APEX MINING CO., INC.
Masara, Maco, Davao de Oro

CERTIFICATION INTERNATIONAL
ISO 9001:2015
ISO 14001:2015
ISO 45001:2018

isri

Sangilo Mine, Itogon, Benguet
ISO 14001:2015 (Environmental Management System)-certified by TUV Rheinland.

MODIFIED DRY STACK TAILINGS (*mDST*)

An Alternative Concept of Tailings Disposal and Management

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Objectives and Rationale – The challenges of synergy between mining and environment is a balance in constant flux, needing of "endurance and innovation" to prosper the sustainability of development.

- **Objectives**
  - To develop and promote alternative tailings disposal and management system other than conventional slurry tailings dam.
  - To give some background on Dry Stack Tailings (DST) where this Modified Dry Stack Tailings (mDST) was derived.
  - To complement current slurry dams with possible additional pondage.
  - Pursue and encourage additional research on sustainability and innovation.
- **Rationale**
  - The basic philosophy of DST or mDST is **"Dewatering"** the slurry tails by **"Filtration"** to separate the solid particles from the liquid medium of tails transport.
  - This can be achieved in many ways like Thickening, Filter Press, Flocculation-Dewatering Filtration, HydroCyclones.
  - The Modified Dry Stack Tailings (mDST) is basically a **"gravity filtration**" from **"upper pervious dam"** draining naturally into a **"lower impervious dam"** as main Polishing Pond, and with a Toe Drain secondary Polishing Pond.

Methods of Tailings Disposal – Phil. Setting

- Convention Slurry Tails Disposal in Engineered Dams: w/ or w/o Flocs and Thickening: Almost all Mines, Old and New
  - Serves also as Reservoir for Mill Process Return Water

- Dry Stack Tailings (DST):   None except Didipio
  - Dry Stack Tailings w/ Paste Fill Plant: Didipio-Oceana Gold
  - Flocculation-Thickening-Dewatering-Filtration Techniques

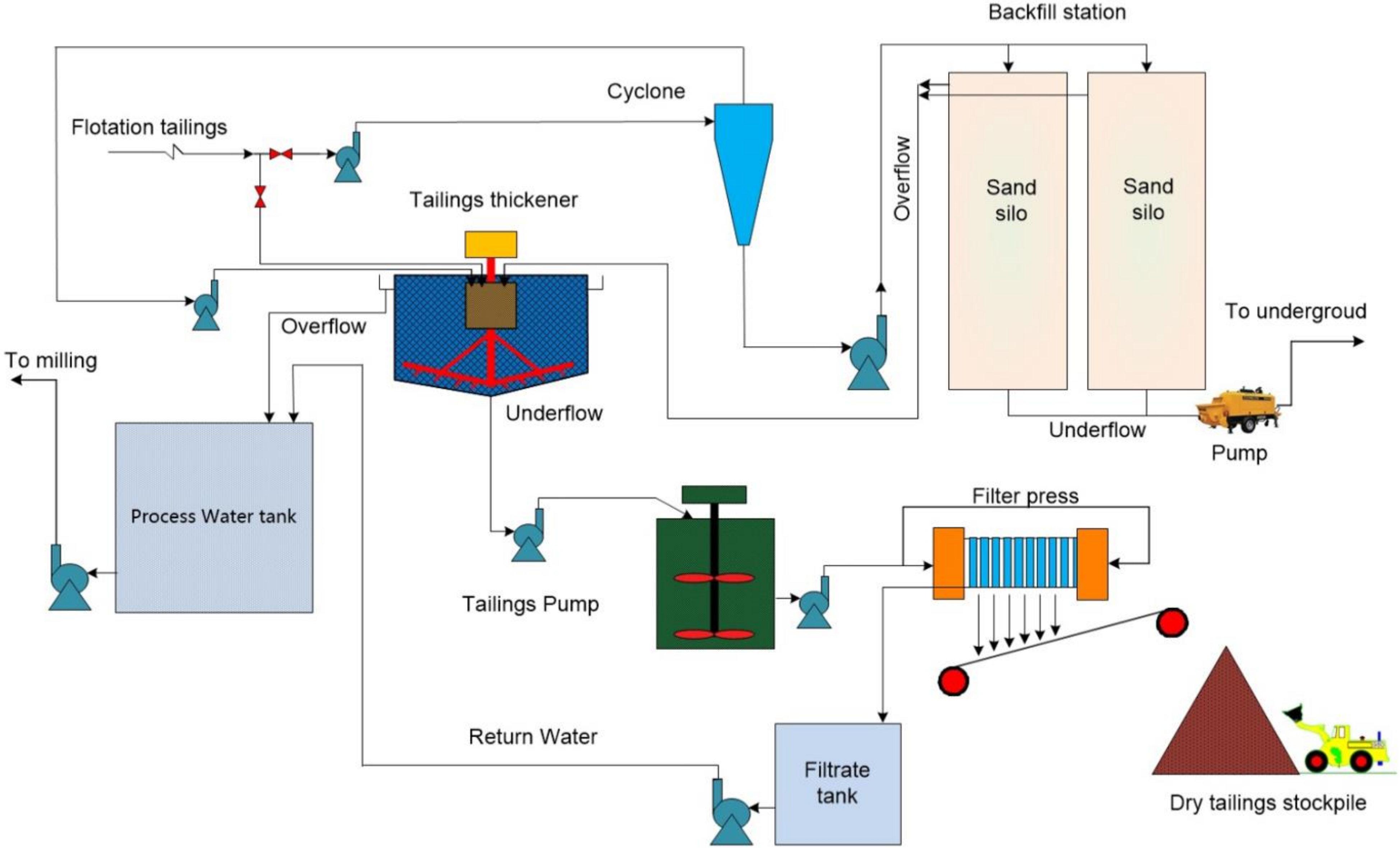
- Modified Dry Stack Tailings (*mDST*) w/ or w/o Paste Fill Plant: R & D of Apex Mines and ISRI w/ EHMC, In Progress

