The Failure of the Embankment of the Red Mud Reservoir at Ajka (Hungary)

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Abstract

The NW corner of the embankment of the Reservoir No. 10 of the Ajka Alumina Refinery of MAL Zrt failed on October 4, 2010, shortly after noon. The basic facts and various explanations which could have been collected by the end of November 2010 were presented as a keynote lecture of the XVIIIth Symposium of ICSOBA in Zhengzhou, China. Over the next year further information was made public by studies, on the legal circumstances, the industrial, governmental and other actions, or their lack, which played a role in the failure of the embankment and the tragic consequences. The scientific study results, the activities of civil organizations, the report of a parliamentary committee, a study report of the "green party" of Hungary, the expert opinion of a leading civil engineer, and a court verdict were summarized in another paper published also in an ICSOBA Newsletter in 2012. This paper recalls the earlier comprehensive studies and provides an insight to a more recent one. The primary objective of the present publication to find an answer to the basic question: "Why did the embankment collapse?"

Keywords: bauxite residue, red mud, storage, embankment, failure.

1. Introduction

The NW corner of the embankment of the Reservoir No. 10 of the red mud storage area of the Ajka Alumina Refinery of MAL Zrt (Hungarian Aluminium Production and Trade Company Limited by Shares) failed on October 4, 2010, shortly after noon. The facts, various explanations which could have been collected by the end of November 2010 were presented as a keynote lecture of the XVIIIth Symposium of ICSOBA in Zhengzhou, China and as a paper in an ICSOBA Newsletter [1].

Over the next year further relevant information was made public by studies, on the legal circumstances, the industrial, governmental and other actions, or their lack, which probably played a role in the failure of the embankment and its tragic consequences. The scientific study results, the industrial and governmental actions, the activities of civil organizations, the report of an ad hoc parliamentary committee, a study report of the "green party" of Hungary, the expert opinion of a leading civil engineer and a court verdict were summarized in a paper that was published also in an ICSOBA Newsletter [2] in 2012.

The facts on the failure of the embankment of the Reservoir No. 10 of the red mud storage area of the Ajka Alumina Refinery and the consequences were summarized in the mentioned two papers. In summary: the amount of slurry containing bauxite residue (red mud) as solid phase may have exceeded 1 million m^3 when it was suddenly released just after the collapse of the NW corner of the embankment. Ten residents lost their life [3], 286 people were given medical care, out of them 120 were hospitalized or treated for a longer period of time. The slurry inundated 1017 ha agricultural land and 367 properties (houses and other buildings). Most of the houses and other properties were demolished, the rest were renovated; a number of new houses were built in Kolontár and Devecser, the two most effected places.

This paper recalls the earlier comprehensive studies, provides an insight to a more recent one, and also a summary on the still ongoing legal procedures. The primary objective of the present publication is to answer: "Why did the embankment collapse?"

2. Schematic of the Red Mud Disposal

A schematic of the red mud disposal system of the Ajka Alumina Refinery is shown in Figure 1 (based on the paper of Baksa and Kajdi [4]).

