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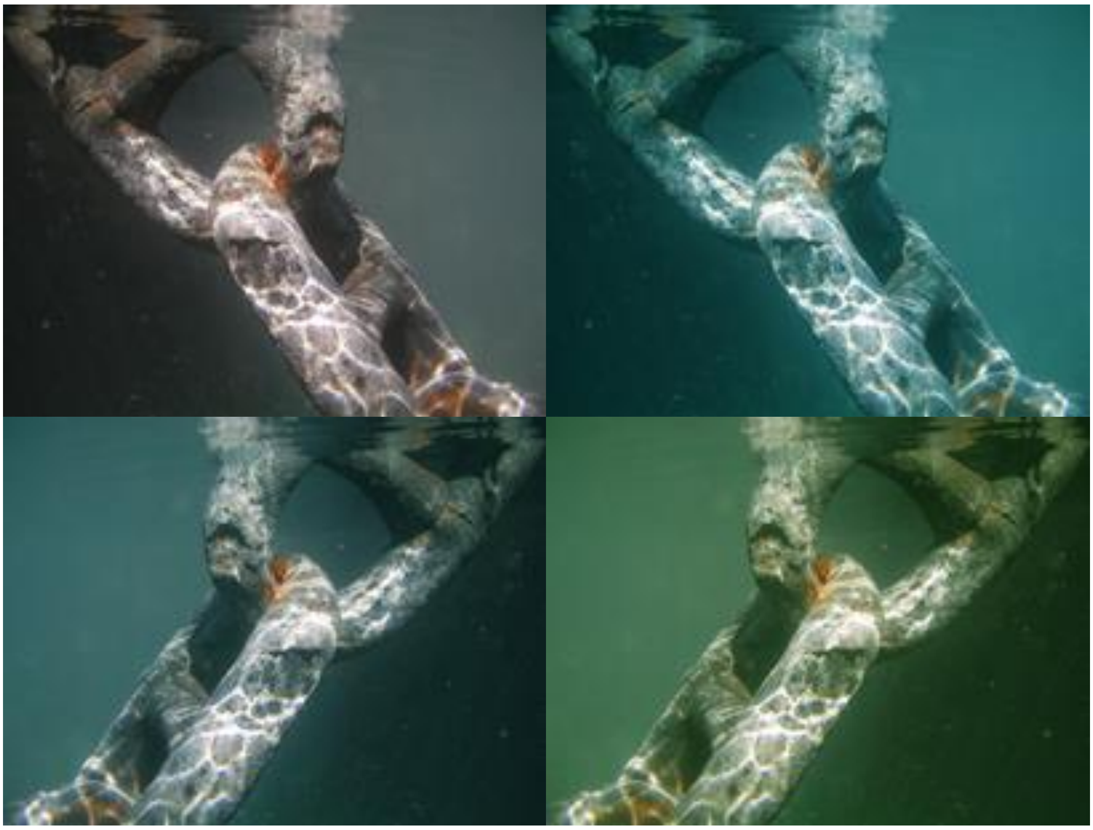

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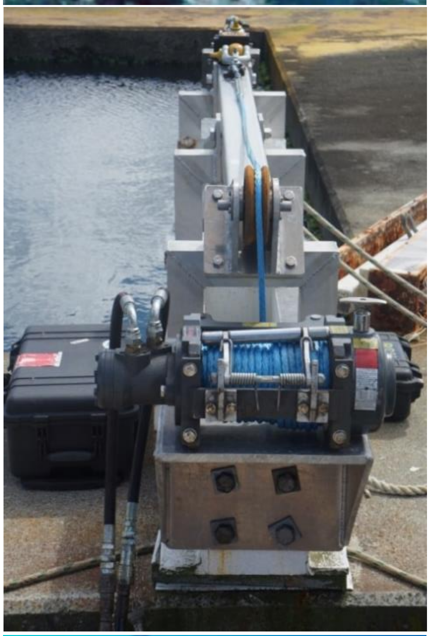

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Preface

Chaffers Marina Limited Concrete Breakwater Long Term Moorings (LTM) and their life cycle management represents a major planning and engineering effort, and as such constitutes a massive investment of capital. For Companies and or Government Authorities to obtain the maximum working life and return on their initial investment from assets in a marine environment it is important that they be maintained to an acceptable and safe working standard. To ensure the quality assurance of their asset it is necessary to complete infrastructure condition assessment surveys, programmed maintenance, and subsequent to inspection findings; remedial works.

When marine structures; which include Long Term Moorings, come into service it is hoped that they are free of all significant faults. This of course depends on the professional standards and quality assurance practises of the numerous involved Parties in design, fabrication, construction, and installation.
To ensure a continuous working life for any marine asset, it is necessary to maintain an adequate inspection programme. Such a programme must be capable of detecting potential problems at an early stage. This allows the designers and engineers time to analyse the inspection information and suggest remedial action if required.

Experience has shown that the vast majority of all faults; damage / defects / deterioration found in marine structures have been done so visually. Visual information is of utmost importance both in programmed visual survey inspection, condition assessment, and general diver observations.
Throughout the progression of these survey inspections personnel observe and record data on numerous components in varying condition states.
The consequences of failure of what initially may only be a single component, especially sudden failure, can be catastrophic and very expensive, both in terms of repairs, lost business, and risks to health, safety and the environment.
Programmed survey inspections / condition assessment / asset audits are completed to ensure the continuing operational function and safe condition of the structure is maintained. Providing the Asset Owner, its operators, and subsequently the users with an assurance of reliability and ensuring the integrity of the structure.

Condition assessment is an important step in the life cycle management process of moorings and other marine structural assets.
One of UCL's major facets of work and experience is in the inspections, condition assessment and reporting on numerous 'in-water' structures throughout New Zealand and Offshore. It is a facet of our work that we can derive immense satisfaction from; when being able to detect potential problems at an early stage, then work in partnership with Clients towards achieving common goals and economic solutions. Thus minimising risk and therefore maintaining the Clients valuable asset in safe and efficient working condition – "fit for purpose".

Introduction

Mooring systems of floating structures consist of long lengths of chain, rope or wire. Chain is typically used at the bottom of a mooring line, connected to the anchor and at the top, connected to the floating structure. The top and bottom of a mooring line, respectively the splash zone and the thrash zone, are particularly exposed to corrosion, wear, axial load and bending.

Mooring lines have to withstand large loads. As part of a station-keeping system, the mooring lines have to keep the movements of the moored structure to a minimum. The mooring lines have to withstand loads on the moored structure in addition to loads acting directly on the mooring components. The environmental loads from wind, waves and currents may be large during extreme weather. Such large environmental loads are normally accounted for. The load with a return period of at least 100 years is considered when designing mooring components. Usually, the mooring lines are designed for an operational life of 20 years.

Periodic inspections are necessary to monitor the structural integrity of mooring lines. If a mooring line fails, the floating structure can lose station and sustain catastrophic damage as well as potentially causing severe damage to other structures, vessels, and environment, economic losses and loss of lives.

Figure 1: Chaffers Marina floating concrete breakwater

- The floating structure constructed from precast concrete with polystyrene core is 200m in length x 10.5m in width x 2.1m in depth; weighing approximately 1500 tonnes
- On the topside surface of the breakwater 20 Anchorpoints secure 23 pretensioned mooring chains, that are anchored at the seafloor by 23 driven Stake-piles

General and Overview

The Chaffers Marina floating concrete breakwater and its mooring systems form a major and integral structure crucial to the location and operation of the marina. The floating breakwater is a continuous post-tensioned pre-stressed concrete structure of 200 metres in length x 10.5 metres wide x 2.1 metres depth.
The floating structure is moored by a series of chains both transversely and longitudinally. At the surface top-end these chains are secured to the concrete structure through heavy steel anchor-points, and at the seabed the chains are secured to driven universal column stake piles.
Construction of the floating concrete breakwater structure was completed in February 1993. The original construction design life for the breakwater was specified as being a minimum of 50 years; with both the breakwater and its mooring systems being designed for 100-year wave conditions.

