OPEN-BERTH STRUCTURES' BED ROCK SCOUR PROTECTION SYSTEM FROM MAIN PROPELLER ACTION: CASE STUDY IN VIETNAM

Dr. Nguyen Thanh Son *

* Vietnam Maritime University
No. 484 Lach Tray street, Hai Phong city, Viet Nam
e-mail: nthson@vimaru.edu.vn, web page: http://www.vimaru.edu.vn

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Abstract. The ship main propeller action is the one of biggest scour impacts to the bed rock protection layers of the berths, especially in the open-berth structures. Nowadays, while the ship size, capacity and characteristics tend to be increase more and more, the scour impact by the main propeller on the rock protection layer is more intense. These negative effects can impact considerably on the open-berth structure.

However, currently in Viet Nam, the design and calculation methods of the bed rock protection layers haven't considered the main propeller action yet. This matter can cause inadequate evaluations on impacts on the bed rock protection system.

The paper presents and analyzes the scour impact of the main ship propeller and discuss the protection solutions for the bed rock layers of the open-berth structure. As the result, the most effective and appropriate solution considering the main propeller action in Vietnamese conditions will be proposed and an example is also presented.

1 GENERAL

In the development countries, the bed rock protection system is designed and analyzed by considering adequately wave action, natural current, ship propeller, etc. Besides, scour protection solutions considering the main propeller action (e.g. rock fill, instu concrete, performance mattress, etc.) have been researched and presented. The calculation results achieved the high reliability and ensure the economic - technical efficiency.

In Vietnam, open-berth structures are being applied for ports most popularly. However, the design and calculation of the bed rock protection currently used in Vietnam have not considered the ship propeller action yet, i.e. only considering effects of waves and natural current.

Nowadays modern ships being built and installed power of the main propulsion system increase rapidly (from 90 up to 100,000 kW), their main propeller actions to the bed rock protection system of open berth are more significant and must be taken into consideration during the design process.

Especially during berthing and unberthing, eroding forces on the seabed in front of the berth or on the slope underneath the berth can be substantial. The ship propeller action causes current velocities which can reach up to 8 m/s near the bottom. While, the tidal current is typically limited to around 1 or 2 m/s. The main propeller currents causes an induced jet current speed directly behind the propeller.

The scour to the solid berth structures is normally the scour of the material in front of the berth, whereas the scour to the open structure is often more complex, including:

- Scour around piles, especially at piles near the front of the quay;
- Scour of the slope underneath the berth structure, even up to the top

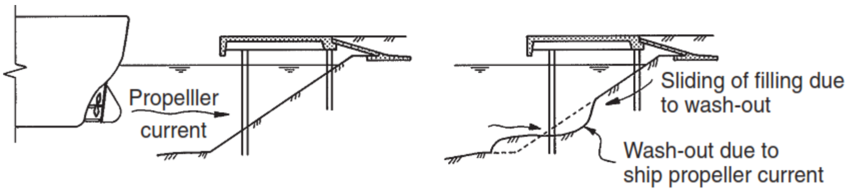

Figure 1: Scour impact to the berth by the propeller current

2 SCOUR DUE TO MAIN PROPELLER ACTION

The operation of main propeller can cause an induced jet current speed directly behind the propeller. The scour due to propeller action on the seabed in front of the berth is shown as follows:

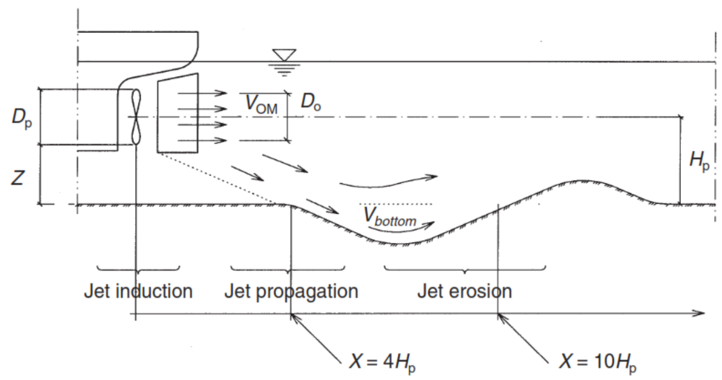

Figure 2: Scour of the seabed in front of the berth due to the action of a main propeller

