SLOPE PROTECTION UNDER PILED QUAYS

M. Hawkswood[1] and M. King[2]

[1]Martin G. Hawkswood, B.Sc. C.Eng. M.I.C.E. M.I.Struct.E. A.M. ASCE.
Proserve Ltd, Princes Drive, Kenilworth CV8 2FD, office@proserveltd.co.uk,
00 44 (0) 1926 512222

[2]Matthew King, M.Eng. Proserve Ltd, Princes Drive, Kenilworth CV8 2FD,
office@proserveltd.co.uk, 00 44 (0) 1926 512222

ABSTRACT

This paper considers scour protection and construction methods for open piled quays.

The Land Infill construction method for piled wharves will be outlined, which can offer time and cost benefits in comparison to construction methods using marine plant. Design which enables constructability is needed for this method, particularly for dredging and slope protection where access is limited by the piled platform.

Stone protection sizes required for modern vessel actions are becoming increasingly large, costly and often impractical, particularly to piled slopes. Design methods for rock and insitu concrete mattress protection are outlined, with reference to recently updated guidance in PIANC Report 180. This includes the effect of local flow acceleration around piles. The design methods for concrete mattress outlined in PIANC Report 180 will be compared, showing the benefits of reliable joint and edge construction, supported by the use of a marine quality control system.

Insitu concrete mattress protection is often more practical and cost effective than rock to piled slopes, but benefits from the use of perimeter rock falling edge aprons. Case histories are presented showing this beneficial combination to be an effective slope protection to open piled quays.

INTRODUCTION

Open Piled Quays are used world-wide as berthing structures and are continually being developed for larger vessels and more modern vessel types. Effective construction methods are required along with practical scour protection to revetment slopes under wharves (Fig. 1) or jetties.

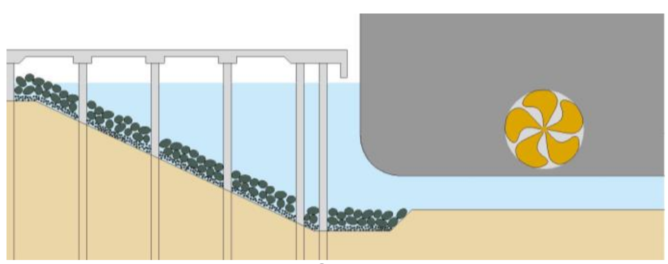

Figure 1. Wharf Scour Protection

Land Infill construction methods for wharf structures are being developed to save time and cost. The piling and platform construction is formed working from Land Infill with slope dredging and scour protection subsequently formed in the wet (Fig. 2). The relative merits of this method for different soil types and the need for appropriate scour protection will be outlined further with reference to recent case histories.

The design and construction of scour protection around piles to underwater slopes is often challenging. An integrated design and constructability approach will be outlined, along with the use of quality control methods to suit the construction method chosen and the local marine working conditions.

The actions to be resisted by revetment protection may include vessel propulsion, waves, tidal movement, and currents. These will be outlined with reference to the recently published guidance by PIANC Report 180 (2015) and other references. The paper will review common vessel actions and give an initial interpretation of actions from modern propulsion types such as podded propulsors, azimuth thrusters, water jets and Voith Schneider propulsors.

Historically, rock protection has been most commonly used. However, larger stone sizes are now generally required to resist action from modern propulsion types, making rock less cost effective. There are also construction difficulties to overcome forming rock layers around piles on slopes. In these situations, insitu concrete mattress has often proven to be readily constructible and cost effective. Concrete mattress can also be installed under piled platforms which enables the Land Infill method to be used. The relative merits of both rock and insitu concrete mattress will be compared in terms of their design, construction, cost and performance. A beneficial combination of insitu concrete mattress protection with rock falling edge details will be described with reference to the following case histories:

- Quetzal Port, Guatemala
- Port Au Prince, Haiti
- Belawan Port, Indonesia

The paper may be of use to port authorities, design engineers, contractors, operators, plus research and guidance authorities.