Dry Stack Tailings (DST) Development and Constraints

- Practiced and accepted in Australia, US, Canada and other countries as early as start of 21st century particularly when water resource is scarce, or cost of water is high for Hydromet Process like in arid regions. Not generally used in areas of high precipitation.
- Generally practiced in areas of low precipitation and in conjunction with Paste Fill for underground support in mine out areas and doubling as tails disposal.
- The need to thicken the tails and separate the fines and coarse particles where the fines are placed somewhere else (co-disposal) and the coarse particles added to Paste Fill. Seldom is the filter cake mixed outright to produce a Paste Fill. The fines are disposed somewhere else.
- High Initial Capital Cost with Thickeners, Filter Press, Water Tank, etc.
- Dry Stack Tailings still need a reservoir, either for the filter cake, or for the leachate.
- Much of the local operating mines are old mines established before the 21st century and younger ones were put on stream at the start of the 21st century where Dry Stack Tailings was still developing.
- Probably, constrained by the initial cost and the lack of information on this technology and a general assumption that this is not favorable in the Philippines because of climatic conditions in relation to economic viability (a function of metal prices) of the project where a phased construction is afforded in the conventional dam, and initial capital cost is only for the starter dam.

Typical Dry Stack Tailings (DST) Set-Up

(Extract from EHMC paper presented in 66th PMSEA, 2019) by JFB Sanchez and HB Cardenas

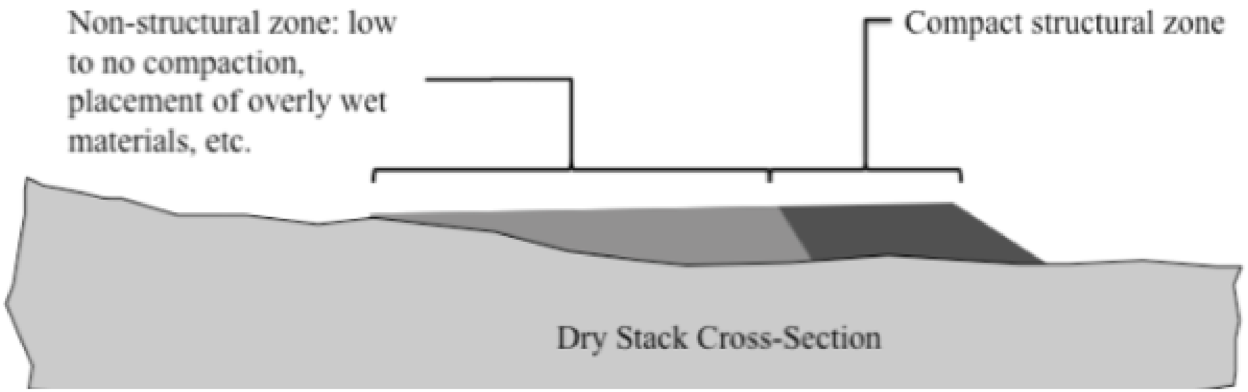


DST Design Considerations

(Extract from Paper of J Lupo and J Hall,
AMEC, Earth and Environmental, Englewood, CO, USA)

DESIGN CONSIDERATIONS FOR DRY STACK TAILINGS (DST)

1	**General Approach**	Balance between material handling and construction with geotechnical properties of filter cake
		Transport and Deposition of the filter cake to facility, either conveyor or truck haulage
		Function of site topography and distance from Filter Plant in relation to tailings properties
		Must consider provisions to handle overly wet tailings should upset conditions occur in the Filter Plant
		Placement and compaction/blending of the filter cake will also need to cater to variable moisture content
2	**Stacking Height**	Stability of Stacked Tailings
		Function of Shear Strength
		Saturation and Surface Water/Groundwater Infiltration
		Seismic Loading and Residual Strength
3	**Stacking Rate**	Stability of Stacked Tailings
4	**Infiltration and Surface Water Management**	Stability of Stacked Tailings
5	**Geotechnical Considerations**	
5a	Particle Sizing	Generally, finer tails require more cost and effort
5b	Shear Strength of Filter Cake	Affects transport/handling, and when used as embankment
5c	Hydraulic Conductivity	Has Bearing on internal Drain and Storm Drain within Pond
5d	Compressibility	Has Bearing on Stacking Rate and Height of Stack
5e	Seating Foundations	Overall Stability of Stacked Tailings