Following completion of a condition assessment survey and mooring technical design analysis reporting on the Concrete Breakwater mooring systems; staged renewal of unserviceable catenary chains, along with the applying of correct pretension to the mooring systems was given approval to proceed.
During 2018 initially the 11 north-leading chain top-end catenary sections were renewed and pretensioned (1 shot length ea. / 27.5 metres).
Followed in 2019 with renewal and pretensioning of the 6 south-leading chain top-end catenary sections (1 shot length ea. / 27.5 metres).

Note: At this time none of the 6 longitudinal chains have been renewed.

Mooring Chains: There are 23 moorings (chain lengths and associated shackles) that comprise to make the floating concrete breakwater structure mooring systems. From the shoreward-side deck of the breakwater there are eleven seaward (north) leading chains; with six having horizontal lengths of 70 metres each, and the middle five having horizontal lengths of 60 metres each.
From the seaward- side deck of the breakwater there are six shoreward (south) leading chains; each with horizontal lengths of 40 metres. Longitudinally six chains are installed: three leading east, and three leading west; all with horizontal lengths of 70 metres each.
The catenary section of the moorings consists of 38mm diameter U3 stud-link chain; while the ground section is 36mm diameter stud-link chain.

Anchor-points: There are 20 anchor-points installed on the deck of the breakwater structure; all constructed from heavy steel flat and channel section. The anchor-points have a chain-locker plate that is designed to securely hold the top-end chain links of the mooring systems. The anchor-points are fixed securely to the breakwater structure through heavy stainless steel threaded rods.

Stake-piles: There are 23 stake-piles; each being 10 metres in length, pile-driven steel 350 UC 177 (universal columns). All are driven into the seabed, to a minimum embedment depth of 8.0 metres. Each stake-pile has a heavy steel pad-eye welded to its face, for anchorage connection of each of the mooring chains.

Cathodic Protection: Each of the 23 stake-piles and 23 top-end chains has sacrificial anodes installed to provide corrosion protection, and therefore extend their service lives.

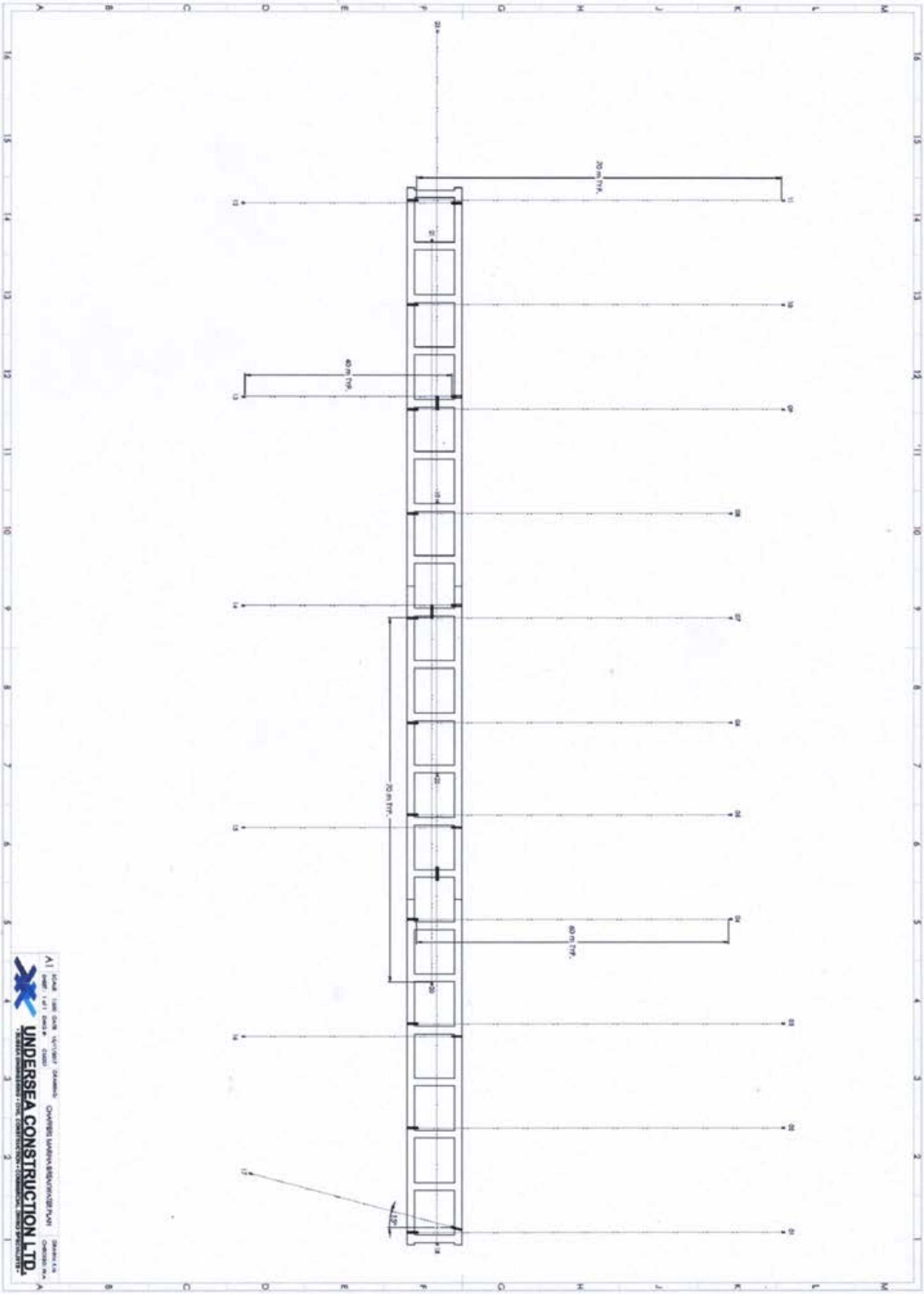

Figure 2: Breakwater and mooring layout diagram (refer to separate drawing for detail in A1 scale)

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RECORD OF MOORING CONDITION ASSESSMENT OR TESTING

DATE OF WORK:	2018 - 2019
NAMES OF PERSONNEL:	Dave Owen, Rian Kriel, Wayne Angus
CLIENT:	Chaffers Marina Ltd.
LOCATION:	Wellington Harbour
INSPECTION / TEST COMPONENT:	Mooring systems (23) securing floating concrete breakwater

MOORING TYPE / DESCRIPTION
Pretensioned catenary anchor leg mooring (CALM)

WORK TYPE	CHECK	PARTICULARS / OBJECTIVE
CONDITION ASSESSMENT	X	Underwater condition assessment survey to verify condition status of moorings
TESTING	X	Use specialised winching equipment and load-cell to bring up mooring pretension to predetermined load and catenary angle
ASSET MAINTENANCE	X	Renew top-end catenary 38mm diameter x 27.5 metre length (shot length) stud-link chain on all 11 north-leading and 6 south-leading moorings
OTHER		

DESIGNATION	COMMENTS / RESULTS
Chaffers Marina floating concrete breakwater – mooring systems (23 units)	As part of a station-keeping system the mooring chains were pretensioned; so to keep the movements of the moored breakwater to a minimum

SPECIALISED EQUIPMENT	EMPLOYED PROCESS
RON 2501, ID: 9018, S/N: 22029257 Load cell WLL 20 M.tons	Measuring applied load
Topcon GTS-229 Electronic Total Station, S/N: UP4038	Position and range monitoring
Broco ultrathermic underwater cutting equipment	Cutting out of old deteriorated chain
Hydraulic winch and associated mounting and rigging equipment	Installation and pretensioning of mooring chains
Liftbags	Suspension of loads

ANY OTHER REMARKS: Refer to Report for details. Note: Further chains will require renewal during the 2020 / 21 financial year

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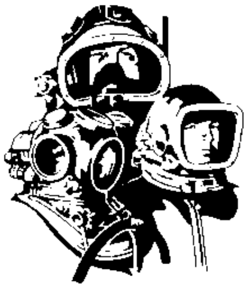
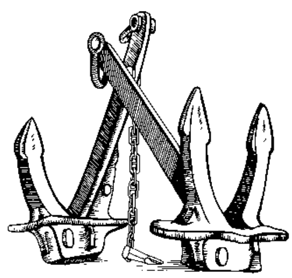
APPROVED
NAME OF SUPERVISOR: Wayne Angus
SIGNATURE: *Wayne Angus*
DATE: February 2020

NAME OF CLIENT'S REP: Mr Andrew Welsh (General Manager)
SIGNATURE:
DATE:



"To solve it easily, detect it early"



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Anchorpoint – MIMSS
Mooring Installation, Maintenance & Survey Services.
(the Mooring specialty services division of UCL).