WHARVES

Wharves are commonly open piled berthing structures above a revetment slope (Fig. 1). The geotechnical stability of the slope and its protection from scour is vital for the stability of the structure and pavement areas for cargo handling behind the deck. Wharves are the preferred type of berthing structure in many areas of the world, particularly where soil conditions are weak. Presently, they are often being used where increased draught is needed for container terminals. These larger wharves are typically formed using reinforced concrete or tubular steel piles with deck / platform construction in reinforced concrete, parts of which are often precast to aid construction over water.

Historically, construction of wharves has generally been undertaken in the wet with a sequence of dredging to form the revetment slope, piling using floating marine plant and then slope protection installed before platform construction.

Land Infill Construction Method. This method is outlined in Fig. 2. It is being used at Quetzal Port, Guatemala where the sand strata is being removed by dredging pumps. The relative advantages and disadvantages are shown in Table 1 below.

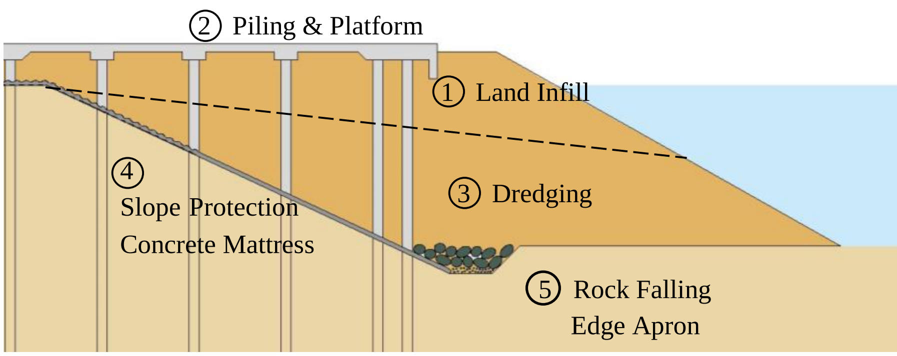

Figure 2. Land Infill Wharf Construction Sequence

Table 1. Advantages and Disadvantages of Land Infill Construction Method

Advantages	Disadvantages
Quicker construction of the structure	Additional soil infill and removal
Piling from land not barges	Restricted working under the platform:
Piling through soil only	• dredging & slope preparation
Platform construction on land	• slope protection

For projects where the soils cannot be reliably removed by dredging pumps, excavation can be by long reach excavators or similar equipment, which operates between piling and transverse beams with platform slab construction omitted until later. This method has been used for the replacement container terminal at Port au Prince, Haiti where the soil types are more variable, comprising sandy gravels with occasional clay layers.

The various Land Infill methods of construction generally speed up construction of the platform and the overall project delivery period. It does however put much greater emphasis on reliably establishing the soil type and marine working conditions, methods for dredging, slope preparation and scour protection, as well as design for constructability. These aspects can be handled by experienced engineers using risk management techniques and a proven quality control system for marine works. Hawkswood & Allsop (2009) further outlines marine constructability and quality control.

Figure 3. Pile Seal

For wharves constructed by the Land Infill method, use of insitu concrete mattress has proven to be an effective method of slope protection. Divers install and zip mattress fabric between piles upon slopes under the platform before pump filling with a sand: cement micro concrete from the bottom upwards. Concrete mattress to pile seals are reliably created using proven mattress seal arrangements and engineering control (Fig. 3).

Constructability. Once a construction method for a wharf has been selected, the design should be developed to allow effective constructability. Insitu concrete mattress can be readily used where access is limited under the platform with a rock falling edge apron to the perimeter. This approach provides an effective combination capitalizing on the materials' respective merits (Figures 2, 7, 8 & 9). The perimeter rock protection can be readily placed outside the plan area of the platform and be monitored and maintained if necessary.

Greater working tolerances to slopes are usually required for slope preparation compared to level beds. The determination of practical working tolerances often needs to take into account the accuracy of survey methods, construction plant capability, pile obstructions, protection type, local geotechnical stability, working conditions, soil behaviour, and the need to minimise diver working time. The thickness of rock bedding layers is usually increased for working on slopes to aid construction reliability.

