Workshop & Lectures on Dam Engineering

TAILINGS STORAGE FACILITIES

Embankment Stability & Staging

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Stability Does not Always mean Embankment Stability!

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It can mean Foundations!

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Consequences of Instability!

The Successful Struggle against STD in Marinduque, Philippines

Prepared by Catherine Coumans and MACEC

*Marinduque is a small island province 160 km south of Manila. The people of Marinduque fought a successful battle to keep **tailings** that were spilled into a river in a 1996 mine disaster from being piped into the sea through Submarine Tailings Disposal (STD). For Marinduqueños, this struggle to protect their sea was the latest in a long history of struggles against Placer Dome, most of which were lost.*

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Marcopper Disaster

A 30-year History of Mining Disasters and Social Opposition

In 30 years of mining under Placer Dome's management, Marinduqueños endured one mining-related environmental disaster after another. For 16 years, from 1975 to 1991, Placer Dome oversaw the dumping of 200 million tons of mine waste (tailings) directly into the shallow waters of Calancan Bay, covering corals and seagrasses and the bottom of the bay with 80 square kilometers of tailings. The food security for the 12 fishing villages around the bay has been severely impacted for more than 25 years. These tailings are also leaching metals into the bay and are suspected to be the cause of lead contamination found in children from villages around the bay. Calancan Bay villagers, who protested the dumping for 16 years, were never asked permission and never compensated for losses. Dumping was not halted until the mine was depleted.

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In 1991, an earthen dam was built in the mountainous headwaters of the Mogpog River to keep silt from a waste dump for the mine out of the Mogpog River. The people of the town of Mogpog actively opposed the building of the dam, fearing impacts on the river they use for food, watering animals, washing themselves and their clothes. In 1993, the dam burst, flooding downstream villages and the town of Mogpog so severely that houses were swept away, water buffaloes and other livestock killed and crops destroyed.

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Stability Does not Always mean embankment Stability! Marcopper Disaster

The Boac River Tailings Spill Disaster of 1996

On March 24, 1996, another massive tailings spill at the Marcopper Mine filled the Boac River with 3-4 million tons of metal enriched and acid generating tailings. The spill happened when a badly sealed drainage tunnel in an old mine pit burst. The mined out pit, high in the central mountains of Marinduque, had been used as a storage place for tailings from an adjacent mine since 1992. An investigative team from the United Nations, which visited the island shortly after the tailings spill, noticed unrelated leaks in other mine structures and concluded, "It is evident that environmental management was not a high priority for Marcopper," and that "it is possible…the present environmental disaster would not have occurred."[2]

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Stability Does not Always mean embankment Stability! Marcopper Disaster

Placer Dome Decides on Submarine Tailings Disposal to "Clean Up" Spilled Tailings

In 1997, Placer Dome stated it would clean up the river by dumping the tailings into the sea using Submarine Tailings Disposal (STD). There was not yet much awareness among the people of Marinduque about this technology, but it was opposed by a core of local people who were concerned about the potential impacts on the sea.

On October 30, 1997, the Philippine Department of Environment and Natural Resources (DENR) turned down Placer Dome's first permit application to use STD. In his denial of the permit then-Secretary of the DENR, Victor Ramos, noted that "under current laws and regulations, all the offshore and submarine areas of the country are considered to be Environmentally Critical Areas (ECA)…. Hence, your application for the submarine placement of redredged channel tailings materials is hereby denied."

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Submarine Tailings Disposal

A major source of concern for Mindoreños opposing the mine is the controversial proposal to dispose of mine waste, some estimated 4 million tons of waste per year, into the waters of Tablas Strait using Submarine Tailings Disposal (STD). The system calls for a pipeline to deposit the **tailings** 4 kilometers from the shoreline of the village of Pili at a depth of 200 meters below sea level. The sea floor declines sharply in this area to about 600 meters.

Case History - Merriespruit Tailings Dam Failure, Virginia, South Africa

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- On the 22nd February 1994 the Merriespruit tailings dam failed by overtopping as a consequence of heavy rains causing a flowslide (static liquefaction) of part of the embankment (Davies 2002). Water mismanagement was to blame that caused 600,000 m3 of tailings (1.2 Million tonnes) to mobilize out of the impoundment where the flow eventually stopped 2 km away in the town of Merriespruit (Penman 1998; Davies 2001). 17 people were killed and scores of houses were demolished (Fourie 2003). Figure 1shows the extent of the damage to the town and the scale of the breached embankment.