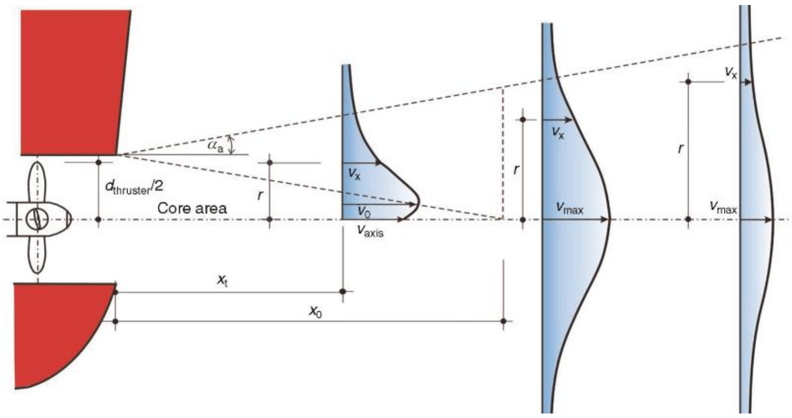

Figure 3: The velocity distribution of the current induced by a propeller

The main propeller action generates the current velocity which diffuses in a cone shape away from the propeller and decreases with increasing distance from the propeller. The maximum seabed velocity (V_{bottom}) is approximately in the range of distance 4×Hp to 10×Hp from the propeller (Figure 2).

The jet velocity generated by operating main propeller is called the "induced jet velocity" and occurs directly behind the main propeller. It is calculated by the following [6]:

$$V_{OM} = c \times \left[\frac{P}{\rho_O \times D_p^2}\right]^{1/3} \tag{1}$$

In which, V_{OM}: initial centreline jet velocity from the main propeller (m/s); c: 1.48 for a free propeller or a non-ducted propeller, and 1.17 for a propeller in a nozzle or a ducted propeller; P: engine output power (kW); ρ_0: density of seawater, 1.03 (T/m^3); D_p: propeller diameter (m).

The bottom velocity can be calculated by using the formula below [7]:

$$V_{bottom} = V_{OM} \times E \times \left[\frac{H_p}{D_p}\right]^a \tag{2}$$

In which, E = 0.71 for a single-propeller ship with a central rudder, and 0.42 for a twin-propeller ship with a middle rudder; H_p: height of the propeller shaft over the bottom (m); a = -1.00 for a single-propeller ship and -0.28 for a twin-propeller ship.

3 THE REQUIRED STONE PROTECTION LAYER

The diameter of required stone to ensure stability against the propeller current can be calculate in the following formula [7]:

$$d_{req} \geq \frac{V_{bottom}^2}{B^2 \times g \times \frac{(\rho_s - \rho_o)}{\rho_o}} \tag{3}$$

In which, d_{req}: Diameter of required stone (m); V_{bottom}: Bottom velocity (m/s); B: Stability coefficient, B = 0.90 for ships without a central rudder, B = 1.25 for ships with a central rudder; g: Acceleration due to gravity, 9.81 (m/s^2); ρ_s: Density of stone, 2.65 (T/m^3); ρ_o: Density of water, 1.03 (T/m^3).

The formula is used to calculate the equivalent stone weight as follows [7]:

$$W = \frac{d_{equ}^3 \times \pi \times \rho_s}{6} \tag{4}$$

In which, W: Equivalent stone weight (kN); d_{equ}: Diameter of equivalent stone (m); ρ_s: Specific gravity of a block unit of stone, 26 (kN/m^3).

The diameter and equivalent weight of required stone will decide in selecting components of protection filling layers seabed and slope underneath the berth.

4 SCOUR PROTECTION METHODS FOR THE BED ROCK PROTECTION LAYER UNDER MAIN SHIP PROPELLER ACTION

Currently, various protection methods against scour of main propeller action for bed water in front of the berth and the slope underneath the open berth are applied. The solution groups can commonly be divided as follows:

- Rocks or stones and rip-rap on a filter layer of gravels and/or a filter fabric;
- Covering with reinforced concrete slabs, flexible composite systems, etc.

