

ARC Marine – Marine Port Structure Guidance

Introduction

The Port infrastructure in mature, well developed, countries is often over 100 years old, long before international or national marine construction standards of build were fully documented and routinely updated as is commonplace with modern construction methods.

This document aims to provide an overview of the key issues typically affecting Marine Port Structures and provides guidance as to current technical references. It also provides a brief overview on the maintenance requirements for port structures and the construction materials used, specifically concrete, steel, stone and timber and issues arising from the use of these materials.

The audience for this document is aimed at Port Manager level and not Port Engineers.

It should be noted that whilst the author refers primarily to a view with respect to UK standards, it does also reference other international standards which should always be consulted as necessary.



General

1. Safety within ports was covered under the Docks Regulations 1988 but this was revoked in April 2014 and superseded by the Health & Safety Executive's (HSE) Approved Code of Practice; L148 Safety in Docks (2014). It should be noted HSE are looking into port operations with a number of guides issued in 2014 relating to container operations and general safety in ports.
2. Where a structure was constructed after 1996 the project would have been covered under the Construction (Design & Management) Regulations 1994 which have subsequently been replaced with the Construction (Design & Management) Regulations 2007 and the associated Approved Code of Practice and as amended in April 2015.
3. The HSE must be notified where a project is either expected to last more than 30 working days or involve more than 500 person days, for example 50 people working for over 10 days. This is classed as a notifiable project and will be applicable for most port work in view of the nature of such work; For example the 'Liverpool 2 New Container Terminal' Project is programmed to take over a year to build and is classed as a notifiable project.
4. The regulations also require a notifiable project to have a Health & Safety file; this will contain the information needed to allow future construction work, including cleaning, maintenance, alterations, refurbishment and demolition to be carried out safely. Information in the file should alert those carrying out such work to risks, and should help them to decide how to conduct work safely.
5. Section 5 of the regulation's introduction states that the time and thought invested at the start of the project will pay dividends not only in improved health and safety, but also in:
 - a. Reductions in the overall cost of ownership, structure is designed with safe & easy maintenance & cleaning in mind, key information is readily available in the health & safety file;
 - b. Reduced time finding relevant information;
 - c. More reliable costings & completion dates;
 - d. Improved communication & co-operation between key parties; and
 - e. Improved quality of the final product
6. This brings in the requirement of the designers to think and plan for the future maintenance requirements of the structure.
7. Most ports in the UK are historically sited and were initially built / developed in the last two centuries. There are some new ports such as London Gateway, other existing ports have had extensive upgrades to reflect changes in the size of vessels using the facilities, notably container vessels.

Feasibility

Feasibility studies are used to identify realistic and cost effective options that meet technical, legislative and environmental requirements for any new development and are carried out prior to any detailed design or impact assessment. Determining the most appropriate place for a jetty breakwater or terminal requires an understanding of all the factors that might impact or impinge on that decision.

Shoreline and seabed changes (morphological change) can be caused by coastal defences or other structures in the environment or due to changes in wider sedimentary and hydrodynamic (flow) patterns resulting from human activities or natural processes (including climate change). Understanding how the shoreline or seabed changes is essential for designing and maintaining coastal and marine structures as well as a key component of any Environmental Impact Assessment (EIA). EIAs are undertaken to ensure the potential environmental

impacts of new developments have been sufficiently considered in the decision making process.

Technical feasibilities include those preliminary studies undertaken to assist in determining detailed design of port structures. Such studies could consider modelling the following:

- Significant and extreme wave heights
- Wave induced current
- Current speed and direction
- Design wind criteria at a range of averaging periods and heights
- Extreme values for given return periods
- Water level variation and tides
- Joint Probability Analysis (JPA)
- Sedimentation

Planning

Early consideration should also be made regarding the legislation and consents that might be necessary. Permissions may be required for both the land and water side elements of the development and could include:

- General Permitted Development Order
- Town and Country Planning (Environmental Impact Assessment) Regulations 2011)
- The Marine Works (Environmental Impact Assessment (EIA)) Regulations (2007) as amended 2011
- Harbour Revision Order
- Marine Licence

The EIA process has three steps as follows:

- Screening Opinion. An application is made to the Marine Management Organisation (MMO) or Local Authority with basic information of the proposed development for determination as to whether an EIA is required for the proposed works. In this case, the scale of works and the local designations are sufficient to make an EIA compulsory and therefore this step can be ignored;

- Scoping Opinion. The aim of the scoping opinion is to precisely define the detailed areas to be assessed in the EIA. Equally, this should also identify and justify areas that do not require further assessment. When a screening opinion is not necessary, the project plan and scoping information should be submitted clearly requesting a Scoping Opinion. This will include the requirements from the MMO or LA statutory consultees, e.g. Natural England (or Welsh and Scottish equivalents), Environment Agency (or Welsh and Scottish equivalents) and the MMO Scientific advisors, Cefas; and...

