

# Gördes Dam – A Turkish Delight

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*Gördes Dam is a nickel and cobalt mine tailings dam situated in a seismically active zone in Manisa Province, Western Turkey. The dam is a conventional cross valley earthfill structure with a fully lined storage basin. The starter embankment with a maximum height of 50 m will be raised in downstream lifts to an ultimate height of 90 m. The total storage capacity is 19 million m<sup>3</sup>. Construction of the starter embankment is planned to commence in late 2012 and the dam will be commissioned in June 2013.*

*The tailings will be discharged from the dam crest and return water will be collected by a floating decant pump at the opposite site of the storage. Decant water has high calcium sulphate levels and will require treatment before re-use in the plant or release. The tailings contain about 33 % of solids and are classified as high plasticity silts and clays with more than 90 % of particles passing the 0.075 mm sieve.*

*The dam is founded on a complex formation of altered sedimentary and metamorphic rocks including mudstones, siltstones, limestones and serpentines. The mudstone blocks, the predominant foundation materials, are juxtaposed with siltstones and serpentines via a complex arrangement of faults. Where exposed, the mudstones are highly to completely weathered with a well-developed structure of smooth bedding surfaces leading to anisotropic strength characteristics. Several landslides, likely associated with the anisotropic character of the mudstones, were identified within the area including a significant landslide under the upstream shoulder of the dam.*

*Mining development in Turkey has a complex legislative environment. There is also standard practice which is not legislated but expected, this can be considerably different to normal design practice in Australia. The Turkish legislation is based on waste management guidelines and may be more appropriate to landfills than large tailings storages. The legislation is very prescriptive in some aspects and silent in others, with little consideration of risk or consequence based design.*

*This paper discusses the design difficulties associated with the challenging foundation conditions, which have been magnified by the requirements and limitations embedded in the approval documentation and the legislative environment in Turkey. It will also address some of the key differences between the design philosophy in Australia and in Turkey with a focus on the major risk elements of the design.*

Keywords: Tailings, Turkey, Liner, HDPE, Nickel laterite

## Introduction

Gördes Lateritic Nickel Mine site is located in Manisa Province, Western Turkey near the town of Gördes, as shown in Figure 1. The mine is owned by Meta Nikel Kobalt a.s. (Meta), a private Turkish company who are financially backed by another private Turkish company.

Since 2003, ore from the mine has been exported for processing in Greece, Macedonia and China. However, in 2008 the Meta Board made a decision to develop an on-site process plant and the exportation of ore was put on hold. The scope of the new process plant includes a tailings dam, known as the Waste Storage Facility (WSF), for the deposition of the metallic nickel and cobalt production waste. The WSF will be constructed in stages and Meta aims to begin construction in 2012 with the first stage completed by mid-2013.

Meta engaged GHD in 2011 to provide design services for the WSF. At that time an Environmental Impact Assessment (Encon 2010) had been approved by the

Government. The EIA included a concept level Planning Report for the WSF (Hidromark 2009).

As noted throughout this paper, GHD came across many differences in approach between legislation and normal practice in Turkey and Australian practice. The design followed the following documentation in order of preference:

- Turkish legislation if specific on the design aspect (Ministry of Environment and Urban Planning 2010 and 2011)
- ANCOLD (2012) Tailings Guidelines were followed if they did not clash with Turkish legislation (2011 draft of guidelines was adopted).
- Turkish practice as recommended by local consultants.
- European Commission (2009) was referred to but is more a description of current practice

rather than specific guidelines and provided limited value.

Often there appeared to be a significant difference in perception of risk associated with dams. This produced a challenging environment as described in this paper.

## Waste Storage Facility

The WSF design criteria were based on the EIA approval and Meta preferred not to modify these during detailed design as this would require re-submission of the EIA. The key parameters were:

- deposition of 1,300,000 tonnes per year of tailings for a 25 year mine life.
- The tailings are delivered to the WSF in a slurry at between 30 % to 35% solids content, further thickening of tailings was not considered feasible because the recovered process water would require significant treatment before re-use.
- The final WSF limited to a maximum crest elevation equivalent to a final height of approximately 90 m and maximum storage capacity of 25 million m<sup>3</sup>.
- The site was identified in the EIA and could not be changed without resubmission. As can be seen in Figure 2, the selected site, being in a steep valley, would suit a large dam but introduced complexity for

this fully lined storage requiring considerable excavation and trimming for the lined area (plan area of 600,000 m<sup>2</sup> for the final storage).

