Making Tailings Lagoons in Critical Condition Safer

Presented by

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BRASIL IS NOT ALONE IN HAVING TAILINGS DAM FAILURES

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Event Title	Date	Location	Casualties	Description of Disaster
El Cobre Landslide	March 28th 1965	Chile	**300**	Shaking from a magnitude 7.1 earthquake caused a failure of two tailings dams at El Soldado copper mine. The resulting flow destroyed the town of El Cobre.
Mina Plakalnitsa	May 1st 1966	Bulgaria	**480+**	Tailing dam at Plakalnitsa copper mine failed. 450,000m^3 of mud and water inundated Vratsa city and the nearby village of Zgorigrad, which suffered widespread damage. The official death toll is 107, but unofficial estimate was more than 480.
Mufulira	1970	Zambia	**89**	Tailings reservoir breached and collapsed into the copper mine below it, killing 89 night shift workers.
Certej Dam Failure	Oct 30th 1971	Romania	**89**	A tailings dam built too tall collapsed, flooding Certejde Sus with toxic tailings.
Buffalo Creek Flood	Feb 26th 1972	USA	**125**	Unstable loose constructed dam created by local coal mining company collapsed in heavy rain. 1,121 injured, 507 houses destroyed, over 4,000 left homeless.
Val di Stava Dam	July 18th 1985	Italy	**268**	Poor maintenance and low margin for error in design; outlet pipes failed, leading to pressure on dam and sudden collapse. 10 people were ultimately convicted of manslaughter and other charges.
Merriespruit Tailings Dam Failure	Feb 22nd 1994	South Africa	**17**	Merriespruit tailings dam failed by overtopping after heavy rain causing a flowslide (static liquefaction) of part of the embankment (Davies 2002). Water mismanagement was to blame - causing a breach of 600,000m^3 of tailings (1.2 Million tonnes). The flow stopped 2km away in the town Merriespruit (Penman 1998; Davies 2001). 17 killed and scores of houses demolished (Fourie 2003).
Taoshi Landslide	Sept 8th 2008	China	**254+**	Iron mine tailings, formerly state owned and then in privately, collapsed into a village at 8am.
Bento Rodrigues Dam Disaster	November 05th 2015	Brasil	**19**	Iron Ore Tailings Dam mine owned by Vale SA and BHP and suffered a catastrophic failure releasing around 60 million m^3 of iron waste into the Doce River which reached the Atlantic ocean.
Brumadinho Dam Disaster	January 25th 2019	Brasil	**224**	A tailings dam at an iron ore mine operated by Vale SA suffered a catastrophic failure.
10 Global Tailings Dam Disasters			**1865 Lives lost**	

209 DAM FAILURES
Causes of Failures 1915-2016

66% = 140 Mines failed due to tailings and the dam becoming fluidised with water

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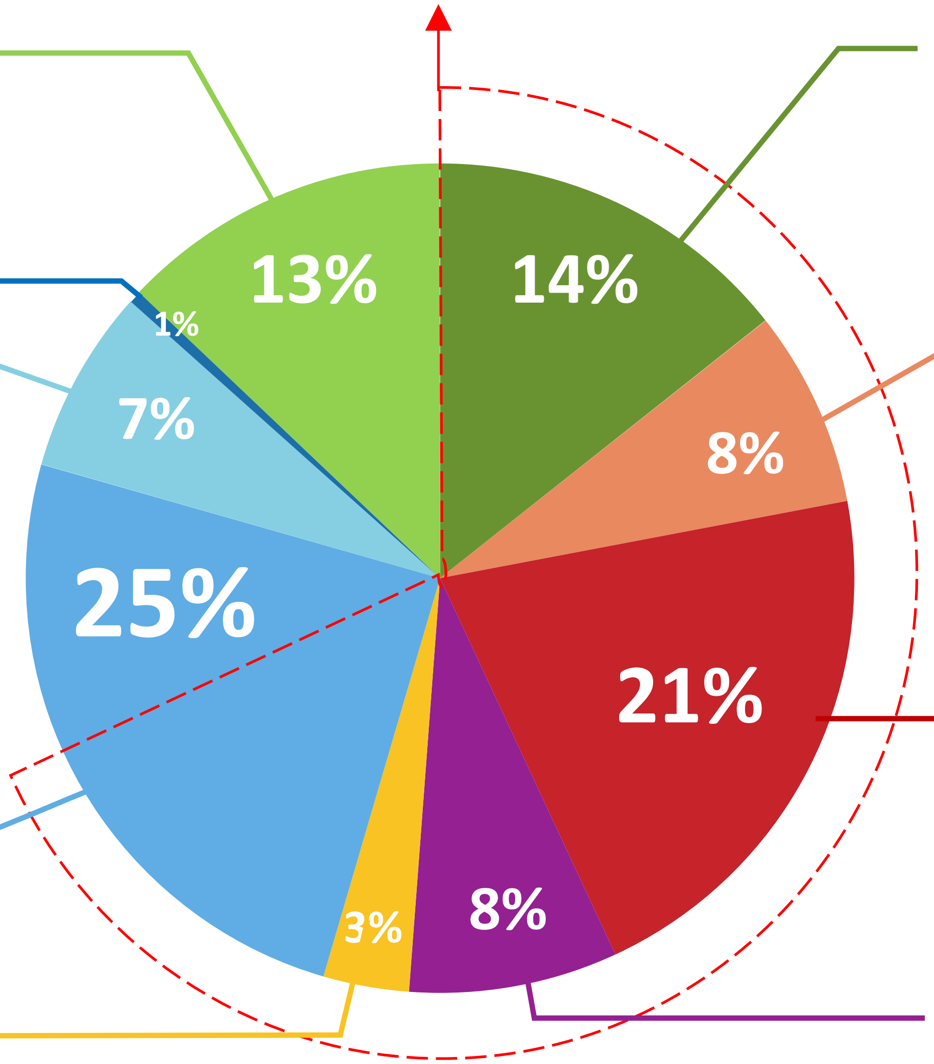


27 Earthquake - Seismic instability
Dams are designed to withstand earthquakes, but if the earthquake is larger than that which was anticipated, the structure can be destroyed by the shaking.

1 Mine Subsidence
If the dam or impoundment is built above an underground mine, collapse of the underground mine workings can lead to release of the impounded tailings.

15 Foundation
Structure and foundation conditions, foundations with insufficient investigations. Failure related to building the dam on a surface that does not provide sufficient support for the weight of the dam. An example is a layer of clay under a dam.

