Warrnambool Breakwater – January 2018

Warrnambool City Council

Port of Warrnambool Asset Management Plan

Breakwater Assessment

August 2018

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1. Introduction

1.1 Background

Warrnambool City Council (WCC) engaged GHD in October 2017 to prepare an Asset Management Plan for assets within the Warrnambool Harbour Precinct. As part of the development of the overall Asset Management Plan, WCC requested GHD conduct a visual inspection and condition assessment of the Warrnambool Breakwater.

The breakwater was visually inspected from ground level to determine the current condition of each component and the nature and extent of deterioration. Maintenance strategies to be incorporated into the overall Asset Management Plan were then determined based on observations from the inspection, and comparison with information obtained through previous investigation and assessment.

A number of previous investigations completed on the breakwater have been reviewed and incorporated into the findings of the breakwater assessment. The findings of the previous assessments were also considered by GHD during the inspection phase and through development of the overall Asset Management Plan. A review of previous investigations has been included in Section 3 of this Assessment Report.

Council conducted a photographic survey of the exterior face of the breakwater both sea side and land side on 9 March 2018 which was provided to GHD for the purposes of comparative assessment with previous investigations and has been included in Appendix A. This survey was undertaken by Council in lieu of GHD due to difficulty of scheduling the inspection in suitable weather conditions.

The inspections have been conducted in accordance with the Ports Australia – Wharf Structures Condition Assessment Manual (2014) with the inspection and reporting methodology customised to suit the requirements of Warrnambool City Council.

The inspection and assessment is intended to provide a baseline for future inspection, monitoring and assessment of the breakwater. This report presents the findings of the inspection and assessment for incorporation in the overall Warrnambool Harbour Asset Management Plan.

1.2 Purpose of this Assignment

Warrnambool City Council engaged GHD conduct a visual inspection and report on the condition of the Breakwater to allow for:

- Up-to-date condition assessment of the condition of the breakwater in line with an established standard to provide a “baseline” for further monitoring, investigation and assessment.
- Identification of the nature and extent of deterioration in the breakwater to enable a risk based approach to management of harbour assets.
- Comparative assessment of the breakwater and defects with previous investigations and quantification of defects and the rate of deterioration over time.
- Development of appropriate remedial and maintenance strategies to maintain the structural integrity of the breakwater in line with the Warrnambool Coastal Management Plan.
- Assess the safety and amenity of the breakwater in accordance with current Australian Standards and Warrnambool City Council’s operational and OH&S requirements.

1.3 Assumptions

- Water-based (vessel) or underwater (diving) inspection was excluded from the assessment due to inclement weather during the time of the inspections. The water-based inspection was supplemented by subsequent photographic survey of the exterior face of the breakwater conducted by Council which was provided to GHD for the purposes of comparative assessment with previous investigations.
- Where access was limited during the inspection (i.e. below water level), the condition of structure is assumed to be consistent with previous observations or consistent with the condition of similar areas which were visible during GHD's inspection.
- No structural analysis, modelling or load rating has been completed as part of the assessment.

1.4 References

Connell Wagner, "Warrnambool Breakwater Condition Inspection & Forward Works Planning", 1998.

Connell Wagner, "Warrnambool Breakwater Condition Inspection & Forward Works Planning", 2006.

Woodhouse Graesser Johnson Warrnambool Breakwater Precinct, Feature and Level Survey, 2008.

Aurecon, "Warrnambool breakwater diagnostic conditions investigation report", 2009.

Mainmark, "Appendix B.02 - Warrnambool Breakwater Joint Condition Investigation for WCC", 2015.

Elstone Diving Services, "Inspection of Breakwater", 2017.

Ports Australia – Wharf Structures Condition Assessment Manual (2014)

AS 1657 Fixed platforms walkways stairways and ladders – design, construction and installation.

AS4997 Guidelines for the design of maritime structures.

AS 2156.2 Walking tracks - infrastructure design.

AS1428.1 Design for access and mobility.

AS 3600 Concrete Structures.

AS 5100 Bridge Design.

1.5 Limitations

This report: has been prepared by GHD for Warrnambool City Council and may only be used and relied on by Warrnambool City Council for the purpose agreed between GHD and the Warrnambool City Council as set out in Section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than Warrnambool City Council and the State Government of Victoria arising in connection with this report.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and project proposal and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report.

GHD has prepared this report on the basis of information provided by Warrnambool City Council, which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

GHD has prepared the preliminary cost estimates set out in Section 11 of this report ("Cost Estimates") using information reasonably available to the GHD employee(s) who prepared this report; and based on assumptions and judgments made by GHD.

The preliminary Cost Estimate has been prepared for the purpose of development of the Asset Management Plan and must not be used for any other purpose.

The Cost Estimate is a preliminary estimate only. Actual prices, costs and other variables may be different to those used to prepare the Cost Estimate and may change. Unless as otherwise specified in this report, no detailed quotation has been obtained for actions identified in this report. GHD does not represent, warrant or guarantee that the works can or will be undertaken at a cost which is the same or less than the Cost Estimate.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

2. Structure Details

2.1 Background

The Warrnambool Breakwater was constructed in the late 1880's and early 1890's and comprised keyed concrete block (masonry) construction. The concrete masonry blocks (approximately 5 ft x 6 ft x variable length) are founded on a cement apron constructed using cement bags of approximately 12 tonne weight and keyed into the rock seabed below. Phase 1 of the breakwater was constructed 30 ft (9 m) wide and approximately 1033 ft (315 m) long and extended from the timber viaduct which serviced the breakwater.

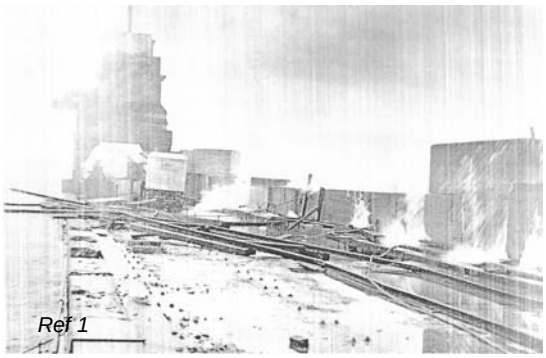
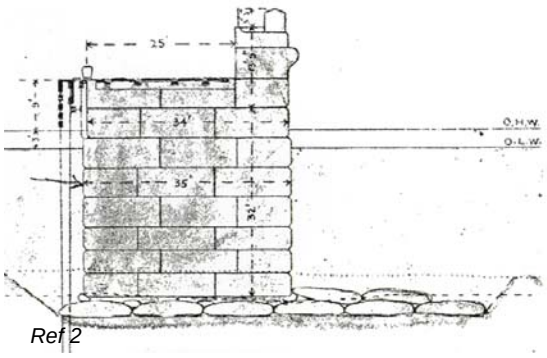


Figure 1 Warrnambool Breakwater construction circa 1890 and completed Breakwater in early 1900's



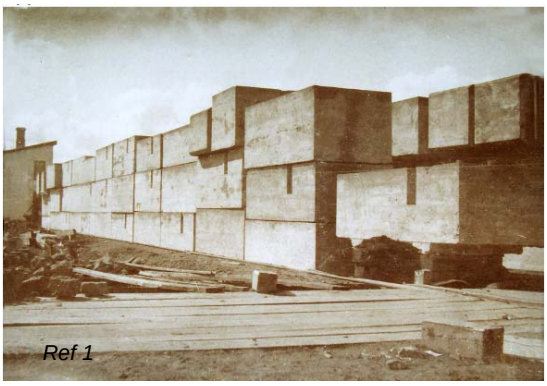


Figure 2 Warrnambool Breakwater keyed concrete block masonry construction

The breakwater was extended by 400 ft (122 m) in 1915 due to provide additional protection to the harbour from storms and swell from the south east direction (Connell Wagner – Condition Inspection Report 1998). The Phase 2 extension comprised of similar (concrete masonry block) construction as the Phase 1 works.

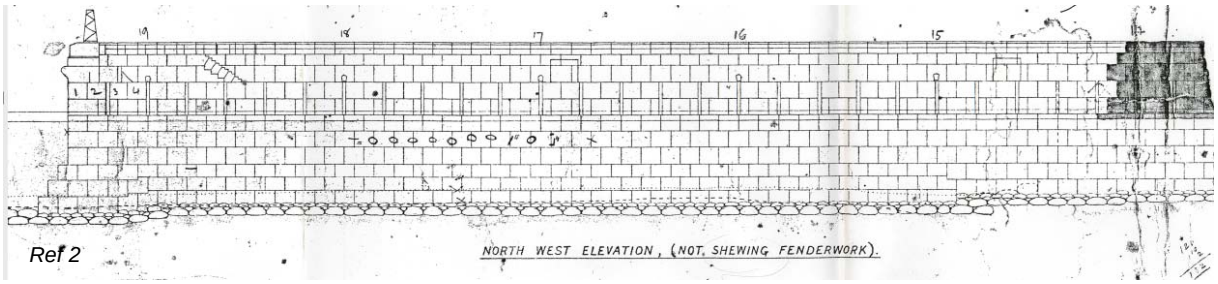


Figure 3 Warrnambool Breakwater extension circa 1915

Ref 1. Photo provided by Warrnambool City Council (sourced from the State Library of Victoria).

Ref 2. Image provided by Warrnambool City Council.

Figure 4 Location of Warrnambool Breakwater

Rock armouring was placed on the ocean side of the breakwater adjacent to the (Phase 2) extension. Anecdotal evidence suggests that the rock armouring and additional extensions to the upper parapet wall were installed in 1975, for the purpose of minimising structural movement by reducing scour that would otherwise allow the breakwater to subside and also by passively resisting further overturning of the breakwater (Connell Wagner – Condition Inspection Report 1998 and 2006).

GHD was not able to verify the extent of the rock armouring and parapet extension works believed to have been conducted in 1975. A detailed account of the breakwater history can be found in Connell Wagner's Condition Inspection Reports for the Breakwater (1998 and 2006).

Figure 5 Warrnambool Breakwater - Current Configuration (2018)

Ref 1. Image curtesy of Google Maps

3. Previous Investigations

3.1 Supplied information

Some relevant documentation has been received from Warrnambool City Council with the tender documents and includes:

- Connell Wagner, “Warrnambool Breakwater Condition Inspection & Forward Works Planning”, 1998.
- Connell Wagner, “Warrnambool Breakwater Condition Inspection & Forward Works Planning”, 2006.
- Woodhouse Graesser Johnson Warrnambool Breakwater Precinct, Feature and Level Survey, 2008.
- Aurecon, “Warrnambool breakwater diagnostic conditions investigation report”, 2009.
- Mainmark, “Appendix B.02 - Warrnambool Breakwater Joint Condition Investigation for WCC”, 2015.
- Elstone Diving Services, “Inspection of Breakwater”, 2017.
- CSE Group, “Level Monitoring Survey” May 2018.

3.2 Summary of previous investigation

A review of the previous assessment reports has be conducted by GHD as part of the Breakwater Assessment and is provided below.

3.2.1 Connell Wagner, “Warrnambool Breakwater Condition Inspection & Forward Works Planning”, 1998.

The report prepared by Connell Wagner in 1998 comprised a comprehensive inspection of the breakwater above and below water level during April 1998. The significant findings/ recommendations of the 1998 inspection report are included below:

- The condition assessment does not indicate an immediate need for major remedial works. However, major remedial works may be required in order to minimise future ongoing structural settlement of the breakwater. These major works would be very costly and difficult to perform.
- Periodic survey monitoring of the breakwater is recommended. Monitoring should be implemented immediately and conducted for at least an 18 month period to establish trends.
- Various minor repairs to the breakwater and jetties are required to address current safety issues. Minor repairs include:
  - Hand railing replacement;
  - Painting of cast iron bollards;
  - Replacement of navigational beacon mounting bracket;
  - Replacement of breakwater and jetty ladders;
  - Replacement of selected lower landing crossheads;
  - Patching of concrete roadways joints;

3.2.2 Connell Wagner, "Warrnambool Breakwater Condition Inspection & Forward Works Planning", 2006.

Connell Wagner conducted a follow-up condition assessment and forward works programme in 2006 which was intended to expand on the previous condition assessment and forward works programme prepared by Connell Wagner in 1998.

The 2006 assignment comprised an on-site review of the condition of the breakwater and associated structures. The review was restricted to an above water visual inspection only (conducted in August 2006). The inspection was intended to assess the structural condition as well as identify hazards to the public and operational personnel using the Breakwater.

The significant findings/ recommendations of the 1998 Inspection Report are included below:

- Undertake survey monitoring of the breakwater at regular intervals (yearly) to establish the ongoing rate of deterioration.
- Installation of plates over gaps created by deterioration to tops of breakwater vertical timber fenders and removal of bollards and the nearby kerb reinstated to a consistent profile.
- Installation of signage warning the public of the slippery surface and falling hazards on the breakwater boat ramp.
- Installation of hand railing at the breakwater edge along the length of the breakwater boat ramp.

3.2.3 Aurecon, "Warrnambool breakwater diagnostic conditions investigation report", 2009.

Aurecon conducted a detailed investigation and report of the Breakwater surface condition in 2009. The investigation consisted of two phases including, a) detailed visual inspections and b) exploratory investigations at selected locations.