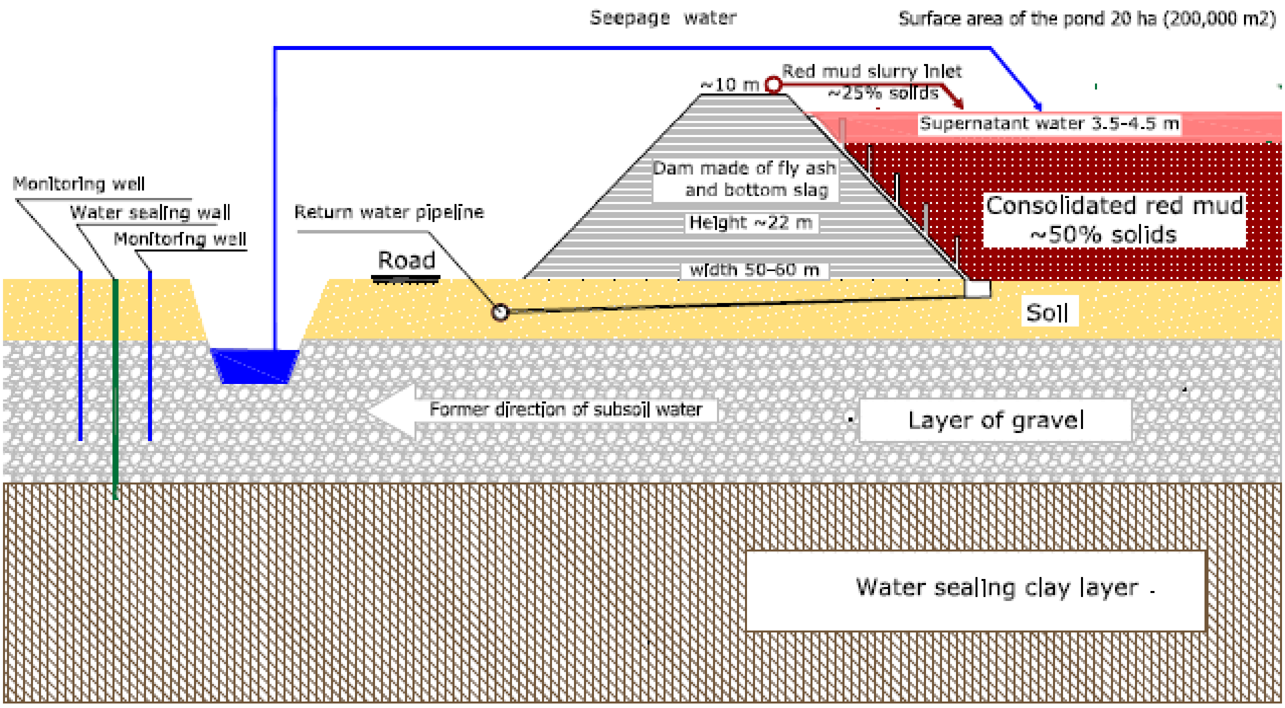

Figure 1. Schematic of the red mud disposal system at the Ajka alumina refinery.

The embankments of the red mud disposal Reservoirs No. 6 – 10 were constructed by utilizing the hydraulic character of the fly ash and bottom slag having considerable CaO content. The fly ash and bottom slag originated from the brown coal fired power plant located in the vicinity of the Ajka Alumina Refinery (and the aluminium smelter when the refinery was constructed). The fly ash and bottom slag were slurried in water and transported to the embankment being built in layers of about 50 cm height. After settling the bottom slag and fly ash, the supernatant water was collected and pumped back to the power plant. The settled mixture solidified by itself in a few days time and a special type of concrete having relatively low quality was formed. The embankment was constructed in stages. This procedure commenced in the 1960s starting with the Reservoir No. 6. By this method a readily available waste, i.e. fly ash and bottom slag was used for the construction of the reservoirs of another waste, the bauxite residue.

The red mud was pumped into the reservoir as a slurry of 300 – 350 g/l solids content and was charged close to the inner wall of the embankment. Therefore, the shape of the bauxite residue (red mud) layer was rather like the bottom of a basin than flat The average height of supernatant water was about 4 – 4.5 m; 0.4 – 0.6 m at the perimeter, up to more than 8 m at the middle of the Reservoir No. 10. The slope of the Northern embankment was 1:1 as shown in Figure 2, at the Western side it was 1:2.

Before the design of Reservoir No. 10, it was found that the seepage of the red mud reservoirs contaminated the surrounding and also the downstream subsoil water with caustic. Implementation of a water sealing wall from the surface downward into the water sealing clay layer located at 6 – 8 m depth was ordered by the Water Management Authority [5]. Construction of the water sealing wall started in 1989. It prevented spreading of the caustic contamination to the downstream subsoil water; and was therefore considered to be a success story [4]. The water sealing wall around the red mud reservoirs was completed in 2000.

