GBC Portland Wharf & Jetty:
Condition Inspection, Analysis & Structural Repair

N. Lee¹, A. Cooper² & P. Misic³

ABSTRACT

Golden Bay Cement’s Portland wharf and associated access jetty are essential components of its product distribution network, and their ongoing serviceability is essential to the day to day operations of the company.

This paper presents the results of a detailed concrete condition survey conducted by Opus on the wharf and allied structures and examines the immediate ramifications of the survey. Particular attention is paid to the deck of the access jetty, which is constructed from slender double tee units. Failures of the pre-stressing tendons in the web of the double tees were found to have substantially reduced the loading capacity of the deck. Flexural analysis demonstrated that the capacity loss in the worst-affected spans had reduced margins of safety to the point where continued use of the rail jigger than runs along the jetty for transport of personnel was no longer tenable. The design and implementation of urgent strengthening repairs to permit the jetty to be reopened to traffic is discussed and long-term strategic considerations for the future management of the wharf facilities presented.

¹ Concrete Technologist, Opus International Consultants Ltd
² Project Manager, Brian Perry Civil
³ Logistics Manager, Golden Bay Cement
SIGNIFICANCE OF THE PORTLAND WHARF

Golden Bay Cement’s Portland Works is New Zealand’s largest cement manufacturing plant, capable of producing in excess of 900,000 tonnes of cement per annum via the energy efficient dry process. The majority of this output is shipped by sea to distribution points around the country from a dedicated wharf and bulk cement loading facility. Consequently these assets are of vital strategic importance and their ongoing serviceability is essential to the day to day operations of the company.

The wharf structures are predominantly of reinforced concrete construction and have begun to develop significant age-related distress, manifesting as cracking and spalling of the concrete elements. In light of this deterioration, Golden Bay Cement have been actively developing a long-term asset management strategy for these structures, consistent with the expectation that the Portland Works will continue operating at the current site for a foreseeable horizon of at least fifty years. In addition to maintenance and repair to maintain existing capacity, the possibility of upgrades and renewals to accommodate larger displacement vessels and the installation of wharf-side cement storage silos are also under consideration.

To assist with this planning process, the specialist concrete section of Opus International Consultants was invited to carry out a thorough condition assessment of the wharf structures during May/June 2010. This assessment was intended to gain a robust understanding of the residual life of the wharf structures, placing their durability and structural issues into context and also provide input for the development of an economic framework to guide the evaluation of design options for both repair and replacement.

A scope of work was developed to evaluate both the current and future corrosion risks facing the structure and the viability and likely long-term effectiveness of possible remediation options. The investigation included a full visual assessment of the wharf elements, with quantification of the visible defects to allow a rough order of repair costs to be estimated and exploratory break-out of deteriorated elements undertaken to confirm the extent of concrete repair required. Chloride analyses were carried out on the principal wharf and jetty elements, taking care to include a range of representative deterioration conditions and spatial positions. The concrete cover over the reinforcement was surveyed to understand the implications of the chloride penetration measured and the extent of the carbonation was also checked.

It was initially proposed to conduct an instrumented survey of the electrochemical potential and resistivity of selected concrete elements to understand future corrosion risk in undamaged elements and the possible rates at which damage could propagate. The majority of this scheduled testing was abandoned in favour of additional analyses to better understand the pervasiveness of the chloride ingress. This choice was made after observing greater than expected incidences of apparent spalling damage with atypical cracking patterns, suggesting a combination of corrosion-related and structural issues needing to be resolved to understand the deterioration patterns.

THE WHARF STRUCTURES

The wharf head is located in the sheltered Portland Reach of the Mangapai Channel, on the western margin of Whangarei Harbour. Built around 1960, it is constructed as a cast in-situ reinforced concrete deck, approximately 65 m long by 6 m wide and 250 mm thick. The deck is supported by two lines of 23 driven pre-cast and pre-stressed vertical concrete piles, with transverse raker piles protruding outwards from the wharf on alternating pile bents. The piles are capped with cast in-situ concrete pile caps.

