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Analysis of Concrete Cracks and damage on Base Slab of Caissons at the Manufacturing Stage taking into account the Settlements of the Backfill and the IP-CCVs

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ABSTRACT

The objective of this article is to analyze the causes and the state of the damaged parts of the caissons during their embarkation on the floating dock, as part of the realization of the new container terminal project at the Djen Djen Port, in Jijel province in Algeria, and to take the necessary measures for the repair and prevention of any recurrence. On the workshop site, following the displacement from the sliding formwork station to the curing station, the appearance of cracks in the base slab of the fifth caisson was observed, with the same characteristics as the cracks that occurred on the base of the previous caissons. We have studied this phenomenon and make analysis with the observations, the explanation and the measures to be taken in order to prevent the repetition of this problem, because the topographic verification of the leveling of the workshop platform stations and the backfill settlement verification of the same platform are carried out with good results; in contrast with the differential settlement of the IP-CCVs, which was shown to be the only reason for the appearance of surface cracks on the base slab of the caissons. Nevertheless, we examined once again the arrangement of their reinforcements, which had confirmed that there was no problem for the reinforcements applied to the caissons, and clarified by a numerical modeling that there is no structural problem. Therefore, we suggest repairing the damages caused to the caissons on the floating dock before they are launched and before proceeding with their installation in the quay wall.

Keywords: Caissons, Cracks, Gantry House, Embankment, IP-CCV, Settlement.

DISCOVERY
SCIENTIFIC SOCIETY

1. INTRODUCTION

Maritime structures are more difficult to build because they depend on several factors that must be respected [1], So the knowledge of these requirements is obliged to this domain. When building a structure it is important to determine which methodologies are applied to each element of the structure [2,3]. When we want to make the choice of a wharf profile; it is necessary to taking into account the absorbing effect of the wall profile, the structural stability, the reduction of the execution time and the minimization of the risk of inconvenience for the exploitation of the existing piers or wharves during construction [4]. The dike is constituted by blocks or caissons made of reinforced concrete which, by their own weight, resist to the forces imposed by the swell and ships [5]: they must therefore be of large dimensions to be sufficiently heavy.

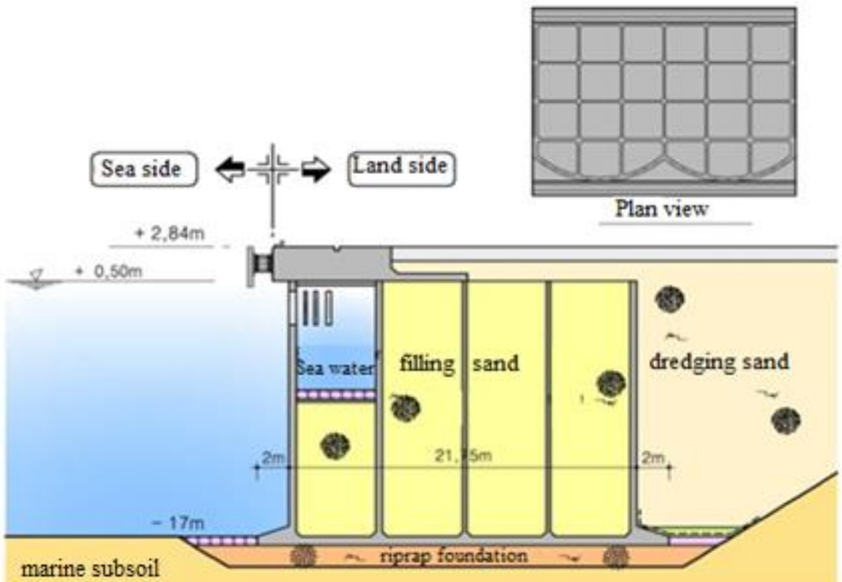

Figure 1: Slotted caissons on curved surfaces [9].

The caisson-type wharf wall (quay wall structure) is a typical gravity structure which supports by the weight of the caissons the thrust of the embankments, the loads of the cranes and the vertical load of the superstructure [6, 3]. This is the most used structure for large tonnage container terminals. The specifications of the caissons are determined taking into consideration the capacity of the marine equipment, the caissons manufacturing time and constructability of superstructures [4,7,8]. To reduce the wave swell and prevent secondary corrugation, it is contemplated to give a curve shape to the frontal walls of the caissons and longitudinal slots (figure 1), in order to maximize the absorbing effect [10,11].

The main materials needed to carry out the construction of a caisson are the concrete, reinforcements and filters [12]. These materials will be controlled according to construction standards, which will be used after obtaining approval from the quality assurance requirements. The characteristics of cracks are the most critical factors affecting its mechanical properties of the concrete structure. Cracks are usually the weakest part of concrete structures, once they expand; the structural masses would be in rupture mode, which in turn would trigger structural catastrophes, which also may affect the quay wall stability. At present, there is little systematic research on the impact of cracks and ruptures during the manufacturing phases on the structural properties of caissons.

The purpose of this article is to present the causes of caissons damage and follow up surface cracks to repair them according to the caissons manufacturing specifications. This study describes the evolution of different widths and lengths of cracks in the base slab of caissons that must be checked. It was made with the aim of obtaining maximum capacity to meet the needs of high quality manufacturing from the first step to installation in the quay wall.

2. THE CAISSONS FABRICATION WORKSHOP WITH SLIDING FORMWORK (SLIP FORM) SYSTEM

About the method for manufacturing and lifting of caissons, slip-forms (sliding formwork), the IP-CCV system and the floating dock will be used to allow the construction of a one caisson every seven days (figure 2), in fourth (04) steps by the following procedure:

- Soffit form installation,
- Spread out of the vinyl film on the bottom,
- Assembly of the slab reinforcements,
- Installation of the water stop strips on the base slab,

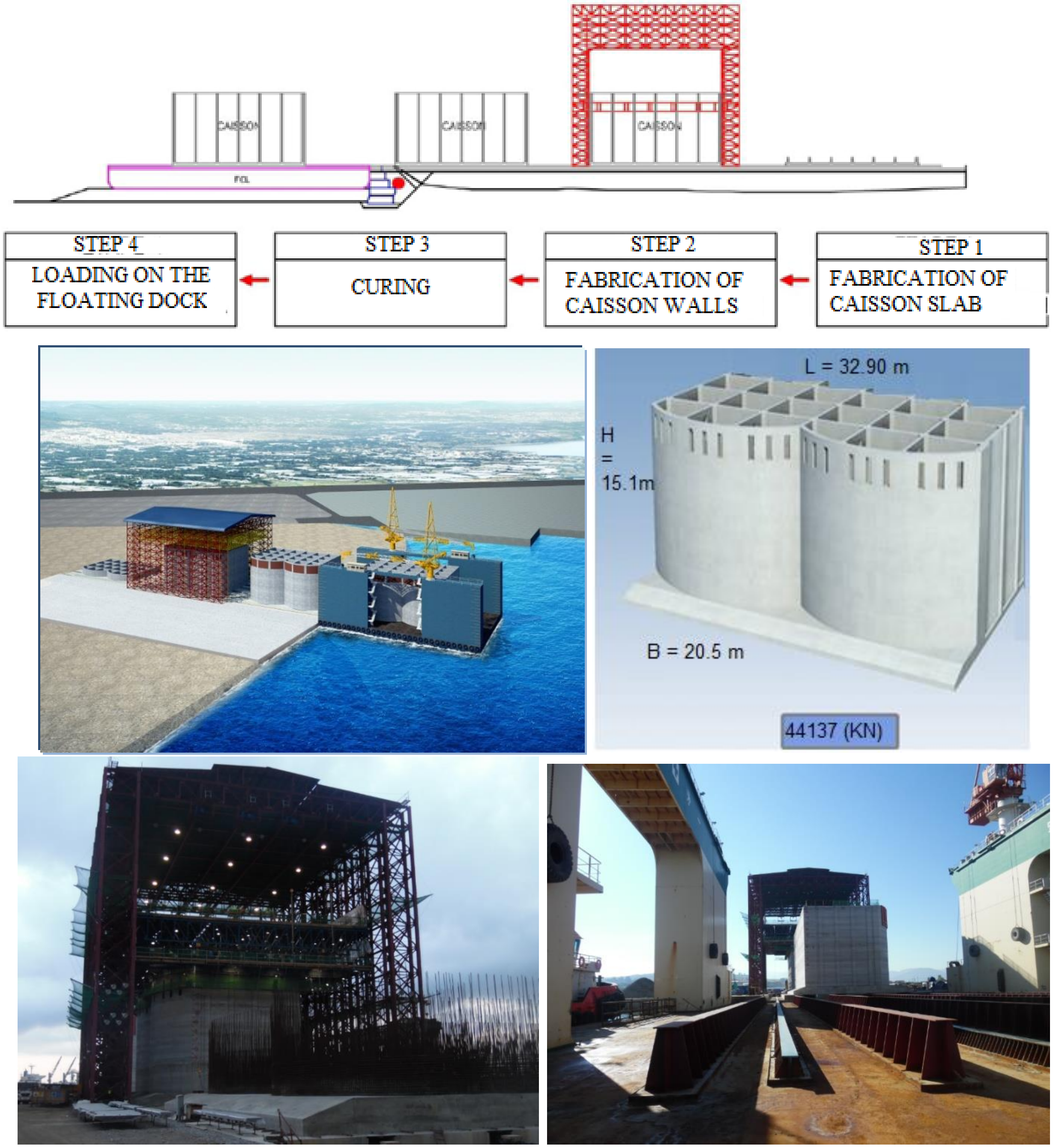

Figure 2: The caisson fabrication workshop Sequence of concrete pouring, and the fabrication procedure of caissons.

