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EFFECTS OF WATER INTAKE LAYOUT ALONG THE WHARF SHORELINE ON SHIPS

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ABSTRACT

The construction of a water intake along the wharf shoreline can realise the intensive and comprehensive utilisation of the shoreline. However, since the water intake will increase the lateral flow at the wharf and also the hydrodynamic forces on ships, it will bring risks to ships mooring and leaving. The effects of the water intake on ships are studied using a physical model, numerical model and standard formulas. The results show that it leads to an increase of the hydrodynamic forces acting on the ship when the standard formulas are used to calculate the forces without considering the water level difference between the two sides of the ship. The results of the physical model are closer to the real situation. Measures that can effectively reduce the influence of the water intake on ships are proposed by increasing the distance between the wharf front and the front of the water intake as well as the depth of the water inlet windows.

Keywords: water intake,physical model,numerical model,lateral flow,hydrodynamic force

INTRODUCTION

A section of coastline is planned for the construction of a large-scale wharf. However, it is also intended to build a water intake in a section of the shoreline area to serve the needs of power plants and desalination projects. This will enable the comprehensive utilisation of the shoreline. The water intake will increase the lateral flow at the wharf and also the hydrodynamic forces on ships. It will have some impact on the security of the mooring and berthing operation of ships.

In previous research, Huang studied the incorporation engineering of the Xiamen Eastern Natural Gas Power Plant water intake and the 1# berth in the eastern port [5]. Liu et al. investigated the interaction between the 50000 ton (t) coal unloading wharf of Suizhong Power Plant and the water intake using a numerical model [6]. A study of the hydraulic structures of the water intake of the second phase of the Dongjiakou Huaneng project in Qingdao Harbour has been carried out by Liu and Qiao [7]. Xie et al. reported the influence of the construction of a water intake on flood defences [10]. Xie and Wu checked the water intake status of Jiaxing Power Plant in Zhejiang Province and determined the reasons for a temperature rise [11]. Ge compared three wharf layouts of Anqing Power Plant, and the one which combines the water intake was recommended [2]. The eclipsed form and march-past method of water intake–outlet arrangements in a power plant were investigated by Cheng and Ying using numerical simulation [1]. Hamrick and Mills studied the cooling water of Peach Bottom Atomic Power Plant and the influence on the water temperature of Conowingo Pond [3]. Zeng et al. studied the transport of waste heat from a nuclear power plant into coastal water using numerical and experimental modelling [12]. Wang et al. evaluated the risk of ice plugging of a cooling water intake of a power station by a numerical simulation method [9]. However, few studies have been done in the past on the water intake using a physical model test and ship model test. In this paper, based on the previous research experiences, a physical model, numerical model and standard formulas were applied by the author to analyse the effects of a water intake on ships. Measures to reduce the impact are also proposed.

The coastline is planned for the construction of a large-scale wharf. The sizes of the design ships are shown in Table 1. The bottom elevation of the wharf is -17.5 m. The layout of the water intake and wharf shoreline is shown in Fig. 1.

Tab. 1. Sizes of design ships

Number	Ship type	Ship size (m)			
		Length	Width	Moulded depth	Draft
1	20000 DWT general cargo ship	166	25.2	14.1	10.1
2	150000 DWT bulk carrier	289	45.0	24.3	17.9
3	150000 DWT container ship	367	51.2	29.9	16.0

