DETERMINATION OF THE APPROPRIATE RAMP ANGLE FOR LAUNCHING CONCRETE CAISSONS

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Abstract

This article aims to investigate the dependences of some parameters on a ramp slope while launching a caisson on the water in a construction marine structure. Illustrative examples propose a method of determining the optimal slope of the ramp. The results have been applied in practice to ensure safety and efficiency.

Keywords: *Caisson; ramp; slope; launch; draft.*

1. Introduction

Currently in Vietnam, in a number of marine construction projects such as embankments, ship locks, breakwaters, etc., the option of using reinforced concrete caissons has gradually been widely used [1, 2]. However, studies on construction of caissons in Vietnam are still very limited. Launching the caisson is a very important step in construction phase. Launching a caisson can use the option of using floating docks or using ramps [3, 4]. The option of using floating docks has the advantage that it is possible to launch the caissons right at the design location, but it must be cast right at the floating dock, so the cost is high, the space is limited, and it requires modern and suitable equipment, suitable for construction conditions near land. The method of launching caissons by the ramp is used for large-scale casting caisson on the casting yard, so the cost is low, the construction period is short, and it is suitable for construction in remote locations with difficult conditions. The slope of the ramps affects many parameters when launching, and also greatly affects the construction cost. Therefore, choosing the appropriate slope is a matter of concern. In this paper, the author studies the dependence of some parameters when launching the caisson on the slope of the ramp, thereby providing a basis for choosing a reasonable slope to apply in actual construction at Phu Quy island, Binh Thuan province.

2. Overview of reinforced concrete caisson and launching construction plan

The reinforced concrete caisson has the shape of a rectangular box. There are 3 dimensions of length × width × height $l \times b \times h$ (Fig. 1). The inside of the caisson is divided into several empty compartments. The caisson is used as a breakwater, suitable for embankment and sea dyke [5, 6].

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The reinforced concrete caisson can be cast on the shore, then launched into the water by the ramp. We can also build a caisson on the floating docks, then launch the caisson into the water. Construction plan of a caisson that is submerged onshore then launched into the water is suitable for offshore works in difficult construction conditions.

Fig. 1. Reinforced concrete caisson.

3. Launching reinforced concrete caissons using ramp

The caisson is constructed (cast) on site, launched into the water using a cart that slides on the track of the ramp [7].

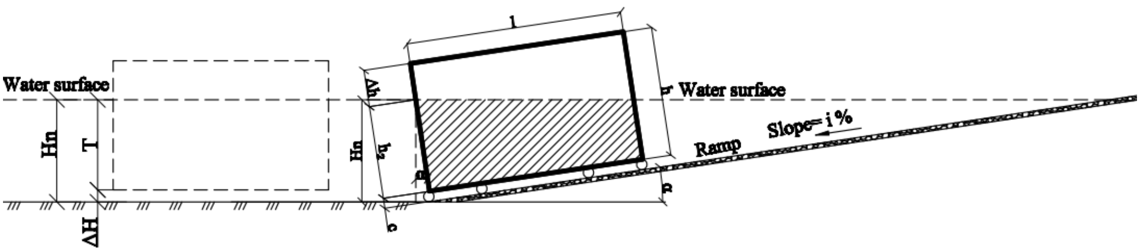

Fig. 2. Diagram of launching the caisson on the ramp.

The ramp has a slope of i, angle of inclination α. H_n is the minimum water depth so that the bottom of the caisson does not touch the seabed when launching. For safety, $H_n = T + \Delta H (m)$ (Fig. 2), where T is the draft of the caisson when the caisson is floating freely in the water, ΔH is the safe depth.

According to the theory of buoyancy calculation presented in the document [8], caisson with a total weight of *G*, there will be a draft of:

$$T = \frac{G}{\delta \cdot \gamma \cdot l \cdot b} \tag{1}$$

where δ is the volume-filling coefficient, γ is the density of water. For caissons with rectangular box shape $\delta = 1$.