MAL took over the Ajka Alumina Refinery and the red mud disposal area in 1997. Reservoir No. 10 (first stage) was commissioned in October 1998, it operated until 2004 in parallel with the Reservoir 9, when the latter became full. Meanwhile the construction of the embankment of Reservoir 10 continued until it reached its final height.

2.1. Supernatant Liquor

A typical composition of the supernatant liquor of the bauxite residue is as follows: 4.6 g/L Na_2O_{total}, 3.7 g/L Na_2O_{caust}, 1 g/L Al_2O_3, pH: 13. This composition is equivalent to a NaOH solution of 0.4 wt %.

The Pannon University (among others) monitored the quality of the released liquid phase beginning with the day of the failure. The highest measured pH value was 12.87 in a sample taken that day [6], which is in good agreement with the typical concentration values shown here.

3. Composition and Structural Integrity of the Embankment

Fügedi and his co-workers of the Geological Institute of Hungary investigated the material of the embankment at the crack [7], which are shown in Table 1 and Table 2.

Table 1. Chemical composition of the dam material and sand pockets.

Samples	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	CaO	MgO	Na_2O	K_2O	$-H_2O$	$+H_2O$	CO_2	SO_3
Western wall (Ny-5)	9.48	0.27	7.93	2.06	0.26	26.1	1.7	1.65	<0,2	18.9	22.4	3.05	6.13
Western wall (Ny-7)	9.81	0.22	6.59	2.29	0.14	35.5	1.89	1.01	<0,2	15.4	13.8	5.82	7.38
Western wall (Ny-11	8.78	0.22	4.36	1.83	0.13	39.4	2.12	0.31	0.395	16.4	14.4	6.88	4.54
Sand (HU07)	76.9	0.59	8.01	1.41	1.54	1.1	0.61	0.81	1.16	1.38	6.3	<0,02	<0,15
Sand (HU11)	69.5	0.66	11.2	2.47	1.5	1.2	1.16	1.7	1.31	2.53	6.2	0.26	0.20

Remarks:

$-H_2O$: adhesive moisture content up to 105 °C

$+H_2O$: chemically combined water between 105 and 1050 °C

Table 2. Mineralogical composition of the dam material and sand pockets.

<table>
<tr><th>Samples</th><th>Quartz</th><th>Calcite</th><th>Ettringite</th><th>Magnetite</th><th>(Na,K)2CO3</th><th>clay</th><th>felspar</th></tr>
<tr><td>Western wall (Ny-5)</td><td>0</td><td>0</td><td>96</td><td>1</td><td>3</td><td>0</td><td>0</td></tr>
<tr><td>Western wall (Ny-7)</td><td>0</td><td>20</td><td>77</td><td>1</td><td>2</td><td>0</td><td>0</td></tr>
<tr><td>Western wall (Ny-11)</td><td>0</td><td>42</td><td>56</td><td>1</td><td>1</td><td>0</td><td>0</td></tr>
<tr><td>Sand (HU07)</td><td rowspan="2">56</td><td rowspan="2">1</td><td rowspan="2">0</td><td rowspan="2">1</td><td rowspan="2">0</td><td rowspan="2">25</td><td rowspan="2">8</td></tr>
<tr><td>Sand (HU11)</td></tr>
</table>

The mineralogical composition data show that the principal constituent of the embankment is ettringite, its amount varies between 56 and 96 % The sand pockets consists of quartz with clay and some feldspar content.

Figure 2. General view of Reservoir 10 one day after the failure of the embankment.

The general view of the reservoir one day after the failure of the embankment helps the reader to get oriented. It should be noted that the Western wall of the breach of the embankment is vertical, therefore Figure 3 shows its cross-section. Figures 3 and 4 demonstrates the inhomogeneity of the material of the embankment. The caustic containing supernatant liquor seems to have penetrated into and through the long pocket of sand and clay.