Aurecon identified a number of remedial repair options and recommendations for the breakwater which included:

- **The 'essential remedial' works** relate to those where defects pose a potential risk to public safety and include:
  - Heavily delaminated and spalled rendering and concrete;
  - Extensive defects along parapet capping; and
  - Other significant defects where further material may become dislodged or surfaces are accessible to the public.
- **The 'near future' work** includes a range of works designed to remedy the defects and include a preventative remedial component for the long term durability of the Breakwater including:
  - Render repairs to the tops of parapet walls;
  - Removal of existing reinforced concrete fascia walls and repair with a suitable face treatment;
  - Prevention of movement related stress in the top of the main wall;
  - Repairs to delamination and cracking in rendered ramp wall;
  - Repairs to cracking and spalling at the interface between the top of the main wall and the new walkway pavement;

- **The 'Ongoing maintenance'** works are required as part of the maintenance of all structures such as these and could form part of an ongoing maintenance program and as part of a maintenance manual and include:
  - Regular removal of salt stains as they appear on the main wall and the prevention of significant salt deposit build up will contribute to maintaining a reasonable wall appearance.
  - Removal of the surface mortar to create recessed joints should reduce fretting in the masonry joints, enhance visual appearance. Raking out the fretting mortar at joints and expressing these joints by recessing them is likely to minimise future fretting of mortar.

3.2.4 Mainmark, "Warrnambool Breakwater Joint Condition Investigation for WCC", 2015.

Mainmark undertook an investigation of the Warnambool Breakwater in September 2015. The investigation was to determine the presence and magnitude of voiding within the wall structure; particularly along the joints between the concrete blocks that form the breakwater. The investigation involved drilling 6 cores into the wall, logging the extracted samples and viewing the core holes with a camera.

The findings of the investigation include:

- Significant deterioration was observed between the block joints of the structure. Wave action over the years has forced sand and water through the joints, resulting in loss of material. In the cores retrieved, and in the camera study of the core holes, it was evident that wave action has eroded the blocks along the joint lines.
- The overall percentage of void discovered based from the cores length range from 4% to 27%. The boreholes that showed the greatest material loss are located mid-way along the Phase 1 construction (Refer to Figure 4 for reference). Although the voids can be found throughout the core logs, the highest proportion of the voids are found to be 7-8m below pavement surface. Furthermore, the action of the water is causing dissolution of the cement matrix, increasing the porosity of the structure.
- Bore holes taken during the investigation intersected a void previously treated with Uretek resin in July 2009. The Uretek resin has provided a long term seal of the joint against water movement and prevented further deterioration. The ductility of the Uretek material, its chemical stability and high bond strength have contributed to the longevity of this solution.
- A cement filler was injected into the joints in 2010. There was no evidence of this filler found and it is most likely that this filler has been washed out by wave action.
- Mainmark recommended the following action be taken for the Breakwater:
  - Fill open joints throughout breakwater with Uretek resin
  - Place gabions to the seaward face to protect against ongoing scour.
  - Place concrete between the gabions and the wall to fill the cavities scoured under the seaward face.

3.2.5 Elstone Diving Services, “Inspection of Breakwater”, 2017.

Elstone Diving Services (EDS) was engaged to conduct a visual/video inspection of the Warrnambool Breakwater in August 2017.

EDS inspected the base of the wall (from sea bed to water level) along the full length of the sea (south) side of the wall. The north side of the wall was not inspected as this area was of less concern.

The inspection identified a number of defects relating to penetrations in the main wall and dislodgement of the concrete block masonry. A summary of the findings is provided in the table below (Chainages given from the aquarium end of the wall) and they are marked on the defect plans in Appendix B.

Table 1 Defects summary

Chainage (m)	Description	Location
27	Undermining and penetration	Underneath the wall. 6 m long and 0.6 m deep
41	Large cracking in the breakwater	Crack extending from seabed up to 1.5 m penetrating 1.5 m (full depth of a block) into the wall
65.5	Large cracking in the breakwater	Crack extending from seabed up to 1.5 m penetrating 2.0 m (full depth of a block) into the wall
67.7	Large hole in the breakwater	Hole 1.2 m wide and 0.7 m high penetrating 1.5 m into the wall
107.5	Large dislodged blocks	Hole of one block size (1.6 m square)
141.6	Large gap in the breakwater	Gap (100 mm wide) extending from seabed up to water level penetrating 1.5 m (full depth of a block) into the wall
163.2	Large hole in the breakwater	Hole 0.1 m wide and 0.1 m high penetrating 2.0 m into the wall
186.6	Large hole in the breakwater	Hole 1.0 m wide and 2.0 m high penetrating 2.0 m into the wall
231.9	Large gap in the breakwater	Gap (100 mm wide) extending from seabed up 2.0 m penetrating 3.2 m (two full block depths) into the wall
237.7	Large gap in the breakwater	Gap (100 mm wide) extending from seabed up 2.0 m penetrating 3.2 m (two full block depths) into the wall

3.3 Review of monitoring survey

Survey monitoring of the breakwater was conducted by CSE Group between May 2008 and April 2018. The monitoring involved conducting survey to a number of points installed along the breakwater and recording the position (latitude and longitude) along with the levels (RL's). The survey also recorded if damage was sustained to any of the monitoring points and if these points were excluded from the survey. A summary of the survey results reported by CSE Group is provided below.

Figure 6 Warrnambool Breakwater – Monitoring Survey Plan

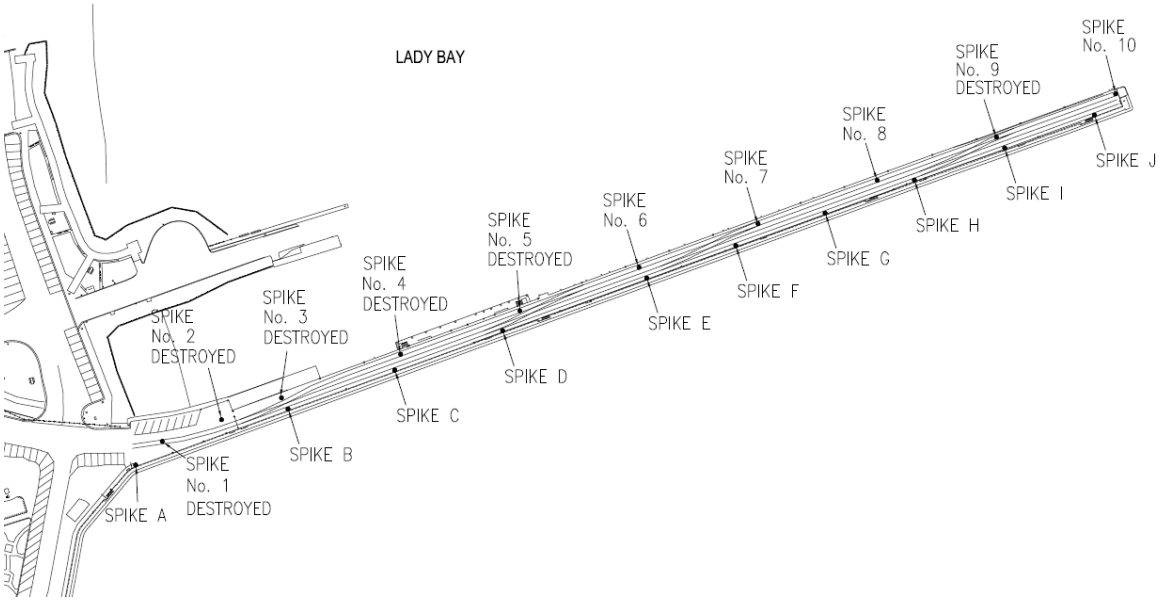
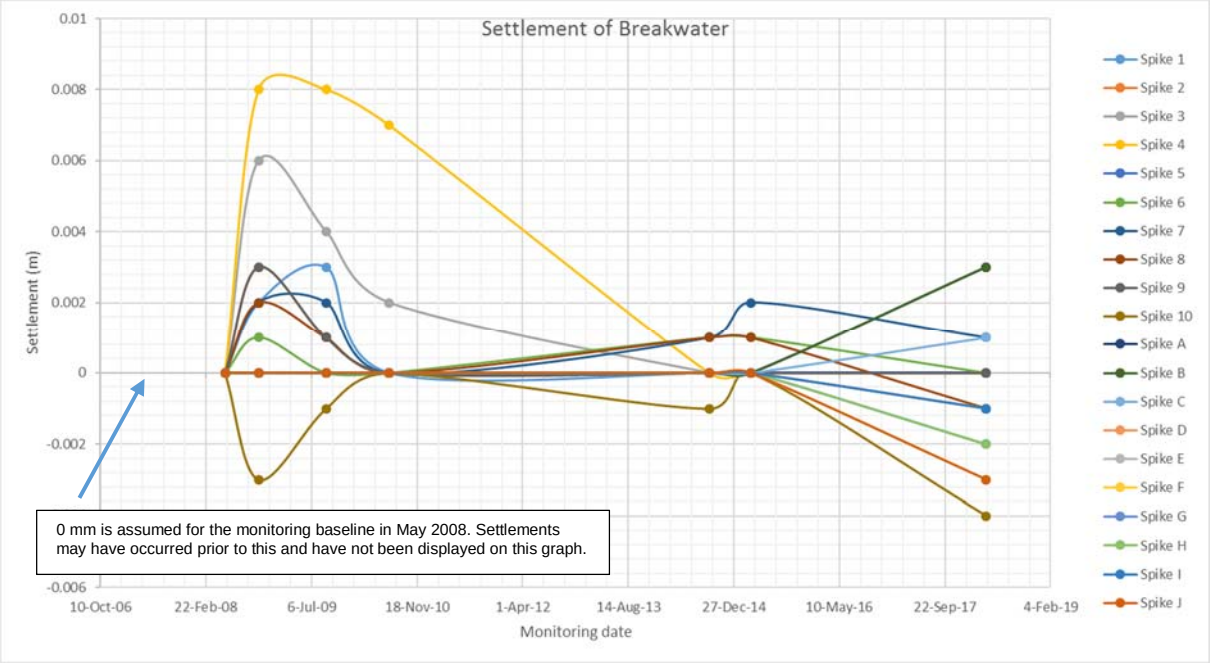


Table 2 Summary of CSE Group survey monitoring data (May 08 – April 18)

Location	Total Movement (over 10 year monitoring period) (m)				Status
	Northing	Easting	Resultant	RL	
Spike 1	-	-	-	0.000	Destroyed
Spike 2	-	-	-	0.000	Destroyed
Spike 3	-	-	-	0.002	Destroyed
Spike 4	-	-	-	0.008	Destroyed
Spike 5	0.000	0.000	0.000	0.000	Destroyed
Spike 6	-0.008	-0.003	0.009	0.000	Current
Spike 7	-0.006	-0.003	0.007	0.001	Current
Spike 8	-0.004	-0.007	0.008	-0.001	Current
Spike 9	-	-	-	0.000	Destroyed
Spike 10	0.005	0.003	0.006	-0.004	Current
Spike A	0.000	0.000	0.000	0.003	Current
Spike B	0.000	0.000	0.000	0.003	Current
Spike C	-0.002	0.003	0.004	0.001	Current
Spike D	0.012	-0.002	0.012	-0.001	Current
Spike E	-0.003	0.000	0.003	-0.001	Current
Spike F	0.000	0.000	0.000	-0.003	Current
Spike G	0.001	-0.005	0.005	-0.002	Current
Spike H	0.000	-0.004	0.004	-0.002	Current
Spike I	-0.002	-0.004	0.004	-0.001	Current
Spike J	-0.002	-0.004	0.004	-0.003	Current

Figure 7 Warrnambool Breakwater monitoring of settlement



The survey monitoring data indicates that minimal movement in both the horizontal and vertical plane has occurred since the monitoring begin in 2008 (an approximate 10 year monitoring period). Maximum vertical settlements of approximately 4 mm was observed at Spike 10 and a heave of 8 mm observed at Spike 4. Maximum horizontal movements of approximately 12 mm were observed at Spike D with all remaining points indicating less than 10 mm movement.

Both horizontal (rotations) and vertical (settlements) of the breakwater appear to have reached a state of equilibrium and may be dormant. Based on our review of the survey data, significant further movement (both horizontally and vertically) is unlikely to occur in the near future without significant changes on the conditions experienced by the breakwater or foundations.

Spikes 1-5 and Spike 9 have been excluded from the survey data due to damage sustained to the points and these should be reinstated to allow for continuation of monitoring in these locations.

There were a number of discrepancies identified between the level data (RL's) provided in CSE's "Level Survey Results Table" and the "Point Table Survey" for the 23 May 2008 survey. The data provided in the Point Table Survey was adopted for the purposes of this review due to this data appearing consistent with the readings on subsequent dates.

3.4 Review of previous investigation

The summary in the table below provides a status on past forward works programs and recommendations from previous investigations.