Thickener and Filter Type for Dry Stack Tailings

(Extract from EHMC paper presented in 66th PMSEA, 2019) by JFB Sanchez and HB Cardenas

Thickener Type	Feedwell & Flocculation	Underflow Yield Stress	Avg Tank Slope	Torque
Conventional	Non-Diluting	< 50 Pa	2°- 3°	K <50
Hi-Rate	Diluting	< 50 Pa	2°- 3°	K <50
Hi-Density	Diluting	75 – 100 Pa	8°- 14°	K <125
Paste	Diluting	125 – 175 Pa	30°- 45°	K >200

$\text{TORQUE} = K * \text{Diameter}^2$

Filter Type	Largest Size	Highest production capacity per filter (MTPD)	Applicable for Clays	Flocculant needed	Typical Filter Cake Moisture Concentration, (wt%)
Vaccum Filter	300 m²	7,200	No	Maybe	20 - 25
Centrifuge	350 kw	1,500	Yes	Yes	20 - 35
Belt Press	4 m wide	1,500	Yes	Yes	25 - 35
Filter Press	2,080 m²	20,000	Yes	Not usually	10 - 25

Typical Slurries, Thickeners and Filter Cakes

Typical slurry concentrations for copper tailings

State of copper tailings	Typical solids concentration
Unthickened tailings slurry ex concentrator	20–25% w/w
High rate thickener underflow	50–58% w/w
High density / high compression thickener underflow	57–68% w/w
Paste thickener underflow	60–71% w/w
Cake from vacuum filter	77–82% w/w
Cake from filter press	80–85% w/w

*TG Fittion and A Roshdieh, Filtered Tailings vs Thicknened Slurry,: four Case Studies, Australian Centre for Geomechanics, Perth, 2013

Table 2 Summary of thickener performance

Type of Thickener	Nature of Feed Tailings	Nature of Thickened Tailings	Application Environment
Conventional thickeners	Low concentration mill tails	Less than 50% solids	Conventional tailings disposal
High rate thickeners	Low concentration mill tails, partially classified tails or cyclone overflow	Less than 55% solids	Conventional tailings disposal or before filtration for cake
High compression	Low concentration mill tails, partially classified tails or cyclone overflow	Less than 70% solids	Thickened tailings disposal
Steep Cone Thickeners	Low concentration mill tails, partially classified tails or cyclone overflow	Less than 75% solids	Thickened tailings disposal or for mine filling
PPSM	Low concentration mill tails, partially classified tails or cyclone overflow	Less than 75% solids	Thickened tailings disposal or for mine filling

**K. Kuganathan and AG Grice, State-of-the-Art in Paste Fill Technology in Mining Industry – A Funtional Review

Filter Type	Nature of Feed Tails	Filter Cake Consistency	Application
Vacuum Belt Filter	Thickened full tails, partially or fully classified tails	80-85% solids	Paste fill making
Vacuum Disc Filter	Thickened full tails, partially or fully classified tails	80-85% solids	Paste fill making
Vacuum Drum Filters	Thickened full tails, partially or fully classified tails	70-80% solids	Concentrate filtration or paste fill making

**K. Kuganathan and AG Grice, State-of-the-Art in Paste Fill Technology in Mining Industry – A Funtional Review

Apex Field Experimental Laboratory Simulation of *mDS*T and Proposed Actual Field Trial(s)