52 Unknown
Many older dam failures that were not sufficiently documented may fall into this category.

7 External Erosion
Simple erosion of a dam face, typically due to precipitation run off that is not repaired.

30 Slope Instability
Static failure. A constant load that causes deformation, to the point at which a dam partially or completely fails. Often caused by partial; saturation of areas of the dam that are designed to remain dry.

16 Structural
Structural inadequacies, inadequate or failed decants. Design errors or failure of a designing component to function as designed. Failed decants (which drain water from the impoundments) are a common cause.

44 Overtopping
Water flows over the top of the dam. Tailings dams are made of erodible material, and overtopping will cause erosion.

17 Seepage
Seepage and internal erosion. Erosion of dam material due to water passing through the area of the dam that are designed to remain dry.

GOODWIN SUBMERSIBLE PUMPS

High Performance for Critical Applications

Goodwin has been designing and manufacturing Submersible Slurry Pumps for over 35 years.

The heavy duty pumps are equipped with a pioneering construction enabling high performance in the most demanding environments.

Goodwin Submersible Slurry pumps are able to pump:

- Slurries at **40%** by volume solids
- Slurries at **65%** by weight solids

200 ANZE

Submersible Slurry Pump

GOODWIN PUMP JETTING RING

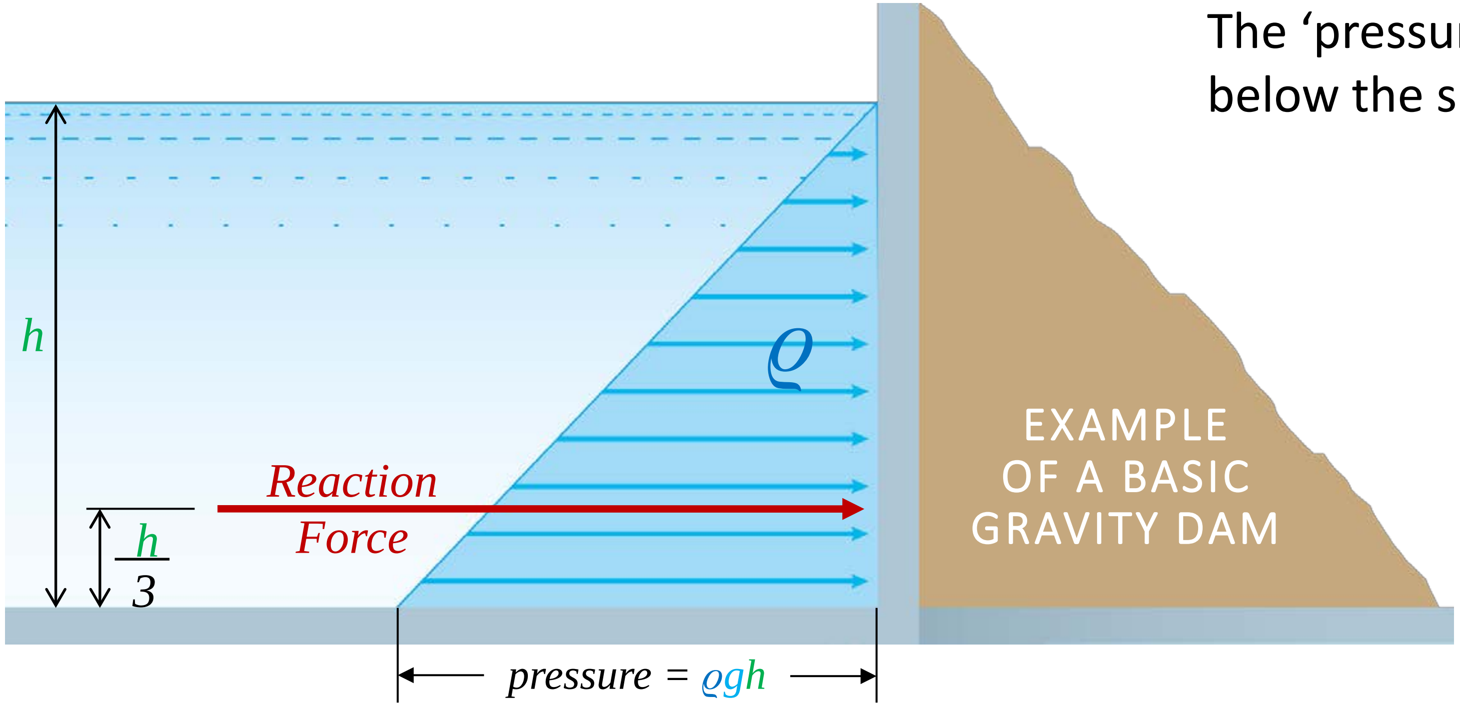
High Performance for Critical Applications

Goodwin has precision engineered a jetting ring system that can be attached on to the base of a Goodwin 200 ANZE Submersible Pump.

The jetting ring acts to disturb and reactivate settled solids to enable the material to be transferred through the pump.

The high powered jetting action created by the jetting ring can be utilised to erode tailings and assist the central agitator, so slurries with high percentage solids content are pumped.

This excavation was achieved using a just one Goodwin 200 ANZE Pump in **one calendar week**



The 'pressure' from the static fluid at a depth h below the surface is given by the expression…

$$pressure = \varrho g h$$

Where ϱ is the density of the fluid

g is the acceleration due to gravity (9.81 m/s^2)

h is the depth below the surface

The force on that acts on the dam from the liquid is defined by…

$$Reaction\ Force = \varrho w g h^2/2$$

w = width & h = Dam width

The dam is filled to a depth (h) of 50 meters and is 600 meters wide.

