

Maritime technologies



Overview of Additive Manufacturing

Testing scheduled at the port of Gijón, Spain

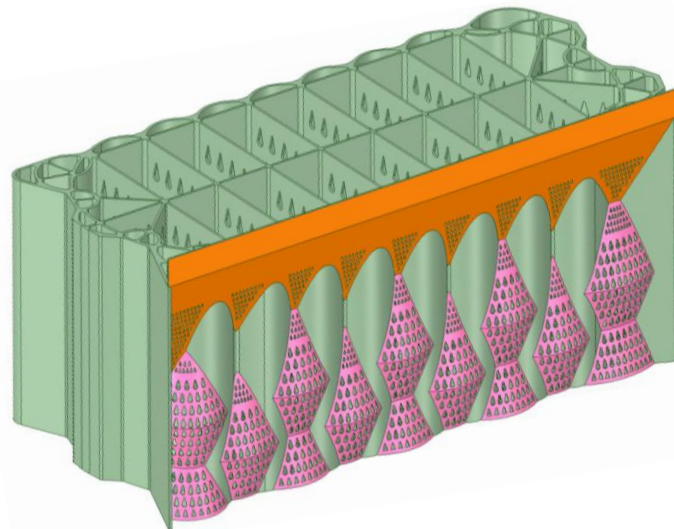
Rafael Ruiz Maestre, ACCIONA

Why «additive manufacturing»?

To achieve 15% cost reduction by Material efficiency and Construction Efficiency through Innovative Design, enabled by 3D printing technology



BEEYONDERS



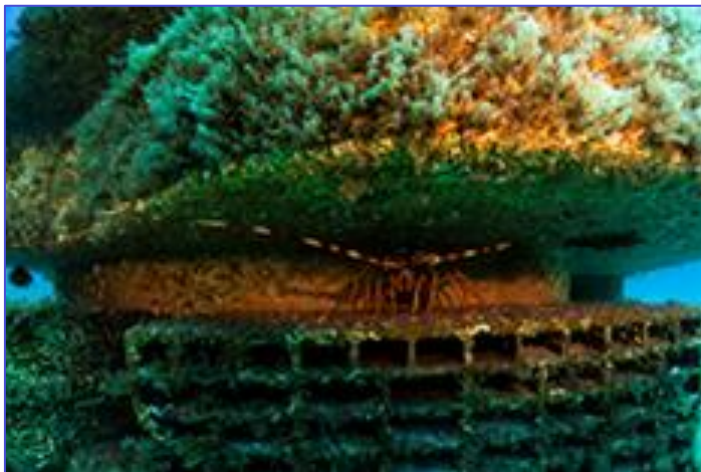
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Funded by The European Union

Why «additive manufacturing»?

To enable the new caissons to increase their bioreceptivity characteristics



Habitation (macro)

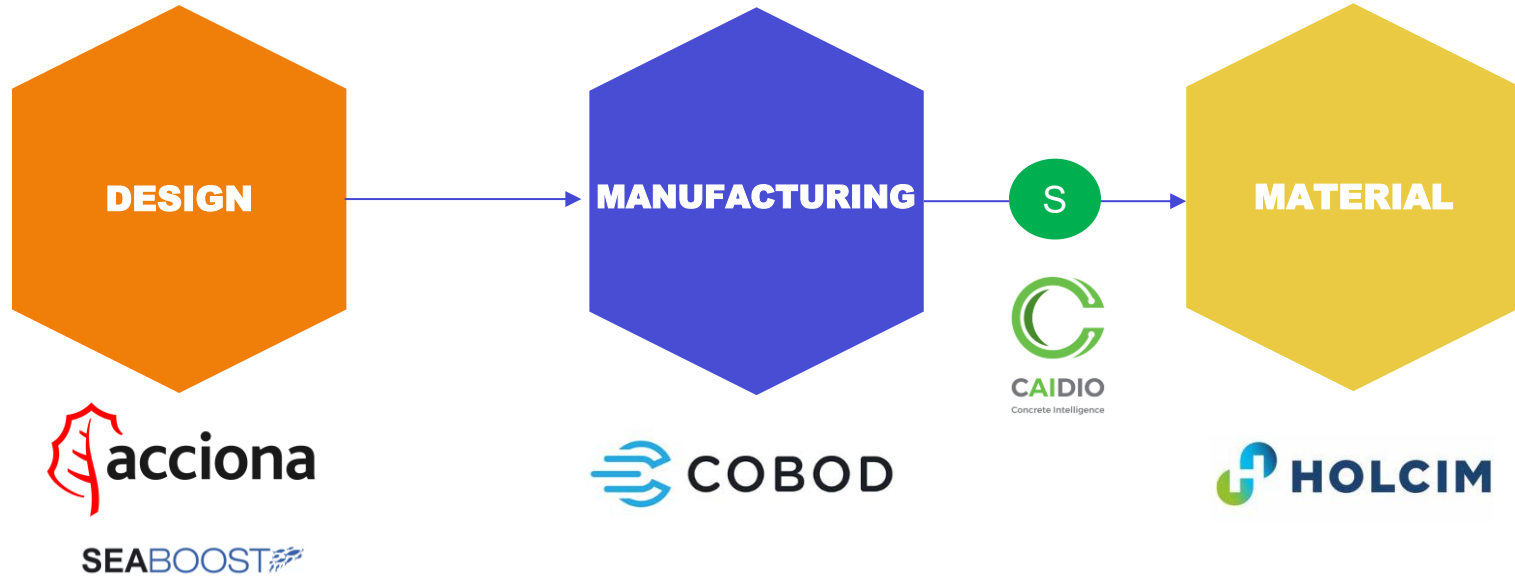
- Created by 3D printing

Material surface (micro)

