Berth Scour Protection for Azipods

Martin Hawkswood[1], George Hawkswood[1] and Josh Groom[1]
[1] Proserve Ltd, Kenilworth, United Kingdom, office@proserveltd.co.uk

Summary

Azipods are increasingly being used particularly to large cruise vessels yet there is presently no established design method for scour protection subject to their action. These vessels can create high flow velocity to berths which can make rock protection impractical. Design methods for insitu concrete mattress or rock protection will be reviewed for single and multiple azipods which are based upon scale model testing recently presented in Hawkswood *et al* (2023). This is part of a programme of scale model testing and guidance for single propellers, twin propellers and azipods.

Keywords: Berth Scour Protection, Azipods, Concrete Mattress Design, Rock Design

1. Introduction

1.1 Azipods

Azipods are driven by electric motors in the rotational hub behind the propeller. The rotational facility gives vessels good manoeuvrability hence azipods are often used on cruise vessels. Azipods are often used in pairs with 3 or 4 azipods being common on larger cruise vessels. Previous scale model testing of propellers has now been extended to azipods. This includes testing of rock and in-situ concrete mattress. The testing demonstrated that azipods are similar to propellers and similar design methods can be used which are presented.

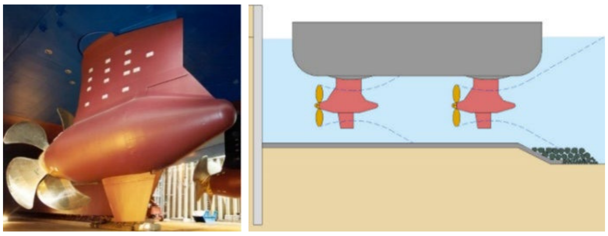

Figure 1. Azipods

1.2 Readership

The paper may assist with design and construction of berth scour protection, aid further testing, and development of design guidance. The paper may be of use to port authorities, design engineers, contractors, operators plus research and guidance authorities.

4. Flow From Azipods

4.1 Introduction

Azipods are often capable of rotating 360˚ which aids moveability of vessels such as cruise ships (Figure 1). On larger cruise vessels 2 or more azipods are common with a pair of rotating azipods and often additional fixed azipods (Figure 1).

Figure 2. Azipods in dry dock

Velocities from azipods are similar to open propellers as demonstrated by testing (Hawkswood *et al* (2023)) and can be taken as follows: -

4.2 Jet Velocity From Azipods

The jet velocity from azipods can be taken from the established formula (1) for propellers: -

$$V_o = (c)\left(\frac{f\,P}{\rho\,{D_p}^2}\right)^{1/3} \qquad (1)$$

Where V_o = Max propeller jet velocity; (c) = coefficient for open propeller (1.48); D_p = propeller diameter; P = engine power; f = ratio of engine power at berth; ρ = water density

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3. Nomenclature

V_o	Max. propeller jet velocity	V_b	Bed velocity	C_S	Stability coefficient for suction
(c)	Coefficient pen/ducted propeller	H_p	Height of propeller axis from bed	g	Acceleration due to gravity
f	Ratio of engine power at berth	D_{min}	Design protection thickness	Δ	Buoyant relative density
P	Engine power (kW)	u	Surface undulation	C_F	Stability coefficient for flow
ρ	Density	w	Width between undulations	S	Azipod spacing
D_p	Propeller diameter	I_Q	Surface undulation factor	D_{S50}	Rock size (sphere), 50%
C	Propeller tip clearance	R	Propeller radius	B_S	Stone stability coefficient

Azipods are capable of high velocities at berth. The percentage of power used at berth should be obtained relative to each design vessel for both straight and rotated azipods.

4.3 Bed Velocity From Azipods

Bed Velocity is also influenced by the number of azipods, the propeller tip clearance, azipod positions, fixed or rotating and the presence of a bottom fin to the hub of the azipod.