- Installation of the formwork (inside and outside reinforcements),
- Pouring of the slab concrete,
- Exterior finishing,
- Treatment and dismantling,
- Transfer (step 1 to step 2),
- Lowering and setting slip-form,
- Assembly of the reinforcements of the walls,

- Pouring concrete of the walls,
- Lifting sliding formwork (slip-form),
- Transfer to the curing step (step 2 to step 3),
- Loading the caisson on the floating dock.

2.1. IP-CCV Transfer System:

An Individual Pushing Caisson Carrier Vehicle (IP-CCV) can support and carry a heavy structure (figure 3). Each IP-CCV can lift 250 tons and carry its load along a therefore designed transfer lane. The IP-CCV was originally developed for the purpose of moving large concrete caissons weighing up to 7000 tons, but IP-CCVs may be combined in different configurations for other heavy loads, such as bridge sections etc. Lifting power is provided by two lifting jacks (1) sitting on a base plate (sliding foot). The base plate (2) has low friction pads attached underneath for sliding on the transfer lane's steel track. When not under load the IP-CCV rests on four spring loaded wheels (3) for easy relocation along the transfer lane. The pushing jack has two 12,5 ton cylinders (4). A grip head (5) has jaws gripping on a steel track mounted on the transfer lane. The 250 ton lifting capacity is provided by two hydraulic jacks with a capacity of 125 ton each. The IP-CCV's two lifting jacks communicate in a common hydraulic system for load equalization. The top of each jack has a ball and socket to allow slight angle deviation from uneven underside of load. A pyramid also sits on top of each jack to reduce the pressure on the bottom of the lifted object [13].

Figure 3: IP-CCV Transfer System.

2.2. Characteristics:

The main characteristics of this type of manufacturing caissons are:
- Good absorbent effect thanks to perforated slots.
- Good preventive effect of swell waves and secondary ripple (corrugating) thanks to the curved shape.
- Possibility to minimize the size of the production site.
- The shortest manufacturing time of the caissons.
- Minimizing the risk of hindering the operation of existing quays by minimizing the size of the production site.
- Low settlement in case of earthquake, prevention of sand loss at the back of the wharf (quay walls).

3. STATE OF THE DAMAGES

Following the need for a hydraulic concrete composition suitable to the requirements of the project, various tests were carried out on 15/25, 8/15 and 3/8 aggregates, as well as on the two sands (marine sand SM 65%, 35% SC quarry sand) which is used as a basis for the preparation of the concrete composition B32 / 1 within the framework of the project (tables 1), and in order to prevent any possible breakage.

Table 1: Characteristics of Caisson concerned by the study and Concrete design (B32/1' with 0,7 % adjuvant) Design Proportion; E/C : 0.40 , G/S :1,62 , Adjuvant : 0,7%.

Designation	**Desired Resistance (Mpa)**		**Type of cement**	**E/C**	**G/S**	**Weight dosage for 1 m3 of concrete (Kg/ m3)**						**Adjuvant dosage (Sika viscocrete 3045)**		**Slump (mm)**
	Fc28	Fc				Ciment	Sable	G15/25	G8/15	G3/8	Eau L/m3	%	L/m3	
B32/1 385 Kg/m3	40	46	CPJ CEM II/B-S 42.5 NES	0.4	1.62	385	740	532	491	176	154	0.7	2.7	180

3.1. Concrete damage

There was damage to the caisson when boarding the floating dock as in figure (4). The size is approximately 80cm X 60cm. Since this damage only occurred in part of the corner of the caisson's slab (figure 4 a), it can be repaired by stitching and concreting (Micro-concrete). The objective is to analyze the causes and the state of the damaged parts of the caissons (Figure 5 to 9) during the loading of the caissons on the floating dock from the step of the base slab, step of slip-form and step of curing, in order to take measurements necessary for the repair and prevention of recurrence.

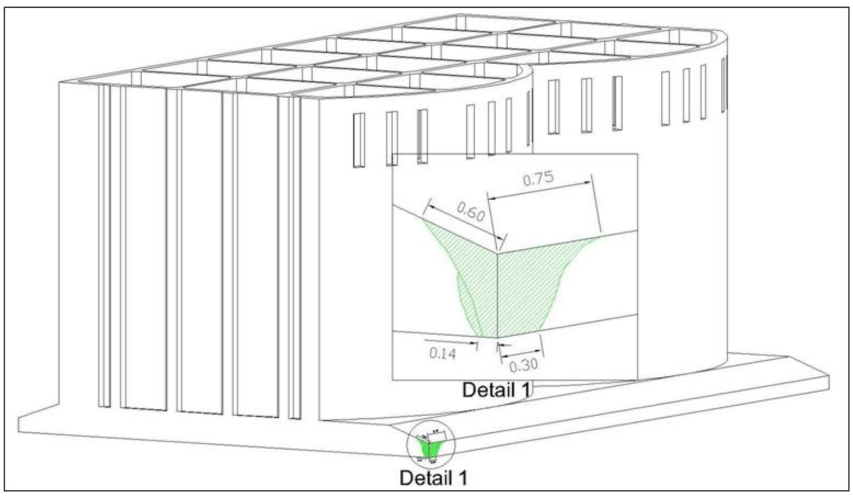

Figure 4: (a) State of the damaged part.

Figure 4: (b) Photographs and details of the damage of a caisson when boarding floating dock (size is about 80cm x 60cm) Since this damage occurred only in part of the corner of the caisson, it is repairable by the chipping and concrete (Micro concrete).

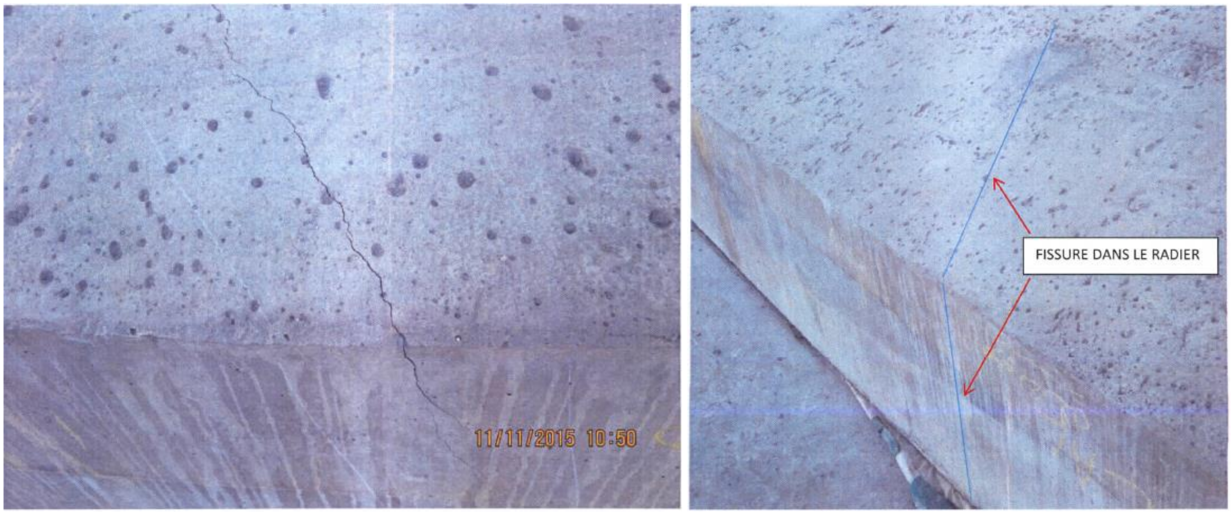

Figure 4: (c) Photographs of the cracks of the caissons' slab.