Investigation	Recommendation / Outcome	Status
Connell Wagner, "Warrnambool Breakwater Condition Inspection & Forward Works Planning", 1998.	Survey monitoring. Various minor repairs to the breakwater and jetties including; replacement of hand railing and navigational beacon bracket, breakwater and jetty ladders, lower landing crossheads, painting of bollards and patching of concrete roadways joints	Completed
Connell Wagner, "Warrnambool Breakwater Condition Inspection & Forward Works Planning", 2006.	Survey monitoring. Install plates over gaps in tops of timber fenders and reinstate bollards Install signage warning the public of the slippery surface and falling hazards on the breakwater boat ramp. Installation of hand railing at the breakwater edge along the length of the breakwater boat ramp	Completed
Aurecon, "Warrnambool breakwater diagnostic conditions investigation report", 2009.	Render repairs to the tops of parapet walls. Removal of existing reinforced concrete fascia walls and repair with a suitable face treatment. Prevention of movement related stress in the top of the main wall. Repairs to delamination and cracking in rendered ramp wall. Repairs to cracking and spalling at the interface between the top of the main wall and the new walkway pavement. Regular removal of salt stains as they appear on the main wall and the prevention of significant salt deposit build up Removal of the surface mortar to create recessed joints and raking out the fretting mortar at joints	Works completed: Hand railing on elevated walkway replaced and new screed surface Stairway 1 and 5 steps reformed to an even surface Ladder rungs replaced Replacement Lower Landing deck New stairs and bollard caps
Mainmark, "Warrnambool Breakwater Joint Condition Investigation for WCC", 2015.	Fill open joints throughout breakwater with Uretek resin. Place gabions to the seaward face to protect against ongoing scour. Place concrete between the gabions and the wall to fill the cavities scoured under the seaward face.	Not completed
Elstone Diving Services, "Inspection of Breakwater", 2017.	Large holes, gaps and cracking observed in the main breakwater wall and undermining and scour observed at the base of the wall. (No recommendations made)	N/A
CSE Group Survey monitoring 2008-2018	Minimal movement in the horizontal and vertical direction observed since the monitoring begin in 2008 (over a 10 year). Maximum movements observed in different locations: 4 mm vertical settlement (spike 10), 8 mm heave (spike 4), 12 mm horizontal movements (spike D).	Ongoing

4. Inspection Details

4.1 Introduction

A visual inspection of the Warrnambool Breakwater was conducted by GHD Engineers between 1 and 2 February 2018. The conditions encountered during the inspection were mild (1-2 m) swell from the south westerly direction and sea temperature of 16 degrees (°C). Low tide of 0.4 m was recorded at 7:51 am with high tide of 0.6 m at 12:36 pm. Strong winds ranging from 15 to 30 knots from the south west and overcast. An ambient air temperature range of between 15 to 22 degrees (°C) was recorded during the inspections for the assessment of structural articulation.

4.2 Access

Access to the Breakwater was by foot from deck level, both along the main deck and the upper parapet walkway.

Inspection of the sea side of the wall and areas with limited access or areas that were considered hazardous or higher risk was completed using video imaging equipment from deck level.

No on water or diving inspection was completed as part of this assessment. The use of traffic management or special access equipment (Elevated Work Platform, or rope access etc.) was not required during the inspection.

4.3 Safety during inspections

Control measures were put in place to eliminate or minimise the potential hazards and risks associated with conducting the inspections in a marine environment. The additional controls implemented during the inspection (above GHD's standard OH&S procedures) includes:

- Use of video imaging equipment to reduce the risks associated with access over water or inspection at heights.
- A minimum of two personnel were present during all inspections to provide assistance in case of emergency and to verify safety control measures were being implemented correctly.
- Appropriate PPE was used at all times while at the breakwater.
- GPS and communications equipment were used to allow for accurate location of personnel and identification of location in case of emergency.
- Call-in procedures were implemented to allow for follow up by safety representatives in case of emergency.
- All additional control measures were included in the Job Safety Environment Assessment and reviewed by all personnel prior to proceeding to site.
- Care was taken around rock revetments and armouring to determine the safest route to access the components.

5. Visual Condition Inspection

5.1 Introduction

GHD conducted visual inspections on the Warrnambool Breakwater between 1 and 2 February 2018. The inspections are visual in nature and include visible components of the structure above ground and water level.

The inspections included:

- Visual inspection of the breakwater main (lower) and upper (parapet) walls and deck.
- Video and photo inspection of the sea side of the main breakwater wall.
- Visual inspection of the navigational aids on the breakwater.
- Visual inspection of the access, ladders, platforms, walkways and handrailing along the breakwater structure.
- Visual inspection of the lower (timber) deck and jetty
- Photographs and high-level mapping of the defects identified.
- Assessment of the condition of each component to determine condition ratings.
- Assessment of the conformance of the structure with respect to current safety standards.

The condition rating, defects and structural information of all components from the deck to water level were recorded (where visible) and visual inspection was used to assess the condition of each element in accordance with the Ports Australia – Wharf Structures Condition Assessment Manual (2014).

Where access was considered hazardous or higher risk, the inspection was conducted using video imaging equipment. Where video imaging equipment has been used, this has been identified in the inspection data. Areas that were not accessible by either video imaging or visual inspection have been outlined in the inspection limitations in Section 5.2 and recommendations for further inspection have been provided where necessary.

The general condition of the structure and of each component was inspected and assessed. Structural defects and items of note were recorded and photographed throughout the inspection. The inspection results were recorded in the inspection data sheets, included in the Asset Management Plan.

5.2 Limitations

GHD could not physically access the seaside or the lower land side (where the bollards and fenders attach to the main structure) of the main breakwater wall without the use of a vessel as obtaining access was considered a safety risk.

Underwater (diving) inspection was excluded from the assessment and no structural analysis, modelling or load rating has been completed as part of the assessment.

Water-based (vessel) inspection was completed by Warrnambool City Council and images from the inspection were provided to GHD for the purposes of comparative assessment.

Access was not available to inspect underneath the lower (timber) jetty on the main breakwater. Access was also limited to above the high water level on the main structure as no diving inspections were conducted as part of this assessment.

The inspections were conducted from ground level on the deck of the main breakwater structure. Zoom photography and video imaging was used to inspect the sea-side of the main Breakwater wall.

Further inspection of the Breakwater from both sea side and land side would yield more detailed results with respect to the findings of the condition inspection.

6. Observations

6.1 General observations

The breakwater has been in service for over 125 years and while it has provided ongoing shelter throughout its service life, it has also sustained significant deterioration of a number of primary structural components over this time. Ongoing maintenance and targeted repairs have been completed throughout the life of the breakwater, in order to maintain it in a serviceable condition and to allow for its continued operation.

The observed deterioration and associated general defects generally relate to long term material degradation processes (erosion of joints, concrete, blockwork, etc.) and coastal processes (scour and settlement of the foundation material). While these processes may not pose an immediate risk to the structural stability, their ongoing combined action will continue to degrade the structure, leading to possible global stability issues over time.

A number of localised voids were identified in the main breakwater deck during Mainmark's investigation in September 2015 and a (limited) number of these voids were confirmed during GHD's visual inspection in 2018. The voids present a risk to the ongoing operation of the breakwater, particularly when located at the southern end of the structure where the risk of localised damage to the deck due to heavy vehicle operation (crane, fuel tanker etc.) is greatest.

While the presence of voids was identified in the main breakwater deck, due to the limited scope of the drilling investigation conducted in 2015 and the limitations of visual inspection of these areas, there is still uncertainty around the extent of the voids throughout the structure (their location and size). In order to mitigate the risk associated with the presence of voids in the main breakwater deck, a number of investigation methods have been explored to identify the extent of voiding, and the preferred method is outlined in Section 10 of this report.

A summary of the critical observations from the visual inspection of the Breakwater is provided in Section 6.2. For the purpose of defect identification, the following nomenclature has been used for the main breakwater components.

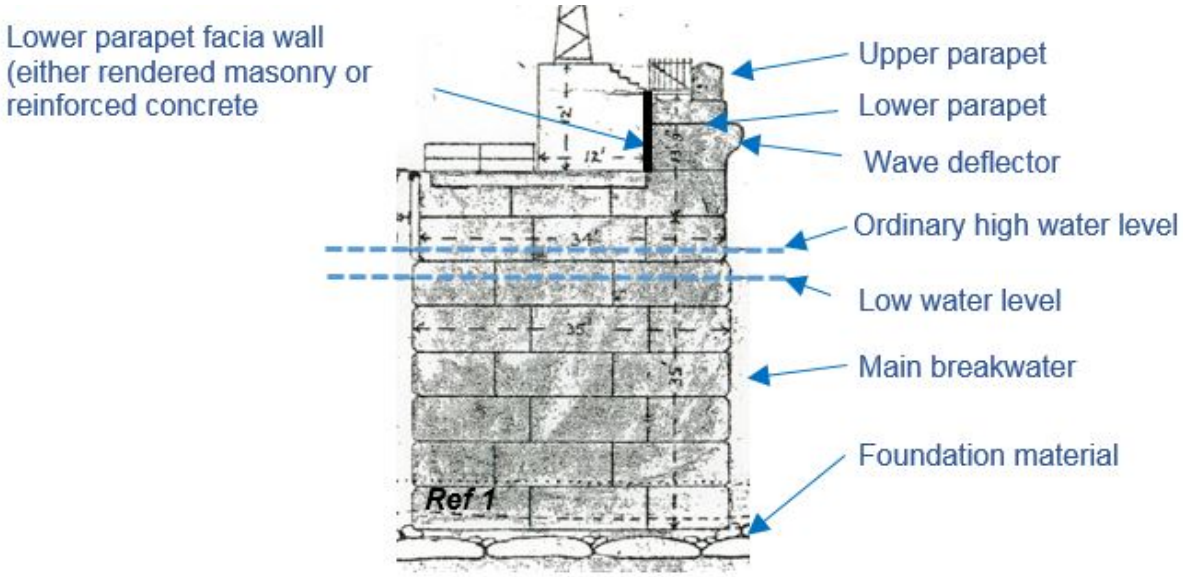


Figure 8 Warrnambool Breakwater - Nomenclature

Ref 1. Image provided by Warrnambool City Council.

6.2 Observation Summary

A summary of the critical observations of the Breakwater is provided below and generally fall into the following categories:

- Scour under the main breakwater structure leading to settlement and rotation seaward;
- Detachment and disintegration of breakwater head, parapet and wave deflector due to scour and wave action;
- Voids in the blockwork matrix caused by wave impact forcing jets of pressurised water through open joints;
- Disintegration of reinforced concrete elements and previous repairs;
- Slower weathering, cracking and erosion of unreinforced blocks and mortar joints;
- Cracking, spalling and delamination of concrete render on deck and parapet facing presenting hazard to users.

Inspection photos and comments for individual bridges and their elements have been provided in Appendix A.

6.3 Condition States

Condition states have been adopted from the Ports Australia – Wharf Structures Condition Assessment Manual (2014) with the categories customised to suit the requirements of Warrnambool City Council. The condition states provide general descriptions of four condition states used when performing the on-site condition ratings. These Condition States were used to quantify the condition of each element assessed for the four structures.

Each inspected component was given a condition rating totalling 100% made up of various combinations of the following four condition states:

Condition State 1 (Good) – Component is in good condition with little or no deterioration.

Condition State 2 (Fair) – Component shows deterioration of a minor nature with primary supporting material which is first signs of being affected. Intervention points for maintenance could be generally as follows: Minor spalls or cracking of no real concern. Paintwork on steel components with spot rusting up to 5%.

Condition State 3 (Poor) – Component shows advancing deterioration and loss of protection to the supporting material which is showing deterioration and minor loss of section. Intervention points for maintenance are generally as follows: Large spalls, moderate cracking and defects should be programmed for repair works. Paintwork has spot rusting of up to 10%, which is the limit for over coating.

Condition State 4 (Very Poor) – Component shows advanced deterioration, loss of effective section to the primary supporting material, is acting differently to design or is showing signs of overstress. Intervention points for maintenance are generally as follows: Very large spalls or heavy cracking and defects should be repaired within the next 12 months. Paintwork beyond repair requires blasting back to bright metal.

6.3.1 Warrnambool Breakwater Inspection Observation Summary

General Component	Description	Defect	Location (refer to defect mapping for accurate location)	Possible Cause	Condition State
Upper parapet and walkway Phase 1 (1890) works.	The upper parapet comprises keyed concrete masonry block construction (similar to the main structure) of approximately 1.1 m wide x 1.0 m high. The parapet has been rendered with a cementitious mortar.	General cracking and spalling of the parapet masonry.	Upper parapet (Bollards 6 to 24).	General wear, movement and shrinkage or mortar/render.	2 - Good
Upper parapet and walkway Phase 2 (1915) works.	The upper parapet comprises keyed concrete masonry block construction (similar to the main structure) of approximately 1.1 m wide x 1.0 m high. A reinforced concrete capping beam has been provided over the parapet.	Cracking and spalling of mortar. Loss of mortar from joints. Opening of joints and large section loss from blocks. Cracking to capping beam and loss of concrete block sections/erosion of concrete block face.	Upper parapet (bollards 0 to 6). Cracks correspond with large movement cracks in the external (sea side) face of the main wall.	Movement of structure and aggressive marine environment and wave action.	3 – Poor to 4 - Very poor
Lower parapet and main breakwater wall and deck Phase 1 (1890) works.	Concrete block (masonry) construction. Masonry blocks are approximately 5ft square x 10 ft long and keyed and grouted together. Masonry is founded on a cement apron constructed using cement bags keyed into the rock seabed below. Phase 1 of the breakwater was constructed 30 ft (9 m) wide and approximately 1033 ft (315 m) long.	General cracking and spalling to parapet render. Loss of concrete fines on main blocks. Voids forming at the main joints. Some loosening concrete with potential to fall. Delamination of most render surfaces. Erosion of the concrete block masonry and the mortar joint matrix resulting in large penetrations in the sea side face of the wall and dis-lodgement of concrete masonry blocks below water level (observed during diving survey). Rotting of the aged timber fender panels below bollards.	Main breakwater wall land side (bollards 6 to 24). Main breakwater wall sea side below water level (Bollards 6 to 24). Full length of breakwater	Structural movement and aggressive marine environment. Wave action and aggressive marine environment causing erosion of block masonry and the mortar joints and scour of sea bed under the main breakwater. General wear and exposure	1 –Good to 2 -Fair