- Fertiliser release
- Texturation

Bio-receptive, 3D-printed caisson

Partner contributions:



3DCP caisson design with biodiversity promoting function

3DCP caisson design with biodiversity promoting function

Status: Deliverable submitted

Actions realized in this tasks:

- Choice of reference caisson design example
- Evolution of 3DPC caisson structural design and integration of ecological considerations
- Structural calculation and structural design refinement with material in-situ performance

Involvement of partners and their major contributions:



Lead Caisson design



3D printable caisson design



Ecological consideration



Coordination, material properties

Organization and resources:

- Modeling and calculation done by Acciona
- Regular update meetings 1-2 times per months with COBOD, Holcim and Seaboost

Caisson design

- **Initial design material properties:**
- During the 3d printed caisson design, tensile strength of concrete was considered **isotropic**.
- $f_{ctd}=4.3$ MPa considered as the limit for design:
- σ_1 (maximum tensile stress obtain in the model) $< f_{ctd}$

6.1. Mechanical properties of the materials

The most relevant mechanical properties of the materials included in the FE model may be found in the table below.

Table 4: mechanical properties of the materials

	Young's modulus	Poisson	Material density	F_{ctd}
Water	-	-	1026 kg/m ³	-
Concrete	37000 MPa	0.2	2400 kg/m ³	4,3 MPa
Sand fill	20 Mpa	0.35	1630 kg/m ³	-

6.3.1. Caisson standing

In this stage, the caisson is considered just printed, standing on the rigid surface of a dry dock and totally empty.

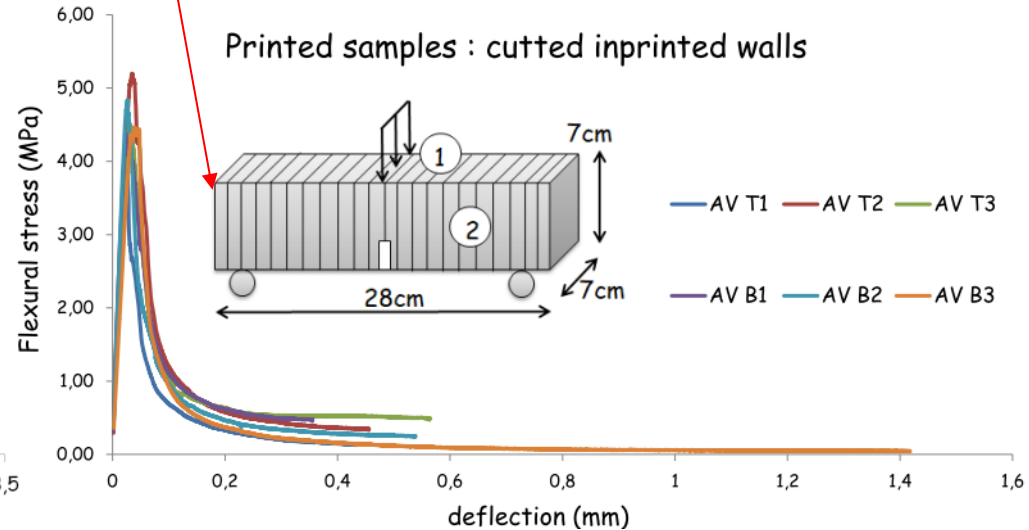
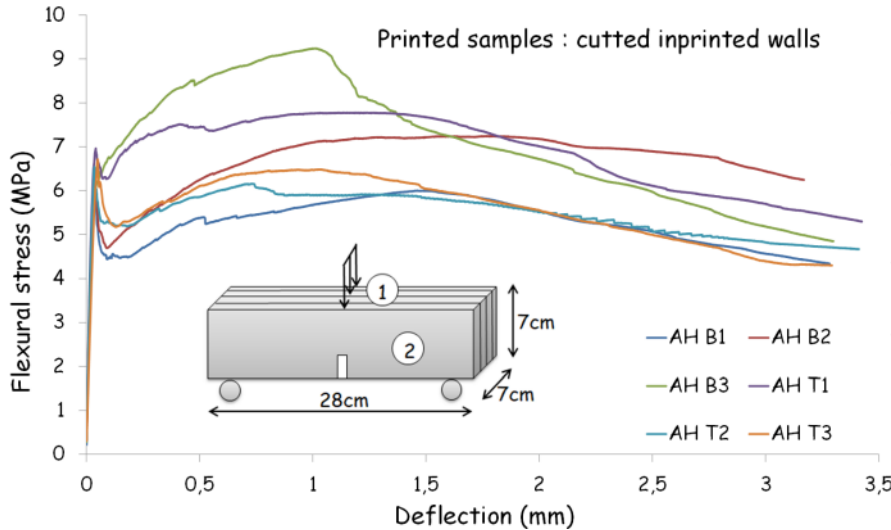
To simulate this situation, only gravity loads are applied, and the bottom surface of the caisson is supported with a rigid compression only boundary condition.

The following figure shows the principal stresses for this case. The maximum stress at this stage is 1,37 MPa, well below the tensile design cracking stress of the material (4,3 MPa).