The dam will be constructed in four stages by a downstream construction method using material excavated from the storage area for the initial stages and open pit overburden for later stages. The staging is summarized in Table 1 below. The final crest elevation governed by the EIA became the controlling factor in the design and limited the actual storage capacity and WSF operation life to only 15 years. Table 1 demonstrates that the WSF site is not an efficient storage site with ultimately 6.1 million cubic metres of fill required for the dam to store 15.7 million cubic metres of tailings.

**Table 1 Proposed Embankment Staging**

Stage	Total Tailings Deposition*(Million m <sup>3</sup> )	Incremental Embankment Volume (Million m <sup>3</sup> )	Dam Height (m)
1	1.9	1.1	55
2	6.8	1.6	69
3	12.9	1.7	81
4	15.7	1.7	90

\*Tailings volume excluding water.



**Figure 1 – Site Location Map**



**Figure 2 – Waste Storage Facility Site**

## Foundation Conditions

The proposed site is within the Erdemircay Formation of Upper Cretaceous age. The Erdemircay Formation is an ophiolitic melange which was thrust over Jurassic and Triassic metamorphic sedimentary rocks (autochthonous units) as the Tethys Ocean closed in the Early Tertiary.

Geological mapping identified fault-bound blocks of mudstone in the valley floor and on significant areas of the eastern valley slopes (right abutment). The mudstone blocks are juxtaposed next to siltstones and serpentinites via a complex arrangement of faults. Localised areas of limestone were also encountered. Boreholes confirmed that the weathering associated with shear zones extends to great depth with zones of completely weathered mudstone found more than 40 m below surface.

The geotechnical investigation was managed by a local Consultant. GHD provided input into the investigation locations and suggested a laboratory testing regime. The quality of geotechnical investigation was less than would be expected in Australia. Drilling was with double tube rotary drilling rather than triple tube which resulted in significant core loss in the weathered foundations. Laboratory testing equipment and procedures were limited, with laboratories unable to do triaxial strength testing on the typically gravelly clay residual materials and unreliable results obtained from direct shear tests. This meant that much of the design was based on engineer and geologist judgment with levels of redundancy built into critical design items. An Engineering Geologist from GHD spent 10 days on site during the design phase carrying out mapping and characterization of the foundations.

Typically the upper foundations (4 m to 6 m below surface) comprised residual soils and completely weathered material before reaching variable moderately to highly weathered rock. The embankment will be constructed on the weathered rock foundations after stripping the low strength residual soils and completely weathered material.

The mudstones are generally very thinly bedded, with medium to high strength beds separated by very low strength interbeds / bedding surfaces that were often observed to be smooth or polished. The mudstones have very anisotropic strength properties. The shear strength is very low when sheared in the direction of the laminations, while shearing across the laminations returns comparatively higher strength parameters. There is no clear bedding orientation because the site has undergone extensive tectonic movement.

A range of stability analyses were carried out considering the possible range of anisotropic strength and bedding direction to determine acceptable excavation slopes and high risk bedding plane orientations within the mudstones. Careful geological mapping will be required during excavations to manage the risks related to the anisotropic properties of mudstones.

A large zone of colluvial material associated with an old landslide was identified in the left abutment of the Stage 1 dam, upstream of the dam crest. This colluvium was estimated to extend to a depth of about 20 m and it was not considered feasible to remove this entire zone. The colluvium is predominantly highly to completely weathered serpentinite rock overlying comparatively weaker mudstones, which appeared to have been sheared along the weak bedding surface. The serpentinite within the slide mass is likely to be of similar strength to the surrounding highly weathered rock. The implications of leaving the colluvial zone within the foundations are:

- Reduced stability of the embankment and excavations due to the presence of a relic slide surface. The upstream face of the embankment was flattened to 3H:1V to meet the required factors of safety compared with slopes of 2.5H:1V which would be possible if the colluvium were removed.
- Increased settlement may occur, this is likely during construction with most settlements completed before installation of the upstream liner. The outlet pipework in the foundation of the dam was aligned to avoid the colluvium to avoid potential damage to the pipes;

- Development of excess pore pressures within the foundation during construction if the colluvium is saturated. As one borehole near the toe of the colluvium was observed to produce artesian water during winter, the development of excess pore pressure was considered a real risk. A foundation blanket filter was provided to assist with draining this zone.

