IFREMER

MAREGAMI

BUOY DEFINITION

REFERENCE : S44478-SEN-STR-REP-001

Date : 02/08/2018

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25/06/18	01	Issue for review	K. Abalain	F. Alix	
13/07/18	02	Final Issue	K. Abalain	F. Alix	
02/08/18	**03**	**Final Issue**	K. Abalain	F. Alix	

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1. INTRODUCTION

1.1. Project Presentation

The aim of the MAREGAMI project is to provide answers to some scientific questions dealing with the mechanical behavior of submerged fault segments in the Marmara sea.

Task 4 of the MAREGAMI project aims to study the conditions under which two permanent underwater observatories for geological hazards could be deployed and operated in the Marmara Sea.

1.2. Scope of the document

The scope of the document is to present the preliminary structural assumptions concerning the buoys of the 2 given locations.

The global definition of the buoy has to take into account the following constraints:

- layout with specific entities as photovoltaic panels, shelter, boat landing area, anti-intrusion device…
- defined swinging area because of the navigation channel proximity;
- defined tensions in mooring lines in order to establish the fixed points type to install on the seabed;
- knew the buoys behaviors.

1.3. Abbreviations

- BV Bureau Veritas
- CoG Center of Gravity
- FEM Finite Element Model
- MTO Material Take Off
- WCF Weight Contingency Factor
- WCR Weight Control Report

2. REFERENCES

2.1. Client References

[1] G93DBB00-MAREGAMI-CDCF bouée - Cahier des charges Fonctionnel pour l'étude de la bouée de surface de l'observatoire MAREGAMI

2.2. Contractor References

[2] S44478-SEN-STR-DWG-001_rev01 – Buoy body General Arrangement
[3] S44478-SEN-STR-DWG-002_rev01 – Buoy body Structural Arrangement
[4] S44478-SEN-STR-DWG-003_rev01 – Swinging area – anchoring lines

2.3. Codes & Standards

[5] BV NR 494 DT R02 E – Rules for the Classification of Offshore Loading and Offloading Buoys, May 2006
[6] BV NR 467 rules – Rules for the Classification of Steel Ships, January 2013
[7] API RP 2A WSD – Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms – Working Stress Design, October 2007
[8] DNV-RP-C205 - Environmental Conditions and Environmental Loads – April 2014

3. BUOY ARRANGEMENT

3.1. Entities description

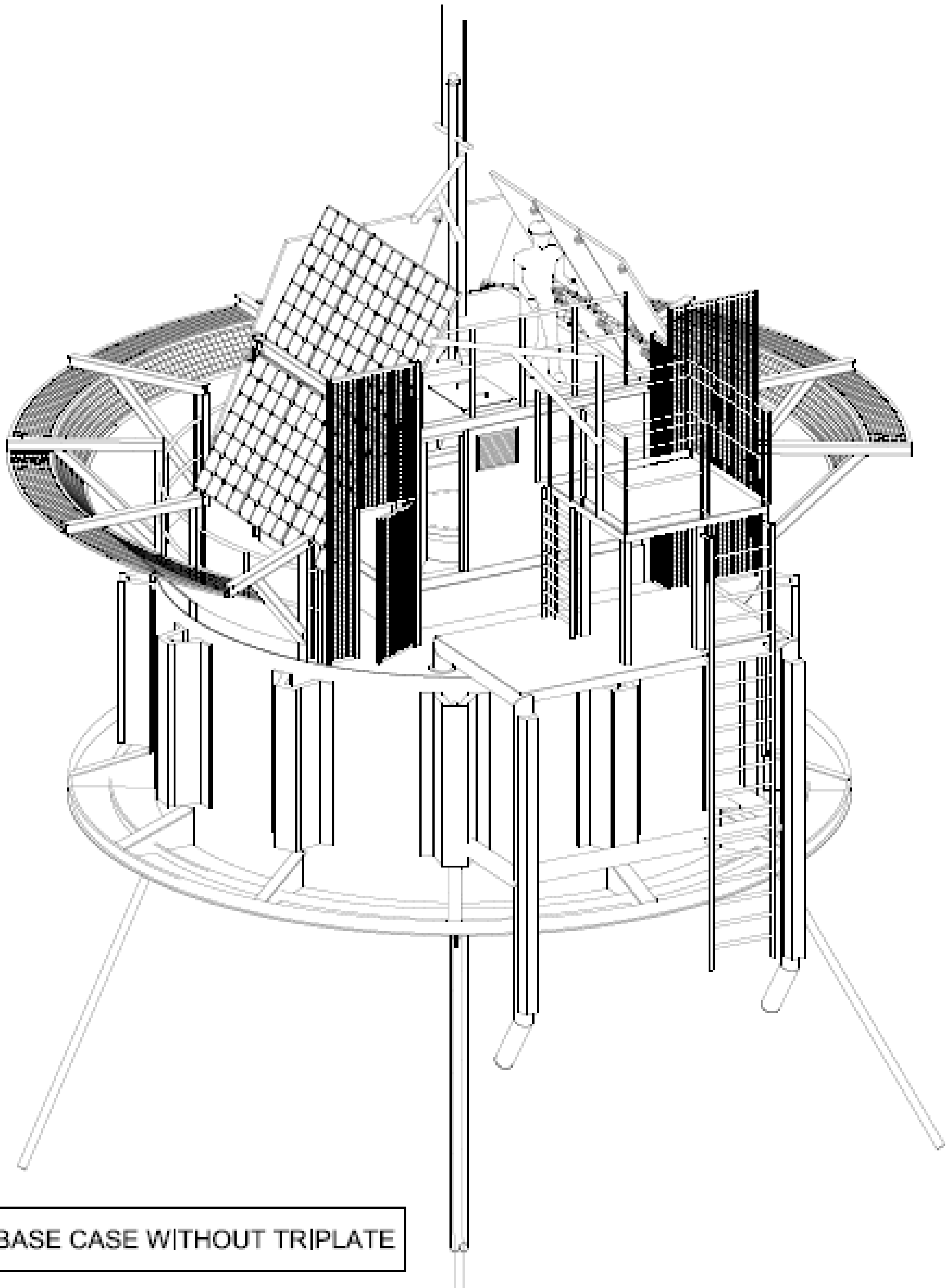
The buoy arrangement is composed of different entities each one having its own utility in the overall operation of the installation. See below a list and a description of the different entities in accordance with the initial requirements ref.[1] and the layout ref.[2]:

- Buoy structure: the structural part of the buoy is designed in order to contain all entities and equipment described below while responding to metocean data in MARMARA sea. Scantling of the buoy is defined according to the BV NR 494 ref.[5]. Fenders are disposed all around the buoy side shell in order to protect the buoy from floating object or boat impact.
- Shelter: a part of the equipment needs a protection from the weather and green sea and also against the risk of vandalism. A structural protection shelter is disposed at the center of the buoy, allowing to protect the equipment and also to support the mast on its roof with telecommunication devices. The shelter structure also allows to support technical staff for maintenance operations on the roof.
- Boat landing: technical staff will need to board the buoy punctually or for annual maintenance operations. Therefore, the buoy must have facilities for berthing. The boat landing is privileged on the north part of the buoy because the others sectors are reserved for the photovoltaic panels.
- Anti-intrusion structure: the buoy is equipped with expensive scientific equipment, so it's important to limit the risk of vandalism with an anti-intrusion structure. It also has a protection role from lateral pressures generated from sea motions on the shelter and the photovoltaic panels.
- Sheltered equipment: some equipment are put in the shelter in order to be protected from weather, green sea and vandalism. They are integrated in two raised storage locker (600 mm) except batteries.
- Off-shelter equipment: the main equipment that are outside the shelter are the photovoltaic panels and various sensors and antennas fixed on the mast. Photovoltaic panels allow to ensure the energy autonomy of the buoy and subsea equipment, they must be optimally oriented to capture radiations.
- Underwater equipment:
  - Umbilical connections: connected to the buoy by the center well. It allows to transmit data and energy between the buoy and the seabed node which collect the sensor data.
  - Anodes: protection by sacrificial anodes of the buoy is to be expected for a period of 5 years.
- Handling devices: allow handling of equipment from the boat to different areas of the buoy.
- Anchoring lines: 3 anchoring lines connected to mooring points at the buoy. Each line is constituted with a cable, a hawser, a string and a fixed point to be defined on the seabed.

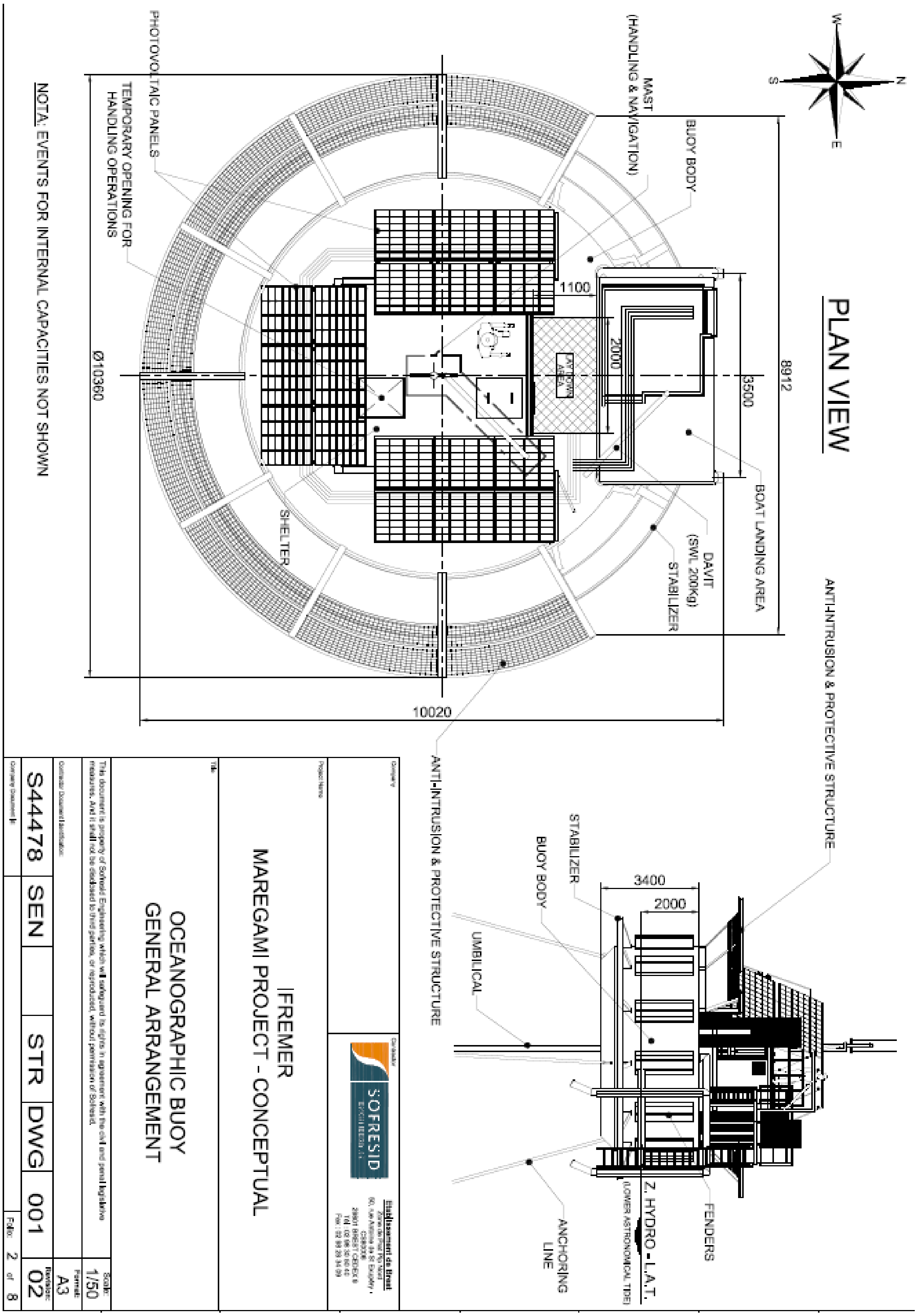
An exhaustive list of equipment is given in 0.

