Hay Point Shiploader and Berth Replacement: Retrofit to Extend the Service Life by 50 Years

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Abstract

One of the three berths at BHP Mitsubishi Alliance (BMA)'s Hay Point Coal Terminal near Mackay in Queensland, Australia, was constructed in the early 1970s and comprises of a shiploader, three concrete berthing caissons, two mooring caissons and five approach caissons. The berth was designed by Rendel Palmer and Tritton, forerunner to Rendel Ltd and shiploader by McDowell-Wellman. The recently completed shiploader and berth replacement (SABR) project at this terminal involved the installation of a new shiploader and an upgrade of the berth, along with associated infrastructure. The new shiploader has a capacity of up to 8,000 tonnes per hour, which is significantly higher than the capacity of the original shiploader which was 6,000 tonnes per hour. The upgraded berth is suitable for larger vessels, which, in combination with the larger capacity shiploader, will increase the export capacity of the terminal. This paper describes how the service life of such marine facilities can be extended by retrofitting to meet the changing needs of the bulk shipping industry, to increase throughput and to adapt to environmental conditions and climate change.

Keywords: shiploader, berth, caisson, retrofit, upgrade

1. Introduction

BHP Mitsubishi Alliance (BMA) appointed Aspec Engineering Pty Ltd supported by Rendel Limited (Aspec/Rendel) to perform an independent review of modifications to the existing berthing caissons and the installation of new structures for the shiploader and berth replacement (SABR) project at Berth 2 of the Hay Point Coal Terminal.

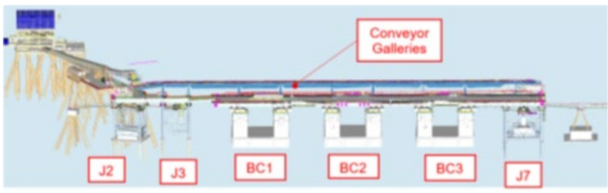

Figure 1 – Hay Point Berth 2 Layout

The detailed design for SABR was carried out by Aurecon Australasia Pty Ltd (Aurecon). The purpose of Aspec/Rendel's review was to confirm that the detailed design for the shiploader and berth replacement has adequate capacity to withstand the required design loads and comply with the project requirements and Australian Standards.

2. Background

BHP Mitsubishi Alliance (BMA) is a mining company formed as a partnership between BHP Ltd and Mitsubishi Development Pty Ltd. It operates several metallurgical coal mines in the Bowen Basin region of Queensland, Australia and exports product through the Hay Point Coal Terminal which is located 40 km south of Mackay.

The history of the Hay Point Terminal can be traced back to the Utah Development Company (Utah) which was a subsidiary of the United States-based Utah Construction Company. Utah was involved in the exploration and development of high-quality metallurgical coal resources in Queensland. In the 1960s, Utah discovered significant deposits in the Bowen Basin, leading to the establishment of mining operations in the region.

To facilitate export, Utah constructed the Hay Point Coal Terminal with an offshore berth (Berth 1) and onshore stockpile facilities. The terminal was strategically located near the mines and had access to deep water, making it an ideal site for exporting coal. The construction of Stage 1 of the terminal began in the late 1960s and was completed in 1971. The berth was designed by Rendel Palmer and Tritton, forerunner to Rendel Ltd and Shiploader 1 (SL1) by Marfleet & Weight Pty Ltd (Marweight).

Utah expanded their operations in the Bowen Basin, leading to increased production. This necessitated the expansion of the Hay Point Coal Terminal with a second berth. The scheme adopted for the berth comprised the construction of three concrete berthing caissons, two mooring caissons and five approach caissons. The design of the berth was by Rendel [4] with the Shiploader 2 (SL2) supplied by McDowell-Wellman.

Construction of Berth 2 was carried out by a joint venture between Christiani & Nielsen and John Holland. Caissons were constructed in a temporary dry dock in Mackay harbour then floated and towed to the site of the offshore berth [6]. The use of caisson construction for an open sea berth was very innovative at the time and served to minimise site labour and disruption to loading operations on Berth 1. The project was completed in 1975. Figure 2 shows SL2 loading a ship.