## Lateritic Nickel Tailings

The ore is processed on site in a High Pressure Acid Leach (HPAL) hydro-metallurgical process which includes high amounts of sulphuric acid and subsequent lime neutralization. The outputs are a liquid concentrate of nickel and cobalt product, with the tailings consisting of the waste solids and water. The tailings were described by laboratory staff as a 'sticky red sludge'. Geochemical testing of tailings from a pilot plant study was carried out by SGS Laboratories in Canada. The geochemical tests determined that the tailings are not acid generating but they do contain high concentrations of sulphate in the order of 20,000 mg/l and moderate concentrations of chromium.

The tailings are classified as 'Hazardous' according to Turkish legislative guidelines (RHWC 2005), due to the high sulphate content in the tailings solids and decant water.

Geotechnical testing of tailings samples was carried out during the detailed design by SGS Canada. The geotechnical properties of the tailings, determined from this testing, are:

- tailings are a high plasticity clay material (CH) with 92 % passing the 0.075 mm sieve, liquid limit of 73 % and plasticity index of 45 %.
- Column settling tests showed a very slow rate of settling and low settled density. After 19 days, the tested tailings settled from an initial dry density of 0.41 g/cm<sup>3</sup> to 0.50 g/cm<sup>3</sup> and the tailings unit weight increased from 1.28 g/m<sup>3</sup> to 1.34 g/m<sup>3</sup>.
- A second column settling test was carried out where a flocculent was added to the tailings to replicate the residual flocculent in the tailings due to thickening in the hydromet process (no additional thickening was proposed). The effect of the flocculent was to accelerate the tailings settlement however the final settled density was similar to the unflocculated settled density.
- Rheology tests were undertaken for unflocculated and flocculated tailings samples using a Haake RS75 Rheometer. The samples were tested after mixing the flocculent, and then again after 3 minutes of "shearing" (to replicate pump and pipe flow and the potential breakdown of flocculated material). At 34% solids content the Yield Stress of the sheared samples ranged from 29 Pa to 20 Pa for unflocculated and flocculated samples respectively and the Plastic Viscosity similarly varied from 11 mPa.s to 7 mPa.s.
- A standard oedometer consolidation test was conducted on a settled sample of tailings. The specific

gravity of the tailings was determined to be 3.2 t/m<sup>3</sup>. The sample was consolidated from the initial void ratio of 5.488 at atmospheric pressure to a void ratio of 1.147 under the maximum consolidation pressure of 1,250 kPa. The final dry density of the sample after consolidation was 1.45 t/m<sup>3</sup>.

The average depth of tailings in the Stage 1 reservoir would be approximately 16.5 m, which, based on the oedometer testing corresponds to a tailings dry density after primary consolidation of 1.17 t/m<sup>3</sup>. Tailings will not be fully consolidated at the end of stage 1, as Cv determined from the consolidation test was 0.001 cm<sup>2</sup>/s. An average consolidated dry density of 1.15 t/m<sup>3</sup> was adopted for design, this will be monitored during operations to confirm the ultimate storage capacity.

## Legislative Environment

Mining development in Turkey has a complex legislative environment, of which GHD have learned a little during the design process, often finding information later than we should have. There is also standard practice which is not legislated but expected, this can be considerably different to normal design practice in Australia. The general regulatory environment is described here and some of the challenges to the design are discussed in the following sections.

The government department, the General Directorate of State Hydraulic Works (DSHW), is responsible for water dam design and construction activities in Turkey. They also provide standard specifications for dam construction which are adopted throughout the industry. Until recently they were responsible for tailings dams but this has now passed to another authority as noted below. However, they do still review some aspects including hydrology and hydraulics.