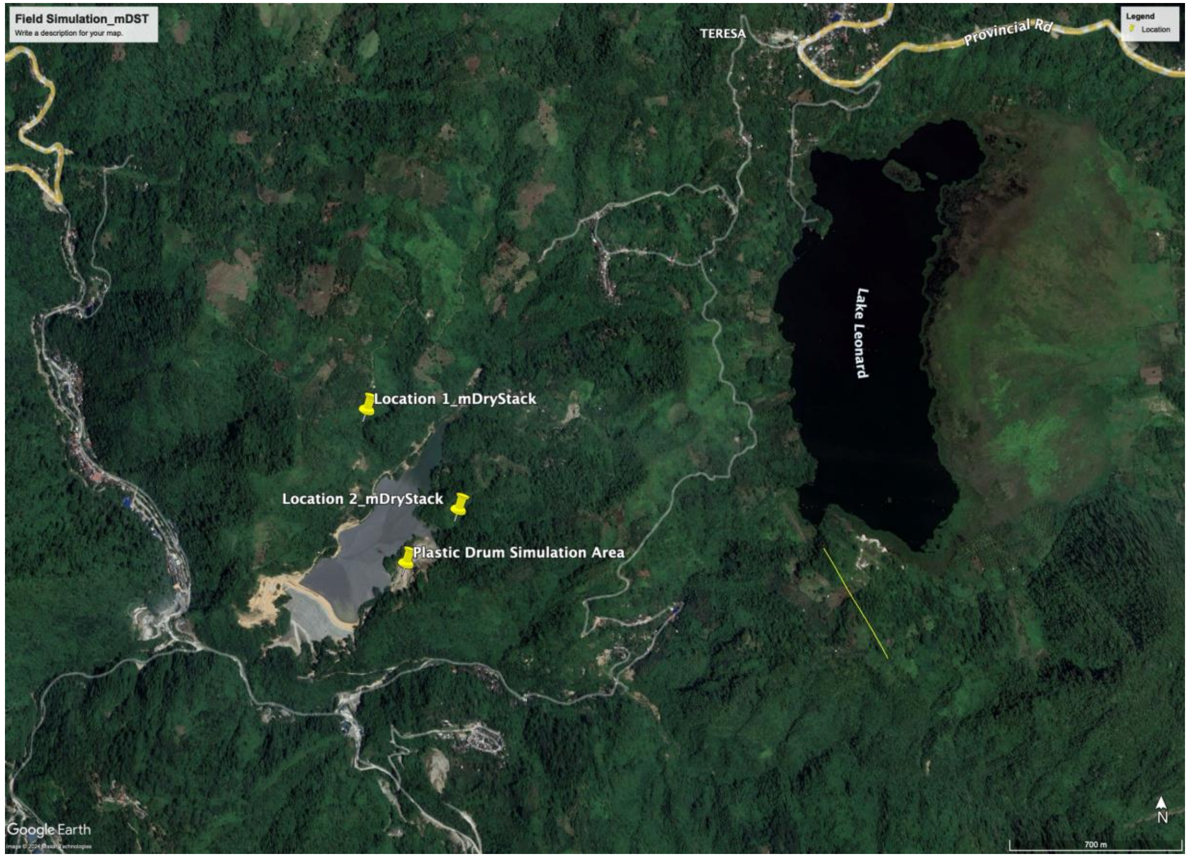


Photo Documentation – Apex Field Lab Simulations

EXPERIMENT # 1

Drum # 1

Drum # 2

Drum # 3

- Variable Tails Thickness, Drums 1 to 3 in Increasing Thickness of Tails
- Variable Water Head Cover, Drum 1 to 3 in Decreasing Head

PHOTO DOCUMENTATION – EXPERIMENT # 2

Start of Experiment

Plastic Drum # 1 with 26-cm Head of Tails H_2O

Plastic Drum # 2 with 15-cm Head of Tails H_2O

Plastic Drum # 3 with 10-cm Head of Tails H_2O

- Constant Tails Thickness
- Variable Water Head

PHOTO DOCUMENTATION - EXPERIMENT # 3

Drum Full of Water Till Brim	After 3rd Day
 Plastic Drum #1	
 Plastic Drum #2	
 Plastic Drum #3	

- Constant Tails thickness
- Constant Hydrostatic head

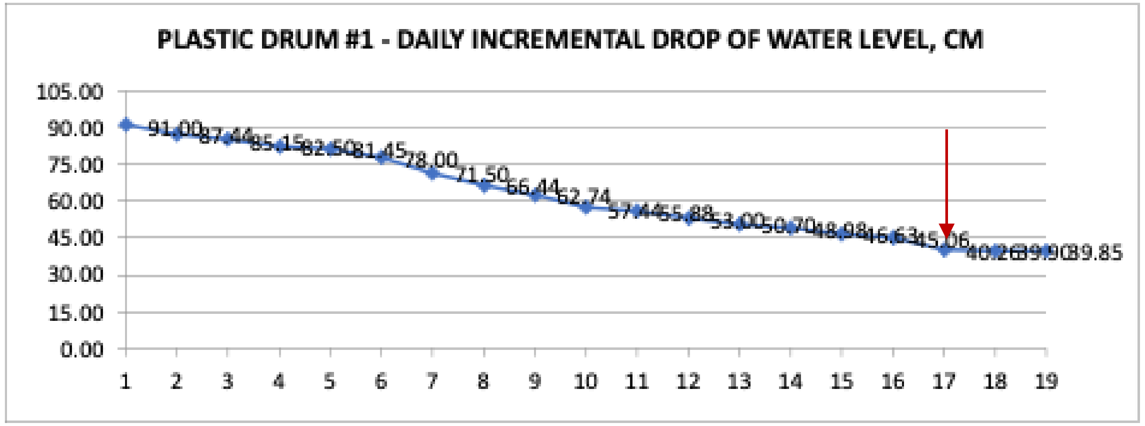
ISRI Sangilo CFRD w/ Modified Dry Stack (mDST) Experimentation within Existing Pondage (Back End)