General Component	Description	Defect	Location (refer to defect mapping for accurate location)	Possible Cause	Condition State
Lower parapet and main breakwater wall and deck Phase 2 (1915) works.	Concrete block (masonry) construction. Masonry blocks are approximately 5ft square x 10 ft long and keyed and grouted together. Masonry is founded on a cement apron constructed using cement bags keyed into the rock seabed below. Phase 2 of the breakwater extended the existing breakwater by 400 ft (122 m).	Significant cracking and spalling of reinforced concrete facia wall. Evidence of reinforcement corrosion visible through (rust staining) larger cracks (estimated over 3 mm in some locations). Some loosening concrete with potential to fall. Delamination of most concrete surfaces. Significant settlement and rotation of main breakwater wall and deck. Rotting of the aged timber fender panels below bollards.	Main breakwater wall land side (bollards 0 to 6). Main breakwater deck (bollards 0 to 6). Full length of breakwater	Structural movement and aggressive marine environment. Scour of seabed and foundation material below the main breakwater structure. General wear and exposure	3 – Poor to 4 - Very poor
Lower (timber) jetty. Eastern (old) section. Underside of jetty not visible.	Timber jetty comprises timber piles supporting timber cross heads (150 x 300 headstocks) and timber decking. Past inspection has noted that a number of cross heads have been replaced with steel PFC members	Timber decking and kerbing weathering and showing signs of rot. Possible deterioration in piles. However, access limitations prevented inspection of piles.	Eastern (narrow) section of jetty	General weathering and aggressive environment	3 - Poor
Lower (timber) jetty. Western (new) section. Underside of jetty not visible.	Timber jetty comprises timber piles and cross bracing, supporting timber cross heads (150 x 300 headstocks) and timber decking. Decking on the Western end of the jetty has been replaced recently. Past inspection has noted that a number of cross heads have been replaced with steel PFC members	Possible deterioration in piles. However, access limitations prevented inspection of piles.	Eastern (narrow) section of jetty	General weathering and aggressive environment	2 - Fair
Access ladders, platforms, walkways and hand railings.	Various access ladders, stairs, walkways and hand railings were observed along the main breakwater structure.	Items were assessed under the Safety Compliance Assessment. Refer to Section 6.3 for non-compliance items.	Main breakwater structure	Various	Various

General Component	Description	Defect	Location (refer to defect mapping for accurate location)	Possible Cause	Condition State
Lighting.	Lighting comprises steel lighting poles up to halogen globes which are fixed via a bolted base plate connection to the foundations.	Nil	Nil	Nil	1 - Good
Navigational aids.	Navigation beacon attached to the concrete plinth with a flange plate and hold down bolts.	General wear slight tea staining (corrosion) observed on mast and bolted connections.	Mast and connections	Exposure to aggressive environment	2 - Fair

7. Comparative Assessment

A comparative visual assessment was completed using the current photographic records obtained during GHD's site visit in February 2018, photos from Council's photographic survey in March 2018 and the photographic records taken during the previous investigations. This was completed to assist with the assessment due to minimal survey and monitoring data available for the Breakwater. The comparative assessment is qualitative only and provides a visual record of both the condition of the structure and any significant structural movements or settlements which may be detected through photographic assessment.

The comparative visual assessment indicates a general deterioration in the condition of the breakwater's surface treatments. This includes noticeable changes in the condition of a number of elements since the 1998 Connell Wagner inspection including:

- Rendered upper and lower parapet surfaces.
- Upper parapet block work.
- Reinforced concrete facia/repair walls.
- Wearing surfaces on the main deck.

A number of components have also had improvement works performed since the 1998 inspection including repairs to gaps in the external block work, repairs to bollards, hand rails and stairs and some concrete works around bollards (presumably for stability of the bollards and connections).

Based on review of council's photographic survey, the prevalence of salt staining around the masonry block joints on the landward side of the parapet appears higher between bollards 5 and 19, with minimal staining observed between Bollard 1 and Bollard 5. This may indicate that the rock armouring between bollards 1 and 5 is effective at reducing the flow of seawater through the joints in the parapet. Refer to Photo 49 in Appendix A for leeching of the masonry block joints.

The comparative assessment does not indicate noticeable settlement or rotation of the main breakwater since the Connell Wagner inspection in 1998. The photo comparison may indicate some evidence of increased crack widths on the main vertical cracking in the breakwater above the rock protection (Refer to photos 39 & 40 in Appendix A). However, the assessment is not a reliable method of assessing movement and is intended to provide an indicative record of ongoing deterioration of the structure as a general guide and is not considered a quantitative assessment of the actual condition or any movements observed within the structure.

Detailed survey monitoring should be continued as part of the breakwater's maintenance strategy, including continuous/ongoing recording of the structural movements over time (verticality and crack widths), to allow for implementation of appropriate maintenance strategies.

The comparative (Photographic) assessment is provided in Appendix A.

8. Safety compliance assessment

A Safety Compliance Assessment was completed on the Breakwater which included visual inspection and review of the safety and amenity of the breakwater access in accordance with current Australian Standards. Standards considered in the review include:

- AS 1657 Fixed platforms walkways stairways and ladders – design, construction and installation.
- AS4997 Guidelines for the design of maritime structures.
- AS 2156.2 Walking tracks - infrastructure design.
- AS1428.1 Design for access and mobility.

The compliance assessment has been completed by way of exception and items not identified in the assessment are assumed to comply with current standards or were unable to be assessed due to limitations on access. Refer to Section 5.2 for limitations on access.

Table 3 Safety compliance assessment

Item/location	Description	Non-compliance	Reference	Rectification
Upper parapet walkway	Hand railing	No kick plate provided	AS1657 CL. 4.6/5.1.5/5.5/5.6.6	Consider installation of a kick plate
Stairs between main and upper deck	landings	Delineation of stair nosing	AS1657 CL. 7.2.3.2	Perform risk assessment and consider signage or relevelling of risers
Stairs between main and upper deck	Risers	Inconsistent height of stair risers	AS1657 CL. 7.2.3.4	Perform risk assessment and consider painting with non-slip surface and delineation of stair nosing
Lower (timber) landing	Hand railing	No hand railing to prevent falls from main deck and lower landing (fall greater than 1.5 m)	AS1657 CL. 5.4.1	Perform risk assessment and consider installation of a handrail. AS4997 allows for provision of unprotected edges in the case where a handrail would hinder normal operation of a wharf or maritime facility.
Boat ramp	Hand railing	No hand railing to prevent falls from main deck to boat ramp (fall greater than 1.5 m)	AS1657 CL. 5.4.1	Perform risk assessment and consider installation of a handrail on both sides of boat ramp.

9. Risk Assessment

9.1 General

GHD's visual inspection of the breakwater and review of previous investigations has identified a number of risks associated with the ongoing operation of the breakwater which Council should consider as part of the Breakwater (and greater harbour) Asset Management Plan.

The Breakwater Risk Assessment is based on a risk matrix approach which has been developed around the Warrnambool City Council's Risk Assessment Matrix (for good controls). Risks identified during the assessment have been allocated a Risk Rating between 1 and 4 which takes into consideration the condition of the element and the consequence of its failure.

The Risk Assessment is based on an assessment of the consequence of failure on the **safety of users and the serviceability and strength of the structure only** and does not take into consideration the risk to the environment, business interruption, public reputation, legal governance/compliance, and public disruption, operation of the breakwater or any flow-on costs.

The Risk Rating is associated with a general time frame for repairs to an element. The time frames are suggested intervals and Warrnambool City Council should adopt time frames which are appropriate to their network's needs and risk profile. The Risk Ratings 1 to 4 are shown below:

- Risk Rating 1 – Extreme (Immediate action required).
- Risk Rating 2 – High (Action required within short to medium term).
- Risk Rating 3 – Moderate (Action required over the medium to long term).
- Risk Rating 4 – Low (Continue monitoring as part of routine maintenance).

Table 4 Determination of Risk Rating

Condition States	Consequence of Failure or Continued Deterioration				
	Insignificant	Minor	Moderate	Major	Extreme
4	3 - Moderate	2 - High	2 - High	1-Extreme	1-Extreme
3	3 - Moderate	3 - Moderate	2 - High	2 - High	2 - High
2	4 - Low	4 - Low	4 - Low	4 - Low	4 - Low
1	N/A	N/A	N/A	N/A	N/A

9.2 Consequence of failure

The consequence of failure has been subdivided into five categories relating to severity:

Insignificant: No impact on strength or serviceability. Predominantly superficial defect with minimal effect on aesthetics.

Negligible health/safety impact on member of public or maintenance staff (no first aid or medical treatment required).

Minor: Minimal impact on serviceability but does not affect the strength of the structure. May lead to premature wear of other elements. Reduced comfort level (vibration or dynamic effects) or significantly effecting aesthetics. OR;

Minor injury illness or health impact (<10 days lost time due to injury/illness).

Moderate: Impacts serviceability or leads to accelerated deterioration of other elements. The strength of secondary or minor elements is compromised. OR;

The defect poses a risk to public safety, without impacting the overall structural integrity of preliminary or secondary elements. Moderate injury illness or health impact (>10 days lost time due to injury/illness).

Major: Structure is unserviceable and the strength of primary components is compromised. OR;

The defect poses a significant risk to public safety, without impacting the overall structural integrity of preliminary or secondary elements. Significant health risk (single fatality or permeant disability)

Extreme: Major structural failure or collapse of primary components. OR;

The defect poses a catastrophic risk to public safety, without impacting the overall structural integrity of preliminary or secondary elements. Extreme health risk (multiple fatalities or pandemic effect).

9.3 Risk Assessment

A risk assessment was conducted on the Warrnambool breakwater based on the findings of GHD's visual inspection and the outcome of GHD's review of previous assessments. The Risk Assessment framework is based on Warrnambool City Councils Risk Assessment Matrix (for good controls) and is shown in Table 2.

Table 5 Risk Assessment

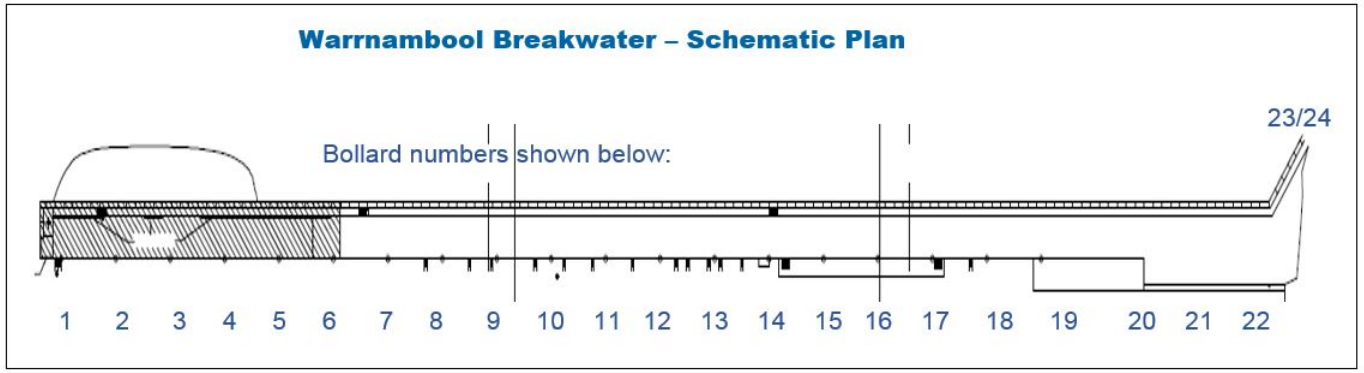
General Component	Location (refer to defect mapping for accurate location)	Defect	Risk	Consequence of failure	Condition State	Risk Rating	Mitigation/Control (Refer to Section 10 for further details on repairs)
Upper parapet and walkway Phase 1 (1890) works.	Upper parapet (Bollards 6 to 24).	General cracking and spalling of the parapet masonry.	Spalling of concrete render on deck and parapet presenting hazard to users.	Minor	2 - Good	N/A	Monitor
Main breakwater wall Phase 1 (1890) works.	Main breakwater wall - land side (bollards 6 to 24).	General cracking and spalling to parapet render. Loss of concrete fines on main blocks. Voids forming at the main joints. Some loosening concrete with potential to fall. Delamination of most render surfaces.	Spalling of concrete render on deck and parapet presenting hazard to users.	Minor	1 –Good to 2 -Fair	4 - Low	Continue to conduct condition inspections.
	Main breakwater wall sea side below water level (Bollards 6 to 24).	Erosion of the concrete block masonry and the mortar joint matrix resulting in large penetrations in the sea side face of the wall and through the breakwater and dis-lodgement of concrete masonry blocks below water level (observed during diving survey).	Scour under structure leading to settlement, seaward rotation and part collapse. (Mechanism likely to be slower with adequate warning to breakwater users).	Extreme	3 - Poor	2 - High	Continue on-going survey monitoring to record movement and settlement over time. Extend existing rock armouring to reduce the risk of undermining, scour and rotation.
	Main breakwater (deck) (bollards 14-22) (Chainage 100-240).	Erosion of the concrete block masonry and the mortar joint matrix resulting in large penetrations in the sea side face of the wall and through the breakwater and dis-lodgement of concrete masonry blocks below water level (observed during diving survey).	Deck failure in Breakwater possible if large voids are present under deck. Heavy vehicles (crane, fuel tanker etc.) may cause punching shear failure. This could result in injury as well as loss of access for the breakwater.	Major	3 - Poor	2 - High	Further investigation into the extent and location of voiding required to determine extent of risk/ rectification method. (Refer to Section 10) Extend existing rock armouring to reduce wave impact.
	Full length of breakwater leeward side	Rotting and deterioration of the timber fender panels located under the bollards	Original design drawings indicate timber panels appear to belong to a remnant fender system and do not appear to have a significance to the structural stability of the breakwater	N/A	4 - Very poor	N/A	Monitor
Upper parapet and walkway Phase 2 (1915) works.	Upper parapet (Bollards 0 to 6).	Cracking and spalling of parapet mortar. Loss of mortar from joints. Opening of joints and large section loss from blocks. Cracking to capping beam and loss of concrete block sections/erosion of concrete block face.	Spalling of concrete render and loss of parapet capping presenting hazard to users.	Minor	3 – Poor to 4 - Very poor	2-3 – Med to High	Conduct repairs to parapet capping.
Lower parapet facia wall (land side) Phase 2 (1915) works.	Lower parapet wall land side (bollards 0 to 6).	Significant cracking and spalling of reinforced concrete facia wall. Evidence of reinforcement corrosion visible through (rust staining) larger cracks (estimated over 3 mm in some locations). Some loosening concrete with potential to fall. Delamination of most concrete surfaces.	Delamination and instability of concrete facia walls presenting a risk of falling	Minor	3 – Poor to 4 - Very poor	2-3 – Med to High	Conduct repairs to reinforced facia walls.