Dam is filled with fluidised tailings with an specific gravity of 1.35 - i.e. ϱ = 1350 kg/m^3

ϱgh = 1350 x 9.8 x 50 = 661,500 N/m^2 or 96psi

Force = $\varrho wgh^2/2$ *(pressure x area)*

Reaction Force = 661,500 x ½ x 50 (height h) x 600 (width w)

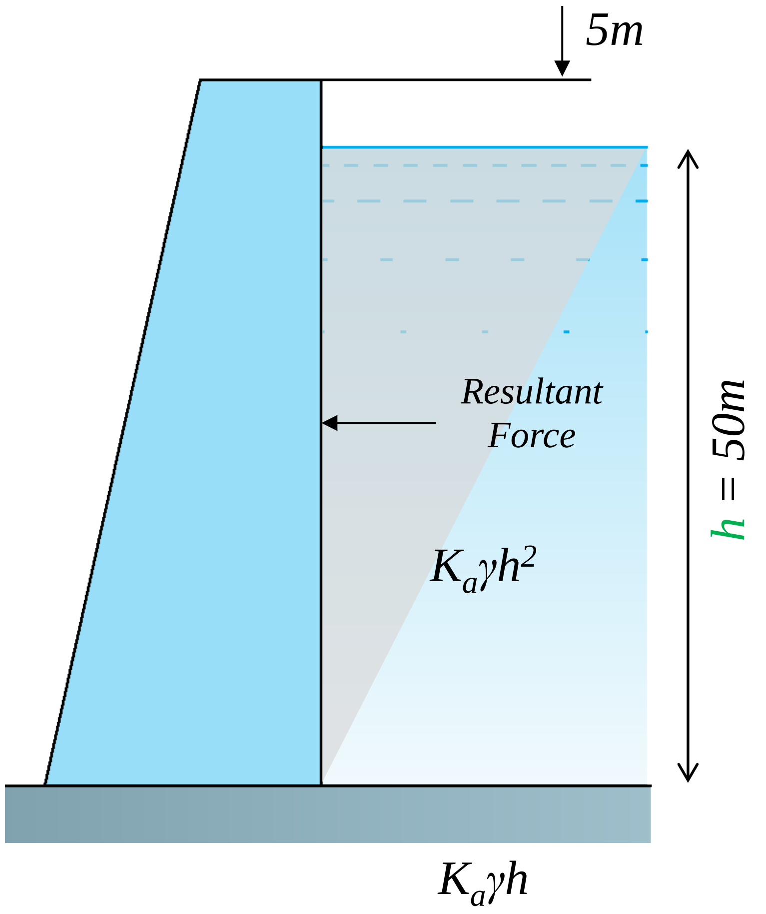
Reaction Force = **9,900 MN equating to 1 million tonne's of total force acting on the dam.**

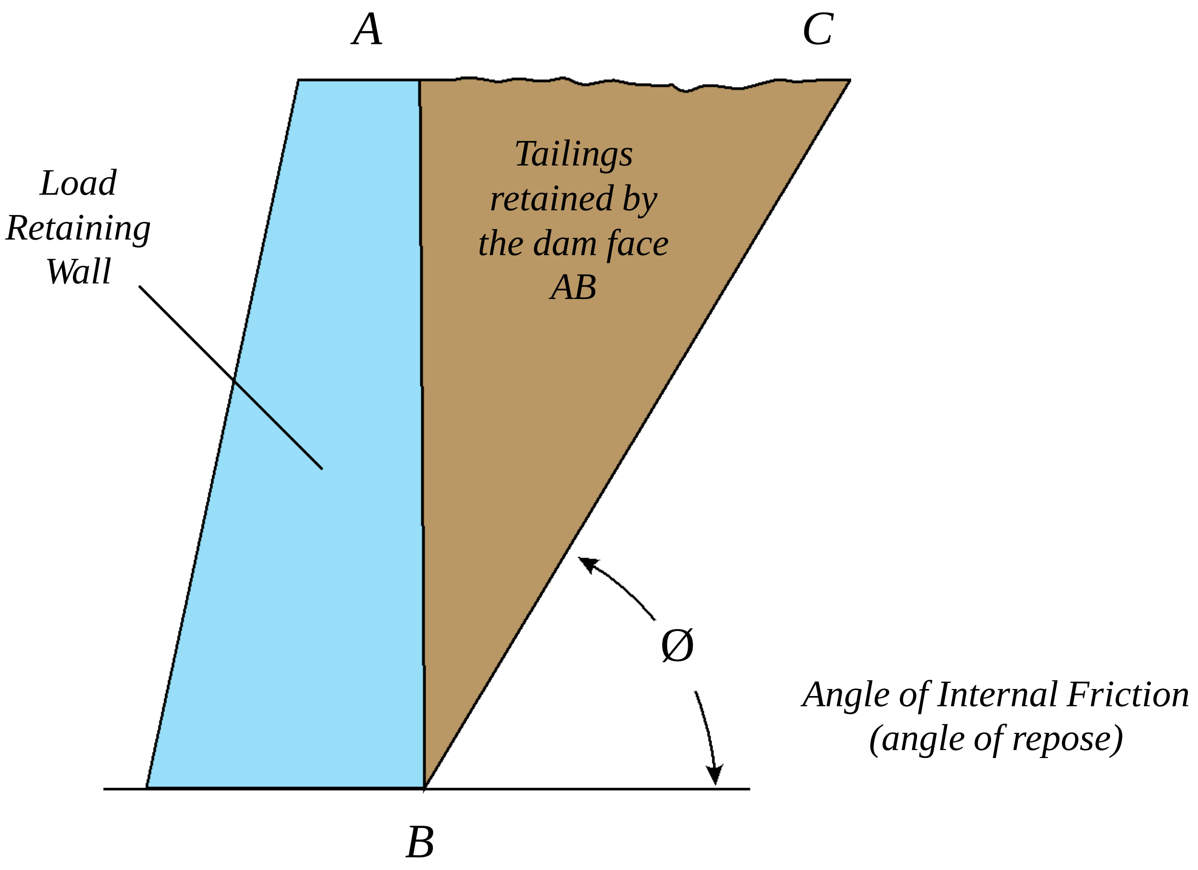
In this case the dam wall has low moisture content tailings against it.

The low moisture tailings do not act as a liquid but as a conglomerated soft solid material.

These dense tailings are very different as the structure has major self-support.

Thus the dam wall only retains the front section of the tailings. The angle of the material retained by the dam is called the Angle of repose, in this case around 60°.





