Some Technical Aspects of the Tailing Dam Failure at the Ajka Red Mud Reservoirs

Quelques aspects techniques de la rupture d'une digue de retenue de boues à Ajka

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ABSTRACT: On October 4, 2010 at 12:25 the North-western part of the dam of the no. 10 red mud reservoir in Ajka (Hungary) has collapsed, and near one million m^3 alkaline red mud mixed with water has plunged in the valley of the Torna stream. The red mud flooded the valley-side parts of the village Kolontár and the town Devecser, then trough the Marcal river it has reached the river Danube in very short time. 10 people died, 123 injured, 260 houses became uninhabitable, and significant ecological damage occurred. This presentation aims at providing an informative fact-based description of the complex reasons resulting in dam ruptures.

RÉSUMÉ : Le 4. octobre 2010 à 12:25 la section Nord-Ouest de la digue de retenue du réservoir No 10 de boues rouges à Ajka, en Hongrie, s'écroulait. Environ 1 million m^3 de mélange de boues rouges alcalines et d'eau était déversé dans la vallée du ruisseau Torna. Les boues rouges recouvrirent les bords de la vallée dans le village Kolontár et dans la ville Devecser, puis atteignirent le Danube par le petit fleuve Marcal. Suite à l'accident, 10 personnes ont été tuées, 126 personnes blessées et 126 maisons sont devenues inhabitables. Egalement, les dégâts écologiques furent considérables. Le but principal de cette présentation est de donner une description objective des causes complexes de cette rupture du digue de retenue, basée sur les faits matériels.

KEYWORDS: tailing dam collapse, red mud reservoir,

1 INTRODUCTION

In Hungary three alumina plants have been built. One of them in the vicinity of Ajka town has been operational since 1942, and collected red mud in a reservoir in the valley of the Torna stream. The product of alumina production, 15.7 million m³ of red mud was deposited in 10 reservoirs in the valley of the Torna stream. The red mud is a waste product of the Bayer process. Bauxite is crushed and ground in mills and heated; alumina is precipitated by washing the bauxite with a hot solution of sodium hydroxide (NaOH) under pressure.

Fig.1.The site and affected localities, (http://www.bbc.co.uk/news)

Around 24-45 percent of red mud is ferrous oxide, but it also contains other metallic compounds. Red mud is not poisonous, but it is a hazardous material, due to its sodium hydroxide content. This highly alkaline (pH 12-13) material was transported by pipeline to reservoirs.
On October 4, 2010 the northwestern part of the dam of red mud reservoir No. 10 has collapsed, and near one million m^3 alkaline red mud mixed with water has plunged in the valley of the Torna stream. Fig. 1.-Fig4.

Fig.2. Natural-color satellite image of the area surrounding the spill

Fig.3. Natural-colour satellite image of the area surrounding the spill (http://redsludge.bm.hu)

The red mud flooded the valley-side parts of the villages, then trough the Marcal river it has reached the river Danube in very short time. 10 people died, 123 injured, 260 houses became uninhabitable, and significant ecological damage occurred.

Fig.4. Aerial photo with the flooded territory of Kolontár (photo: MTI)

2 GENERAL CONDITIONS

The embankment of the reservoir in question must be examined as part of the entire reservoir system, as the different parts of the system have a mutual impact on each another. The tragic tailing dam failure of the north-western corner of reservoir No. 10 highlighted the importance of a complex analysis.
Important aspects of the study are:

- the geological-geotechnical conditions and the morphological properties of the area;
- the conditions changed as a result of favourable technical interventions or technical interventions believed to be favourable;
- the extreme weather, precipitation and dynamic wind load conditions;
- the specific features of the substance stored in the reservoirs;
- the resistance reducing effects of pressures due to the transition of the substance from a more favourable condition to an unfavourable state of liquefaction;
- the different rigidity properties of the unfavourable embankment connections;
- and several other factors that could not have been considered by earlier regulatory systems.