Moorings

Mooring lines are used to keep floating structures at a fixed location. Lines must withstand forces from the moving floating structure and from the environmental loads that act directly on the mooring lines.
The Chaffers Marina floating concrete breakwater mooring lines are pretensioned in order to minimize the movements of the moored structure.

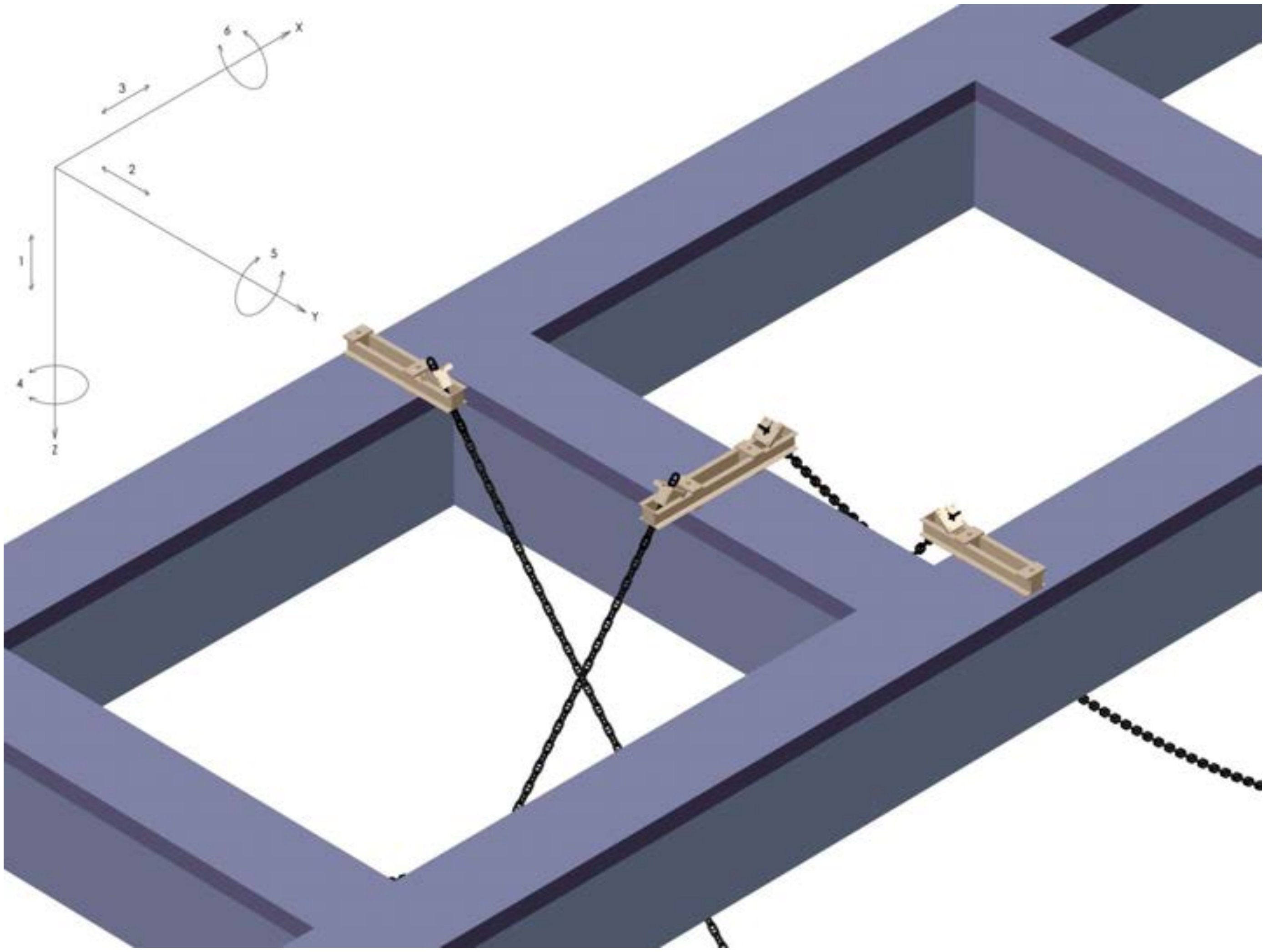


Figure 3: As being similar to a vessel, the floating concrete breakwater has six degrees of freedom in a three-dimensional space: three displacements and three rotations.
1, 2, 3, 4, 5 and 6 are respectively heave, surge, sway, yaw, roll and pitch

Failure of Mooring Systems:

A long-term mooring system is supposed to withstand the design load at the end of its service life. This means that the mooring system has to withstand a 100-year storm after approximately 20 years of wear, fatigue and corrosion.

Figure 5 illustrates some of the main factors that affect a mooring system's service life. Bending occurs at abrupt changes of the slope of the mooring line and the largest line tension occurs where the slope is at its steepest. Most of the cyclic movements occur in the so-called thrash zone, at the end of the catenary line where the chain comes in contact with the seabed. The chain is exposed to abrasion and surface damage due to movements in the thrash zone. If the chain is studded, another problem arises: the stud may loosen and move freely in the link. If so, the end of the stud and the side of the link are particularly exposed to corrosion.

Causes of Mooring Line Failure:

Overload may lead to plastic deformations, yielding and ductile failure. On the other hand, cyclic axial load, cyclic bending and / or cyclic torsion of non-critical size may lead to crack propagation and brittle failure. Cyclic loading as well as changes in geometry may cause high stresses and crack propagation. Plastic deformations due to proof loading or overload and notches or surface damages due to wear or corrosion will lead to changes in the cross-section geometry. Sometimes these geometric changes give unexpected effects.

Consequences of Mooring Line Failure:

A mooring system is designed to withstand one line failure without further damage of the remaining mooring lines. However, the safety factors on the remaining lines should be raised until it has been determined with reasonable confidence why the original line failed.

If several mooring lines fail, the remaining lines are overloaded, resulting in loss of position of the floating structure.

The following factors increase the likelihood of multiple line failure:

- Design - The presence of a systematic weakness in the mooring system will apply to all lines.
- Age - Fatigue, corrosion and wear will tend to deteriorate all mooring lines, particularly in the same quadrant, to roughly the same extent over time.
- Detection - Where no programmed monitoring occurs, failure of a single line may go undetected. This may expose the remaining lines to larger loads for an extended period.

DETERIORATION

The progressive deterioration of a component of the system under fatigue, corrosion and wear.

FIRST FAILURE

Followed by failure of the component under moderate storm conditions. This could go undetected.

UNZIPPING

Overload of adjacent lines, perhaps after further deterioration if the initial failure goes undetected.

EXCURSION

Loss of integrity of the mooring system could be identified from the loss of station keeping after failure of several lines.