In the conditional application of Viet Nam, the following protection methods are presented and analyzed:

4.1 Rocks or stones on a filter layer

This protection system is one of the most frequently used. The scour protection system using rock or stones as fill under the open pile berth structure is illustrated in figures 4 & 5.

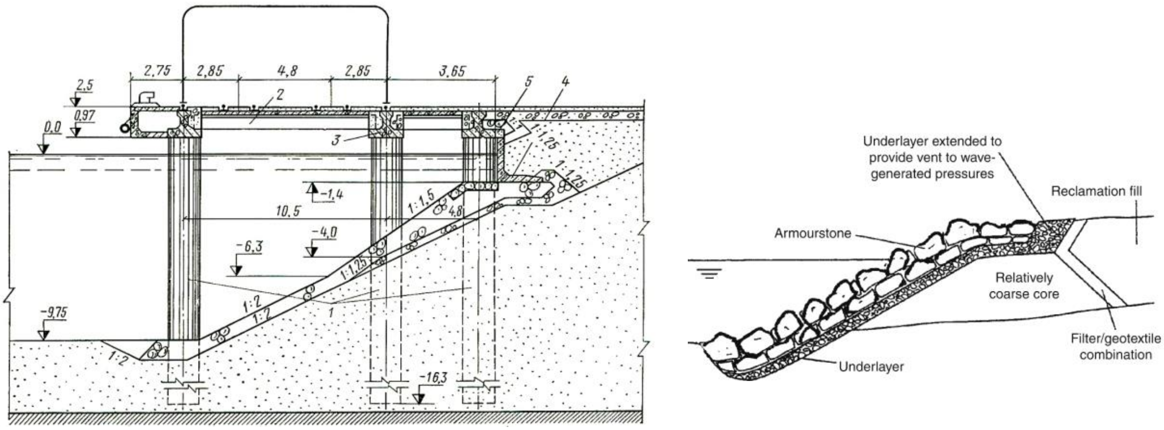

Figure 4: Scour protection using a stone fill and its detailed structure

Outstanding advantages of the stone protection method in Vietnamese conditions includes:

- Construction techniques are uncomplicated and can widely apply in many different conditions.
- Used materials are common and available, not require to be processed and manufactured.
- This method is especially suitable for underwater construction, where water level changes.

However, there are some its considerable disadvantages:

- It is difficult to ensure the uniformity of the thickness of scour protection according to the design due to the free fall of the stone.
- During construction, the material can be lost, the displacement of the stone will surely occur.
- The achieved stability of stones are due to the material bonded together by the frictional angles of the edges, which are susceptible to being impacted by external forces such as waves, natural currents, ship propeller actions.
- Unexpected negative impacts on piles of the berth can occur during construction of the bed rock protection layer.

4.2 Covering with reinforced concrete mattress

A progressive scour protection method being applied at some of the world's most advanced ports is covering with reinforced concrete mattress. The thickness of the protective layer can be applied more accurately with a thickness of 30 cm to 80 cm or more. The mattress is placed on the prepared slopes and sea bottom, joined together and pumped full of concrete then.

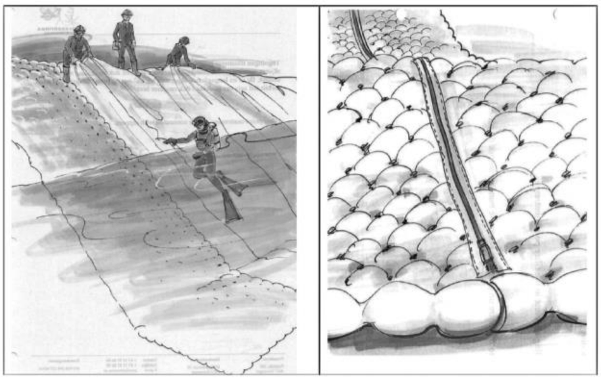

Figure 6: Construct to filling the concrete mattresses [5]

The mattresses supplied in the widths of 3.75 m and up to 100 m can be attached to panels in advance for rapid installation in the area to be protected. The thickness of the mattresses can be 7.5 cm up to 60 cm, with area weights, when filled with concrete of approximately 150 - 1200 kg/m^2. The mattresses used for berth protection are usually delivered with a thickness of at least 20 cm, to give an approximate weight of around 500 kg/m^2. The concrete be designed for pumping. When the concrete is pumped into the mattresses, it will cause the water to evacuate through the fabric. The individual mattresses should be connected by zippers. The concrete used to fill the mattresses must be suitable for pumping through a pipeline of 50 - 75 mm diameter.