General Component	Location (refer to defect mapping for accurate location)	Defect	Risk	Consequence of failure	Condition State	Risk Rating	Mitigation/Control (Refer to Section 10 for further details on repairs)
Main breakwater wall Phase 2 (1915) works.	Main breakwater (bollards 0 to 6).	Significant settlement and rotation of main breakwater wall and deck.	Scour under structure leading to settlement, seaward rotation and part collapse. The rock armouring installed in 1975 may have stabilised this area to further settlement.	Extreme.	3 – Poor.	2 – High.	Further investigation required to determine extent of risk/ rectification. Continue on-going survey monitoring to record movement and settlement over time.
	Main breakwater (deck) (Bollards 0 to 6).	Significant settlement of main deck. Regular transverse cracking and spalling of concrete slab.	Unevenness of pavement presenting a hazard to pedestrians and wheeled access (bicycles and wheelchairs).	Minor.	3 – Poor.	3 – Med.	Conduct repairs to pavement surface, and consider improved lighting locally.
Lower (timber) jetty. Eastern (old) section.	Eastern (narrow) section of jetty.	Timber decking and kerbing weathering and showing signs of rot.	Failure of timber decking cross heads or piles resulting in local collapse of jetty. This could result in injury as well as loss of access for the jetty.	Moderate.	3 – Poor.	2 – High.	Continue to conduct condition inspection and consider replacement of timber decking and any damaged lower timbers identified as a result of further inspection.
Lower (timber) jetty. Western (new) section.	Eastern (narrow) section of jetty.	Possible deterioration in piles. However, access limitations prevented inspection of piles.	Failure of timber decking cross heads or piles resulting in local collapse of jetty. This could result in injury as well as loss of access for the jetty.	Moderate.	2 – Fair.	4 – Low.	Continue to conduct condition inspections.
Access ladders, platforms, walkways and hand railings.	Main breakwater structure.	Items were assessed under the Safety Compliance Assessment. Refer to Section 9 for non-compliance items.	Injury from slips trips, falls. Inadequate access requirements for personal use (wheelchair/bicycle/pedestrian) or operational use (maintenance staff/operational personnel). Refer to specific items in Section 9.	Various.	Various.	Various.	Various.
Lighting.	Nil.	Nil.	Nil.	N/A.	1 – Good.	N/A.	Monitor.
Navigational aids.	Mast and connections on breakwater beacon.	General wear slight tea staining (corrosion) observed on mast and bolted connections.	Deterioration of navigational aid resulting in malfunction.	Minor.	2 – Fair.	4 – Low.	Continue to conduct condition inspections.

9.4 Diagrammatic risk profile

The Risk Assessment has been shown diagrammatically in order to graphically represent the level of risks associated with the observed defects and the ongoing function and operation of the breakwater.

The risk assessment considers the apparent risk due to a number of possible (structural) failure mechanisms relevant to the observed defect on the breakwater. The risk assessment is shown in Figure 9 below.



	RISK RATING																							
Description of risk / Bollard	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	21-22	22-23	23-24
Scour under structure leading to settlement, seaward rotation and ultimately collapse	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4
Detachment and disintegration of head due to scour and wave impact	3	3	3	3	3	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Voids in structure resulting in punching failure	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	2	2	2	2	2	2	N/A	N/A	N/A	N/A
Delamination and instability of concrete facia walls /repairs	N/A	3	3	3	3	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Spalling of concrete render on deck and parapet presenting hazard to users.	2	N/A	N/A	N/A	N/A	N/A	3	3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4
Unevenness of pavement presenting a hazard to pedestrians and wheeled access (bicycles and	3	3	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4	4	4	4	N/A	N/A	N/A	N/A
Critical Risk Rating	2	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	4	4	4

Figure 9 Warrnambool Breakwater – Diagrammatic risk assessment

10. Recommendations

10.1 General

The defects observed during the site inspection and through review of previous assessment reports have been assigned a priority rating based on the Risk Assessment process. The Risk Rating is associated with specific controls and mitigations and a recommended timeframe for implementing the proposed actions.

The Risk Assessment and proposed actions are intended to be used as a guide to allow for incorporation into the overall Asset Management Plan and to allow for prioritisation of works and to facilitate the planning of repairs and maintenance. A summary of prioritised summary of risks recommended actions id provided in the table below.

Table 6 Summary of Actions Based on Risk Rating

Risk Rating	Risk	Location	Recommended Action
1 – Extreme (Immediate action required).	N/A.	N/A.	N/A.
2 – High (Action required within short to medium term)	Scour under structure leading to settlement, seaward rotation and part collapse.	Main breakwater wall sea side below water level (bollards 1 to 24).	R1 - Extend existing rock armouring to reduce the risk of undermining, scour and rotation. R2 - Monitoring survey to monitor on-going movements.
	Deck failure in Breakwater possible if large voids are present under deck. Heavy vehicles (crane, fuel tanker etc.) may cause punching shear failure.	Main breakwater (deck) (bollards 14-22) (Chainage 100-240).	R3 - Further investigation into extent of voids.
	Spalling of concrete render and loss of parapet capping presenting hazard to users.	Upper parapet and lower breakwater wall (Bollards 0 to 6).	R4 - Repairs to parapet blockwork rendered surface.
	Delamination and instability of concrete facia walls presenting a risk of falling.	Lower breakwater wall (Bollards 0 to 6).	R5 - Investigation into stability of facia wall and ongoing monitoring of condition.
	Failure of timber decking cross heads or piles resulting in local collapse of jetty. This could result in injury as well as loss of access for the jetty.	Lower (timber) jetty. Eastern (old) section.	R6 - Replacement of deck timbers and inspection of sub-structure components.
3 – Moderate (Action required within medium to long term)	Unevenness of pavement presenting a hazard to pedestrians and wheeled access (bicycles and wheelchairs).	Main breakwater (deck) (bollards 0 to 6).	R7 - Provide re-surfacing to asphalt and concreter wearing surfaces.
4 – Low (Continue monitoring as part of routine maintenance).	Spalling of concrete render on deck and parapet presenting hazard to users.	Main breakwater wall - land side (bollards 6 to 24).	R8 - Monitor.

Risk Rating	Risk	Location	Recommended Action
	Failure of timber decking cross heads or piles resulting in local collapse of jetty. This could result in injury as well as loss of access for the jetty.	Lower (timber) jetty. Western (new) section.	R8 - Monitor.
	Deterioration of navigational aid resulting in malfunction	Mast and connections on breakwater navigational beacon	R8 - Monitor

10.2 Risk Rating 1 – Extreme (Immediate Action Recommended)

No immediate actions were identified as an outcome of the Risk Assessment.

10.3 Risk Rating 2 – High (Action required within short to medium term)

10.3.1 Scour under main breakwater structure and seaward rotation

Scour under the main breakwater structure was observed in a number of locations along the sea side (between CH 0 and 237) of the main breakwater wall and foundations during diving inspection of the breakwater by PDI in 1998 and EDS in 2017. Scour is also suspected to have contributed to seaward rotations which are evident in the newer (1915) section of the main wall. However, rock armouring placed over this section (circa 1975) currently limits access to this area to allow for inspection.

Based on the monitoring survey conducted by CSE Group (between 2008 and 2018) and the comparative visual assessment (refer to Section 8) of the main wall settlements and rotations, it appears that no significant movement of the wall has occurred since the inspections conducted by Connell Wager in 1998 and 2006. This suggests that rock armouring placed on the sea side of the wall (around 1975) may have stabilised this section of the breakwater.

While the breakwater appears to be stable at the current time, ongoing scour combined with settlement and material degradation will continue to degrade the structure, leading to possible global stability issues over time. Although the timeframe in which stability could be compromised is not known, the consequences would be major (collapse of part of the breakwater) and therefore it is recommended that the scour issue be addressed as a preventative measure.

Several options for remediation were recommended during previous investigation, in order to mitigate the risk associated with the ongoing scour and erosion of the base material. These options for remediation were initially recommended by Connell Wagner's in 1998 and included rock armouring and foundation grouting (including containment of the grouting operation by sheet piling).

Recommendation 1

In order to limit further scour of the foundation material and the settlement and rotations of the main breakwater, we recommend placement of rock armouring on the sea side of the breakwater from sea bed, to above the high water level (to match the existing armouring). The armour would extend from the existing armour (at approximately bollard 5) to the end of the breakwater close to the aquarium.

As well as preventing further scour, the rock armour will reduce the wave impact forces on the wall, thereby reducing erosion of the surface and reducing the flow of water through the joints and voids in the structure. The armour will also provide passive resistance to rotation.

Based on comparative assessment in Section 7, there is evidence to suggest that the existing rock armouring has reduced flow of water through joints in the protected area.

Foundation stabilisation/grouting and the associated installation of a sheet pile wall on the seaward side to contain the grout, as recommended by previous studies, is not considered necessary at this time because monitoring indicates the breakwater is currently stable and the rock armour should effectively halt any further scour while providing additional support to the structure. These measures would also add significantly to the complexity and cost of the remediation.

Rock armouring will impact on the ability to fish from the seaward side of the Breakwater and a number of alternative measures have been considered.

Installing a waterproof membrane on the seaward side of the breakwater to prevent water ingress has been suggested to limit deterioration of the breakwater blocks and rendering on the landward side of the parapet. This membrane could take the form of a chemical treatment applied to the surface, a grout, a plastic membrane or a combination of these. As a standalone measure none of these would be effective as they do not address the scour issues and a membrane will not maintain its integrity for long under the sustained wave impacts loading that occurs on the southern side of the breakwater. Even used in combination with the rock armouring we do not consider the membrane is warranted as the breakwater would remain saturated with salt water, which is not in itself saturation is not deleterious to the unreinforced concrete making up the main blocks. All repairs to surfaces, such as rendering, should be suitable for a high salt marine environment and make provision for escape of pore water in the concrete.

Another alternative considerd is a new offset rock breakwater located on the southern side of the existing structure. This could be low-crested structure which builds upon the existing reefs, disconnected from shore with no pubic access. Our preliminary assessment is that while a new ‘reef’ breakwater would provide some wave protection to the existing breakwater, it would not perform as well as the armouring solution in a number of areas: it would be less effective at reducing scour and wave impact forces on the breakwater. It may require a larger quantity and size of rock. And it would have a greater environmental impact due to a larger footprint on a relatively undisturbed reef and greater potential modification to coastal processes (wave, currents and sediment transport).

A concept section for the proposed rock armouring is shown in the below figure.

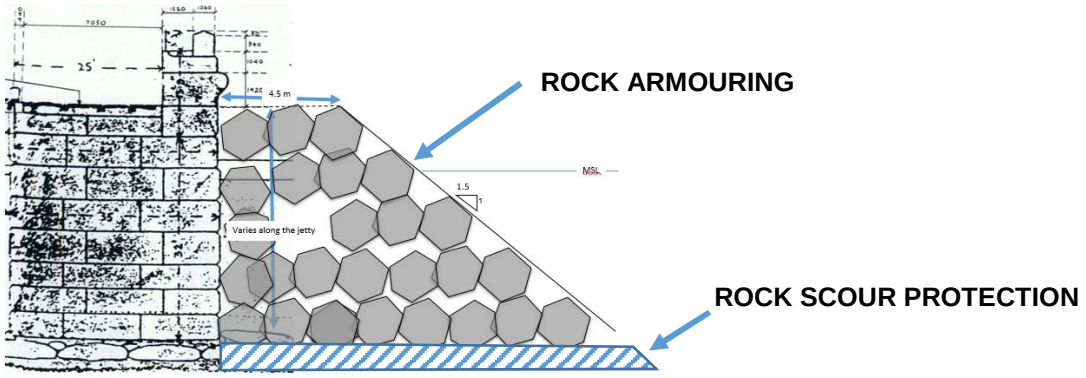


Figure 10 Warrnambool Breakwater – Proposed Rock Armouring

Continued rotations of the wall (if observed in the future) may require underpinning of the foundations or stabilisation/grouting works to minimise further rotations. Installation of the rock armour as discussed above should significantly reduce the risk of this occurring. While not considered a priority at this time, this work would be dependent on the outcome of further monitoring.