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Case History - Merriespruit Tailings Dam Failure, Virginia, South Africa

- The 31 m high embankments had problems prior to the major failure. Small slips had caused the impoundment to close temporarily, and only mine water with small amounts of tailings were deposited. The deposition of these tailings caused the supernatant pond to move to the opposite side of the impoundment which rendered the decant system useless (ICOLD and UNEP 2001). A satellite recorded the transition stages of the decant pond relocation as more tailings were deposited with the mine water (ICOLD and UNEP 2001). Heavy rains that fell on the day of the failure (30 – 55 mm in 30 minutes) caused the overtopping (Blight 1998).

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Case History - Merriespruit Tailings Dam Failure, Virginia, South Africa

- The failure could have been prevented if a suitable operating manual and emergency plan had existed. The operation of the facility leading up to the major failure was a complete disregard to the designed operating procedures. The facility had been closed as a result of earlier embankment slips but still process water and tailings were being discharged to the impoundment. This suggests that an emergency plan was not in place to implement intervention actions or documented procedures were overridden by an individual making an executive decision. Which ever the case may be, the lack of understanding of the operational procedures and the seriousness of the events prior to the main failure had not been realised. If a well structured and executed operational plan had existed then the tailings operator(s) would have known to implement the emergency plan, continually monitor the closed impoundment for change and prevent further discharge to the facility.

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Case History - Merriespruit Tailings Dam Failure, Virginia, South Africa

- The position of the supernatant pond and its ability to decant had been lost which suggests that the monitoring procedures had been inadequate to notice the change in the pond geometry and location. Alternatively the tailings operators may not have been trained to realise the consequences of pond migration as a result of single point deposition of the process water and tailings. However, the operation of the facility and the reaction to emergency situations were inadequate and fall short of any tailings management system. A simple management structure documenting individual responsibilities, operating procedures and contingency measures would have been suffice to identify and prevent the initial localised slips and how the facility was to be managed thereafter. Having a suitable tailings management system could have prevented this failure from occurring.

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Case History - Stava tailings dam failure, near Trento, Italy

- At 12h:22':55" on 19th July 1985 the bank of the upper basin gave way and collapsed onto the lower basin, which, too, collapsed. The muddy mass composed of sand, slime and water moved downhill at a velocity approaching 90 km/h, killing people and destroying trees, buildings and everything in its path, until it reached the river Avisio. Few of those hit by this wave of destruction survived.
- Along its path, the mud killed 268 people and completely destroyed 3 hotels, 53 homes, and six industrial buildings; 8 bridges were demolished and 9 buildings were seriously damaged. A thick layer of mud measuring between 20 and 40 centimetres in thickness covered an overall 435,000 square metres over 4.2 kilometres.
- Approximately 180,000 cubic metres of material poured out of the dams. A further 40,000 - 50,000 cubic metres came from erosion, buildings demolished by the flow and hundreds of uprooted trees.

  The July 19th 1985 disaster in the Stava valley was the most tragic of its kind. With its toll of 268 lives lost and 155 million Euros in damage, it was one of the worst industrial catastrophes in the world, second in Italy only to the Vaiont tragedy.

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Case History - Stava tailings dam failure, near Trento, Italy

- Over a period lasting more than 20 years, the tailings dams underwent no serious stability checks whatsoever or any other monitoring by Public Departments obliged to supervise safety levels in order to guarantee safety to the mines and nearby communities.
- In 1974, the Municipality of Tesero asked for checks to be carried out in order to assess the safety of the dam. The Mine Bureau of the Autonomous Province of Trento entrusted the licensed company (Fluormine, which belonged to the Montedison and Egam groups at that time) with the task of carrying out these checks. They were performed in 1975.
- Although a number of vital checks were not made, it was established that the bank of the upper basin was "exceptional" and that its stability had been taken "to the limit". In his first report the technician carrying out the checks goes on record as saying: "it's hard to believe that they are still standing". In any case, Fluormine's response to the Mine Bureau, and the latter's response to the Municipality of Tesero was positive. This was followed by more waste being poured into the basin, marked by a lower degree of inclination.
- The ministerial Commission of Inquiry and the experts appointed by the Law Court of Trento ascertained that "the settlement system as a whole constituted a continuous threat looming over the valley. The system collapsed because it was designed, built and managed in such a way as not to provide the security margins that society expects of constructions liable to threaten the existence of entire communities. The upper bank was bound to collapse as a result of the slightest alteration to its precarious balance".