A smooth vertical wall supporting a mass of tailings at rest has a lateral pressure on the wall defined by…

$$pressure = K_a \gamma h$$

Where: K_a = coefficient of dry tailing pressure. – calculated from repose angle and is typically 0.07

γ = force produced by one cubic meter of tailings (= ϱg)

Assume tailings have an s.g. of 2.65 as they are compacted over time: ϱ = 2.65 x 1000 = 2650 kg/m3 g= 9.8 m/s^2

Thus: γ is a load of 25.9 kN / m^3 or 2.64 tonnes force /m^3

Resultant horizontal pressure is: $\varrho = K_a \times \gamma\, h$

$\varrho = 0.07 \times 25.9 \times 50$ = **90.65 kN/m^2** or **13.15 lb/in^2**

$$pressure_{total} = 90650 \text{ x } ½ \text{ x height}$$

$$pressure_{total} = 90650 \text{ x } ½ \text{ x } 50 = 2{,}266 \text{ kN per meter of wall length}$$

Thus the total load on the 600 m long dam with low moisture tailings is

600 x 2266 = 1359.6 MN or **138,750 tonne force total load.**

This is only 13.7 % of the fluidised tailings loads which were over 1 million tonnes

SLURRY FLUIDISATION

Hydraulic Pressure & Heavy Rainfall

More often than not, it is the fluidisation of the slurry behind the dam that results in the full hydraulic pressure to the depth of the tailings slurry acting on the dam resulting in catastrophic failure of the Dam, especially in flat face rather than curved face dams.

Some of the “Ruptures” are caused by flood rain taking the water level in the dam to above the design limit but the mine operators have not developed adequate mechanisms of removing excess rain water from the lower part of the dam.

This excess of rain water that sits against the inner edge of the dam again, has the effect of fluidising the settled tailings slurry and also fluidising the compacted dam itself.

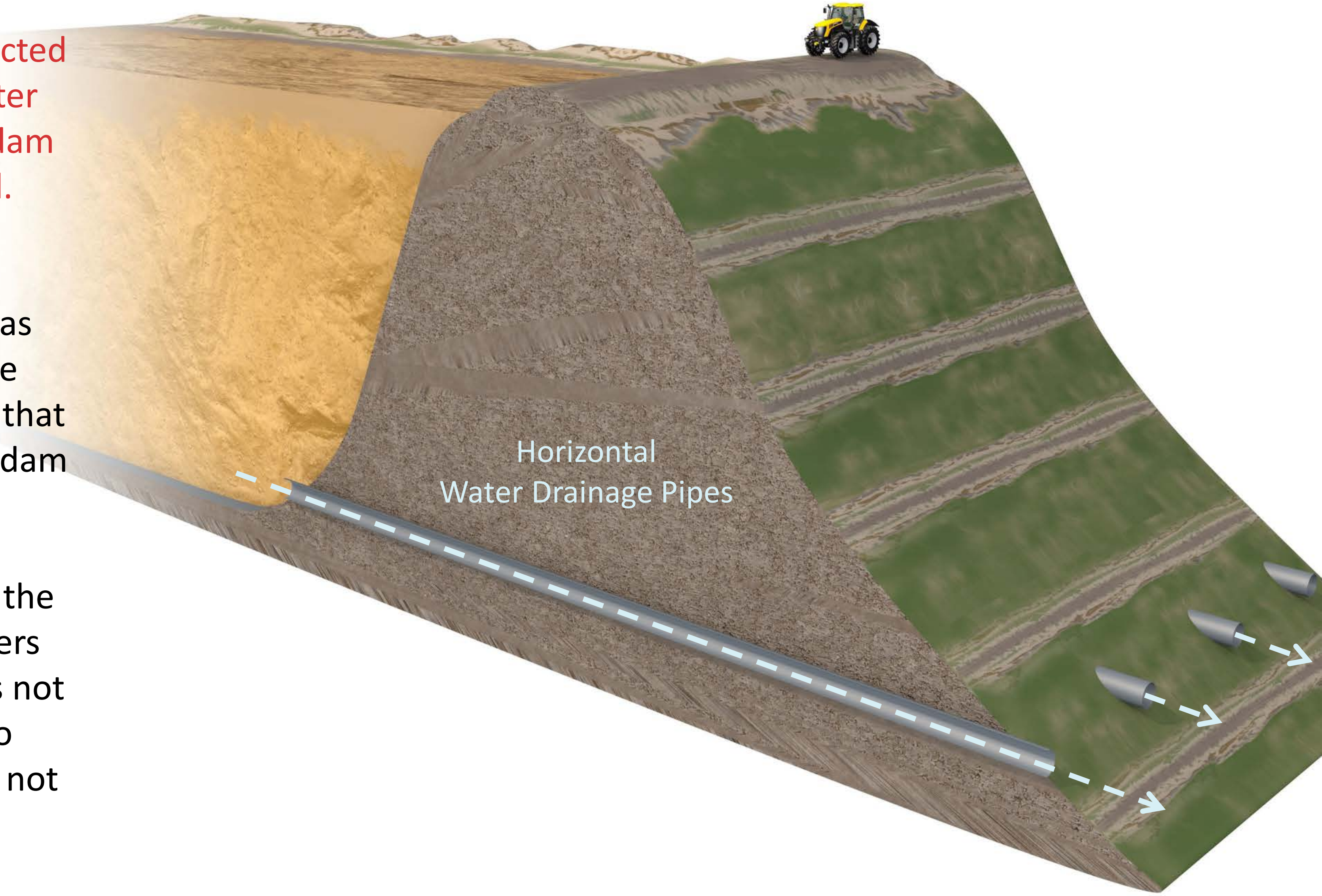
TAILINGS DAM DESIGNS

Water Drainage & Blockages leading to breach

Many dam designs (except dams constructed from concrete) often have horizontal water drain pipes built into the bottom of the dam to avoid fluidisation behind the dam wall.

During initial filling of these dams with tailings, these pipes are kept closed, but as the tailing slurry increases in height in the dam, these pipes are used to vent water that has seeped to the bottom of the tailings dam wall to the downstream side of the dam.

This removal of water assists in ensuring the slurry behind the dam for up to 100 meters upstream of the dam, dries out and does not become fluidised. The problem is what to when these pipes become blocked or do not exist.