The method of covering with reinforced concrete mattress can be considered as the advanced solution with its following advantages:

- The thickness of protection layer can be constructed more accurately.
- The linkage and uniformity of material is better and more stable withstand external forces such as wave actions, natural current, ship propeller, etc.
- The process of construction can be controlled better to ensure the uniformity and satisfaction of design requirements.

In case this protection method is applied in Vietnamese conditions, it also have some disadvantages as follows:

- The construction of underwater concrete is more complicated and expensive.
- The mattress production to ensure technical requirements and durability has not been yet available in Viet Nam.
- The construction of covering the empty mattress requires the high precision which is difficult to construct at where water level changes.
- This is a new method, so the current domestic technology is limited and need more time to study, transfer and apply.

- For open berth with piles, production and construction of mattress for pile net are very complicated. The process of pumping concrete into spaces between piles is so difficult to ensure uniformity.

As the above analysis, the bed stone scour protection is currently most commonly used in open berths in Viet Nam due to its convenience in construction especially with marine structures (constructed at the changeable water level), availability of materials and the ability to apply to many different types of berth and other conditions.

5 THE CASE STUDY IN VIET NAM

5.1 Introduction

The name of project: "Improve the infrastructure and the berth of the shipyard - 189 Co., Ltd."; its location: Dinh Vu-Cat Hai Economic Zone, Hai Phong City, Viet Nam.

Specifications of berth:

- Total length of berth: 190.00 m; Width of berth: 22.40 m; Top altitude: + 4.75 m ; Bottom altitude: -8.70 m; High design water level: + 3.75 m; Low design water level: + 0.80 m.

Design Ship Characteristics:

- Type of ship: Container vessel; Tonnage: 10,000 DWT; Length: L_t = 141.00 m; Width: B_t = 22.4 m; Laden draught: T_c = 8.0 m; Power output of main propeller: P = 2.250 kW; Diameter of main propeller: D_P = 4.500 mm. The main propeller propulsion system consists of twin propellers with central rudder.

Figure 7: Location of the berth of Company Limited 189 in Cat Hai - Dinh Vu Economic Zone

5.2 Calculate the bottom velocity of current by the main propeller

The initial centreline jet velocity from the main propeller is given by the formula:

$$V_{OM} = c \times \left[\frac{P}{\rho_O \times D_p^2} \right]^{1/3}$$

Where: c: 1.48 for a free propeller or a non-ducted propeller; P: engine output power (kW), P = 2.250 kW; ρ_0: density of seawater, 1.03 T/m^3; D_p: propeller diameter (m), D_P = 4.5 m

=> VOM = 7.05 (m/s)

The bottom velocity can be calculated:

$$V_{\text{bottom}} = V_{\text{OM}} \times E \times \left[\frac{H_{\text{p}}}{D_{\text{p}}}\right]^a$$

Where: E = 0.42 for a twin-propeller ship with a middle rudder; H_p: height of the propeller shaft over the bottom (m), H_p = 3.55m; a = -0.28 for a twin-propeller ship

=> V_{bottom} = 3.16 (m/s)

5.3 The required stone protection layer

The diameter of the required is calculated by the following formula:

$$d_{\text{req}} \geq \frac{V_{\text{bottom}}^2}{B^2 \times g \times \frac{(\rho_s - \rho_o)}{\rho_o}}$$

Where: d_{req}: required diameter of the stone (m); B: stability coefficient, B = 1.25 for ships with a central rudder; g: acceleration due to gravity, 9.81 m/s^2; ρ_s: density of stone, 2.65 T/m^3; ρ_o: density of water, 1.03 T/m^3