The buoy arrangement is presented in sections below with the different structures and components modelized, for more details see drawing ref.[2].

3.2. Buoy views



BASE CASE WITHOUT TRIPLATE


PLAN VIEW
W
N
S
E
MAST
(HANDLING & NAVIGATION)
BUOY BODY
PHOTOVOLTAIC PANELS
TEMPORARY OPENING FOR
HANDLING OPERATIONS
NOTA: EVENTS FOR INTERNAL CAPACITIES NOT SHOWN
Ø10360
1100
2000
3500
8912
LAYDOWN AREA
BOAT LANDING AREA
DAVIT
(SWL 200Kg)
STABILIZER
SHELTER
10020
ANTI-INTRUSION & PROTECTIVE STRUCTURE
ANTI-INTRUSION & PROTECTIVE STRUCTURE
3400
2000
STABILIZER
BUOY BODY
UMBILICAL
FENDERS
Z. HYDRO - L.A.T.
(LOWER ASTRONOMICAL TIDE)
ANCHORING
LINE
IFREMER
MAREGAMI PROJECT - CONCEPTUAL
OCEANOGRAPHIC BUOY
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SOFRESID
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4. PRE-DIMENSIONAL DEFINITION

4.1. Methodology

The methodology for the pre-dimensional definition of the buoy is presented in the table below by a step by step pattern between structure analysis and naval analysis:

STRUCTURE	*Step 1*	Outline of an overall plan
		Buoy outer diameter needs to be fixed
		Modelisation of the different structures (shelter, boat landing, photovoltaic panels supports...)
		Buoy height proposal (still water approach in order to have a sufficient freeboard)
	Step 2	Scantling of the buoy defined as per BV NR 494 : preliminary MTO of the buoy
	Step 3	Preliminary WCR of the buoy including all estimated structures and equipment masses
	Step 4	Data for NAVAL analysis : geometry, mass, center of gravity, inertia…
NAVAL	*Step 5*	Modelisation in ORCAFLEX software of the buoy with structure data from "step 4"
	Step 6	Anchoring line preliminary modelisation (cable + hawser + string + fixed point)
	Step 7	Friction coefficient of the string on the seabed taken into account = 0,5
	Step 8	Conservative environmental data taken into account : wind + wave + current
	Step 9	Buoy behavior needs to be satisfactory : swinging, motions, freeboard
	Step 10	Buoy height needs to be fixed
STRUCTURE	*Step 11*	MTO update
NAVAL	*Step 12*	Calculation update
	Step 13	Tension in anchoring lines : design of the line components
	Step 14	Calculation update
STRUCTURE	*Step 15*	Pre-design or estimate of the others structures than the buoy
	Step 16	MTO update
NAVAL	*Step 17*	Calculation update if necessary

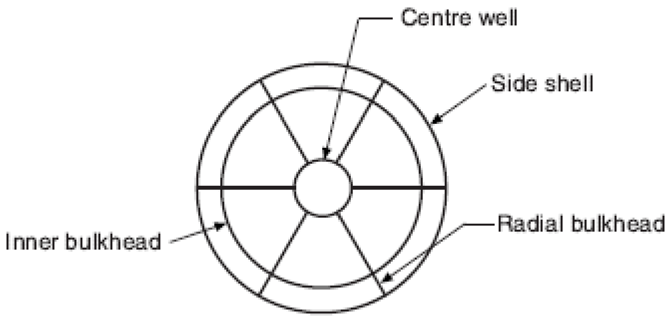
4.2. Buoy Body

4.2.1. Conceptual

The diameter and the height are the main dimensions of the buoys, they are respectively defined due to the arrangement (see section 3) and to the mooring analysis (see section 7).

The different structural elements of buoy body are identified and defined as per BV NR 494 reference [5].

Figure 1 : Identification of structural elements



The thickness of the plating is to be not less than the values given in tables below:

Table 2 : Minimum thickness of plating

Plating	Minimum thickness, in mm
Side shell	$[\,5 + 0{,}1\, D\, k^{1/2} + 5\,(s - s_0)\,]$
Bottom	$[\,6 + 0{,}1\, D\, k^{1/2} + 5\,(s - s_0)\,]$
Deck	$[\,4 + 0{,}1\, D\, k^{1/2} + 5\,(s - s_0)\,]$
Radial bulkhead	$[\,4 + 0{,}08\, D\, k^{1/2} + 5\,(s - s_0)\,]$
Inner bulkhead	

- or -

Table 3 : Thickness of plating subjected to lateral loads

Structure	Pressure, in kN/m^2	Thickness of plating, in mm
Side shell **(1)**	$p = 10\left(T + \alpha \frac{H_m}{2}\right)$ not to be taken less than 17,5 T	$t = 1{,}3\, r_p\, \mu\, s\, p^{1/2}$
Bottom		
Deck	$p = 10\left(T + \alpha \frac{H_m}{2} - C\right)$ not to be taken less than 15	
Radial bulkhead	$p = 10\, d$ not to be taken less than 10	$t = 1{,}25\, \mu\, s\, (k\, p)^{1/2}$
Inner bulkhead		
Radial bulkhead **(2)**	$p = 10\, d$ not to be taken less than 10	$t = 1{,}3\, r_p\, \mu\, s\, p^{1/2}$
Inner bulkhead **(2)**		

(1) According to the environmental load condition on which the structural design of the buoy is based, another side shell load distribution may be considered by the Society.
(2) In case where liquid storage is provided in the buoy.

The section modulus of ordinary stiffeners subjected to lateral loads is to be not less than the values given in table below:

Table 5 : Section modulus of ordinary stiffeners subjected to lateral loads

Structure	Pressure, in kN/m^2	Section modulus of ordinary stiffeners, in cm^3
Side shell **(1)**	$p = 10\left(T + \alpha \frac{H_m}{2}\right)$ not to be taken less than 17,5 T	$w = 0{,}56\ r_S\ p\ s\ \ell^2$
Bottom		
Deck	$p = 10\left(T + \alpha \frac{H_m}{2} - C\right)$ not to be taken less than 15	
Inner bulkhead	p = 10 d not to be taken less than 10	$w = 0{,}42\ r_S\ p\ s\ \ell^2$
Radial bulkhead		
Inner bulkhead **(2)**	p = 10 d not to be taken less than 10	$w = 0{,}56\ r_S\ p\ s\ \ell^2$
Radial bulkhead **(2)**		

(1) According to the environmental load condition on which the structural design of the buoy is based, another side shell load distribution may be considered by the Society.
(2) In case where liquid storage is provided in the buoy.

Scantling values obtained are presented in tables below.

- For plates thicknesses:

Minimum thicknesses are calculated according to ref.[5], as well as the lateral pressure thicknesses necessary to withstand the lateral pressures. Corrosion values are estimated according to ref.[6] and take into account that it will have anodes on the buoy structure.

On one hand a gross thickness is determined by taking into account the maximum value between “minimum thickness” and “lateral pressure thickness” with 20% more. On the other hand the corrosion value is added to the maximum value between “minimum thickness” and “lateral pressure thickness”. The final plate thickness is chosen between the maximum of these two calculated values with taking into account a margin value by engineering judgement.

Structure	Minimum thk (mm)	Lateral pressure (kN/m²)	Lateral pressure thk (mm)	Corrosion (mm)	Gross thk mini = net thk*1.2 (mm)	Mini thk + corrosion (mm)	**Chosen plate thk (mm)**
Deck	5.9	15.0	3.7	2.0	7.1	7.9	**10.0**
Bottom	7.9	32.5	5.4	2.0	9.5	9.9	**12.0**
Side shell	6.9	32.5	5.4	2.0	8.3	8.9	**10.0**
Radial bulkhead	5.7	10.0	2.9	1.0	6.9	6.7	**8.0**
Centre well	6.9	32.5	5.4	2.0	8.3	8.9	**10.0**

- For primary stiffeners:

Scantling sections of primary stiffeners are defined by engineering judgement in the conceptual phase. These sections will validate by an FEM analysis during the detail phase (capability to support the deck loads and the shell loads).

Structure	**Primary stiffeners**
Deck	**T300x200/10x15**
Bottom	**T300x200/10x15**
Side shell	**T300x200/10x15**
Radial bulkhead	**n/a**
Centre well	**n/a**

- For ordinary stiffeners (BV NR 494, table 5 above):

Structure	Section modulus (cm3)	**Ordinary stiffeners**
Deck	20.4	**HP160x8**
Bottom	20.4	**HP160x8**
Side shell	20.4	**HP160x8**
Radial bulkhead	10.2	**HP120x8**
Centre well	20.4	**HP160x8**

4.2.2. Detail phase

Some structural entities subjected to non-negligible loads are fixed on the buoy (boat landing, shelter, mooring ...). It will be necessary to make local analyzes of these connections to the buoy. Because of the proximity of the different elements to each other, it seems simpler to first modelize an overall model of the buoy for a global verification with coarse mesh elements, and then make fine mesh modelisation in the identified connections areas that will allow to perform detailed analysis.