JETTIES

Jetty berthing structures (Fig. 4) usually extend seawards in various configurations typically for the mooring of a range of vessels types other than container vessels. Usually no bed scour protection is provided to these structures. It is often more cost effective to design the piles and structure for a reasonable lowering of the bed due to scour actions.

Bed protection can be provided where scour depths would be significant, and also to revetment slopes at the landward end of jetties.

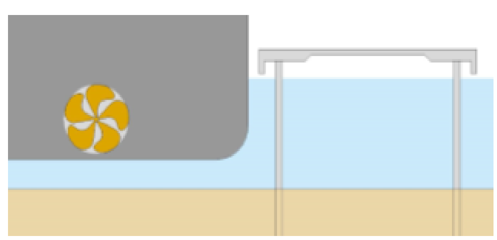

Figure 4. Typical Jetty Section

VESSEL ACTIONS

Guidance on vessels movement and propulsion actions at berths are given in the PIANC Report 180 (2015) and earlier guidance. This can be readily applied to piled wharves and jetties along with other useful sources of guidance outlined in the following sections.

Propellers. Guidance on engine power used at berth is now updated in PIANC Report 180 (2015). This guidance may, however, be exceeded if a single tug pulling astern is used for berthing (Fig 5), where the propeller thrust could match that of the tug, Hawkswood et al. (2014). The prospect of this action in the design life of a berth is perhaps best reviewed with the port owners. Full rudder deployment may be infrequent for some vessels and berths but is a likely prospect in the design life of a berth. A probabilistic review and sensitivity check may also be useful in some cases.

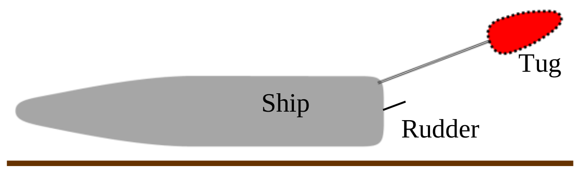

Figure 5. Berthing with a Single Stern Tug

For wharves, the extent of scour protection is generally designed to suitably protect the important zone for geotechnical slope stability and area to form an effective toe detail. Further extension should be considered where the expected savings in maintenance dredging to remove siltation and mounding would offset the additional protection cost, and where improved availability of the berth is of value.

The maximum velocity behind an open propeller (V_o) can be taken from equation 8-26 or 8-23 PIANC Report 180 (2015). If protection extends under or near the propeller, bed velocity for rock design can be most accurately obtained from curves given by Römisch and Hering in PIANC Bulletin 109 (2002) for use with the German approach.

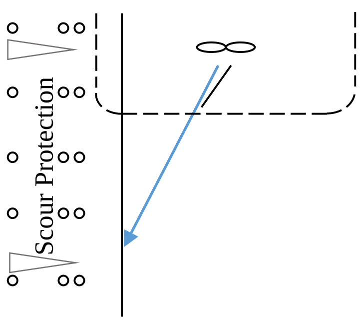

Figure 6. Rudder Deflection Plan

For wharves, where the scour protection only usually extends just under the side of the vessel, the maximum design bed velocity on the scour protection is usually from propeller flow deflection by rudder deployment onto the scour protection as shown in Fig. 6.

Guidance for this condition is not covered in PIANC Report 180, but the design bed velocity on the scour protection can be estimated using equation 8-28 for propeller jet velocity decay with distance (for a straight rudder) and applying appropriate coefficients for jet deflection and velocity reduction due to rudder deployment as outlined by Hawkswood et al. (2014). For shorter jet lengths, the deflected design bed velocity should be checked not to exceed the bed velocity given in PIANC Bulletin 109 for a straight rudder. Other vessel angles to wharves with other angles of rudder deployment may need to be considered in some cases. New research via scale model testing on this condition is underway.

