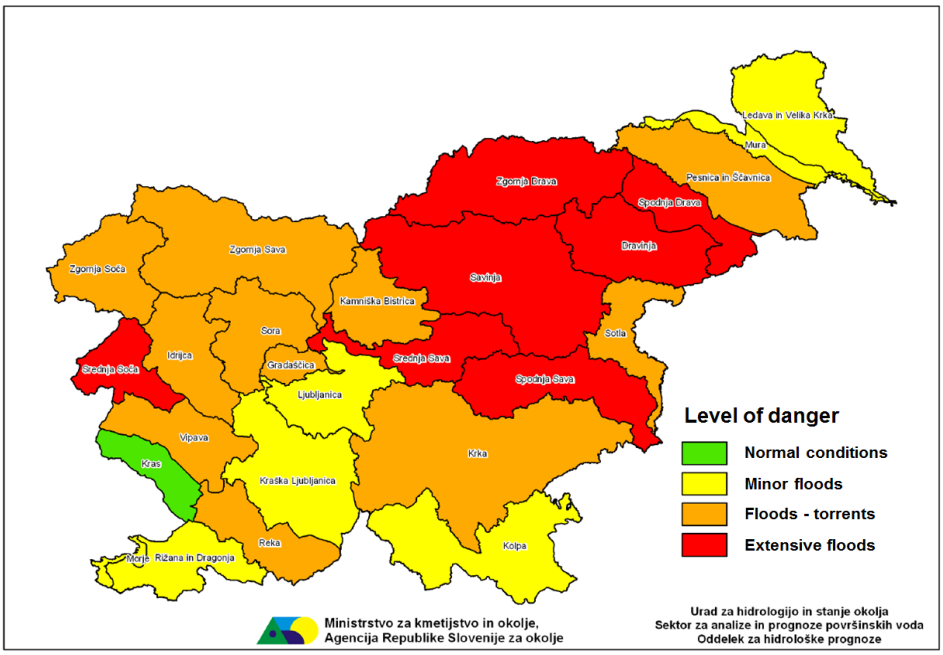

Fig. 5. Flood forecast for Slovenia for the afternoon of 5th November 2012 - issued on 5th November at 13:30 CET at Slovenian Environment Agency (Source: ARSO archive).

Fig. 6. Extensive floods of the Drava River in Hajdoše near Ptuj (downstream from Zlatoličje HPP) on the 6th November 2012 at 10:50 CET (Photo: Prlekija on net photo archive).

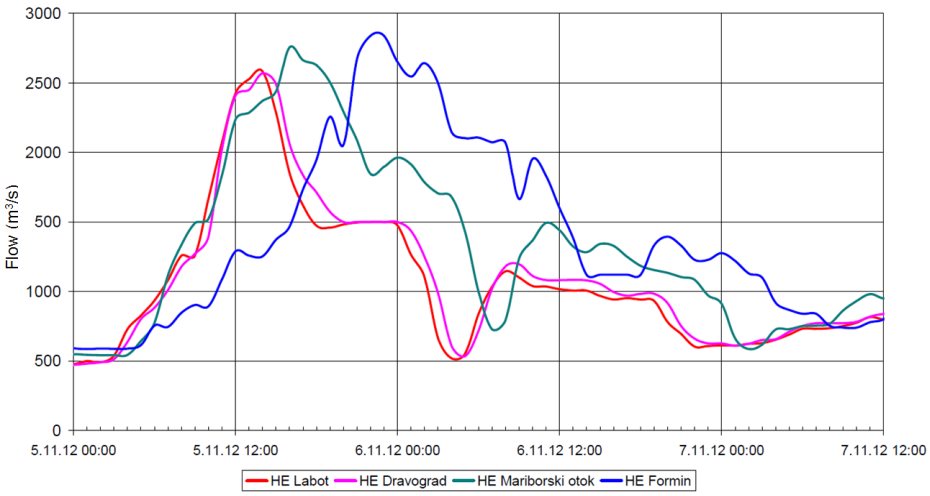

Fig. 7. The flood wave along the Drava River in Slovenia (from Dravograd HPP to Formin HPP) between the 5th November and 7th November 2012 (Source: DEM archive).