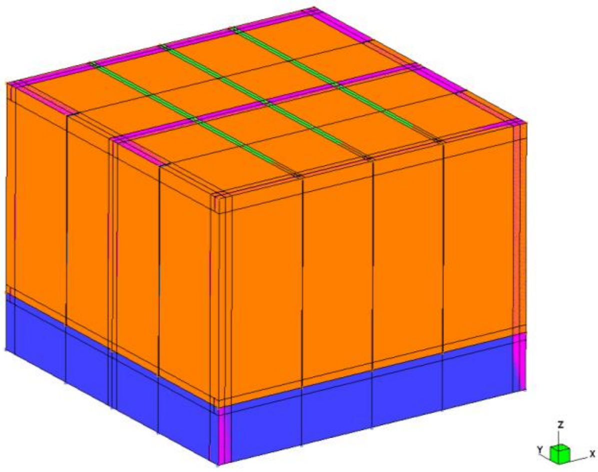
So, during the detail phase the buoy structure will be validate by a FEM calculation according to BV NR 494 ref.[5] and BV NR 467 ref.[6] in order to defined loads and criteria to validate the structure.

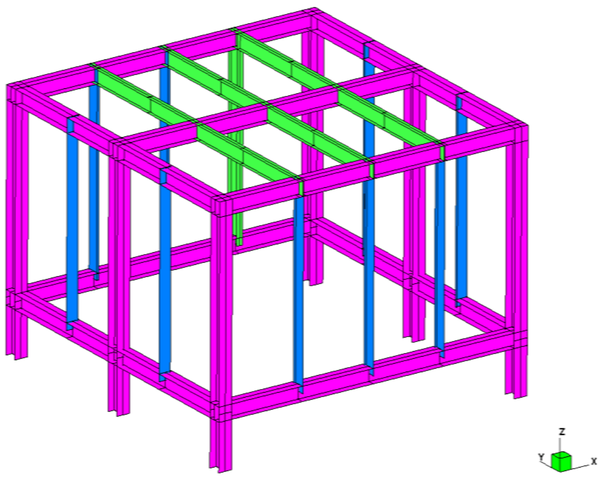
4.3. Shelter

4.3.1. Conceptual

- Model:

Scantling estimation of the shelter is made using an ISYMOST model with bar and plate elements as presented in figures below:





Shelter size and position are defined depending of the general arrangement ref.[2].

- Loads:

Applied loads on the shelter are:

  - ;
  - Acceleration values, taking equal to $5 m/s^2$ in each direction (estimated value by engineering judgement): conservative assumptions (see accelerations calculated in section Gravity **Error! Reference source not found.**.
  - Wind effect, calculated in accordance with API RP 2A WSD ref.[7] and the metocean data from ref.[1];
  - Photovoltaic panels weight distributed on the roof edges in the west, south and east directions;
  - Live load applied on the roof of the shelter equal to $250 kg/m^2$.

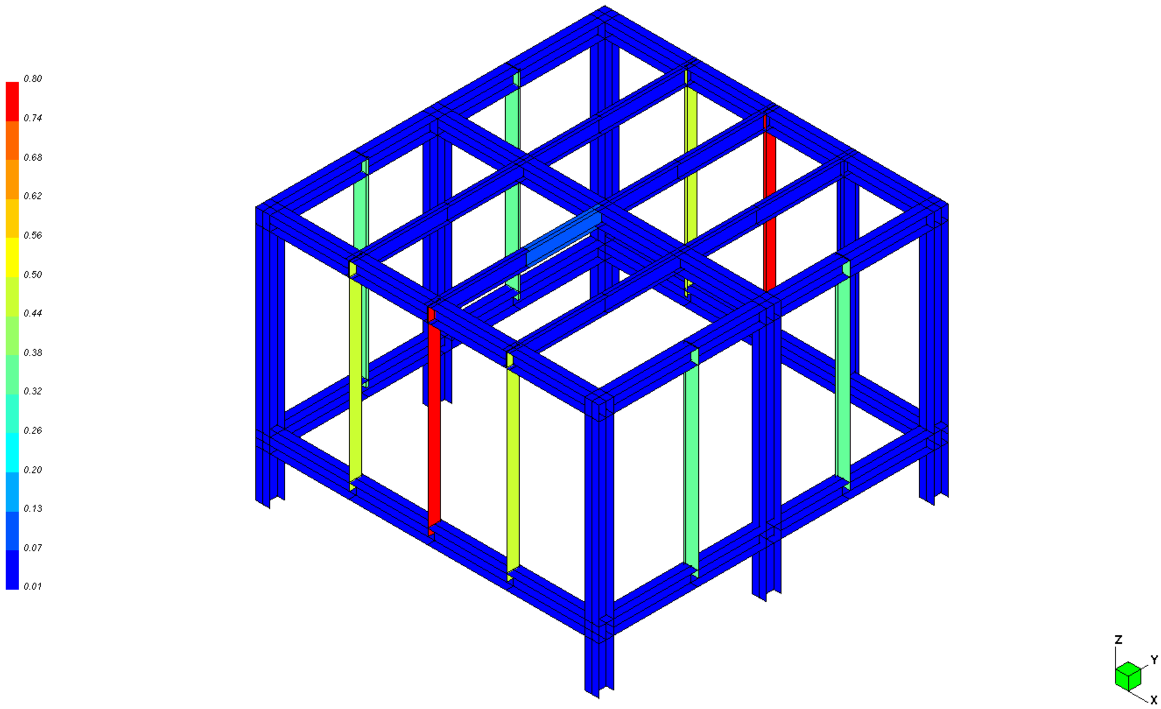
Note that a weight contingency factor estimated to 1.2 is applied.

Note that the shelter is considered protected from lateral pressures by the anti-intrusion structure and by the boat landing, see general arrangement ref.[2].

- Criteria and results:

Elements are checked using AISC code and taking into account a S235 steel material.

The maximum ratio obtained in bar elements is equal to 0.80.



- Mass:

Description of the shelter mass:

- Structural mass without plating = 1.86 mT
- Structural mass with plating = 4.88 mT
- Total estimated mass with mast and miscellaneous outfitting (door, foundations, handrails…) = 6.3 mT.

See detailed MTO in section 6.

4.3.2. Detail phase

Detailed FEM (equipment supports, mast definition, photovoltaic panels supports) using AISC Code.

4.4. Boat landing

4.4.1. Conceptual

The pre-design of the boat landing structure is defined without calculation but with feedback information issued from previous projects.

Total estimated mass equal 3.7 mT = primary structure (2.1 mT) + fenders + grating + davit (not shown) → sea layout ref.[2] and MTO in section 6.

4.4.2. Detail phase

FEM using AISC Code, considering chosen supply.

It would be important to investigate the supply size for the detail phase with taking into account the buoy size and the buoy freeboard.

Local check will be performed depending of the supply and the boat landing philosophy: supply impact or buoy mooring on supply.

4.5. Anchoring line outfitting and associated reinforcement

4.5.1. Conceptual

Weight estimation is described in the WCR (section 6).

4.5.2. Detail phase

FEM using BV Class and using tensions values calculated during conceptual phase in the mooring analysis in section 7.

4.6. Others outfitting and photovoltaic supports

4.6.1. Conceptual

Weight estimation of photovoltaic supports and others outfitting (listed below) are presented in the MTO (section 6):

- photovoltaic supports
- anodes
- anti-intrusion system
- mast
- handling devices
- ombilical connection
- cable trays and supports
- equipment foundations

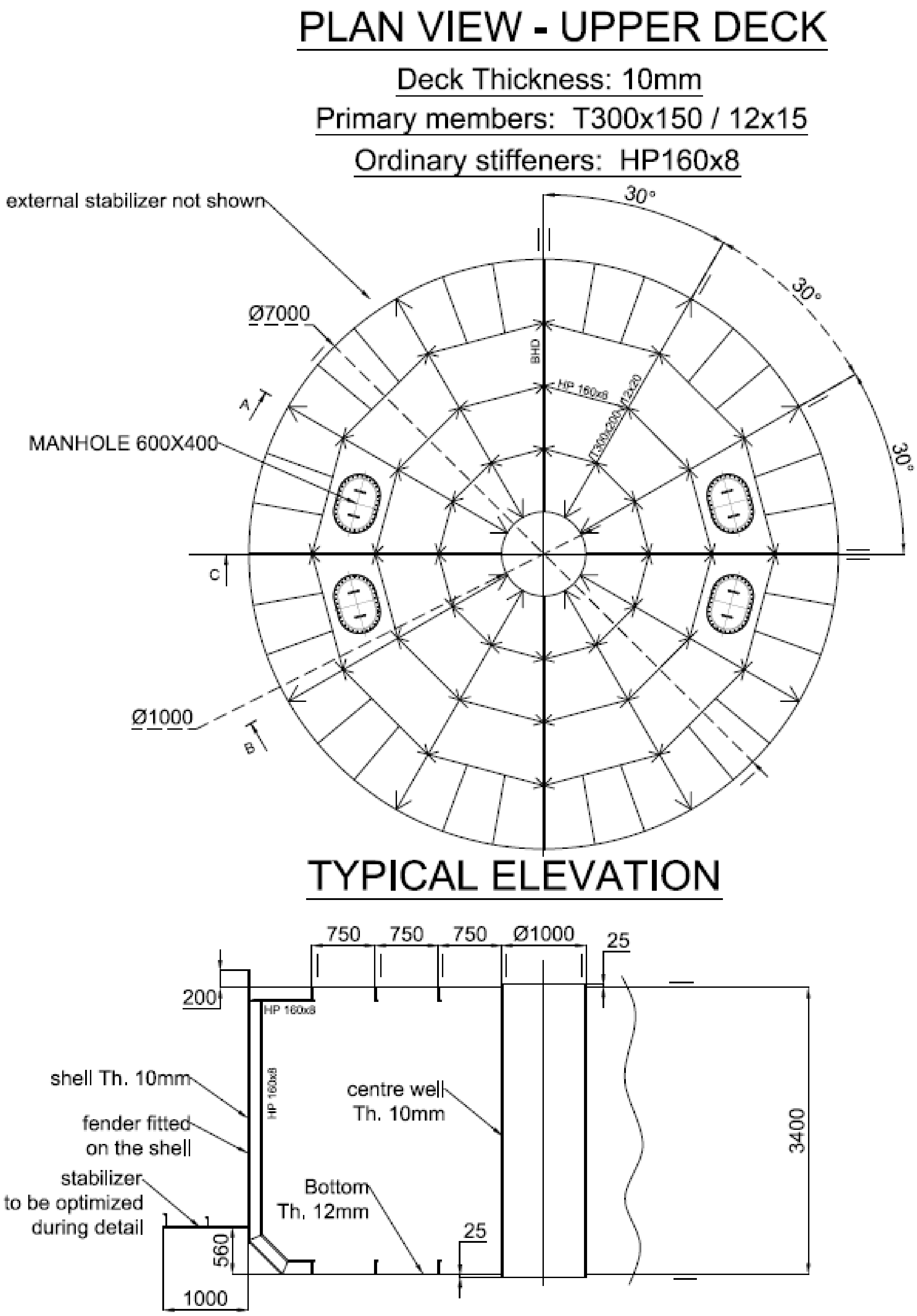
4.6.2. Detail phase

Detailed FEM using BV Class (ship type) and / or AISC (lattice structures).