The wharf was originally designed to support a 2,700 dead weight tonnage vessel, but is now primarily used for the 4,100 tonne ‘MV Golden Bay’ and the 2,000 tonne barge ‘Marsden Bay’. In light of the greater structural demand imposed by berthing the ‘Golden Bay’, the concern that some of the current damage to the wharf may have resulted from its lateral load capacity being exceeded was an important consideration during the condition assessment.

A contemporaneous concrete jetty connects the wharf to the Portland manufacturing plant (Figure 1). In addition to carrying a pair of cement delivery pipelines, it also hosts a narrow gauge railway track upon which runs a motorised jigger that provides for transportation of up to six people and approximately one tonne of equipment. This function is critical to enabling the berthing and loading of delivery vessels, an operation that is required, on average, every second day.
Figure 1. A view of the access jetty looking shoreward to the Portland cement works from the wharf head. The double tee units supported on concrete headstocks to form the deck of the jetty can be seen, along with the independently supported cement delivery pipelines.

The deck of the jetty consists of slender pre-cast pre-stressed ‘double tee’ units, 1.25 m wide and spanning a distance of 12.2 m, supported by pre-cast concrete piles and a pre-cast concrete headstock, as illustrated by Figure 2. There are 103 such units, giving a total jetty length of approximately 1.25 km; approximately half this length is over clear water with the remainder running through mangrove-covered mud flats.

Cast in-situ concrete is placed on top of the headstocks to locate the double tee units in place. The piles are arranged in a repeating sequence as symmetrical vertical pairs, or as two vertical piles and a raker, with the raker alternating in transverse and longitudinal orientations relative to the main span. The cement delivery pipelines span directly from pier to pier and do not load the deck units.

Figure 2. Cross section through access jetty showing general arrangement of principal elements.
CONDITION SURVEY RESULTS

Wharf Head
The condition of the wharf head was unsurprising for a ca. 50 year old marine-exposed structure employing standard Portland cement concrete, particularly one with a relatively low deck positioned less than 1.5 m above mean high water. Significant defects were observed to many of the structural elements due to corrosion of the reinforcement, followed by subsequent cracking and spalling of the cover concrete in response to the expansive pressures generated by the formation of oxidation products (rust). Especially noticeable were the large sheet spalls developing on the deck soffit (Figure 3) and extensive cracking to the majority of the pile capitals (Figure 4).

Figure 3. Sheet spall from corroding reinforcement on the underside of the wharf deck.

Figure 4. Examples of cracking and spalling observed in pile capitals.
As demonstrated by Figure 5, chloride concentration vs. depth profiles measured on the deteriorated elements were elevated and, at typical reinforcement cover depths, exceeded the well-recognized thresholds considered indicative of a high probability for corrosion development. [1] This confirmed that the likely origin of the spalling was chloride-induced corrosion, which arises due to breakdown of the passivating gamma ferric oxide coating that ordinarily protects steel in highly alkaline materials such as concrete.

![Figure 5. Examples of measured chloride profiles adjacent to a spall on the wharf deck soffit (left) and in a cracked pile capital (right).](image)

There was some initial suspicions that the amount of cracking on the pile capitals was disproportionate to the apparent section loss on the reinforcement due to corrosion, and that the cracking pattern often did not bear a simple relationship with the geometry of the underlying reinforcement, thus suggested at least a partial structural contribution to the deterioration. However a careful consideration of the likely moments in the wharf arising from berthing operations indicated the pattern of cracking was unlikely to be attributable to the lateral loading capacity of the wharf being exceeded, irrespective of how marginal this capacity might be.

The wharf piles were generally in reasonable condition, possibly because greater water saturation of these elements was suppressing corrosion rates by reducing the oxygen permeability of the concrete. However the chloride concentrations measured at the depth of the critical pre-stressing strand were high enough to be a potential concern.