The Turkish Ministry of Environment and Urban Planning General Directorate of Environmental Management (the Ministry) have recently become responsible for approvals of mine waste management activities. GHD believes that in this process, mine wastes became characterised under the 2010 'Regulation of Landfilling', in other words tailings dams are considered as landfills which has introduced some requirements which may not be appropriate to all tailings dams.

By their own admission, the Ministry are inexperienced in major mining developments and they do not have sufficient current technical knowledge. The Gördes WSF will be the largest tailings dam in Turkey by a considerable amount.

The Ministry began a process of staff exchanges with European countries. They were also very interested to speak with Australian engineers and GHD are assisting by introducing AusTrade staff to the ministry with the aim of arranging a secondment of staff to Australian regulatory authorities. GHD have also provided a copy of the ANCOLD (2012) tailings guidelines to the Ministry and presented to them on the current state of practice in Australia for tailings dam design and operations. The Ministry are interested in updating their legislation. However, early in the design process, GHD and Meta met

with the Ministry to discuss the design criteria and potential alternative design options which GHD considered more appropriate to this site. Following a presentation to the Ministry, they declared that as this was the largest tailings dam to be built in Turkey, they were not willing to approve any aspects which did not comply with existing legislation and practice in Turkey.

The WSF detailed design prepared by GHD was submitted to the Ministry for approval. A detailed design may only be submitted to the Ministry by an approved engineering company, which GHD are not as yet. Meta engaged an approved local consultant, EKASU, to work with GHD in the design and submit the final design drawings and documentation as a joint submission. EKASU's roles on the project included:

- Hydrology and hydraulics including diversion drain design as these needed to comply with DSHW requirements.
- Review of GHD's design to confirm it complied with Turkish legislation and normal practice.
- Design of the storage area liner system to comply with legislation and locally available materials.

After submission of the design to the Ministry, another approved consultant was engaged to review the submission. This consultant becomes the Ministry's Engineer and after approving the design becomes responsible for monitoring the construction to ensure compliance with the approved design. This is a significant deviation from Australian practice where the owner maintains control over construction activities and only reports to authorities as required by approvals.

## Technical Requirements

### Consequence Assessment

In early discussions with the Ministry and Meta, GHD advised that it is standard practice in many countries to determine the consequence category of a dam to inform design decisions based on consequences of failure. GHD were advised that whilst Turkish legislation for dams categorises water dams as either high or low hazard, there is no such legislation for tailings dams. Both the Ministry and Meta were pleased to adopt ANCOLD guidelines for consequence assessment, although later design decisions (eg. design earthquake event) were generally based on Turkish legislative requirements rather than the consequence category. The dam consequence category

was assessed by GHD to be High A based on a population at risk of approximately 120 and a medium to major severity of downstream impacts.

### Seepage Control and Liner

Turkish legislation (Ministry of Environment and Urban Planning 2010 and 2011) for tailings dams containing 'hazardous' waste requires that the storage area including lateral (side) slopes be lined with a composite liner and drainage system as described below. The required arrangement is shown in Figure 3. The floor of the storage was defined as the valley floor, approximately 70m wide, which had generally low slopes and could be trimmed to a near horizontal surface for lining. The storage side slopes were then the much steeper valley slopes above this, typically sloping at between 2H:1V to 4H:1V with localised small cliffs and steep gully features.

### Floor of Storage Area

For the floor of the storage (from top down):

- The drainage system between tailings and liner comprises a 250mm thick layer of sand to protect the HDPE liner then drainage gravel (500 mm thick), with a 250 mm thick layer of sand above to prevent the tailings washing into the gravel. A system of herringbone drains are placed in the drainage gravel to collect the seepage and convey it towards the embankment. A discharge pipe leading through the foundation of the embankment will convey the collected seepage into a sump downstream of the dam. A pump system will then pump the seepage water back into the WSF.
- A composite impermeable liner. The Concept Design (Hidromark 2009) provided a 5.0 mm thick HDPE liner over 0.5 m of clay in accordance with Turkish legislation at that time. After much negotiation, the Ministry agreed that 5.0 mm thick HDPE was impractical and accepted a modification to a 2.0 mm HDPE liner over a geosynthetic clay liner (GCL) placed on the top of a 0.5 m thick clay liner, ie. a 3 layer impermeable liner.
- An under drainage system to divert groundwater consisting of 0.2 m sand layers sandwiching a 0.5 m thick gravel drain. Some boreholes identified perched groundwater associated with flow in shear zones forming gullies at the site. During winter some of these perched aquifers were fully charged