5. STRUCTURAL ARRANGEMENT

The structural arrangement of the buoy is designed in order to contain all entities and equipment described in section 3.1 while responding to metocean data in MARMARA sea.

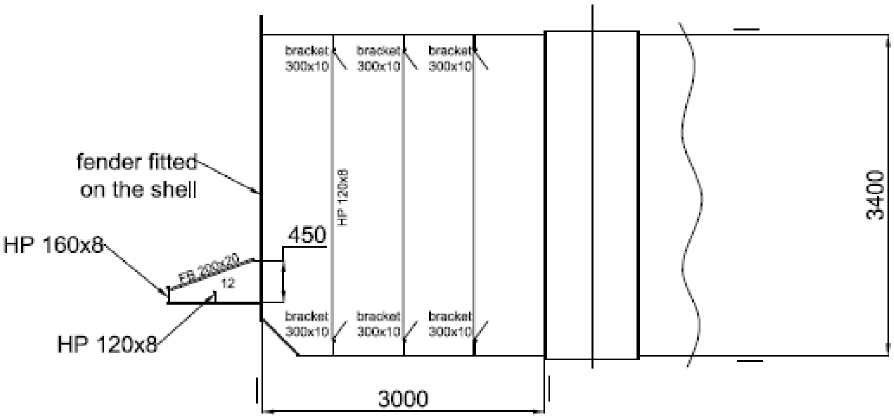
Scantling of the buoy is defined according to the BV NR 494 ref.[5] as presented in section 4.2. The weight estimation of the structure is detailed in the MTO (section 6) and in accordance with the drawing from ref.[3] presented below:



BULKHEAD ELEVATION

Deck Thickness: 8mm

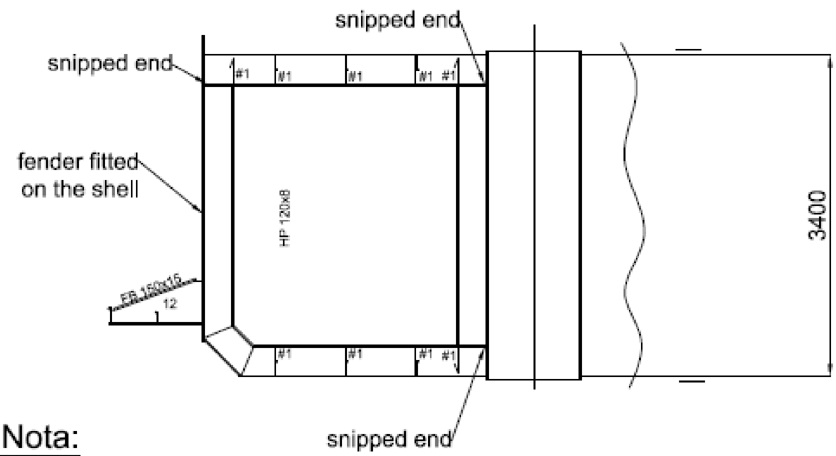
Ordinary stiffeners: HP120x8



MAIN FRAME ELEVATION

Primary members: T300x150 / 12x15

#1: Flat Bar 80x8



Nota:

- additionnal reinforcement to be added for anchoring line outfiitings

Note that the stabilizer will need to be optimized during the next phase depending of the mooring analysis (section 7).

6. MTO / WCR

The MTO / WCR is presented below according to section 4. Global weight and CoG position are data used for the mooring analysis presented in section 7.

	designation	lenght (m) / area (m²)	qty	Weight (mT)	CoG x(m)	CoG y(m)	CoG z(m)
Buoy body							
deck							
plate	plate Th. 10mm	37.70	1	2.96	0.00	0.00	3.40
ordinary stiffeners	HP160*8	3.10	12	0.47	0.00	0.00	3.40
primary members	T300x200/12x20	3.00	8	1.10	0.00	0.00	3.40
brackets	plate Th. 10mm	0.11	24	0.21	0.00	0.00	3.40
brackets	plate Th. 10mm	0.18	16	0.23	0.00	0.00	3.40
bottom							
plate	plate Th. 12mm	37.70	1	3.55	0.00	0.00	0.00
ordinary stiffeners	HP160*8	3.10	12	0.47	0.00	0.00	0.00
primary members	T300x200/10x15	3.00	8	1.10	0.00	0.00	0.00
brackets	plate Th. 12mm	0.18	16	0.27	0.00	0.00	0.00
radial bulkhead (x4)							
plate	plate Th. 8mm	10.20	4	2.56	0.00	0.00	1.70
ordinary stiffeners	HP120*8	3.40	12	0.38	0.00	0.00	1.70
brackets	plate Th. 10mm	0.09	24	0.17	0.00	0.00	1.70
side shell							
plate	plate Th. 12mm	74.77	1	5.87	0.00	0.00	1.70
ordinary stiffeners	HP160*8	3.40	24	1.04	0.00	0.00	1.70
primary members	T300x200/10x15	3.40	8	1.25	0.00	0.00	1.70
centre well							
plate	plate Th. 12mm	10.68	1	0.84	0.00	0.00	1.70
primary members	T300x200/10x15	3.40	8	1.25	0.00	0.00	1.70
stabilizer							
plate	plate Th. 10mm	25.13	1	1.97	0.00	0.00	0.50
primary members	T300x200/10x15	1.20	12	0.66	0.00	0.00	0.50
ordinary stiffeners	HP160*8	28.27	1	0.36	0.00	0.00	0.00
ordinary stiffeners	HP120*8	25.13	1	0.23	0.00	0.00	0.00
miscellaneous (handrails,...)				1.00	0.00	0.00	3.40
subtotal (contingency 1,1)				**30.73**	**0.00**	**0.00**	**1.38**
Shelter							
plate	plate Th. 12mm	7.14	1	0.67	0.00	0.00	3.87
plate	plate Th. 8mm	37.47	1	2.35	0.00	0.00	5.39
primary members	HEB140	45.10	1	1.52	0.00	0.00	5.06
ordinary stiffeners	IPN140	12.13	1	0.17	0.26	-0.19	5.86
ordinary stiffeners	HP120*8	1.94	9	0.16	-0.18	0.05	5.10
miscellaneous and provision (mast, handrails,equipment foundations)				1.40	0.00	0.00	3.87
subtotal				**6.28**	**0.00**	**0.00**	**4.81**
Photovoltaic panels supports							
				2.00	**0.00**	**-2.00**	**5.00**
Boat landing structure							
grating	55 kg/m2	8.93	1	0.49	0.26	2.85	4.42
handrail	25 kg/m	6.90	1	0.17	0.78	2.85	5.55
primary members	OD219.1x12.7	28.10	1	1.82	0.00	3.24	2.47
primary members	L100x100x10	17.10	1	0.26	0.78	2.85	5.04
miscellaneous and provision (davit, fenders, tertiary structures)				1.00	0.00	2.85	4.42
subtotal				**3.74**	**0.12**	**3.04**	**3.57**

Mooring system structure							
				1.00	0.00	0.00	2.30
Equipment list (contingency 1,1)							
				1.26	0.00	-1.00	5.00
Anti-piracy system							
				3.00	0.00	-1.00	2.30
Ombilical connection							
				0.50	0.00	0.00	2.30
TOTAL				48.5	0.01	0.13	2.18

7. MOORING ANALYSIS

7.1. Data

7.1.1. Environmental data

7.1.1.1. Marine Growth

As per Ref [1], marine growth is present from the surface down to 20:m depth. The maximal overall diameter of the marine growth is 300mm.

As per Ref [8], the density of the marine growth is set to 1325 kg/m^3.

7.1.1.2. Waves

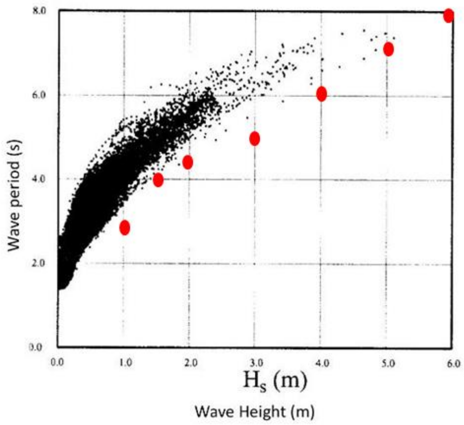
As per Ref [1], the waves are almost unidirectional (from the North-East) with a maximum of 6m significant height (Hs) with 8 seconds period (Tp).

The statistics show an average Hs of 1m coupled with 4 seconds period.

The operating conditions will therefore be based on this conditions.

In order to analyze the response of the buoys with all possible waves scenarios (orientation from the North-East), the following couple Hs/Tp are considered.

Hs (m)	Tp (sec)
1	3
1.5	4
2	4.5
3	5
4	6
5	7
6	8



A Dean stream function order 5 is used to model the waves.

A wave height (trough to crest) of 1.86 times the Hs is used for all simulation.

In order to simulate the stabilization of the buoy due to the current and wind forces, the simulation length is set to 45 times the wave period (5 period of ramp-up and 40 period of simulation).

7.1.1.3. Current

As per Ref [1], the current is considered as unrelated to the waves and wind and is oriented from the North-East at the surface down to 20m depth with a mean speed of 0.8 m/sec, and oriented from the South-West at the seabed with a mean speed of 0.3 m/s. The transition between the surface and bottom currents is consider as smooth.

7.1.1.4. Wind

As per Ref [1], 3 different wind speed are considered (oriented from the North-east)

16 knots (8.2 m/sec) which corresponds to an operating conditions.

23 knots (11.8 m/sec) which corresponds to winter conditions.

64 knots (33 m/sec) which corresponds to the extrema values.

7.1.2. Mooring lines Physical properties

3 mooring lines per buoys is considered.

Each mooring lines is constituted by 3 different segments:

- Steel wire rope for the 50 first meters
- Synthetic rope which shall not be in contact with the seabed.
- Steel chain to ensure the connection with the anchor.

Note: as the final properties of the wire/synthetic rope and chain will be given by the supplier during the next engineering phase, Orcaflex data (based on several project/suppliers) are used.