The caisson moves on a trolley, along the ramp from the shore to the water. The moving speed of the caisson is so small that it can be considered as causing negligible hydrodynamic effects, which can be ignored. Part of the caisson is submerged in water, called V_1 is the volume of the submerged part of the caisson. Then, the Acsimetric thrust acting on the caisson is:

$$F_{asm} = \gamma \cdot V_1 \tag{2}$$

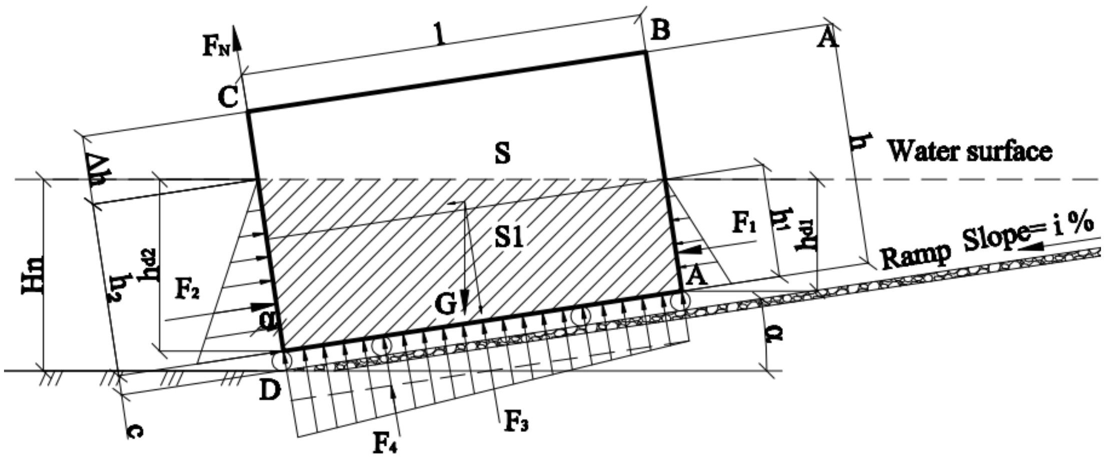

Fig. 3. Forces acting on the caisson when it is launched.

Ratio of the volume of the submerged part V_1 and the total volume of the caisson V is equal to the ratio of the area of the submerged part of the side surface S_1 and side area S, it means:

$$\frac{V_1}{V} = \frac{S_1}{S}$$

In Fig. 3, S_1 has a trapezoidal shape and is calculated by the formula:

$$S_1 = \frac{\left(h_2 + (h_2 - l \cdot tg\alpha)\right)}{2} \cdot l$$

S has the shape of a rectangle with dimensions $l \times h$ and is calculated by the formula:

$$S = l \cdot h$$

From there, get:

$$\frac{V_1}{V} = \frac{\dfrac{\left(h_2 + (h_2 - l \cdot \mathrm{tg}\alpha)\right)}{2} \cdot l}{l \cdot h} = \frac{\left(2 \cdot h_2 - l \cdot \mathrm{tg}\alpha\right)}{2 \cdot h}$$

It turns out:

$$V_1 = \frac{\left(2 \cdot h_2 - l \cdot \mathrm{tg}\alpha\right)}{2 \cdot h} \cdot (l \cdot b \cdot h) = \frac{\left(2 \cdot h_2 - l \cdot \mathrm{tg}\alpha\right)}{2} \cdot l \cdot b$$

From this get the Acsimeter thrust:

$$F_{asm} = \gamma \cdot V_1 = \gamma \cdot \frac{\left(2 \cdot h_2 - l \cdot \mathrm{tg}\alpha\right)}{2} \cdot l \cdot b \tag{3}$$

Call the trolley height is c. In Fig. 3, at the end of the ramp, the height of the most submerged part of the caisson is $h_2 = \dfrac{H_n}{\cos\alpha} - c$, deduce:

$$F_{asm} = \gamma \cdot V_1 = \gamma \cdot \frac{\left(2 \cdot (\dfrac{H_n}{\cos\alpha} - c) - l \cdot \mathrm{tg}\alpha\right)}{2} \cdot l \cdot b \tag{4}$$

The hydrostatic pressures acting on the caisson are:

Vertical side AB: $F_1 = \dfrac{1}{2} \cdot p_1 \cdot S_{c1} = \cdot \dfrac{1}{2} \gamma \cdot h_{d1} \cdot S_{c1} = \dfrac{1}{2} \cdot \gamma \cdot h_1 \cdot \cos\alpha \cdot h_1 \cdot b$

$$= \frac{1}{2} \cdot \gamma \cdot (h_2 - l \cdot \mathrm{tg}\alpha) \cdot \cos\alpha \cdot (h_2 - l \cdot \mathrm{tg}\alpha) \cdot b$$

Vertical side CD: $F_2 = \dfrac{1}{2} \cdot p_2 \cdot S_{c2} = \dfrac{1}{2} \gamma \cdot h_{d2} \cdot S_{c2} = \dfrac{1}{2} \cdot \gamma \cdot h_2 \cdot \cos\alpha \cdot h_2 \cdot b$

Base DA: $F_3 = \dfrac{1}{2} p_1 \cdot S_{c3} = \dfrac{1}{2} \cdot \gamma \cdot h_1 \cdot \cos\alpha \cdot l \cdot b = \dfrac{1}{2} \cdot \gamma \cdot (h_2 - l \cdot \mathrm{tg}\alpha) \cdot \cos\alpha) \cdot l \cdot b$

$$F_4 = \frac{1}{2}(p_2 - p_1) \cdot S_{c4} = \frac{1}{2} \cdot \gamma \cdot (h_2 \cdot \cos\alpha - h_1 \cdot \cos\alpha) \cdot l \cdot b$$

$$= \frac{1}{2} \cdot \gamma \cdot (h_2 \cdot \cos\alpha - (h_2 - l \cdot \mathrm{tg}\alpha) \cdot \cos\alpha) \cdot l \cdot b$$

The sum of the forces in the vertical direction is equal to the buoyancy force Acsimeter:

$$F_{asm} = -F_1 \cdot \sin\alpha + F_2 \cdot \sin\alpha + F \cdot \cos\alpha + F_4 \cdot \cos\alpha$$

The conditions to ensure safety when launching the caisson are:

- At the end of the ramp, the caisson is still on the trolley. The value of the moment about point A of the forces consisting of the self-weight of the caisson itself and the hydrostatic pressure F_1 must be greater than the moment due to the hydrostatic pressure F_2, F_3 and F_4:

$$(G \cdot \cos\alpha \cdot \frac{l}{2} + G \cdot \sin\alpha \cdot h_1 + F_1 \cdot \frac{h_1}{3}) > (F_2 \cdot \frac{h_2}{3} + F_3 \cdot \frac{l}{2} + F_4 \cdot \frac{2 \cdot l}{3})$$

Transform the above formula to get:

$$\begin{aligned}
&(G \cdot \cos\alpha \cdot \frac{l}{2} + G \cdot \sin\alpha \cdot (h_2 - l \cdot \mathrm{tg}\alpha) + \\
&+ (\frac{1}{2} \cdot \gamma \cdot (h_2 - l \cdot \mathrm{tg}\alpha) \cdot \cos\alpha \cdot (h_2 - l \cdot \mathrm{tg}\alpha) \cdot b) \cdot \frac{(h_2 - l \cdot \mathrm{tg}\alpha)}{3}) > \\
&> (\frac{1}{2} \cdot \gamma \cdot h_2 \cdot \cos\alpha \cdot h_2 \cdot b \cdot \frac{h_2}{3} + \frac{1}{2} \cdot \gamma \cdot (h_2 - l \cdot \mathrm{tg}\alpha) \cdot \cos\alpha) \cdot l \cdot b \cdot \frac{l}{2} + \\
&+ \frac{1}{2} \cdot \gamma \cdot (h_2 \cdot \cos\alpha - (h_2 - l \cdot \mathrm{tg}\alpha) \cdot \cos\alpha) \cdot l \cdot b \cdot \frac{2 \cdot l}{3})
\end{aligned}$$

- At the end of the ramp, the Acsimeter thrust (the sum of the forces in the vertical direction) plus the lifting force from the excavator placed on the floating barge, is equal to the weight of the caisson:

$$F_{asm} + F_N = G$$

$$\gamma \cdot \frac{\left(2 \cdot (\frac{H_n}{\cos\alpha} - c) - l \cdot \mathrm{tg}\alpha\right)}{2} \cdot b \cdot l + F_N = G \tag{5}$$

where F_N is the lifting force of the excavator placed on the floating barge.