Figure 4: Potential failure scenario when multiple lines fail

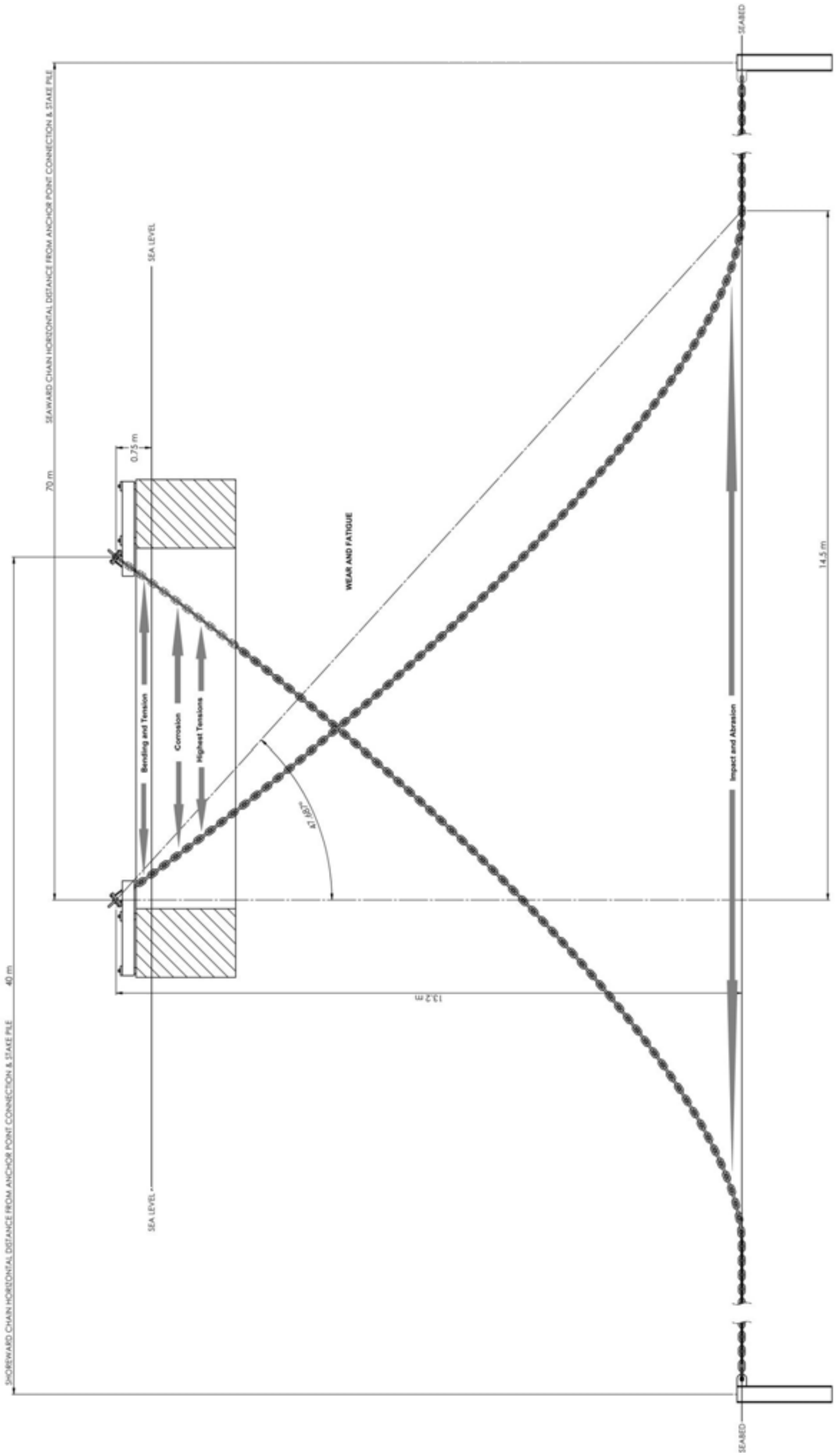


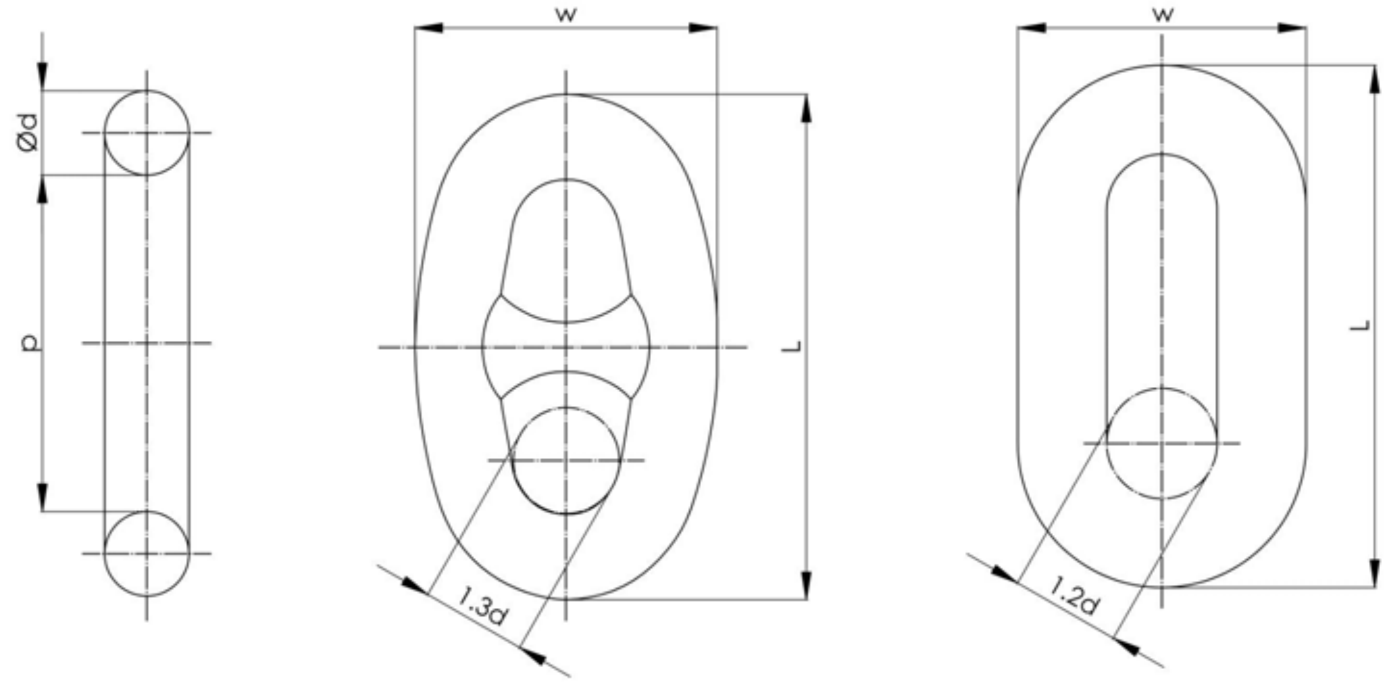
Figure 5: Wear, fatigue and corrosion of a catenary mooring line

Abstract

Chain links:
There are primarily two types of chain links, stud links and stud-less links. Stud links have, as the name implies, a transverse stud that connects the link at midpoint. The design of stud links is standardised and described in ISO 1704. The design of stud-less links is not standardised, but it is common practice to use the dimensions provided by IACS W22.

Common stud links have length 6.00 D, width 3.60 D and an inner link radius equal to 0.65 D. Common stud-less links have length 6.00 D, width 3.35 D and an inner link radius equal to 0.60 D. The letter D stands for nominal diameter.

Enlarged links can be used as connectors between common links and end links. The nominal diameter of the enlarged links is 10% larger than the nominal diameter of the common links, giving D_1 = 1.10 D. the length and width of enlarged links are calculated by replacing D with D_1 in the formulas for common links. The increased diameter of enlarged links result in increased strength, thus, enlarged links are ideal in critical areas with large loads.



a) Side view of chain link
p = 4.00 D

b) Stud link
L = 6.00 D, w = 3.60 D

c) Stud-less link
L = 6.00 D, w = 3.35 D

Figure 6: Common link design.
L is the total length of the chain link
w is the total width of the chain link
D is the nominal cross-sectional diameter

Technical Notes:

Critical Stress Locations in Chain Links

The geometry of chain links leads to complex interaction between forces. Structural parts are exposed to bending, shear, tension and torsion, and often in more than one plane. The risk of failure increases if the chain includes flaws of critical size or if the chain is exposed to fatigue or corrosion.

The bending stresses can be high and cause failure if the chain is overloaded. The stress distribution caused by bending is illustrated in Figure 7.