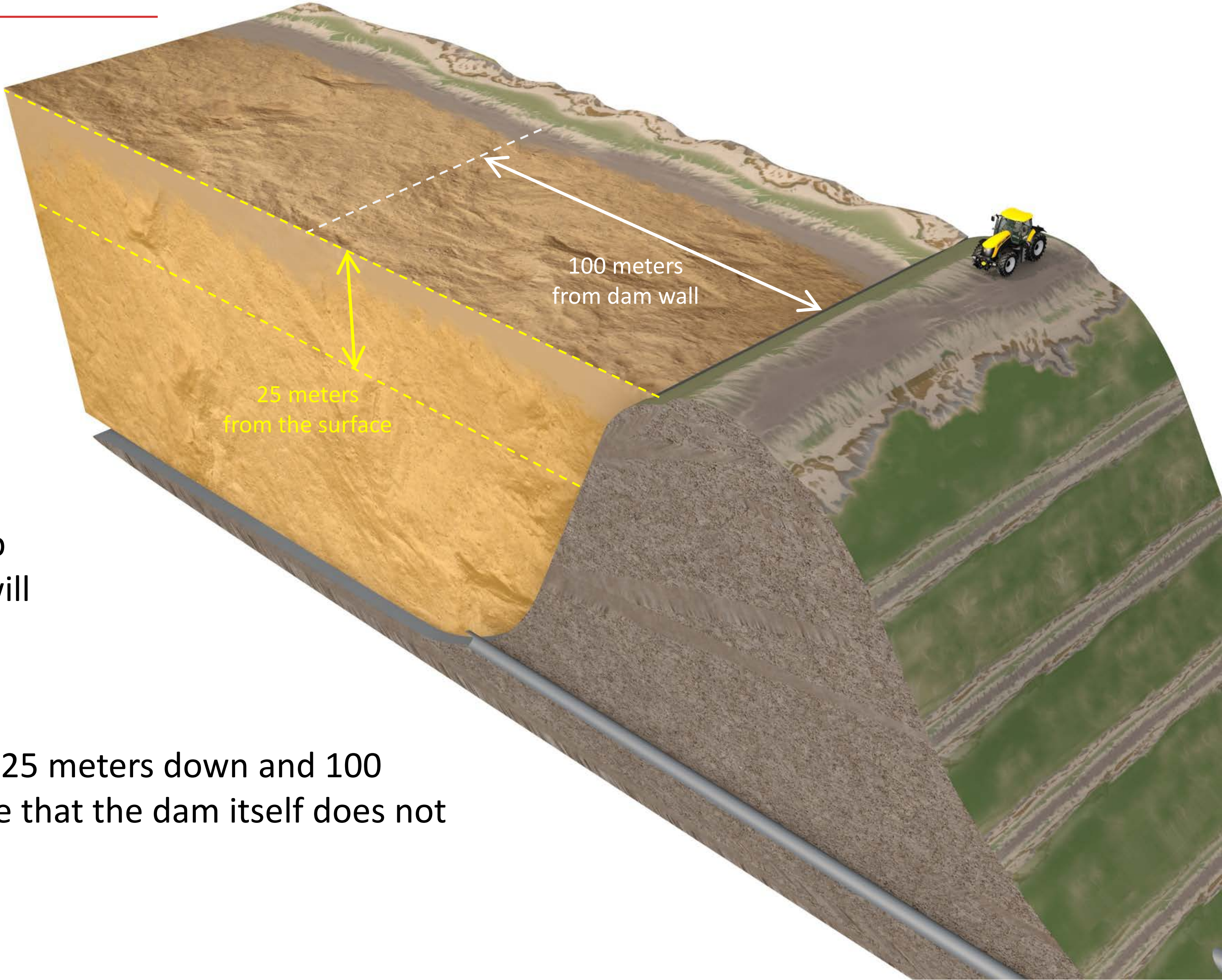


Making Tailings Lagoons in Critical Condition Safer

The purpose of this document is to describe a mechanism and process that will help ensure fluidisation does not occur of tailings material close to the dam wall on tailings pits that have been inactive for a period of time or that are active but are considered at risk of “Rupture”.

The issues with tailings pits that are considered at risk of “Rupture” is that they are inherently unsafe and nobody wants to venture out onto the dam or into the tailings lagoon and even if they did, they are uncertain how to remove water and or de-fluidise the tailings . The Goodwin Pontoon can be manoeuvred, operated and controlled with no one on board from a land based cabin linked to the pontoon by Industrial Wi Fi and provides CCTV over this Wi Fi of the pontoon and it’s surroundings.

Making Tailings Lagoons in Critical Condition Safer



In the following slides is a description of how Goodwin would propose to make dams at "Risk" more inherently safe.

This by ensuring the tailings behind the dam (say from the surface to 25 meters down and up to 100 meters from the dam wall) are not subjected to water.

Thus, the material in the dam above this level will not become fluidised and as such, will stop exerting hydraulic force on the dam wall and will actually assist the dam wall hold back tailings material higher up the tailings lagoon.

By defluidising the tailings from the surface to 25 meters down and 100 metres upstream of the dam, it will also ensure that the dam itself does not become fluidised.

GOODWIN PUMP PONTOONS

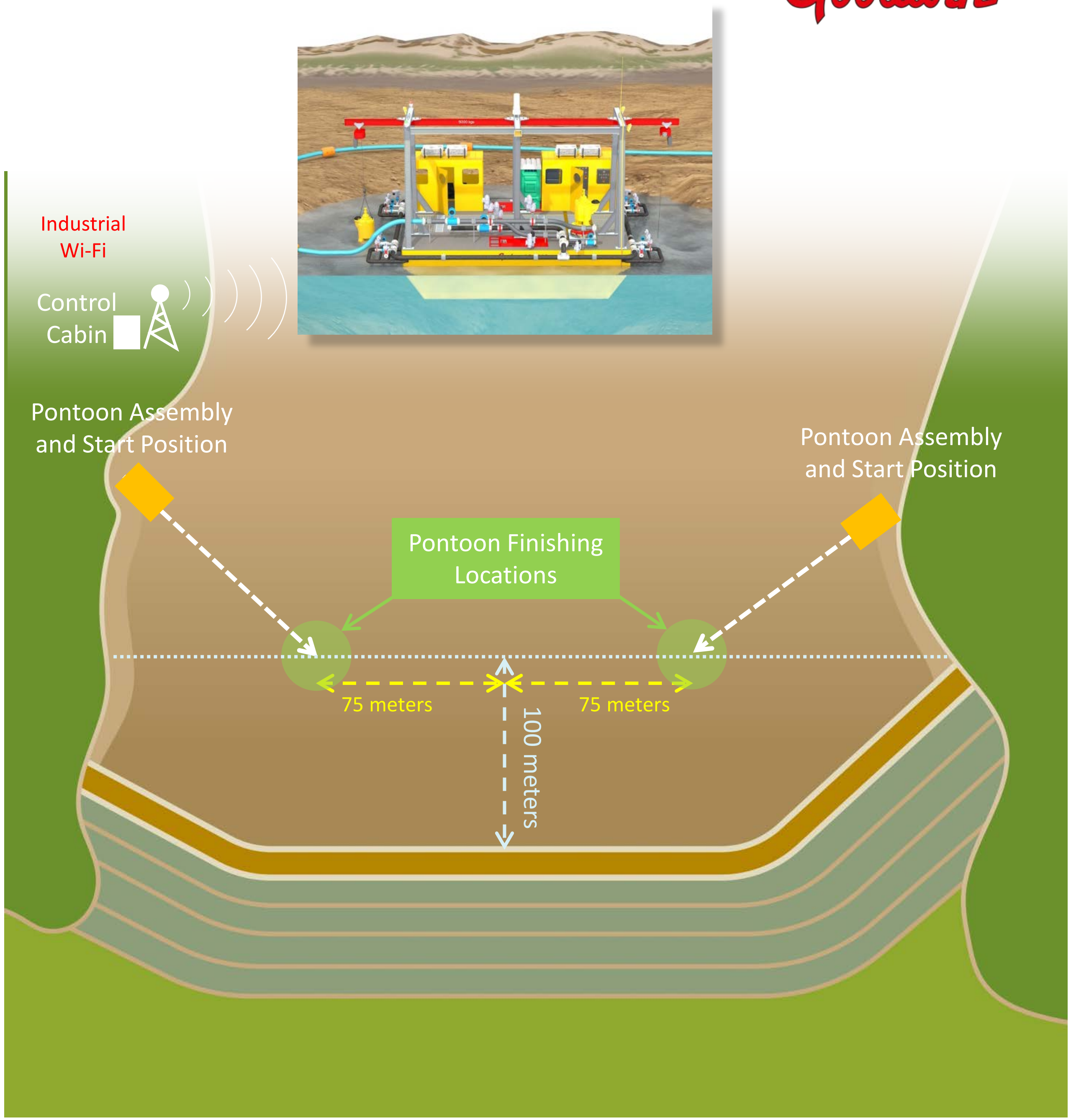
High Performance for Critical Applications