- The maximum submerged depth of the caisson wall does not exceed the allowable value $[h_2]$:

$$h_2 = \frac{H_n}{\cos\alpha} - c \le [h_2] \tag{6}$$

where $[h_2] = h - \Delta h$ (7)

Δh is the distance from the edge of the water to the top of the caisson to ensure that water does not overflow into the caisson. This value Δh takes into account that there is no need to take the extra measure of attaching a float to the mouth of the caisson.

In addition to ensuring the above safety factors, the cost of installing ramps depends mainly on the length of the ramps flooded with water L due to difficult installation conditions, underwater construction is required, the value of L calculated according to the formula:

$$L = \frac{H_n}{\sin\alpha} \tag{8}$$

From the above expressions, it can be seen that the angle of inclination α of the ramp affects the values of the parameters when launching the submersible, and also affects the installation cost. The selection of suitable angle of inclination value α is quite complicated because it depends on many parameters. In the following, the author conducts a survey of the problem for the specific case of a caisson built in practice at a seaport project to illustrate the method of determining the appropriate angle of inclination α.

The angle of inclination α (or slope $i(\%)$) is selected according to the condition that the length of the ramp L under the water reaches the minimum value, while ensuring the safety of the caisson when launching.

4. Survey results

The object of the survey is a reinforced concrete caisson whose dimension in the direction of the slope is $l = 8.5$ m, the dimension in the cross-sectional dimension of the ramp is $b = 19.95$ m, height $h = 7.75$ m, self weight G = 950 T, applied to the actual construction of sea embankment works on Phu Quy island, Binh Thuan province.

According to (1), the draft of the caissons: $T = \dfrac{G}{b \cdot l \cdot \gamma} = \dfrac{950}{19.95 \cdot 8.5 \cdot 1} = 5.6$ m

To ensure safety, the bottom of the caisson does not touch the bottom of the sea when launching, choose a minimum water depth of 0.7 m deeper than the draft of the caisson, it means $\Delta H = 0.7$ m, and then the water depth is $H_n = 5.6 + 0.7 = 6.3$ m.

To prevent water from entering the caisson when the caisson is tilted at the end of the ramp, choose the distance from the edge of the water to the top of the caisson to be $\Delta h = 1.0$ m. The maximum allowable submerged wall depth is $[h_2] = h - \Delta h = 7.75 - 1 = 6.75$ m. Wheelchair height of the trolley $c = 0.3$ m.

Calculation results of the parameters when launching the caisson depends on the slope of the ramp according to the formulas (5), (6) are presented in the table below.

Tab. 1. Parameters when slope changes

Ordi-nal numb-er	Slo-pe	Slope length	Water depth	Maximum depth of water submerge-d outside the wall of the caisson	Moment of the force holding the caisson on the cart about point A	Moments of buoyant thrusts the caisson about point A	Acsimet buoyancy force (the sum of the forces in the vertical direction)	Lifting force of excava tor is on barge
0	%	L, m	H_n, m	h_2, m	M_g, kN.m	M_d, kN.m	F_{asm}, kN	F_N, kN
1	1	630	6.30	6.003	47631	50245	10107	-607
2	2	315	6.30	6.004	47702	50043	10036	-536
3	3	210	6.30	6.005	47779	49843	9967	-467
4	4	158	6.30	6.007	47861	49646	9899	-399
5	5	126	6.30	6.010	47949	49450	9831	-331
6	6	105	6.30	6.014	48040	49257	9765	-265
7	7	90	6.30	6.018	48136	49065	9700	-200
8	8	79	6.30	6.022	48236	48876	9636	-136
9	9	70	6.30	6.028	48339	48689	9573	-73
10	10	63	6.30	6.034	48446	48504	9511	-11
11	11	57	6.30	6.040	48556	48322	9450	50
12	12	53	6.30	6.047	48668	48142	9390	110