Transverse Thrusters. Bow and stern thrusters are used to aid berthing and unberthing (Fig. 7). Methods to estimate slope and bed velocities are given in PIANC Report 180 (2015). Where transverse thrusters are located near the centre of the hull, the jets usually defray to modest levels compared to deflected rudder flow from propellers, however transverse thruster action is usually a more regular action onto slopes.

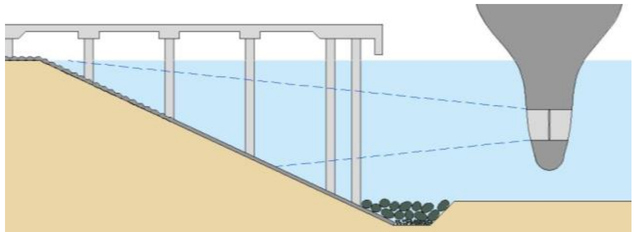

Figure 7. Transverse Thruster

Podded Propulsors. Podded propulsors are often used by modern cruise vessels and generally have an open propeller in front of a rotating pod which are termed 'Pullers'. For unberthing, some pods are likely to be jetting directly onto wharf slopes (Fig. 8). Initial guidance on the effect of the pod upon scour velocities is given in PIANC Report 180 (2015), pending research to better establish flow onto slope and bottom surfaces.

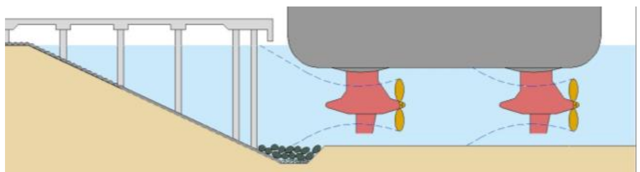

Figure 8. Podded Propulsers

Azimuth Thrusters. Azimuthing thrusters are similar to podded propulsors, but the propeller is located behind a rotating hub or pod, and they are termed 'Pushers' as conventional propellers. They are usually used on smaller vessels than podded propulsors. Scour velocities on slopes and beds can be obtained from PIANC Report 180 (2015) using appropriate methods for open or partially ducted propellers as the specific case may dictate.

Water Jet. Highly powered water jets are commonly used by vehicle carrying Ro Ro fast ferries. The mooring jetting action of these vessels can cause significant scour and damage to berthing structures (Fig. 9). Information on bed velocities and protection guidance is given in Hawkswood, Evans & Hawkswood 2013)

Figure 9. Water Jet

Voith Schneider Propulsors. Guidance on flow velocities are given in PIANC Report 180 (2015) and can often be obtained from manufactures for specific propulsors. The jet can be directed in any direction by orientation of the rotating blades.

SCOUR PROTECTION TYPES

Scour Protection types can be characterised by their nature, failure modes and design methods, summarised as rock, insitu concrete and prefabricated mattress types in Hawkswood et al. (2014). Of the insitu concrete types, tremie concrete and grouted rock are not considered practical to install upon slopes due to the concrete's fluidity during placement. Only insitu concrete mattress has the preferred reliability, particularly where access for maintenance is difficult. Prefabricated mattress types are also generally impractical to use due to problems working around piles, need for accurate slope preparation, and the difficulty of forming reliable joints underwater.

Rock Protection. Rock protection generally comprises two layers of rip rap or armour stone upon a bedding/ filter stone layer and often a geotextile filter membrane (Fig. 1). The design, specification and construction of the rock protection can follow authoritative guidance by PIANC Report 180 (2015) and PIANC WG22 (1997). The Rock Manual (2007) gives construction guidance. Rock protection has many good qualities. Being porous and flexible, it performs well as falling edge aprons and is relatively easy to repair unless the bedding layer is lost.