From the testing shown in Hawkswood *et al* (2023), azipods with a bottom fin as Figure 3, were found to create bed velocities similar to an open propeller with a central rudder as Figure 4. Azipods with no bottom fin as Figure 5, produce bed velocities similar to an open propeller without a central rudder as Figure 6. The presence of a bottom fin splits the rotational propeller flow into two jets and creates higher bed velocities similar to a central rudder.
Bed velocities for various arrangements of azipods can be taken from Figure 7 following scale model testing, Hawkswood *et al* (2023).

For single azipods bed velocities are similar to single propellers following the original work by Fǖhrer & Rȫmisch (1977) and PIANC Bulletin 109 (2002). For multiple azipods, bed velocities were found to be similar to advice for twin propellers from Hawkswood, Groom & Hawkswood (2018). This comparison for flow action from azipods is summarised: -

Azipod with bottom fin = Propeller with Rudder
Azipod no bottom fin = Propeller with Rudder
Multiple Azipods = Twin Propellers

5. Rock Design For Azipods
5.1 Introduction

Design methods for rock bottom protection under azipod propelled vessels are based on recent testing presented in Hawkswood *et al* (2023). Rock protection generally comprises two layers of rip rap or armour stone upon a bedding/filter stone layer and often a geotextile filter membrane as typically shown in Figure 8. Rock protection often needs to be grouted at walls and structures to prevent wash out from flow down or along walls, Figure 8. The rock construction depth can have a significant effect on structures, increasing the effective span height to piled walls and increasing the depth of gravity walls.