- The EIA addresses the topics identified in the Scoping Opinion.

Design

8. The standards for design will be set by one of a number of International Standards Developing organisations.
9. In the UK the British Standards Institution was set up to produce national standards. Now known as BSI it is an International Standards Developing organisation with their standards used internationally, (www.bsigroup.com).
10. BSI has developed a number of codes of practice relating to design of jetties – BS 6349 Maritime Structures. These are regularly reviewed and updated as necessary. Indeed this also reflects the need for more information with BS 6349-1 being split into 4 sub-sections in recent years.
11. It should be noted that depending on the individual country, they may produce their own standard or refer to another, for example Australia provides guidance which refers to BS 6349.
12. The American equivalent is ANSI (American National Standards Institute) which provides a similar service to that of BSI, (www.ansi.org).
13. There is an international association responsible for addressing the issues in the field of navigable waterway traffic on rivers, ports and canals. The association is called PIANC – Permanent International Association of Navigation Congresses and is also referred to as “World Association of Waterborne Transport infrastructure”. (www.pianc.org)
14. PIANC provides a forum for guidance, recommendations and technical advice through technical reports, commissions, technical groups and congresses, both national and international for practitioners.
15. Turning back to BSI, changes have been made to the concrete section with the clauses being updated to align with BS EN 206-1 (European Standard - Concrete: Specification, Performance, production & conformity) and BS 8500 (Requirements for standardised prescribed & designated concretes). It updates the durability requirements within the concrete section in respect to minimum cement, type, cover and water/ cement ratios for 30, 50 and 100 years design life. These changes incorporate the latest cement and cement replacements as given in BS EN 197-1:2011 (European Standard – Cement) and provide more accurate data for mix designs to achieve adequate durability. BS 6349-1-4 replaces section 7 within BS 6349-1:2000 and is now a standalone document.
16. The codes do not generally cover maintenance although BS 6349-1-1: 2013’s last chapter covers maintenance and this may reflect the industry need for improved guidance in this area.
17. The current published BSI standards are¹:
 - a. **BS 6349-1-1: 2013** Maritime structures. Code of practice for planning & design for operations
 - b. **BS 6349-1-3: 2012** Maritime structures. Code of practice for geotechnical design
 - c. **BS 6349-1-4: 2013** Maritime structures. Code of practice for materials
 - d. **BS 6349-2: 2010** Maritime structures. Design of quay walls, jetties and dolphins (Under revision)
 - e. **BS 6349-3: 2013** Maritime structures. Design of shipyards and sealocks
 - f. **BS 6349-4: 2014** Maritime structures. Code of practice for design of fendering & mooring systems
 - g. **BS 6349-5: 1991** Maritime structures. Code of practice for dredging & reclamation
 - h. **BS 6349-6: 1989** Maritime structures. Design of inshore moorings & floating structures (Temporarily withdrawn – under revision)
 - i. **BS 6349-7: 1991** Maritime structures. Guide to the design & construction of breakwaters
 - j. **BS 6349-8: 2007** Maritime structures. Guide to the design & construction of Ro-Ro ramps, linkspans & walkways
 - k. **BS 6349-9:** Maritime structures. Guide to the design & construction of port surfacing (New standard – currently being developed)
18. There are also British Standards for the materials used in construction to ensure consistent standards, an example being BS1200 which covers chloride levels in aggregates.

