FAILURE MECHANISM and KINEMATICS
of AJKA TAILINGS POND INCIDENT, 4 Oct. 2010

Magyar Aluminium ZRt (Hungarian Aluminum Co.)
Ajka - Hungary

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Istanbul, Turkey
On 4 October 2010, a “red mud” spill had occurred following a tailings pond failure at an aluminum processing plant in Hungary. *(The subject plant, is not a mining operation)*

Red mud driven by the pond water flooded downstream 2 villages *(Devecser and Kolontar within 5 km distance of pond)* and travelled through a creek leading to the Danube River, approx. 160 km. to the Site.

As of 10 December 2010, there is no apparent water quality impact on the Danube River and an EU Task Force Report on this matter is pending.

The Processing Plant restarted operations in about 2 weeks after the incident.

*(NOTE: This presentation does not cover the “environmental aspects” of the Pond Failure)*
The Failed Tailings Pond (impoundment) is called “Magazin 10”.

Reportedly, 600-700,000 m$^3$ tailings sludge was released at the incident.

The remaining red mud solids in the pond are apparently in the form of lightly consolidated (non-viscous) sediments.
Post-Failure Aerial View of the Ajka Tailings Pond (Oct. 2010)

Apparantly, about 10% of the tailings solids were washed-out by scouring effect of the run-away water.

Please note the “vortex in the tailings” and the “diagonal fracture” on the North Dike (for their relevance in the triggering mechanism of the failure).
Note the blocks of failed dike material (fly-ash) ...
**DIKE MATERIAL**

**Dike Features:**
- Built directly on natural soil with NO “bottom lock” or any “Impermeability Feature”
- Design slope is 1.1V:1H.
- Western Dike has a benched geometry with 1V:2.5H average downgradient slope angle

**Dike Material:**
- “Fly Ash” from the Ajka Thermal Power Plant
- Compacted Fly Ash behaves (d) like a low quality concrete (as observed at post-failure cracks & blocks)

DIKE STABILITY and Structural Issues

Dike Layout and Geometry:
- The North Dike has a non-uniform crest geometry and width, built in three segments.
- The West Dike has a uniform crest geometry with a benched slope

Dike Stability Issues:
- No “Apparent” circular slope failure or foundation failure (bulging downstream of Slopes)
- No “Apparent” differential settlement or displacements in dikes (No pre-failure fractures)

Therefore;
NO Apparent DIKE Slope and Foundation Stability concern.

However; there are:
Apparent Structural Weaknesses due to:
- 116° concave geometry which generates excess tensile stresses in the dike structure at the northwestern corner.
- Weak connection of the dikes at the northwestern corner of the pond structure (connection of North and West Dikes having different cross-sections without extra retaining soil).

Maintenance and/or Monitoring Oversight in:
- seepage monitoring in the north dike of the impoundment
- and/or disregard of the ongoing seepage (specifically at point vicinity).
EARLY WARNING SIGNS OF THE FAILURE

Post-Failure Shear Fractures are Located at the Seepage Area
Pre-failure Seepage and Crest Erosion Marks on the North Dike of AJKA Pond
(26 June 2010)

Post-failure Shear Fractures on the North Dike
(Note the vortex cone in the tailings revealing discharge through the shear fracture)
Post-failure Shear Fractures and Settlement on North Dike of AJKA Pond

(Note the vortex cone in the tailings revealing discharge through the shear fracture)
An aerial view shows workers working on a dyke of a reservoir containing the sediment red mud of an alumina factory is seen near Ajka, 150 kms southwest of Budapest, Hungary, Friday, Oct. 8, 2010. Rescue services say they have found two more victims of Hungary's catastrophic flood of red sludge, bringing the death toll to seven. (AP Photo/MTI, Dobias Mohai)
Post-Failure Shear and Tensile Fractures in the Dike

Vortex in the Tailings and Discharge along the Diagonal Fracture is an Indicator of:
- a Shear Failure under “increased Pore Water Pressure” due to seepage
- where Shear Strength of the Dike Material was exceeded Shear Stresses applied by the displaced dike segment (which was driven by the hydrostatic pressure of the tailings sludge).
AJKA Tailings Pond Failure was due to “Wash-Out” of a Dike Segment at the Northwestern Corner of the Pond.