7.1.2.1. Steel wire

As a first approach, a 6x19 steel wire rope with wire core (40mm diameter) is considered.

The metallic cross section is assumed to be : $A = 0.455 \times \frac{\pi \times d^2}{4}$.

The Young's Modulus is taken as 113 000 MPa.

The axial stiffness is then : $= 4.04 \times 10^7 \times d^2\ kN$

7.1.2.2. Synthetic rope

As a first approach, a synthetic nylon rope (50mm diameter) is considered.

The axial stiffness is taken as : $= 1.18 \times 10^5 \times d^2\ kN$.

7.1.2.3. Chain

A studless chain is considered, with d the diameter of one bar (40mm).

The combined cross section area is then: $A = 2 \times (\pi \times \frac{d^2}{4})$.

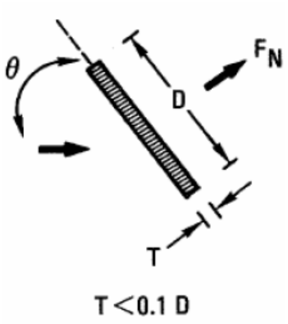
The axial stiffness is then: $= 0.854 \times 10^8 \times d^2\ kN$

7.1.3. Drag coefficients

7.1.3.1. Wind panels coefficients

The drag and lift coefficients used to calculate the forces induced by the wind on the buoys (by the solar panel and the anti-intrusion panel) are determined as per ref [8].

9. Thin flat plate inclined to flow



$$C_N = \begin{cases} 2\pi \tan\theta, \theta < 8^\circ \\ \dfrac{1}{0.222 + 0.283/\sin\theta}, 90^\circ \geq \theta > 12^\circ \end{cases}$$

$$C_L = C_N \cos\theta$$

$$C_D = C_N \sin\theta$$

7.1.3.2. Mooring lines coefficients

7.1.3.2.1. Chain

The drag coefficient for the Chain is set to 2.4 as per ref [8].

The inertia coefficient is set to 2.0

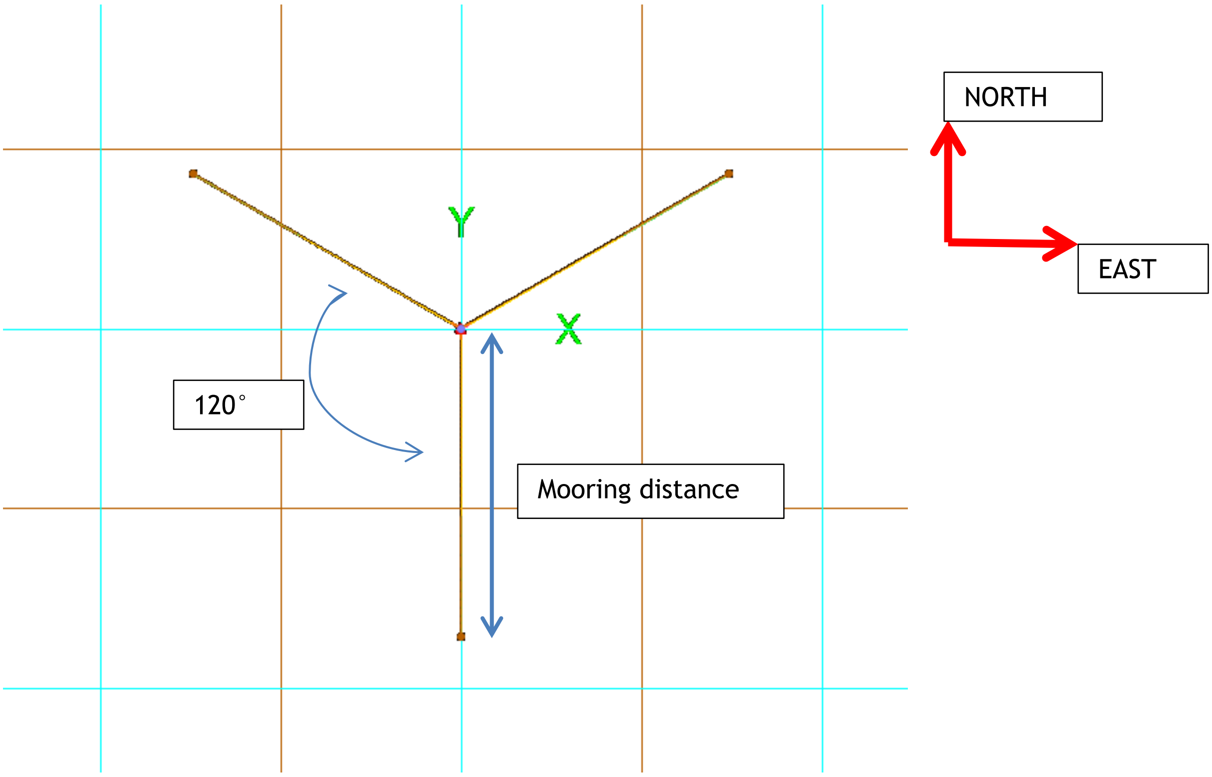
7.1.3.2.2. Steel wire, synthetic rope & umbilical

For circular cross sections, as per ref [8], the following set of properties are used.

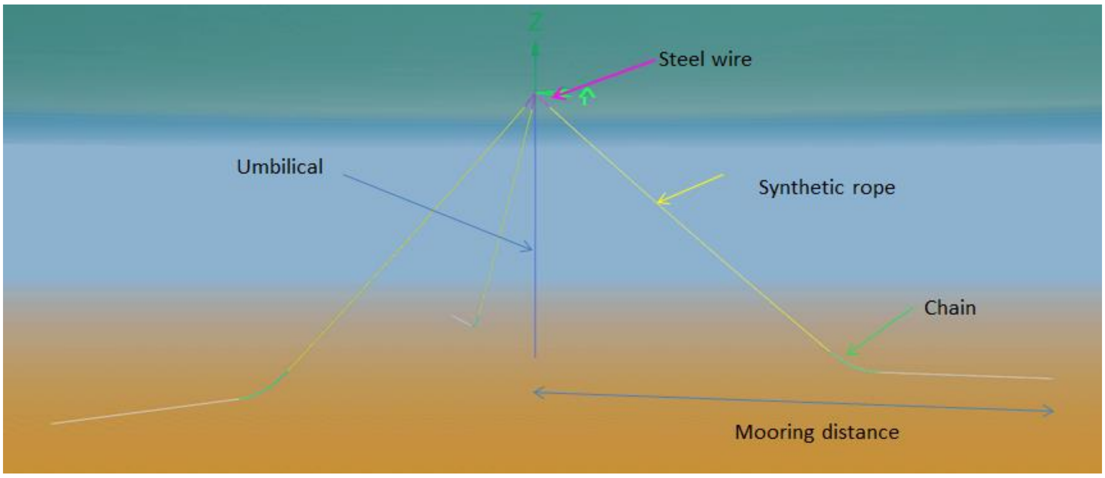
- Drag coefficient : 1.2
- Inertia coefficient: 2.0

7.1.4. Mooring lines arrangement

The mooring lines are positioned in order to have a 120° angle between each lines with one line oriented toward the south.



A sensitivity study about the mooring distance and the chain length is performed.



In the conceptual phase, a mooring distance of 2 times the water depth is considered.

For the 665m depth buoy, the chain length is set at 625m.

The anchoring lines arrangement is presented in reference [4].

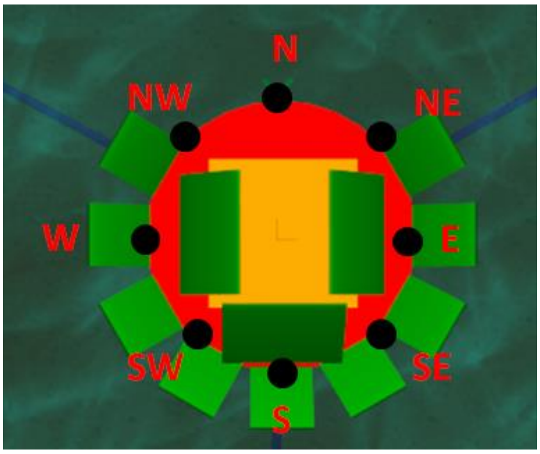
Note: the umbilical diameter is 50mm (weight of 4.5 kg/m in air).

7.2. Criteria

The following criterions will be checked to validate the preliminary mooring analysis:

7.2.1. Positive freeboard

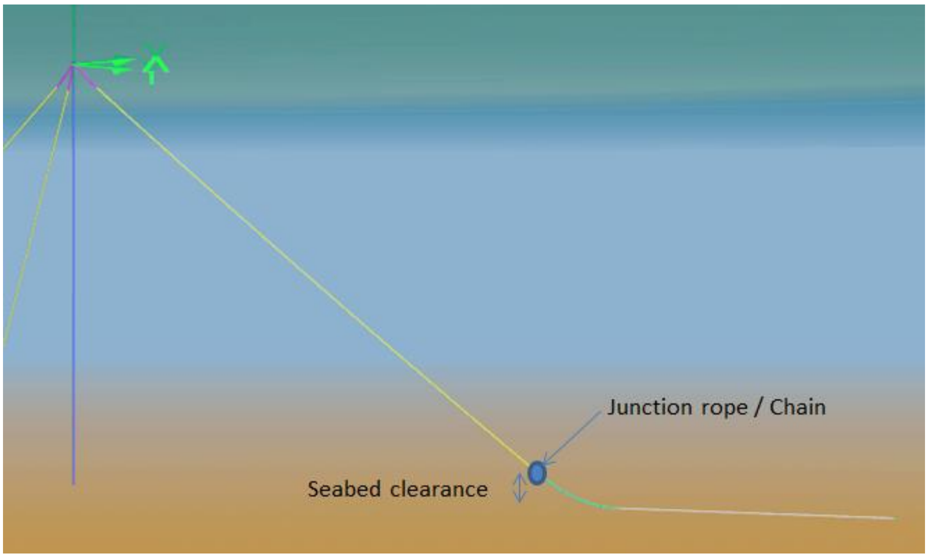
The freeboard is computed at 8 different points of the buoy and checked to be positive.



7.2.2. Synthetic rope seabed clearance:

The seabed clearance is computed for the 3 mooring lines.

A minimum clearance of 5m is considered acceptable.



7.2.1. Minimum tension in the mooring lines:

To avoid issues with fatigue of the mooring line assembly, mooring lines should not be subjected to slack.

7.2.2. Swinging

As the buoys are located in the shipping canal of the Marmara sea, the buoys displacements should me minimize as possible.