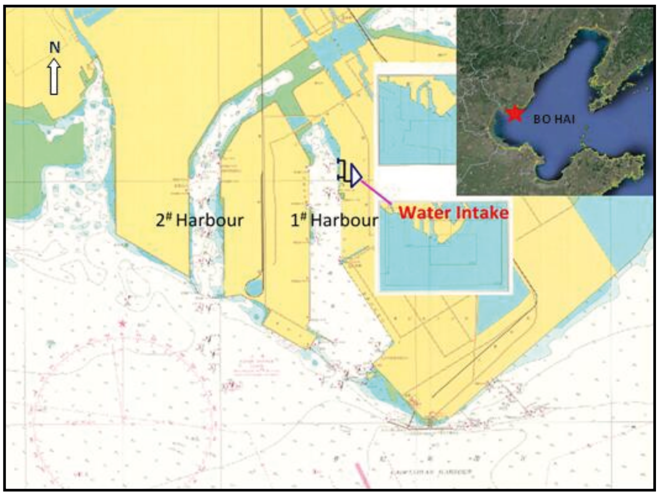

Fig. 1. Position of the project

Submerged caissons were used to draw water into the water intake of this project. The plane view and structures of the water intake are shown in Fig. 2 and Fig. 3. There are two water intakes, namely $1^{\#}$ and $2^{\#}$. Intake $1^{\#}$ is arranged at the north side of the temporary water diversion channel and 160 m of the shoreline is occupied. Intake $2^{\#}$, which also occupies 160 m of the shoreline, is located on the north side of $1^{\#}$. The distance between them is 400 m. The distance between the connecting shaft and the wharf front is about 110 m. The water inlet windows are set up on the water side of the caissons. There are 32 water inlet windows for each water intake. Of these, there are 28 windows with a hole size of 4.2 m × 4.2 m, and 4 windows with a temporary hole size of 3.7 m × 3.7 m. There are three elevation schemes for the water inlet windows, namely -6 m (Project 1), -8 m (Project 2) and -10 m (Project 3), respectively. The flow rate of both $1^{\#}$ and $2^{\#}$ is 105.43 m^3/s.

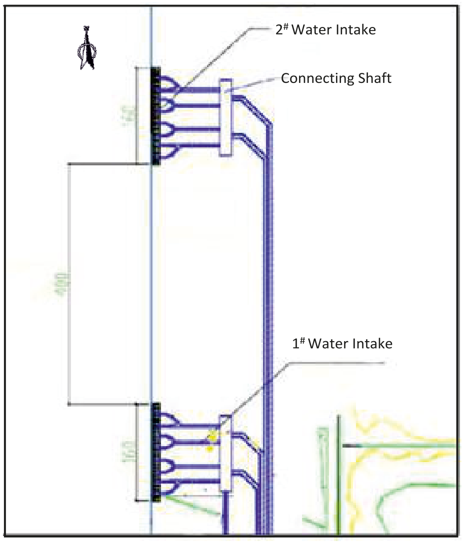

Fig. 2. Arrangement of the water intake

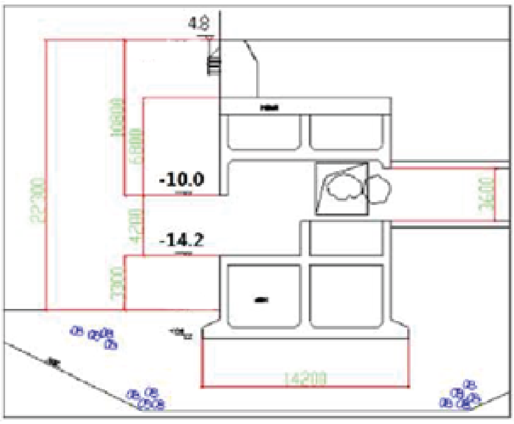

Fig. 3. Structures of the water intake

METHODS

In order to study the influence of the water intake on ships, a physical model, numerical model and standard formulas are adopted. The tidal current in the area is simulated using the numerical model. Then the results are applied in the physical model. The effects of the water intake on ships are then analysed.

TWO-DIMENSIONAL NUMERICAL MODEL FOR TIDAL CURRENT

The governing equations consist of the following continuity and momentum equations:

$$\frac{\partial h}{\partial t}+\frac{\partial(hu)}{\partial x}+\frac{\partial(hv)}{\partial y}=0 \quad (1)$$

$$\frac{\partial hu}{\partial t}+\frac{\partial huv}{\partial y}+\frac{\partial}{\partial x}(hu^2+\frac{1}{2}gh^2)=gh(S_{fx}+S_{0x})+f_c hv+f_w\sqrt{w_x^2+w_y^2}\,w_x+S_{vx} \quad (2)$$

$$\frac{\partial hv}{\partial t}+\frac{\partial huv}{\partial x}+\frac{\partial}{\partial y}(hv^2+\frac{1}{2}gh^2)=gh(S_{fy}+S_{0y})-f_c hu+f_w\sqrt{w_x^2+w_y^2}\,w_y+S_{vy} \quad (3)$$

where u and v are the depth-averaged velocity in the x and y direction, respectively; g is the gravitational acceleration; h is the water depth; S_{fx} and S_{fy} are the bottom friction term in the x and y direction, respectively; S_{0x} and S_{0y} are the bottom slope term in the x and y direction, respectively; f_c is the Coriolis parameter; w_x and w_y are the wind speed in the x and y direction, respectively; f_w is the wind drag coefficient; S_{vx} and S_{vy} are the horizontal viscosity term in the x and y direction, respectively. The tidal elevation is imposed on the open boundary. The normal velocity is set to zero at the land boundaries. The initial sea level and velocity are set to zero.