Caisson design

Material testing:

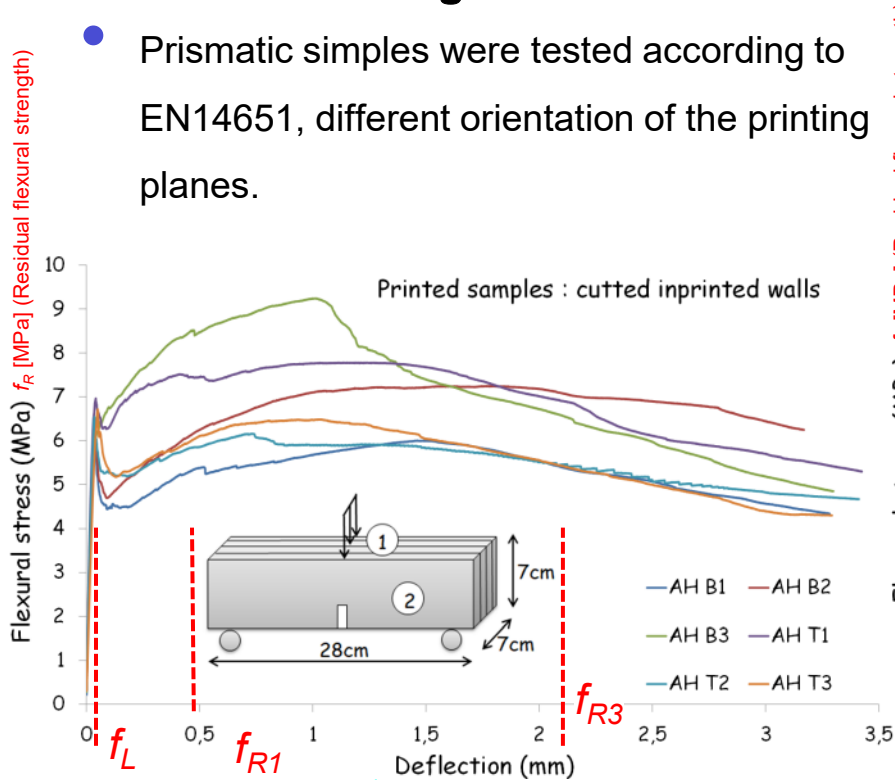
- Prismatic samples were tested according to EN14651, different orientation of the printing planes.



Caisson design

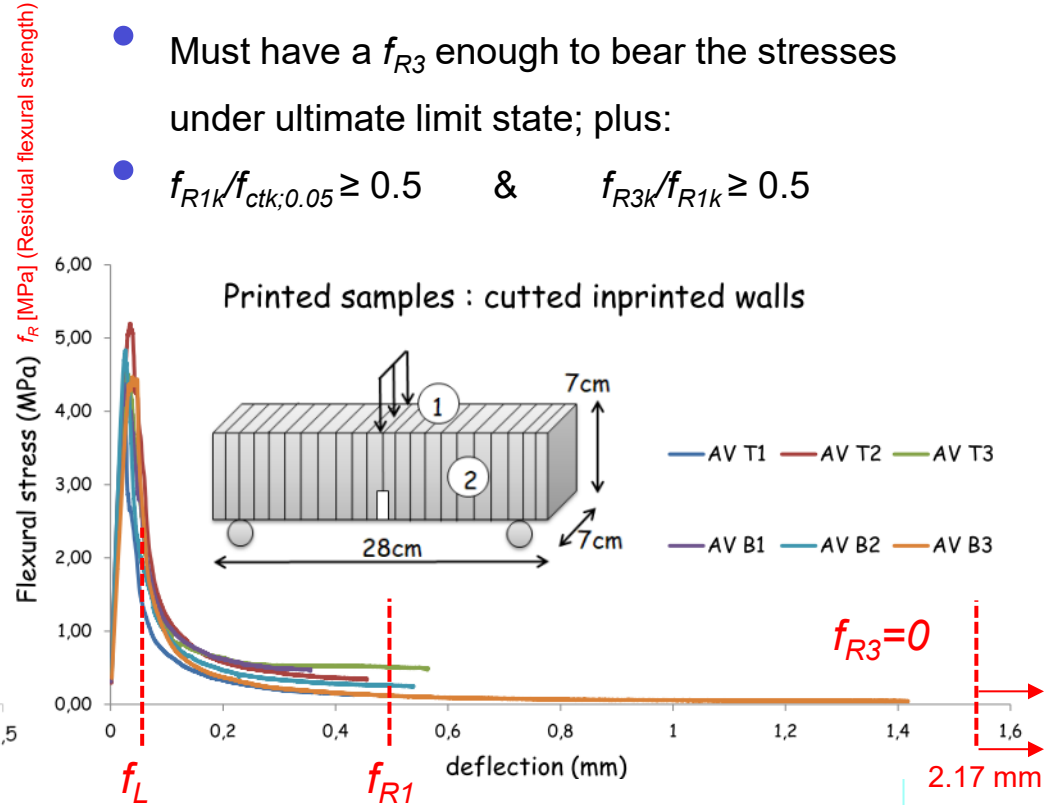
Material testing:

- Prismatic samples were tested according to EN14651, different orientation of the printing planes.