¹ www.shop.bsigroup.com

Asset Management Systems

19. An Asset Management System (AMS) can be used to monitor and maintain things of value (assets) for a port group, port or department within a port. It can be applied to tangible assets such as buildings, cranes and quay walls as well as to intangible assets such as human capital, intellectual property and financial assets. The level of detail can vary in granularity from the concept of treating a whole port as an asset down to the finer details of an asset within an asset group.
20. PAS 55 and ISO 55000/55001 Asset Management Systems have been adapted for use in ports to enable the structured and methodical recording of a ports asset base throughout the asset lifecycle. AMSs are broken down into guidance notes, tools and enablers to ensure that ports can:
 - a. Record all of the required information for each asset
 - b. Assess the current status of their asset base
 - c. Review and amend contingency
 - d. Future plan their assets
 - e. Link their assets to the port and/or group 5 year plans
 - f. Assess asset condition and criticality
21. Port specific AMSs are designed to be used by all departments within a port group with a continuity of processes that ensures that asset management is implemented equally in all departments. An AMS should provide a location for the recording of all active processes, thus enabling an objective view of these processes, highlighting and facilitating any areas that have a short fall of effort, discontinuity or need for change. Once implemented an AMS should become the foundation for management decisions, investments needs, acquisition criteria, maintenance schedules, managed decline, renewal, disposal, workloads and costs.
22. Port specific AMSs cover the following key areas:
 - a. Plan
 - b. Policy
 - c. Strategy
 - d. Process Map
 - e. Asset Creation and Acquisition
 - f. Project Management Process
 - g. Procurement of Plant and Equipment
 - h. Local Asset Management Objectives
 - i. Utilisation Specification
 - j. Local Maintenance and Inspection Plans
 - k. Renewal and Disposal
 - l. Business Planning Process
23. The BSI AMS that are adhered to are:
 - a. **PAS 55** Optimised management of physical assets
 - b. **ISO 55000** Asset management -- Overview, principles and terminology
 - c. **ISO 55001** Asset management -- Management systems – Requirements

Maintenance

24. Maintenance will need to be carried out during the life of a maritime structure in order to ensure that it can meet its design. The costs of such maintenance can be greatly reduced by adopting an appropriate planned maintenance programme from inception.
25. The principles of such a maintenance programme will cover:
 - a. Programmed inspections
 - b. Timely inspections of reported damage / defects
 - c. Maintenance / Repair work carried out in good time
 - d. Effective management and replacement of protection systems
 - e. The replacement of worn-out components in sufficient time to avoid additional work
 - f. Proper record keeping of all inspections put together with planned and unplanned maintenance
26. With maintenance requirements / guidance having been excluded from the BS standards in general, the inspection and maintenance guidance for port structures in the UK has historically been drawn from the UK Highways Agency Design Manual for Roads and Bridges BD 63/07 Inspection of Highway Structures.
27. The rationale for this approach is that the consequences of any failures with the structure will be similar to that of a damaged bridge and there are similarities with regards environmental conditions.

28. There are five categories of inspection described in the Design Manual for Roads and Bridges (DMRB) BD 63/07:

Inspection Type	Description
Safety Inspection	Where a defect has been identified.
General Inspection	Visual inspection every 24 months.
Principal Inspection	Close visual inspection every 6 years.
Special Inspection	Inspection after a special event, e.g. extreme high tide event.
Inspection for assessment	Part of a structural assessment.

Table 1 – Design Manual for Roads BD63/07 Inspection of Highway Structures

29. It appears to be widely accepted within the industry that quays should be visually inspected every two years from the quay and by boat as necessary and that a diver inspection should be carried out, where the diver can reach any joints, connections or supports every six years which ties in with the general and principal inspections above.
30. When building or developing a port consideration should be given to the general sighting and alignment of the structure, the civil and structural design requirements allowing for the location and the proposed use, frequency of use, projected vessel growth in size for that trade, the weather, tidal and other marine aspects together with the use of fenders for impact protection for the ship and structures to minimise the risk of damage to either.
31. The principal survey of a quay wall may be carried out by divers or ROVs however for budgetary purposes the wall survey may be broken down into sections with a section surveyed every second year in detail and falling in line with the visual inspection. This allows the cost to be budgeted over 6 years.

- 32.** A detailed report should be issued every two years and after any safety or special inspections. This report should cross-reference previous survey work and include a section on any appropriate repairs or issues of maintenance which should then be addressed.
- 33.** There is clear guidance regarding how any defects should be addressed and it is common for a remedial works plan to be prepared which will prioritise works depending on the severity of the defect and consequences. Where issues arise it is normal to list the defects, prepare budget estimates for the works and advise on the cost of managing the work to restore the integrity of the asset structure.
- 34.** For any new jetty structure there should be a baseline inspection and report covering the whole site but only to the extent of diving and other inspections undertaken at that time. In addition it would be appropriate to have a programmed strategy to ensure the principal quays are inspected with sufficient frequency to identify at an early stage any defects and enable measures to be put in place to address these effectively. The baseline report on the as-built condition would be issued as a record for all future reference and, if appropriate, a recommendation on any repairs or maintenance which should be undertaken in the first year.
- 35.** An additional source of information is the Oil Companies International Marine Forum (OCIMF) publication "Jetty Maintenance & Inspection Guide" which provides effective maintenance of critical items of equipment at oil and gas terminals; it gives advice on different items of equipment together with proactive & reactive maintenance guidance.
- 36.** OCIMF has developed this as part of their ongoing anti pollution and environmental protection stance. The result of pollution generally has a high cost and associated bad publicity. It was recognized that the major risk for pollution is at the interface between ship and shore – the jetty.