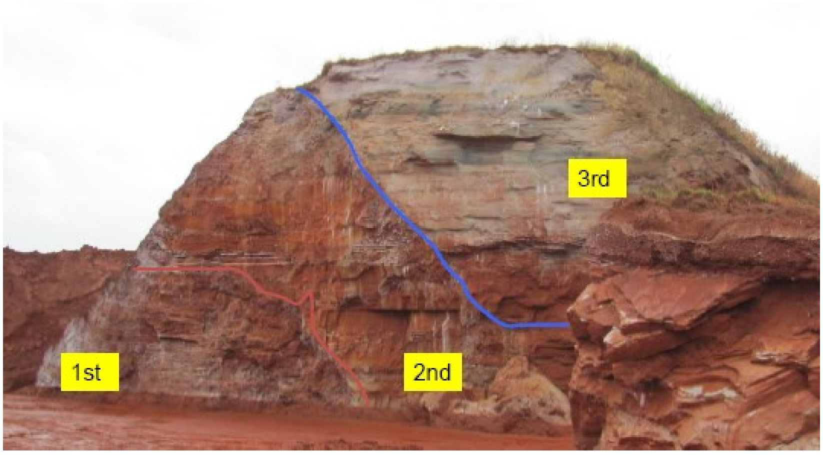

Figure 3. Stages of building of the embankment [7].

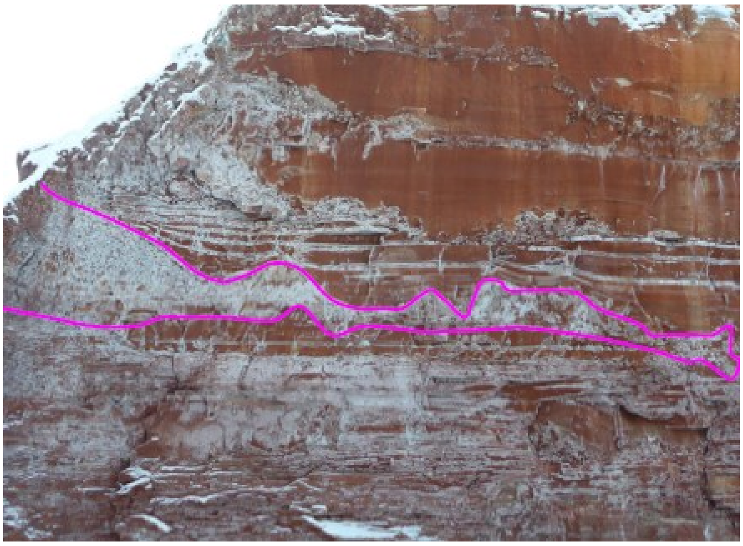

Figure 4. Caustic corrosion pocket in the embankment [7].

Figure 5. Western wall having removed the fresh surface of the break [8].

Fugro Consulting found that the strength of the embankment is highly variable, i.e. there were great differences in strength between the Northern and Western walls of the embankment at the break. There were parts of the embankment which consisted of very low strength fly ash.

It can be concluded that the material of the embankment is highly variable, with sacks of sand and clay. All of these negatively affect the integrity of the material of the embankment.

4. Comprehensive Studies

4.1. Study Report of LMP Party

A comprehensive report [9] was initiated and organized by the parliamentary party LMP (Politics Can Be Different). LMP considers itself as the "green party" of Hungary.

The report revealed, among other points, that the relevant legislation of the European Union had not been fully applied in Hungary and there were "holes" in the procedures of issuing permits, checking and supervising of the integrity of the embankment.