Recommendation 2

We recommend that the monitoring survey conducted by CSE Group be continued on the main breakwater structure at regular frequency (approximately 2 year intervals) to allow for recording of the movements over time and to allow for the implementation of appropriate repair methodologies should further movements be observed. The scope of the survey monitoring should be increased to include monitoring of the significant cracks observed in the main wall. This may be done by installation of permanent instrumentation to measure the crack widths.

A number of the monitoring points were observed to be damaged over the course of the survey monitoring and these points should be reinstated (whenever identified) to allow for continuation of monitoring at these locations.

10.3.2 Voids under the main deck in the breakwater

A number of large voids were observed in the main breakwater between CH 100 and 240 (Bollards 14-22) at sea bed level and beneath the main deck and internal to the main wall. The voids were observed during diving inspection by Connell Wagner in 1998 and later confirmed by Mainmark during a drilling investigation on the main breakwater in 2015. EDS further observed large voids in the lower sections of the breakwater in 2017.

The drilling investigation by Mainmark indicated that “significant deterioration was observed between the block joints of the structure. Wave action over the years has forced sand and water through the joints, resulting in loss of material. In the cores retrieved, and in the camera study of the core holes, it was evident that wave action has eroded the blocks along the joint lines. Furthermore, the action of the water is causing dissolution of the cement matrix, increasing the porosity of the structure”.

In addition, Mainmark’s investigation intersected a void previously treated with Uretek resin in July 2009. The Uretek resin appears to have provided a long term seal of the joint against water movement and prevented further deterioration.

Mainmark also suggested that cementitious filler or mortar was injected into the joints in 2010. However, no evidence of the material was found during drilling suggesting that it is likely that this filler has been washed out by wave action.

The presence of the voids can present a risk to overhead traffic if significant axle loads are able to penetrate the deck material. The voids and cracks opening up between the block work also presents a point of weakness in the main block matrix and continued deterioration may lead to instabilities or collapse in the masonry.

GHD's visual inspection was unable to verify the location or extent of voids below the deck level. However, a number of voids were visible at the base of the upper wall and high pressure water was observed to pass through these voids. Mainmark's investigation indicated that the majority of the larger voids were located approximately to 7 – 8 m below the pavement surface, which would present less of a risk to vehicles using the deck. However, the limited scope of the investigation means that there is uncertainty surrounding the location of voids throughout the main breakwater and therefore the risk of local punching failure due to voids close to the deck level is unclear without conducting further investigation.

The methods available for identifying the location and extend of voids throughout the main breakwater are limited given the construction type (gaps between the masonry blocks) and the presence of seawater generally above the level of investigation. A number of non-destructive methods were explored for investigation into the extent of voids, with Ground Penetration Radar (GPR) being the preferred method due to it being a simple and versatile method which we have had success with on similar projects.

Recommendation 3

While it is not clear whether the results of GPR scanning will yield usable results, the method is relatively cheap to employ and we recommend conducting a limited trial scan using GPR to determine whether further scanning of the remaining breakwater is likely to yield usable results. GHD can develop a trail scan methodology and conduct the scanning at council's request.

The installation of rock armouring as outlined in Section 10.3.1 would also reduce the effects of wave impact loading which is driving jets of water through the deck, slowing the development of void propagation within the deck.

10.3.3 Spalling of concrete render and loss of parapet capping

Cracking and spalling of the concrete render to the leeward face of the upper a lower parapet walls was observed between bollards 1 and Bollard 6. The render has become detached in a number of locations and presents a risk to safety due to sections of the render falling on the walkway below.

Delamination and detachment of the upper parapet capping was also observed between bollards 1 and Bollard 6. The capping appears to comprise of reinforced concrete capping fixed to the top of the parapet masonry block work. The capping shows signs of reinforcement corrosion and spalling of the concrete surface. The capping has fully detached from the masonry over large lengths of the parapet.

Recommendation 4

We recommend conducting repairs to the concrete render on the upper and lower parapet walls and the parapet capping between Bollard 1 and Bollard 6 to prevent further spalling and detachment of the render and capping. The repairs should accommodate the extreme exposure and conditions on the breakwater and should be appropriate for a marine environment. This may include the use of stainless steel reinforcement and dowel connections back to the masonry.

10.3.4 Delamination and instability of concrete facia walls

A number of the concrete facia walls (which appear to have been constructed to protect the face of the underlying block masonry) were observed to have become detached or separated from the face of the main blockwork. It is unclear if the stability of the walls has been compromised as the connections back to the main wall or the deck below were not visible during the inspection. The walls may present a risk of falling onto the main deck which is a hazard to users of the breakwater.

Cracking to the concrete panels and corrosion staining around the cracks was also observed and indicates that corrosion to the underlying reinforcement is likely to have occurred is likely to cause spalling of the concrete face and section loss of the reinforcement in the future.

Repairs to the corroded underlying reinforcement and the general condition of the walls is likely to be difficult as this requires some form of catholic protection or excavation and treatment of the reinforcement followed by a cementitious repair, both of which are likely to have significant associated costs. It is also likely that the corrosion to the reinforcement is occurring on the inside face of the wall which is not visible from the outside. Given the difficulty of repair and the relatively small extent of the walls, Council may wish to confirm the stability of the walls and continue to monitor the deterioration until the condition presents a risk or consider full removal and replacement of the walls.

Recommendation 5

Further inspection of the concrete facia walls is required to determine the extent of the delamination and to confirm the stability of the wall. This inspection should be conducted by a qualified structural engineer.

10.3.5 Failure of timber decking cross heads or piles

Deterioration of the timber decking and kerbing was observed on the norther section of the lower (timber) jetty adjacent to the main breakwater. Rotting, splitting and warping of the timbers was evident with uneven deck levels along the pier indicating substructure components (headstock and piles) may be in poor condition as well.

Recommendation 6

Timber decking should be replaced and further inspection of the lower headstock and pile components should be completed to confirm the condition and any further repairs completed as required from the outcome of the inspection.

10.4 Risk Rating 3 – Moderate (Action required over the medium to long term)

10.4.1 Unevenness of pavement on main breakwater deck

The inspection identified cracking, potholing on the main breakwater deck extending from approximately bollard 1 to bollard 14. Significant settlement of the deck was observed between bollard 1 and bollard 5 and lateral cracking to the concrete pavement was evident in these locations. Exposed steel rail cast into the deck is showing signs of advanced corrosion.

Unevenness in the deck wearing surface represents a potential risk to the public and to the functional operation of the breakwater. Unevenness creates risk to pedestrian traffic and wheeled vehicles including wheelchairs, bicycles, motor vehicles and stationary equipment or machinery operating on the deck.

Recommendation 7

Resurfacing of the deck asphalt and repairs to the concrete deck surfaces are recommended in order to re-level the deck wearing surface.

10.5 Risk Rating 4 – Low (Continue monitoring as part of routine maintenance)

Recommendation 8

A number of defects were identified which require ongoing monitoring and maintenance. The defects include:

- Minor spalling of concrete render on deck and parapet between bollard 6 and bollard 24.
- Deterioration of timber piles and cross heads on the lower (timber) jetty adjacent to the main breakwater.
- Minor deterioration of navigational aids on the main breakwater

11. Cost Estimates

11.1 Basis for cost estimates

All cost estimates in this report have been prepared for the purpose of the Port of Warrnambool Asset Management Plan and must not be used for any other purpose.

The cost estimates are high-level preliminary estimates only and have been developed for the purpose of estimating the costs associated with adopting various maintenance strategies for the breakwater and may not have been fully scoped. Actual prices, costs and other variables may be different to those used to prepare the cost estimate and may change based on a number of unknown variables.

Unless as otherwise specified in this report, no detailed quotation has been obtained for tasks identified in any future construction project. GHD does not represent, warrant or guarantee that the works can or will be undertaken at a cost which is the same or less than the cost estimate.

The cost estimates have been prepared using information reasonably available to GHD and is based on assumptions and judgments made by GHD including no allowance for Council costs (including but not limited to costs associated with staffing, project management, supervision, contract management, tendering, approvals, associated works, etc) to undertake the work and that all work is undertaken in the quickest and most efficient manner without delays for reviews, procurement, installation and shutdowns.

The options described within this report are of a specific nature, and much of the work would need to be conducted in difficult marine conditions. As such, associated uplifts to the typical unit rates / costs may apply and have not been outlined here.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected at the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for planning purposes will vary depending on the conservatism of the estimation and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

11.2 Preliminary cost estimates

Preliminary cost estimates have been prepared on the various remedial works/strategies described in this report. The strategic costs for these options have been allocated a preliminary risk contingency of +/- 30% which may be low by comparison to that used by other authorities.

Table 7 Summary of Cost Estimates

Recommendation No.	Description of works	Details of work	Location	Unit	Quantity	Rate	Associated cost (excl. GST)
R1	Rock armouring	Placement of rock armouring along the seaside of the breakwater wall.	From existing armour at bollard 6 to the wall end at the aquarium.	Tonne	90,000	$60/t	$ 5,400,000 +/- 30% ($3,780,000 to $7,020,000)
R2	Monitoring survey (ongoing).	Monitoring survey of the main breakwater wall movements and settlements including diving inspection. This item is intended to facilitate estimation of the repairs required to stabilise the main breakwater and to prevent undermining if required. These repairs are likely to be significant cost items and are covered under provisional items below.	Full length of breakwater.	Item.	Yearly.	$ 10,000	$ 10,000 / year
R3	Investigation into extent of voids.	Conduct trail scanning investigation of the main breakwater deck. The extent of further investigation determined from the outcome of the trial scan.	Main breakwater deck (bollards 14-22) Chainage 100-240).	Item.	1	$ 5,000	$ 5,000
R4	Repairs to parapet blockwork and wave deflector	Conduct repairs to block work surface including repointing and rendering to exposed concrete masonry.	Upper and lower parapet walls on northern (trafficable) side (bollards 0 to 6) and 25 m of wave deflector.	M2. Lin.m	625 25	$ 175 $ 4,000	$ 110,000 $ 100,000
R5	Investigation into stability of facia wall and ongoing monitoring of condition.	Structural inspection of the facia walls to confirm the wall stability.	Lower breakwater wall (Bollards 0 to 6).	Item.	1	$ 5,000	$ 5,000
R6	Replacement of deck timbers and substructure components headstocks/bearers/joists) on lower timber landing.	Replacement timbers, (Including labour, plant, equipment and crainage). Costs exclude pile replacement/repairs as a replacement jetty may be more cost effective.	Lower (timber) landing. Eastern (old) section approx. 60 m between bollards 14 and 18.	Item	1	$ 120,000	$ 120,000
R7	Provide re-surfacing to asphalt and concrete wearing surfaces.	Provide asphalt resurfacing. Provide concrete resurfacing.	Bollard 6 - 14 Bollard 1 - 6	M2. M2.	1300 1000	$ 35 $ 105	$ 46,000 $ 105,000
R8	Monitor.	Conduct routing maintenance inspection.	Full length of breakwater	Item.	Yearly.	$ 5,000	$ 5,000 / year

Costs for provisional items to be determined upon further investigation.							
-	Stabilisation (grouting underneath breakwater foundations)	Pressure grouting underneath the breakwater foundations to provide stability. Requirement and extent unclear at this stage. Details to be determined based on outcome of ongoing monitoring and diving inspection.	Extent to be determined	Item	1	N/A	N/A
-	Grouting of voids in deck	Epoxy resin grouting of voids in deck Extent of grouting to be determined based on outcome of void investigation (Item 2)	Extent to be determined	Item	1	N/A	N/A
Costs for safety compliance items (basd on the outcome of Council risk assessment)							
Safety compliance Item 1	No kick plates provided	Provide kick plates to handrails	All elevated handrails	Item	1	$ 120,000	$ 120,000
Safety compliance Item 2	Stair nosing becoming loose or non existant	Delineation of stair nosing	All landings	Item	1	$ 12,000	$ 12,000

11.3 Assumptions Used in Cost Estimations

11.3.1 Rock Armour

The estimated rock quantity required to armour length of approximately 400 m from existing armour at bollard 6 to the wall end at the aquarium along the breakwater is 80,000-90,000 tonnes. Assuming a typical section of the armour as is presented in Figure 10. The rock units are assumed to be in the range of 3.0-6.0 tonnes with nominal dimension of 1.0-1.5 m and density of 2.6 t/m^3 as per existing rock armour shown in Figure 11.

Figure 11 Armour Rocks at Breakwater Head

Rock Sources

In order to achieve a preliminary understanding of rock availability and cost, we contacted some quarries in the Warrnambool area. Results from this preliminary investigation is presented in Table 8. These quarries were contacted based on their capability of extracting boulders of size of 1.0-1.5 m diameter (mentioned on their website and/or confirmed by members of sales team).

Table 8 Possible Rock Sources and Indicative Supply and Transport Cost

Rock source	Company	App. Distance from Warrnambool breakwater	Indicative price for supply of armour rock	Indicative price for transport to Warrnambool	Total cost of Supply and freight
Tarrone quarry	Holcim	36 km northwest	Not provided	-	-
Port Fairy	Bamstone	28 km west	$15/ton	$15-20/ton	$35/ton

Assumed Construction Method

Rocks are delivered from the quarry directly to breakwater as required. A mobile crane operating on the breakwater lift rocks over the parapet and lower them into the water.

Crane productivity is assumed to be one lift every 10 minutes, 10 hours a day and 6 days a week. Based on this productivity rate the operation is estimated to last for approximately 37 weeks.