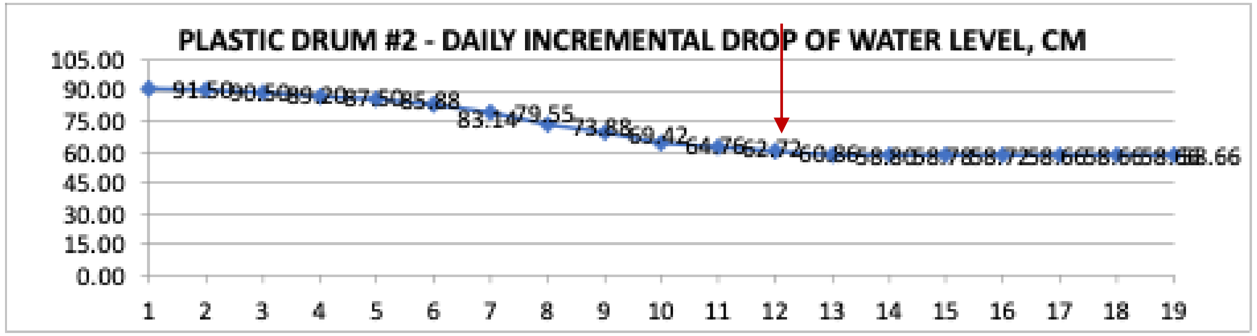
ISRI Sangilo Modified Field Experiment –Aug/Sept

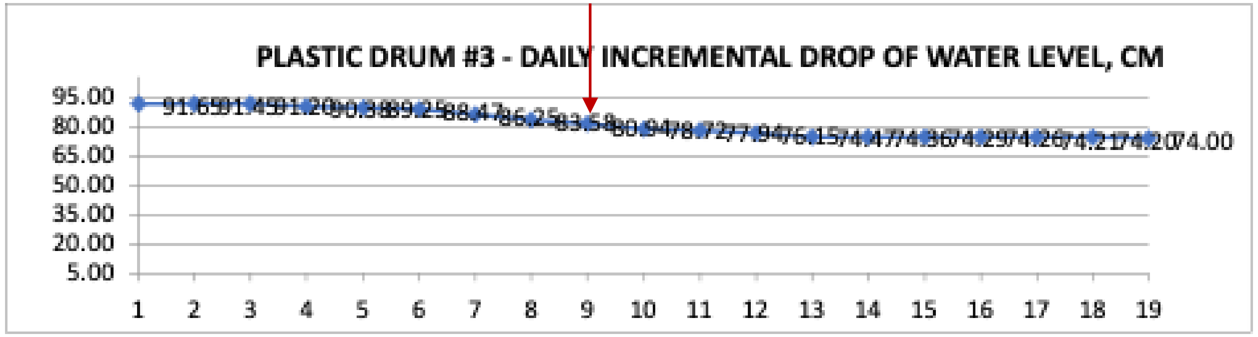
Recent Photos as of November 2024 of ISRI TSF and Experimental mDST

Data - Experiment # 1-

- Variable Tails Thickness, Drums 1 to 3 in Increasing Thickness of Tails
- Variable Water Head Cover, Drum 1 to 3 in Decreasing Head or Water Cover