4.2. Report of the Parliamentary Committee

On 30 November 2010 the Parliament of Hungary established an ad hoc committee to determine the responsibility for the environmental catastrophe and to prevent similar ones in the future. After 10 months of investigation the report [10] concluded:

- There were deficiencies during the design of the storage facility, such as: site selection and soil mechanics below the foundation of the embankment, the collection of the supernatant liquor was placed at the perimeter instead of a central position of the pond, the tensions arising in the embankment having a height of 20 – 25 m and their consequences were not considered.
- There were deficiencies during the permitting process. The red mud waste was improperly classified as non-hazardous waste, the local notary issued the permit for the construction and the mining authority had not been consulted beforehand. The Directorate for Disaster Management did not classify the facility under the effect of the Directive 96/82/EU (SEVESO II), therefore it did not control the operation. Further, the environmental permit did not clarify if the facility was a waste disposal facility or a process facility and the cooperation among the various authorities was not seamless.
- The principal cause of the disaster was the large amount of caustic liquor stored having high pH, the allowed height of the supernatant liquor was 1 m as average and 1.5 m as maximum as per the permit [11], the actual value was 4.45 m on average, in the middle of the pond 8 m; this caused high load to the dams. The monitoring and checking of the operation of the reservoir was not satisfactory, there were no instruments installed to monitor the micro-motions of the embankment, the yearly environmental inspections by the authorities were formal, they did not go into the details of the facility and its operation.
- The responsibility assignment is very complex, however the disaster cannot be considered a consequence of the nature, it is rather the consequence of the industrial activity.
- Responsibility of the deficiencies of the designers and constructors during the design and construction can also be claimed.
- The Environmental Authority made substantial mistakes in the course of the classification of the waste, the supervision of the construction of the embankment and its operation.
- MAL has serious responsibility for the deficiencies during the operation.
- There have been deficiencies in the legislation which constitute the rules of the permitting, design and operation.
- The statements above may not replace the legal procedures.

MAL stressed some 300 000 m^3 process media, containing bauxite residue which is a non-hazardous material was released due to the breach of the embankment. A soil failure which was caused by the excessive amount of rain in 2010 and the reaction of montmorillonite of the clay-rich soil below the embankment with the caustic content of the process liquor being stored, caused the breach of the embankment.

A measurement at a later date by the Environmental Authority concluded that the red mud sludge released might have been 1 644 000 m^3, and one third of which was bauxite residue.

There are discrepancies in the pH of the released liquor. Zoltán Illés Environmental Secretary claimed the pH of the red mud slurry was 12.5 – 13 [12]. The Environmental Authority claimed the pH in the failure reservoir was likely 13.7. The highest field test results of Pannon University showed a pH of 12.87 (see above).

4.3. Expert Opinion of a Civil Engineer

Dr István Kertai is a hydraulician (civil engineer), having enormous expertise in the design of dams and assessment of their operation, including their failure in extreme circumstances. On 3 November 2010 he was assigned with the steering of the Complex Assessment and Design Program [13].

Based on an extensive drilling program, geotechnical and building material expert assessments by various institutions, companies, professionals of the Geological Institute of Hungary, Eötvös Loránd Geophysical Institute of Hungary and the Technical University of Budapest, Dr Kertai prepared a Summary Memorandum [14]. The following information in this section is based on this Summary Memorandum.

The soil failure of the fat clay soil being found at the surface of the original soil just below the basement of the embankment almost exclusively at the affected section is claimed to be the primary reason of the failure of the embankment. The fat clay became saturated with water, was submitted to the chemical effect of the caustic content of the liquor accompanying the bauxite residue over years and the clay lost most of its strength. The lower section of the dam which was built out of fly ash weakened due to the permanent load of water. Due to these effects the soil below the failed corner of the embankment lost much of its strength, to the own weight of the quasi rigid dam and also to the load of the stored red mud slurry of low solids content, the affected corner mosaically fissured and bursted. The plastic behavior of the soil below the embankment changed and it sank a few decimeters over the rigid break of the affected corner.

A hydraulic model suggests that about 1.2 million m^3 of thin red mud slurry may have discharged when the dam ruptured.

