A story of elevated leakage, whales and the forensics journey…

AKA…Brittle Stress Cracking of HDPE Geomembrane caused by Localized Over-Heating of Fusion Wedge Welds

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Presentation highlights (because we only have 15 minutes + question time)

1. Brief introduction
2. What was causing the leakage
3. What was causing the whales
4. And how the two were interconnected

The asset in question…

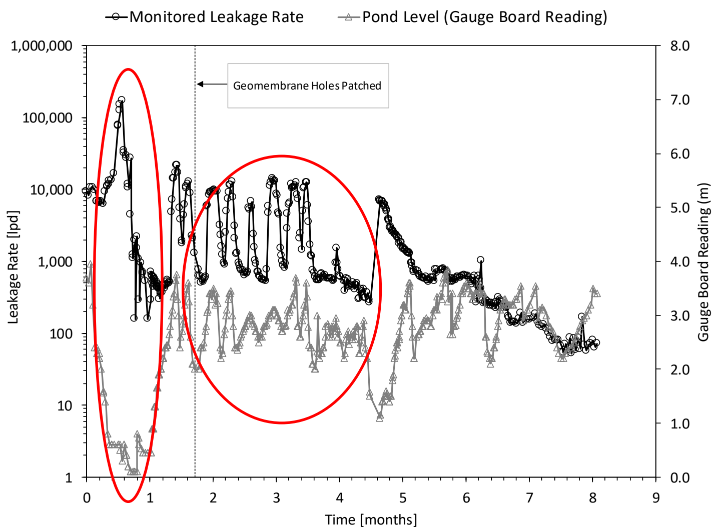
A geomembrane lined dam in Australia which was temporarily decommissioned due to elevated leakage rates (in excess of 10,000 lpd) and observed development of geomembrane 'whales', after it was in service for only 4 years. The surface area of the installed geomembrane is approximately 9.3 hectares and the operational fluid head is 6.7 m, which provides 290 ML of storage volume for treated water produced from coal seam gas extraction. The lining systems consists of 2.0 mm thick HDPE geomembrane underlain by a leakage collection layer comprising a central 2 m wide geocomposite strip drain, which was connected to a 'herring bone' shaped network of 1 m wide geocomposite strip drains with a typical perpendicular spacing of 20 m. There was supposed to be a150 mm thickness compacted clay across the floor. It is important to note that there were ballast tubes across the floor and around the upstream batter.

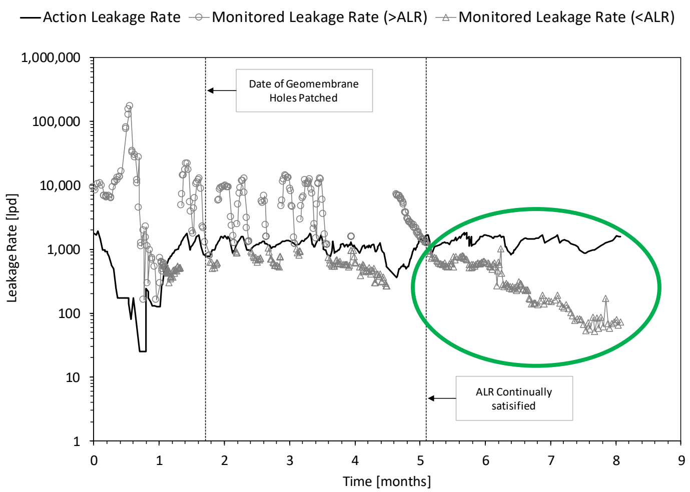
Introduction

- It can be said that a geomembrane liner system is only as strong as its weakest weld
- Peak leakage rate in excess of 10,000 lpd which was >>>> the Action Leakage Rate (ALR)
- Whales developed during operations which contained gas (in this case air)
- A number of geomembrane cracks (or splits) were identified in the vicinity of the whales
- Failure analysis of one of the geomembrane splits was undertaken

Leakage it's not ideal

- The good news is that leakage was being monitored against established ALRs
  - The term 'action leakage rate' is used to quantify the limit between acceptable and unacceptable leakage rates
- The not so good news is that leakage was >>>> ALRs
- This exceedance required the Trigger Action Response Plan (TARP) to be followed
- The importance of composite action and loss of intimate contact – peak leakage rate > 100,000 lpd
- When filling commences and you have a clear hydraulic connection and a very small time-lag it's usually a clear indicator of large 'holes' in the geomembrane.