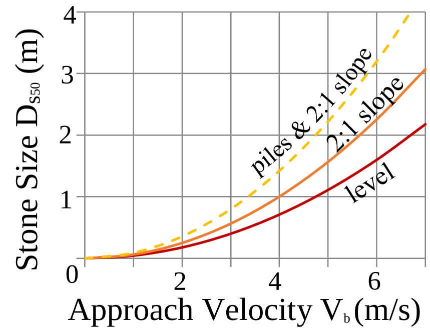

Figure 10. Stone Stability

The increased flow and turbulence around piles upon slopes can cause rock stability failure. For propeller flow with a rudder, Fig. 10 compares the stone size estimated for a level bed and a 2:1 slope with piles, using a slope factor by Pilarczyk, and a pile effect factor estimated from Van Doorn, interpreted from PIANC Report 180 (2015).

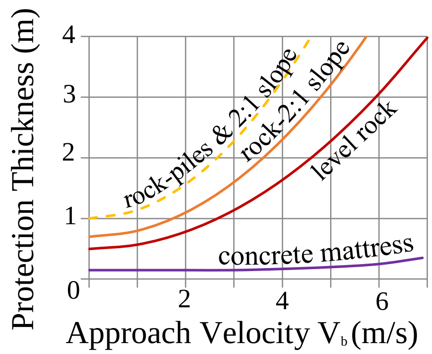

Figure 11. Protection Thickness

Rock construction to piled slopes is more difficult and costly than to level beds, particularly if the stone size exceeds 0.5 m. Rock and concrete mattress protection thickness is established in Fig. 11, and relative cost is estimated in Fig. 12 based upon the following budgets: Rock £60 /m³, Geotextile £8 /m², Dredging £24 /m³ and a minimum layer thickness of 0.75 m to slopes and 0.5 m to beds. Comparisons are better made using relevant local costs.

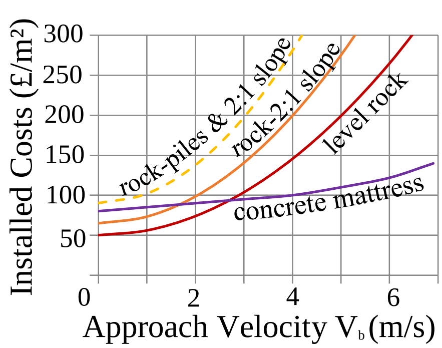

Figure 12. Relative Cost

No suitable design method for rock protection against the inclined water jets of Ro Ro Fast Ferries, is presently established as noted by Hawkswood, Evans and Hawkswood (2013).

Concrete Mattress. Insitu concrete mattress aprons are formed by divers rolling out mattress fabric underwater which is zipped and clipped around piles and pump filled with highly fluid small aggregate micro concrete typically of 35 N/mm² strength. Joints between mattress panels form 'ball and socket' shear joints as shown in Fig. 13 to a Constant Thickness mattress type. This produces an apron of interlocked concrete slabs underwater, which gives high resilience against currents, propeller and jet flows where edges are suitably protected. Concrete mattress installation by divers is only practical in currents up to some 0.5 m/s and in wave action up to some 0.5 m with appropriate protection before the concrete sets.

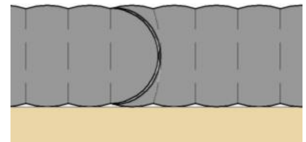

Figure 13. Ball and Socket Joint

Current Flow. Concrete mattress thickness can be taken from stability curves by Pilarczyk (2000) also shown in Fig. 14. This applies to interlocked mattress panels between 3-5 m wide with protected edges as outlined in Hawkswood & Assinder (2013).

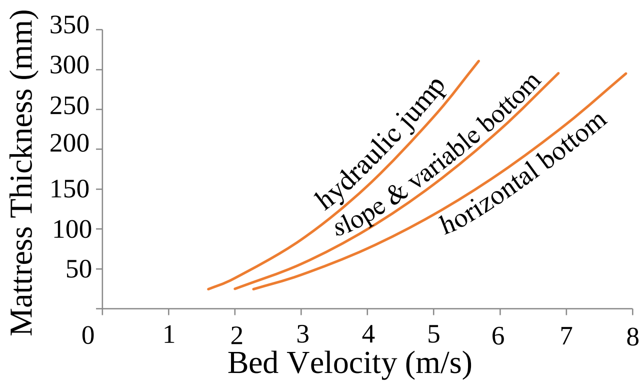

Figure 14. Matt Thickness for Current Flow

Propeller Action. For slope protection under wharves, jet impact from propellers and thrusters generally creates a zone of stabilising positive pressure. The stability curves by Pilarczyk can be safely applied, where factors are used appropriately for blockage of the piles and pile size/ slab thickness ratio, see Hawkswood & Assinder (2013).