- 37.** There is wide ranging guidance on the minimum inspection intervals for a range of equipment used on jetties including electrical, hydraulic, lifting equipment etc.; Table 2 below gives the regime for bollards as an example:

Type / Frequency	Pre-berth	6 Months	1 Year	5 Year
Visual	✓			
Nuts & Bolts		✓	✓	✓
SWL Markings		✓	✓	✓
Bollard Support Structure		✓	✓	✓
Bollard Surface wear / damage		✓	✓	✓
Measurement of movement or subsidence				✓

Table – 2 OCIMF Bollard Inspection Frequency

- 38.** This guidance is not often used for non hazardous berths in the author's experience however it is critical as an increased number of larger vessels use berths possibly not designed for such large vessels with the consequence of overloading the bollards.
- 39.** OCIMF provide a recommended maximum interval between inspections for a typical saltwater jetty as given in Table 3 below:

Type / Frequency	1 Year	5 Year
Above Water	✓	
Under Water		✓

Table – 3 OCIMF Inspection Frequency – Saltwater Jetty

- 40.** A difference can be seen in Tables 1 & 3 between BD63/07 and OCIMF although Table 3 is the very basic OCIMF recommendation.
- 41.** It should be noted for any particular structure the frequency of inspection is determined by the environment and the traffic which gives a "rate of decay" and the specific inspection regime for that jetty should be based on that.

Fendering

- 42. There is a wide range of effective fender designs, from simple timbers, "D" type rubber type fendering to more complicated roller systems. The use of tyres whilst cheap to use and widespread is not ideal as they or their mounting system are easily damaged as seen in Fig. 3 below.
- 43. Tyres which have broken off are a particular menace through the risk of fouling a ships propeller or thrusters as tyres generally float just below the surface which makes them very hard to spot.
- 44. Fendering is designed to stop the structure being damaged but can only do so if the fendering itself is in good condition, as such it only takes one heavy landing to require maintenance / replacement thus prompt reporting of any incident / damage and more frequent inspection schedules are required for fendering.

Materials

- 45. The normal materials used nowadays will be steel and concrete. Timber was often used for lock gates, fendering, and as piles for jetties. Stone was extensively used in the 19th and early 20th century but largely overtaken by concrete and also jetty design. The modern use of stone is principally with Gabions.

Steel

- 46. Steel is very suitable for the construction of marine structures particularly where there are high design loads however it readily corrodes in a marine environment where it is exposed to salt water and oxygen.
- 47. It is also used for machinery and parts such as lock hinges, bollards, handrails and access ladders. For machinery the manufacturer will supply the maintenance procedures.
- 48. Components such as bollards will have been installed with a design working load however with age this should be revisited either through testing or use of a civil engineer to survey the structure to ensure the foundations and fixtures such as bolts are still suitable.

- 49. Provided the steel has been effectively protected by a suitable system the effect of corrosion can be minimised but there is a need for a planned maintenance system to ensure this. There are two principle protection systems; coating and cathodic protection.
- 50. Coatings will normally be a paint system which dependent upon quality of product, surface preparation and application can give a life of 10 to 20 years (dependant on manufacturer's recommendations and intermediate maintenance). The issues with maintaining coatings are access, preparation and application of the new product in situ.
- 51. Cathodic Protection, such as sacrificial anodes or impressed current cathodic protection (ICCP) systems using DC power and long life anodes protect the surrounding steel work. ICCP will have a greater initial cost than paint or sacrificial anodes.
- 52. Either cathodic system only protects the wetted areas. Areas which may dry out still require a coating for the steel's protection from corrosion.
- 53. Referring to Fig. 1, the "traditional" corrosion zone for steel is the splash zone; that point around the high water mark where a protective coating can be damaged by contact with floating material or a vessel.