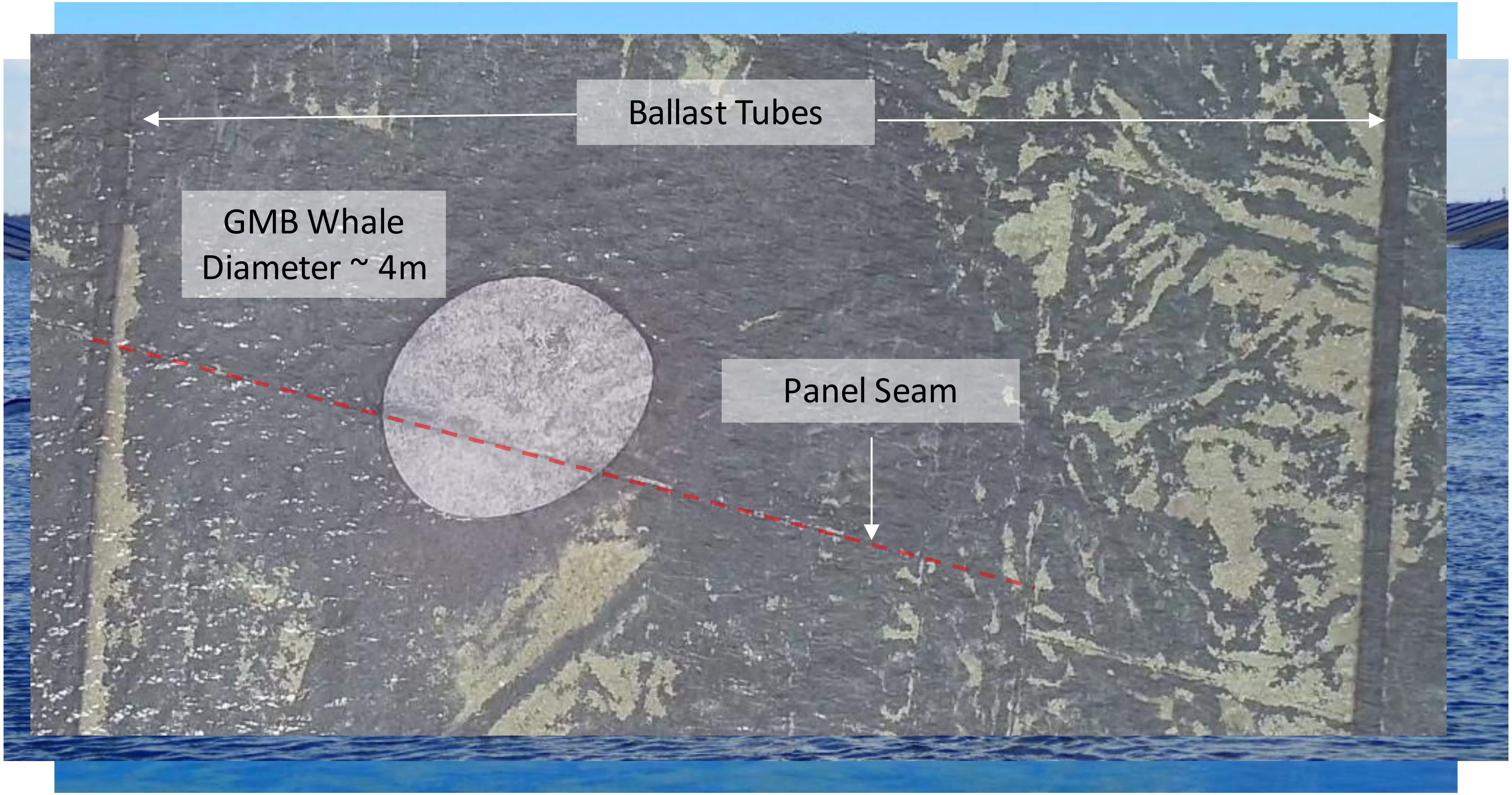


Whales…why did they appear

- Geomembrane whales developed on the pond floor while the pond was in service
  - Whales are bubbles of air (or other types of gas in some cases) that develop under the geomembrane and appear as ‘whale backs’ above the surface of the water
  - They exert out-of-plane stresses in the geomembrane
  - Once initial geomembrane deformation occurs, the air tends to concentrate in localised areas beneath the geomembrane, causing the whale to grow over time
  - It is possible for whales to cause bursting failure[1] of the geomembrane.
- There are many possible causes of whales, including:
  1) Trapped air (typically in wrinkles) during construction which has not been expelled
  2) Air is potentially entering at geomembrane hole locations (via syphoning)
- The whales were ‘walked out’ towards the batters where air vents were installed near the crest

[1] multiaxial tensile deformation associated with large strains and thinning of the material) until holes/tears appeared, allowing the gas to escape.