Figure 2 – SL2 Loading ship at Berth 2

In the 1980s, as the mining industry in the region grew, BHP acquired Utah. BHP and Mitsubishi then formed a partnership to consolidate their mining operations in the Bowen Basin. This partnership gave rise to the BHP Mitsubishi Alliance (BMA) and marked the beginning of their joint involvement in the development and operation of the Hay Point Coal Terminal. Under the ownership and management of BMA, the terminal underwent several expansion projects to increase its capacity. These expansions included the construction of an additional berth (Berth 3) and Shiploader 3 (SL3) as part of the HPX3 Project which was completed in 2014. Figure 3 shows Berth 3 and SL3 constructed as part of the HPX3 Project.

Figure 3 – SL3 Loading ship at Berth 3

Once SL2 reached 30 years of age it required increased maintenance due to deterioration and obsolescence of equipment on the machine. A significant refurbishment was undertaken in 2009/2010. At the same time the original arch fenders on the berth were replaced with cell fenders and frontal panels which could be more readily maintained.

One of the main objectives of the Shiploader and Berth Replacement (SABR) Project was to extend the design life of Berth 2 by 50 years maximising use of the existing structure where possible. This particularly focussed on the reuse of three large existing concrete berthing caissons. The berth and caissons needed to be adapted to new project requirements, such as new climate conditions with higher wave loads and tide levels, larger design vessels and increased superstructure and shiploader loads.

The berth was extended to optimise the accommodation of larger design vessels. This was achieved through the construction of three new jacket structures. The consideration of jacket structures for the berth expansion enabled the berth to remain in operation during prefabrication of the structures, minimising operational downtime.

The project included a new shiploader (SL2A) similar to SL3 with a capacity of 8,000 tonnes per hour to replace the original 6,000 tonnes per hour McDowell-Wellman machine.

3. Wave Immunity

Following the Australian Standards (AS 4997-2005), ultimate design conditions for normal marine structures such as the Hay Point Berths are typically based on 10% probability of exceedance in 50 years. The corresponding event to this would have a return period of 500 years. Metocean studies found that the Berth 2 deck would be subject to wave impact for such events.

Cyclone Ului impacted the Queensland Coast in March 2010 and caused damage to ancillary structures at the Hay Point Coal Terminal. The track of the cyclone can be seen in Figure 4. This raised the awareness of the vulnerability of the facility to cyclonic waves.

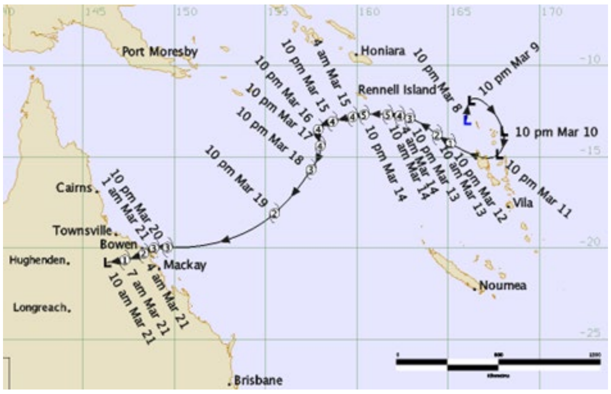

Figure 4 – Cyclone Ului (2010) Track

Wave heights recorded from Cyclone Ului in March 2010 at Hay Point Berth 2 were found to be slightly higher than the original design wave. To mitigate the risk to the berth from higher wave loads in the future, BMA decided to modify the berth to resist higher wave loadings with a 1000-year return period as shown on Figure 5.

