

# SBR RETROFIT AFTER MIDWINTER LINER RUPTURE

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## ABSTRACT

A processing facility operates a wastewater treatment plant (WWTP) that includes an anaerobic lagoon, sequencing batch reactor (SBR) and wetlands. During the winter of 2015 an electrical failure culminated in the over drawdown of the HDPE lined SBR lagoon causing mechanical damage to the liner. Production at the facility was forced to halt, placing pressure on the business's ability to fulfil customer orders and requiring a remediation of the SBR lagoon during the winter months.

This paper outlines the works undertaken to dewater, strip and clear the 6 metre deep benched lagoon of 12,000 m<sup>3</sup> volume of sludge laden material ready for relining. Even though a tight construction programme was presented, the opportunity and challenge was taken to futureproof the lagoon for increased inflows, reline, refill, reseed and provide an operational SBR within a 10 week period.

Construction had to deal with the subgrade beneath the existing damaged liner which needed to be removed by excavator without damaging the clay base and embankment material that was soft due to wet winter conditions. Of concern were the winter groundwater conditions, embankment stability with the presence of the 5 m deep anaerobic lagoon directly adjacent to the now empty SBR lagoon and local river on the opposite side of the SBR, which flooded due to heavy rain during the construction period.

The paper describes how cooperative management, onsite design and supervision, and client consultation overcame compaction complications of working with clay in winter, laying HDPE liner in trying conditions of wind, rain and winter temperature variations and the installation of a concrete anchor trench to provide the client with an improved and operational SBR ready to receive process flows in time for the restart of processing.

## KEYWORDS

**Sequencing batch reactor, WWTP, construction, repairs, operation, retrofit, HDPE liner, contract management**

# **1 INTRODUCTION**

A large food processing plant located in the Waikato region operates an on-site biological wastewater treatment facility comprising of an anaerobic lagoon, activated sludge plant operated as a biological nitrogen removal (BNR) sequencing batch reactor (SBR) and constructed wetlands. The final treated wastewater is discharged to surface water.

In 2000, as part of the requirements to manage increased production, the then shallow oxidation lagoon was deepened and converted to an aerated lagoon. This lagoon was located at the end of a river terrace and as such had less than ideal natural underlying subgrade materials. To this end, the lagoon was excavated with a mid-level 2-metre wide berm around the side wall resulting in a stepped dual depth lagoon approximately five metres deep with an operating water level of four metres. The lagoon was lined with a 1.5 mm high density polyethylene (HDPE) liner attached to an existing concrete waveband. The upgrade works were undertaken at the end of summer in 2000.

The aerated lagoon was converted to an SBR to promote nitrogen removal in 2005. The submersible floating pump decant system was installed to allow controlled decanting of the clear supernatant following the settle phase in the SBR cyclical treatment sequence. The SBR operation was controlled using a programmable logic controller (PLC) with the electrical/instrumentation work associated with the upgrade undertaken by the site.

Since 2005, the SBR system has been operating without any faulting of the electrical/instrumentation until in May 2015 when a fault was reported on the PLC in relation to the pump level controller. This fault was investigated and a replacement level controller card was installed.

## **2 LINER DAMAGE AND FAILURE**

### **2.1 LINER MECHANICAL DAMAGE AND EMERGENCY REPAIR**

Following the replacement of the failed level controller card on the SBR PLC, the site had identified a risk with the continuing reliance on an older generation PLC. A scheduled replacement to a new generation PLC was planned within the year.

Two weeks following the replacement level controller card, the PLC level controller operation faulted during the decant mode whilst the pump was drawing down the supernatant from the SBR. This meant the decant pump was no longer receiving the signal from the controller to stop pumping at the nominated low operating level. There was no automatic rebooting and/or resetting of the PLC in the event there was a fault and the downstream equipment continued to operate in the state they were left in. Since the level controller had faulted, there was no corresponding level alarm signal sent from the PLC to alert the site operators.

Since the pump was continuing to run, when the timer sequence triggered the mechanical aerators to turn on, three of the aspirating aerators came on-line and ploughed into the liner as the water level was well below the operating point. This mechanical damage was not immediately discovered as the failure had occurred over the long weekend and it was not until the next working day following the break that the damage became apparent.

Since the site was continuing processing, an emergency repair was undertaken. The SBR was further drained to expose the mechanically damaged areas and an HDPE patch repair was undertaken. The SBR was refilled and the treatment plant re-started within three days of discovery of the failure.

### **2.2 SECONDARY LINER RUPTURE AND LINER REPLACEMENT DECISION**

Within one week of operation, the site discovered that the liner had ripped near one of the earlier damaged holes and a large part of the liner was floating near the surface. The second failure that had occurred within a week was unexpected.