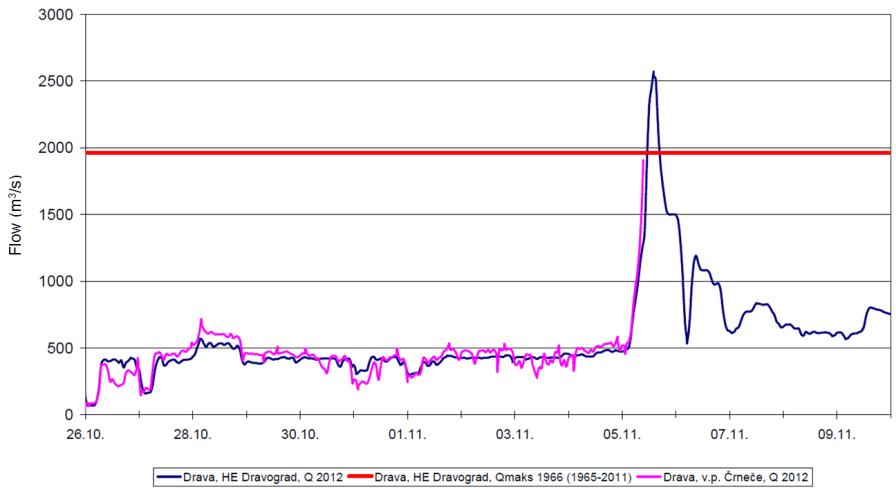

Fig. 8. The flow of the Drava River at Dravograd HPP and at Črneče (3.6 km upstream of the HPP) from 26th October to 10th November 2012, and the maximum flow in the period 1965-2011 (Source: ARSO archive).

4 Extraordinary surveillance of the banks of reservoirs

4.1 Performance of visual inspections

A detailed extraordinary visual geotechnical inspections of the upstream (the reservoir area) and the downstream (the area just below the dam) natural and artificial river banks as well as levees of derivation channels, in order to determine any instability of them, were carried out immediately after this extreme event. Visual inspections were carried out as a combination of inspections performed from the water side (i.e. by using a boat) and inspections performed from the land side (i.e. by walking on the banks of the river and of derivation channels). Topographic maps with recorded damage of the previous regular inspections of river banks, in which newly identified damage was registered, were used as a basis for the inspection. In addition, the damaged areas were also carefully photographed. After that, extraordinary reports were prepared, where a detailed inventory of all noticeable damage was made and suggestions for preferential rehabilitation of damage were given.

As a result of extraordinary visual inspections numerous landslides and landslips were identified, as well as damage due to erosion in the zone of water level fluctuations, damage to nearby buildings and retaining structures, and also damage and threat to nearby transport infrastructure (i.e. roads, railway lines, bicycle trails) (see Fig. 9). It was found out that the most damaged banks of reservoirs and levees of the derivation channels, as well as the damaged infrastructure, should be rehabilitated as soon as possible [12].

Fig. 9. Some examples of damaged banks of reservoirs on the Drava River after extensive floods (Photos: A. Geršak).

4.2 The area with the most extensive damage

The most extensive damage was registered in the area of the derivation channel of the Drava River, about 1.5 km downstream of the Formin HPP (see Figs. 10 and 11), where the flood waters of the Drava River caused an additional river flow, which first broke through the right levee of the derivation channel and then also broke through the left levee of the derivation channel (see Figs. 12 and 13), where caused the erosion of the left bank of the derivation channel (see Fig. 14). Of course, the concrete diaphragm walls, installed in levees on both sides of the derivation channel, which prevented the drainage of groundwater into the derivation channel, were also demolished in this area (see Fig. 15). In addition, the flood waters of the Drava River transported large amounts of gravel into the derivation channel (see Fig. 14), which dammed water in the channel, with that caused rising of the water level in the channel and consequently flooding of the machine hall area of the upstream located Formin HPP [12-14]. Due to the high risk of additional damage and deterioration of the stability of the damaged banks of derivation channel, the main rehabilitation works began immediately after the detailed inventory of all noticeable damage was made, and they were completed quickly and successfully.

Fig. 10. General location of the discussed area (Source: Google Earth).