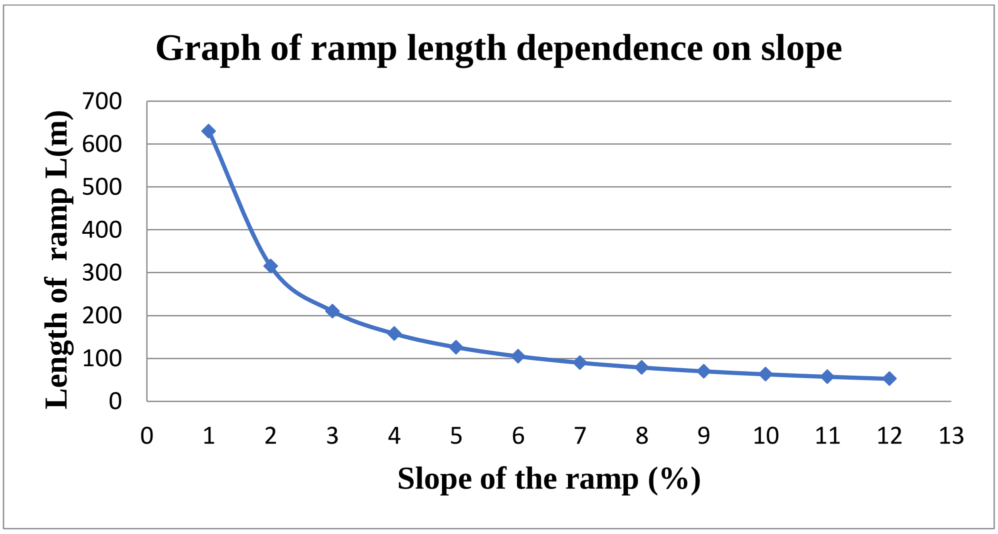

Fig. 4. Change of slope length under water when slope changes.

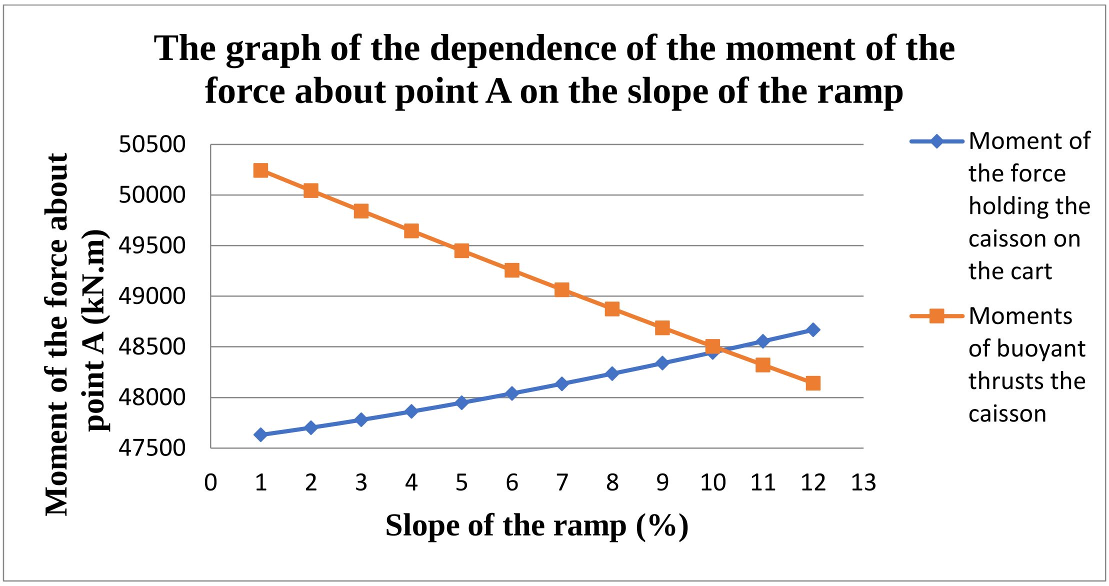

Fig. 5. Variation of moment of the force about point A when slope changes.