Goodwin modular section, quick build pontoons are designed to provide the ideal platform for Goodwin Submersible Pumps to operate to their maximum capability and are **easy to transport to local mine sites using three 40ft flat bed lorries with no single module weighing more than 9 Tonnes.**

The pontoons would be constructed on the edge of the lagoon 140 meters upstream of the dam, one on each side of the lagoon.

These pontoons, that are remotely controlled using industrial Wi-Fi from a land based cabin, would make a channel for themselves by displacing solids and pumping the resulting slurry some 750 meters towards the upper end of the lagoon.

The pontoons will continue until they reach 75 meters either side of the centre line of the lagoon and 100 meters distance from the dam wall.

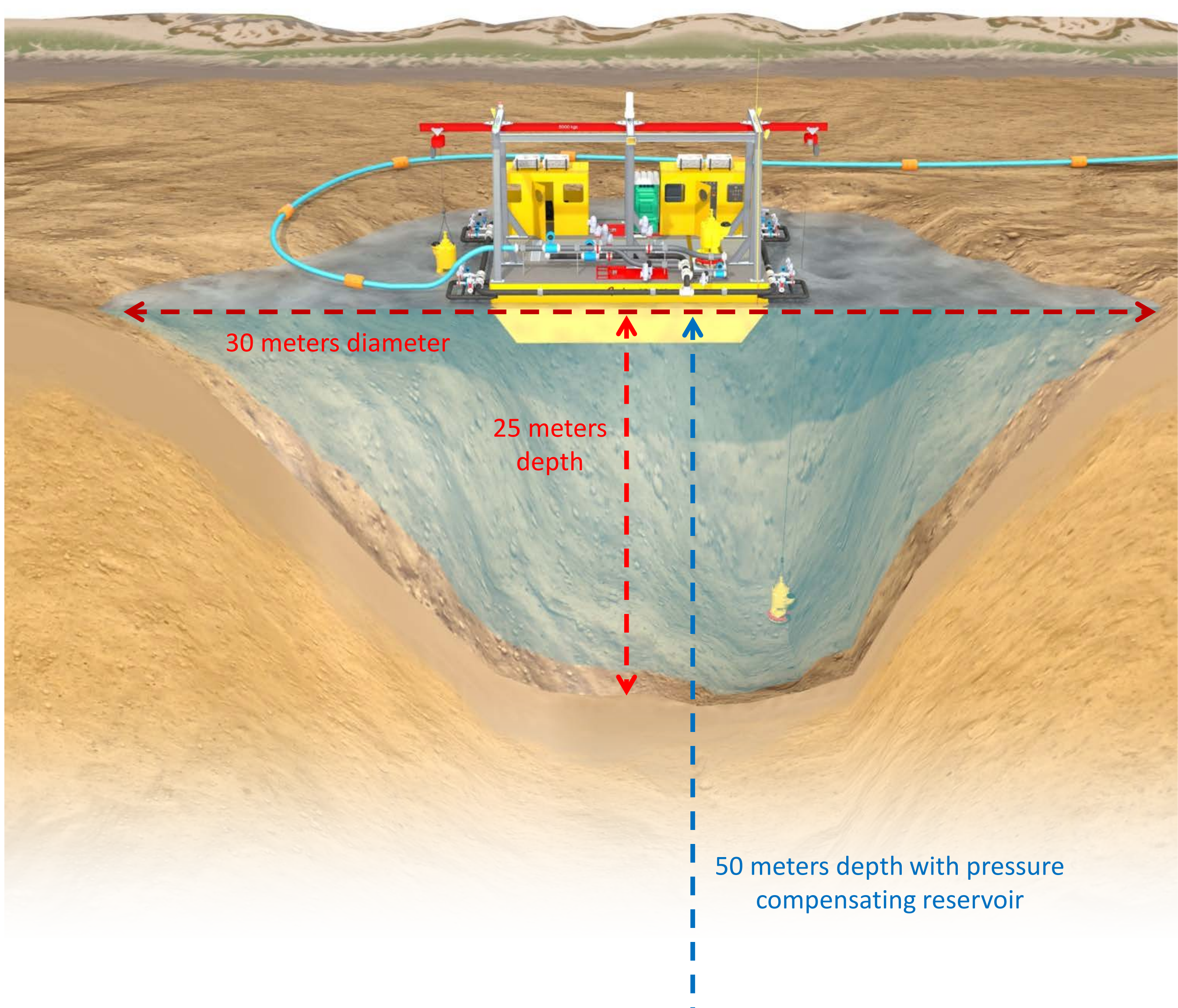


Purpose Built Platforms for Pumping Applications

Goodwin Pump Pontoons equipped with Goodwin Submersible Slurry Pumps can be operational 95% of the time from the shore with an intelligent control system linked to a shore based control cabin via industrial Wi-Fi.