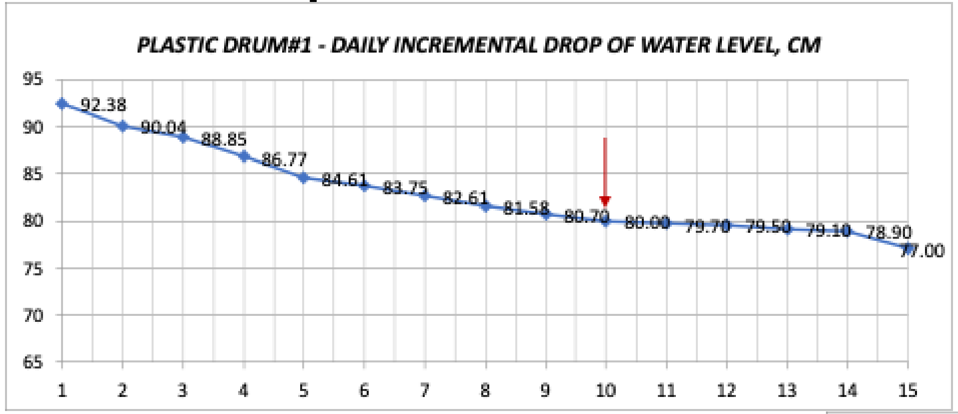


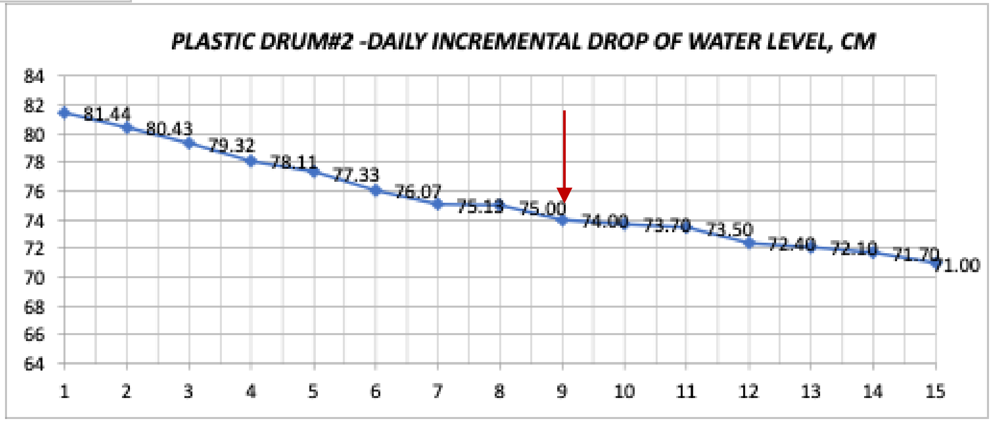


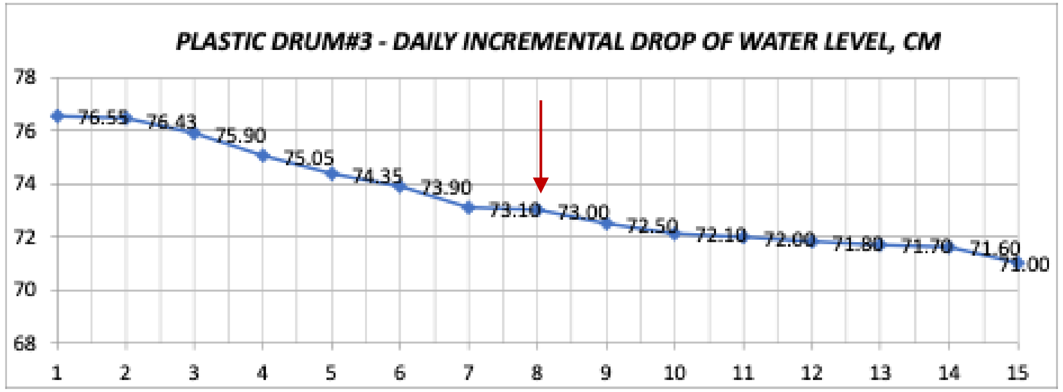


Data -Experiment # 2-

- Constant Tails Thickness
- Variable Water Head

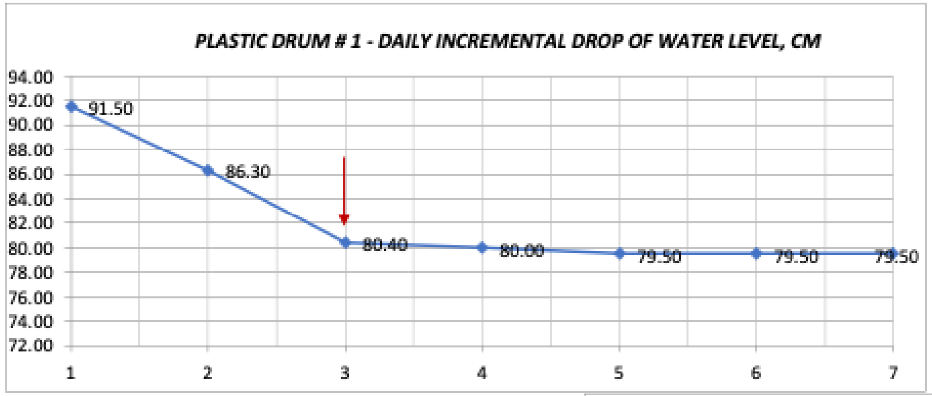


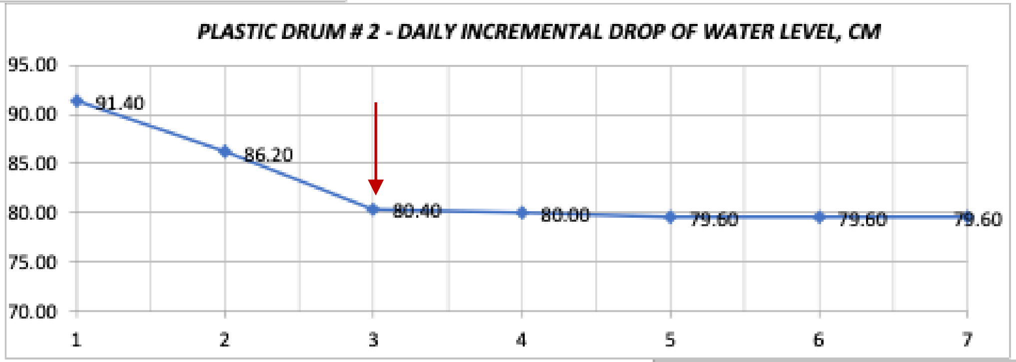


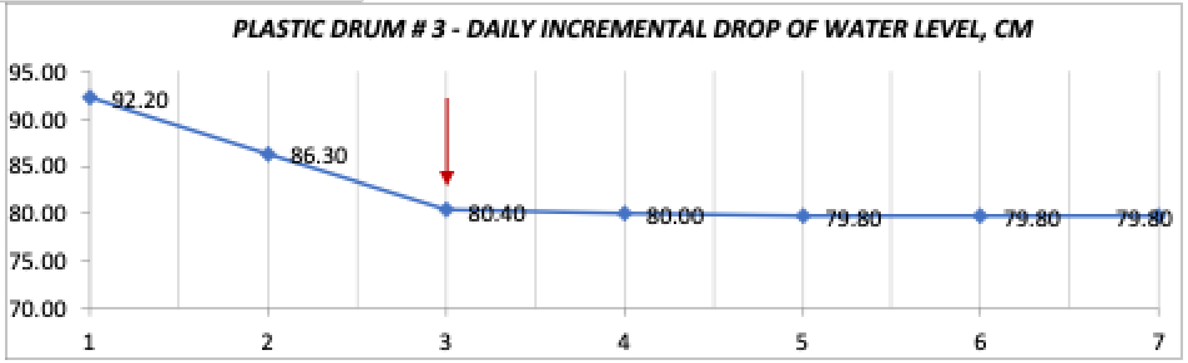


Data -Experiment # 3- :