Standards/codes/recommendations:

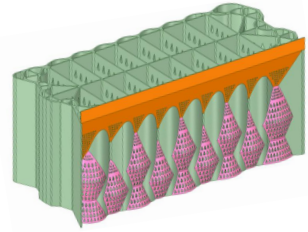
- Must have a f_{R3} enough to bear the stresses under ultimate limit state; plus:
- $f_{R1k}/f_{ctk;0.05} \geq 0.5$ & $f_{R3k}/f_{R1k} \geq 0.5$



Caisson design

Adjustments

- **According to standards/codes/recommendations.**
- Minimum conventional Steel rebars should the printing layers:



$$A_{s,vmin} = 0.0012 \cdot A_c = 0.0012 \cdot 200 \text{ mm} \cdot 1000 \text{ mm} = 240 \text{ mm}^2 \equiv 5\phi 8 \equiv 4\phi 10 \equiv 3\phi 12$$

Three vertically placed 12-mm diameter bars per meter are recommended for the entire height of the caisson. Depending on the site-specific meteorological conditions, the loading conditions may need adjustment, and the reinforcement design may vary accordingly.

Caisson design

Adjustments

- **Initial design material properties:**
 - During the 3d printed caisson design, tensile strength of concrete was considered **isotropic**.
 - During material testing, strong ortotropic behaviour was found.

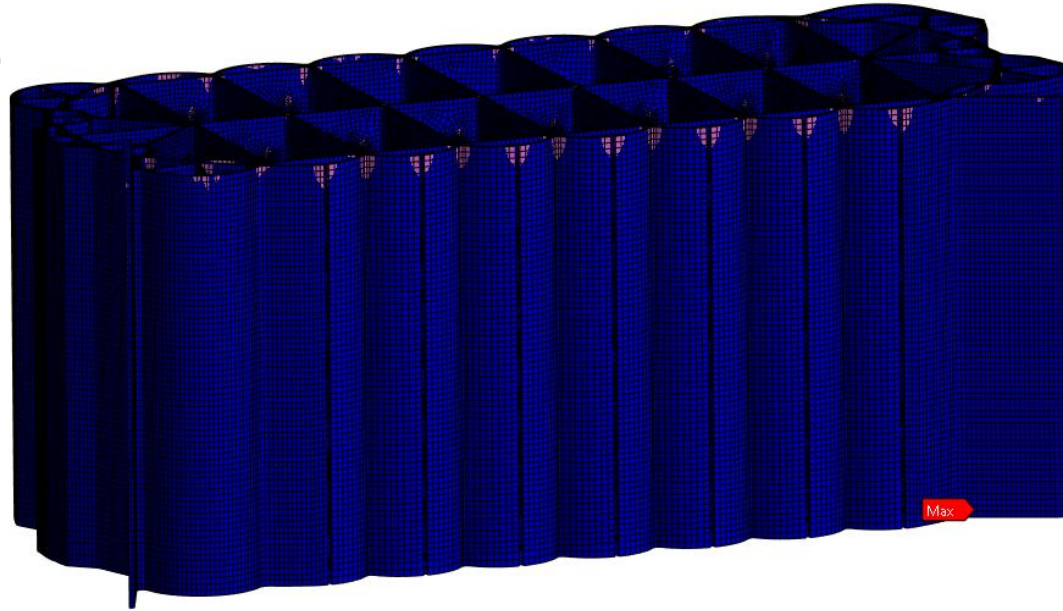
Caisson design

Load cases: Caisson standing

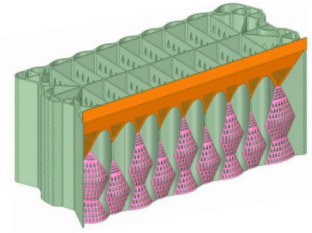
$\phi 12$ each 30 cm $\rightarrow$ 0.48 MPa

N: V24 Empty standing
Normal Stress
Type: Normal Stress(Z Axis)
Unit: MPa
Global Coordinate System
Time: 1 s
11/12/2024 8:18

0.94698 Max
0.48
0
-1.5683 Min



Normal stress z axis



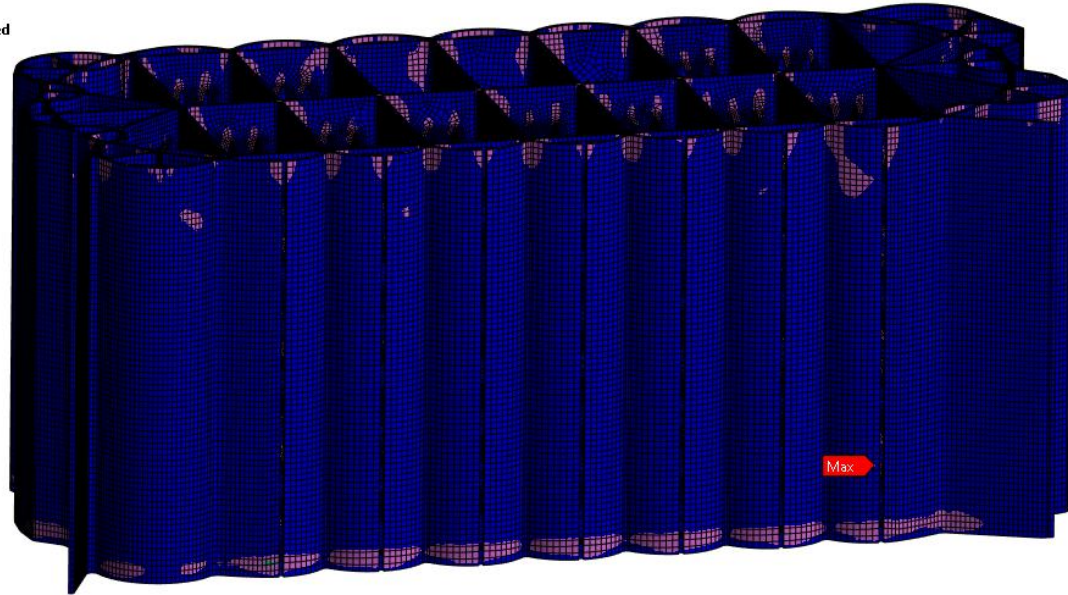
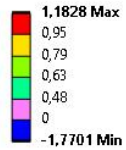
Caisson design