The processing plant had to be stopped and immediate drawdown of the SBR had to be initiated. Once the drawdown was completed, the extent of the ripped liner was realised. The liner had ripped at one of the seam

weld locations and the progression of failure continued for around 15 metres (lineal length) up the internal wall. This failure certainly raised the doubt on the reliability of the remaining seam welds.

An independent laboratory testing of the liner was initiated and two pieces of liner were cut from the SBR. One of these pieces was the exposed area above the top water level and the other piece was from an area that was always submerged. The testing was undertaken for stress crack resistance for geomembranes (ASTM D 5397), oxidative induction time (OIT) (ASTM D 3895) and high pressure oxidative induction time (HPOIT) (ASTM D 5885). While the test results showed that the liner had good stress crack resistance, the low OIT and HPOIT values (as shown in Table 1) showed that the anti-oxidant properties had been substantially depleted indicating that the HDPE membrane was at the end of its serviceable life.

*Table 1: In-situ HDPE Geomembrane Test Results*

<b>Parameter</b>	<b>Sample 1 (exposed)</b>	<b>Sample 2 (submerged)</b>	<b>Minimum Liner Specs</b>
Oxidative Induction Time (minutes)	6	29.5	> 100
High Pressure OIT (minutes)	99	236	> 400
Stress Crack Resistance (hours)	> 1000	> 1000	> 500
<i>Notes:</i>			
1. <i>Oxidative Induction Time test undertaken as per ASTM D 3895.</i>			
2. <i>High Pressure Oxidative Induction Time as per ASTM D 5885.</i>			
3. <i>Stress Crack Resistance as per ASTM D 5397, App.</i>			
4. <i>Testing undertaken by TRI Australasia Pty Ltd.</i>			

Although the HDPE liners in New Zealand are generally provided with a 20-year serviceable life guarantee, the results were slightly surprising with OIT reducing to the extent that it had. The life of the liner was then 15 years.

It has been noted that the service life of HDPE membranes is essentially determined by the slow loss of stabilisers due to migration (Rowe *et al*, 2003). The oxidation starts only after the depletion of antioxidants and then quickly leads to brittleness of the membrane. It is generally accepted that oxidative degradation of HDPE geomembranes is not a relevant factor with regard to normal geotechnical applications, in which service lives of around 30–50 years are expected and repair work is possible (Mueller & Jakob, 2003). However, the OIT values for the exposed above top water line sample was very low, showing that a large amount of sunlight related oxidation had occurred over the years and that antioxidants were almost completely consumed. This could have resulted in the liner being brittle and unreliable for continued service after repair.

The liner tear and the area of liner utilised for testing is shown in Photograph 1. The mechanical damage could be seen in the sections cut from the liner. Given that the stress crack resistance was still high, the tear shows the enormous amount of stresses put on the liner where a mechanical score line was present that propagated the failure.

*Photographs 1 & 2: Liner showing tear line, detailed damage of various areas and testing area*



Before the results were received from the independent laboratory, the existing liner was cleaned and a visual inspection was carried out. There were a number of defects including small holes, wrinkles and in some area the liner showing a “waterbed” nature with ripples. There were also extensive mechanical scores on the liner and some of the seam welds had shown fatigue. Advice was sought from liner suppliers and installers on the likely reasons for the failure. Given that the liner had failed on one of the seams of the double welded seam, it was postulated that poor field welding under cold conditions may have contributed to the crystallisation at the weld line, that could have contributed to the failure. The company made a decision to replace the liner prior to receiving the liner test results, but the outcome of the testing validated that decision.

### **3 REMEDIAL WORKS DESIGN DECISION MAKING**

As part of the remedial works there were three key aspects that needed to be addressed. These were:

- i. Whether to retain the current concrete wave liner anchoring (bolt and batten) system;
- ii. Creating the opportunity to increase the active treatment volume; and
- iii. Whether the liner trench anchoring required a concrete anchoring system.

Pricing was sought from the liner company on the liner attachment as per the previous anchoring system and it was realised that the costs as well as the timeframe to implement a “like-for-like” liner anchoring was not practicable. The change to the liner anchoring to a trench anchoring system meant that additional earthworks were required on the crest.

The south-east corner of the existing SBR crest embankment was lower than the western side crest and the decision was made to lift the embankment to meet the minimum crest level that the western side of the SBR allowed for.

The remedial works also provided an opportunity to future proof the site in respect of allowing for additional aeration, management of waste activated sludge and emergency overflows.