OVERVIEW OF PHYSICAL MODEL TEST EQUIPMENT AND MEASUREMENT SYSTEM

The ship model and the physical model are designed according to the gravitational similarity criterion. The geometric scale of the model is determined to be 80 according to the test site, ship scale and water flow. A pump is used for water supply. The water level is accurately measured by the probe. The flow rate of the water intake is controlled by a weir. The flow velocity is accurately measured by a Vectrino ADV. In the model, the length of the harbour is 25 m and the width is 15 m. There are also 32 water inlet windows for each water intake. There are 28 windows with a hole size of 0.053 m × 0.053 m, and 4 windows with a temporary hole size of 0.046 m × 0.046 m. The elevations of the water inlet windows for the three projects are -0.075 m, -0.1 m and -0.125 m, respectively. The flow rates of both intakes 1# and 2# are 1.84 L/s and are controlled by weirs and valves. The layout of the physical model can be seen in Fig. 4. The model ship is similar in scale to the prototype vessel and is shown in Fig. 5. The ballasting method is utilised, i.e., the appropriate weight is placed in the right place. This meets the weight and distribution requirements and ensures that the draught and displacement are similar. The measurements and data recording start after the pumping flow rate becomes steady.

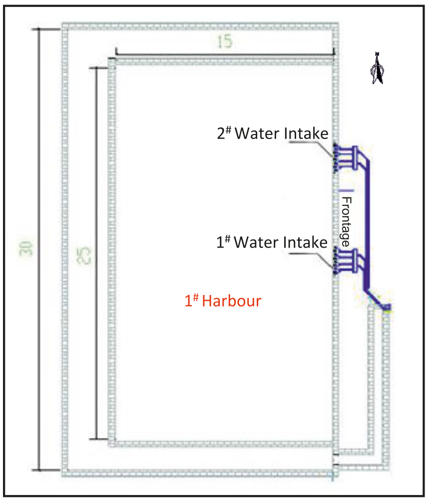

Fig. 4. Layout of the physical model

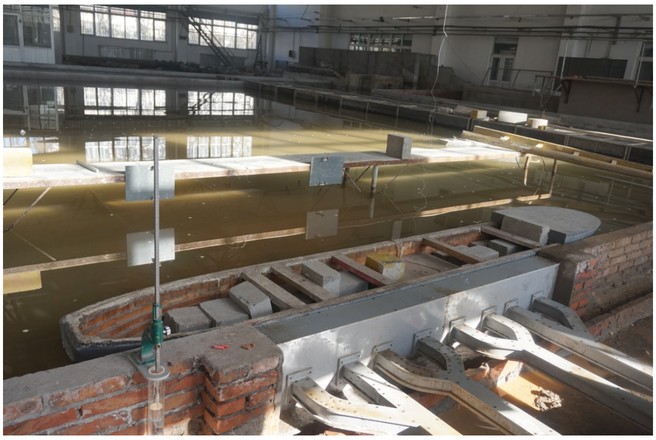

Fig. 5. Ship model in the test

The impacts of mooring ships on the water intake of a power plant are investigated. The water level in the connecting shaft and the flow rate around the water intake are measured when different types of ships dock at the front of the wharf. The tests include: flow rate measurement and flow regime observation around the water intake in the condition of no ship; flow rate measurement at the water inlet windows in the condition of no ship; water level measurement at the ship side, water intake and in the connecting shaft when different types of ship dock.

Th effects of the water intake on the mooring and berthing operation of ships are studied. The hydrodynamic forces on different types of ship are measured in conditions of different elevation schemes for the water inlet windows.