3 HYDROGRAPHICAL AND SUBSOIL CONDITIONS

Figure 5 shows the subsoil conditions of the area based on detailed soil tests performed between 1975 and 1980. The territory had a basin-like character, fill with course gravel and sand and cover fine sand and silt, hence is had a swampy character, collected the water. The gravel terrace is gradually thinning towards the northern embankment. The „gravel basin" is bounded by a soft, easily liquefiable sludge layer of a plasticity index of Ip=6.8-8.5% and a water permeability of $k=10^{-5}$ cm/sec.
In the year 1989 soil excavations and geophysical measurements were conducted at the leg of reservoir No. 10.'s tailing dam, and the soil profiles were recorded. Figure 6 shows the soil profiles near the north-west corner. It is important to remark that near the north-west corner of reservoir No.10 sand-silt soils are to be found, and sandy-gravel layers above the fat clay. This soil layer unfavourable is that in fine sandy-silt fractions may move under higher water pressure conditions.

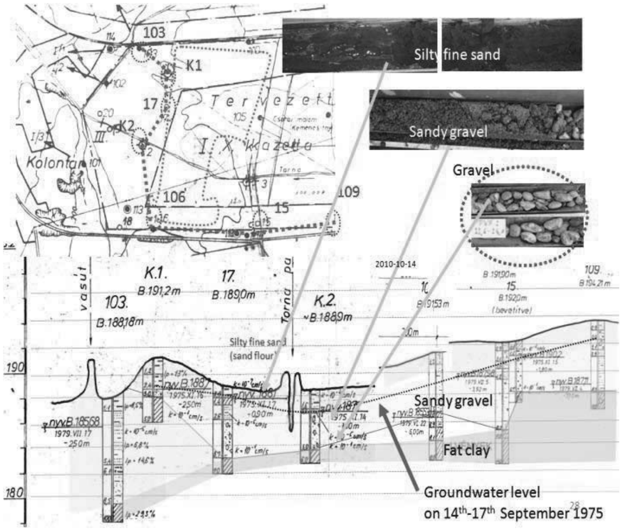

Fig.5. Illustration of the subsoil conditions of the reservoir system based on the original plans.

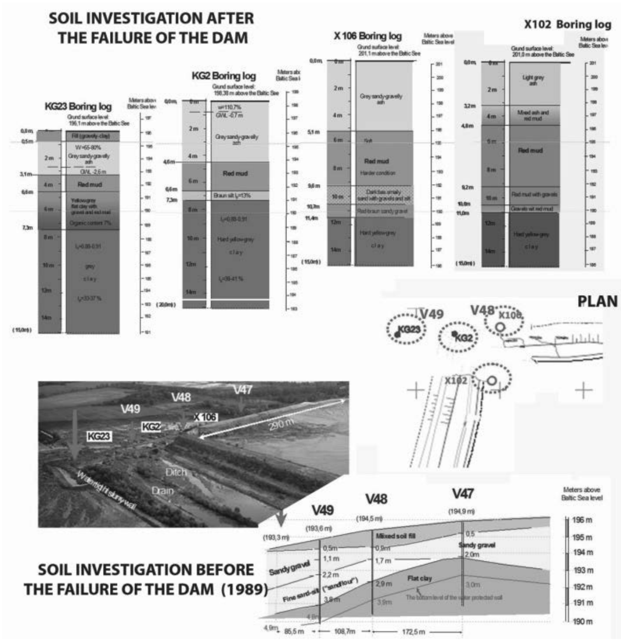

Fig.6. Soil profile near the West –North corner of the reservoir No. 10.

As a result, grain size becomes coarser on the inner side, while a „clay plug" may develop towards the edge of areas in motion. Such a clay plug is characterized by a sudden movement under a significant change in pressure and consequently a mudflow-like grain movement may evolve. Such a process may be extremely fast and unexpected.