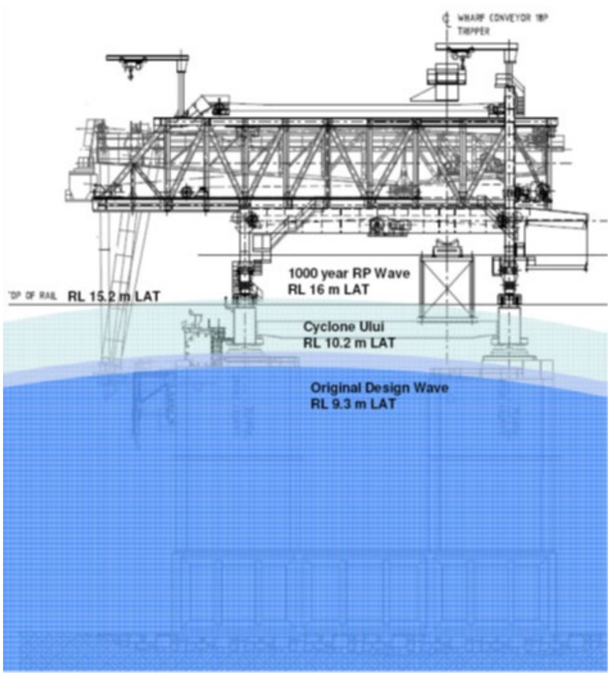

Figure 5 – Wave Events on Berth 2

Cyclone Dylan in January 2014 and Cyclone Debbie in March and April 2017 also impacted the Hay Point Coal Terminal in a similar way to Cyclone Ului with elevated wave levels. Figure 6 shows a photograph of the waves during Cyclone Dylan.

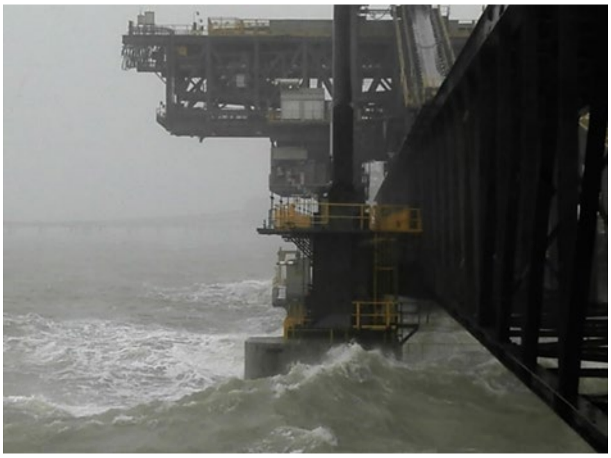

Figure 6 – Cyclone Dylan Waves at Hay Point (Source: BMA)

To address the observed wave events, the adopted design raised the berth deck so that the higher waves will not impact the deck girders. However, wave forces on the caissons will still be increased from the original design. There were concerns that the caissons could not resist such forces. In particular, the resistance of the caissons against sliding on the foundations was found to be inadequate.

4. Original Caisson Construction

Figure 7 and Figure 8 show a diagrammatic representation of Hay Point Berth 2. Three large berth caissons (BC's) were used for forming the support for No. 2 berth. The bases of BC1 and BC3 are 46 m long, 39 m wide and 8 m deep, each divided into 99 cells in plan. BC2 is 4 m wider, having 110 cells, to provide extra buoyancy to transport the shiploader to Hay Point.

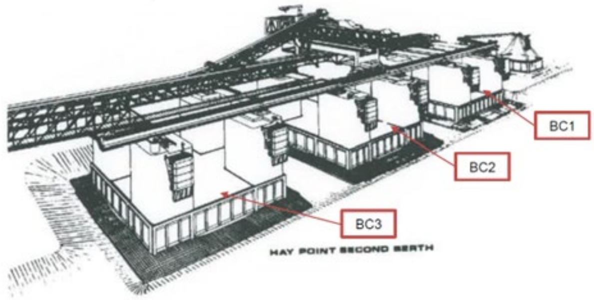

Figure 7 – Hay Point Second Berth Caisson Structures

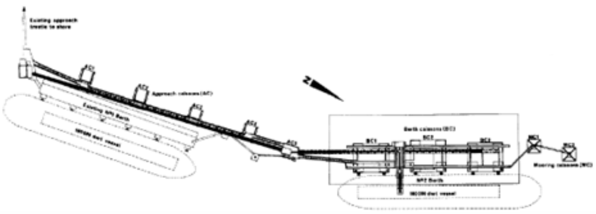

Figure 8 – Plan View of Berths

Each BC has a 12 m square and 18 m high reinforced concrete cellular column on each corner. These columns have three main functions - to support the superstructure above high tide level, provide flotation stability during grounding of the caisson, and resist ship berthing forces on the finished berth. The top of the BC bases are about 9m below extreme low tide and the underside of the superstructures approximately 6m above extreme high tide.