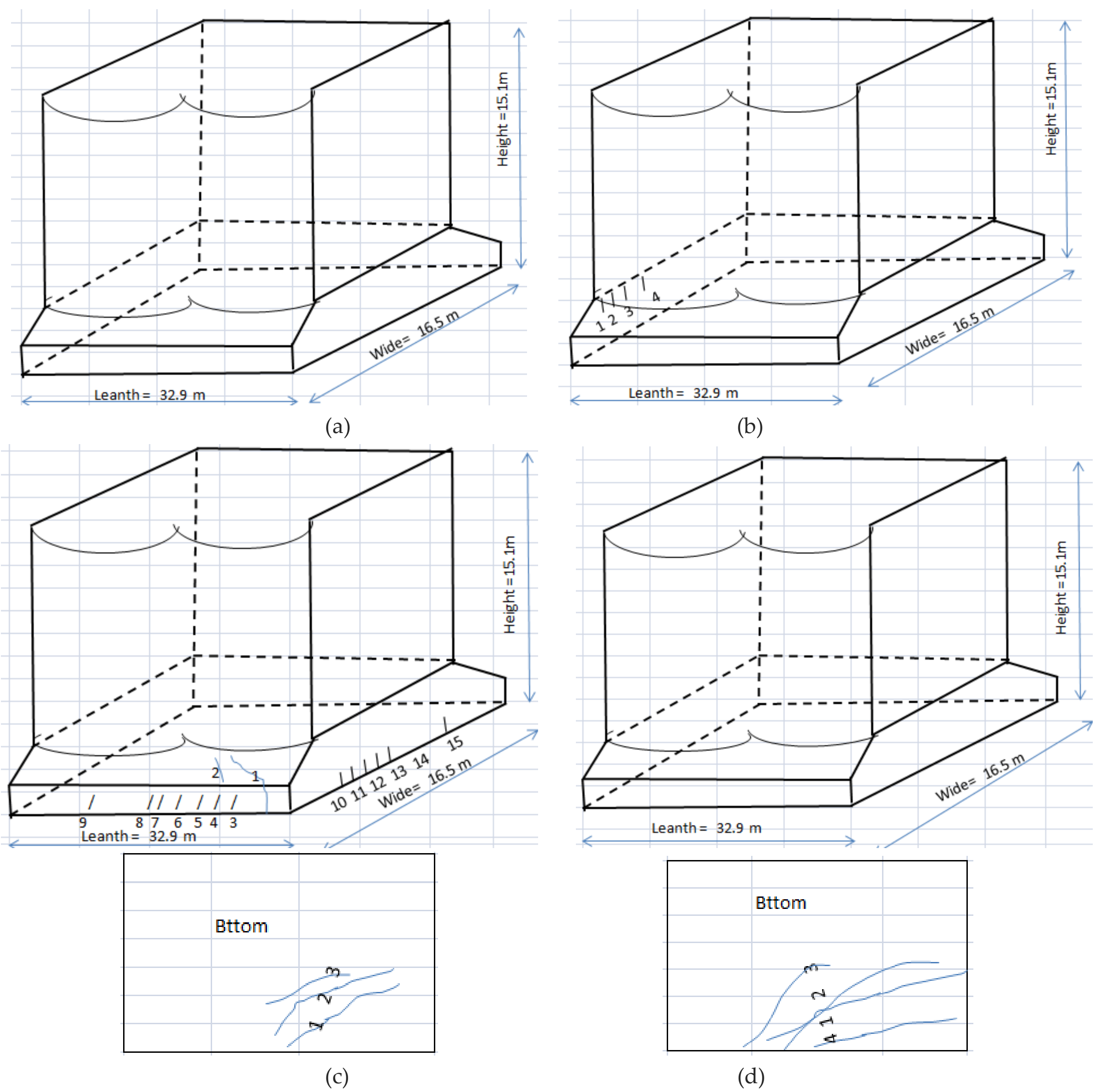

Figure 5: Checking the cracks of the caisson N°1; (a) step 1 (slab), (b) step 2 (wall), (c) step 3 (curing), (d) step 4 (on floating dock).

We can notice the appearance of four to fifth cracks on the left side parts of the caissons' slab after the start of manufacture of its walls with the exception of the second caisson (N°2) which showed two cracks on the foot of the caisson, and for the third (N°3) and fourth (N°4) caissons, which appear a superficial shrinkage of its concrete on the foot of the caisson, but most of the cracks appear after moving the caissons from fabrication of caisson walls area (step 2) to the curing area (step 3), where these cracks reach down to the bottom of the caissons' slab. It has also been shown that an increase in the length of some of the existing cracks, some of which may reach the top face of the caissons slab (figure 8), without any new cracks occurring during transfer from the curing area (Step 3) to the floating dock (Step 4).

We can notice that all the cracks are apparent with the beginning of the manufacture of the walls of the caissons (Step 2); this indicates that the cracks are not due to poor concrete quality or a concrete formulation (Design) that does not meet the necessary requirements.

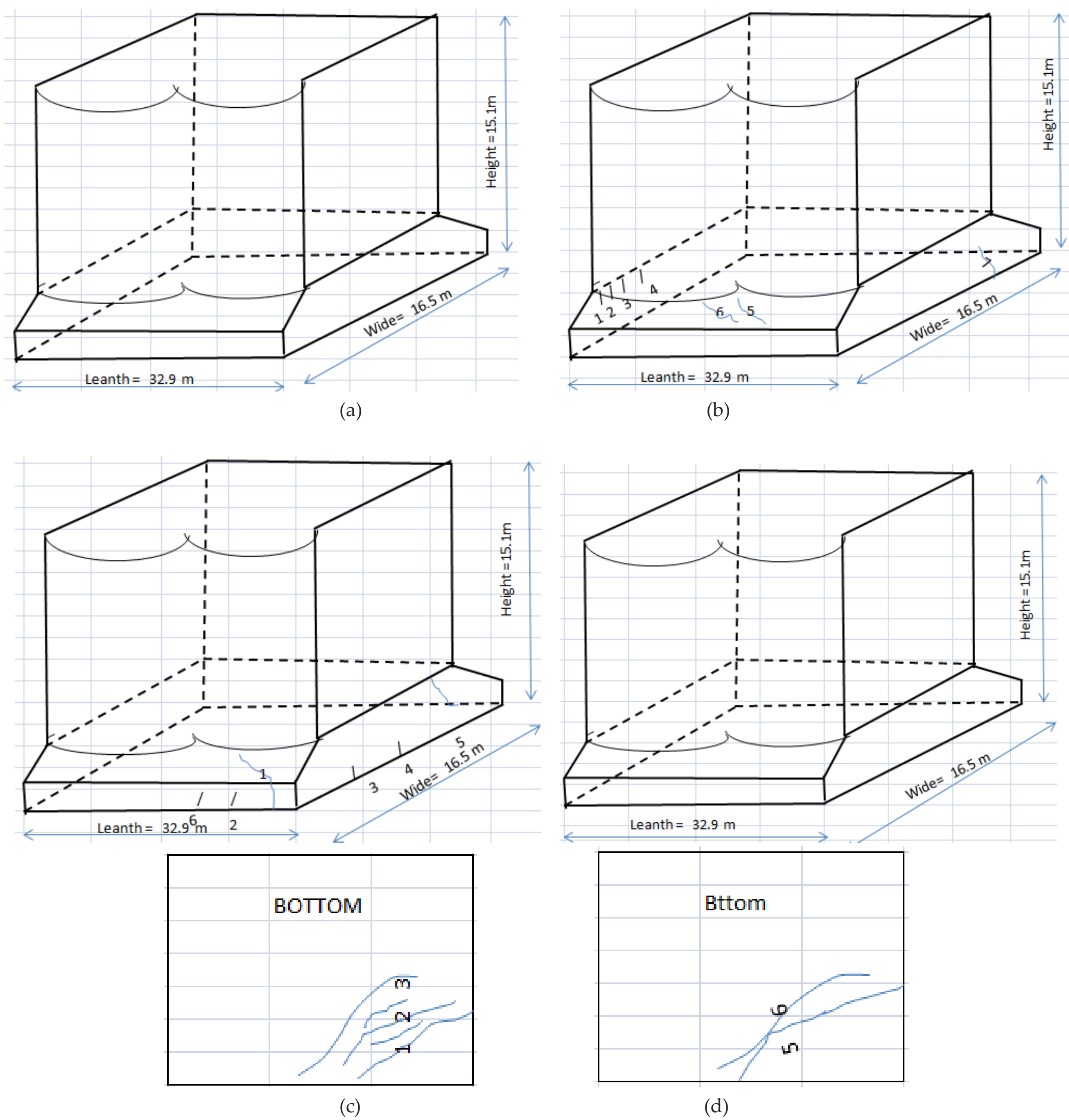

Figure 6: Checking the cracks of the caisson N°2; (a) step 1 (slab), (b) step 2 (wall), (c) step 3 (curing), (d) step 4 (on floating dock).