Construction Cost Estimation

The cost includes supplying rock from the quarry, transporting the rocks to the breakwater (within the reach of the crane) and placing the rocks using a crane. The indicative transport price in Table 8 does not include price of stock piling the rocks on the breakwater. In order to cover price of delivering rocks on the breakwater and stockpiling them within the reach of the crane, $5/ton is added to the indicative freight price.

Preliminary estimation of the placement cost is assumed as $1,600,000 based on results from an inquiry made to “Warrnambool Crane Hire”. Indicative unit price for supply, transport and placement of rocks at Warrnambool breakwater is presented in Table 9.

Table 9 Indicative price for supply, freight and placement for armouring Warrnambool Breakwater

Indicative supply price	Indicative freight price from the quarry to the breakwater	Indicative placement price using mobile crane of the breakwater	Total indicative price for armouring Warrnambool breakwater
$15/ton	$25/ton	$20/ton	$60/ton

11.3.2 Repairs to elements

Estimates for the repairs to the rendered surfaces, timber elements and pavement surfaces are based on rates from the Rawlinsons Construction Handbook plus a 30% contingency and includes a build-up of the following components:

Item	Rawlinson's rate (incl. 30% contingency)	Quantity	Cost Estimate (incl. 30% contingency)
Repairs to rendered surfaces:			
Preparation of substrate including raking out mortar joints and hacking brickwork:	$ 21/m2	625 m2	$ 14,000
Stainless steel mesh reinforcement and placement	$ 78/m2	625 m2	$ 49,000
Prepare and install stainless steel dowels into substrate	$ 17.9/m2	625 m2	$ 12,000
Cementitious render face to masonry (19 mm thick)	$ 57.9/m2	625 m2	$ 37,000
Total Rendering costs			$ 110,000
Repairs to lower (timber) landing:			
Timber decking	$ 221 / m2	190 m2	$ 42,000
Timber bearers/joists/headstocks	$ 37.7 / m	111.6 m	$ 5,000
Labor for jetty repairs	$ 104 / man hr	360 hrs	$ 38,000
Crane hire	$ 195 / hr	80 hrs	$ 16,000
Plant and equipment	$ 130 / hr	160 hrs	$ 21,000
Total timber landing costs			$ 121,000
Bitumen pavement resurfacing	$ 35.4/m2	1300 m2	$ 46,000
Concrete pavement resurfacing (100 mm thick F72 reinforcement)	$ 104.9/m2	1000 m2	$ 105,000

11.3.3 Monitoring and investigations

Costs in Table 5 associated with the following items have been estimated based on costs incurred by GHD during recent similar bridge monitoring investigations across Victoria and include a 30% contingency:

- Ground penetrating Radar (GPR) investigations
- Structural inspection of stability of facia walls
- Ongoing monitoring survey
- Routine maintenance inspections

12. Conclusion

12.1 Inspection

The breakwater has been in service for over 125 years and while it has provided ongoing shelter throughout its service life, it has also sustained significant deterioration of a number of primary structural components over this time.

The observed deterioration and associated general defects generally relate to long term material degradation processes (erosion of joints, concrete, blockwork, etc.) and coastal processes (scour and settlement of the foundation material). While these processes may not present an immediate risk to the structural stability, their ongoing combined action will continue to degrade the structure, leading to possible global stability issues over time.

A number of voids were identified in the main breakwater deck during Mainmark's investigation in September 2015. The voids present a risk to the ongoing operation of the breakwater, particularly when located at the southern end of the structure where the risk of localised damage to the deck due to heavy vehicle operation (crane, fuel tanker etc.) is greatest.

There is uncertainty around the extent of the voids throughout the structure due to the limited scope of the drilling investigation and the limitations of visual inspection of these areas. In order to mitigate the risk associated with the presence of voids in the main breakwater deck, a number of investigation methods to identify the extent of voiding have been explored and are outlined in Section 10 of this report.

12.2 Observations

A summary of the critical observations from the visual inspection and review of previous inspections of the Breakwater includes:

- Scour under the main breakwater structure leading to settlement and rotation seaward;
- Disintegration of breakwater upper parapet head and sea side wall facing due to scour and wave action;
- Voids in the blockwork matrix caused by erosion of mortar joints and pressurised water due to wave impact traveling along open joints;
- Disintegration of reinforced concrete elements and previous repairs;
- Slower weathering, cracking and erosion of unreinforced blocks and mortar joints;
- Cracking, spalling and delamination of concrete render on deck and parapet facing presenting hazard to users.

12.3 Review of monitoring survey

Survey monitoring of the breakwater was conducted by CSE Group between May 2018 and April 2018. The monitoring involved conducting survey to a number of points installed along the breakwater and recording their position and level.

The survey monitoring indicates that minimal movement in either the horizontal or vertical plane has occurred since the monitoring begin in 2008. Both horizontal (rotations) and vertical (settlements) of the breakwater appear to have reached a state of equilibrium and appear to be dormant. Based on our review of the survey data, significant further movement (both horizontally and vertically) is unlikely to occur in the near future without significant changes on the conditions experienced by the breakwater or foundations.

12.4 Risk Assessment

A risk assessment was conducted on the breakwater which is based on an assessment of the consequence of failure of each element on the safety of users and the serviceability and strength of the structure.

No immediate actions were identified as an outcome of the risk assessment. However, a number of “high” risk items were identified which include:

- Scour under main breakwater structure and seaward rotation.
- Voids under the main deck in the breakwater.
- Delamination and instability of concrete facia walls.
- Failure of timber decking cross heads or piles.

A number of “moderate to low” risk items were identified and have been outlined in Section 9.

12.5 Comparative assessment

A comparative visual assessment was completed using the photographic records obtained during GHD’s site visit in February 2018 and the photographic records taken during the previous investigations.

The assessment indicates a noticeable deterioration in the condition of the surface treatments of a number of elements since the Connell Wagner inspection in 1998.

The prevalence of leeching in the masonry block joints appears to increase between bollard 5 and Bollard 19. The leeching appears to correspond with sections of the breakwall which have no rock armouring installed on the seaside, suggesting that saturation of the main breakwall masonry and joints may be reduced in locations where rock armouring has been installed previously (between bollards 2 and 5).

The assessment does not indicate noticeable settlement or rotation of the main breakwater since the Connell Wagner inspection in 1998. However, some evidence of increased crack widths on the main vertical cracking in the breakwater was observed above the rock protection (Refer to photos 39 & 40 in Appendix A).

13. Recommendations

A number of proposed actions were developed based on the outcome of the Risk Assessment and summary of recommendations is provided below:

13.1.1 High Risk items:

Recommendation 1 - Installation of rock armouring along the sea side of the main breakwater (from the existing armouring at bollard 5, to the rock reef at bollard 19).

Recommendation 2 - Continue monitoring survey to identify any ongoing settlement and rotation in the main breakwater wall.

Recommendation 3 - Further non-destructive investigation into the extent of voids in the deck, for example ground penetrating radar.

Recommendation 4 - Repairs to rendered surfaces of the upper and lower parapet blockwork and capping.

Recommendation 5 - Investigation into the stability of the facia walls and ongoing monitoring of their condition.

Recommendation 6 - Replacement of deck timbers, bearers, joists and headstocks on the northern section of the lower landing.

13.1.2 Moderate Risk items:

Recommendation 7 - Provide re-surfacing to asphalt and concrete wearing surfaces between bollard 1 and bollard 14.

13.1.3 Low Risk items:

Recommendation 8 – Monitor:

- Piles on lower (timber) landing.
- Navigational beacon on main breakwater.

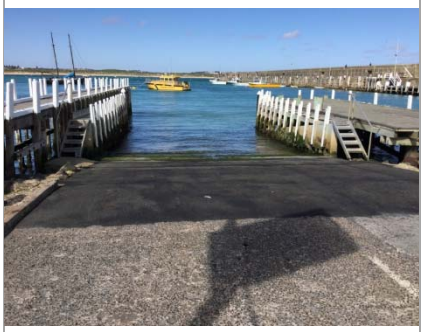
13.1.4 Safety Compliance items:

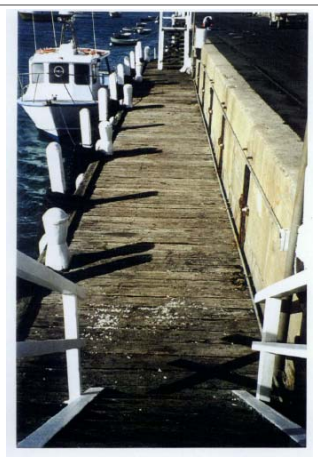
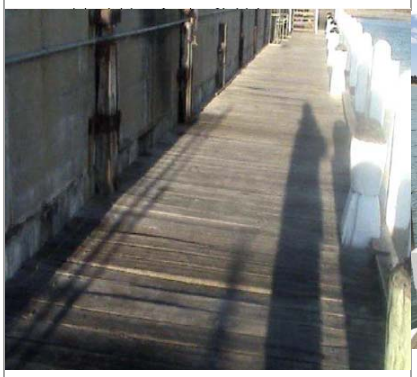
Recommendation 9 – Provide:

- Kick plates to all elevated handrails.
- Stair nosing to all stair landings.

Appendices

Appendix A - Comparative (Photo) Assessment

Connell Wagner report, 1998	Connell Wagner/Aurecon report, 2006/2009	GHD/Council Photos, 2017/18
 Photo 1: Concrete roadway and boat ramp	(No Image)	 Photo 2: Concrete roadway and boat ramp
 Photo 3: Southern Jetty adjacent to boat ramp	(No Image)	 Photo 4: Southern Jetty adjacent to boat ramp
 Photo 5: Breakwater boat ramp	(No Image)	 Photo 6: Breakwater boat ramp
 Photo 7: Lower parapet around vicinity of bollard 9	 Photo 8: Lower parapet around vicinity of bollard 9	 Photo 9: Lower parapet around vicinity of bollard 9

Connell Wagner report, 1998	Connell Wagner/Aurecon report, 2006/2009	GHD/Council Photos, 2017/18
 Photo 10: Reinforced concrete wall adjacent to Bollard 6	(No Image)	 Photo 11: Reinforced concrete wall adjacent to Bollard 6
 Photo 12: Concrete blockwork stairs at eastern end of breakwater	(No Image)	 Photo 13: Concrete blockwork stairs at eastern end of breakwater
 Photo 14: Decking plan to lower deck	 Photo 15: Decking plan to lower deck	 Photo 16: Decking plan to lower deck

Connell Wagner report, 1998	Connell Wagner/Aurecon report, 2006/2009	GHD/Council Photos, 2017/18
		
Photo 17: Typical masonry blockwork along elevated parapet wall	Photo 18: Typical masonry blockwork along elevated parapet wall	Photo 19: Typical masonry blockwork along elevated parapet wall
	(No Image)	
Photo 20: Lower parapet roadway overview		Photo 21: Lower parapet roadway overview
		
Photo 22: Rotation of elevated parapet blockwork at east end of breakwater	Photo 23: Rotation of elevated parapet blockwork at east end of breakwater	Photo 24: Rotation of elevated parapet blockwork at east end of breakwater)

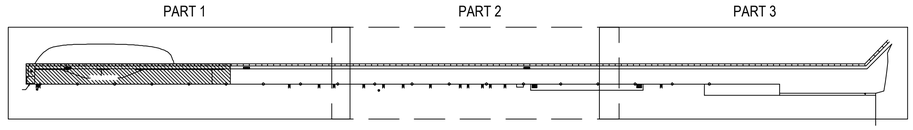
Connell Wagner report, 1998	Connell Wagner/Aurecon report, 2006/2009	GHD/Council Photos, 2017/18
		
Photo 25: Waterside view of breakwater wall	Photo 26: Waterside view of breakwater wall	Photo 27: Waterside view of breakwater wall
(No Image)		
	Photo 28: Upper parapet wall facing East	Photo 29: Upper parapet wall facing East
(No Image)		
	Photo 30: Upper parapet wall facing West	Photo 31: Upper parapet wall facing West

Connell Wagner report, 1998	Connell Wagner/Aurecon report, 2006/2009	GHD/Council Photos, 2017/18
(No Image)	 Photo 32: Lower Parapet near bollard 0 - End of parapet wall	 Photo 33: Lower Parapet near bollard 0 - End of parapet wall
 Photo 33: View towards breakwater boat ramp – Bay side	(No Image)	 Photo 34: View towards breakwater boat ramp – Bay side
(No Image)	 Photo 35: Breakwater end – Bay side	 Photo 36: Breakwater end – Bay side
(No Image)	 Photo 37: Eastern End of Breakwater	 Photo 38: Eastern End of Breakwater

Connell Wagner report, 1998	Connell Wagner/Aurecon report, 2006/2009	GHD/Council Photos, 2017/18
(No Image)	 Photo 39: Eastern End of Breakwater, seaward face	 Photo 40: Eastern End of Breakwater, seaward face
(No Image)	 Photo 41: Seaward (southern) face of breakwater at western end of rock armouring	 Photo 42: Seaward (southern) face of breakwater at western end of rock armouring
 Photo 43: Gaps observed at Bayside	 Photo 44: Gaps observed at Bayside	 Photo 45: Gaps filled at Bayside
 Photo 46: Blockwork failure due to settlement observed at Bayside	 Photo 47: Blockwork failure due to settlement observed at Bayside	 Photo 48: Blockwork failure due to settlement observed at Bayside
		

Connell Wagner report, 1998	Connell Wagner/Aurecon report, 2006/2009	GHD/Council Photos, 2017/18
		Photo 49 – Leeching of masonry block joints commencing at Bollard 5-6