There was clear evidence of earlier repairs to the wharf head, demonstrating that issues with durability were not a new development, but it proved difficult to assess the full extent of these repair cycles, or distinguish their chronology. This was due to the application of a partially-delaminating polymer-modified cementitious coating to all of the exposed concrete surfaces on the underside of the wharf, presumably in an attempt to reduce chloride ingress. Annotations to existing construction drawings indicated 29 cracked piles were identified as early as 1967, presumably damaged during driving. Remediation was reportedly undertaken around 1971 by forming and pouring a reinforced jacket around the top 1.5 m of the vertical piles. These repairs appear to have been poorly executed and were failing badly by 1988 when a condition survey was undertaken by Construction Techniques, who also reported a limited amount of spalling from the slab soffit and perimeter beam and significant cracking at the corners of pile capitals. Extensive repairs, including replacement of at least some of the pile jackets, plus patching to the pile capitals and spalled soffit appears to have been carried out as per the recommendations of that 1988 report.

**Access Jetty**

While significant defects were encountered on the wharf head, these proved less worrying than the discoveries made during the assessment of the access jetty, which, on first impression, appeared to be in better condition. The variation in concern related to the nature of the reinforcement suffering corrosion in each structure and the viability of potential repair methods: The conventionally reinforced deck soffit and
Pile capitals are readily amendable to either conventional patch repair (i.e. removal of local chloride-contaminated concrete at spalls, followed by cleaning or replacement of the reinforcement and reinstatement with cementitious mortar) or an impressed current cathodic protection system, depending on the desired future service life of the wharf. In contrast, the most severely-affected elements on the access jetty were found to be the pre-stressed double tee deck units.

Remediation of pre-stressed elements is problematic once deterioration commences. Due to the highly stressed nature of the tendons, no loss of section is acceptable and failure can be very rapid and abrupt after corrosion initiates. Nor can the elements be practically repaired using standard patch techniques due to the compressive forces imposed on the concrete by the high tensile forces in the tendons. Moreover, the pre-stressed strand is composed of multiple wound wires with microscopic interstices between them. These can act to ‘wick’ chlorides and moisture along the wires and provides a space for the formation of corrosion products, which can generate localised and severe corrosion from within the strand. By the time rust-staining and corrosion are visible on the surface of the concrete the strand is usually corroded to the point where it has lost its tensile capacity and cannot be restored. Consequently the appearance of a pre-stressed concrete element is not necessarily a reliable guide to its integrity.

Deterioration in the double tee units of the access jetty was observed to occur in a very distinctive pattern, consisting of highly localized cracks and spalls in the web, developed within 1 – 2 m of the pier headstock (Figure 6). Characteristically, damage was associated with a single position on the units with approximately 80% of the defects observed on the northern web at the eastern or wharf end of the affected beams. It is believed that this location represents a severe accumulation point for chlorides due to upwardly-directed splashing from wave action against the piles under the predominant wind direction and sea state. Chloride profiles confirmed that concentrations of this contaminant were substantially elevated at the typical spall locations relative to mid-span, although clear evidence for the north web being more heavily contaminated than the south web at a similar distance from the piers was elusive.

Figure 6. Typical splitting observed in the web of a deteriorating double tee beams on the access jetty, located 1 – 2 m away from the pier.

It is possible that a pre-existing defect may also have contributed to the susceptibility of particular beams with the cracking and spalling frequently associated with a rough ‘plucked’ surface on the interior face of the web, suggestive of difficulty in cleanly removing the beams from the formwork during the pre-casting process. It is hypothesized that the roughness and irregularity of this texture, combined with the resulting increased surface area would act to trap chloride aerosols and prevent quick drainage of wave splashing.
While this association was not absolute, it was notable that the plucking was largely absent on undeteriorated spans.

The spalling of the double tees had a clear environmental origin, i.e. it is certain they were associated with chloride deposition rather than a structural cause such as torsional loading. This was demonstrated by low levels of contamination together with a corresponding absence of deterioration in the first 52 spans of the jetty that passed through the mangroves and mudflats.