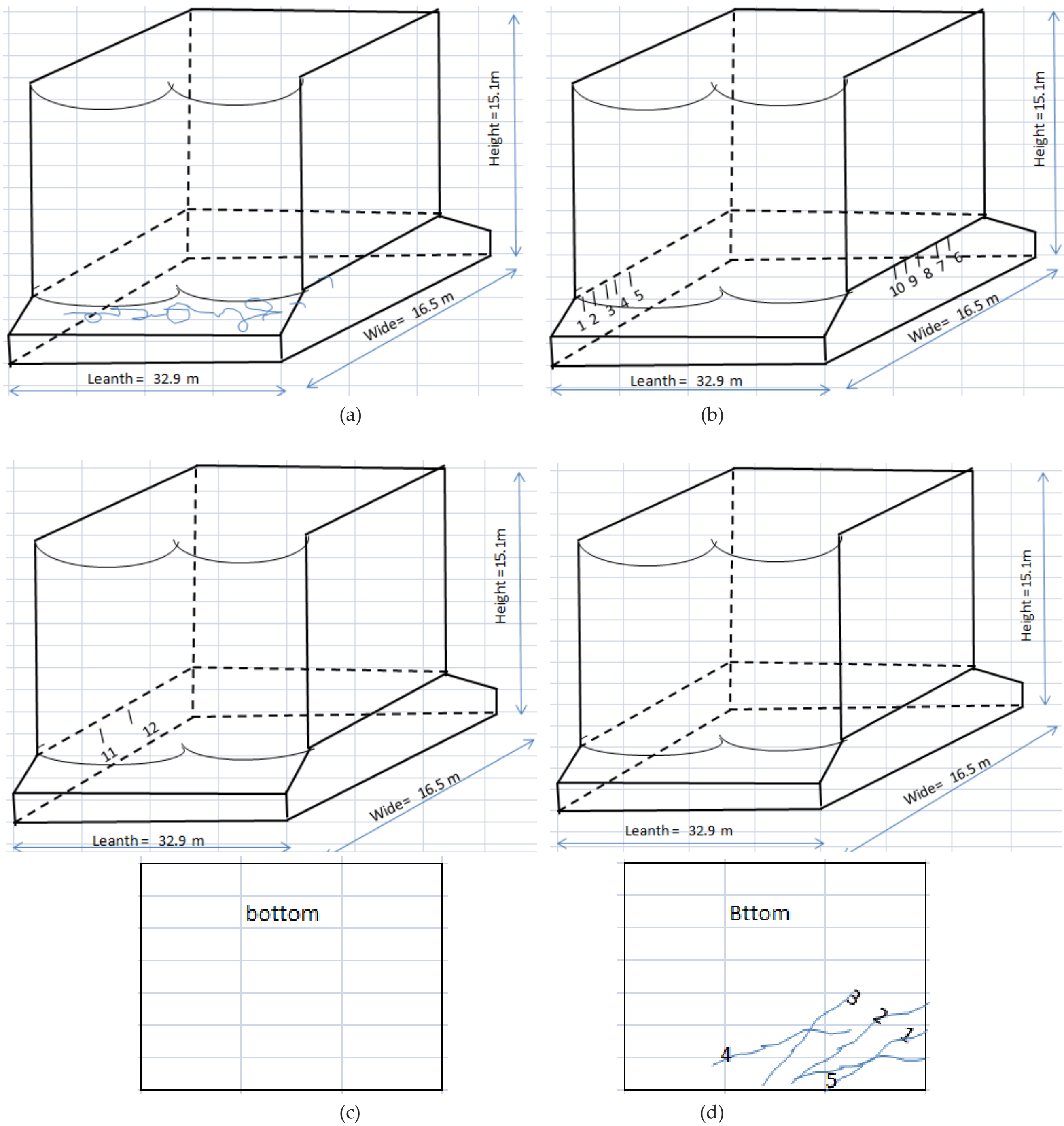

Figure 7: Checking the cracks of the caisson N°3; (a) step 1 (slab), (b) step 2 (wall), (c) step 3 (curing), (d) step 4 (on floating dock).

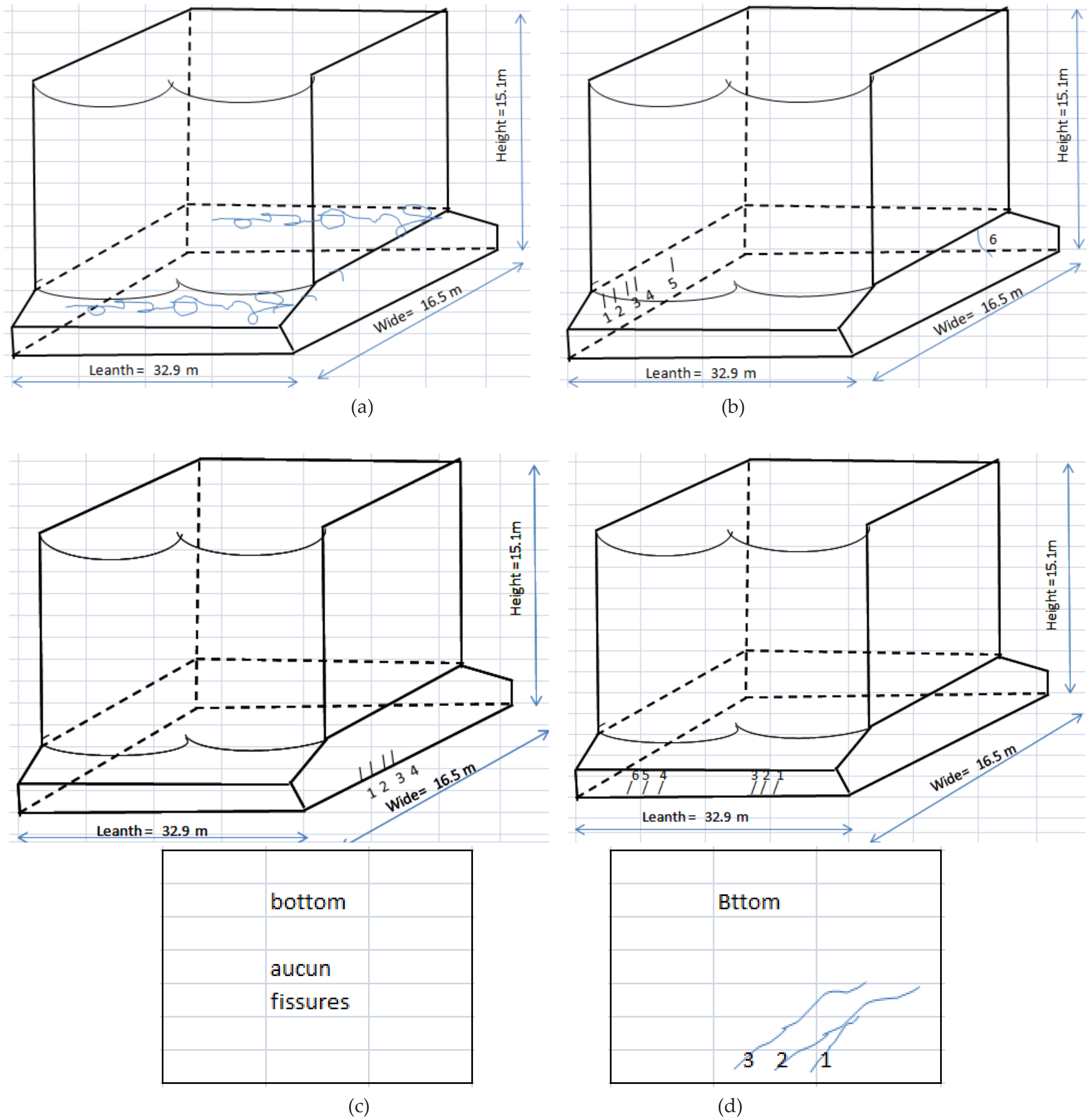

Figure 8: Checking the cracks of the caisson N°4; (a) step 1 (slab), (b) step 2 (wall), (c) step 3 (curing), (d) step 4 (on floating dock).

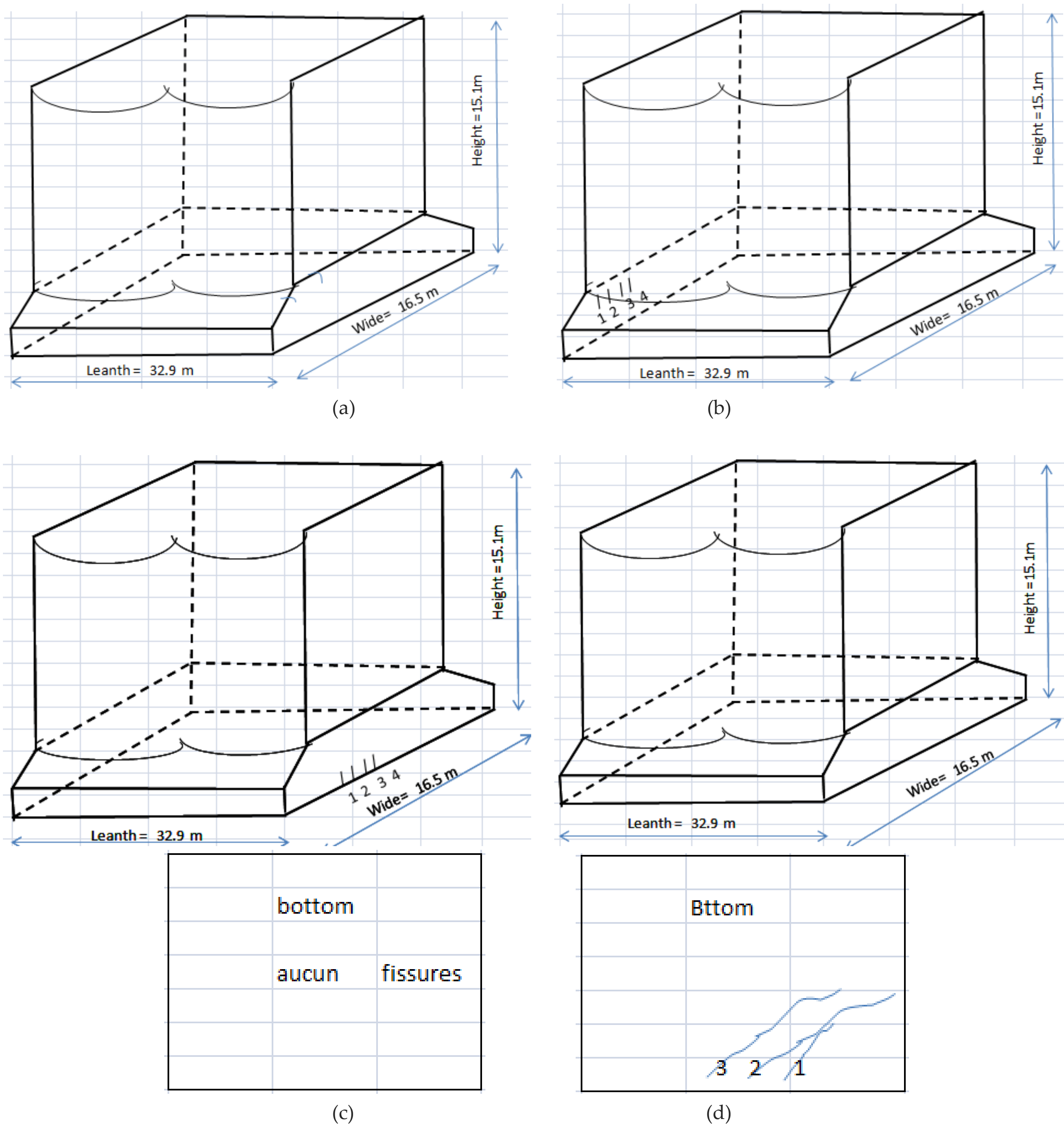

Figure 9: Checking the cracks of the caisson N°5; (a) step 1 (slab), (b) step 2 (wall), (c) step 3 (curing), (d) step 4 (on floating dock).