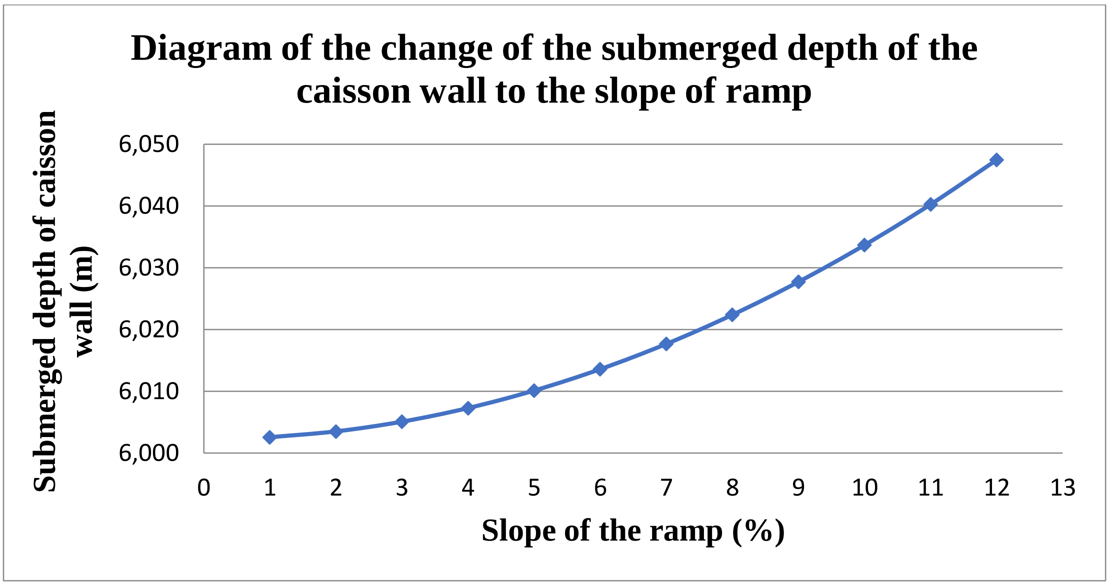

Fig. 6. Change of the submerged depth of the caisson wall when slope changes.

From the above diagrams, it can be seen that for a fixed water depth, as the slope increases, the ramp length decreases, thereby allowing the cost of ramp installation to be reduced. However, when the slope is increased, the thrust force of Acsimeter decreases, which will affect the self-floating condition of the caisson at the end of the ramp. And when the slope increases, the maximum submerged wall depth also increases, affecting the safety against water overflowing into the caisson. Therefore, in order to optimize, it is necessary to choose the slope of the ramp so that the cost of installing the ramp is minimal, but still ensuring the condition of self-floating of the caisson when at the end of the ramp, ensuring that water does not overflow into the caisson.

In the specific case of a caisson with the above dimensions, the water depth is $H_n = 6.4$ m, in order to make sure the caisson floats on water when it is still on the trolley at the end of the ramp, then the Acsimeter buoyancy force plus the lifting force from the excavator placed on the floating barge needs to be greater than or equal to the weight of the caisson, i.e. $F_{asm} + F_N \geq 9500$ kN, then the slope of the ramp should not less than 11%. Furthermore, the submerged depth of the wall of caisson is $h_2 = 6.04$ m, less than the allowed value is $[h_2] = 6.75$ m. From there, the slope $i = 11\%$ is a reasonable slope, ensuring the condition of self-floating of the caisson and satisfying the condition that the ramp length reaches the minimum value. Select the slope $i = 11\%$ to lauch the caisson in practice.

Some pictures of applying the above optimal slope determination method to the actual construction of sea embankments at Phu Quy island, Binh Thuan province are shown in Figures 7, 8. The process of launching the submerged caisson on the ramp is safe. In actual construction, the time to move the caisson on the ramp about 50 m long is about 1h, i.e. the speed $v = 50$ m/h (converted to $v = 0.8$ m/min or $v = 0.014$ m/s). This is a very very small velocity, which can be considered as causing negligible hydrodynamic effects.