- Constant Tails thickness
- Constant Hydrostatic head







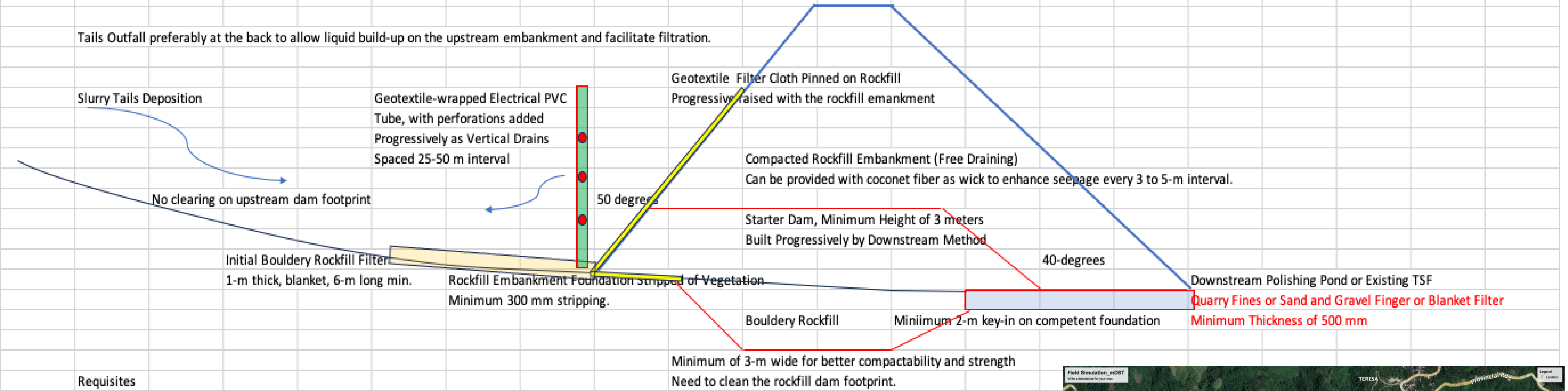
Experimental Results – Modified Dry Stack (mDST)_1

- There is uniformity of tails permeability even with insignificant variations in the mesh of grind; k- values ranging from minus 6 to minus 7 cm/sec.
- Drawdown is in the order of 2.5 to 3 cm/day which means that with thicker bed, the time for natural gravity filtration is longer.
- There seems to be a 2-stage natural filtration process: an initial that is a function of the tails permeability, and second which is part of the consolidation process, a function of the mineral grains absorption, and maybe, the pressure head. Initial drawdown rate is 2.5 to 3 cm/day with secondary consolidation of < 1.5-cm/day and diminishing value with time.
- An inference that with actual multiple tails impoundment in the same location, there is partial water-compaction and progressive consolidation with increasing water cover not possible in conventional slurry dams.

Experimental Results –Modified Dry Stack *(mDST)*_2

- The effectiveness of *mDST* is unrestrained gravity flow leachate from pervious dam to impervious dam. Both dams have to be engineered dams, but permeation is still possible as long as there exist a difference in pondage water levels. There is such thing as initial and secondary gravity drain.
- In the secondary gravity drain for full consolidation, the water content of the tails could be a bit higher than from true *DST* by filter press or mechanical dewatering), but not much of disparity.
- It is possible that the gravity-filtered tails can be fully drained in summer for Types 1 and 3 Coronas climate classification but could be difficult for Types 2 or 4. Low to moderate seismicity in the area can also help in the consolidation process for *mDST* not achievable for conventional slurry dams.
- Corollary to above, it might be necessary to have multiple cells to allow further consolidation either for additional space, and/or retrieval for other purposes like backfill, blending or paste fill.