The serious mistakes of the site selection, design, construction and the supervision by the authorities resulted in the failure of the embankment as follows:

- the foundation of the embankment was inappropriate. The soil below the embankment was highly heterogeneous and a rigid embankment was constructed.
- the design calculations did not take into account the strength loss of the clay due to the caustic content of the liquid phase, nor the strength loss of the lower third of the embankment (constructed out of fly ash) due to the permanent load of water.
- the cross section of the embankment was not satisfactory, the bank slopes were steep, the tension of the embankment toe was high.
- the design did not cover the effects of the uneven saggings.
- the material of the embankment is largely heterogeneous both in horizontal and vertical directions and this facilitated the formation of fractures.
- the embankment was not properly sealed, an inner water sealing wall [15] was not applied
- the filling of the red mud slurry was not consistent, the red mud was randomly distributed at certain places. The safety of the embankment having a height of 25 m should not have been based on such a process technology.
- the embankment integrity checks were substantially defective.

4.4. Comprehensive Expert Opinion

At Spring 2011 The MAL Zrt assigned Dr József Pusztai, Head of Geotechnical Department of Budapest University of Technology and Economics and CEO of Fugro Consulting Ltd to prepare a "Detailed Comprehensive Forensic Expert Opinion and Clarification of the Reasons and Circumstances of the Failure of the Red Mud Storage Reservoir No 10 of the MAL Zrt. that

Happened on 4th October, 2010". This section is based on the "Complemented Forensic Expert Opinion" [16].

4.4.1. Design Issues

Site selection: During the preparation of the Reservoir No. 10, ten sites were considered. For various reasons all the alternatives were rejected and the site where it was actually built was most probably selected due to the lowest investment and operating cost. The low probability hazards, like any risk to the population downstream were neglected. The distance of the embankment from the closest village, Kolontár was about 1 km. The bottom of the embankment was 10 m higher than the potentially affected lower part of Kolontár. The anticipated height of the stored red mud and supernatant liquor was an additional 21 m.

As per the relating Hungarian Standards**, the safety factor of an embankment should have been 1.5 as a minimum**. In this case, the safety factor shows how much load must the embankment stand compared with the anticipated maximum load.

The number (density) of the soil mechanical drillings complied with the relating standard, however, the depth of the drillings did not. Some checking calculations (positional stability, critical condition of the embankment, requirements for the embankment) were not presented for the permitting authorities in full. The authorities nevertheless signed off the presented design calculations without requesting any further details, or making any comment. If all the requirements of the relating standards and rules had been kept strictly, the checking calculations had been carried out properly, these would have revealed that the embankment design did not reach the minimum safety factor of 1.5. This is crucial, since the design documentations that were available for the principal and subsequent operators, claimed a safety factor of the embankment being ≥1.5. The documentation that comprised the basis of the permitting and also that of the detailed design did not contain all the stability checking calculations and their proofs.

There were contradictions between various maps. E.g. there was a 40 m deviation of the indicated place of North-West corner of the embankment, which actually collapsed, and the real place. At a place where the composition of the soil is complicated, this is relevant, since the clay-rich soil bottom has a slope just below the NW corner of the embankment.

It should be pointed out that the stability checks of the design documentation related only to the embankment itself. Some circumstances and scenarios, e.g. the quality of the bottom soil (at places clay, montmorillonite included), seepage of the contained liquid throughout the embankment, the level of the subsoil water may reach the surface, etc.) were not considered during the checking calculations. When Fugro repeated the original design calculations, a safety factor value of 1.5 was arrived at (for the embankment itself). However, when the stability calculations of the original design were checked with three methods (manual, two-dimensional by computer and three dimensional, by computer), it was revealed that the calculations of the earlier study [17] contained errors and results which could not have been verified. When Fugro [18] made checks for the original design, with the manual and two-dimensional calculations, they arrived at safety factor values of between 0.8 and 1.3. The calculations with the 3D model resulted in a safety factor of 1.02. Two other geotechnical experts with a similar computational method arrived at a safety factor of 1.08. It can therefore reasonably be claimed that the safety factor of the embankment did not reach the minimal requirement of 1.5.