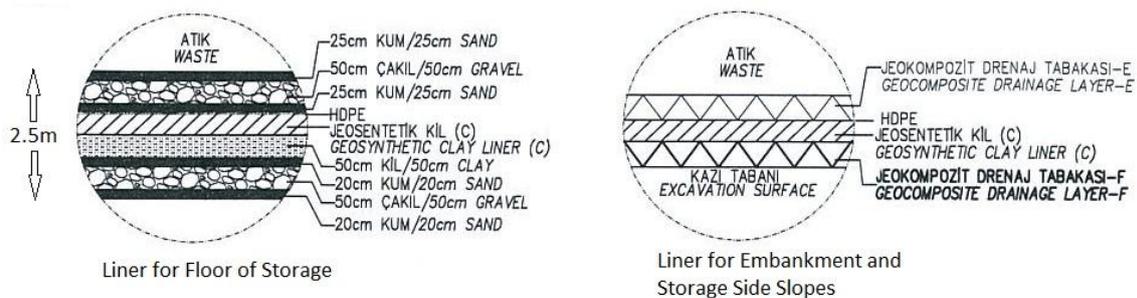


Figure 3 – Composite Drainage and Liner for Storage Area

(groundwater was flowing out of standpipes), and hence, the under drainage system was considered appropriate to avoid uplift of the impermeable liner.

As can be seen in Figure 3, this arrangement results in a 2.5 m thick composite drainage and liner system over the floor of the storage area. It seems that the Turkish legislation is considerably more conservative than normal Australian practice in this respect with 'zero tolerance' for seepage as described by a local engineer.

### Side Slopes

For the entire side slopes of the storage including the upstream face of the dam embankment (from top down):

- A geocomposite drainage system;
- A minimum 2.0 mm thick HDPE liner;
- An appropriate second liner, this may be a geosynthetic clay liner (GCL) or 0.5m compacted clay liner; and
- An under drainage system to divert groundwater. This consists of drains in the floor of natural water courses (gullies) as groundwater was observed to only be associated with the sheared zones in these areas.

GHD demonstrated that the WSF site has a natural blanket of low permeability soils overlying fractured rock which is generally low permeability. Permanent groundwater was only encountered in one of four deep bores drilled near the WSF site, and this was first encountered at a depth of 60 m in what was inferred to be discontinuous fractured rock aquifer. Localised perched groundwater was observed during geotechnical drilling associated with fault controlled high permeability zones in valleys, but this did not appear to link with the deeper groundwater system. Hence, it was considered a very low risk that seepage from the WSF could contaminate an underlying body of groundwater. However, discussions with the Ministry confirmed that the composite liner was a non-negotiable requirement.

### Storage Area Shaping

The topography of the storage area undulates significantly with many ridges and valleys. As noted above, typical valley slopes are approximately 4H:1V to 2H:1V with localised small cliffs at rock outcrops. Provision of a liner on the slopes of the storage will require that most of the storage slopes be 'shaped' to provide smooth, even surfaces for liner installation. This 'shaping' is a major task and will involve excavations up to 10 m deep over considerable height up to 70m. It is likely that large bulldozers can be used to initially strip topsoil and organics, and then push down the weathered rock material into stockpiles for construction of the embankment. Some minor areas of hard rock excavation will be required when less weathered rock is encountered; this may require blasting or the use of rock hammers.

To avoid very extensive excavation, it was necessary to provide some areas of fill within the shaping. These fills vary from localised thin zones to large fills in deep valleys. Despite the use of fill, the total excavation required for installation of the Stage 1 liner is approximately 1.6 million cubic metres of material. This

material will be used for construction of the dam embankment, while the excess 0.5 million cubic metres will be placed in a berm at the downstream toe forming part of the Stage 2 embankment.