Walking the whales…



Leakage and whales don’t work synergistically

Leakage starts

- Small ‘holes’ initiate leakage

Whales develop

- Geomembrane starts to float

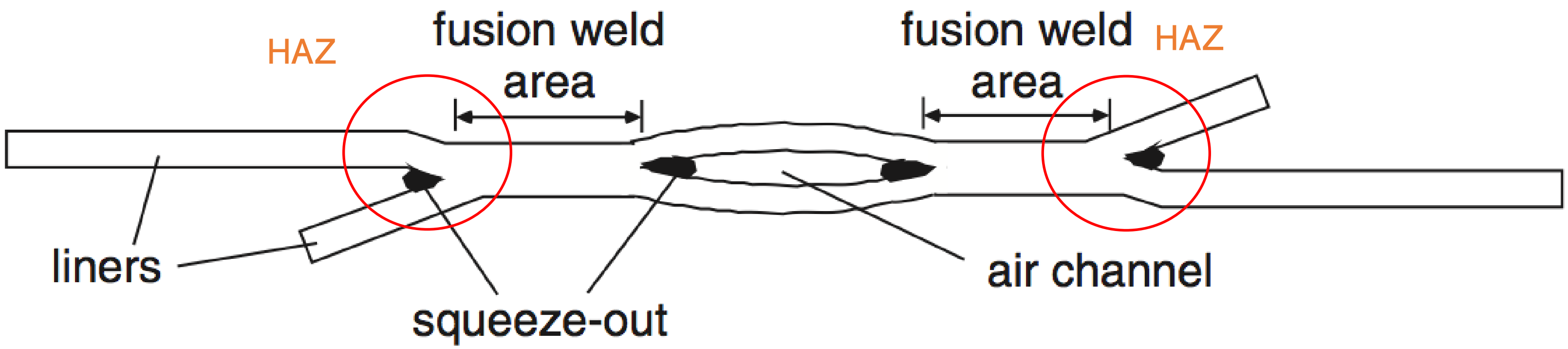
Whales ‘breathe’

- Cyclic flexing (i.e. growing and shrinking over time as temperature and water levels change

…things can get worse e.g., increased leakage, more weld failures and potential regulatory non-compliance.

Why did the splits occur…the pathway to answers

- Select the appropriate tests to help your hypothesis, there are many to choose from
- The splits were located in the Heat Affected Zone (HAZ)
- Based on the HAZ observations we selected the following tests:
  - Assessing weld profile changes – thick-thin transitions in the weld profile impose stress concentrating geometries
  - Std OIT – consumption of antioxidants during welding reduces stress cracking resistance
  - Flexural cycle – subjects the weld track (including the HAZ) to low amplitude cyclic stress in the form of flex cycles



The results are in…

Weld profile dimensions…~10% thickness reduction

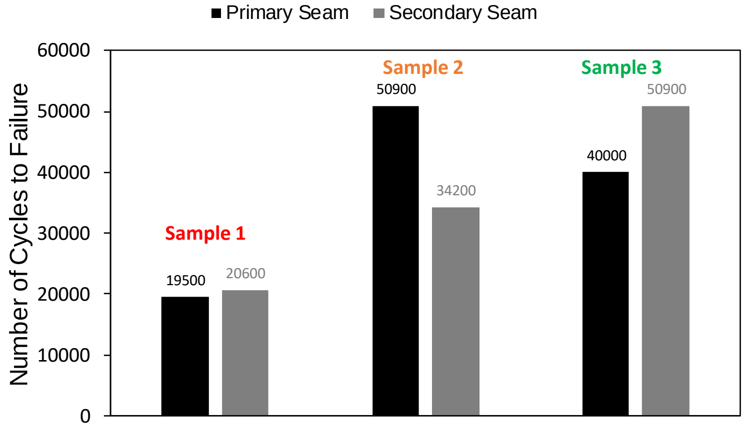
Dimension (mm)	Sample 1	Sample 2	Sample 3
Thickness of liners	3.93	3.91	3.93
Thickness of seam	3.54	3.49	3.55
Seam reduction thickness	0.39	0.42	0.38
Air channel width	8.72	8.37	8.96
Weld width	11.8	11.8	12.2
Width of squeeze out bead	4.81	4.88	4.98

Std-OIT…comparison with GRI GM13 (100 minutes)

Test Location	Sample 1	Sample 2	Sample 3
Split surface (mins)	126	129	-
Weld bead on split (mins)	66	69	-
Weld bead away from split (mins)	-	-	133

~50% reduction between bead on the split versus away from the split.

Flexural cycle testing…comparing samples near the split versus away from the split



Sample 1 – brittle cracking (i.e., stress cracking) and fails directly on the edge of the weld

Sample 2 – brittle cracking (i.e., stress cracking) and fails directly on the edge of the weld and approx. 20 mm from the edge of the weld track

Sample 3 – ductile failure approx. 30 mm from the edge of the weld track

The end is near…

The hypothesis following observations on site is the fusion weld (i.e., the split) was overheated during welding and subsequently stressed sufficiently during service to cause brittle cracking failure.

The source of stresses during service are likely to have been whales, which can impose cyclic stress via flexing

This flexing is likely to have been exacerbated by the fact that the whales were locked in by the ballast tubes installed across the floor of the pond.

Additionally, the irregular surface of the subgrade may have created a topographic environment where whales were unable to move laterally to upstream batters, where they can be vented (originally no vents were installed).

Laboratory flex testing using the accelerated flex life apparatus has confirmed that the fusion weld (i.e., the split) is more susceptible to stress cracking than the weld located 400 mm further away from the edge of the split, where the failure mode was more ductile.

The other factors that have contributed to the observed brittle failure of the split are raised crystallinity on the edge of the weld (in the HAZ) - usually due to slow cooling - and also the thick-thin transition that occurs across the weld profile (a geometric effect).

When all three factors occur in the field, namely; the raised crystallinity, the geometric stress concentrating feature (which is inevitable with fusion welds) and the cyclic stresses imposed by whales, brittle cracking is likely to occur directly at the edge of the weld track.

Yes you can walk a whale out…

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The end…happy to take questions