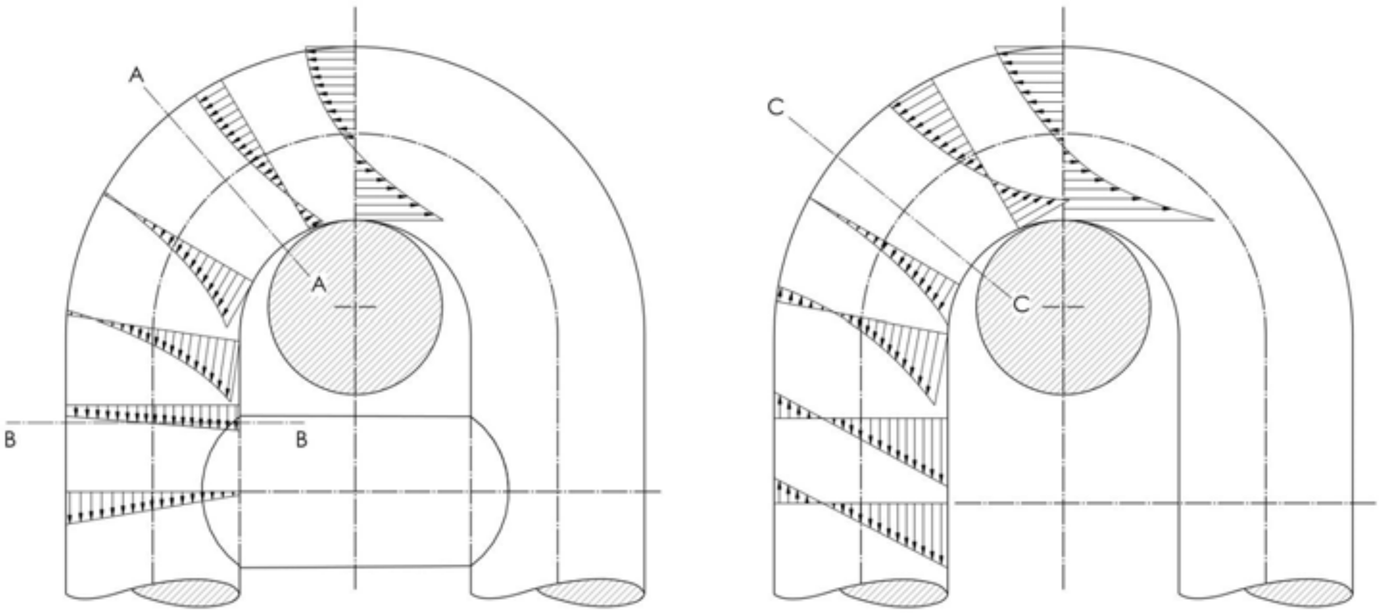


Figure 7: Bending stress distribution in a stud-link (to the left) and a stud-less link (to the right). Section A-A, B-B and C-C represent areas with zero bending moment and zero bending stresses

Figure 7 shows that stresses can be very high in the bended section. The highest shear stresses are located between the crown and the straight parts. The shear stresses are critical and may lead to failure in chains with low or medium hardness. As the hardness increases, the normal stresses become critical and may lead to failure.

When a chain is overloaded, ductile failure occurs. The steel yields in the most loaded areas, primarily at the curved parts of the chain links.

When a chain is exposed to fatigue, the stresses in the chain links change. The failure is due to propagation of cracks and huge stresses in the surrounding areas. The material will experience brittle failure. Finite element analysis has shown that the curved parts and the area at the weld in a chain are particularly exposed to fatigue.

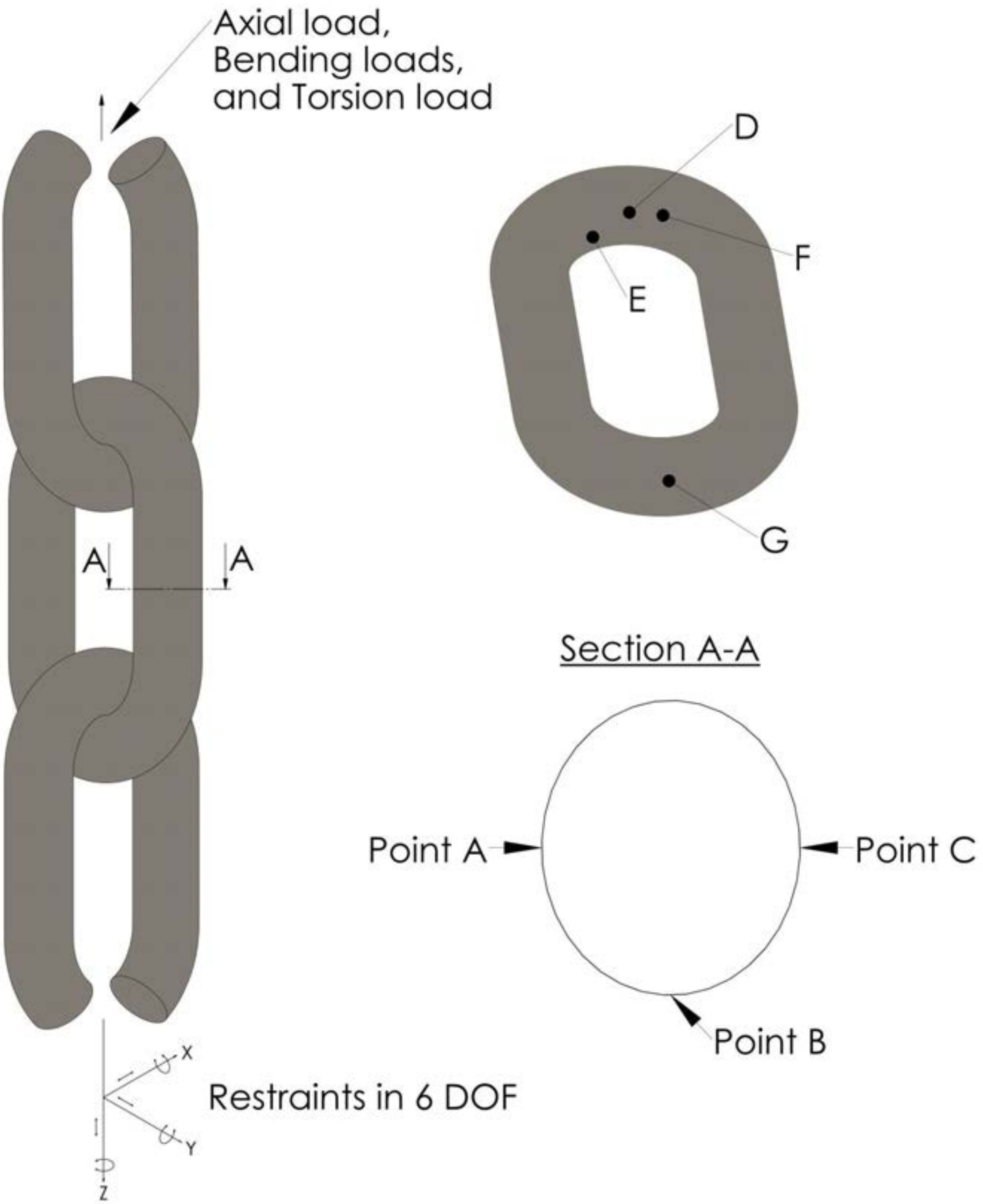


Figure 8: Critical locations in stud-less links exposed to cyclic loading. Fatigue may take place at point A, B, C, D, E, F or G due to cyclic axial load, bending and / or torsion

Critical areas where fatigue may occur are:

Point A: Inner surface of link at weld, stresses in axial direction. This point will be critical primarily because of the weld and the accompanying stress concentration factor. The weld may have residual stresses due to heat treatment or the weld may have a flaw due to impurities or lack of bond between the bar ends. In the case of stud-links, the stud may displace, causing high stresses at this point.

Point B: Lateral surface of link at weld, stresses in axial direction. This point will receive the highest stress due to out-of-plane bending.
Point C: Outer surface of link at weld, stresses in axial direction. This point will receive the highest stress due to in-plane bending. Use of stud-links will reduce the stresses at this point.
Point D: Inner surface at crown, stresses in the direction of maximum stress range. This point will receive the highest stress range due to out-of-plane bending.
Point E: Inner surface at bend, stresses in the direction of the maximum principal stress. This point will receive the highest stress due to in-plane bending.
Point F: Inner surface at bend. Maximum stress range due to torsion is seen at this point.
Point G: Crown of link. This point will receive high stresses due to tensile loading.

Corrosion

Corrosion is an electrochemical oxidation of metals which degrades material properties such as strength and permeability.
The following factors will influence the corrosion rate:

- Dissolved oxygen,
- Temperature,
- Salinity,
- Velocity of water particles,
- Sulphate reducing bacterial count.