### Design Flood and Spillway

Turkish legislation (2010) requires that all tailings dams be designed for the 1 in 100 year Average Exceedence Probability (AEP) flood event. Diversion drains to divert the surrounding catchment must meet this flood capacity and the WSF must have sufficient freeboard to retain this rainfall event on the storage area. GHD suggested that this is an unacceptable risk for a 90 m high dam with an estimated population at risk of 120.

GHD proposed to design the WSF in accordance with the ANCOLD (2012) guidelines, requiring 1:10,000 AEP flood protection for a High A dam and that all tailings dams must have an emergency spillway. However, the Ministry directed that the WSF should not be designed to spill under "any circumstance", although the disparity between their legislated 1 in 100 year AEP flood protection and not providing facility for rarer events could not be resolved. The spillway in GHD's concept design was removed at the direction of Meta to comply with the Ministry requirements.

As an alternative to the emergency spillway, Meta directed GHD to increase the WSF freeboard to avoid overtopping the dam crest during rainfall events of up to 1:10,000 AEP. GHD advised that this approach imposes greater risk than the inclusion of an emergency spillway as the freeboard maintenance depends solely on the WSF operations. An operational error can compromise the freeboard and the dam crest may be overtopped during events with much greater probability of occurrence than the designed 1:10,000 AEP. Meta were made aware of this risk.

### Water Management Philosophy

A water balance for the WSF based on average annual conditions showed that during full operation an excess of 1.7 million m<sup>3</sup> of decant water and rainfall would accumulate in the WSF each year.

The decant water quality is not appropriate for downstream releases without treatment. Therefore it was proposed to provide a water reclaim system to remove excess water from the storage. Recycling of the excess water to the process plant is preferred; however the high levels of calcium, magnesium and sulphate in the water would cause significant problems with the plant operation. Treatment of this water to a level suitable for re-use in the plant or disposal downstream requires almost drinking water quality and means a reverse-osmosis or similar process at very high cost. Evaporation in ponds was considered, however the estimated costs were higher even than a water treatment plant due to the relatively low evaporation rates at the site. As there is likely to be a shortage of fresh water when the plant is in full operation, a water treatment plant was considered the preferred option.

To defer upfront capital costs, Meta has decided to delay commissioning of a water treatment plant until the end of the second year of operations. The effect of this decision can be seen in Figure 4, which summarises the WSF filling schedule. The figure plots the top level of both tailings and water so that when the water level plots above the tailings level, the tailings are all submerged; while when the tailings top level is higher, there is a beach of deposited tailings and supernatant pond away from the embankment. As can be seen in Figure 4, when the stage 1 storage limit is reached, the water depth over the top of tailings will be almost 15m, and the tailings remain submerged, ie. sub-aqueous deposition, until mid-way through Stage 3 of the storage life. This has the following implications on the WSF operation:

- The WSF must store both tailings and water, requiring a significantly larger storage volume for Stage 1 than in the EIA and an associated greater volume for the Stage 1 dam.
- The tailings will be deposited underwater, therefore they may have a lower initial density and may

consolidate to a lower final density than sub-aerial tailings.

- The Turkish legislation requires a dry cover for the completed dam, it may take considerable time for the sub-aqueous deposited tailings to consolidate sufficiently for construction of the cover.

Water will always be in contact with the drainage system above the storage liner. If unrestrained, this drainage system will then run at full capacity taking water from the storage to the downstream sump for pumping back into the reservoir in a continual loop. A valve is required at the end of the outlet pipe and this valve will be closed during the initial stage until sufficient quantity of tailings have been deposited to prevent direct contact of free water with the drainage system. The drainage system was provided as it is a legislated requirement, but it is unlikely to be useful. This demonstrates that the legislated requirements of the “Guidelines on Landfilling” (2010) are not appropriate for all tailings dam arrangements.