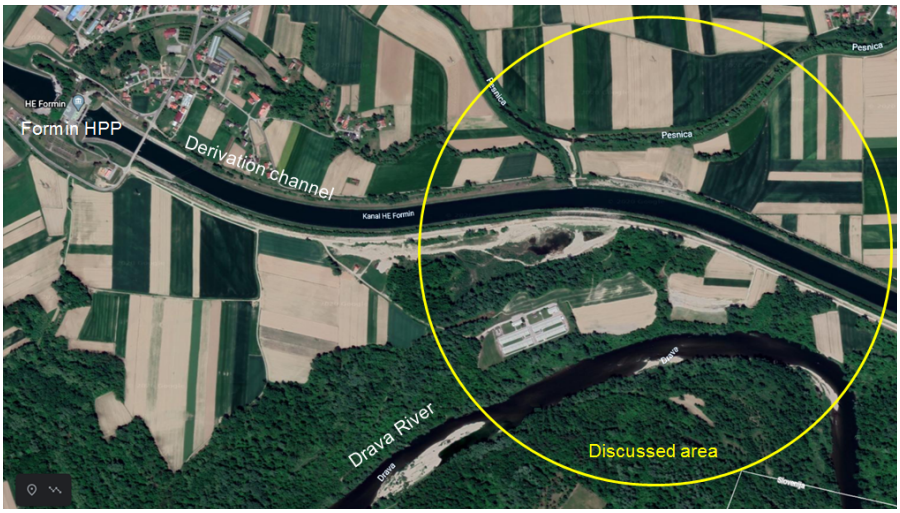

Fig. 11. Detailed location of the discussed area (Source: Google Earth).

Fig. 12. The area with the greatest damage - during flooding (Photo: Mensuras photo archive).

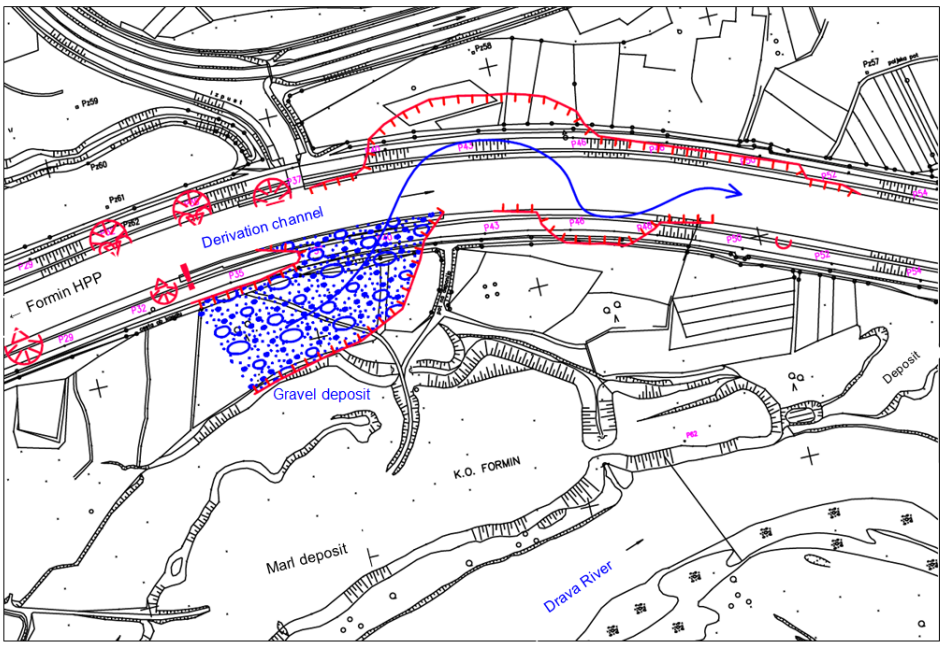

Fig. 13. Topographic map with registered damage at the area with the greatest damage.

Fig. 14. Erosion of the left bank of the derivation channel and large gravel deposits in the derivation channel (Photos: DEM photo archive and A. Geršak).

Fig. 15. Demolished and exposed diaphragm walls (Photos: A. Geršak).

5 Conclusion

Following the extensive flooding of the Drava River in Slovenia in November 2012, the detailed extraordinary visual geotechnical inspections of the banks of reservoirs and levees of the derivation channels were carried out to determine their possible instability. Numerous landslides and landslips were identified, as well as damage to nearby buildings, but also damage and threat to transport infrastructure. The greatest damage was registered in the area of the derivation channel of the Drava River, about 1.5 km downstream of the Formin HPP, where the flood waters of the Drava River caused an additional river flow, which caused major damage of levees on both sides of the derivation channel. The main rehabilitation works began immediately after the detailed inventory of all noticeable damage was made, when it was found out that the most damaged banks of reservoirs and levees of the derivation channels, as well as the damaged infrastructure, should be rehabilitated as soon as possible. The rehabilitation works were completed quickly and successfully.

In the future, it is necessary to perform regular and extraordinary surveillance of the banks of reservoirs and levees of the derivation channels - which should include detailed visual inspections, terrestrial measurements and also the increasingly accessible use of so-called space technologies - drawing attention to damage that needs immediate rehabilitation, thus preventing the occurrence of eventual catastrophic consequences.

In addition, a lot of attention needs to be paid also to water management in reservoirs in the near future, as extensive floods – also due to inadequate water management - can cause disastrous consequences, such as the loss of many lives, major economic losses and severe ecological effects.

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