STANDARD FORMULAS FOR HYDRODYNAMIC FORCE ON SHIP

The hydrodynamic forces on a ship usually include lateral force, longitudinal force and yaw moment. For the bollard pull required, the maximum lateral forces exerted by a crosswise current are important. In order to calculate the lateral force, the standard formula recommended by Tug Use in Port:

A Practical Guide [4] and also Design Code of General Layout for Sea Ports [8] is given:

$$F_{yc} = 0.5 C_{yc} \rho V^2 L_{BP} T \tag{4}$$

where F_{yc} is the lateral force; C_{yc} is the lateral force coefficient; ρ is the density of water; V is the flow velocity; L_{BP} is the length between perpendiculars; T is the draft. The C_{yc} differs according to a ship's underwater shape, draft, trim and angle of attack, and is also affected strongly by the under-keel clearance. Therefore, a simplified formula is applied in this paper:

$$F_{yc} = 150 V^2 L_{BP} T \tag{6}$$

This requires that the under-keel clearance is about 20% of the ship's draft. It should be mentioned that the outcome is given in kilograms (kg) instead of Newtons (N).

RESULTS AND DISCUSSION

TIDAL CURRENT

The flow fields at maximum flood and ebb tide are shown in Fig. 6 and Fig. 7. It is suggested that the flow in the harbour is restricted by the boundary and the flow direction is almost north–south. It is also weak due to the existence of the breakwater at the entrance. The maximum velocity is less than 0.2 m/s.

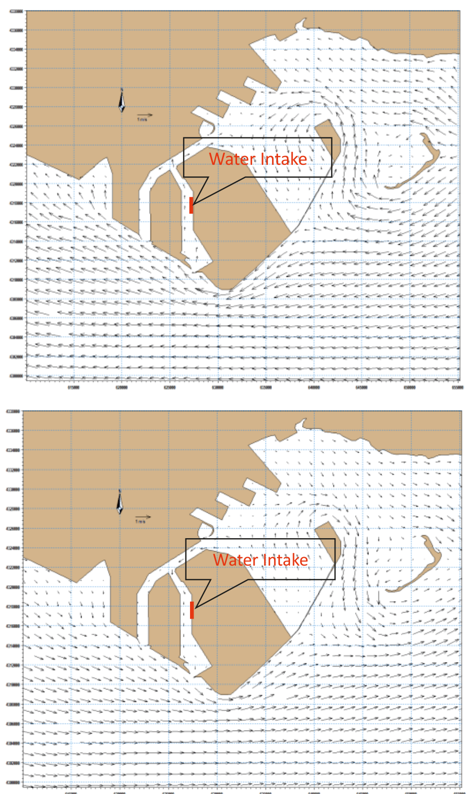

Fig. 6. Flow field at maximum flood tide (Top) and maximum ebb tide (Bottom)

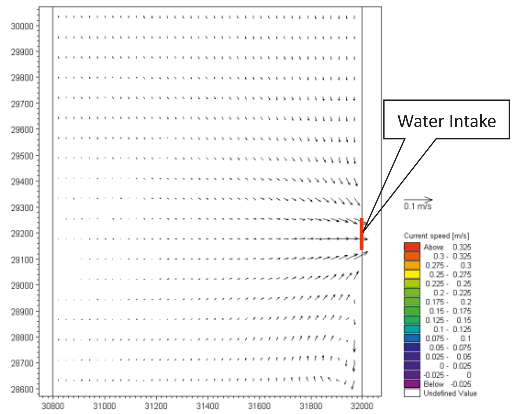

Fig. 7. Flow field near the water intake at maximum flood tide

The model results also show that the water intake has a small effect on the flow. The maximum change of velocity is 0.02~0.03 m/s at 50 m in front of the wharf and the influence range is within 150 m in front of the wharf.

PHYSICAL MODEL TEST

The flow velocity near the water intake is measured first. Fig. 8 gives the flow field at the maximum flow rate of the water intake. It should be mentioned that the results have been converted into prototype units hereinafter. This indicates that the flow velocity is larger in the middle of the two water intakes and it decreases on the two sides. The maximum velocity at the water inlet windows is about 0.30 m/s and the average velocity is 0.19 m/s. This is less than 0.35 m/s, which is the velocity limit of ship operation. The flow velocity is no more than 0.10 m/s at a distance of 64 m and farther. The velocity distribution in the vertical direction is smaller for the surface layer and the bottom layer. It is also compared with the numerical simulation. It shows that the measured maximum velocity is a little larger than the simulated one in front of the wharf without the ship.