It should also be pointed out when real starting data were used (subsoil conditions, geometry, loading, etc.) and the weakest point of the embankment was sought by the 3D model, the NW corner was found to be the place, where the embankment actually failed.

4.4.2. Permitting Issues

The Authority issued the permit for implementation, however the stability checks (aquaplaning, slipping, overturning, checking of stability of the slope, slipping of the whole embankment, checking of the safety factor for the soil failure, checking of deformation of the embankment) had not been presented in full.

4.4.3. Construction

Preparation of the basement of the embankment was unprofessional. Beside the topsoil, the next layer which had low shear stress, should have also been removed, the water permeability of the soil, and also the seepage should have been effectively prevented. These were not done.

In the course of the design of the embankment, the engineering company (MÉLYÉPTERV) prepared a thorough study [22] on the characteristics of the bottom slag and fly ash of the neighboring coal fired power plant. However, there was no rigorous sampling and analyses program in place for the construction of the embankment which most probably would have prevented the substantial inhomogeneities of the embankment, which caused the extreme differences in its mechanical characteristics. It also seems that there was no regular and effective supervision of the construction on behalf of the engineering company either.

4.4.4. Operational permits

The Authorities should have paid attention not only to the design, but also to the as-built documents. There was not any request or comments on behalf of the Authorities at this stage, either. That was the case over the regular yearly supervisions of the reservoir.

4.4.5. Operation

It can be claimed that the operators fully complied with the values that were prescribed by the engineer and/or accepted by the Authorities. It was prescribed that during the operation about 0.50 m height of water should be kept above the highest level of bauxite residue in order to prevent its dusting in dry and windy weather. As it was reconstructed from the latest operational data, this height of water was above the highest level of bauxite residue at the embankment. There was not any constraint regarding the amount of water that could have been kept in the Reservoir. The amount of water that was calculated by the latest measurement of the depth of water at various points of the Reservoir (the morning before the collapse of the embankment) showed 835 000 m^3 water.

4.4.6. Monitoring

There was not any monitoring system regarding the embankment, designed by the engineer or prescribed by the Authorities. There was a certain gap in the legislation in this respect. Nevertheless, due to the fact, that the structure of the embankment was rigid, realistically, any monitoring system, that would have indicated measurable deformity of the embankment could not have led to any kind of action, because the collapse of the embankment took place in minutes.

4.4.7. External Effects

4.4.7.1. Sealing Wall

The **water sealing wall** that was ordered by the Environmental Authorities, was completed around the red mud reservoirs in 2000. It effectively prevented the surrounding subsoil water from being contaminated with caustic. Nevertheless, as a “side effect” the caustic concentration of the subsoil water continuously increased. The clayey minerals of the topsoil, especially its montmorillonite content reacted with the caustic. As the result, the topsoil under the NW corner of the embankment largely lost its strength, which was certainly harmful to the stability of the embankment. To be fair, it should be noted that the risk of such a reaction was not known in the technical literature or in operational experience at the time of design [20,21].

4.4.7.2. Earthquake

In the course of the year before the failure of the embankment there were 17 earthquakes with a magnitude (ML) of 0.7 – 2.7 within a radius of 100 km. Out of them, there were 5 earthquakes with a magnitude of 1.7 – 2.7 in the months preceding the failure of the embankment. There is no way to claim that the earthquake was the reason of the embankment failure. However, one cannot exclude the possibility that the earthquakes had some role in weakening of the strength of the rigid, inhomogeneous structure of the embankment.

4.4.7.3. Precipitation/Rainfall

The average of the 6 months’ rainfall in 1997-2010 years was 397 mm. The amount of the precipitation in the preceding 6 months in 2010 before the failure of the embankment was extreme high, 838 mm. The stored amount of red mud and the supernatant liquor did not exceed the permitted level, however, the seepage due to the high amount of supernatant liquor further soaked the slope of the topsoil. The level of the subsoil water was at the surface at the critical period.