A steel superstructure to carry the shiploader and conveyor is mounted on top of the BC columns as shown in Figure 9.

The caissons were assembled from pre-cast wall units varying in thickness from 200 mm to 400 mm, with cast-in-place floors and roofs, as shown on Figure 10. The BC columns were also slip formed for speed of construction and to eliminate construction joints as far as possible [4].

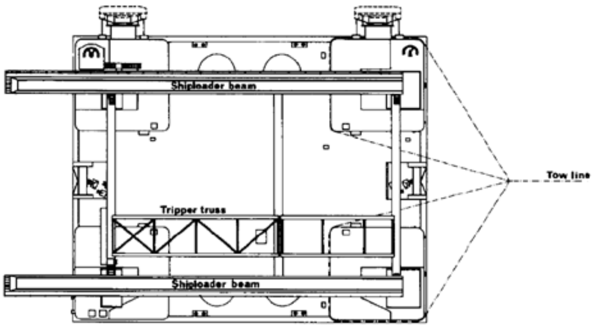

Figure 9 – Plan on Berth Caisson (in Final Flotation Arrangement)

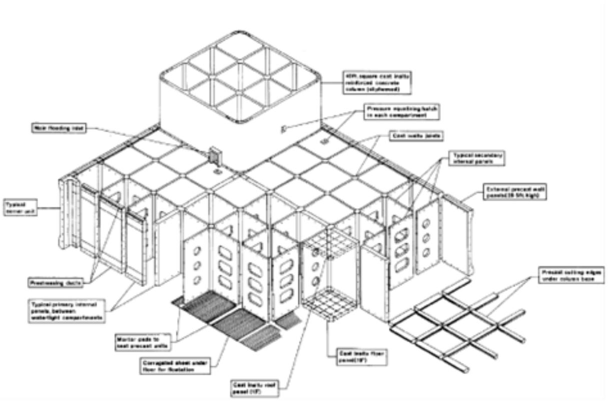

Figure 10 – Construction of Caissons

The foundations of the berth caissons in their final position at Hay Point are shown on Figure 11.

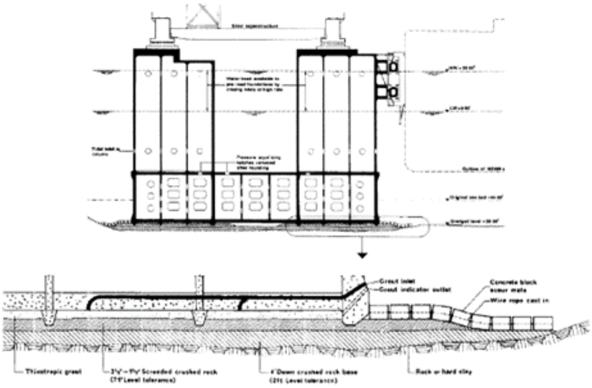

Figure 11 – Berth Caisson Foundations

The caissons are seated on four screeded stone pads each 12 m square, directly under the four columns. The seating areas on the underside of the caisson were fitted with 380 mm deep cutting edges, which were designed to penetrate 230 mm into the stone beds.

To simulate future loading due to cyclones, wave forces, ship berthing and passage of the shiploader, the foundations were pre-loaded. The spaces between the stone beds and the underside of the caissons were then grouted using a mix comprising 1:1 sand and cement with 0.6 to 0.7% Bentonite.

After model testing in wave conditions, it was also decided to place anti-scour mats around the caissons to protect the bed material as illustrated on Figure 11.

The University of Queensland (UQ) determined the wave forces on the smaller caissons (BC1 and BC3) by means of a hydraulic model [1]. UQ's approach also incorporated additional conditions in calculating the design wave forces [2]:

- Water was allowed to enter the space inside each column through holes, located one in each inward facing side of the columns.
- The gaps along the lower edges of the caisson base were not left unobstructed. These gaps were closed for 90%of their area.