Figure 3. Azipod with fin

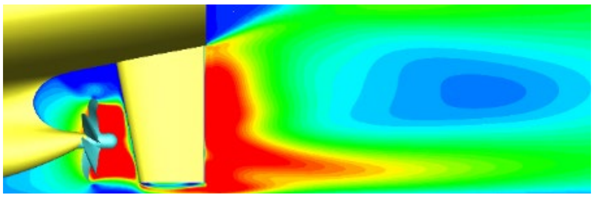

Figure 4. Velocity - with straight rudder

Figure 5. Azipod without fin

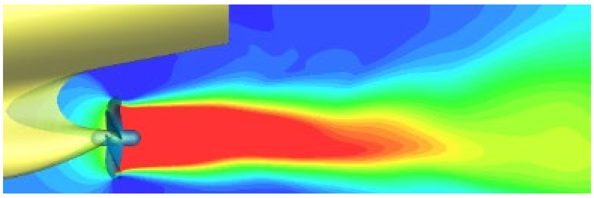

Figure 6. Velocity - no rudder

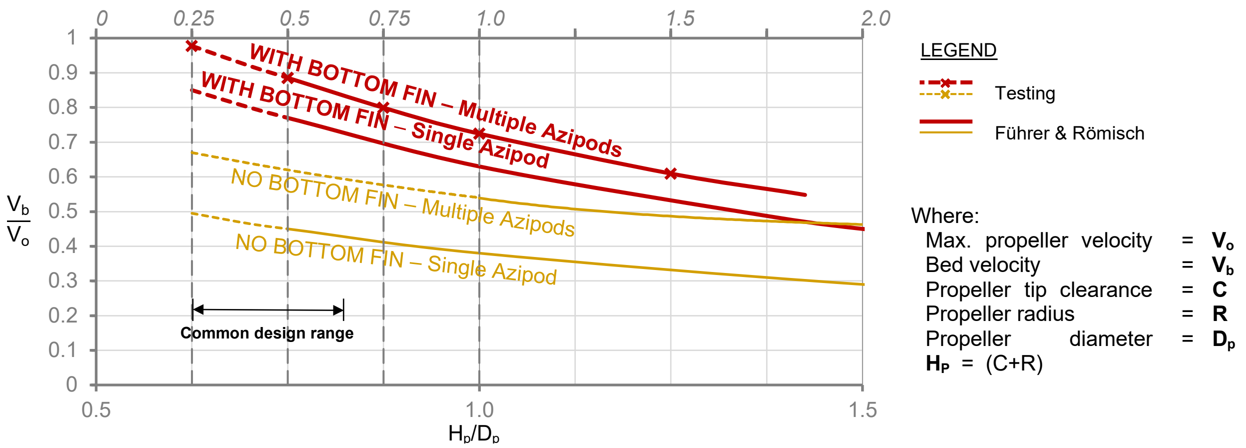

Figure 7. Bed velocity, V_b graph for azipods

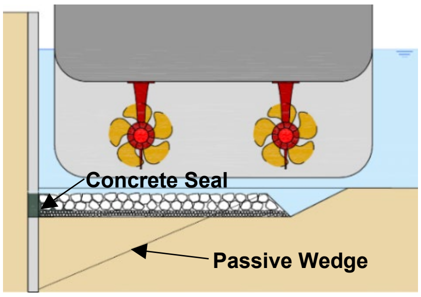

Figure 8. Rock protection to quay wall

Design of rock for no movement is particularly important where rock movement would cause grounding or loss of berthing clearance. Bed velocities from larger azipods can often be too high for a rock solution to be feasible or practical.

5.2 Level Rock Protection under Azipods

Design methods for rock stability have generally been based upon the 'threshold of motion' for no movement or scour with effectively a safety factor = 1.0. The most common design method emanates from the original testing work of Führer & Römisch (1977) who produced curves for bed velocity Vb for single propellers included within Figure 7. They also provided a design method for the size of rock protection as Equation (2) BAW (2005). The testing has shown Equation (2) can be used for azipods, with bed velocities taken from Figure 7 for single or multiple azipods with or without a bottom fin:-

$$D_{s50} = B_s \frac{V_b^{\,2}}{g\Delta} \qquad (2)$$

Where D_{s50} is Rock size, with no movement.

Following recent testing, the following stability coefficients B_S are proposed: -

Azipod with a bottom fin	$B_S = 0.64$
Azipod no bottom fin	$B_S = 1.55$

The above method and stability coefficients were well supported by the testing in as Hawkswood *et al* (2023). The stability coefficient for an azipod with no bottom fin of $B_s = 1.23$ by Führer & Römisch (1977) was found to be too low and $B_s = 1.55$ is proposed. This is similar to the case of a propeller without a rudder, Hawkswood, Groom & Hawkswood (2016).

The relationships of rock size D_{s50} to bed velocity V_b are shown in Figure 9 for the general case with a bottom fin, and with no bottom fin. The higher stability coefficient B_s for no bottom fin is created by the increased rotation and turbulence within the critical area of the flow acting upon the bed. For berths with low clearance which would be affected by rock movement, designers should consider increasing the safety factor or possibly using a mattress type scour protection.

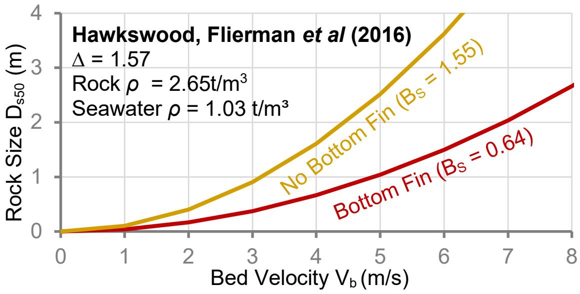

Figure 9. Stone size for azipod flow

The testing by Hawkswood, Flierman *et al* (2016) also showed that the design tip clearance C can be taken from the centre of the top layer of rocks as Figure 10. This takes into account the increasing stability effect for larger rock sizes which has also been demonstrated in the testing for azipod action (Hawkswood *et al* (2023)). This effect can make a useful saving to larger rock sizes.