4. THE CLOSURE OF THE RESERVOIRS

Water pollution was detected in the groundwater monitoring wells near the reservoir system in the 1970s–1980s. In compliance with the regulatory requirements, a watertight slurry wall was constructed to close down the southern and the western sides of the reservoir. Figure 7.
Later, as the pollution spread over towards the north, the construction of a new type of grout curtain was started around the reservoir system in 1999. Depths of 6.0-9.0-12.0 m appear on the south-eastern side.

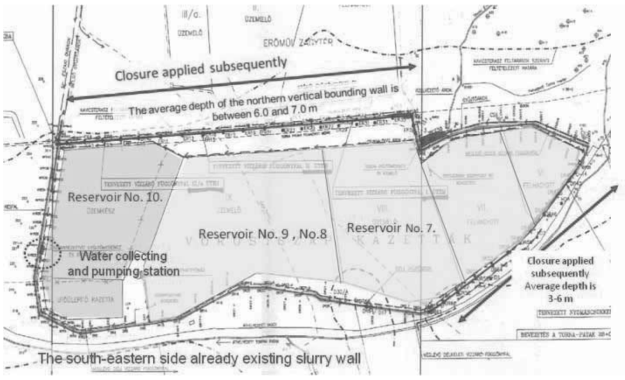

Fig.7. Soil profile near the West –North corner of the reservoir No. 10.

5. THE EMBANKMENTS MATERIAL

The boundary embankments show some special features. As they were made of slag and ash from the power plant, their weight is relatively low. Fig.8.

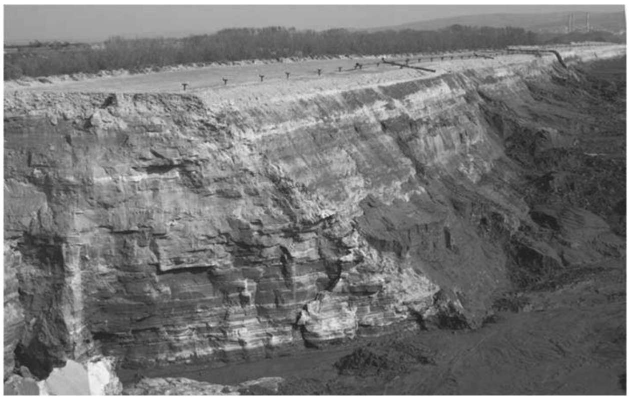

Fig.8. Material of the northern embankment of Reservoir No10 after the embankment failure.

Their average density is ρ= 1.5-1.55 gr/cm^3, while their dry density is ρ_s= 0,7-0,8 gr/cm^3, which is lower than that of water. The embankment is quasi-saturated with water. Due to the hydraulic chemical bond, the embankment is characterised by a relatively large strength. As a result of the construction technology applied, the embankment is layered and is of inhomogeneous structure, which manifests both in its strength and its water permeability characteristics.

6. PROPERTIES OF THE “RED MUD”

The description of the substance as „red mud” is not appropriate in terms of soil mechanics, as considering plasticity index, it belongs to the group of substances of medium to high plasticity and should be described as medium and fat clay.
Chemical effects, such as that of sodium hydroxide added to the swollen clay in the course of the technological process, may also have a role in the special behaviour of “red mud”.
It can conclusively be stated that the substance shows special thixotropic behaviour, it does not easily lose its water content and assumes the behaviour of a thick, plastic liquid upon significant loading. (Asbóth et al 1982.)

7. PRECIPITATION DATA

Comparing the total precipitation of the period between January and the end of September 2010 was 907÷980 mm, comparing the average of the 2000-2009 years data 513÷567 mm with 121÷131 mm standard deviation. (Fig 9.)

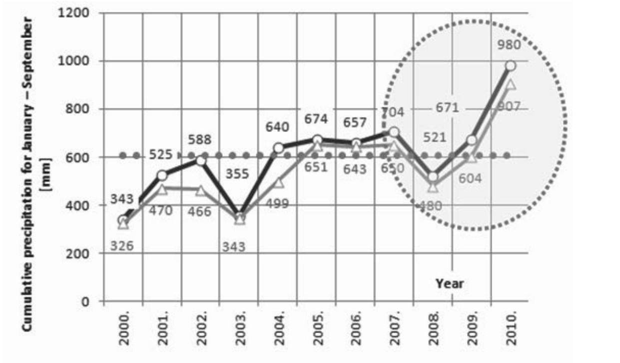

Fig.9. Total precipitation data in the 1st– 3rd quarter year between 2000 and 2010.