4.4.7.4. Wind

During the day of the failure of the embankment, the direction of the wind was SE which otherwise was rare and “attacked” the NW corner of the embankment. The strength of the wind reached its daily maximum at noon with a value of 13.4 m/s (48.24 km/h). The effect of wind most probably was not the “cause” of the failure of the embankment, however, as a “butterfly effect” it may have played some role in the collapse of a rigid structure that stood above a weakened and soaked clay-rich topsoil.

It is worth noting that some of these external effects cannot be fully verified, and others may have been marginal in contribution. However, when the safety of an embankment is far from the required value, even these marginal effects may constitute real risks.

5. Legal actions

MAL was sued by victims who personally suffered or their heirs for those sufferings and/or losses which had not been compensated by the state. The Court of Law made an intermediate verdict as follows: The failure of the embankment happened due to joint effects of several reasons. These reasons were, among others, deficiencies revealed in connection with the construction and maintenance of the facility, imperfection of the soil investigation, design, foundation and stability checking deficiencies, inadequate embankment construction technology and the soil failure due to the detrimental effect of the caustic seepage water [22]. The verdict was upheld by the Court of Appeals [23].

15 employees of MAL from the Chief Executive Officer to a pump operator were put on trial in a criminal case. They were accused of

- professional misconduct of causing deaths,
- impairing the environment
- impairing nature
- breach of the rules of waste management.

The top management was accused of all of these accusations. Those who had lower levels of responsibility were accused of one or two of the listed items. After 152 days of trial from 24 September 2012 to 28 January 2016, the verdict of the Court of Law was that the indicted did not commit the crimes what they were accused of, therefore all of them were exempted [24]. The substantial reasons of the failure of the dam were the errors made during its design. The companies which were in possession of Reservoir No 10 had all the permits during the design, construction and operation, and there was no clear signs of the hazard until the embankment failed [25]. The Court of Appeals found the reconnaissance of the case by the Court of Law to be of high level. However, there were significant issues with the justification of the verdict. In February 2017 the Court of Appeals revoked the verdict of the Court of Law and ordered another trial [26]. The second round of the Court of Law level trial started on 11 December 2017 and has not concluded as yet.

6. Latest Events

The so-called dry mud stacking was introduced in early 2011. MAL commenced liquidation of late February 2013 and the state took over the facilities of MAL. Later, a set of new companies were established which have continued the operation of the non-metallurgical hydrate and alumina production. Subsequent to complaints due do red mud dusting, processing of bauxite ceased at the end of July 2013.

7. Concluding Remarks

- The material of the embankment is highly variable, with patches of sand and clay. There were parts of the embankment which consisted of very low strength fly ash. These negatively affected the integrity and the stability of the embankment.
- The strength of the clay-rich topsoil below the embankment decreased over the years at the critical NW corner due to the chemical reaction of clay minerals, montmorillonite included with the caustic content of the seepage.
- There were information gaps in the design procedures and in the procedures of issuing permits.
- The safety factor of the embankment was 1.02 – 1.08, below the required minimum value of 1.5.
- There was no rigorous and effective quality control during the construction of the embankment.
- The water sealing wall around the storage area was successful in preventing the caustic contamination of the surrounding subsoil water, meanwhile it retarded the rainfall and the caustic containing seepage liquor and as a result of complicated effects, weakened the clay-rich subsoil below the critical NW corner.
- Application of a water impermeable plastic seal at the bottom and the embankment of the Reservoir 10 could have prevented the harmful reactions of the caustic seepage liquor with the material of the embankment and subsoil. However, this probably would not have been sufficient to overcome the design and construction issues.
- The design, permitting, construction and some of the supervisory faults had been made before MAL acquired the Ajka Alumina Refinery in 1997.

8. Acknowledgements

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