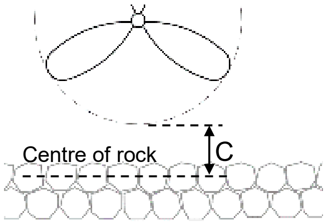

Figure 10. Propeller tip clearance, C

5.3 Slopes and Piles

The increase in rock size needed for slopes can be obtained using a slope factor by Pilarczyk, PIANC Report 180 (2015). The increased flow and turbulence around piles can cause rock stability failure. A pile effect factor estimated by Van Doorn, interpreted from PIANC Report 180 (2015) can be used. Slope protection under piled quays is also described in more detail in Hawkswood & King (2016).

5.4 Rock Falling Edge Aprons

For azipod flow, the quantity of armour rock needed in a falling edge apron should give at least 1 layer of armour on a 3:1 slope down to the required scour protection level, Figure 11 Their design is the same as for propeller flow as outlined in Section 7.5 of Hawkswood, Groom & Hawkswood (2018).

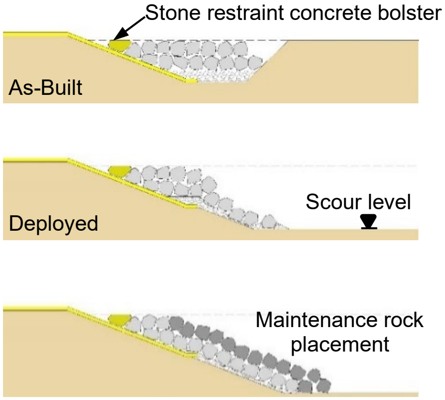

Figure 11. Falling edge apron

6. Insitu Concrete Mattress Design Under Azipods

6.1 Introduction

Figure 12 shows a typical concrete mattress arrangement for a berth with vessels propelled by azipods. Insitu concrete mattress aprons can resist high velocity actions such as azipods and have a much lower thickness than rock. This can lead to significant savings in quay structures as outlined in Hawkswood, Groom & Hawkswood (2018). This protection has also been used for high velocity inclined jet action from HSS vessels up to 12.5m/s Hawkswood, Evans & Hawkswood (2013).

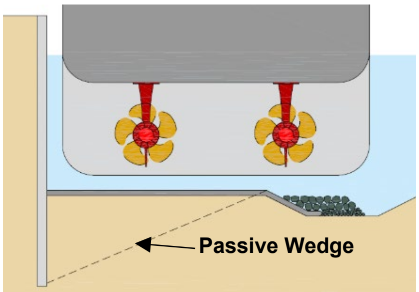

Figure 12. Typical section

Constant Thickness Mattress types (CT) as Figure 13 is a 'sealed' protection type which prevents flow entry and is normally used to beds and permanently submerged slopes. Porous mattress types are needed to wave zones, Hawkswood & Assinder (2013).

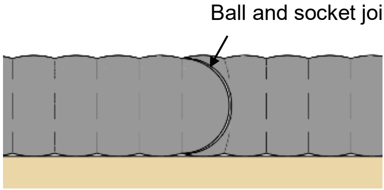

Figure 13. Constant thickness mattress (CT)

Insitu concrete mattress aprons are formed by divers rolling out mattress fabric underwater which is zipped together and pump filled with highly fluid small aggregate concrete. High performance joints between mattress panels are formed using zipped 'ball and socket' concrete shear joints, Figure 13Figure 14. CT mattresses are typically pump filled with a sand: cement micro concrete mix of 35 N/mm² strength. This produces an apron of interlocked plain concrete slabs underwater. The fabric mattress is essentially a temporary works system. Seals to walls are achieved by using a concrete bolster detail as Figure 14.

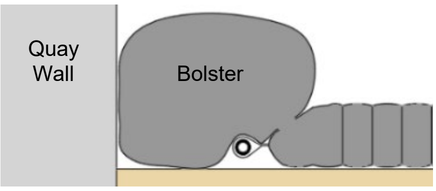

Figure 14. Wall Bolster Seal

Further background information on insitu concrete mattress is given in Hawkswood, Groom & Hawkswood (2018) along with guidance for installation using an established marine quality control system.