A series of exploratory breakouts carried out on affected double tee beams revealed that the damage was often severe, with up to three of the five pre-stressing tendons present in the webs completely compromised and the fourth often suffering at least some degree of corrosion, as illustrated by Figure 7. The confining action of the shear steel in the vicinity of these areas is also typically lost, although the extend of the corrosion seldom extended for more than two or three stirrups distance.

Figure 7. Broken out double tee beam showing complete loss of lower two pre-stressing tendons due to corrosion and significant deterioration developed in two more.

During the initial Opus condition assessment, nine units were identified as having two pre-stressing strands broken through corrosion and two units were found with three or more broken strands. In light of the potential significance of this problem a more intensive examination was undertaken by Bryan Perry Civi; this revealed both the number of affected beams and the extent of strand breakage had been underestimated. In the final analysis, 32 of the 52 double tee units that crossed open water displayed cracks and all 32 of the damaged units were subject to exploratory breakout to evaluate the corrosion state of the pre-stressing. Eighteen of the damaged 32 units were revealed to have lost at least two strands due to corrosion and 11 had three or more broken.

In addition to the distress observed in the double tee units, active spalling was presented on some of the piles and headstocks. In the case of the headstocks, their durability was primarily compromised by incidences of displaced reinforcing cages resulting in substandard covers, rather than systemic chloride contamination. Three of the headstocks displayed a significant loss of longitudinal reinforcement and were considered to required urgent attention to restore structural capacity. However, the majority appeared amenable to remediation by conventional patch repair as the need arose.
Chloride levels in the piles were elevated to the point where active spalling was occurring on the outer conventional reinforcing cage provided to the tops of the piles, in the atmospheric / splash zone where access to oxygen is plentiful. If long-term retention of the access jetty substructure is contemplated then it will be necessary to take prompt action to prevent the chlorides penetrating to the only slightly deeper pre-stressed tendons.

**STRUCTURAL ANALYSIS OF JETTY CAPACITY**

In light of the advanced stage of corrosion observed on some of the deteriorating double tee beams it was considered prudent that a structural analysis was immediately conducted on the superstructure of the jetty. This was carried out despite the naïve expectation immediately following the condition survey that it probably remained serviceable because the majority of spalling was observed within 2 m of the ends of the units; if not quite at the point of contra-flexure of the beams this is certainly away from the areas of maximum flexural demand. There was also no sense of insecurity or movement discernable while riding the jigger.

The structural analysis was undertaken by the specialist marine engineering team in Opus’ Christchurch office, with the ultimate limit state conditions for the jetty loaded in flexure determined using concrete capacities derived from NZS 3101 *Concrete Structures* [2] and load factors derived from BS 6349-2, the British Code of Practice that covers design of jetties [3]. The assumed demand on the jetty was based on Golden Bay Cement’s design drawings for the rail jigger, which indicated a maximum loaded jigger weight of 1,600 kg (6 people) drawing an auxiliary trailer with 1,000 kg of equipment. The results of the structural analysis are shown in *Figure 8*. Because the cement supply pipes spanned the pile heads they did not load the deck units and could be neglected, although it was noted that the piles themselves were showing evidence of corrosion and that any failure of these would affect the structural integrity of the pier with consequent likely damage to the pipelines in addition to further loss of support to the deck units.

![Figure 8](image-url)

*Figure 8. Flexural assessment of jetty superstructure showing bending moments vs. span position for different loading scenarios, compared against the capacity of the double tee units suffering from various levels of degradation (loss of pre-stressing strand).*
These results are most easily interpreted in the form of ‘fractions of capacity’, which is simply defined as the load demand on the member divided by its load-bearing ability. Thus for a member to be sufficiently strong to perform satisfactorily without risk of failure, its fraction of capacity must be less than one.