Corrosion has a very detrimental effect on the fatigue strength of engineering materials, primarily because of the subsequent metal loss. Uniformly corroded surface areas are generally taken care of by a corrosion allowance in the design of structural components.
However, it is the corrosion pits, with more severe metal loss, that are crucial when it comes to fatigue. The pits are in fact notches that work as stress raisers. The irregular shape of a corrosion pit and the stress concentration in the surrounding area may lead to the initiation of cracks.

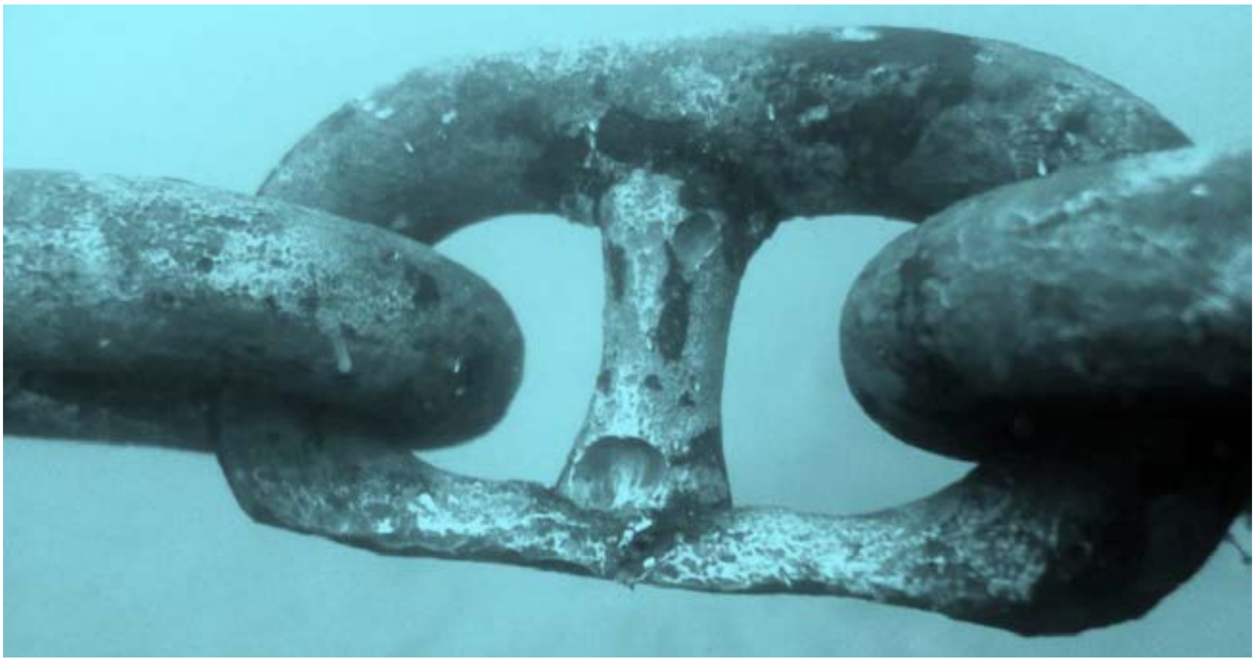


Figure 9: Example of a chain link located in the Thrash Zone – wear and corrosion are clearly evident. The irregular shape caused by wear and corrosion has resulted in cracking adjacent to the stud

Summary of Completed Works

Moorings

Following completion of a condition assessment survey and mooring technical design analysis reporting on the Concrete Breakwater mooring systems; staged renewal of unserviceable catenary chains, along with the applying of correct pretension to the mooring systems was given approval to proceed.

- During 2018 initially the 11 north-leading chain top-end catenary sections were renewed and pretensioned (38mm diameter Studlink Chain: 1 shot length ea. / 27.5 metres).
- Followed in 2019 with renewal and pretensioning of the 6 south-leading chain top-end catenary sections (38mm diameter Studlink Chain: 1 shot length ea. / 27.5 metres).

Notes: At this time none of the 6 longitudinal chains have been renewed.
Further transverse ground chain lengths will require renewal in the 2020 – 21 financial year.

Pretension testing and analysis

- Comprehensive testing and analysis was carried out to calculate the pretension required per mooring leg to achieve optimum station keeping and the correct chain catenary angle.

Figure 10: UCL custom built a load testing and pretensioning system for the purpose of checking wear in old chains; installation and setting pretension of new chains

Figures 11 & 12: Load testing of mooring leg

Figure 13: A pretension of 0.40 M.tons achieved the correct catenary angle on mooring chains
Angle of chain at top connection to horizontal = 54° (approximate: BW at rest, however tidal influenced)
Angle of chain at top connection to vertical = 36° (approximate: BW at rest, however tidal influenced)