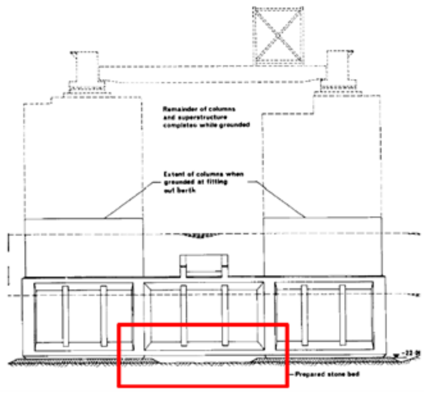

Figure 12 – Openings under Berth Caisson

By having small openings at the base of the columns, it is possible to achieve a near constant water level within the columns, corresponding to still water level. This reduces the net vertical forces on the caisson.

5. Caisson Site Investigations

The Hay Point caissons are now around 50 years old. Hence, there was a need for site investigation and testing to determine the requirements for a 50-year life extension. Testing was carried out on the original approach caissons (which became redundant) to determine the condition of the concrete, reinforcement, and prestressing strands. These site investigations showed that the prestressing strands were in a degraded state [7].

Since the three berthing caissons were of the same construction and were installed at the same time, it was assumed that the degradation of the prestressing strands observed in the approach caissons should also be considered for the condition of the Berth 2 caissons. It was therefore considered that the prestressing may not be effective for the full 50-year life extension, and this should be considered when analysing the capacity of the caissons.

No significant signs of corrosion were present in the underwater reinforcement bars of the berthing caisson and full reinforcement capacity was considered in the structural assessment.

Figure 1 – Damage of prestressing wires in redundant approach caisson (Source: BMA)

Material properties for the existing caissons concrete and reinforcement were derived from core samples taken from the hull roof slab and one of the columns of one of the berthing concrete caissons.

The characteristic strength of concrete was assessed to be 37.6 MPa. Reinforcement steel yield strength for the structural assessment of the existing concrete caissons was:

- 265 MPa for #4 and #6 bars
- 255 MPa for #9 bars

6. Project Design Criteria

As the cyclonic event adopted for design of the SABR project was based on a 1,000 -year return period, Berth 2 was redesigned to accommodate new wave heights and tide levels. This included an allowance for climate change (sea level rise).

A 3D physical model test was undertaken by National Research Council Canada [3], to assess the stability of the Berth 2 caissons under the reassessed cyclonic conditions shown in Table 1. Global loads and moments due to wave actions were measured in the three berthing caissons. These were used to determine wave pressure distributions on the concrete caissons' walls and superstructure.

Table 1 – Design waves at Berth 2

Return Period (years)	(m LAT)	(s)	(m)	(m LAT)
20	7	8	7.8	10.3
100	7.5	9	10.7	12.9
1,000	7.9	11	13.2	16.0

Since the original design of Hay Point Berth 2, global shipping trends have shifted towards larger bulk carriers in the world fleet. The original design was for a bulk carrier vessel of 100,000 DWT. However, the Newcastlemax bulk carrier of 210,000 DWT was adopted in as the maximum design vessel for SABR project design. The characteristics of both vessels can be found in the table below.

Table 2 – Design vessel properties – 100,000 DWT and Newcastlemax bulk carriers

Property	Original Berth 2 Project	SABR Project
DWT	100,000 t	210,000 t
LOA	262 m	300 m
Beam	40.5 m	50 m

The larger Newcastlemax bulk carriers required the shiploader long travel rail beams to be extended to provide full coverage of the vessel without the need to move the ships during loading (warping).

7. Jackets

Prefabricated jacket structures were adopted for the extensions to the berth rather than traditional piling. These were designed for the new superstructure and wave loading. This construction type was selected to enable fabrication off site, to reduce the extent of site marine work and facilitate faster construction.

As well as accommodating the extension to the shiploader rails, Jacket 7 included an integral berthing dolphin to protect the wharf. For mooring of the larger ships, two new mooring jackets at the southern end of the berth (Jackets 2 and 3 shown in Figure 14) were provided.