8. WIND SPEED AND WIND DIRECTIONS

The prevailing wind direction in the vicinity of Reservoir No. 10 is northern–north-western as shown in the wind direction frequency chart. Wind parallel with the direction of the embankment failure is very rare (Figure 10).

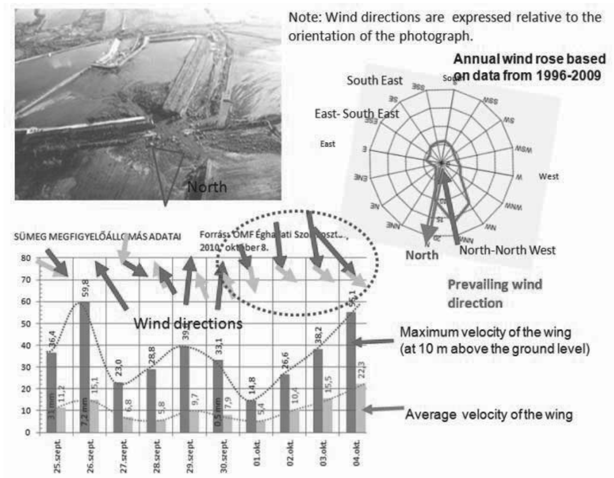

Fig.9. Vectors of prevailing wind directions and wind speeds between September 25.

Peculiar wind conditions were observed in the area between September 25 and October 4. Between October 1 and 4, a gradually strengthening, unfavourable wind speed toward the direction of the embankment failure was accompanied by casual wind gusts (Weather data services, National weather Services, October 8, 2010). The observations of the wind direction and speed were at 10 m over the ground surface, but the top surface the reservoir is 23-24m. It is mean that the wind speed in site should be significant more than the measured value. The highest wind speed values were measured on October 4, with an average of 22 km/h and occasion wind gusts of 60 km/h.
There is reason to assume that these unusual wind direction and wind speed conditions contributed to the development of the embankment failure. The sucking effect of the wind on the northern side of the embankment must be taken into consideration.

8. CIRCUMSTANCES OF THE EMBANKMENT FAILURE

The area is located in the lowest part of the drainage basin of the Torna stream, i.e. in the valley of the stream. In its original condition, the area, together with the subsurface stream valley formed a surface and subsurface water flow unit which was very sensitive to weather conditions. The area had been gradually involved in and shaped by industrial operations, through the construction of surface and subsurface structures. The northern, so called intermediate embankment of Reservoir No. 10, constructed in a smaller size with a view to the possible extension of the reservoir system, served as an external, i.e. boundary embankment. As a result, it was the surface run-off and flow conditions that were first changed significantly by the industrial use of the area in the stream valley.

It can be concluded that according to an engineering approach to finding the causes, the failure of the rigid embankment of large bearing capacity was a combined result of a number of unfavourable conditions.

The base width of the northern embankment is significantly different from the size of the other embankments, as it was considered a temporary structure, bearing in mind the possibility of a future extension. The slightly more than 20 m height of the solid part of the embankment is lower than the 26–27 m heights of the other embankments. Its effect manifested at the northern embankment – being by 25 m less in base width than the western embankment – as the resistance against displacement here was significantly lower, and also because the rigidity of the western and northern embankments showed significant difference at an unfavourable connection at the corner of the reservoir. (Figure 10.)