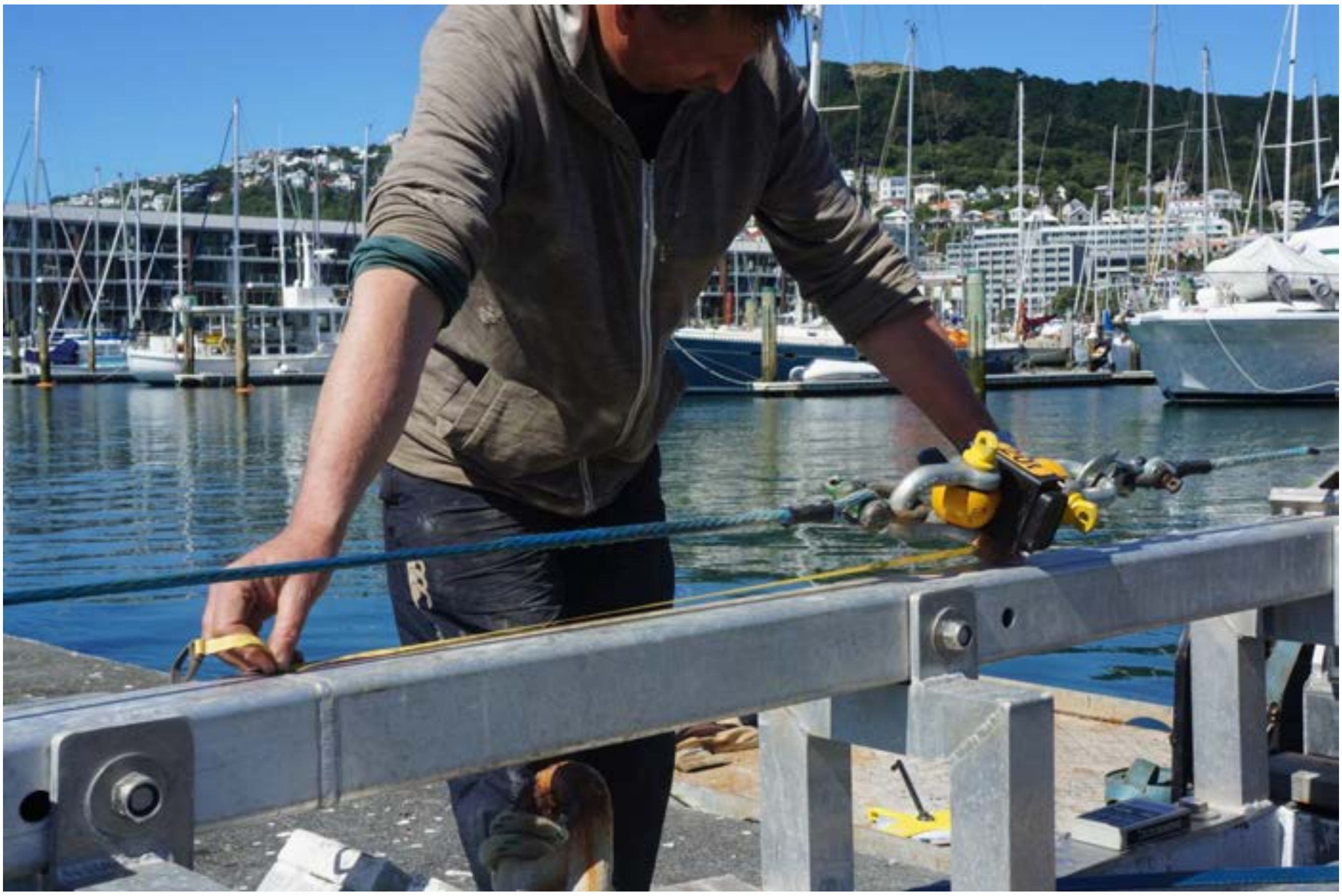
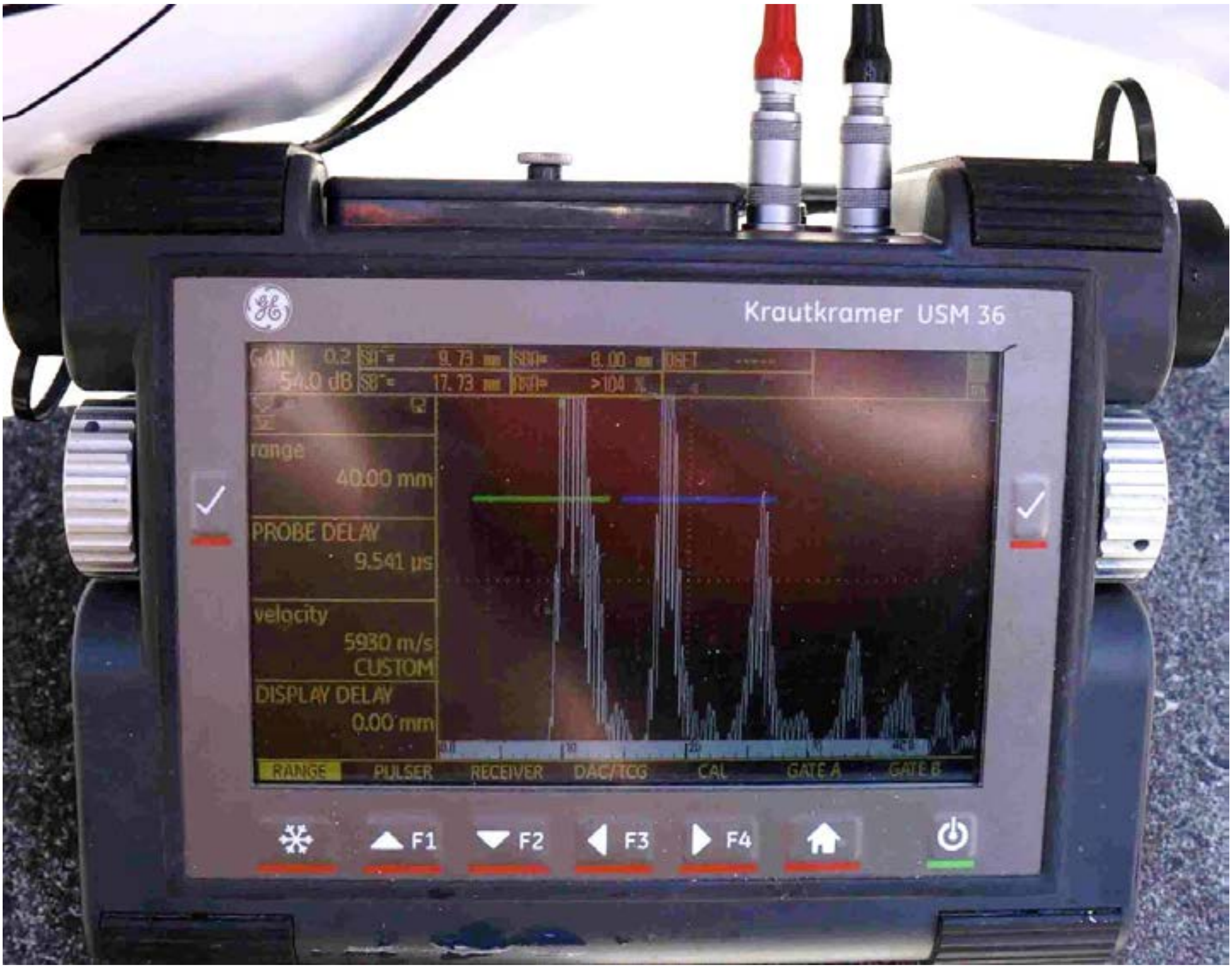


Figure 14 : The distance of travel checked with varying test loads being applied

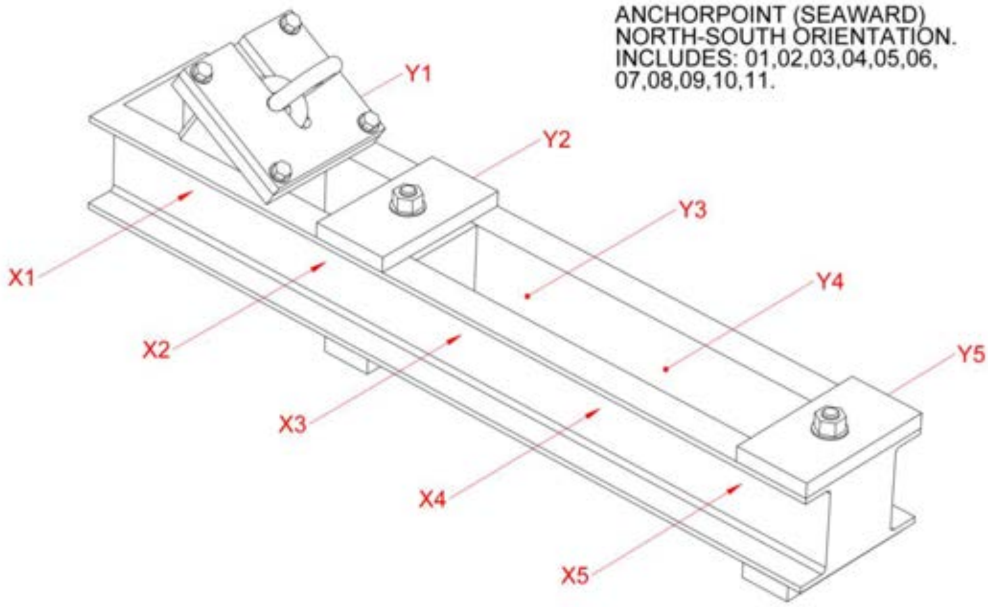
Figure 15: Monitoring ‘Station’ (Breakwater) movement under the influence of applied test loads

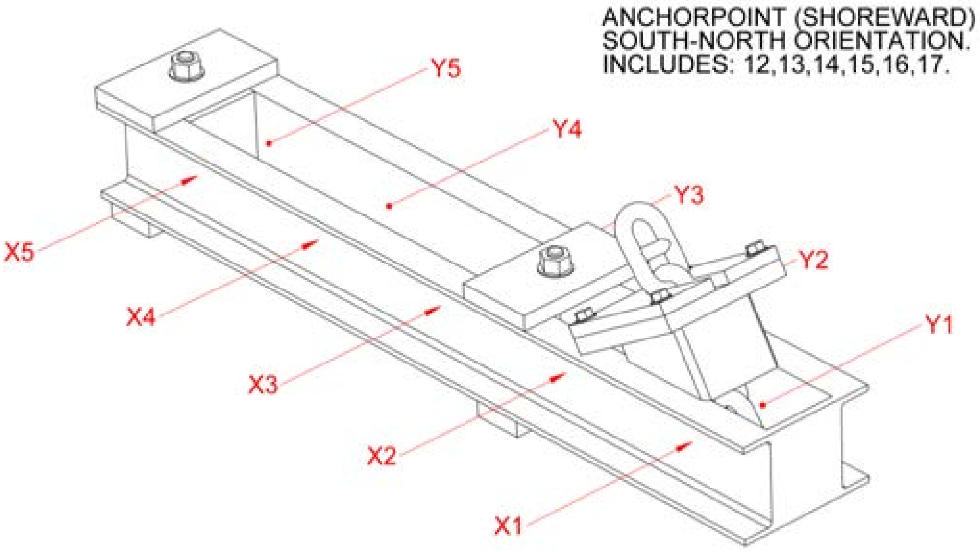
Anchorpoints

- Non-destructive testing (NDT) Ultrasonic Thickness Measurement (UTM) was carried out on all Anchorpoints to measure for loss of steel thickness.
- Where reduction in steel thicknesses (due to corrosion) were found to be greater than 40% of that of the original steel member design thickness, stiffening plates were weld installed to both strengthen the position and also improve the overall current structure integrity of the Anchorpoint.
- Rust descale, and protective paint coating application is currently in progress.