6.2 Design Introduction

Insitu concrete mattress under azipod propellers should be designed for:-

- Azipod propeller suction
- Azipod propeller flow

Design methods for both suction and flow can be taken from comparable situations for open propellers from Hawkswood, Groom & Hawkswood (2018). The design methods relate to 'sealed' protection with the following parameters:-

- Sealed joints and edges (protected from underscour)
- Concrete panels 3 to 5m wide between interlocked joints
- Concrete strength 35 N/mm^2 (MPa)

At lower clearance ratios C/R, suction is usually the design condition for azipod actions. Where protection is offset from propeller locations, design of suitable edge details are very important to prevent underscour and can be rock falling edge aprons as Hawkswood *et al* (2023) or falling hinged edges.

The surface undulation ratio is given by *u/w*. as shown in Figure 15.

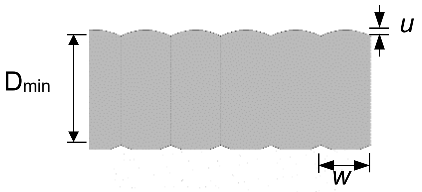

Figure 15. Low surface undulation

The surface undulation factor I_Q for design is taken from Figure 16.

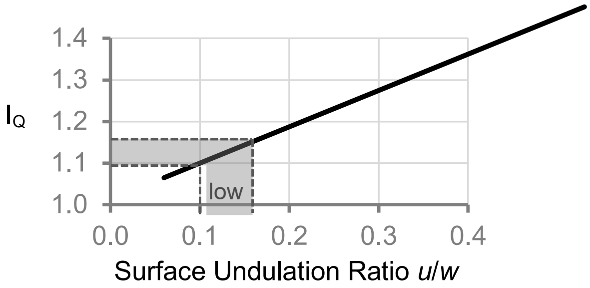

Figure 16. Surface undulation factor I_Q

6.3 Design for Azipod Propeller Suction

Insitu concrete mattress creates an apron of plain interlocked concrete slabs which have good load distribution properties and can be designed for the large area of bed suction which occurs to the intake side of a propeller as outlined in Figure 17.

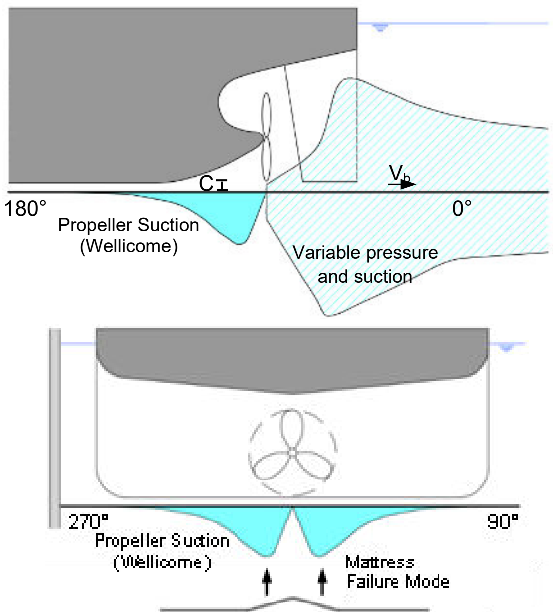

Figure 17. Propeller Suction

The testing presented in Hawkswood *et al* (2023) established that azipods are comparable to open propellers therefore, the dead-weight design method for suction from open propellers by Hawkswood, Groom & Hawkswood (2018) can be used for azipods for a 'sealed' protection. This method applies to azipod propellers with or without a bottom fin as this has no effect on propeller suction on the bed. The design method for concrete mattress thickness D_{min} is based upon the propeller exit velocity V_o, and is presented in Equation (3): -

Simplified dead-weight design method

$$D_{min} = C_S \frac{{V_o}^2}{2g\Delta} \times \frac{I_Q}{1.15} \tag{3}$$

Where C_s = Stability coefficient for insitu concrete mattress propeller suction; I_Q = Mattress surface undulation factor (Figure 16)

The stability coefficient for propeller suction C_S is taken from Figure 19. Propeller suction upon the bed reduces as the bed clearance ratio increases. Where two azipods are in line as Figure 18, the area of suction can combine, and suction coefficient can be taken from Figure 19.