Having the decision to raise the embankment being made, the anchoring system for the trench required a concrete perimeter beam rather than the traditional compacted clay filled trench. This was decided due to winter earthworks providing poor clay compaction and also the liner anchoring was on a crest shared with the existing anaerobic lagoon, and existing large granulated unsuitable fill on the crest, that would be unsuitable to lay the liner against.

## 4 CONSTRUCTION PREPARATION AND SEQUENCING

### 4.1 DESLUDGING AND BASE PREPARATION

Prior to any construction being undertaken the remaining sludge had to be removed from the lagoon base. The subgrade also needed to be removed. The majority of the sludge above the liner was capable of being pumped for removal and this was transferred to the neighbouring onsite sludge holding pond, itself close to capacity due to the first dewatering of the SBR and winter rainfall. Every effort was made to minimise the amount of sludge coming directly into contact with the SBR subgrade and sludge was assisted towards the temporary desludging wet well (depression) via handheld squeegee blades.

### 4.2 GROUNDWATER LEVELS AND RISK

During the desludging of the SBR, additional assessments were underway in parallel to ensure the lagoon embankment was safe enough to be working behind, both for human safety and asset protection, due to the presence of the anaerobic lagoon adjacent to the unlined embankment, during winter with high ground water levels. A slope stability investigation was carried out to determine the stability of the dividing embankment located between the fully drained SBR lagoon and the adjacent anaerobic lagoon (at operational level), a hydraulic difference of 5 m. The investigation involved hand augers within the dividing embankment, installation of groundwater monitoring standpipes within the auger holes and a slope stability analysis to determine the factor of safety of the dividing embankment. The analysis indicated that the factor of safety was 1.43. Lowering the level of the anaerobic lagoon by 1 m as a temporary measure allowed for the increase of the factor of safety to 1.59.

The wet weather conditions generated increased groundwater inflow into the empty lagoon and in some cases soft spots formed in areas with increased permeability. A slight gradient across the lagoon base allowed for pooling in the lowest northwest corner of the lagoon. A submersible pump was operated via a duckfoot float system to automatically dewater the lagoon. However, due to shifting sands from the original subgrade the temporary wet well regularly became inundated requiring continual maintenance and manual operation of the pump to remove accumulated groundwater.

*Photograph 3: Dewatering pump working in the low corner of the lagoon base*



### 4.3 REMEDIAL EARTHWORKS

When the original oxidation lagoon was upgraded to an SBR a concrete waveband was installed, onto which the liner was bolted. It was assumed at the initial liner placement that the waveband was level, however, soon after the liner was placed and the lagoon filled, it was apparent that the wave band was not constructed at level

around the internal perimeter of the oxidation lagoon, negating any contingency volume provided for the SBR during the upgrade.

Although, there was enough hydraulic retention time in the present SBR volume to ensure treatment processes were not compromised, the replacement of the liner provided an opportunity to allow for an increase in the SBR volume that could accommodate expected increases in future processing indicated by the Site.

To provide the site with an increased operating volume and provide additional protection from increasing annual flood levels within the neighbouring river, it was proposed to dismantle the bolt and batten system and increase the height of the liner by installing an anchor trench at the embankment crest. The corner of the lagoon that had the inaccurate waveband level also translated to an embankment crest level that was inaccurate. A minor cut to fill operation was required to raise the crest level by 400 mm in the low corner. To provide a suitable subgrade for strength and particle size to place the liner on clay was required for this fill. Clay spoil from the original lagoon excavation had been used as fill in close proximity to the SBR lagoon. This source was checked for dryness and suitability prior to using it as fill on the new raised embankment. Other off site clay sources could not be guaranteed to be dry enough or accessible due to the winter weather.

The physical cut to fill operation was hampered by wet weather and due to the confines of the site only a single track around the crest of the lagoon meant the continual movement of heavy machinery around the crest created movement and sponginess in any clay that had been disturbed, which is a typical occurrence when attempting to work clay during winter.

#### **4.4 INCLEMENT WEATHER DELAYS**

Inclement weather was the biggest risk throughout the whole project for affecting the completion time for new liner installation. Short stretches of fine weather had allowed the earthworks contractor to strip, fill and compact the embankment subgrade so it would be suitable for lining, then intermittent rain events would hamper the earthworks and cause soft spots around the embankment and within the lagoon base. This required continual remediation and rework of rilling, piping around the original subbase venting pipes and minor slumping in soft areas, which delayed the overall liner installation programme.