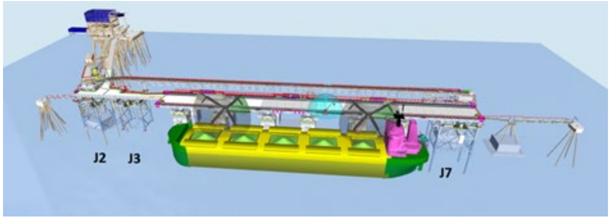

Figure 14 – Location of jackets – Berth 2 layout (Source: BMA)

The new jackets geometry is presented in the following figure. Mooring Jacket 2 (J2) and Jacket 3 (J3) comprised four legs with piles inside and the berthing Jacket 7 (J7) comprised five legs with piles inside and they all have a cut off level of Mean High-Water Springs (MHWS). Mooring points were located in each one of the jackets.

J7 differs from the other jackets as it is equipped with a fender to take berthing loads whereas J2 and J3 take mooring loads only

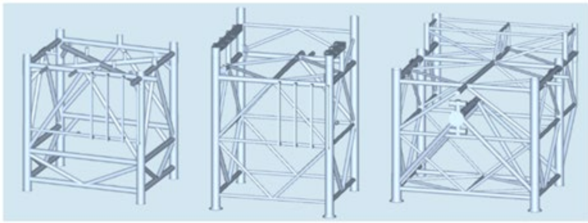

Figure 15 – Jackets geometries (Left to right – Mooring Jacket J2, Mooring Jacket J3 and Berthing Jacket J7)

The fendering system was analysed under extreme berthing conditions by means of a non-linear finite element analysis (FEA) model as shown in Figure 16. This demonstrated that during a fender overload event the first plastic region occurred at the horizontal element of the fendering system (shown in green in Figure 16). The benefit of this was to facilitate any repairs following an overload event in a region above the water level [5].

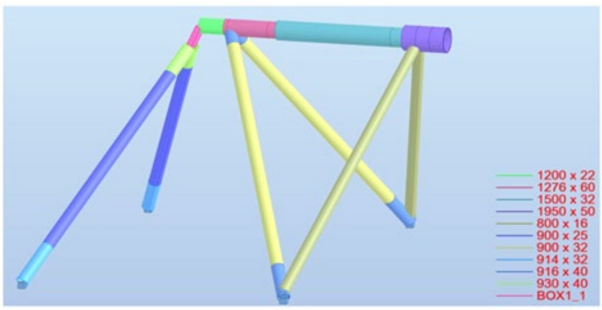

Figure 16 – Jacket 7 fendering system non-linear finite element model

All members and tubular joints of the jackets were checked using ASAS software as described below.

The wave module was used to calculate wave, current and wind loading. The effect of marine growth was also considered. The structural analysis FEA model module was used to analyse the jackets as framed structures. Supports were defined as springs to allow for soil-structure interaction.

A post-processing module was used to check the structures for the results of elements analysed by the structural analysis module. The code checking procedures for the jackets used the API Recommended Practice 2A-LRFD which is the widely used industry standard for jacket design.

A fatigue calculation module was used for the estimation of fatigue life for tubular and beam joints. The module automatically retrieves wave information from a previously generated analysis database and calculates fatigue life using S-N curves and Miner's Rule (cumulative fatigue damage).

8. Caisson Modifications

To achieve the increased cyclone immunity, the superstructure and the berth link were replaced and raised by several metres to adapt them to the required tide levels and wave heights. The geotechnical stability of the caissons against sliding, overturning, and bearing was assessed with the increased wave loadings and the new above deck structures. It was found that additional ballast was required in each caisson.

To raise the superstructure, the design adopted retrofitted steel girders on top of the caisson columns of the existing caissons as shown on Figure 17. These were colloquially called "super dog bones (SDB)". These structures served multiple purposes in the design including:

- Connecting the front and rear columns of the caissons to induce a portal action perpendicular and parallel to the berth, reinforcing the caissons in both directions.
- Transferring the various applied loads evenly through the structure and into the concrete caissons.
- Providing a platform to raise the bearing level by the required amount.
- Providing filling compartments to facilitate the necessary ballasting required for caisson stability.
- Providing platforms for mooring equipment.