7.3. Base case configuration - Analysis

7.3.1. Static conditions

In static conditions, with the line arrangement proposed, the water draft is 1.7m.

As the buoy is 3.4m high, the freeboard is then 1.7m.

The modal analysis of the system gives the highest mode at 3.7 seconds.

Note: a detailed analysis around the highest mode period shall be performed in detail phase.

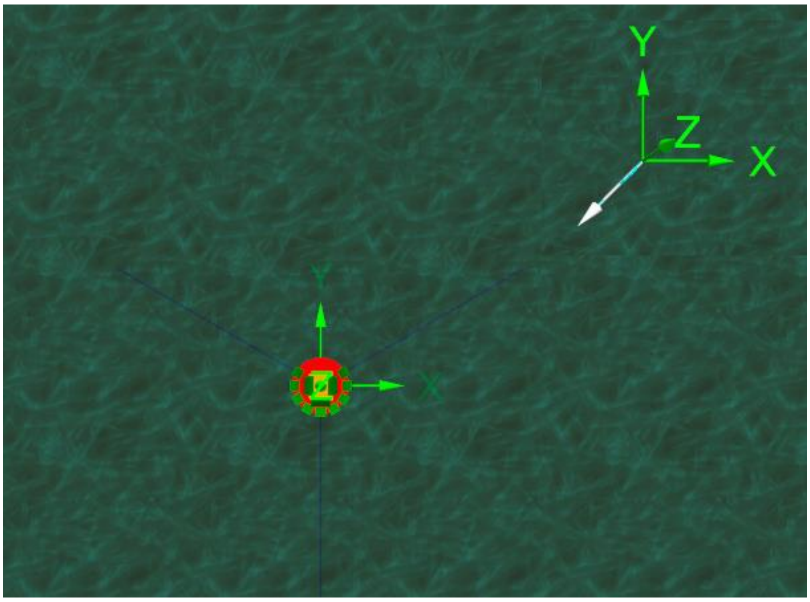
In the base case configuration, the bend stiffener for the umbilical is located at the bottom of the buoy.

7.3.2. Operating conditions

As shown in §7.1.1, for the operating conditions, the Hs is set to 1 m with a 4 seconds period, associated with a 8.2m/s wind and 0.8 m/s current.

In order to determine a swinging area for operating conditions, the analysis is performed with waves and wind oriented every 45° (even though some cases are unlikely to happen).

The current, however, stays oriented from the North-east for all cases.



In these conditions, the freeboards calculated at the point shown in §7.2.1 are:

Wave/Wind Direction	Free board (m)							
	E	NE	N	NW	W	SW	S	SE
West	0.8	0.9	0.9	1.0	1.2	1.2	1.1	1.0
SW	0.7	0.5	0.7	0.9	1.2	1.1	1.2	0.9
South	1.0	0.8	0.7	0.8	1.0	1.1	1.2	1.1
SE	0.8	0.7	0.7	0.8	1.1	1.2	1.1	1.0
East	0.7	0.6	0.7	0.9	1.1	1.2	1.2	1.0
NE	*0.7*	*0.5*	*0.6*	*0.9*	*1.1*	*1.2*	*1.2*	*1.0*
North	0.8	0.6	0.6	0.8	1.1	1.2	1.1	1.0
NW	1.0	0.9	0.8	0.9	1.1	1.2	1.2	1.0

The values for the North-East direction are highlighted as it is the predominant direction.

The rotation around the axis (see sketch above) are:

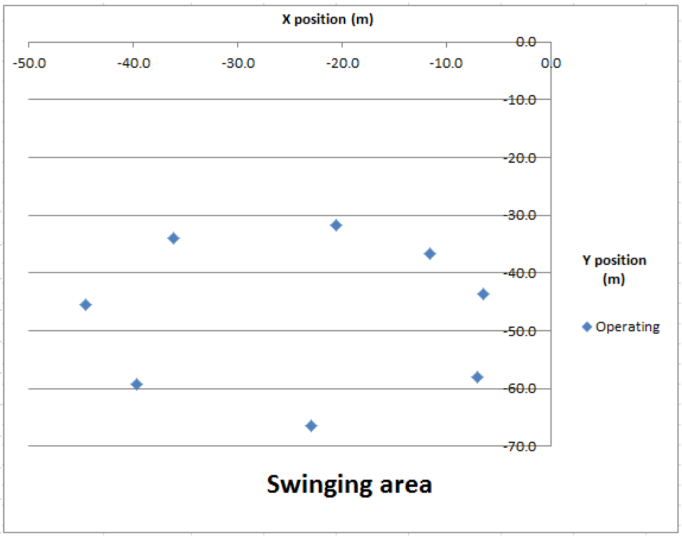
Wave/Wind Direction	Rotation (deg)					
	X min	X max	Y min	Y max	Z min	Z max
West	-3.9	-0.1	-13.9	16.7	-3.5	3.4
SW	-16.1	12.0	-11.5	14.3	-1.7	2.6
South	-18.9	15.0	0.2	2.4	-2.3	1.6
SE	-12.6	8.0	-8.3	10.6	-3.3	3.6
East	-4.5	-0.2	-8.8	12.2	-2.1	2.9
NE	*-11.0*	*5.2*	*-5.3*	*8.1*	*-0.5*	*0.9*
North	-15.4	8.5	0.3	2.2	-1.7	1.2
NW	-13.0	7.7	-7.2	8.9	-2.9	3.0

The acceleration at the top of the shelter are (in g):

Wave/Wind Direction	Acceleration (g)					
	X min	X max	Y min	Y max	Z min	Z max
West	-0.4	0.5	0.0	0.0	-0.2	0.2
SW	-0.4	0.4	-0.4	0.4	-0.2	0.2
South	0.0	0.0	-0.5	0.5	-0.2	0.2
SE	-0.2	0.2	-0.2	0.2	-0.1	0.1
East	-0.3	0.3	0.0	0.0	-0.1	0.1
NE	*-0.2*	*0.2*	*-0.2*	*0.2*	*-0.1*	*0.1*
North	0.0	0.0	-0.2	0.3	-0.1	0.1
NW	-0.2	0.2	-0.2	0.2	-0.1	0.1

The position of the buoy during the latest wave of the simulation are given in the table and graph below.

Wave/Wind Direction	Position (m)	
	X	Y
West	-6.5	-43.7
SW	-11.5	-36.7
South	-20.5	-31.6
SE	-36.1	-34.0
East	-44.6	-45.4
NE	-39.7	-59.3
North	-22.9	-66.4
NW	-7.0	-57.9



7.3.3. Extreme conditions

In order to analyze the behavior of the buoy in all possible conditions (waves/current/wind aligned from the North-East), the following cases are studied:

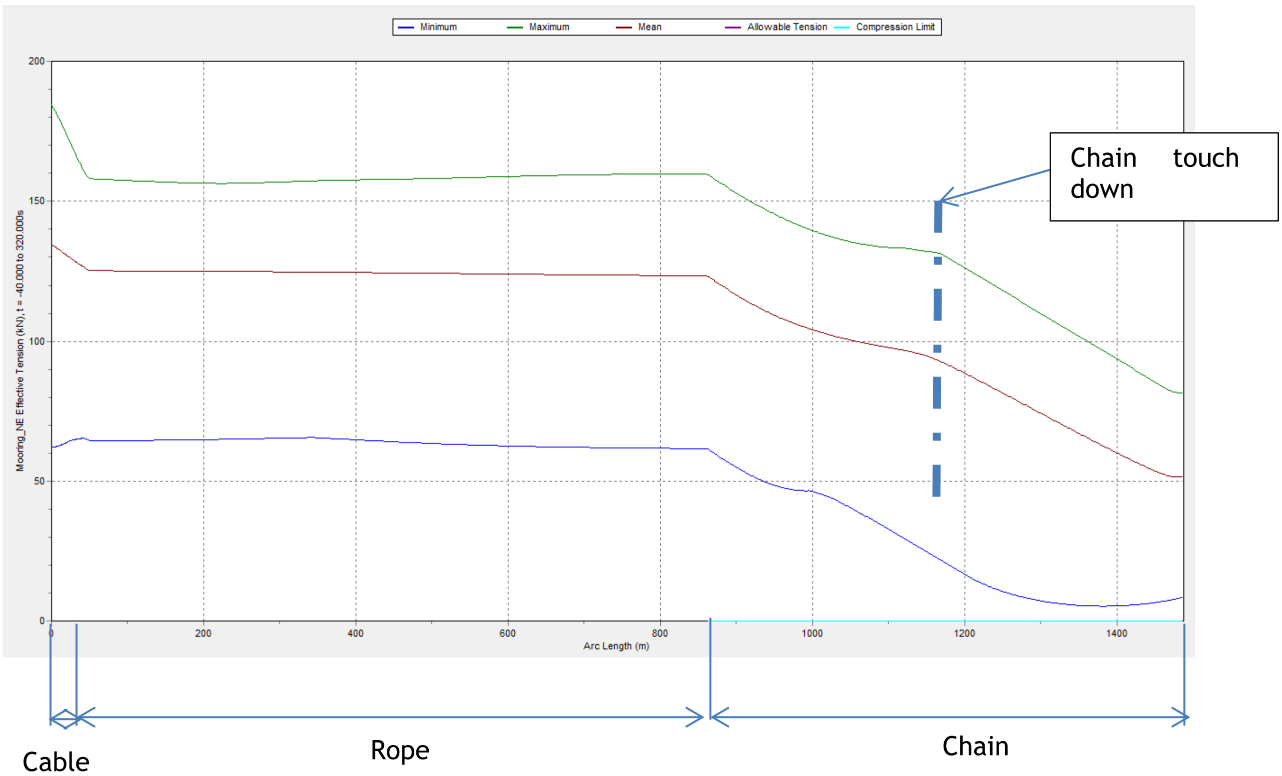
Case	Waves			Wind		Current	
	Hs (m)	Tp (sec)	Orientation	Speed (m/sec)	Orientation	Speed (m/sec)	Orientation
1	1	3	NE	8.2	NE	0.8	NE
2	1.5	4	NE	8.2	NE	0.8	NE
3	2	4.5	NE	8.2	NE	0.8	NE
4	3	5	NE	11.8	NE	0.8	NE
5	4	6	NE	11.8	NE	0.8	NE
6	5	7	NE	33	NE	0.8	NE
7	6	8	NE	33	NE	0.8	NE

7.3.3.1. Tension in the mooring line

The minimal and maximal tensions at buoy mooring points are reported in the table hereafter:

case	TENSION at Buoy mooring points (kN)					
	min NE	Max NE	min NW	Max NW	min South	Max South
1	64.0	158.7	56.2	94.6	8.0	88.8
2	59.7	135.7	59.4	91.7	33.8	89.9
3	53.5	152.3	54.2	98.0	30.9	98.5
4	40.5	181.9	31.4	110.2	7.8	115.1
5	55.0	172.1	45.5	96.8	10.0	100.6
6	69.6	185.8	45.4	90.7	13.3	90.3
7	73.2	184.4	48.8	87.9	15.1	85.1

The tension in the North-East line over its length is shown in the curves below (case 4):



The minimum tension occurs at the anchor.