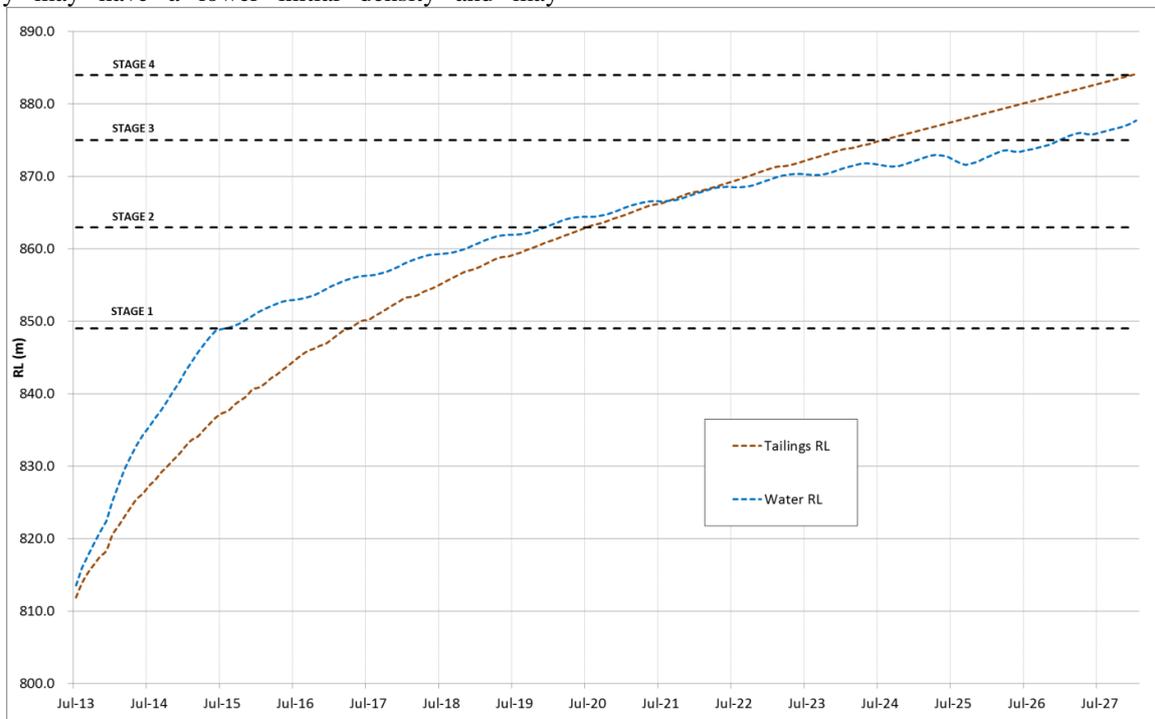


Figure 4 WSF Filling Schedule and Embankment Staging

### Embankment Arrangement and Zoning

The starter (i.e. Stage 1) embankment will be constructed from earth and rockfill materials excavated from the storage area. The dam will be raised in 3 downstream lifts to an ultimate height of 90 m. The typical cross section of the embankment is shown in Figure 5.

A vertical 2.0 m thick filter zone (Zone 2A) will be placed in the centre of the stage 1 cross section, downstream of the low permeability earthfill material. Embankment raises have an inclined filter. It is considered very unlikely that any seepage will occur through the

composite storage area liner, however, it was considered a potential risk that an extreme event such as a major earthquake could result in a rupture of the liner. This chimney filter is provided as an additional line of defence if such an event should occur and is considered appropriate for a High A hazard dam. The inclusion of a filter was problematic to Turkish authorities because of the perception that seepage must be expected if a filter is required, GHD argued repeatedly for the inclusion of a filter and it was eventually accepted.

Beneath the downstream shoulder of the embankment, a horizontal sandwich blanket filter (sand filter zones either

side of a gravel drain) will be placed. This is provided to collect and drain any groundwater within the foundation to avoid saturation of the downstream fill and prevent washing out of fine particles from the foundation materials.