=> d_{reg} = 0,4 (m)

The corresponding weight of the stone is given by:

$$W = \frac{d_{\text{equ}}^3 \times \pi \times \rho_s}{6}$$

=> W = 0,1 (T)

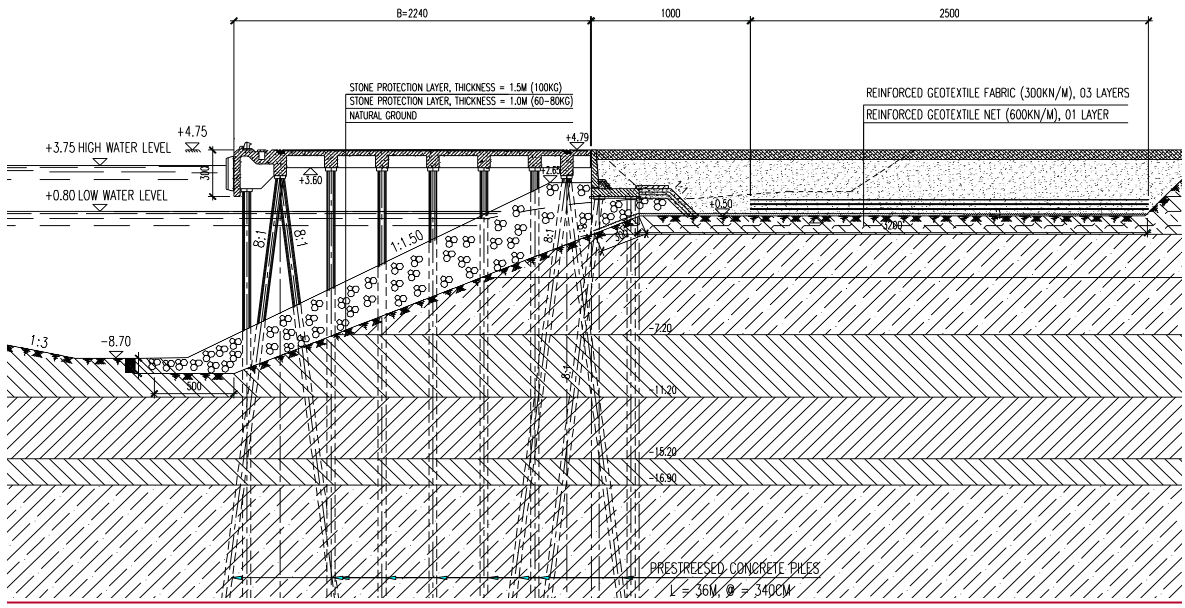

Figure 8: Cross Section of the berth and its bed rock scour protection layers

Based on the above calculation results, the bed stone protection system underneath of the berth is designed as follows:

- The minimum required stone size of the protection layer is 40 cm.
- The minimum corresponding stone weight of the protection layer is 100 kg.
- The thickness of the protection layer $L \geq 3*D_{50}$ (3*40 cm) => L = 1.5 m with the ratio of slope 1:1.5 spread out from the altitude +2.65 m to -9.7 m.
- The bed stone protection system is composed of two layers, the thickness of the below layer is 1 m thick, the stone weight is 60 - 80 kg.
- In order to ensure stable and safe conditions, the stone protection slope is lengthened more 5 m from the front edge of the berth.

6 CONCLUSIONS

In the current development trend, cargo ships and specialized vessels tend to increase capacity and more new features. In addition, the demand for self-propelled ships in the process of berthing and unberthing the port is also required higher. The impact of the ship propeller on the bed water in front of the berth and the slope underneath the berth should be adequately considered in the construction design to ensure the safe, technical - economic efficiency for the life time of the berth.

The article presents the scour impact of ship main propeller on the bed stone protection layer of the open piles berth. Besides, some scour protection methods for bed water in front of berth and slope underneath the open berth under impact of main ship propeller is also discussed here. The bed rock protection layer is proposed as its convenience in the conditions of Viet Nam where the open piles berths are applied most commonly. Therefore, the proposed method and the calculation procedure are expected to improve the quality of designing port and marine structure in Viet Nam.

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