The Cracks 1, 2, 3 and 4 (figure 10) are the first that they appear in Step 2 with lengths of 60 cm, 85 cm, 50 cm and 80 cm and widths of 0.1 mm, 0.2 mm, 0.35 mm and 0.2 mm respectively. In Step 3 there is an evolution of the crack (1) up to 350 cm in length and 1 mm in width, and of the crack (2) up to 120 cm in length and 0.3 mm in width, With the appearance of new ten (10) cracks (5, 6, 7, 8, 9, 10, 11, 12, 13 and 14) with a maximum length of 80 cm and a maximum width of 0.4 mm. A large increase of the widths of cracks 1 (700 cm), 2 (440 cm), 3 (350 cm), 4 (300 cm), 5 (400 cm) and 6 (350 cm) in Step 4 is remarkable, unlike cracks 7, 8, 9, 10, 11, 12, 13 and 14 that they remain with the same widths, therefore; its widths remain stable except cracks 4 and 5 increase to 0.3 and 0.5 respectively.

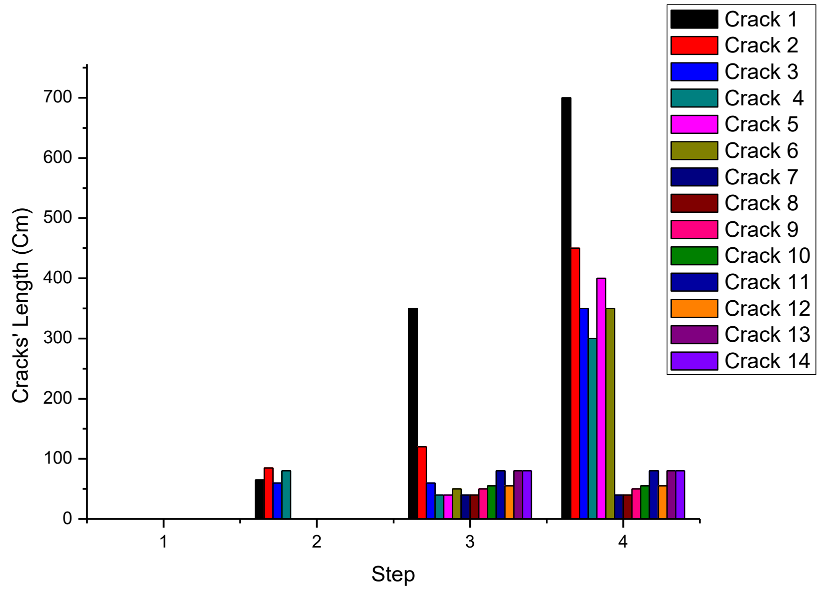

Figure 10: (a) Length of the Cracks.

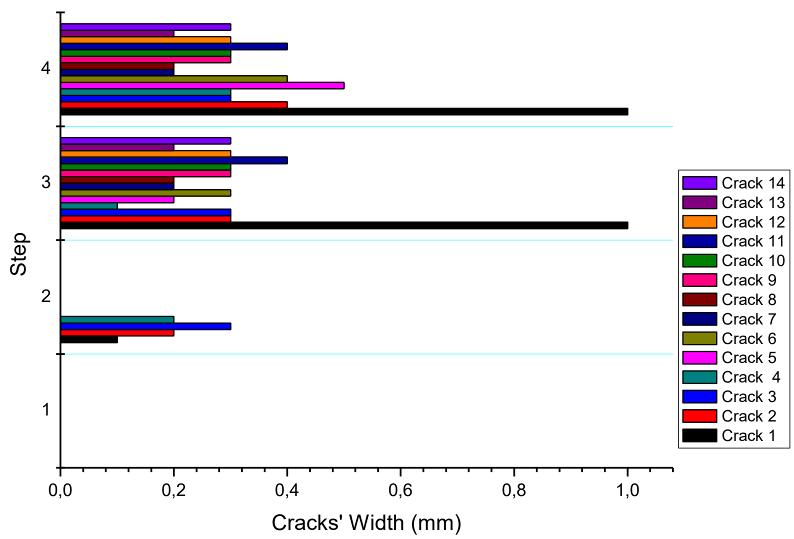

Figure 10: (b) Width of the Cracks.

This cracks conduct us to check their causes, so, we start with checking settlements of the workshop embankment. Figure (11) shows that there are four (04) lines at a length of 112 m and a width of 38 m of the platform already monitored between August 2015 and June 2017, which show a maximum settlement of 25 mm in a period of two (02) years, as well as the curves settlement have stabilized since May 2015, and that the maximum difference between the first line (L1) and the fourth line (L4) is 12 mm, so these amounts of settlements cannot be a problem, so they are considered as negligible quantities, especially considering the enormous dimensions of the caissons (figure 2).

Consequently; the results are perfectly satisfactory, no soil settlement was observed and no geotechnical problem was encountered [14], which compelled us to start monitoring a concrete platform of 1.75 m thick on the compacted backfill (figure 12 a), in order to verify its influence on the cracking of the caissons.

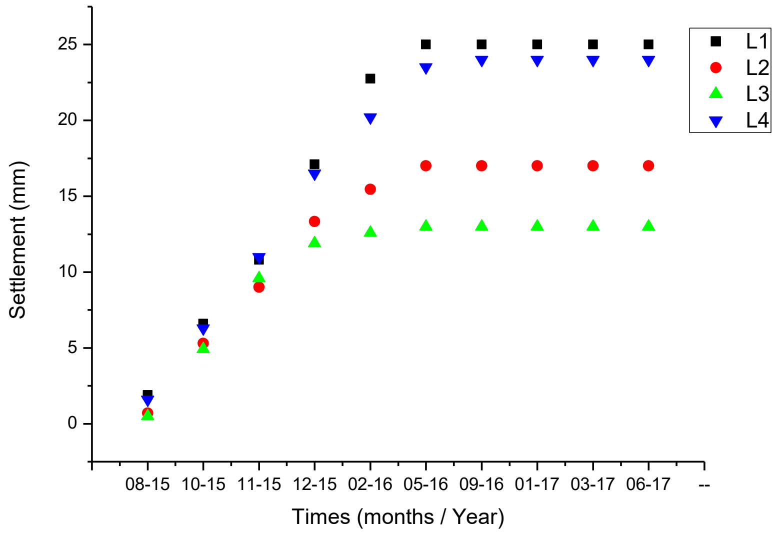

Figure 11: The results of the settlement of four (04) lines monitoring of caisson's workshop after platform implementation.