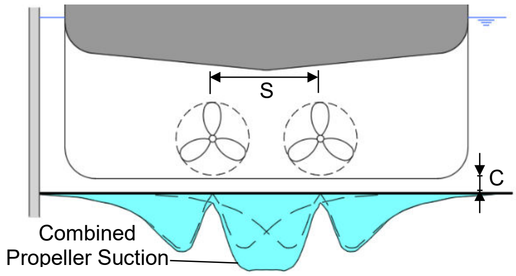

Figure 18. Suction distribution - twin azipod

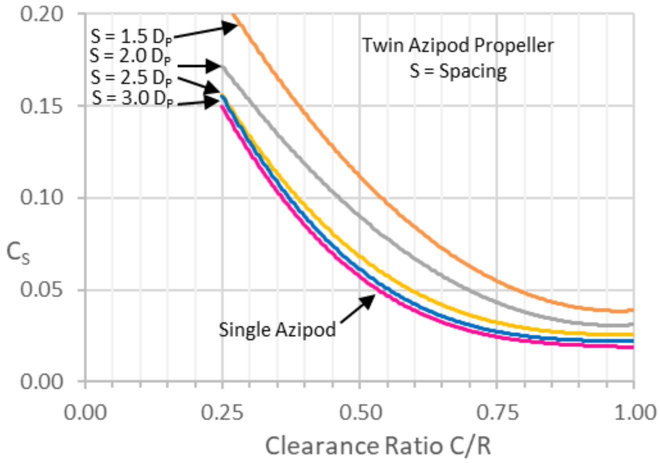

Figure 19. Suction coefficent C_s

6.4 Design for Azipod Flow

The design method for 'sealed' insitu concrete mattress under azipod flow as Figure 20, can be applied to both with a fin and without a fin as Equation (4):-

$$D_{min} = C_F \frac{{V_b}^2}{2g\Delta} \times \frac{I_Q}{1.15} \tag{4}$$

Where C_F = Stability coefficient for insitu concrete mattress under propeller flow; I_Q = Mattress surface undulation factor (Figure 16); V_b = The maximum bed velocity V_b is taken from Figure 7 for the appropriate fin arrangement and single or 2-3 azipods.

The coefficient for azipod propeller flow C_F can be taken from Table 1. Mattress flow coefficient C_F. A variable bottom is assumed when bed undulations/ construction tolerances exceed 600mm. Where changes in bed levels cause large areas of accelerated flow and suction, uplift can be estimated using Bernoulli's equation or CFD Modelling and mattress thickness designed accordingly.

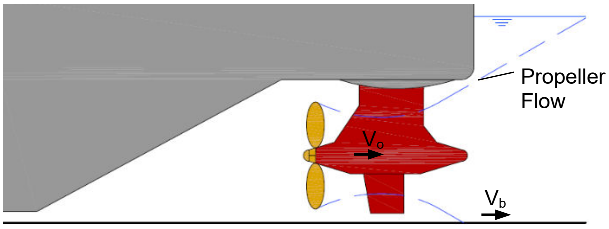

Figure 20. Propeller flow

Table 1. Mattress flow coefficient C_F

Design Condition	**C_F**
With fin, level beds	0.12
With fin, slopes and/or variable bottom	0.16
No fin, level beds	0.19
No fin, slopes and/or variable bottom	0.23

7. Design Of Sloping Insitu Concrete Mattress

Where cruise vessels berth to open piled quays, insitu concrete mattress protection needs to be designed for the high flow conditions during unberthing from twin rotated azipods, Figure 21. Azipods rotated towards pile quay. Insitu concrete mattress is reliably installed to quay slopes and around piles with experienced engineering support, Hawkswood & King (2016).