Triggering Mechanism of the dike failure was likely a SHEAR FAILURE at seepage area located at Approx. 300 meters east of the northwestern corner.
1. Shear Failure at the Seepage Area “A”
2. Easterly incremental Slide of the Dike Segment & Tensile Fractures at “B”.
3. Washed-out Dike Block
In Summary,

- The in-place fly-ash dike material behaves like a low-quality concrete fill,
- Apparently, the dike slopes are stable and there is no bearing-capacity concern.
- The north dike geometry is not uniform, showing a staggered pattern in plan view,
  - Likely presence of a discontinuity in material at the narrowest points, occurred during construction (a possible reason for the seepage at the Shear Zone),
- The corner of the north and west dikes have deficient connection/reinforcement design,
- Inadequate monitoring and remediation for the seepage apparent on the north dike for the last two years.

- The dike failure, likely:
  - was triggered by a shear failure in the dike at the seepage area located about 300 meters east of the northwestern corner of the impoundment, due to increased pore water pressures,
  - was caused by separation of the north dike at the northwestern corner of the impoundment and tensile fracturing in the easterly displaced north dike segment,
  - was propagated by incremental eastern movement of the dike segment (west of the shear zone) where the fractured blocks in the northwestern corner of the dike were pushed out by the water in the impoundment causing the ultimate structural failure.

- Apparently, only approx. 10% of the tailings solids were released after the breach, the remaining tailings are of lightly consolidated nature and remain in the pond.
- The remaining (fractured) dike segments and the tailings appear to be stable.
POTENTIAL REMEDIATION MEASURES:

Despite the fact that the existing impoundment structure has deficiencies in terms of the current regulatory and dike design criteria, under the circumstances, the following remedial actions can be taken into consideration:

- Filling of the breached segment of the dike in the northwestern corner of the pond with compressed fly-ash, following cleaning up of the mud in this area.
- Reinforcement of the overall northern slope of the north dike with fly-ash to at least 1V:2H slope configuration.
- Pressure grouting the post-failure fractures in the displaced dike segment and the edges of the reconstructed breach area.
- Installing a grout curtain and a groundwater extraction system downstream of the impoundment to cut-off migration of contaminated groundwater from the tailings pond. The extracted groundwater may be pumped back to the repaired pond.
- Setting-up of a seepage and groundwater monitoring program around the pond.
- Using the repaired pond for disposal of clean-up materials collected from the downstream flooded areas.
- Continuation of usage of the repaired pond for process tailings, until decommissioning upon filling.
The impoundment dikes were apparently “mechanically STABLE”… (as seen in performance of similar dikes since 1942 and this one being the 10th impoundment at site).

**HOWEVER:**

**MORAL of the STORY:** No leak/seepage is **INSIGNIFICANT** for the water retaining structures!!!!
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Dr. Zanbak, is a 1971 graduate of Istanbul Technical University, has completed his Ph.D. at the University of Illinois, USA. His academic experience includes Istanbul Technical University until 1981, Kent State University, Ohio, South Dakota School of Mines, Rapid City, South Dakota as an associate professor and at Illinois Institute of Technology, Chicago, Illinois as an adjunct full professor until 1994.

Dr. Zanbak has worked as a consultant to the USEPA and numerous industry facilities on hazardous waste management, remedial investigations, feasibility studies and remedial design for Superfund projects during the 1984-1994 period.

Dr. Zanbak is the principal author of “Hazardous Waste Management” section of the National Environmental Action Plan coordinated by the Turkish State Planning Organization and the “Report on Environmental Non-Tariff Trade Barriers and an Action Plan for Turkey” prepared for the Turkish Businessman’s Association (TUSIAD). He has taken an active role in preparation of the “Sustainable Development – Business Community and Industry”, Johannesburg (Rio+10) Conference Country Report for Turkey, prepared by the CEVKO Foundation.

Since 1994, Dr. Zanbak is the coordinator of the Responsible Care© Program of the Turkish Chemical Manufacturers Association. Currently, he is a standing member of the following organizations:

- **Environmental Advisor** for the Turkish Chemical Manufacturers Association
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