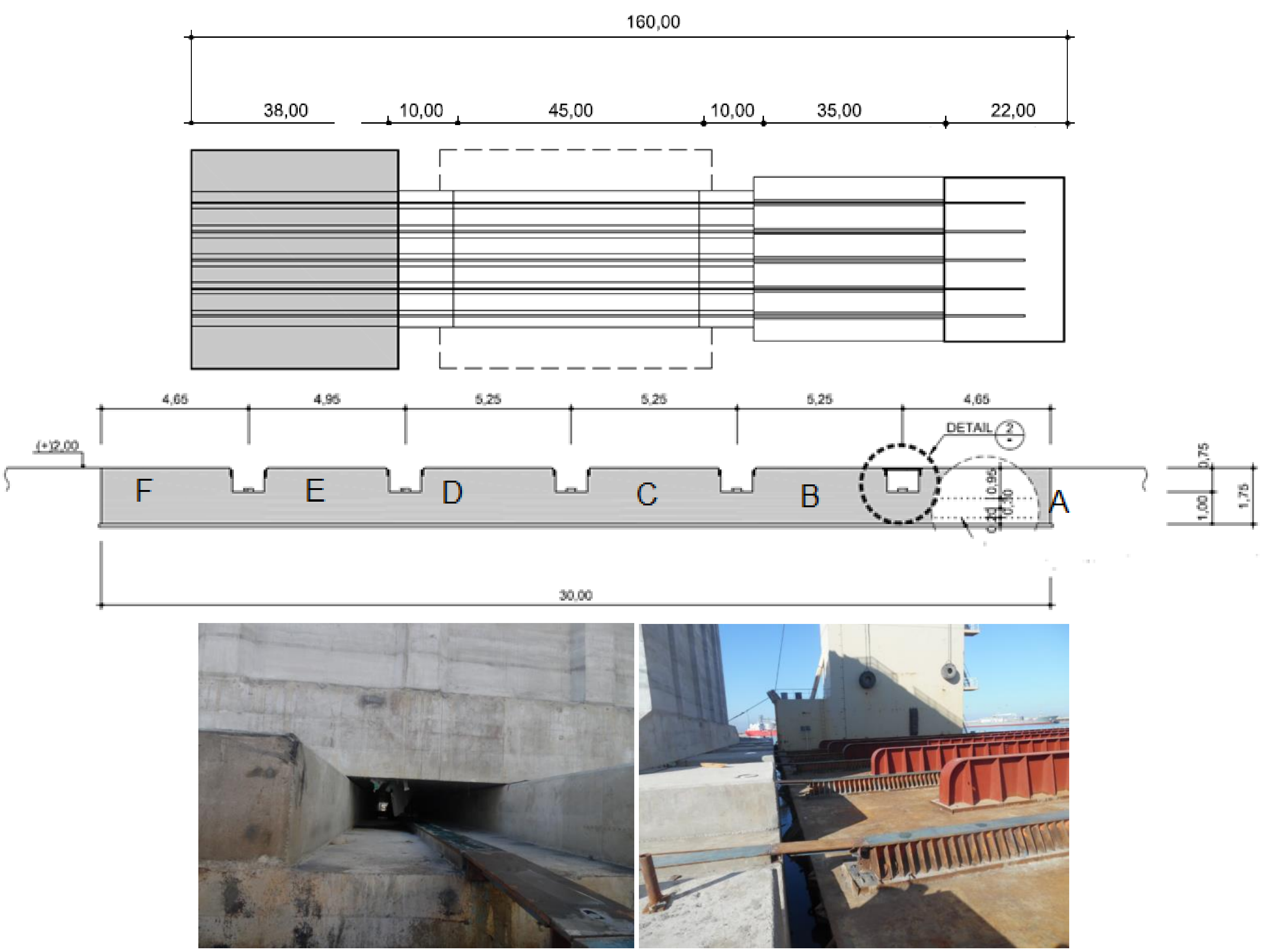

Figure 12 a: Platform of caisson manufacturing workshop.

The reinforced concrete platform of the curing station (Step3), at a length of 38 m and a width of 30 m, was monitored in order to define the difference in the vertical warp along the third station (Step 3) between the six Pistes/ Tracks (A, B, C, D, E and F) forming the 1.75 m high platform, with 3 m for each track/ piste (figure 12a), in order to know the possibility of its impact on the cracks that occurred. Therefore, we arranged the measurements in a precise manner that includes all the pistes from its beginning to its end with a longitudinal spacing of about 2.5 m, in the sides and middle of each piste with distance of 1m between each transversal measured point. By taking into account that the landmark of designed vertical concrete surface is +/- 2 m (figure 12b), It can be observed in the left side of the piste A, that the maximum vertical warps are - 4mm, -5mm and -8mm along the piste's distance of 15m, 20m and 22.5m respectively. In the middle of the piste B; the maximum vertical warps are +4mm, -5mm and -5mm along the piste's distance of 25m, 30m and 32.5m respectively. In the middle of the piste C; the maximum vertical warps are -4mm, -5mm, -7mm, -4mm, -4mm and -7mm along the piste's distance of 2.5m, 7.5m, 22.5m, 32.5m, 35m and 37.5m respectively. In the middle of the piste D; the maximum vertical warps are -7mm, -4mm, -7mm, +4mm and -5mm along the piste's distance of 12.5m, 15m, 17.5m, 25m and 37.5m respectively. In the middle of the piste E; the maximum vertical warps are +5mm, -5mm, -5mm, -5mm, -6mm and -9mm along the piste's distance of 2.5m, 5m, 12.5m, 15m, 32.5m and 37.5m respectively. Finally in the right side of the piste F; the maximum vertical warps are +4mm, -4mm, +6mm and +5mm along the piste's distance of 10m, 15m, 25m and 27.5m respectively. Consequently; these amounts of warp cannot be a problem, so they are considered as negligible quantities, especially considering the enormous dimensions of the caissons (figure 2) and the huge surface of the concrete platform itself.

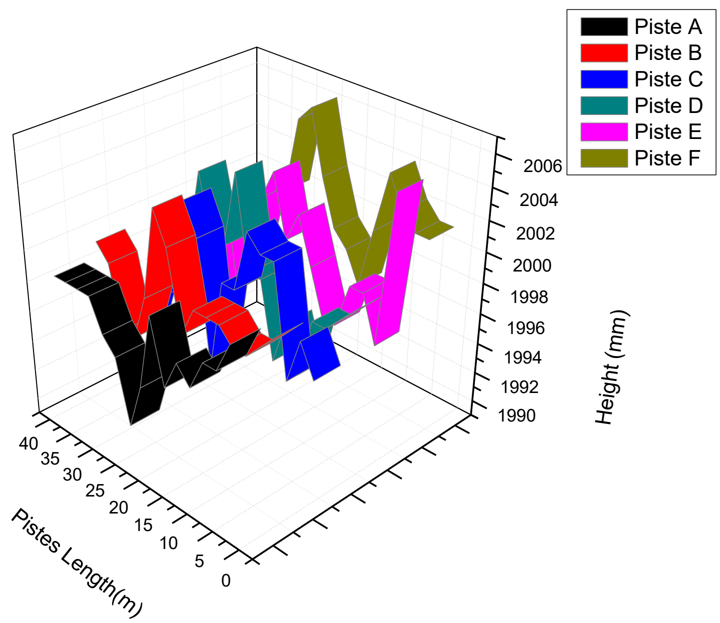

Figure 12 b: Monitoring results of the concrete warp of the 1.75 m thick platform.

3.2. Examination of the maximum reinforcement spacing at cracking:

The base slab reinforcements that join the wall are arranged as below (figure (13) for the layout of the base slab reinforcements). We examined the stability of the base slab against cracking, taking into account the spacing of the slab reinforcement between the vertical reinforcement of the wall.

3.2.1. Current state of disposition of the base slab reinforcement (direction of M11) and member force generated:

In figure (14) below, we can see the current state of the member force towards the direction of M11 of the base slab. Through the wall, this force decreases a lot in the base slab which joins the walls A, B, C, D. The real member force (in case of Service Limit State "SLS") generated in the base slab which joins the walls A, B, D is as follows:

- front wall (Wall-A), member force of the base slab towards direction M11: -159.50 kN • m.
- partition wall (Wall-B), member force of the base slab towards direction M11: -77.07 kN • m.
- rear wall (Wall-D), member force of the base slab towards direction M11: -12.10 kN • m.

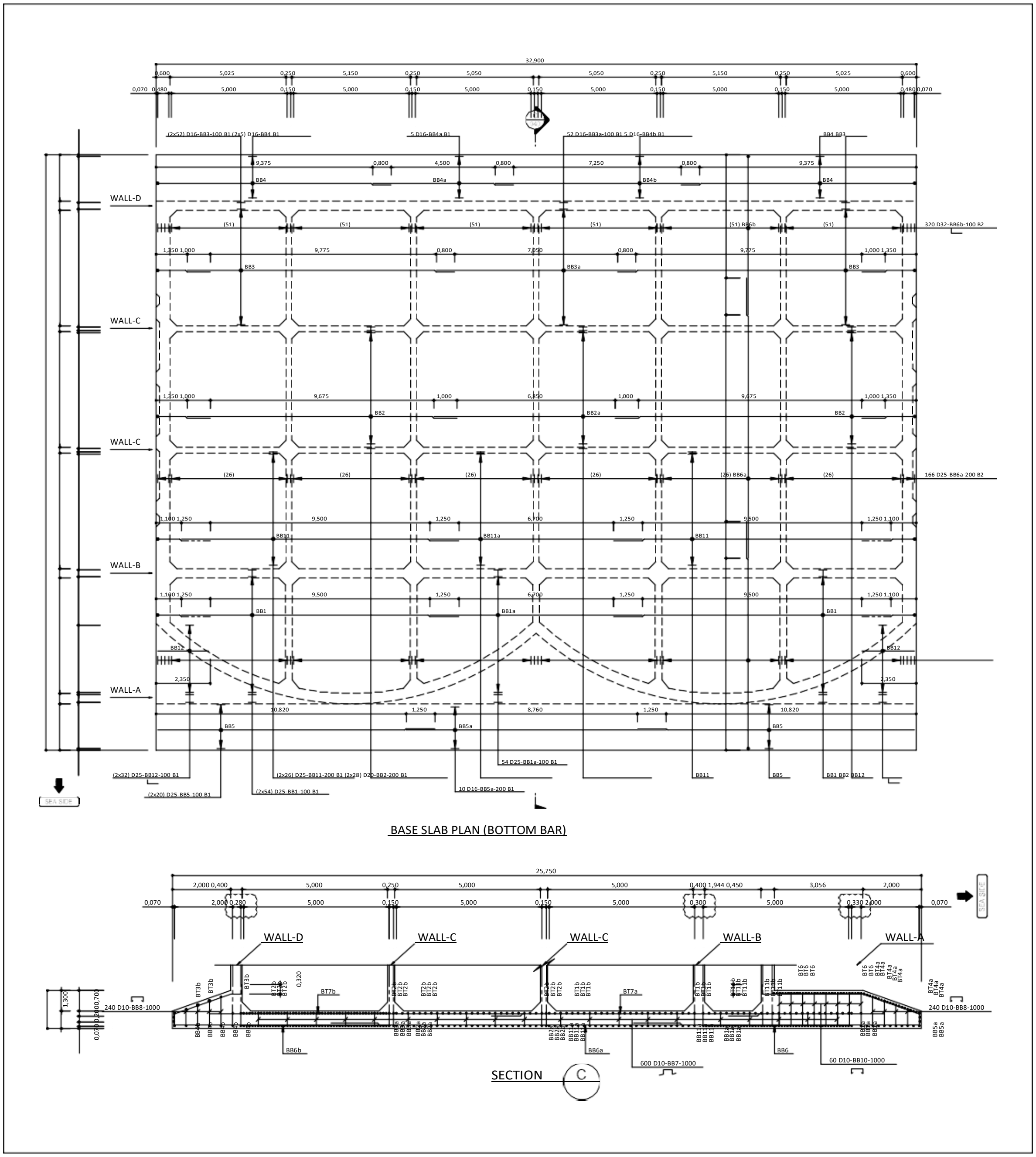

Figure 13: the layout of the base slab reinforcements.