Load cases: Floating caisson

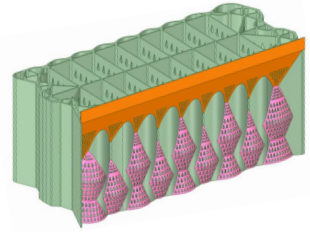
$\phi 12$ each 30 cm $\rightarrow$ 0.48 MPa

O: V24 Floating compensated

Normal Stress
Type: Normal Stress(Z Axis)
Unit: MPa
Global Coordinate System
Time: 1 s
11/12/2024 9:17



Normal stress z axis



Caisson design

Load cases: Sinking of the caisson, low tide sinking

$\phi 12$ each 30 cm $\rightarrow$ 0.48 MPa

P: V24 Compensated standing

Normal Stress

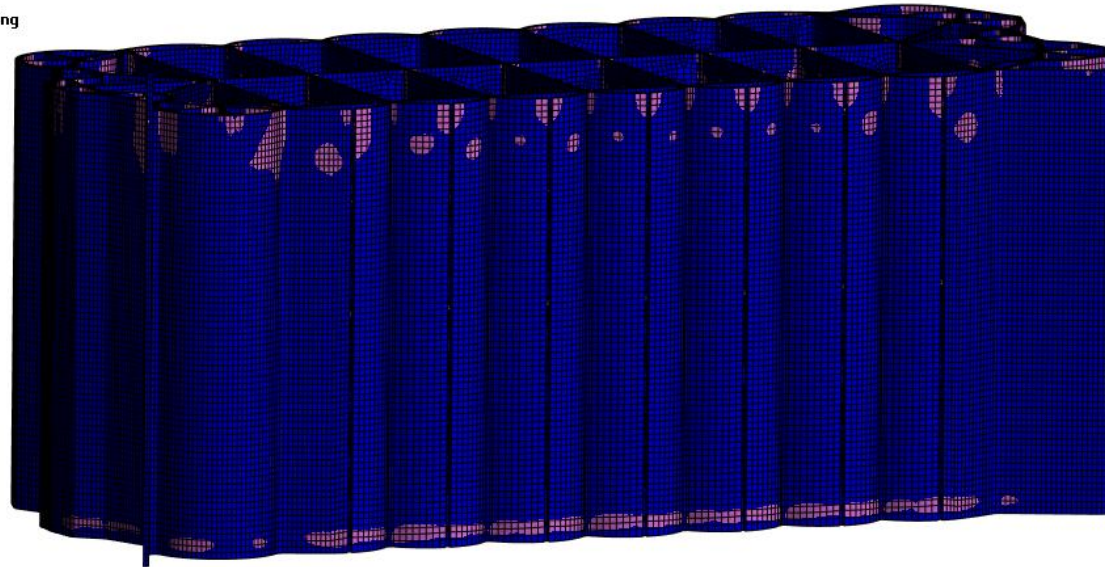
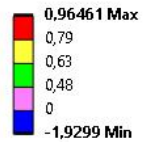
Type: Normal Stress(Z Axis)

Unit: MPa

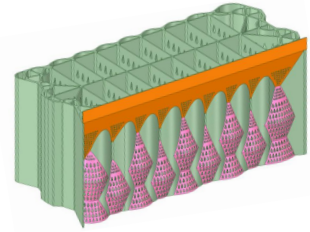
Global Coordinate System

Time: 1 s

11/12/2024 9:22



Normal stress z axis

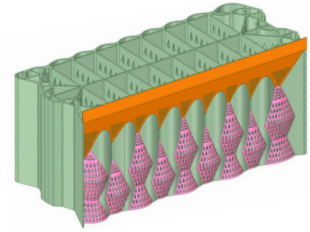
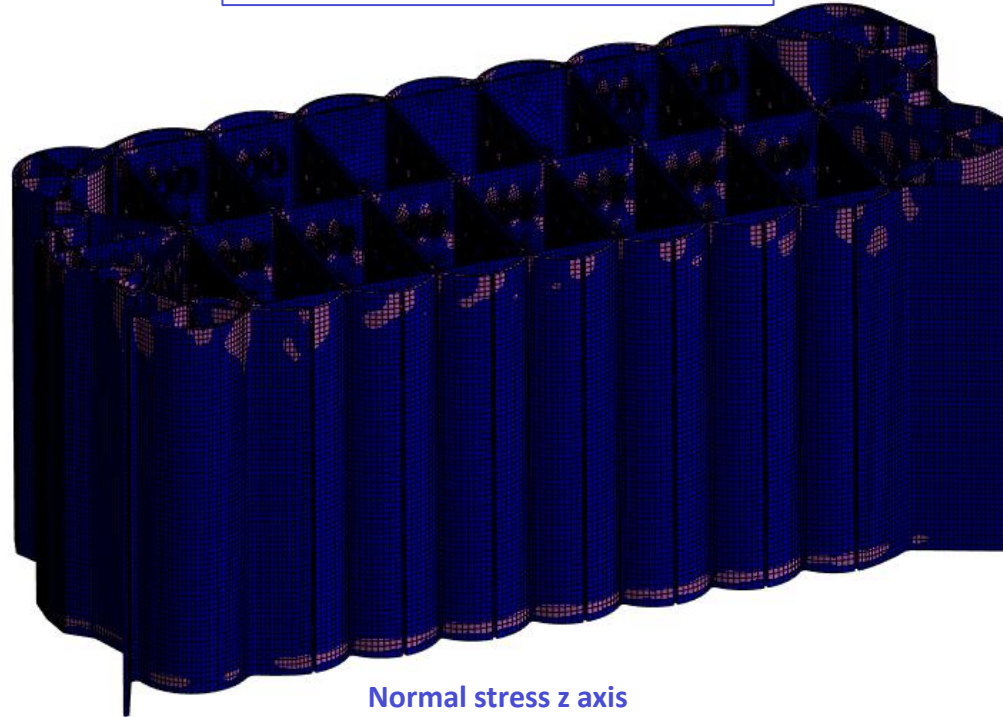
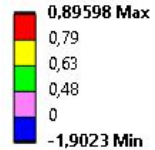