Conceptual Design of Actual Field Trial for Apex



Requisites

1 Peripheral Drainage for Storm Diversion

2 Pumping Requirements during Extreme Precipitation or Provide Emergency Spillway

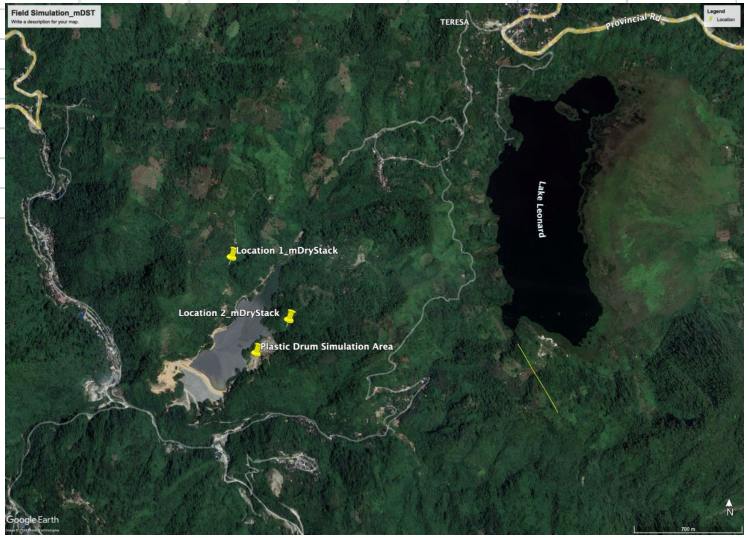
If Tails deposition is on Upstream Embankment, pumping will be at the back,

If Tails Deposition is at the back, pumping will be at the upstream embankment

3 Stability Analysis

Being a filtration process, the greatest important inter-related parameters for the design of the pervious rockfill dam are:

1. The time-dependent in-situ transient permeability of the impounded slurry tails with daily variable impounded slurry profiles as well as bed thickness on continuous milling operations.
2. The variability of mineral and grains size composition of the mill tails.
3. The climatic condition, topographic terrain and effectivity of peripheral drains.
4. The effectivity and sustainability of detox facilities.



Comparison of Pros and Cons of Diff. TSFs, (This Research)

COMPARISON OF VARIOUS TSFs: DRY STACK TAILINGS (DST), DEWATERING TECHNIQUES, CONVENTIONAL SLURRY, AND MODIFIED DRY STACK (mDST)					
Item	Requisites/Index of Comparison	Dry Stack Tailings (DST) TSF	Other Dewatering Tecnhniques	Conventional Slurry TSF	Modfied Dry Stack (mDST) TSF
1	Engineered Dam and Size (for Same Mill Throughput)	Yes/Small Dam, ++	Yes	Yes/Large Dam, +++	Yes/ Small Dam as Main Polishing Pond, +
2	Dam Design for Mill Return Requirements	Yes, ++	Yes, ++	Yes, +++	Yes, +
3	Dam Footprint	Yes, +	Yes, ++	Yes, +++	Yes, ++
4	Upstream Rockfill Dam for Gravity Filtration	None	None	None	Yes, +
5	Surface Water Diversion	Yes, ++	Yes	Yes, +++	Yes, +
6	Thickener	Yes	Yes	Yes/No	None
7	Filtration/Dewatering Process Equipment	Vaccum or Mechanical Press,+++	Yes, ++	Not Applicable	None, Gravity Filtration
8	Mill Retrun Water Pond	Yes, +	Yes	Yes, +++	Yes, +
9	Rockfill Buttress	Yes	Yes	No, Dam Stability Itself	Subsumed by Item 4
10	Stability of Dry Stack Tails (Filtered Tails)	Yes, stable, +	Yes, stable, ++	Not Applicable- Stability of TD	Yes, More Stable than Conventional , +++
11	Tails Transport	Yes	Yes	Yes	Yes
12	Staging Area, Transport, DST Plant	Yes, +++	Yes, +++	None, +	None, +
13	Ease of Recovery of Tails for Paste Fill	Yes	Yes	None	Yes
14	Detox and Secondary Polihsing Pond of Toe Drains	Yes	Yes	Yes, +++	Yes, +
15	Use of Flocculants	Yes, +++	Yes, +++	Yes/No	No, +
16	Alternative Use and Closure Operations	Yes, ++	Yes, ++	None	Yes, ++
17	Need for Toe Drain Polishing Pond	Yes, +	Yes, +	Yes, +++	Yes, ++
18	Capex/Construction Schedule	Yes, +++	Yes, ++	Yes, +++	Yes, ++
19	Opex and Maintenance	Yes, ++	Yes, +++	Yes, +	Yes, +
20	Suveillance and Monitoring	Yes, +	Yes, +	Yes, +++	Yes, ++
	Plus (+) sign indicates degree of necessity/advantage				

Research Implications

- Lower Impervious Dam Height, about 30 to 40% less compared to conventional slurry dam thus more stable and could reduce sizing of emergency/closure spillway and diversions. Rockfill pervious dams are more robust in that it is almost always fully drained unlike in zoned embankments where it is generally partially saturated
- Need for Additional Pervious Dams preferably in compartments to allow transfer from one cell to another and promote accelerated natural filtration and consolidation. Still, need for peripheral drains and water diversion.
- Filtered Tails can be retrieved for Ordinary Sandfill or Paste Fill.
- Maybe less Dam Footprint, less cost, less height of embankments, and less care and maintenance of water during and after operations to be more environment-friendly.
- Can be a policy direction for government regulations where the Dry Stack Tailings (DST) or Modified Dry Stack Tailings (mDST) TSFs have the great advantage at closure over conventional slurry dams. The mDST pervious dams can be easily covered, and the impervious dam dewatered or use for irrigation or other possible purpose.

THANK YOU

"Necessity is the Mother of Invention"

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