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Case History - Stava tailings dam failure, near Trento, Italy

- According to the subsequent inquiries, the collapse was caused by the chronic instability of the dams, especially in the upper one, which were below the minimum factor of safety required to avoid collapses. In particular, the causes of instability were found to be as follows:
- deposited slime had not settled for the following reasons:
- the marshy nature of the soil on which the dams were built, where it was impossible for the mud to settle;
- the bank of the upper basin was not built correctly, and therefore made drainage very difficult;
- the upper basin was built very close to the lower one: as the bank continued to grow, it began to spread to the unsettled slime in the lower basin;
- this made drainage more difficult and stability more precarious;
- excessive height and inclination of the dams:
- the bank of the upper basin measured 34 metres in height;
- inclination reached 80 per cent, in other words a 40° angle;
- the tailings dams were built on a slope whose average inclination was approximately 25 per cent;
- the decision to enlarge the bank according to the "upstream" method, which was the quickest and most inexpensive, but also the most dangerous;
- the drainage pipes were installed incorrectly (on the basin beds and through the banks).

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Case History - Los Frailes, Spain

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Case History - Los Frailes, Spain

- Minas de Aznalcóllar is located near the town of Aznalcóllar in southwestern Spain and approximately 40 km west of the large city of Sevilla (Figure 1). It is within the Iberian Pyrite Belt which has a well known mining district for at least a few millennia. The minesite is drained by the Agrio and then Guadiamar Rivers. This river system extends to the south-southwest, under a road bridge near the town of Sanlúcar la Mayor, and into Doñana National Park.
- The Aznalcóllar orebody was discovered in 1956 and brought into production 1979 by Andaluza de Piritas, S.A. (Apirsa) owned by Banco Central S.A. (Eptisa, 1998). Boliden purchased Apirsa in 1987. A second orebody, named Los Frailes with more than 70x106 t of ore, was then discovered and will be mined shortly.
- The tailings impoundment at the minesite is roughly rectangular in shape (Figure 2). The east and west sides are approximately 2 km long and the north and south sides are roughly 1 km long, enclosing 200 ha. Waste-rock dams are located on the north, east, and south sides, with a maximum height of 27 m. There is also a internal east-west dike which separates the "pyrite pond" section (specific weight of 4.8 with a 45 m average grain size) in the south from the "pyroclastic pond" section (specific weight of 3.0 with a 450 m average grain size) in the north (Eptisa, 1998).

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Case History - Los Frailes, Spain

- The Failure
- Just before 1 AM on April 25, 1998, a power line near the dam toe had failed, signaling the start of the dam failure (Eptisa, 1998). Around 3 AM, an electrician inspecting the line noticed cracks in the dam crest and only a little ponded water in the pyroclastic section of the impoundment, indicating most of the tailings outflow occurred before 3 AM. A staff gauge near Sanlúcar la Mayor (Figures 1, 3, and 4) reported the peak water level at 3:30 AM. Outflow from the impoundment stopped around 8 AM, and the level at the downstream staff gauge fell until 6 PM when normal levels were attained.
- The release of tailings solids and water occurred through a breach in the eastern side of the impoundment, at the southeast corner of the pyroclastic section (Figures 5 and 6). This was initiated by a failure in the dam along the pyrite section just to the south, which resulted in a 700-m-long section of dam, alluvium, and marl moving as much as 67 m laterally to the east with a maximum reduction in dam-crest elevation of 2.4 m. The breach was later enlarged by the water and solids flowing through it.
- An estimated 1.5x106 m3 of tailings solids and 5.5x106 m3 of acidic tailings water (pH 2-4) were eventually lost (Eptisa, 1998). Approximately 0.3x106 m3 of the solids were deposited upstream of, and near, the dam breach, and the remainder flowed downstream into the Agrio and Guadiamar Rivers, covering 3500 ha of agricultural land (Robinson and Freeman, 1998). The thickness of lost tailings reached approximately 4 m near the minesite (Sassoon, 1998). The loss of tailings from the pyrite section was attributed primarily to liquefaction, whereas the pyroclastic-section loss was primarily from tailings-water erosion.

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Case History - Los Frailes, Spain

- The Cause of Failure

- The 25-m-high dam rests on roughly 4 m of river-terrace alluvium (Figure 7), which is underlain by 70 m of blue marl (composed of roughly 25% carbonate). At a depth of approximately 10 m into the marl, overstressing of the marl beyond its peak strength by construction-induced pore pressures allowed the dam, alluvium, and shallow marl to slide along a near-horizontal bedding plane to the east (Eptisa, 1998). This resulted in liquefaction of the pyrite tailings, which in turn increased the loading on the dam as the foundation resistance was decreasing. These processes account for the 60 m horizontal displacement of the dam, which is considered unusually high. Other factors like earthquakes, blasting, acidic drainage, and seepage of groundwater have been ruled out as contributors to the dam failure.