To provide a satisfactory margin of safety, design standards require that structural elements are deliberately designed to withstand factored loads (i.e. some multiple of the combined effect of dead loads plus live loads times impact). On the basis of Figure 8, the capacity fraction of the double tee beams in flexure is 1.2 at mid-span. Consequently, even in its undamaged state, the strength of the jetty deck is theoretically insufficient to support the maximum loading that was permitted for operation of the jigger & trailer, once the appropriate BS 6349-2 safety factors were applied. In fact, perusal of the original plans for the jetty indicate that the deck formed by the double tee units was only ever designated as a pedestrian walkway, with the jigger and railway presumably being a later addition.

With regard to the double tee units that are actively deteriorating, loss of a single pre-stressing strand through corrosion is sufficient to reduce the flexural capacity of these units to a level very similar to that of the unfactored load demand, effectively eliminating any margin of safety in the structural performance of the jetty. Breakage of two and three strands increases the fraction of capacity to 1.1 and 2.0 respectively for factored loads at the defect locations, indicating the jetty was potentially being subjected to overloads of up to twice its nominal capacity.

Recommendation for Temporary Closure
The results of the analysis thus clearly demonstrated the unexpected result that the existing double tee units are over-stressed, even in un-deteriorated condition, for normal loading. The loss of even one pre-stressing strand in the webs of the units through corrosion had the result that the units were relying on undesirable secondary actions to resist dead loads and imposed loads rather than behaving as designed. Furthermore, the spans in which three or more strands had been lost were at risk of collapsing without warning, even under their own dead load, although the operational running of the cement delivery pipelines would not be affected even under such extreme circumstances.

On this basis, it was strongly recommended to Golden Bay Cement that the jetty structure was closed to all normal traffic immediately. Understandably this option proved unpalatable since transfer of personnel to the wharf was essential for docking and loading operations. The likely outcome of any inability to load vessels would be the need to truck product to Auckland at significant cost and time delays and potential for disruption to customers. While it was possible for personnel to access the wharf head by boat, the mangroves and tidal estuary nature of the coast immediately surrounding the Portland plant eliminated any locally-convenient launching spots.

Due to these difficulties, Opus’ blanket closure recommendation was re-visited through examination of a reduced imposed loading case in which the jigger plus two men only were permitted to access the jetty. Based on this configuration, all the spans except those with three broken strands in their double tee beams were found to be able to support the load. Given that the first such badly deteriorated beam did not occur until pier 71, it was thus permissible that the jigger could be used to transport two people without equipment from the Portland plant to approximately ⅓ of the way along the jetty. At this point it would be necessary to disembark and walk along the tracks for the remaining distance to the wharf head. This proved to be an acceptable compromise until a strengthening repair could be developed and implemented.

REPAIR STRATEGY

Given that the adoption of this ‘reduced loading factors’ strategy still involved inconvenience and, more critically, a raised risk profile for the jetty, Golden Bay Cement were quick to recognize the necessity for an immediate repair that would restore the lost serviceability and provide a breathing space to permit considered decisions to be made regarding the long-term management of this asset.

Developing an appropriate repair detail for the double tee units posed a number of challenges. Conventional patch repairs were obviously unsuitable because the corroding pre-stressed strand could not be reinstated through the welding or lapping techniques applicable to conventional reinforcement, eliminating the possibility that the required level of flexural capacity could be restored. The addition of external post-tensioning could possibly provide this but, from a durability perspective, would not prevent on-going deterioration due to continued spalling of concrete; however, retention of the existing cross-
sectional area of the double tee webs is essential for the post-tensioning to successfully resist structural actions. A further problem with external pre-stressing or providing additional reinforcement such as carbon fibre wraps is the difficulty of successfully anchoring the ends of the strands or fibre to the existing structure.

Complete concrete encapsulation of the deteriorating webs with a new conventional reinforcing cage tied into the deck of the units was rejected due to the potential adverse consequences of such a heavy repair. These included the torsional loading effect on the deck where only a single web needed encapsulation and the additional burden placed on the bearing capacity of the piles if a symmetrical repair of both webs was attempted. The need to transport and place significant volumes of concrete, for which use of the jigger seemed the only practical solution, also conflicted with the ongoing operational requirements of the jetty.