Additional mass over and above that required for ballasting was added to the SDBs so that gravity connection to the top of the caisson columns could be achieved. This resulted in a substantial reduction in site work for connecting the SDBs to the columns. The total amount of ballast added to each caisson is as follows:

- BC1: 7,652 tonnes
- BC2: 6,629 tonnes
- BC3: 7,996 tonnes

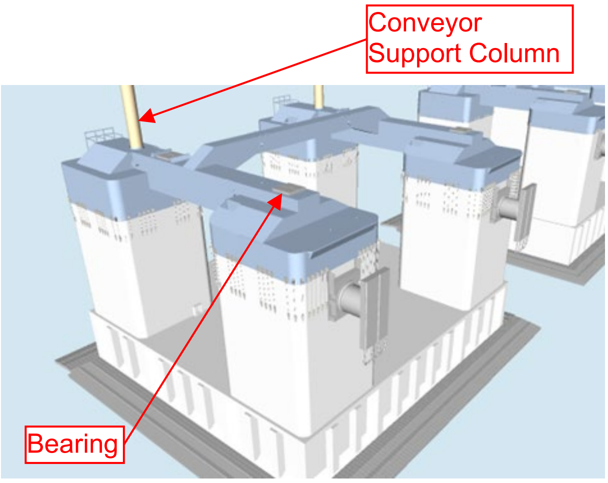

Figure 17 – SDB (blue) and concrete berth caisson with deck omitted (Source: BMA)

New conveyor loads are transmitted to the top of the concrete caissons' columns by the conveyor support columns. The bearings and the conveyor support columns are shown in Figure 17.

Figure 18 shows the structural model used for the caisson assessment [5]. This ignored the effect of the caisson hull as a conservative assumption should the prestressing become ineffective during the remaining life of the structure.

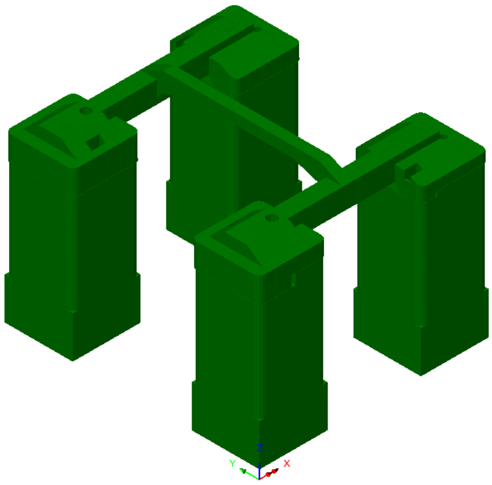

Figure 18 – Finite Element Model of BC2 with modifications

Geotechnical modelling using Plaxis 2D software was undertaken to determine the response of BC2 to the proposed loading arrangement for the modified caisson. The spring stiffnesses beneath both the ribs and slabs of BC2 were determined to enable a structural assessment of the internal forces within the caisson due to the proposed loading condition.

The structural resistance of the existing concrete caissons with the SDB design was analysed both with the caisson hull intact and with the portal action as shown in Figure 18. Finite element modelling and post-processing checks showed that the existing structure was fully compliant with Australian Standards if some prestress was present.

Floor slab overutilisations were identified in the case of total loss of prestress. All other structural elements pass code checks. However, it was found that the structure can withstand redistribution of loads if the floor slabs become ineffective.

9. Superstructure

The existing superstructure (including topsides, wharf deck structure, link structure and associated conveyor structures) and Shiploader SL2 were dissembled allowing the new Berth 2A superstructures and Shiploader SL2A to be fabricated and installed on top of the existing caissons and the new jacket structures. The new SL2A weighs 1,900 tonnes, compared to the SL2 which was 1,100 tonnes.