Soft substrate also had the potential to cause stress points on the liner if the liner was installed over these without prior remediation. Several soft spots developed on the benched area of the lagoon and around the main embankment toe (above the bench). These areas were complicated to fix as they were at the limits of, or out of reach of, a long arm excavator. An *ad hoc* solution of rolling a trailer containing sand and cement down the internal slope of the lagoon was used to access the soft spots. The materials were manually mixed with the in-situ soft material to form a stiff cementing material suitable for laying liner over. Time became of essence as every day without the liner being installed meant continued remediation of the subgrade to fix rilling, and sand movement with localised groundwater damage. The continual remediation itself held up the lining process and in the end both lining and subgrade preparation had to occur in parallel. Wet weather also hampered welding of the liner. The lining contractor employed their own portable lighting on site to extend work outside of daylight hours when fine dry weather was available, to complete the liner installation within the given tight timeframe.

In addition to the wet conditions, the local topography exacerbated windy conditions that also did not help with the lining works. The existing liner, once desludged, was destroyed by wind gusts, tossing aside water filled 200 L drums that had been tied together and placed on the leading edge of the unsecured liner. This event almost caused the liner to make contact with overhead 11 kVA power lines, directly above the lagoon. To avoid a repeat of this situation, liner installation was held off until after forecasted wind events, and once lined, a significant number of sandbags were placed at about 1 m centres on top of the liner along any unsecured edge to minimise the risk of damage by wind. The number of sandbags was not counted but they are estimated at about 700 and all of these sand bags were removed by hand at the end of the project as filling occurred.

There was a considerable difference in temperature throughout the day during the installation period. Early mornings would begin with a temperature that was as low as 1°C and then rise to 17°C during the day on a calm clear sunny day), meaning that the liner material could contract and expand quite significantly, creating folds in the liner. To counter this, upon completion of liner installation, refilling of the lagoon was undertaken at night when the liner was in a contracted state, thereby reducing the risk folds and creases in the material.



#### **4.4.1 LINER WORKS**

Preparation works to retrofit the new liner included the removal of the existing damaged liner. The existing installation consisted of a bolt and batten system upon a concrete waveband approximately two metres below the embankment crest. A total of 740 bolt sets had to be removed which meant cutting and grinding each individual bolt flush with the concrete waveband so that no sharp edges could cut through the new liner material. The undertaking of this process was difficult due to the steep side slope (1 in 2 gradient) of the embankment. All the offcuts of the bolts and the nuts needed to be collected to avoid any sharp material falling to the lagoon base and then damaging the new liner once installed.

### **4.5 CHALLENGES AND LEARNINGS**

#### **4.5.1 NON-TRADITIONAL CONSTRUCTION CONTRACT**

PDP undertook the role of Contract Manager completing the project as the lead contractor but using Client selected subcontractors for 100% of the work. Sub-contractors were preselected prior to the works beginning except for the lining Contractor which required some negotiating between two leading lining companies to provide the site with the best option.

Due to the tight timeframe and immediate remediation being required after the liner rupture, the subcontractors were all contracted under a time and expense basis (excluding the lining contractor). Invoices from subcontractors were checked by PDP before being passed to the client for payment. PDP was aware through communications and onsite supervision of the works carried out on a day to day basis.

The Site's on-site team oversaw the overall project management and provided significant resources in time and personnel to assist the day-to-day work required.

#### **4.5.2 CONCRETE ANCHOR TRENCH**

Clay backfilled anchor trenches are normally cost effective to construct. However, as this construction was in winter, suitable clay was in short supply and the ability to work that clay and obtain a suitable compaction for the anchor trench was deemed too risky to the project. Clay was used as a suitable subgrade on the embankment crest for the liner to lay over. A mass concrete anchor trench was proposed that would provide a suitable mass to hold down the liner without being affected by weather conditions during construction.

Due to time pressure, remediation and construction for relining of the lagoon had been progressing before the design of the anchor trench was confirmed. The earthworks contractor was constantly remediating around the embankment due to the unpredictable weather conditions, and this meant that the embankment levels and location of the crest of the embankment were also continually changing.

The anchor trench was designed to be 500 mm from the crest of the embankment. The photograph below shows the design co-ordinates (white crosses) and onsite mark-up (pink dashed lines) of the start of the anchor trench. The design had been based on a survey completed at the beginning of the project and embankment levels had changed somewhat significantly after that.

It was decided on site that some parts of the lagoon would have a greater separation distance than 500 mm between the crest and the start of the anchor trench. These parts were particularly soft after multiple rain events. Some parts were also stripped more than other parts to dispose of unsuitable material and were filled with clay. The increased separation distance between the anchor trench and internal slope was employed to increase the soil shear strength and ensure that this critical part of the embankment would not slump after the installation was complete.