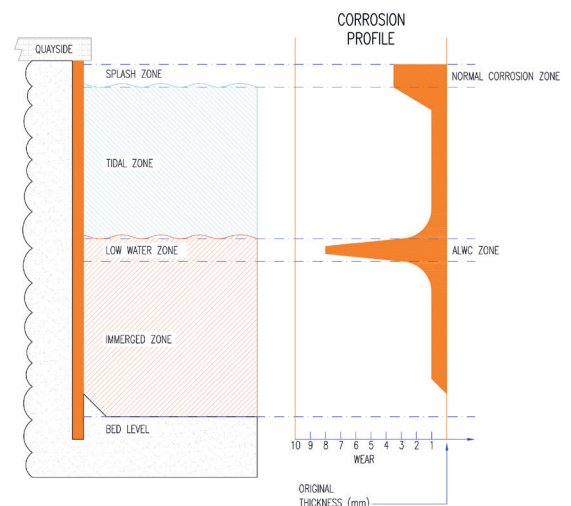


Fig. 1 Steel Quay Corrosion Profile

- 54. The atmospheric zone is above the splash zone and below the top of the structure and as such is in a salt laden environment where any bare steel will corrode. This sort of corrosion will have an average rate of 0.1 to 1.4mm over 5 years².

- 55.** A relatively new identified problem for carbon steel in port environments is Accelerated Low Water Corrosion (ALWC) caused by microbially influenced corrosion, ALWC is also known as biocorrosion.
- 56.** In reality the problem has been around for many years, identified in the 80's but was generally thought to be down to local conditions until the number of cases resulted in a revised opinion.



Fig. 2 Steel Quay with severe ALWC

- 57.** Carbon steel has been used in sheet piles for many years and ALWC is a widespread problem which particularly affects steel between mean low water springs and the lowest astronomical tide. ALWC can be very aggressive, greatly reducing the strength of a structure in a vertically concentrated section along its whole length; Fig 2 shows a severe case where there is significant reduction in strength. ALWC corrosion rates of up to 4mm per year have been reported although 1mm per year appears to be the norm³.
- 58.** A lesser problem in the submerged zone is where the sheet piles suffer abrasion from a vessel's propeller/s wash or wave/tidal action. Where holes appear the ballast behind the sheet pile can be washed out causing sinkholes or depressions to appear at ground level. These symptoms can also appear with stone walls where one or several stones have been displaced.

Concrete

- 59.** Concrete is extensively used, often with reinforced steel bar for a cap on top of steel piles, steel sheet piles, stone or concrete sides. It is fairly easy to use above and below water provided the correct procedures and standards are used. Fig. 3 below shows a standard use.

- 60.** Concrete is susceptible to two main problems; chloride ingress and Alkali Silica Reaction (ASR).

- a. The impact of chlorides on the structure is twofold. Firstly the reinforced bars will corrode following the ingress of chlorides through whatever source. This mainly happens just around the high water mark where the structure is not kept saturated. It can be dealt with using cathodic protection such as ICCP or sacrificial anode as with steel. Secondly as the steel corrodes it also expands causing secondary damage if contained within the concrete resulting in cracks.



Fig. 3 Quay side made up of Concrete cap with steel piles

- b. The second problem found with concrete is ASR where either the cement or aggregate used for making concrete contained high level of chlorides; this problem was identified in the 1940s although guidance was not issued till many years later.

ASR produces a hygroscopic gel that absorbs moisture and swells. ASR shows up as surface deposits, swelling and random cracking and is associated with wetting and drying cycles. In some cases it can cause severe concrete deterioration which can result in serviceability loss and lead to the concrete being susceptible to damage from other sources, such as chlorides.

- 61.** In the UK the level of chlorides for aggregate are governed by BS 1200 which discusses washing aggregates etc. to ensure chloride levels are satisfactory. Cement is classed as low, medium or high alkali; low alkali cements have little risk whereas high alkali cements require greater management when mixing with aggregates. The majority of damage from ASR, in Britain, is from high alkali cement⁴.

³ Ocimf Jetty Maintenance & Inspection Guide 2008

⁴ Concrete Society - July 2009 – Concrete magazine

Stone

- 62.** For commercial ports stone was cut to provide a flat quayside surface generally with rubble type infill, a standard layout is seen in Fig. 4 below. The type of stone used will have an impact on its durability. Regular inspection of such quay faces is required to give early notice of any problems such as stones becoming loose either through wear or damage. Unless there was sufficient damage to warrant replacement or further work, the loose stone would be reset in place and grouted, this can be done above and below surface subject to access.