Aspec/Rendel independently estimated the design loadings for the galleries from information provided in the Basis of Design (BoD) and loading information from the shiploader audit. This included structural and mechanical dead loads, flooded belt loads, spillage loads and loading from the tripper. The entire gallery structure with support structures and the head and tail end were modelled. The Strand7 analysis model is shown in Figure 19. The galleries and head frame were found to be adequate for strength, serviceability and fatigue.

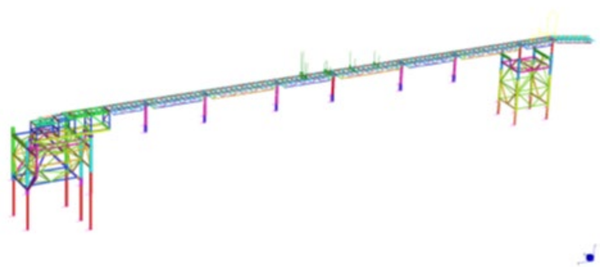

Figure 19 – Strand7 model of conveyor galleries

The rail girders that support the deck and the rails are 3.5m deep. Decking is provided across the full extent of the wharf. The deck slab thickness is 550 mm. Aspec/Rendel built a model in Strand7 based on the information provided. The caissons are treated as springs in series with the springs for the elastomeric bearings.

Figure 20 shows the Strand7 model of the deck structure with the shiploader positioned near the centre and the 4 springs per pedestal for the bearing pads on rigid bases. At the northern jacket, the pads are mounted on the jacket structure. The wharf deck structures were found to be adequate for strength, serviceability and fatigue.

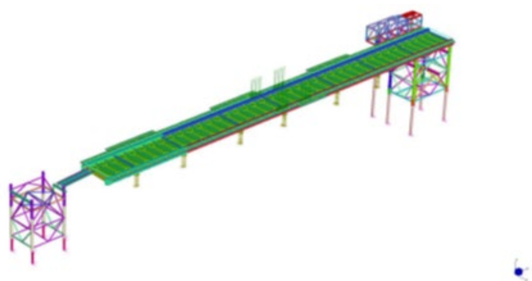

Figure 20 – Strand7 model of the wharf deck

10. Shiploader

The new shiploader SL2A is a rail mounted, long-travelling, luffing, shuttling boom machine. The machine is designed for manual operation from an A-frame mounted operator's cabin, with operator visibility augmented via CCTV cameras. SL2A has a nominal throughput of 8,000 tonnes per hour. However, the structural design is for 10,000 tonnes per hour operation to enable a future capacity upgrade.

The design of SL2A was subject to an independent design audit in accordance with AS 4324.1 by Aspec/Rendel. Key parameters for the shiploader are shown in Table 3.

Table 3 – Machine Parameters Summary

Description	Value	Unit
Nameplate throughput	8000	t/hr
Surge throughput	9800	t/hr
Conveyor belt width	2500	mm
Conveyor belt trough angle	35	Deg
Conveyor belt speed	4.0	m/s
Boom length	50.6	m
Rail centres	21.0	m
Wheelbase	18.0	m
Luff range (operating)	-6.5 to +90	deg

Figure 21 shows the completed shiploader being unloaded onto Berth 2 at Hay Point.

Figure 21 – Shiploader SL2A and Berth 2 (Source: BMA)

The following tasks were carried out as part of the shiploader audit.

- Review of BMA's design criteria
- Structural audit to AS 4324.1-2017

- Mechanical audit
- Audit of machine operating parameters and coal handling capacity
- Fatigue assessment of the machine
- Review of compliance with BMA requirements
- Review of design for transportation
- Verification of machine mass and final inspections

Figure 22 shows the structural model of Shiploader SL2A. SL2A was found to be adequate for strength, serviceability, and fatigue.

Figure 22 – Structural Model of Shiploader SL2A

11. Conclusion

Sustainability through reuse of the caissons was a significant theme of the SABR project which has extended the service life by 50 years and increased resistance to withstand cyclones. The modifications will allow the existing concrete berthing caisson structures to be conserved and reused. Construction using jacket structures has been effectively utilised to extend the berth. Benefits include fabrication offsite reducing marine works and berth downtime. Replacement of SL2 with a new machine designed to current standards should improve the efficiency of the terminal.

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