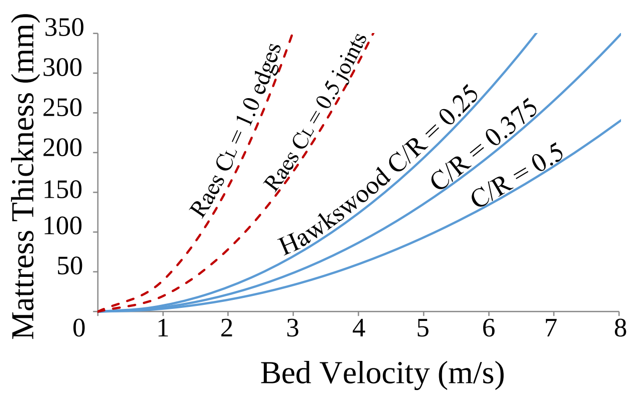

Figure 15. Matt Thickness for Propeller Action

Where protection extends under or near the propeller, PIANC Report 180 (2015) suggests use of Equation 10-33, which applies where joints are open, overlapped or not reliably interlocked and flow pressures can get under the protection layer. Alternatively, where reliable joint interlock and edge protection is provided, PIANC Report 180 suggests design can be based upon the suction generated in front of the propeller, described by Wellicome, summarised by Hawkswood & Assinder (2013).

Figure 15 provides a comparison of the two methods based upon a subsequent paper by Hawkswood et al. (2014) using propeller tip to bed clearance C, propeller radius R and a safety factor Sf = 1.5. The curves based upon Equation 10-33 do not include safety factor, PIANC Report 180 (2015) suggests a suitable safety factor should be considered and applied. Bed velocity is obtained using PIANC Bulletin 109 (2002).

The construction reliability needed for the latter method should follow a proven marine quality control process as outlined in Hawkswood et al. (2014) and (2013) which should be specified and supervised. Many examples of reliable construction from case histories are shown in references to this section.

Edge details are particularly important to prevent concrete mattress underscour and failure. Formulas for prediction of scour depths are given in PIANC Report 180 but these generally overpredict scour depths that occur, particularly for small grained cohesionless materials such as sand. Normally rock falling edge aprons are used to manage the significant risk of edge scour, Hawkswood et al (2014). The design and extent of falling edge aprons should be agreed with Port Owners/ Authorities who will subsequently have to monitor and maintain them.

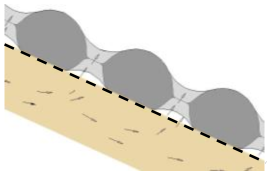

Figure 16. Filter Point

Wave Action. Insitu concrete mattress used in the tidal range needs a degree of porosity. Filter Point type (Fig. 16) or Open Hole type (Fig 17) can be used.

The relative porosity of the mattress and underlayers is important to determine mattress thickness; design methods are outlined in Hawkswood and Assinder (2013).

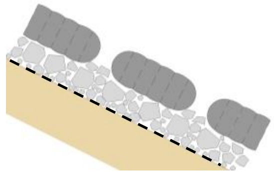

Figure 17. Open Hole

CASE HISTORIES

Quetzal Port, Guatemala

Contractor: Copisa SA, 2015

The Land Infill construction method was chosen mainly to reduce the project delivery time to 1.5 years. After construction of the reinforced concrete piles and platform, the sand infill was removed to low water level by excavation plant working under the platform. The remaining submerged sand strata was removed by dredging pumps handled by purpose made barges.