Figures 16, 17 & 18: Krautkramer USM 36 in operation – taking Anchorpoint PFC web thicknesses





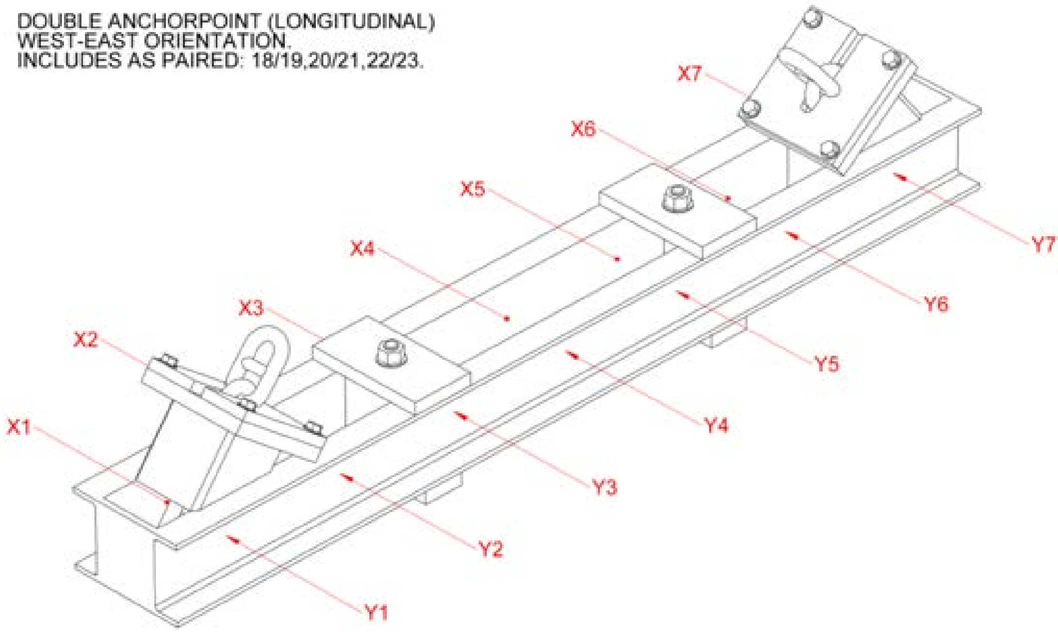


Figure 19: Anchorpoint (web) test positions

Cathodic Protection

- A50 (50kg ea.) sacrificial anodes and bond cables have been installed and cathodic potential testing completed: connected to all top-end catenary chains to protect against corrosion.

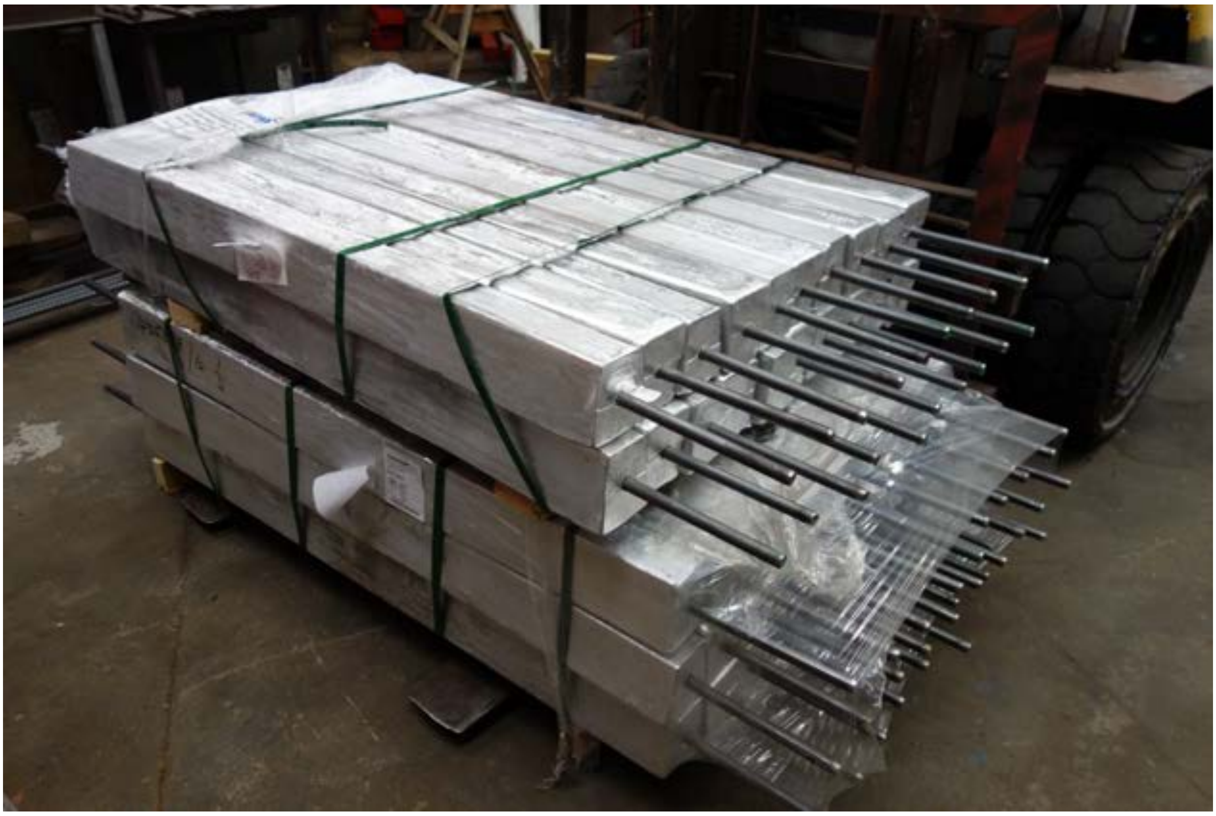


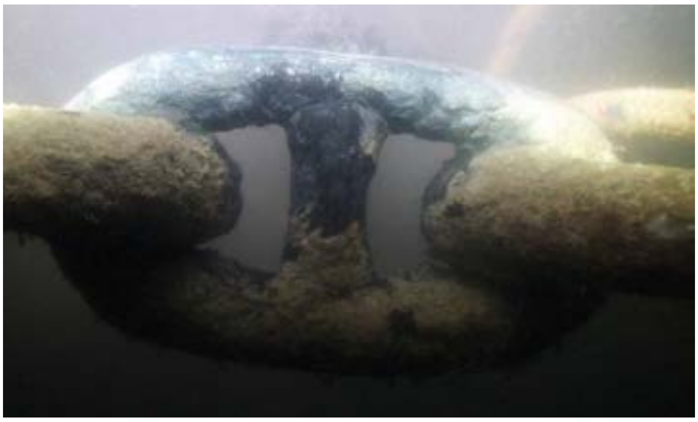
Figure 20: A50 (50kg ea.) sacrificial anodes

Figure 21: Electrical continuity bond cables

Recommendations

Visual inspection survey of all mooring system components; e.g. Anchorpoints, chains, shackles, CP, and stake-piles should be completed on an annual basis.

While engaged in the installation of the 6 new south-leading catenary chains it was observed that several of the ground chain (buried in seabed) sections exhibited excessive wear in many of their chain links.
This has meant slightly greater pretensions have needed to be applied in an effort to achieve catenary connection into a suitable chain link.
It's recommended that budget be brought forward to allow renewal procurement and installation to replace the existing 6 south-leading ground chain lengths within the 2020 – 21 financial year.



Figures 22, 23 & 24: South-leading ground chain – temporarily elevated out of seabed with use of a Lift-bag.
It's believed that due to dredging when the OPT was operating, the seabed was reduced down to where a tight bound sedimentary layer of shell and stone composition now immediately underlies the current shallow mud and silt layer. This material is proving to be quite aggressive on the mooring chains within and beyond the thrash zone.
With the correct pretension now being applied to the moorings, and subsequently minimised movement in Station, the affected zone should be significantly reduced

"To solve it easily, detect it early"

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Marine Civil works. Welding. Structural survey.

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Anchorpoint – MIMSS
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(the Mooring specialty services division of UCL).