Fig. 4 Quay side made up of stone (circa 1909)

- 63.** Any repairs must leave the original drain channels clear to allow water runoff. When carrying out repairs it is also important to check the infill is still in place otherwise it must be replaced as per original specification.
- 64.** Because of the higher cost with producing and working stone, it's is largely avoided unless for environmental impact or aesthetic considerations both of which relate more to ports concentrating on the leisure market.
- 65.** Gabions are a modern use of stones for smaller projects. Gabions are not used for loading surfaces as they are not solid structures, unlike a steel or stone wall, the gabion infill can move around and in an active marine environment this will give rise to accelerated wear. They can be used to protect banks or approaches. The containing structure is made up from either galvanized wire or plastic coated wire.



Fig 5 Different methods of gabion use

- 66.** Gabion revetments are generally preferred to gabion walls in coastal environments as they allow the wave energy to dissipate rather than being partly absorbed whilst reflecting it, increasing the lifespan of the gabion, as seen in Fig. 5. The use of Gabions for repairs can provide an effective short term solution but should not be considered long term unless there is sufficient room to deploy the gabions in accordance with the manufacturer's recommendations and what is observed to be good practice.

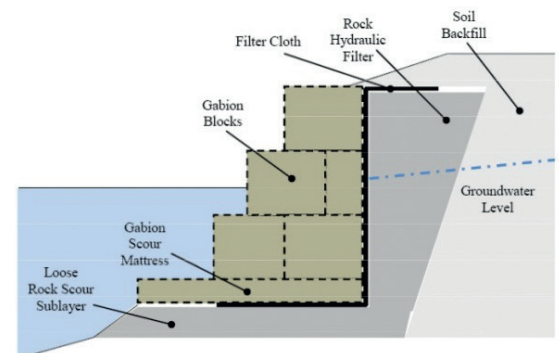


Fig. 6 Gabion structured use

- 67.** There is plenty of good constructive guidance on gabion use in a marine environment for either short or long term, refer to Fig. 6 as an example.
- 68.** Near vertical gabion walls are more likely to suffer toe scour and structural collapse as they are less able to dissipate wave energy during storm waves. A suitable geotextile should be used to prevent underlying material from being washed out through the gabions.
- 69.** The gabion revetments are also likely to suffer from local scour and flanking at the junction between structure and adjacent unprotected bank face. Regular basket maintenance is required to maximize the life of gabions.

- 70.** Severely damaged baskets should be refilled and closed with mesh panels. Replacement mesh should be laid over the entire structure if abrasion or corrosion is widespread. Under exposed conditions a maximum life of 10 years should be anticipated, after which a replacement structure may be required.

Timber

- 71.** The use of timber has many applications in marine structures although construction methods using timber piles are rarely used for commercial ports in view of the higher maintenance required.



Fig. 7 Neglected timber pilings

- 72.** The principle source of timber deterioration is by rot or attack by marine organisms which is greatly accelerated in warmer climates. There are two principal types of borers – crustacean and mollusc. In the UK the *Limnoria* species (most common type of crustacean) attach themselves to the pile and eat into the timber; typical pile diameter reduction rates are 15-25 mm per year⁵. Mollusc or shipworm bore into the pile and consume the timber along the pile's axis leaving large interior cavities so the reduction in strength is not readily visible.
- 73.** Greenheart timber is often used for quayside fendering, normally bolted to the quay wall, as sacrificial pieces their lifespan depends on traffic density and impact. Timber piles are often used for smaller jetties and have a fairly short life of up to 15 years. Soft wood should not be used for structures as whilst they can absorb preservatives readily, they are also very susceptible to abrasion which in turn makes their use for fendering in certain applications subject to higher maintenance to maintain their effectiveness.
- 74.** Plastic sheeting is wrapped around timber piles to prevent attack by marine organisms in more temperate locations than the UK. The sheeting prevents water circulation and reduces oxygen content. The sheeting is susceptible to damage from floating debris or ice.
- 75.** Timber structures should be subject to a regular inspection regime to note any deterioration in condition and then monitor that over time with repairs conducted as necessary.
- 76.** Older timbers would have been treated with creosote which was very effective but is generally considered unacceptable for use in the marine environment nowadays. Preservatives do not penetrate to the centre of piles which leaves them vulnerable as the preservative starts to age. It is expected as harbour waters become cleaner marine borers will become an increased issue.
- 77.** In addition to the poor condition of the timbers in Fig. 7 another hazard from poorly maintained structures, in general, is the risk to passing traffic or machinery such as sluices or locks from timbers which have broken away.

⁵ Ocimf Jetty Maintenance & Inspection Guide 2008

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