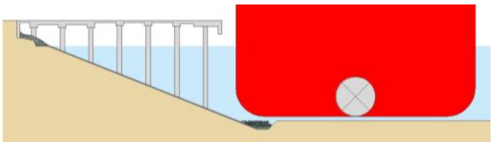

Figure 18. Quetzal Port

Constant thickness mattress was used on the underwater slope, with permeable Open Hole mattress to the wave zone and a rock falling edge apron to the toe and sides. A slope construction tolerance of ±0.45 m was used. Fig. 18 shows the resulting section.

Port Au Prince, Haiti

Contractor: GLF (USA) Engineer: Technital, 2015

The new piled wharf replaces the container berths which collapsed due to liquefaction in the 2010 earthquake. The land based construction method was used with piles and deck beams constructed on infilled ground before slope excavation between these beams. A porous filter point mattress was used in the wave zone. The resulting section is shown in Fig. 19.

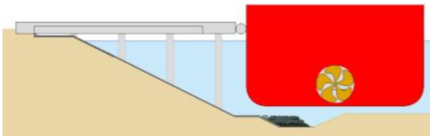

Figure 19. Port Au Prince

Belawan Port, Indonesia

Engineer: Halcrow and Partners, 1984

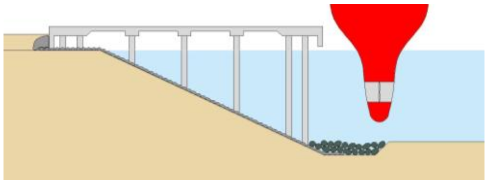

Figure 20. Belawan Port

This jetty was constructed using the traditional marine method. Concrete mattress scour protection was used as it was more cost effective than the rock protection originally designed, Loewy et al. (1984). The Port Authority reports that it continues to perform well. Fig. 20 shows the typical section.

CONCLUSIONS

The Land Infill construction method can be used for piled wharves to save time and cost. The effectiveness of the method is influenced by soil types which can be readily dredged and a design approach enabling constructability.

Insitu concrete mattress scour protection can be installed under piled quays, where other systems are difficult to use. Comparisons with rock protection show concrete mattress is often more cost effective, particularly for higher scour velocities. Design methods are available supported by case history performance.

The combination of insitu concrete mattress with a rock falling edge apron to the perimeter provides an effective combination for slope protection under piled quays.

REFERENCES

Hawkswood, M.G., Allsop, W., (2009), Foundations to Precast Marine Structures, Coasts, Marine Structures & Breakwaters 2009, ICE, Edinburgh

Hawkswood, M.G., Assinder, P., (2013) Concrete Mattress Used for Berth Scour Protection, GhIGS GeoAfrica 2013, Accra, Ghana.

Hawkswood, M.G., Evans, G., and Hawkswood, G.M., (2013), Berth Protection for Fast Ferry Jets, Coasts, Marine Structures and Breakwaters 2013, ICE, Edinburgh

Hawkswood, M.G. Lafeber, F.H., Hawkswood, G.M., (2014) Berth Scour Protection for Modern Vessels, PIANC World Congress, San Francisco, USA.

Loewy, E., Burdall, A.C., Prentice, A.G., and Sir William Halcrow and Partners (1984), Revetment Construction at Port of Belawan, Indonesia, I.C.E. London

PIANC Bulletin 109, Römisch, K. & Hering, W., (2002), Input Data of Propeller Inducted Velocities for Dimensioning of Bed Protection Near Quay Walls.

PIANC Report of Working Group 22, Bulletin no 96 (1997), Guidelines for Design of Armoured Slopes Under Open Piled Quay Walls.

PIANC Report 180, (2015) Guidelines for Protecting Berthing Structures from Scour Caused by Ships.

Pilarczyk, K.W. (2000). Geosynthetics and Geosystems in Hydraulic and Coastal Engineering. Taylor and Francis, New York, USA.

The Rock Manual. (2007). The Use of Rock in Hydraulic Engineering, Manual on the Use of Rock, CIRIA, CUR, CETMEF.