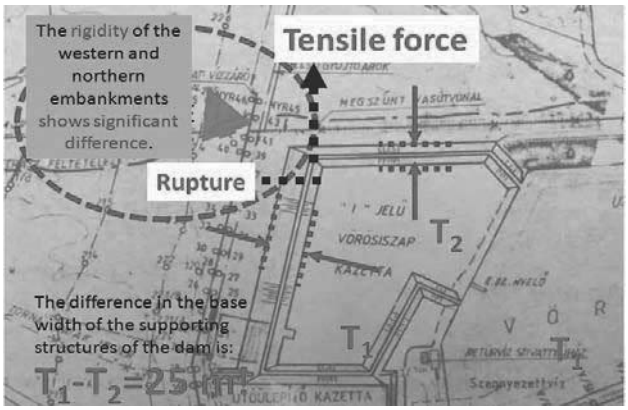

Fig.10. Dimensions of the western and southern dams.

The geotechnical conditions were determined by the fact that at the northern boundary embankment of the reservoir there are beds of easily liquefiable muddy fine sand (or sand flour as described earlier) in a layer of 3-4 m located in the closest vicinity of the critical corner of the reservoir, adjacent to a sandy-gravelly layer.

Significant pore water pressure may have developed in the soil layer underlying the embankment as a result of the geological properties of the enclosed gravel terrace functioning as a drainage basin and due to extremely high precipitation levels causing high water pressure conditions.

The increase of load on the slope surface of the embankment might have contributed to the excess load – and the increase of soil stress – in the subsoil on the inner side and as a consequence, to excess subsidence, while it probably caused a slighter rate of expansion on the outer side due to the rigid body like movement of the embankment.

The extremely rigid but light embankment and the soft, liquefiable subsoil provided highly unfavourable static conditions.

The liquefaction property and special thixotropic behaviour of the "red mud" may have also contributed to the disaster.

Chemical effects, such as that of sodium hydroxide added to the swollen clay in the course of the technological process, may also have a role in the special behaviour of "red mud".

The extremely unfavourable wind direction and wind speed conditions may have given a final push toward the very sudden embankment failure.

It is also an important factor for the stability of the dam, that by what kind of filling technology is used. In what magnitude and distribution of water heights may occur within the area of the reservoir?

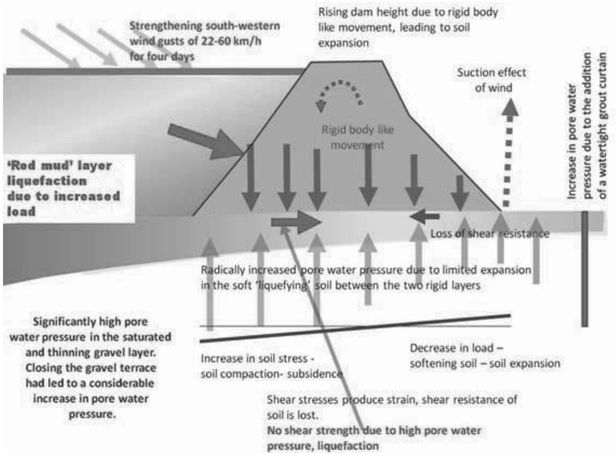

Fig.10. Summarizing some effects for the dam failure

The list of contributing factors could be further extended and it will readily be conceived that it is the accumulation of unfavourable conditions that led to the sudden rupture of the embankment.

9. SUMMARY CONCLUSIONS

The present study aims to provide a background to a non-exhaustive list of factors contributing to the embankment failure, while attempting to give a clear picture of the complex technical conditions.

The rupture of the embankment and the highly serious disaster emerging thereof serve as a lesson in several aspects for professionals performing technical or legislative tasks, as well as for those working in the area of the administration of justice and performing official control duties.

It is not an aim of the present study to identify scapegoats for the incident.

The findings and conclusions derived from the examinations may be further refined and supplemented in the future in light of further facts and data yet to be revealed.

The objective of the author of the present analysis is, led by deep sympathy for the victims and those who suffered damage, to provide an insight into the technical causes and the circumstances of the tragic incident, as well as to promote, with a humble approach to sciences, all endeavours to avoid such disasters in the future.

9. REFERENCES

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