The minimal and maximal tensions at anchor points are reported in the table hereafter:

case	TENSION at anchor points (kN)					
	min NE	Max NE	min NW	Max NW	min South	Max South
1	8.8	30.8	8.6	8.8	8.5	8.8
2	9.4	30.2	8.9	9.2	8.5	8.8
3	9.8	37.4	9.1	9.3	8.6	9.0
4	10.4	55.9	9.1	9.3	8.6	9.0
5	10.2	54.0	9.0	9.2	8.6	9.0
6	11.3	79.1	8.9	9.1	8.5	8.9
7	11.8	83.1	8.8	9.0	8.5	8.9

The coefficient friction between the chain and the seabed is set as first approach to 0.5. It is highly dependent on the type of soil.

Therefore, in case of the anchor cannot sustain the maximal tension (around 9 mT), in order to decrease the tension at the anchor points, the length of chain can be increased (in line with the mooring distance) to let the friction absorb the tension.

7.3.3.2. Forces at the umbilical connection

The maximum tension in the umbilical at the connection is 107.7 kN.
The maximum shear force at the umbilical connection is 4.2 kN.

Note: these values are calculated with an umbilical weight of 4.5 kg/m.

With an umbilical weight of 2.5 kg/m (0.35 kg/m in water), the maximum tension is 60 kN. As stated in §7.3.4, the influence of the umbilical on the buoy behavior is low.

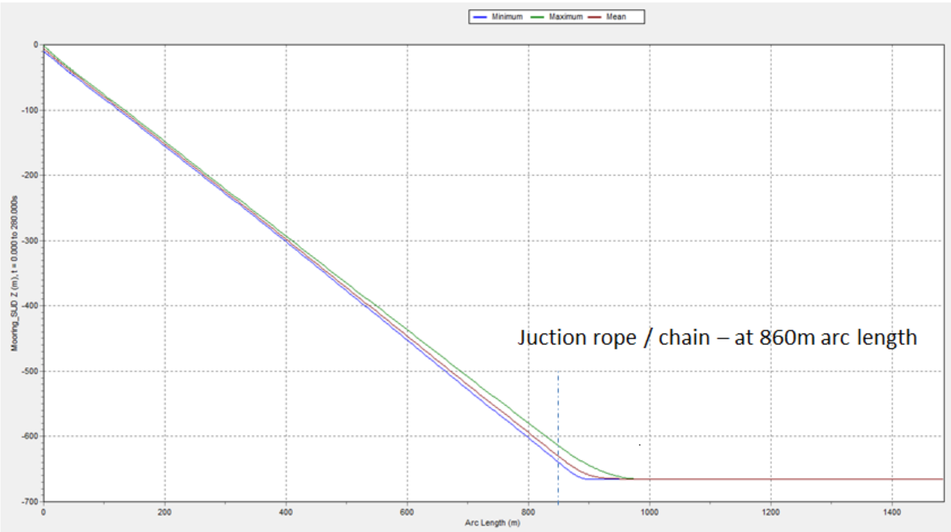
7.3.3.3. Synthetic rope seabed clearance

The following table gives the maximum depth of the junction between the synthetic rope and the chain.

The water depth being 665m, there is a minimum clearance of 18m on the south mooring line.

case	Depth junction rope / chain (m)		
	NE	NW	South
1	-616.4	-622.4	-633.7
2	-615.5	-621.7	-632.9
3	-614.8	-622.1	-635.4
4	-613.8	-623.6	-640.5
5	-613.2	-623.4	-640.8
6	-611.9	-626.9	-645.7
7	-611.2	-626.9	-647.1

The following graph shows the elevation profile of the south mooring line for the case 7.



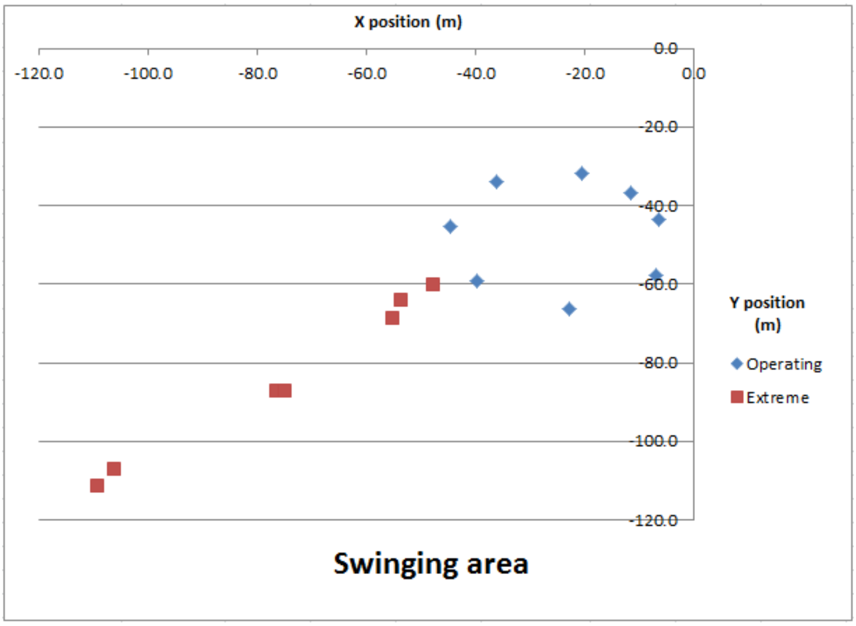
7.3.3.4. Freeboard

The freeboards calculated at the point shown in §7.2.1 are:

case	Free board (m)							
	E	NE	N	NW	W	SW	S	SE
1	0.5	0.3	0.5	0.6	0.4	0.1	0.0	0.0
2	0.2	0.1	0.2	0.7	0.8	0.8	0.9	0.7
3	0.1	-0.2	0.1	0.7	0.6	0.7	0.8	0.8
4	-0.3	-0.7	-0.2	0.6	0.1	-0.2	0.2	0.7
5	0.4	-0.1	0.2	1.0	0.6	0.4	0.7	1.2
6	0.7	0.4	0.6	1.1	0.5	0.3	0.9	1.3
7	0.6	0.2	0.4	1.0	0.7	0.5	1.0	1.3

7.3.3.5. Swinging

The position of the buoy during the latest wave of the simulation are given in the table and graph below.



7.3.3.6. Angles & Accelerations

For information, the rotation angles and the accelerations in extreme conditions are given below:

The rotation around the axis (see sketch above) are:

case	Rotation (deg)					
	X min	X max	Y min	Y max	Z min	Z max
1	-25.5	18.0	-16.7	15.5	-1.8	2.6
2	-15.2	7.8	-8.0	11.8	-0.7	1.7
3	-17.5	9.0	-9.8	14.5	-1.0	2.8
4	-23.7	17.0	-16.1	20.0	-1.5	7.2
5	-19.9	10.9	-10.1	12.9	-1.2	2.6
6	-13.5	9.5	-12.3	7.3	-1.3	3.2
7	-12.9	7.7	-11.2	5.0	-1.6	3.1

The acceleration at the top of the shelter are (in g):

case	Acceleration (g)					
	X min	X max	Y min	Y max	Z min	Z max
1	-0.5	0.4	-0.7	0.4	-0.5	0.4
2	-0.2	0.3	-0.2	0.3	-0.4	0.4
3	-0.5	0.5	-0.4	0.4	-0.6	0.5
4	-0.9	0.8	-0.8	0.7	-0.8	0.8
5	-0.5	0.4	-0.5	0.5	-0.5	0.5
6	-0.3	0.4	-0.3	0.4	-0.5	0.4
7	-0.3	0.3	-0.3	0.4	-0.4	0.4

7.3.4. Base case conclusion

The freeboard criteria is not satisfied for extreme waves conditions.

As the analyses have been performed with extreme envelop couple wind/waves (which may be very unlikely to happen – especially the case Hs 3m / Tp 5sec), a more detailed metocean data with its according scatter diagram may discard several case studied. The waves spectrum may have also have an influence on the response of the buoy (current analyses done with regular waves).

An option presenting satisfactory results under these conservatives assumptions is presented hereafter.

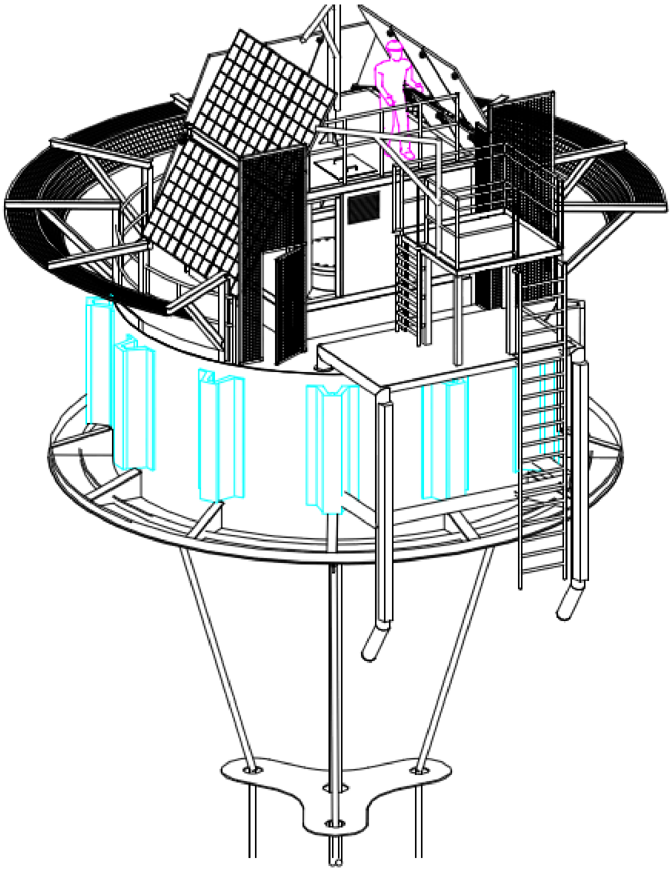
Note: a sensitivity study has been done without the umbilical. Its influence is relatively low as the freeboard changes about 10cm.