*Photograph 4: Difference between the anchor trench design done in-house and on site*



#### **4.5.3 CONCRETE ANCHOR TRENCH – EXCAVATION WORKS**

A live electrical cable that supplied power to neighbouring farm fences located around two sides of the SBR and close to the alignment of concrete anchor trench (600 mm wide by 500 mm deep) provided an ongoing challenge due to different drivers from within the Site's business structure. Communications were required between PDP's client contact and 3rd party farm managers who received the benefit of the electric fence power. The site was resistant to replacing the cable. To remove this cable created backfilling and compaction issues from the wet winter clay, over a length of about 110 m, if excavated due to its proximity to the lagoon crest and the location of the new anchor trench.

The cable was also originally identified as being deep enough, once filling was completed that it would remain unaffected. However, due to shear strength readings of the fill sections of the embankment reducing below 50 kPa after swelling from rain, it was decided to increase separation between the embankment edge and the anchor trench to 800 mm rather than the initial 500 mm distance. The realigning of the anchor trench created complications with the electric fencing supply cable where its alignment took it on the inside of the anchor trench and beneath aerator post locations. The site conceded that the control box could be relocated the cable replaced to a location completely removed from the SBR lagoon enclosure. The existing supply cable was disconnected and abandoned but left in place to avoid complications with the need to backfill and compact.

#### **4.5.4 OPERATIONAL RISK MANAGEMENT**

The site undertook further actions to ensure that the future operations and the maintenance works on the SBR liner can be undertaken safely and efficiently.

Two separate internal access ladders were installed to allow safe entry and egress into the SBR during maintenance and desludging operations. For the area where it was expected that temporary equipment may be put, the liner was double skinned with a thicker sacrificial lining material. This would allow temporary desludging pipes to be slid down the internal wall of the SBR.

In order to ensure that in future, there were no operational problems with aerators or decant pumps running if there was a low level, an independent level sensor and level-controller was installed in the SBR. This allowed separate monitoring of the SBR levels and independent electrical isolation of the pumps and aerators from the SBR PLC.



The PLC was replaced and connected to the processing plant SCADA system with alerts sent via short messaging system (SMS) to operator cell phones. In addition a field camera was installed to provide a visual of the operations within the SBR.

#### **4.6 DISPOSAL OF OLD LINER**

There was around 2,400 m<sup>2</sup> of old liner recovered from the SBR. The liner was salvaged for use by the local farmers for silage pit lining. This saved the site in disposal fees for the liner to a landfill and allowed for the suitable reuse of the material.

#### **4.7 REFILLING OF THE SBR AND PROCESS CONTROL**

A separate water take permit needed to be applied for taking of water and filling of the SBR. The SBR was filled during each night to avoid the liner being affected by the direct sunlight and temperature gradients. The fill was controlled to allow the liner to “seat” properly.

As the plant had to start its processing season without delay, the SBR lagoon was filled before the anchor trench was completed. Active microbial biomass was brought from a neighbouring industrial wastewater treatment facility (activated sludge treatment plant) for re-seeding the SBR.

Since the processing did not start at peak, there was an opportunity to feed the SBR with a higher strength primary treated effluent to allow an increase in the rate of biomass development. As the production increased over 2-3 weeks, the high strength diverted wastewater was progressively reduced until peak aeration demand to service the wastewater treatment was achieved.

During commissioning the SBR was able to manage the loads presented to the wastewater treatment system and compliance continued to be met.

*Photograph 5: Relining of the SBR underway*



The completed anchor trench works and the aerators placement, with decant pump and outlet pipes are shown in Photograph 6.

*Photograph 6: Completed Relined SBR in Normal Operation*



## **5 CONCLUSIONS**

An unexpected PLC level controller failure resulted in mechanical damage to the SBR liner that triggered an emergency repair and allowed the processing plant to continue operations. A subsequent unrelated liner rupture occurred within a very short time of the first failure. Once the SBR was drained to examine the failure, it was realised that a seam weld tear had occurred. A decision to replace the liner was made by the site.

A quick turnaround was required for the liner replacement in the middle of winter and various contractors were mobilised to assist with the liner replacement. Inclement weather hampered the operations with earthworks and liner installation required to be fitted between large rain events. Additional work was involved with levelling of the crest and the original liner bolt and batten securing was replaced with a concrete anchor trench. Further operational controls were put in place to manage the SBR operational risks and avoid a repeat of the original failure mechanism. The overall works and liner replacement were completed within a short time frame to the site's satisfaction.

## **ACKNOWLEDGEMENTS**

PDP is pleased to work alongside the client and selected contractors to deliver the replacement liner in a short timeframe and without compromising the processing capacity for the site.

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