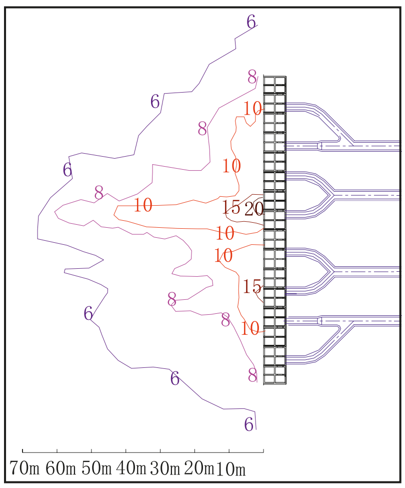

Fig. 8. Flow field near the water intake (0.01m/s)

Then the effect of the positions of different ships on the water level in the connecting shaft is investigated. The position of the vessel relative to the water intake and the position of the probes are shown in Fig. 9. The results of water level measurement without a ship and with different types of ship are given in Table 2. It can be seen that the bigger the berthing ship, the greater the impact on the water level in the connecting shaft. The 150000 DWT container ship and the bulk carrier berthing just in front of the wharf (ignoring the fender effect, i.e., the distance between the ship and wharf front is 0.0) have the largest impact on the water level in the connecting shaft. The water level is reduced by about 0.24 m relative to the non-ship condition for the 150000 DWT container ship and about 0.26 m for the 150000 DWT bulk carrier. For the 20000 DWT general cargo ship, the water level in the connecting shaft is basically the same as that when there is no ship. The maximum difference is no more than 0.02 m. It is also demonstrated that the farther away from the wharf, the smaller the influence on the water level in the connecting shaft. When the distance exceeds 5 m, there is almost no influence.

Tab. 2. Water level measurement with and without ship

Conditions		Probe number		
		1#	2#	3#
Water level (no ship, m)		0.53	0.53	0.53
Ship type	Distance between ship and wharf front (m)	Water level reduction relative to the non-ship condition (m)		
150000 DWT container ship	0.0	0.02	0.02	0.24
	1.0	< 0.01	< 0.01	0.07
	2.0	< 0.01	< 0.01	0.02
	4.0	< 0.01	< 0.01	< 0.01
150000 DWT bulk carrier	0.0	0.02	0.02	0.26
	1.0	< 0.01	< 0.01	0.07
	2.0	< 0.01	< 0.01	0.02
	4.0	< 0.01	< 0.01	< 0.01
20000 DWT general cargo ship	0.0	< 0.01	< 0.01	0.02
	1.0	< 0.01	< 0.01	< 0.01

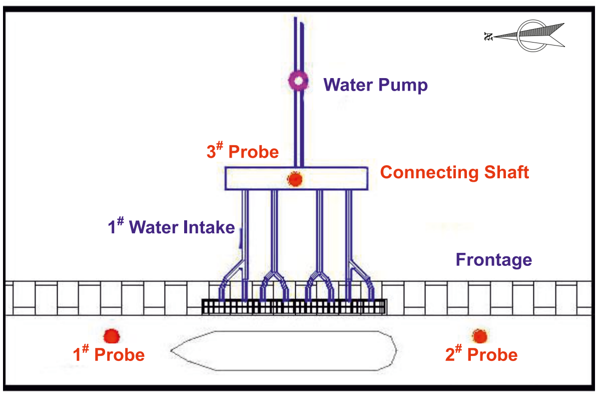

Fig. 9. Water level measurement in the test

The lateral forces on different types of ship in full load condition are measured under different elevation schemes for the water inlet windows. The results are shown in Table 3 and Fig. 10. The unit of the lateral force has been converted from kg to t. It is shown that the larger the distance between the ship and the wharf front is, the smaller the lateral force is. Taking the 150000 DWT container ship in Project 3 as an example, the lateral force on the ship is 129.5 t, 103.9 t and 81.4 t at a distance of 1.0 m, 1.8 m and 2.5 m, respectively. It is also found that the lower the location of the water inlet windows is, the smaller the lateral force is. For example, when the distance from the wharf front is 1.0 m, the lateral force on the 150000 DWT container ship is 198.1 t, 141.8 t and 129.5 t at the elevation of -6 m, -8 m and -10 m, respectively.