This unmanned capability minimises the risk of operators being out in the tailings lagoon when there is a risk of dam rupture.

Each Pontoon having used its pumping capability and density control system to ensure the concentration of solids does not go above 40% by volume, would be used to create in their location an excavated pool some 30 meters in diameter that was tapered as it went down to a depth of up to 25 meters - or if needed 50 meters with a special pressure compensating reservoir fitted to the submersible pump.

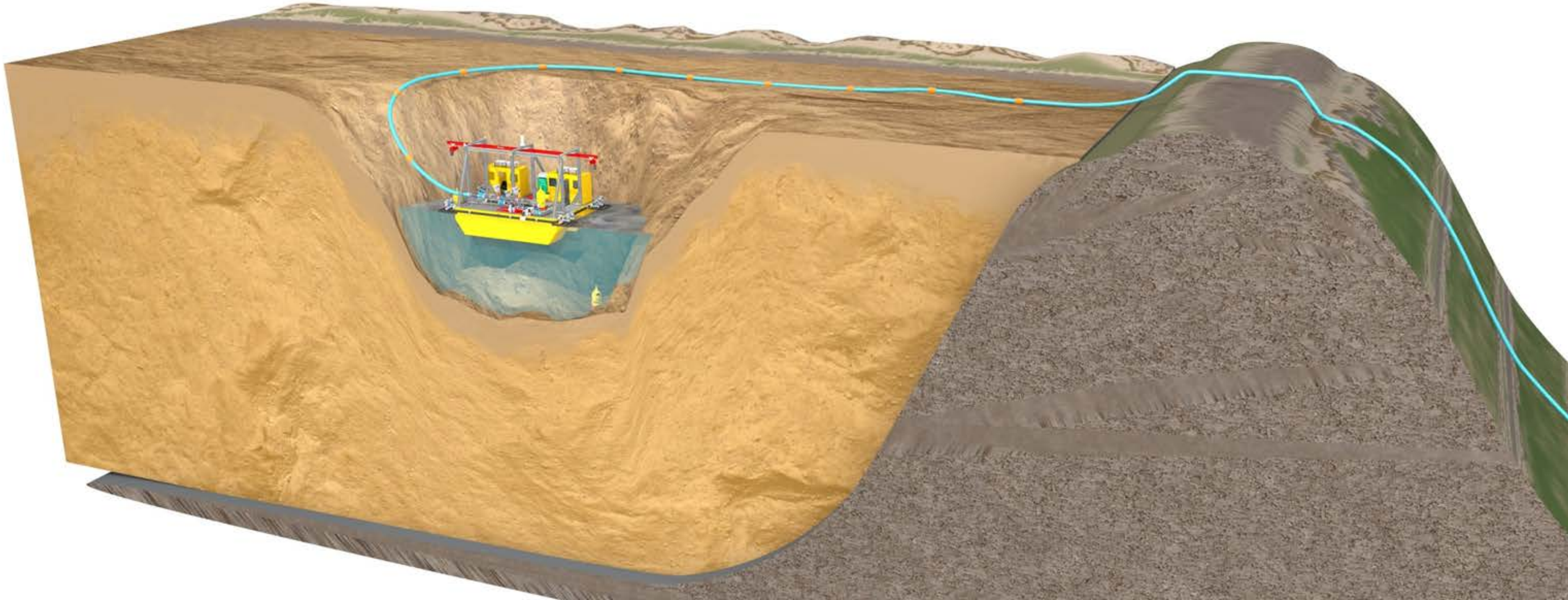


Goodwin

Once the excavation of the two conical holes had been completed, the Pontoon and Submersible Pumps will be used to pump any water that permeates into the holes down flexible pipes over the dam wall to the downstream side of the dam.

If this runs 24 hours per day then dewatering of the dam in the most critical areas would be very much improved. Also, when rain water flows down the lagoon towards the dam it would naturally migrate via the two trenches to the two 30 meter diameter holes so that it can be pumped away. This process is designed to keep the water table in the tailings lagoon near the dam wall between 10 and 20 meters below where it would naturally be.

This will prevent fluidisation of tailings material near the dam and also assist in preventing the fluidisation of the dam itself especially in the rainy season when rain flows down the lagoon and sits along the dam wall.



GOODWIN PROPOSAL

Making Tailings Lagoons in Critical Condition Safer

Whilst Goodwin can provide Pontoons, Submersible Pumps, Land Based Control Cabins, Industrial Wi-Fi Anatel compliant and pre-written software for the control of operations, Goodwin does not have enough manpower in Brasil to operate and manage the amount of pontoon systems that are needed in Brasil.

There would be the need for some company or the army that Goodwin could train such that they could operate the many dam defluidising operations that are needed in Brasil.

It could be argued that to use two pontoons that increases the price including land based control cabin by US $3.5 million is too much, but it is safer to work either side of the centre line of the dam to de-water the lagoon and to have a back up when the rains come, rather than just have one pontoon. Consider the US $ millions if not billions of damage when a dam wall “ruptures” and the associated loss of life.