Caisson design

Load cases: Sinking of the caisson, high tide sinking

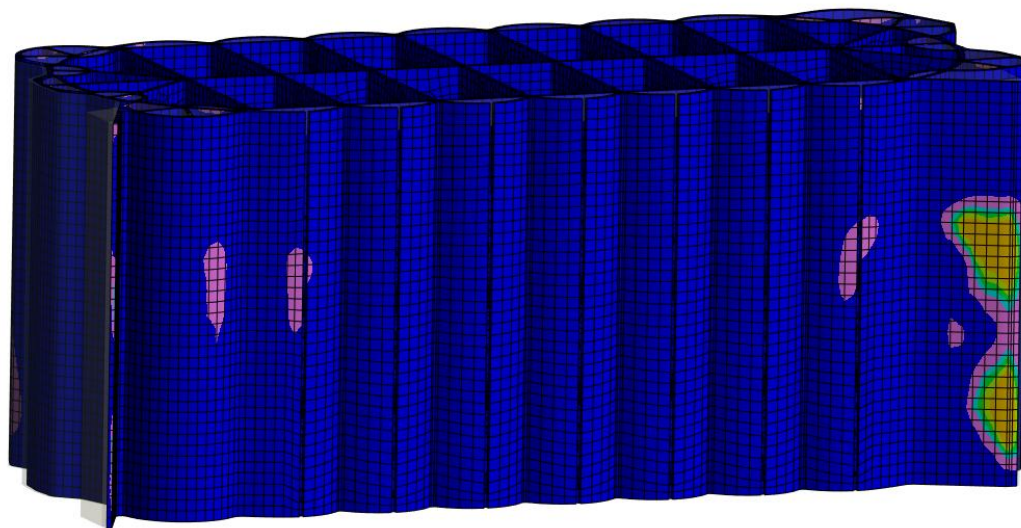
$\phi 12$ each 30 cm $\rightarrow$ 0.48 MPa

R: V24 high tide sinking
Normal Stress
Type: Normal Stress(Z Axis)
Unit: MPa
Global Coordinate System
Time: 1 s
11/12/2024 9:27



Caisson design

Load cases: (ULS) low tide wave suck, front view



AG: V24 ULS Low tide wave suck
Normal Stress 9
Type: Normal Stress(Z Axis)
Unit: MPa
Global Coordinate System
Time: 1 s
10/12/2024 16:28

3,3438 Max
1,58
0,95
0,79
0,63
0,48
0
-5,2515 Min

Normal stress z axis

AG: V24 ULS Low tide wave suck
Normal Stress 11
Type: Normal Stress(Z Axis)
Unit: MPa
Global Coordinate System
Time: 1 s
10/12/2024 16:39

3,3438 Max
1,58
0,95
0,79
0,63
0,48
0
-5,2515 Min



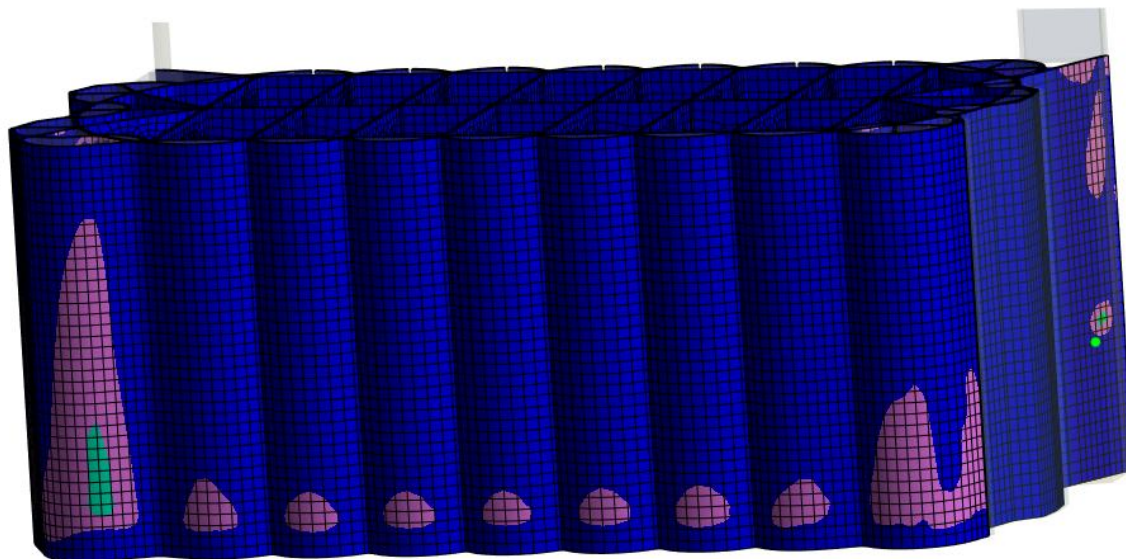
AG: V24 ULS Low tide wave suck
Normal Stress 9
Type: Normal Stress(Z Axis)
Unit: MPa
Global Coordinate System
Time: 1 s
10/12/2024 16:29