Ultimately, the geometry of the piers provided the key to a simple repair using conventional steel universal (I) beams to form a ladder-like frame supported on the tops of the pier cross-heads into which the loads from the failing double tee units could be transferred. This repair detail, developed by Opus’ Christchurch office in conjunction with Bryan Perry Civil, who were responsible for the on-site execution and Fletcher Construction who provided project management, is shown schematically in Figure 9.

![Figure 9. Temporary strengthening repair developed for Portland access jetty based on spanning between the pier crossheads with universal beams and then installing transoms at the quarter points to support the deteriorating double tee beams.](image-url)

A pair of 310UB40 primary beams are installed on each remediated span, running from headstock to headstock, with each beam sitting just outside lines of the existing double tee deck. Three 150UC30 secondary beams are then bolted to the underside of the primary beams to provide transoms at the quarter points of the span such that they are in contact with the soffit of the double tee webs. To transfer the load carrying of the deck units into the frame, jacking is undertaken between the webs and the two outer secondary beams until a 20 mm displacement is achieved. Packing is then inserted between all the secondary beams and the double tee webs for the full width of the beam flange and lateral stiffeners welded in place between the primary and secondary beams, as shown in Figure 10.

No protective system was specified for the steel work because it is envisaged that the repair will be purely a short-term solution (in the order of two years) and that the rate of corrosion of unprotected steel will not be an issue over this timeframe. However, all the fastenings (bolts, washers, nuts etc) used were hot-dip galvanized to ensure that the steelwork is demountable without difficulty in the future, should it be decided that re-decking with retention of the original pile substructure is the optimal long-term strategy for the access jetty.
Figure 10. Strengthening repair showing installation of transoms at quarter points to support deteriorated double tee units.

Ultimately, the twelve worst-affected spans of the jetty were strengthened in this fashion to improve their structural integrity. In combination with a risk-based management approach and careful monitoring, this was considered adequate to permit lifting of the loading restrictions on the jigger and restore the jetty to full functionality while decisions were made on its long term future. Three badly damaged pier headstocks were also remediated with simple external bracing to increase the lateral confinement provided to the piles at these locations, as illustrated by Figure 11.

Further remediation of jetty and head to address the less critical defects identified by the condition survey are contingent upon future strategic decisions by Golden Bay Cement regarding the desired level of service from these facilities. Important considerations include the size of vessels to be accommodated, the possibility of cement storage adjacent to the wharf and the delivery pipeline capacity necessary to support this, and the desirability of providing a jetty deck that could be trafficked by conventional vehicles. Once these issues are resolved, life cycle costings will permit the evaluation of options such as repair versus full replacement.
CONCLUSIONS

The unfortunate fact that a condition assessment originally intended to assist with the development of a long-term asset management plan for a strategic asset quickly evolved into an urgent repair to ensure ongoing serviceability emphasizes the need for careful monitoring of aging concrete structures, particularly once evidence of deterioration becomes apparent.

Happily, many of the design practices for reinforced concrete structures exposed to marine environments that are now enshrined in the ‘Durability’ chapter of NZS 3101 would have eliminated or greatly reduced the problems described, with commensurate benefits to service life. These include increased cover to the steel and use of supplementary cementitious materials to reduce the chloride diffusivity of the concrete.

The possible pitfalls of using slender pre-stressed elements as a design solution for structures exposed to aggressive marine conditions are worth highlighting in light of the current experience with the Portland jetty. While their light weight and speed of erection offer compelling advantages during the construction phase, they are far less amenable to repairs for extending their serviceability than conventionally reinforced elements. This can eventually become an important consideration when the desired life from an asset exceeds the original design life, as often proves to be the case. In this particular instance, the 50 years of service achieved by the jetty deck is hardly inconsequential; however, this is as much a testament to the relatively benign conditions presented by the inner Whangarei Harbour as it is to the suitability of the double tee units for a marine environment.

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REFERENCES