Fig. 7. Launching the caisson on the ramp.

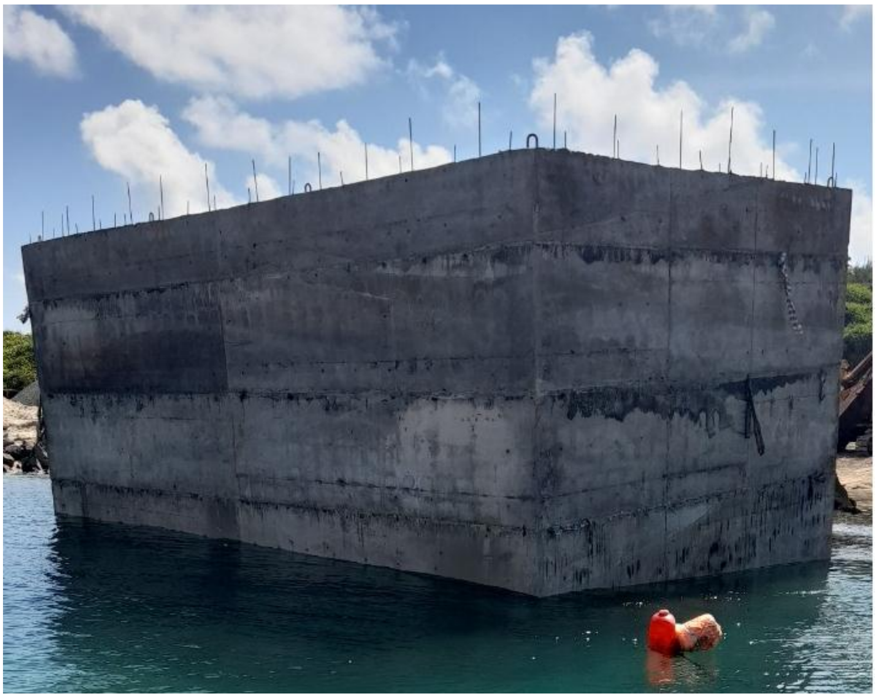

Fig. 8. Caisson when partially submerged in water.

5. Conclusion

From the above study, it can be concluded that the slope of the ramp is an important parameter that greatly affects the construction cost as well as the safety of launching. The reasonable slope of the ramp is determined by finding the slope where the length of the ramp line is the shortest in water, and at the same time, it ensures two safety conditions when launching: the caisson is still on the trolley, the caisson is floating in the water by Acsimeter force plus lifting force from the excavator placed on the float barge, and the wall of the caisson is not submerged in water.

The above calculation results have been applied to the actual construction, which is the initial basis to confirm the correctness of the method of choosing the optimal slope of the ramp when launching the caisson. Thereby saving costs, ensuring safety during construction. This is practical experience that can be used as a reference for units operating in the field of seaport construction, especially seaports using reinforced concrete caissons. Because this is a relatively new issue, there are not many documents mentioned. The authors hope to be able to discuss these issues with colleagues in order to continue to study more deeply and completely.

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XÁC ĐỊNH ĐỘ DỐC PHÙ HỢP CỦA ĐƯỜNG TRIỀN HẠ THỦY THÙNG CHÌM BÊ TÔNG CỐT THÉP

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Tóm tắt: *Bài báo trình bày việc nghiên cứu khảo sát sự phụ thuộc của một số tham số vào độ dốc đường triền khi hạ thủy thùng chìm trong thi công công trình kè biển. Từ đó đề xuất phương pháp xác định độ dốc đường triền hợp lý bằng ví dụ minh họa. Kết quả xác định độ dốc phù hợp này đã được áp dụng trong thực tế thi công, đảm bảo tính an toàn và hiệu quả.*

Từ khóa: Thùng chìm; đường triền; độ dốc; hạ thủy; mớn nước.

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