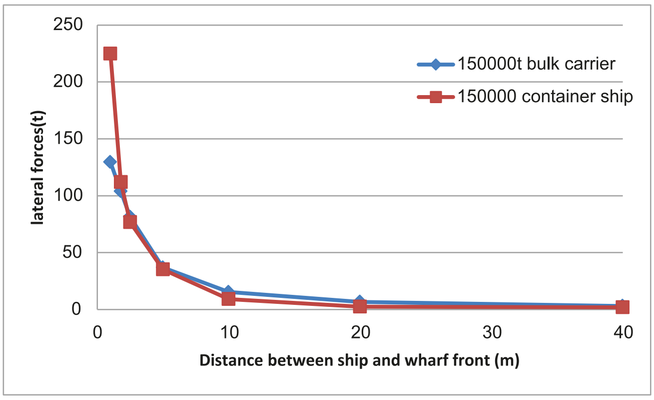

Fig. 10. Measured lateral force in the test (Project 3)

Tab. 3. Measured lateral force in the test

	Ship type	Distance between ship and wharf front (m)	Lateral force (t)
Project 1	150000 DWT container ship	1.0	198.1
		1.8	157.2
		2.5	108.5
		5.0	63.0
		10.0	18.4
		20.0	8.2
		40.0	4.6
	150000 DWT bulk carrier	1.0	224.8
		1.8	112.1
		2.5	76.8
		5.0	35.3
		10.0	9.2
		20.0	2.6
		40.0	2.0

	Ship type	Distance between ship and wharf front (m)	Lateral force (t)
Project 2	150000 DWT container ship	1.0	141.8
		1.8	102.4
		2.5	77.3
		5.0	37.9
		10.0	18.4
		20.0	8.2
		40.0	4.1
	150000 DWT bulk carrier	1.0	160.9
		1.8	73.2
		2.5	55.3
		5.0	21.5
		10.0	9.7
		20.0	2.6
		40.0	1.0
Project 3	150000 DWT container ship	1.0	129.5
		1.8	103.9
		2.5	81.4
		5.0	36.9
		10.0	15.4
		20.0	6.7
		40.0	3.1
	150000 DWT bulk carrier	1.0	136.0
		1.8	83.1
		2.5	57.0
		5.0	22.5
		10.0	9.2
		20.0	1.0
		40.0	0.5

The calculated lateral forces using Eq. are given in Table 4. The flow velocity is set as 0.2 m/s in terms of the numerical model results. It can be seen that the calculated lateral force in the full load condition is quite different from the measured one when the ship is very close to the wharf front. For example, the calculated lateral force is only 31.0 t, while the measured is 224.8 t for the 150000 DWT bulk carrier in Project 1. The latter is about 7.3 times as large as the former. The reason for the gap is that the lateral force calculated by the standard formula does not take into account the difference in the water level on either side of the ship. The flow structure is changed near the wharf front due to the presence of the ship and the force increases. The force induced by the difference of water level on the two sides of the ship cannot be ignored. When the ship is far away from the wharf, the water level difference between the two sides of the ship decreases rapidly. When the distance reaches 5.0 m, it can be seen that the lateral force calculated by the standard formula is equivalent to that measured by the test.

Tab. 4. Calculated lateral force using the standard formula

Ship type	Lateral force (t)
150000 DWT container ship in full load condition	35.2
150000 DWT container ship in ballast condition	24.2
150000 DWT bulk carrier in full load condition	31.0
150000 DWT bulk carrier in ballast condition	14.9

CONCLUSIONS

The physical model, numerical model and standard formulas are applied to investigate the influence of a water intake along the wharf shoreline on ships. The conclusions and suggestions are as follows. The flow velocity in the harbour is small. The influence range of the water intake on the flow field is only near the water inlet windows. The distance between the ship and wharf front and the location of the water inlet windows have impacts on the hydrodynamic forces acting on ships. The larger the distance and the lower the location is, the smaller the lateral force is. Therefore, the increment of distance between the wharf front and the front of the water intake, as well as the depth of the water inlet windows, are effective measures to reduce the influences of the water intake on ships. It is suggested that the fender size should be adjusted in the wharf design so that the distance between the wharf front and the front of the water intake is at least 5.0 m. Meanwhile, the elevation scheme for the water inlet windows in Project 3 should be utilised. It is also advised that the wharf structure should be adjusted from gravitational caissons to a high-piled wharf in order to reduce the lateral force.

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