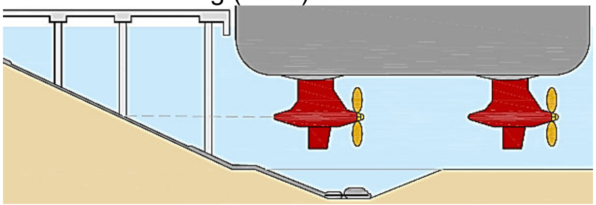

Figure 21. Azipods rotated towards pile quay

Design methods and scale model testing for this condition are shown in Hawkswood *et al* (2023).

8. Falling Hinged Edges

Falling edges are often used with edge embedment trenches to provide edge scour protection as Figure 22 where: -

- Rock size is not practical in high velocities.
- Rock costs are high.
- Saves additional plant/ process of rock laying.

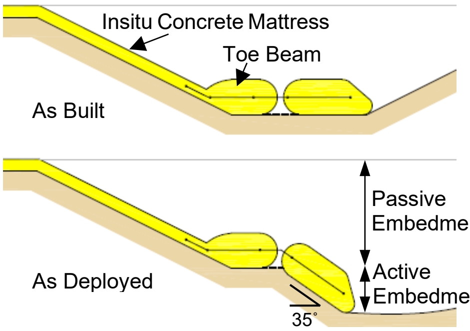

Figure 22. 1 Row Hinged Edge Block

Further guidance and the development testing back ground is provided in Hawkswood *et al* (2023).

9. Conclusion

Design methods for azipod flow and scour protection design have been presented based upon the scale model testing. The testing has shown that azipods are similar to open propellers allowing design formulas and concepts for open propellers to be applied to azipods. In particular, azipod hubs with a bottom fin are similar to propellers with a central propeller as they split the flow and increase bed velocity azipod hubs without a bottom fin are similar to propellers without a rudder. Both types of hub are common to cruise vessels.

Arrangements of multiple azipods were tested that are common to cruise vessels including pairs of rotated azipods. A design method based upon a method for twin propellers has been proposed with limits suggested for azipod spacing. The proposed design methods can aid effective scour protection design for cruise berths particularly where flow velocity from azipods is typically higher than for conventional propeller vessels.

10. Acknowledgments

This paper presents the views of the authors, not necessarily their employers, clients or organisations however, no liability or responsibility of any kind can be accepted in this respect by the publishers or the authors. Any subsequent amendments will be listed at www.proserveltd.co.uk

11. References

[1] BAW (2005), Principals for the Design of Bank and Bottom Protection for Inland waterways, Bulletin 85, Karlsruhe, Germany

[2] Führer M., Römisch (1977), Effects of Modern Ship Traffic on Inland and Ocean Waterways , 24th International Navigation Congress, PIANC, pp. 236-244.Leningrad, Russia,

[3] Hawksoood, M.G., Hawkswood, G.M., Groom, J.A. (2023) Berth Scour Protection Design For Azipods, Falling Hinged Edges & Maintenance Dredging, PIANC America 2023, Fort Lauderdale, Florida, USA.

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

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

[6] Hawkswood, M.G., Flierman, M., De Haan, R., King, M.G., & Groom, J.A., (2016) Propeller Action and Berth Scour Protection, PIANC-COPEDEC IX, Rio de Janeiro, Brasil.

[7] Hawkswood, M.G., Groom, J.A. & Hawkswood, G.M., (2018) Berth Protection For Single & Twin Propellers, PIANC-World Congress, Panama City, Panama.

[8] Hawkswood, M.G., King, M. (2016), Slope Protection Under Piled Quays, ASCE COPRI Ports 2016, New Orleans, U.S.A.

[9] PIANC Bulletin 109, (2002).,Input Data of Propeller Inducted Velocities for Dimensioning of Bed Protection Near Quay Walls, RÖMISCH, K. & HERING, W.

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

[11] PIANC Report of Working Group 22, Bulletin no 96 (1997), Guidelines for design of armoured slopes under open piled quay walls.