3,3438 Max
1,58
0,95
0,79
0,63
0,48
0
-5,2515 Min

Caisson design

Load cases: (ULS) low tide wave suck, back view

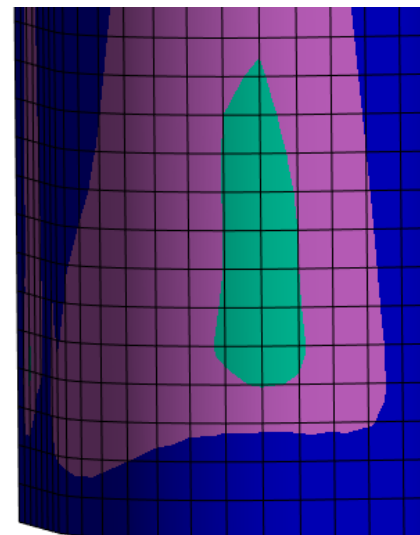
AG: V24 ULS Low tide wave suck
Normal Stress 11
Type: Normal Stress(Z Axis)
Unit: MPa
Global Coordinate System
Time: 1 s
10/12/2024 16:39



AG: V24 ULS Low tide wave suck
Normal Stress 11
Type: Normal Stress(Z Axis)
Unit: MPa
Global Coordinate System
Time: 1 s
10/12/2024 16:39

3,3438 Max
1,58
0,95
0,79
0,63
0,48
0
-5,2515 Min

3,3438 Max
1,58
0,95
0,79
0,63
0,48
0
-5,2515 Min



Normal stress z axis

Caisson design

Load cases: (ULS) low tide wave push

AH: V24 ULS Low tide wave push

Normal Stress 3

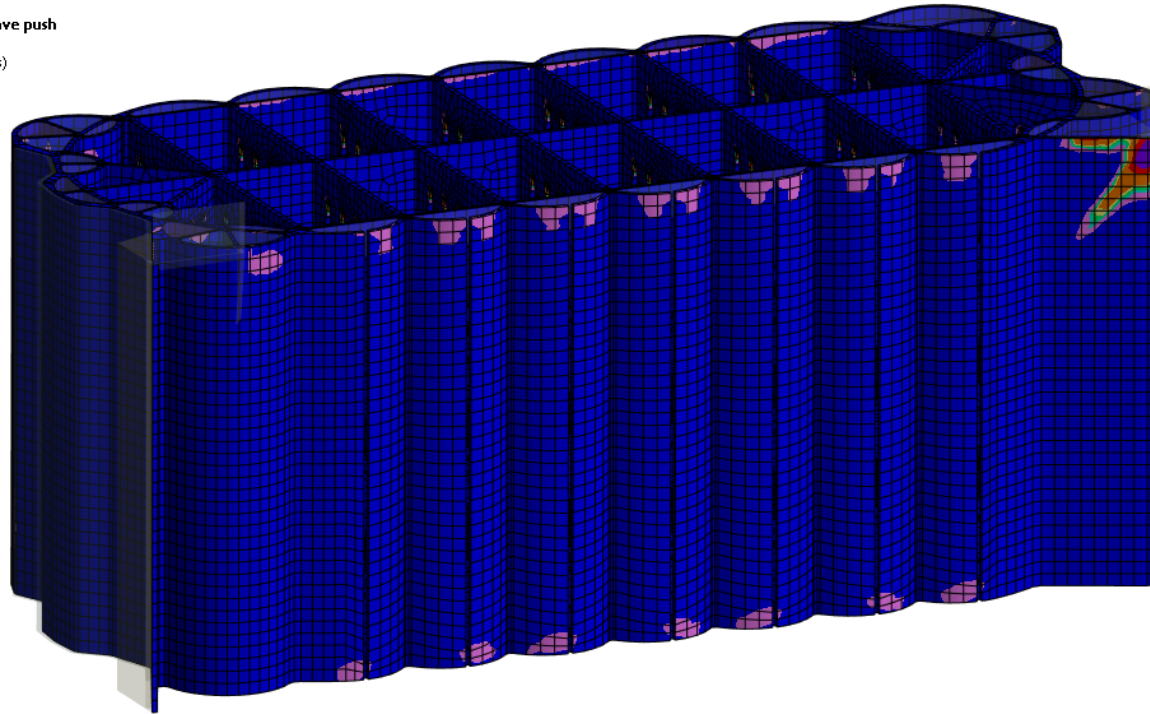
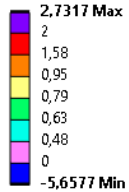
Type: Normal Stress(Z Axis)