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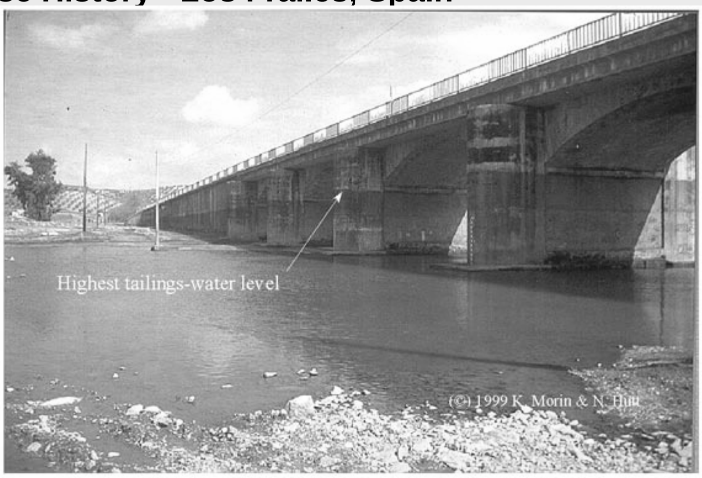
Case History - Los Frailes, Spain



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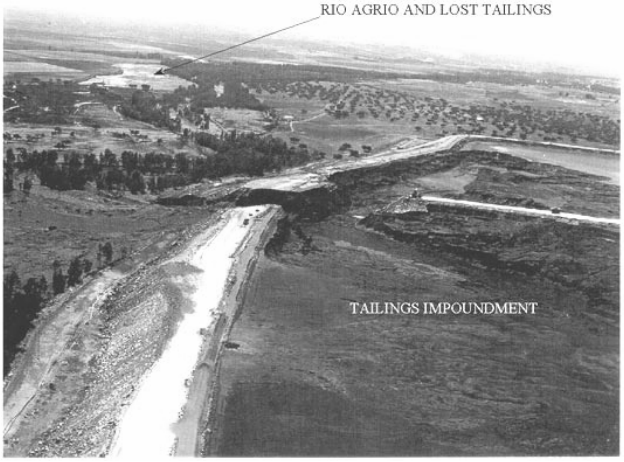

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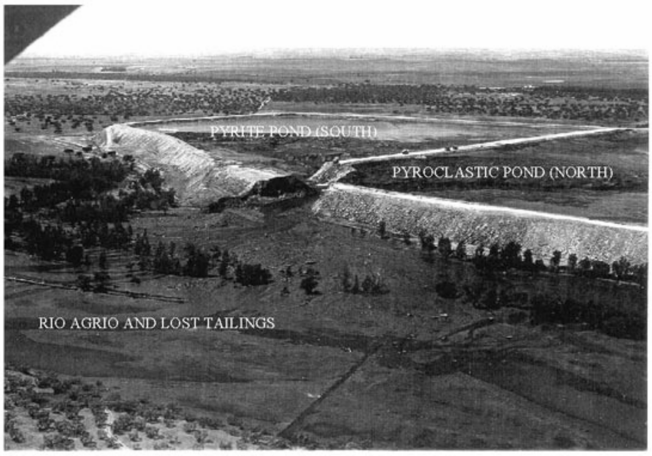

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Staged Construction of Tailings Dams

Staged Construction of Tailings Dams

Ranger Tailings Dam

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History of Development

- STAGE I – RL36 – Completed in 1980
- STAGE II – RL39 – Completed in 1983
- STAGE III – RL41 – Completed in 1985
- STAGE IV – RL 44.5 – Completed in 1990.
- STAGE VA – RL 47.5 – (Stage A of the Stage V lift) Completed in 2006
- STAGE VB – RL 51.0 – (Stage B of the Stage V lift) Completed in 2007