Stability analyses were carried out in accordance with Turkish guidelines as advised by EKASU, these are generally in line with international practice except for seismic loading. A seismic hazard assessment (Hidromark 2009) confirmed the site to be in the highest seismic hazard zone in Turkey. The ‘Maximum Credible Earthquake’ was assessed as a 0.18 g event corresponding with approximately a 1 in 500 year ARI event according to probabilistic methods. Turkish guidelines require that this event be applied to both the post operations and end of construction cases in a pseudo-static analysis. While it seemed onerous to adopt the MCE for the end of construction case, the ARI of the MCE also seems low for the post operations case. In addition to complying with the Turkish requirements, GHD adopted the 1:10,000ARI event of 0.44g and carried out a deformation analysis of the final embankment post operations case to ensure the high hazard dam could withstand this event.

## Conclusions

The design of the Gordes Waste Storage Facility had several technical challenges as well as identifying significant disparities between current practices in Australia with those in Turkey.

The complex geological conditions and high seismicity of the region were compounded by a lack of reliable geotechnical investigation results. Extensive foundation characterisation was carried out by an Engineering Geologist to produce a geological model considering the uncertainties. A range of redundancies were introduced into the design to account for the geological risk.

The lateritic nickel tailings are fine grained high plasticity clays with a very low settled density. The density will be lowered further by the sub-aqueous deposition in the first 7-8 years of operation. This has resulted in a significantly reduced storage operating life compared with the original expectations.

Turkish legislation for tailings dams poses a range of challenges for designers, this appears to be due to the recent decision to characterise tailings dams under the same legislation as landfills. Tailings dam design in Turkey is a rigid approach based on legislated requirements rather than a risk based approach adopted in Australia. It seems that this approach has produced a significant unbalance in risk of various aspects of tailings

dam design. Particular examples include:

- The design flood event for all tailings dams is legislated as the 100 year ARI event (MEUP 2010), which leaves a considerable risk of overtopping. Spillways for flood events are not permitted for dams storing hazardous waste and GHD are concerned that water management has been largely ignored in Turkish practice, instead focusing on a no-release / no-seepage requirement.
- Tailings dams storing waste characterized as ‘hazardous’ in Turkey must have a composite HDPE and clay liner with over and under-drainage systems, which is typical of a landfill. The requirement for a fully lined impoundment resulted in a very high cost and complex construction for the storage facility, with limited risk reduction for the extra cost.
- Some other aspects of legislation and practice in Turkey are very prescriptive and do not allow design flexibility to focus on major risks. For example, the diversion drains must be designed for a 100 year ARI event even though the Stage 1 diversion drain is only in place for 2 years.

The Turkish Ministry have recognised their legislation is not in line with current international practice and are trying to improve their knowledge through links to other countries including Australia. They were very pleased to receive a copy of the new ANCOLD (2012) tailings guidelines.

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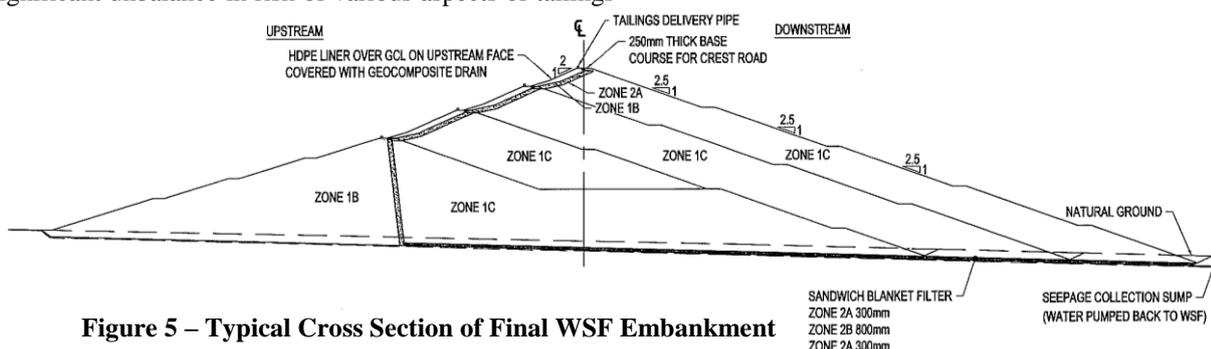


Figure 5 – Typical Cross Section of Final WSF Embankment