Goodwin Bombas Technical Installation & Support Team

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Goodwin Tailings Removal

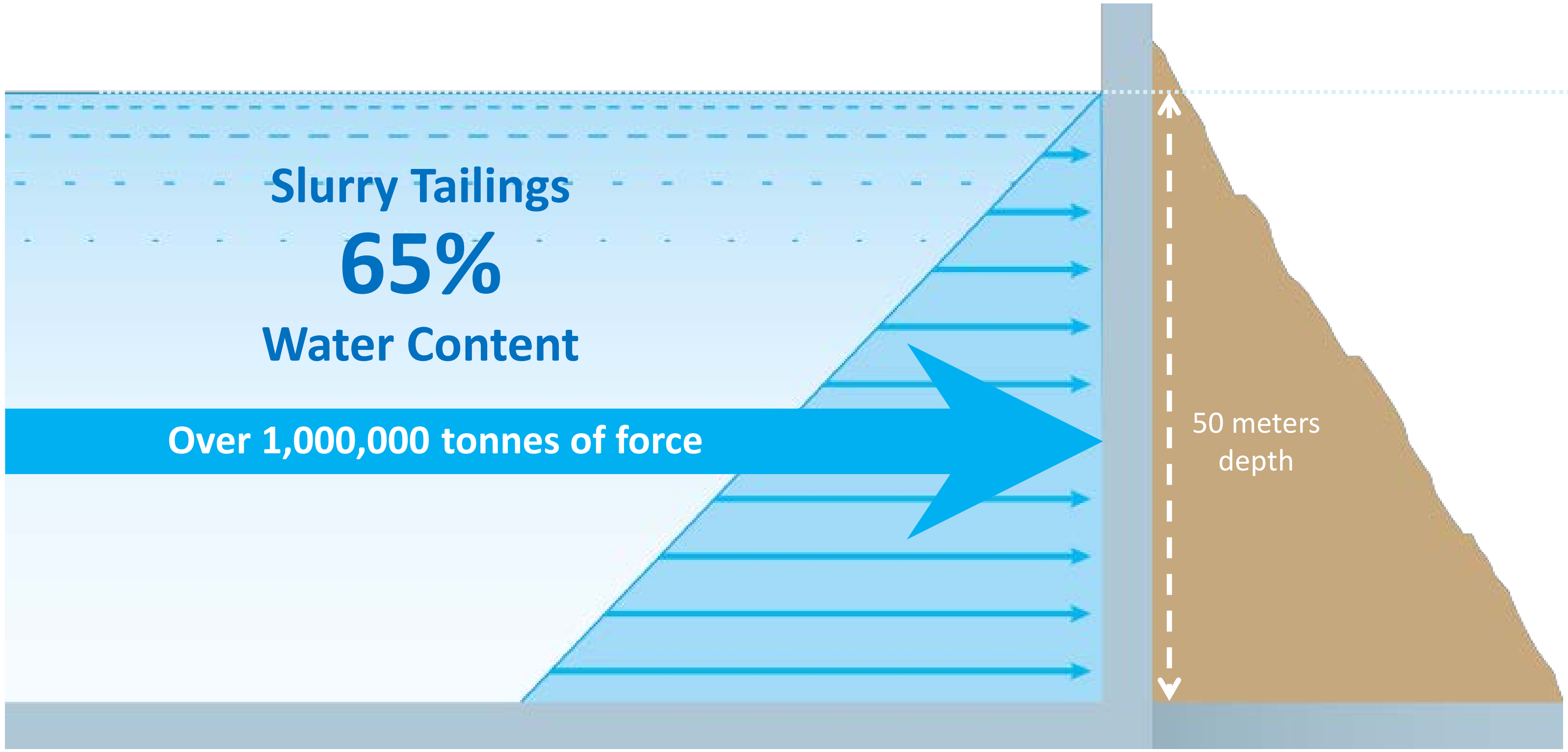
Reducing Water Content & Strain on a Tailings Dam Wall

The Video animation that follows shows pictorially how already fluidised tailings with a water content of between 55% to 80 % can, over a period of time, have the water content reduced by between 30% and 50 % and thereby reduce the loadings on the Dam wall by as much as 80 %.

The presentation of the Loadings on the Dam wall relative to the moisture content are included in the handout that you will be given when you leave the conference Hall.

A Dam wall only 600 meters long and say 50 meters high can easily have over one million tonnes of force acting on it by ‘fluidised tailings’ and if the tailings are defluidised then this load can be reduced by as much as 80 % and the tailings will act to compliment the strength of the Dam wall.

Dam Wall – 600 meters long



In more recent months, Andrew MacKenzie CEO of BHP, the world's largest mining company has stated that there is need in the industry to focus on **'Nuclear Levels of Safety'** to avoid any repeats of the last two dam failures in Brasil.

Exactly what Andrew means by 'Nuclear Levels of Safety', I am not absolutely sure, but my guess is that it will involve some of the following, all of which can be satisfied by using the unmanned (Industrial Wi-Fi controlled) Goodwin pontoon and submersible pump solution as has been described in the last video:

1. Avoid putting humans in the area of Danger on Fluidised lagoons and Dams that are classified as "Being at Risk" – there are, I understand 17 of these in Brasil at present.

2. Carry out very large amounts of planning and ensure the dewatering process is extremely controlled and monitored – To do this, the historic comments of good solutions just being too expensive are no longer applicable as everyone has now seen that by failing to take safe and appropriate actions (indeed any action at all) has costs a thousand fold greater and many lives.

3. Stopping individual companies operating and making decisions solely based on short-sighted commercial grounds and have an independent (NEW) body of people to overview and approve plans of actions to **defluidise** tailings near Dam walls.

4. Provide those operating equipment, processes and others in the area with an alarm system and a backup with a means of rapidly vacating the danger area when monitoring and recording of a given lagoon parameters such as fluidity and very sensitive seismic equipment show detrimental changes on an already "Critical Lagoon".

GOODWIN PROPOSAL

Reducing Water Content & Strain on a Tailings Dam Wall

Christy 7186 Cargo hovercraft as a possible transport mechanism to and from the pontoon.

REMOTE / UNMANNED CONTROL

Intelligent Control Systems for added safety

Goodwin Pontoons and Submersible Slurry Pumps can be controlled remotely, meaning that there is no need to send personnel into a potentially at risk Tailings Lagoon.

Goodwin provide control systems and panels for the operation of two Goodwin 200mm ANZE Submersible Pumps. These systems offer touch screen capabilities with intelligent software to control flow and measure density to ensure a pumping system will run efficiently without problems over a long period of time. There is dual control, one in the pontoon control cabin and one in the land based control cabin and both have identical control capability of the pontoon pumping activities and movement of the pontoon.

Pontoon movement and pump operation can be controlled remotely via a HMI screen in the shore based control cabin which transmits to the Pontoon using an industrial strength self tracking Wi-Fi signal. CCTV video on the pontoon and surroundings is also transmitted via Wi Fi to the land based control cabin TV.

GOODWIN PUMP PONTOON

Goodwin Submersible Pump Pontoons are built by the pump and marine technicians within our Sao Paulo Brasil facility.

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G O O D W I N PUMP PONTOON

Goodwin Submersible Pump Pontoon assembled on-site in a ready excavated tailings lagoon.

GOODWIN PUMP PONTOON

Goodwin Submersible Pump Pontoon fully assembled, afloat and ready for operation in a water filled excavated hole in a tailings lagoon.

Goodwin

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Goodwin Pontoon Assembly

Goodwin
BOMBAS

Thank you for your time

Presented by

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