Each stage takes about 1.500,000 cu.m of soil and rock fill

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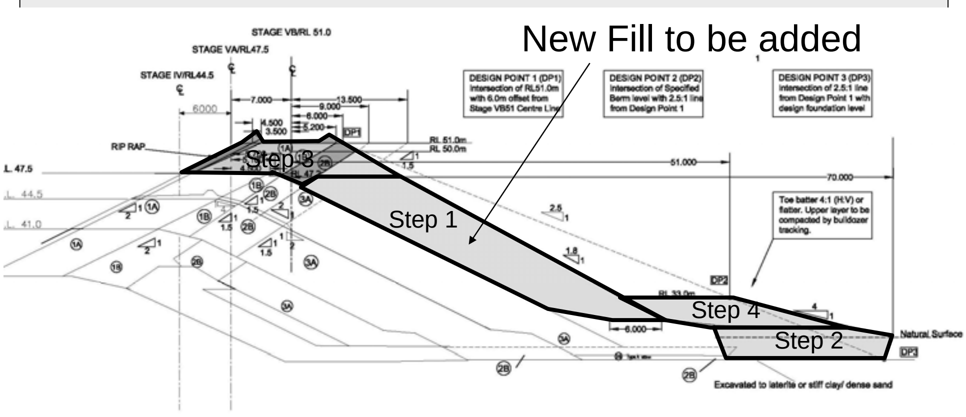
Typical Cross Section – Stage VB / RL51



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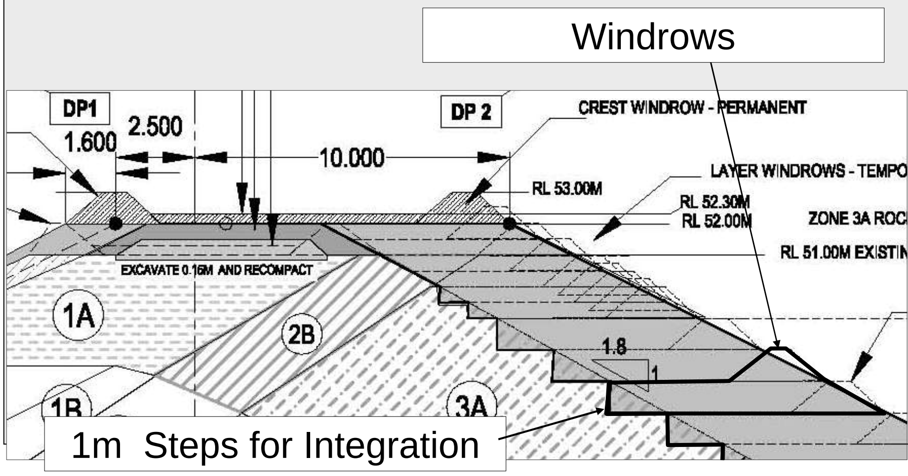
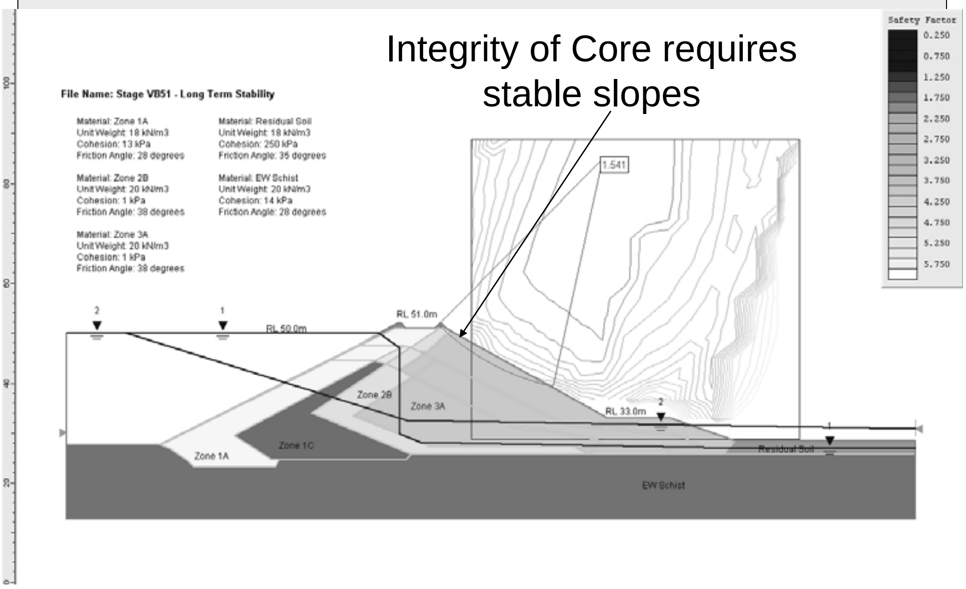
Embankment Integration and Windrows - Detail



Embankment Stability

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29/06/2007


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30/07/2007


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