Unit: MPa

Global Coordinate System

Time: 1 s

10/12/2024 16:50



Normal stress z axis

Caisson design

Load cases: (ULS) high tide wave push

AJ: V24 ULS High tide wave push

Normal Stress 2

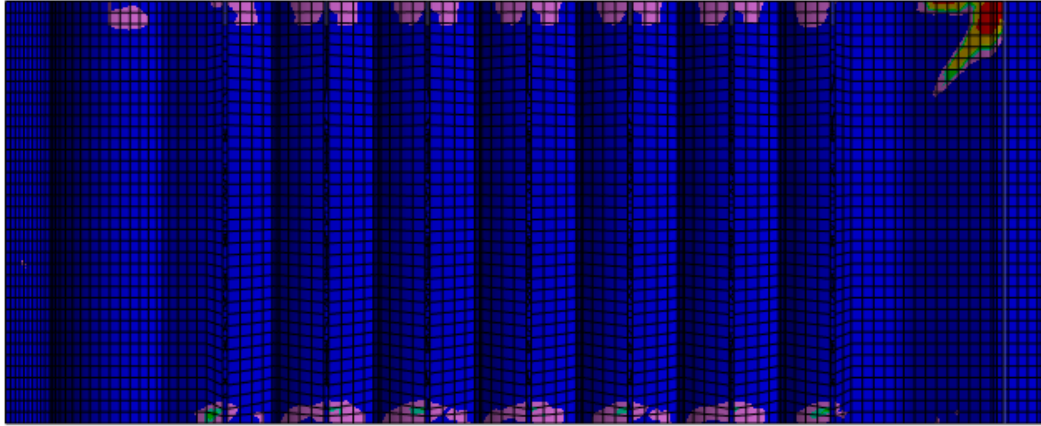
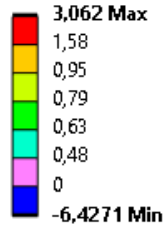
Type: Normal Stress(Z Axis)

Unit: MPa

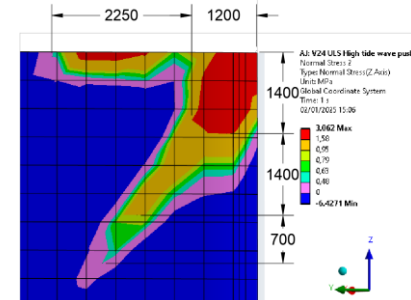
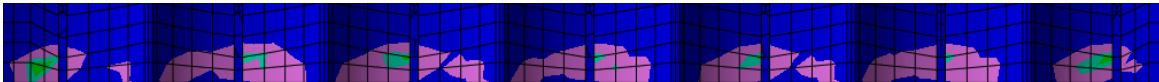
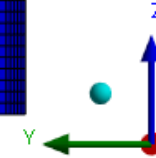
Global Coordinate System

Time: 1 s

02/01/2025 14:59



Normal stress z axis



Drawing caisson



Caisson reinforcement

Reinforcement quantity

[illegible]

	width	height	rebar	space	Weight	Weight*	Peso [kg]
	[mm]	[mm]	[mm]	[mm]	[kg/m]	[kg/m]	
Corner D-A	1000	4300	16	300	1.63	0.71	10.18
Outside wall B	1000	13000	20	300	2.55	1.63	70.63
Central curve A	24460	2000	20	300	2.55	1.63	265.80
Outside wall	4000	18700	25	300	3.98	3.06	762.96
						suma	1110

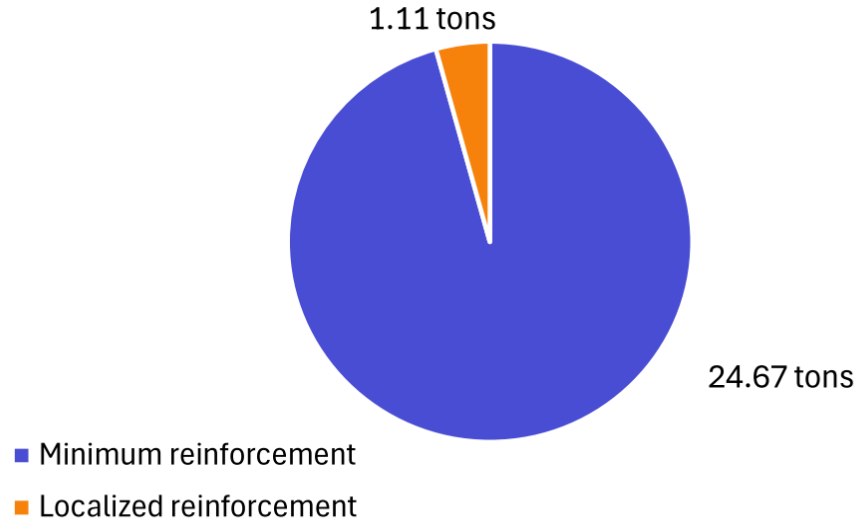
Todo el acero considerando este extra **25.78** tons

Este ajuste es para sumar directamente estas barras al acero que ya nos daba rellenar todo con phi12

Steel reinforcement required for the minimum reinforcement ratio ($\phi 12$ each 30 cm): 24.67 tons
Steel reinforcement required including localized stresses pointed in the model: 25.78 tons (25.78-24.67=1.11 tons for specific locations)

Caisson reinforcement

Reinforcement quantity



Steel reinforcement required for the minimum reinforcement ratio ($\phi 12$ each 30 cm): 24.67 tons

Steel reinforcement required including localized stresses pointed in the model: 25.78 tons ($25.78 - 24.67 = 1.11$ tons for specific locations)