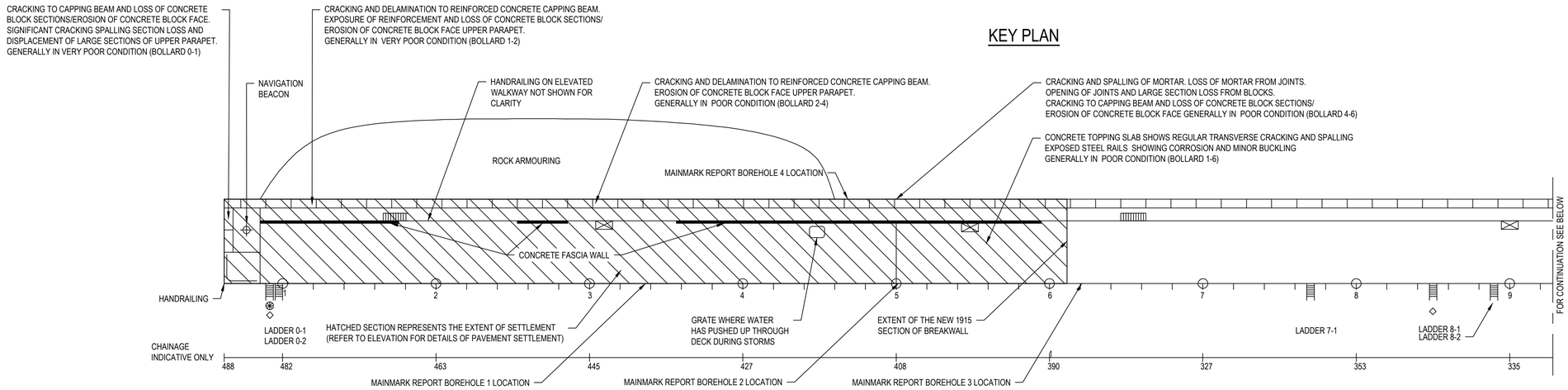
Appendix B - Defect Mapping



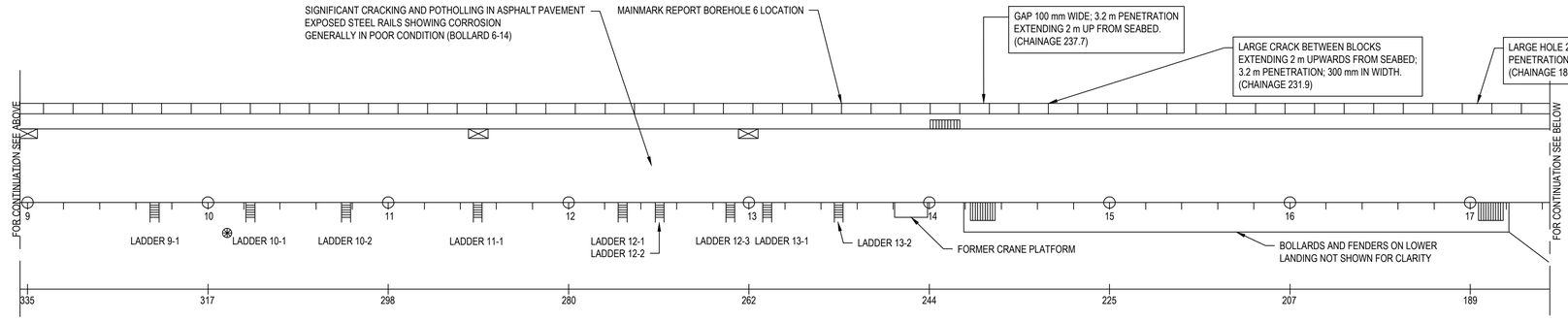
LEGEND

	FENDER
	LADDER
	WALL RECESS
	STAIR
4	BOLLARD NUMBER
	CONCRETE WALL
	STILES DO NOT EXTEND PAST TOP OF BLOCKWORK (WALKING SURFACE)
	STILE BROKEN

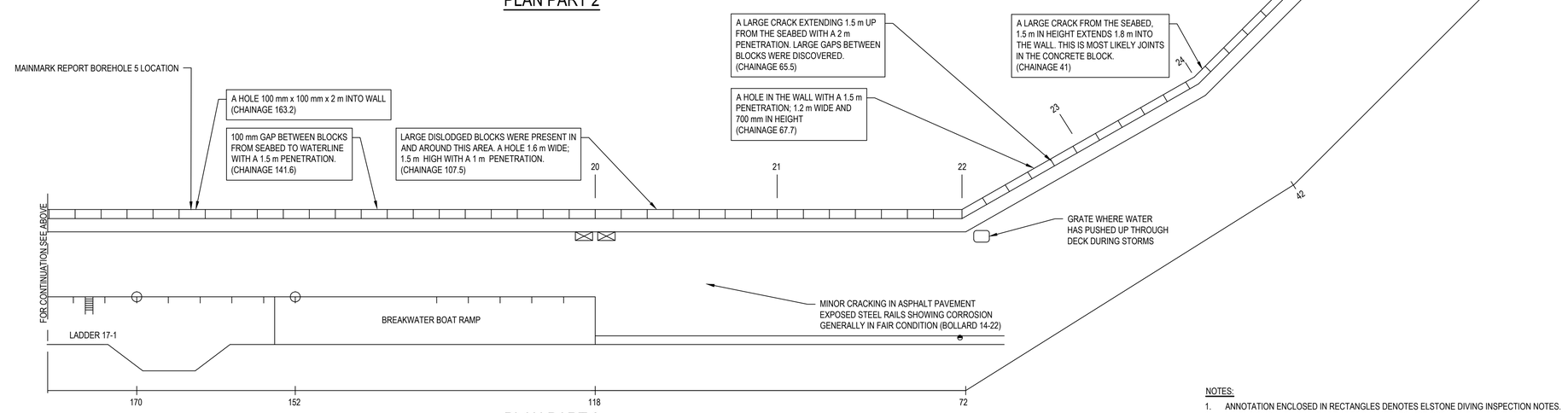
KEY PLAN



PLAN PART 1



PLAN PART 2



PLAN PART 3

NOTES:

1. ANNOTATION ENCLOSED IN RECTANGLES DENOTES ELSTONE DIVING INSPECTION NOTES.
2. DIMENSIONS AND LEVELS ARE APPROXIMATE. DO NOT OBTAIN MEASUREMENTS FROM SCALING DRAWING.

PRELIMINARY

No	Revision	Drawn	Job Manager	Project Director	Date
A	FOR INFORMATION	PJ	CT*	RH*	18.05.18

Note: * indicates signatures on original issue of drawing or last revision of drawing

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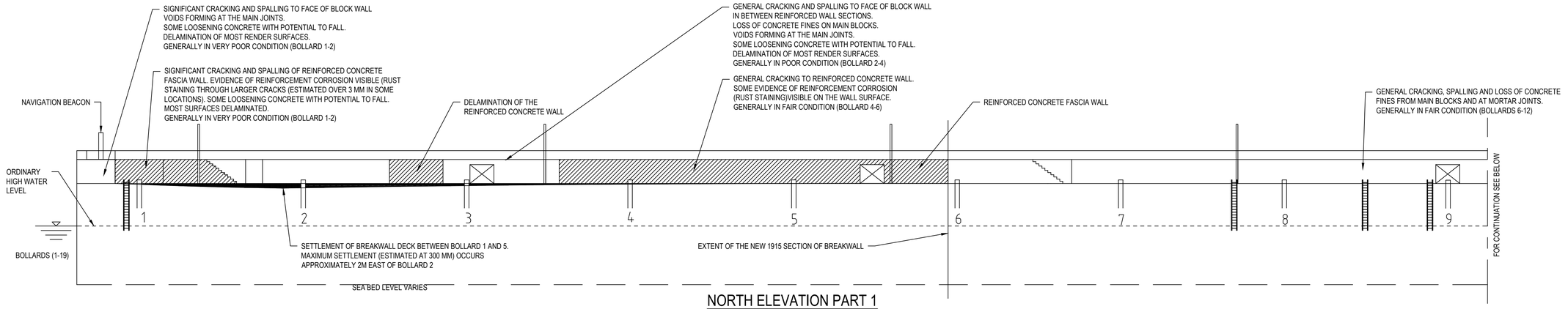
Drawn	P.DJIUARDI	Designer	A.RITCHIE
Drafting Check		Design Check	
Approved (Project Director)			
Date			
Scale	AS SHOWN	This Drawing must not be used for Construction unless signed as Approved	

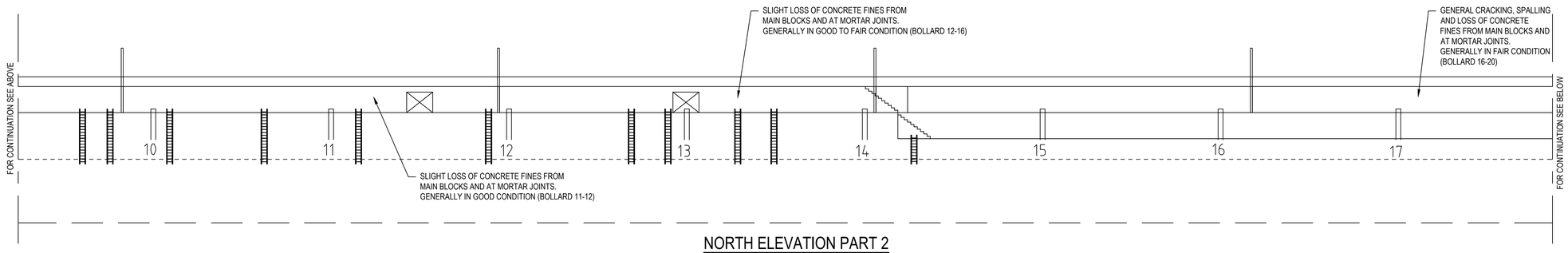
Client **WARRNAMBOOL CITY COUNCIL**
Project **PORT OF WARRNAMBOOL ASSET MANAGEMENT PLAN**
Title **WARRNAMBOOL BREAKWATER CONDITION INFORMATION PLAN VIEWS**

Original Size **A1**
Drawing No: **31-35687-S010**
Rev: **A**

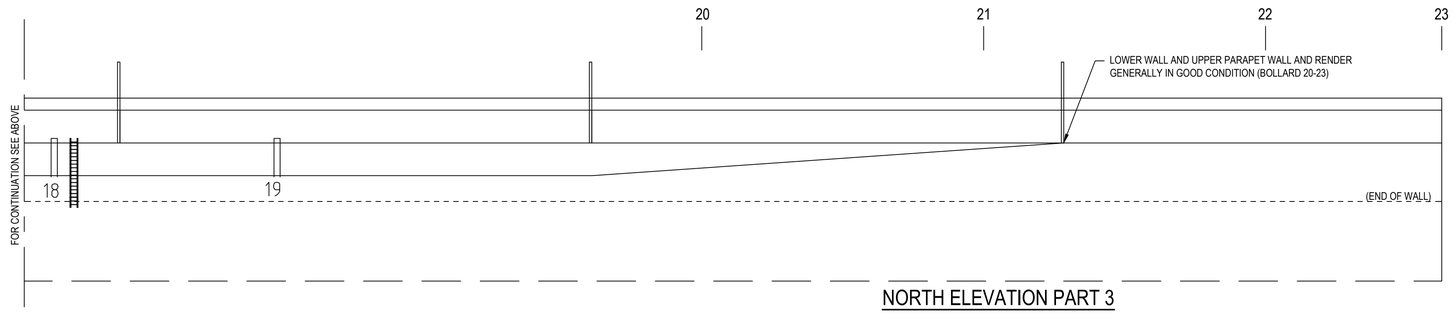
Plot Date: 18 May 2018 - 9:33 AM
Plotted by: Dave Comben
Cad File No: G:\31\35687\CADD\Drawings\31-35687-S010_S011.dwg



NORTH ELEVATION PART 1



NORTH ELEVATION PART 2



NORTH ELEVATION PART 3

NOTES:

1. DIMENSIONS AND LEVELS ARE APPROXIMATE. DO NOT OBTAIN MEASUREMENTS FROM SCALING DRAWING.

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No	Revision	Drawn	Job Manager	Project Director	Date
A	FOR INFORMATION	PJ	CT*	RH*	18.05.18

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Drafting Check		Design Check	
Approved (Project Director)			
Date			
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Client **WARRNAMBOOL CITY COUNCIL**
Project **PORT OF WARRNAMBOOL ASSET MANAGEMENT PLAN**
Title **WARRNAMBOOL BREAKWATER CONDITION INFORMATION ELEVATION VIEW**

Original Size **A1**
Drawing No: **31-35687-S011**
Rev: **A**

Plot Date: 18 May 2018 - 9:38 AM Plotted by: Dave Comben Cad File No: G:\31\35687\CADD\Drawings\31-35687-S010_S011.dwg

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https://projects.ghd.com/oc/Victoria/portofwarrnamboolass/Delivery/Documents/3135687-REP-1_Breakwater Assessment.docx

Document Status

Revision	Author	Reviewer		Approved for Issue		
		Name	Signature	Name	Signature	Date
A (Draft)						23/03/2018
0	A Ritchie	C Taylor		R Hill		18/05/2018
1	A Ritchie	C Taylor		R Hill		05/06/2018
2	A Ritchie	C Taylor		R Hill		06/07/2018
3	A Ritchie	C Taylor		R Hill		07/08/2018

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