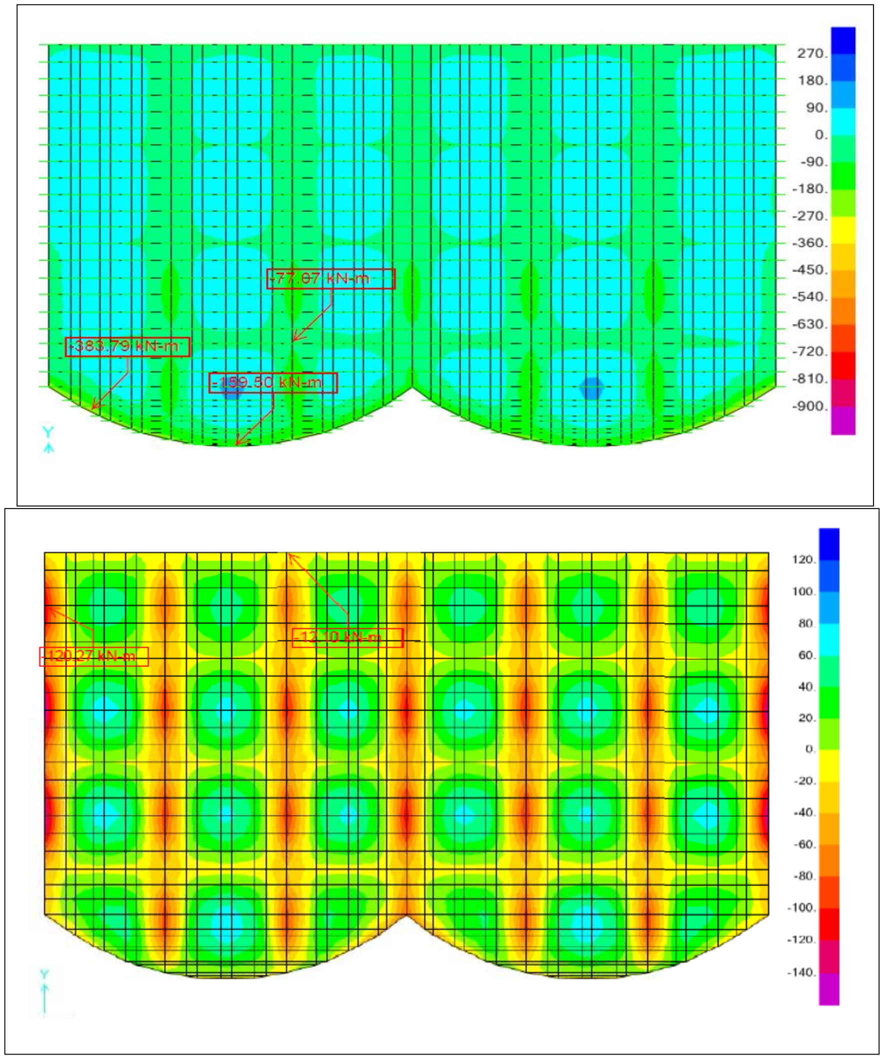

Figure 14:: the member force generated in the base slab (direction of M11) (SAP-2000), (a) when operating the quay walls (Service Limit State), (b) when caissons' floating stage (Service Limit State).

Regarding the base slab that joins the vertical wall (table 1), the profile examination of the base slab must include the wall, however, we examined the cracking with the application of the general profile of the base slab (H = 600mm).

Table 2: Member force applied to the calculation, Reinforcement applied and Current state of arrangement of the slab reinforcement.

Distinction		Cell	member force applied to calculation (SLS, kN·m)	Applied reinforcement	Spacing of reinforcement in the joint part of the wall	
Base slab reinforcements	M11 (direction)	Cell 1	–383.79	D25@100	front wall (WALL-A)	330 mm
		Cell 1	–383.79	D25@100	partition (WALL-B)	300 mm
		Cell 4	–120.27	D16@100	rear wall (WALL-D)	280 mm

According to 'Fig 7.2' of 'BS EN 1992-1-1: 2004_7.3.4 Calculation of Crack Widths' [15], for the calculation of the crack width, if the maximum spacing is in accordance with the standard (≤ 5x (cover + dia/2)), there will be no problem. The maximum reinforcement spacing for the cracking examination of the base slab is as follows:

maximum reinforcement spacing : 5 x (70 + 25/2) = 412.5 mm (for D25)
5 x (70 + 16/2) = 390.0 mm (for D16)

Therefore, since 330mm spacing for the front wall, 300mm spacing for the partition, 280mm spacing for the rear wall all comply with the maximum reinforcement spacing (412.5mm and 390.0mm), there is no problem for the spacing of the reinforcements (table 3).

Table 3: the result of the member force cracking examination of the base slab

Distinction		Position of the reinforcements	member force (SLS, kN·m)	Applied reinforcement	Crack width (mm)	Exam result
base slab reinforcements	M11 (direction)	front wall (WALL-A)	-159.50	D25, center, distance of 330	0.10	O.K
		partition (WALL-B)	-77.07	D25, center, distance of 300	0.08	O.K
		rear wall (WALL-D)	-12.10	D16, center, distance of 280	0.05	O.K

3.2.2. Cracking examination on the member force of the base slab at the workshop cure station:

Concerning the resistance of the concrete at the stage of the curing station (Step3), we apply the resistance at 9 days (Concrete resistance at 9 days = 27.04 MPa) taking into account the manufacture and the curing of the caisson: 6 days for the stop and the base slab and 3 days for the wall (9.0m) [16]. For the rest of the wall (7.8m), the load is applied, See figure (15a) below for the concept of the examination on the walls' manufacturing station (step 2).

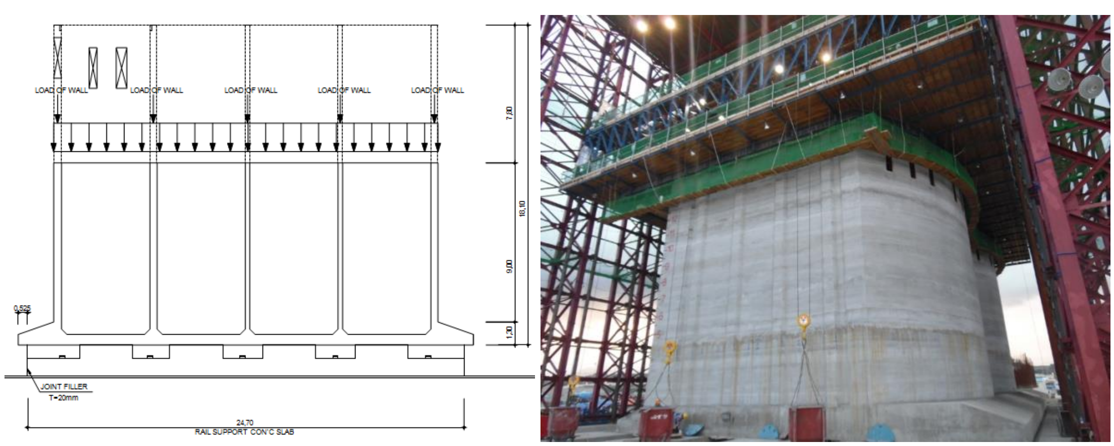

Figure 15 a: Concept of the examination on the Step 2.

Regarding the base slab that joins the vertical wall, the profile examination of the base slab must include the wall (figure 15b), however, we examined the cracking with the application of the general profile of the base slab (H = 600mm) for the calculation of the cracking width, if the maximum spacing complies with the standard (≤ 5x (cover + dia/2)) [15], there will be no problem.

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5 x (70 + 16/2) = 390.0 mm (for D16)

Therefore, since 330mm spacing for the front wall, 300mm spacing for the parition, 280mm spacing for the rear wall all comply with the maximum reinforcement spacing (412.5mm and 390.0mm), there is no problem for the spacing of the reinforcements.

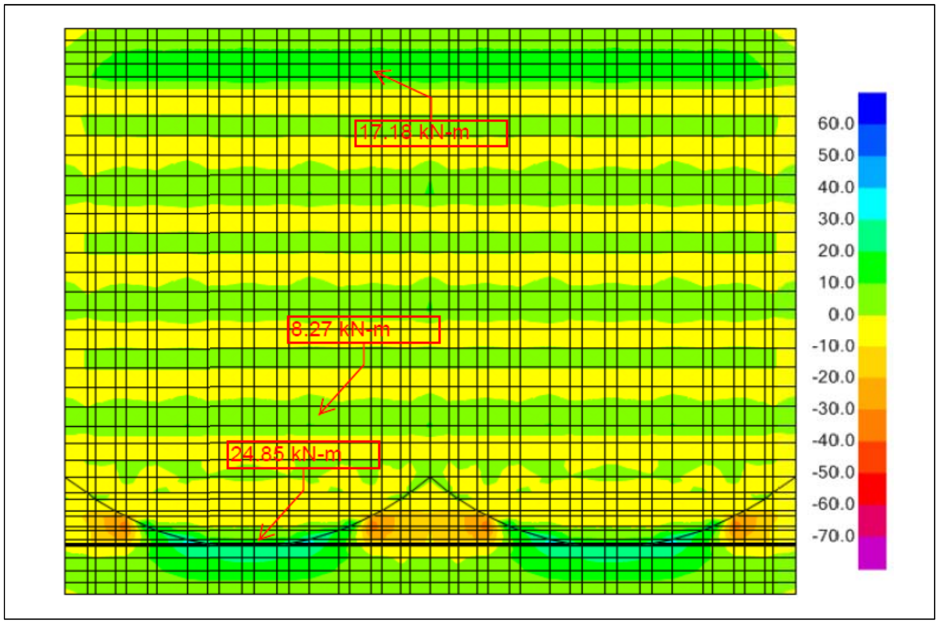

Figure 15 b: Base slab member force generated at the cure station towards the direction of M11 (SAP-2000).

According to the cracking examination for the reinforcing bars (reinforcements) which meet with the wall, taking into account the current spacing of the reinforcing bars, all of them comply with the standard of admissible cracking (table 4). In addition, it is always less than the maximum spacing to control cracking. As a result, it has been observed that there is no problem for the spacing of the reinforcements of the base slab.

Table 4: examination result on the cracking width of the base slab in the cure station (step3).

Distinction		Position of the reinforcements	member force (SLS, kN·m)	applied reinforcement	crack width (mm)	exam result
base slab reinforcements	M11 (direction)	front wall (WALL-A)	24.85	D25, center, distance of 330	0.02	O.K
		partition (WALL-B)	8.27	D25, center, distance of 300	0.01	O.K
		rear wall (WALL-D)	17.18	D16, center, distance of 280	0.07	O.K

4. DISCUSSION

The causes of damage to the caissons' base slab are varied. A small space of the caisson supports on the floating dock can cause this type of damage. We have experienced this phenomenon a few times after boarding the first caisson on the floating dock, but the cracks' size was still minor. So, taking into account the current state, it would probably require another cause. We have examined the possibility of damage by a difference in level of the support of the caisson, but the difference is always less than 1 to 2mm, so it is difficult to see it as a cause for this damage. As well; almost all cracks observed are less than 0.3 mm, which implies that there is no problem, since the admissible width of cracking is 0.3mm. The main reason can be explained by the particularity of the slip form hydraulic system. The IP-CCV is a hydraulic system that raises or lowers (moves up or down) the caisson with 30 devices (figure 16). Since there is always a time lag to react for these devices, the IP-CCV is divided into two groups (front area (1), and back area (2)) to minimize time lag. The current damage has occurred in the front area which supports half the weight of the caisson when lifting the caisson and reacts in a short time. It is estimated that this area is found with IP-CCV before other areas and this to accelerate the damage, which means that it is a differential settlement of the caisson.

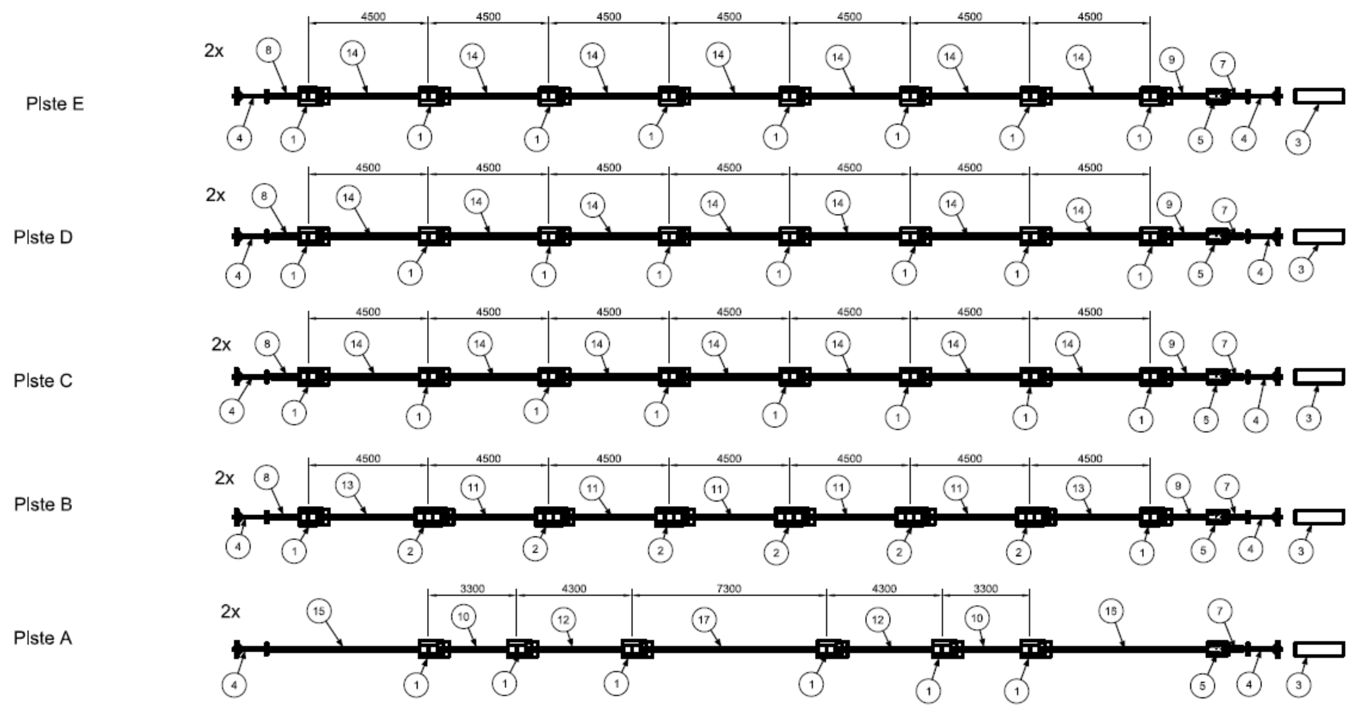

Figure 16: the complete chain of IP-CCVs.

During the operation of the IP-CCV, the contractor will have a staff for each corner (front and back) and will communicate continuously by radio to monitor the operation to the millimeter and ensure the regular lifting and lowering of the caisson. And also, when lifting and lowering the IP-CCV, the contractor will have a supervisor to do to unforeseen cases. In addition, after completion of caisson fabrication, the contractor will invite the supplier supervisor (Bygging-Uddemann) to verify any problems that have occurred. In addition, to prevent the problem, the rubber plate will be partially cut to further minimize the difference in level between the caisson slab and the support (figure 17), and also, because there is a great distance between the extra supports on the floating dock as step 2 (walls) and step 3 (curing).

Figure 17: the rubber plate on the plat-form of the curing station (step 3).

The damaged part is quite large and it is difficult to repair it with the crack repair method (figure 4a & 4b). Therefore, as below, we will destroy the damaged part, expose the reinforcement, install the formwork, and then repair with the concrete (for caisson) or the micro-concrete, according to the following methodology;

- ✓ Chipping;
- Stitching/ chipping of the bottom and lateral part.
- ✓ Formwork;
- Installation of the formwork for the base slab with wood (or metallic).
- For the exterior wall, install higher (h = 100 to 150m / m from the damaged area).
- ✓ Injection of the repair product;
- The repair materials will be the one mentioned in the methodology.
- During injection, up to the height of the installed formwork.
- When injecting, compacting and leveling with wooden hammer, etc.
- ✓ Using the repair product;
- We can use a repair product (EMACO, other products) in case of insufficient micro-concrete.
- ✓ Curing;
- Curing by water in the surface of the mortar injection zone.
- ✓ Finishing;
- After stripping, finish the protruding parts of the mortar.

So we must define the formulation of micro concrete intended for the unconventional repair of reinforced concrete structures in almost inaccessible structures (table 5). This composition is based on the Dreux-Gorisse calculation method [17], the materials constituting this micro concrete are as follows; Gravel 3/8, Cement (CPJ CEM II 42.5 N), mixture of sands (Sea sand SM 65%, Quarry sand SC 35%), Admixture Sika viscocrete 3045 and water. The objectives of this formulation is to have a fluid micro concrete, easy to implement with low vibrations to ensure its homogeneous spread in the damaged parts (difficulty of tight formwork).

Table 5: Micro concrete design for repair

E/C	Cement (kg)	Water (l)	Gravel (3/8)	Mixture of sand	Viscocrete adjuvant 3045	Slump Obtained
0.42	400	168	49%	51%	0.7%	25 cm

5. CONCLUSION

This paper has discussed the possible issues that can cause cracks with different locations and different stages incurred in fabricating caissons by the slip-form system. Then, the process of propagation of concrete cracks in the caissons with different situations was analyzed by an on-site investigation. The results showed that as the length and width of the cracks increased, with the displacement of the caisson from one stage to another in the fabrication workshop, and that the average crack width was less than 0.3mm, with the exception of a few cracks which did not reoccur after knowing their causes and treated them, with almost no effect on the concrete quality of the caissons. Thus, damage occurs in a part of the corner of the caisson slab during their embarkation on the floating dock with a size of approximately 80 cm X 60 cm, it can be repaired by pitting and concreting (Micro-concrete).

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Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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