7.4. Tri-plate configuration - Analysis

In order to limit the movement of the buoys, one configuration with a tri-plate 5m below the buoy has been studied.

Note: other configurations (with clump weight along the mooring lines for instance) may also present satisfactory results.

Indeed, as the predominant direction of the waves, wind & current in aligned with a mooring lines (the North-East), a connection directly at the buoy tends to amplified the movement as the lines is constantly “pulling down” one side of the buoy.



Note: the definition of the ”tri-plate” or equivalent system shall be designed in the detailed phase (symbolic representation shown above).

The bend stiffener for the umbilical is considered to be at the tri-plate level to avoid any clashes with the mooring lines.

7.4.1. Static conditions

In static conditions, with the line arrangement proposed, the water draft is 1.7m.

As the buoy is 3.4m high, the freeboard is then 1.7m.

The modal analysis of the system gives the highest mode at 3.7 seconds.

7.4.2. Operating conditions

The operating conditions are the same as the ones defied for the base case.

In these conditions, the freeboards calculated at the point shown in §7.2.1 are:

Wave/Wind Direction	Free board (m)							
	E	NE	N	NW	W	SW	S	SE
West	0.9	0.9	1.1	0.8	0.7	0.9	1.1	0.9
SW	0.7	0.7	0.7	1.0	0.9	0.8	0.8	1.0
South	1.0	0.9	0.9	0.9	1.0	0.8	0.7	0.8
SE	0.7	1.0	1.2	1.1	1.2	1.1	0.8	0.7
East	0.6	0.7	1.0	1.2	1.3	1.3	1.1	0.8
NE	***0.7***	***0.5***	***0.6***	***0.9***	***1.2***	***1.3***	***1.3***	***1.1***
North	1.0	0.6	0.5	0.7	1.0	1.3	1.3	1.3
NW	1.2	1.0	0.7	0.6	0.8	1.2	1.3	1.1

The values for the North-East direction are highlighted as it is the predominant direction.

The rotation around the axis (see sketch above) are:

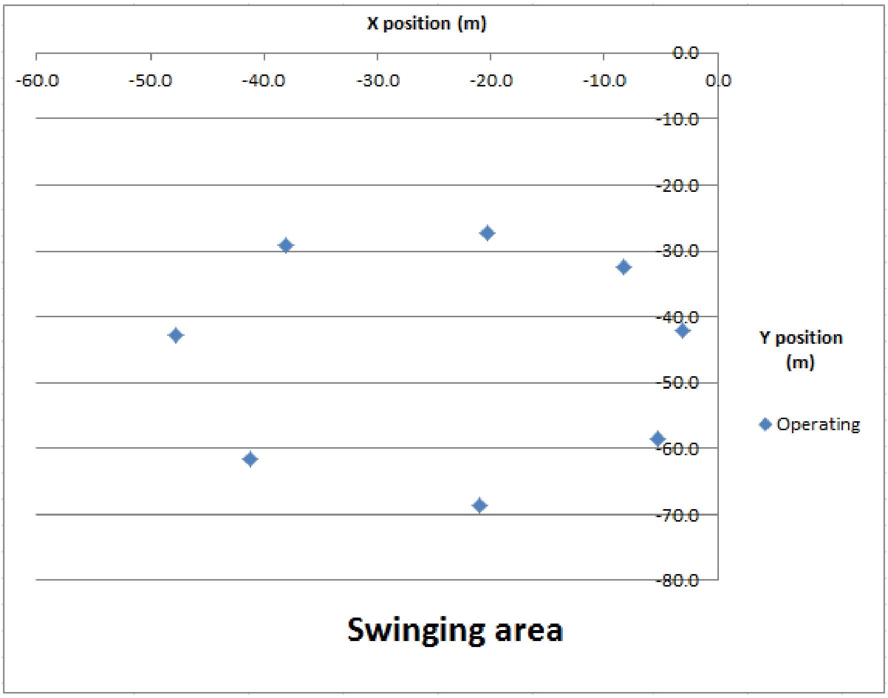
Wave/Wind Direction	Rotation (deg)					
	X min	X max	Y min	Y max	Z min	Z max
West	-1.8	0.2	-5.6	12.3	-0.8	-0.2
SW	-9.6	4.4	-4.3	9.5	-0.2	1.0
South	-12.1	6.0	-0.5	0.9	0.1	0.4
SE	-7.5	3.8	-7.3	3.9	-1.0	0.0
East	-1.8	0.2	-9.0	5.2	-0.5	0.1
NE	***-3.7***	***5.8***	***-6.0***	***3.5***	***-0.1***	***0.7***
North	-5.0	8.7	-0.2	0.8	0.0	0.4
NW	-3.9	7.0	-3.4	7.3	-1.0	0.0

The acceleration at the top of the shelter are (in g):

Wave/Wind Direction	Acceleration (g)					
	X min	X max	Y min	Y max	Z min	Z max
West	-0.4	0.2	-0.1	0.0	-0.2	0.2
SW	-0.3	0.2	-0.3	0.2	-0.2	0.2
South	0.0	0.0	-0.4	0.3	-0.2	0.2
SE	-0.2	0.3	-0.2	0.1	-0.3	0.2
East	-0.2	0.3	-0.1	0.0	-0.3	0.3
NE	***-0.1***	***0.2***	***-0.1***	***0.2***	***-0.3***	***0.3***
North	0.0	0.0	-0.2	0.3	-0.3	0.3
NW	-0.2	0.2	-0.2	0.3	-0.3	0.2

The position of the buoy during the latest wave of the simulation are given in the table and graph below.

Wave/Wind Direction	Position (m)	
	X	Y
West	-3.1	-42.1
SW	-8.3	-32.4
South	-20.2	-27.2
SE	-38.0	-29.2
East	-47.7	-42.8
NE	-41.3	-61.5
North	-21.0	-68.7
NW	-5.3	-58.4



7.4.3. Extreme conditions

The cases analyzed are the same as for the base case configuration.

7.4.3.1. Tension in the mooring line

The minimal and maximal tensions at buoy mooring are reported in the table hereafter:

case	TENSION at Buoy mooring points (kN)					
	min NE	Max NE	min NW	Max NW	min South	Max South
1	58.1	139.1	64.1	90.1	37.2	89.2
2	52.6	143.6	56.7	95.2	26.6	95.1
3	47.6	150.4	50.2	99.7	18.4	100.8
4	39.4	167.5	39.6	107.7	6.0	106.2
5	47.4	162.0	44.8	102.9	9.2	100.1
6	66.4	189.2	42.7	91.8	6.1	94.2
7	68.8	189.3	49.1	87.0	9.9	88.6

The minimal and maximal tensions at anchor points are reported in the table hereafter:

case	TENSION at anchor points (kN)					
	min NE	Max NE	min NW	Max NW	min South	Max South
1	8.7	23.2	8.5	8.6	8.4	8.6
2	9.2	30.1	8.9	9.0	8.4	8.8
3	9.4	35.2	9.0	9.3	8.5	8.9
4	9.9	49.5	9.0	9.3	8.5	8.9
5	10.0	51.1	9.0	9.4	8.5	8.9
6	11.1	81.1	8.8	9.0	8.4	8.8
7	11.6	84.2	8.7	8.9	8.4	8.8

7.4.3.2. Synthetic rope seabed clearance

The following table gives the maximum depth of the junction between the synthetic rope and the chain.

The water depth being 665m, there is a minimum clearance of 16m on the south mooring line.

case	Depth junction rope / chain (m)		
	NE	NW	South
1	-617.8	-622.9	-632.3
2	-616.9	-623.0	-634.9
3	-616.0	-623.2	-636.6
4	-615.0	-624.1	-641.0
5	-614.5	-624.1	-642.1
6	-613.1	-628.2	-647.6
7	-612.5	-628.2	-648.9

7.4.3.3. Forces at the umbilical connection

The maximum tension in the umbilical at the connection is 138.7 kN.
The maximum shear force at the umbilical connection is 4.1 kN.

7.4.3.4. Freeboard

The freeboards calculated at the point shown in §7.2.1 are:

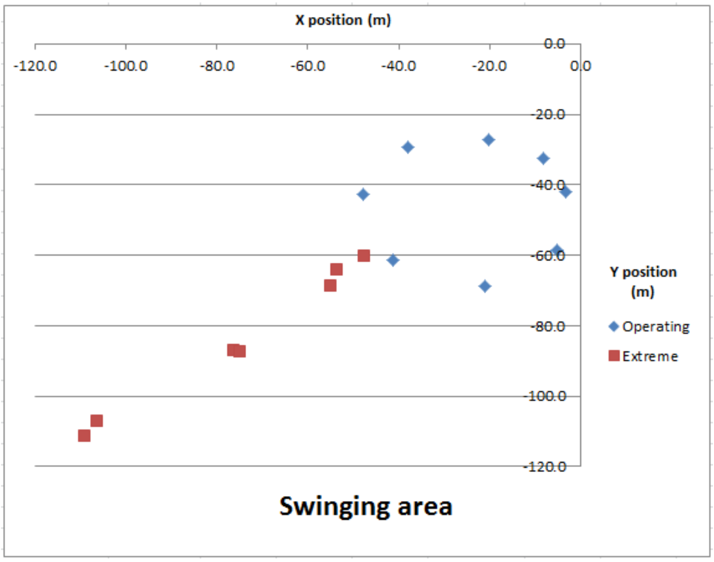
case	Free board (m)							
	E	NE	N	NW	W	SW	S	SE
1	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.6
2	0.5	0.2	0.3	0.7	1.0	0.9	1.1	0.9
3	0.5	0.2	0.4	0.8	1.0	0.9	1.1	1.0
4	0.5	0.2	0.4	0.8	0.8	0.6	0.9	1.0
5	0.8	0.5	0.7	1.1	0.9	0.7	0.9	1.3
6	1.2	1.0	0.9	1.1	0.3	-0.1	0.5	1.4
7	1.3	1.1	1.0	1.1	0.2	-0.1	0.4	1.4

The negative freeboard (10cm) for cases 6 & 7 are considered are acceptable as they are calculated for extreme conditions. Moreover, the buoys are equipped with a 60cm bulwark and scupper to limit the green water.

7.4.3.5. Swinging

The position of the buoy during the latest wave of the simulation are given in the table and graph below.

case	Position (m)	
	X	Y
1	-53.5	-64.3
2	-47.6	-60.3
3	-55.0	-68.8
4	-76.3	-87.1
5	-74.8	-87.3
6	-106.2	-107.0
7	-109.1	-111.3



7.4.3.6. Angles & Accelerations

For information, the rotation angles and the accelerations in extreme conditions are given below:

The rotation around the axis (see sketch above) are:

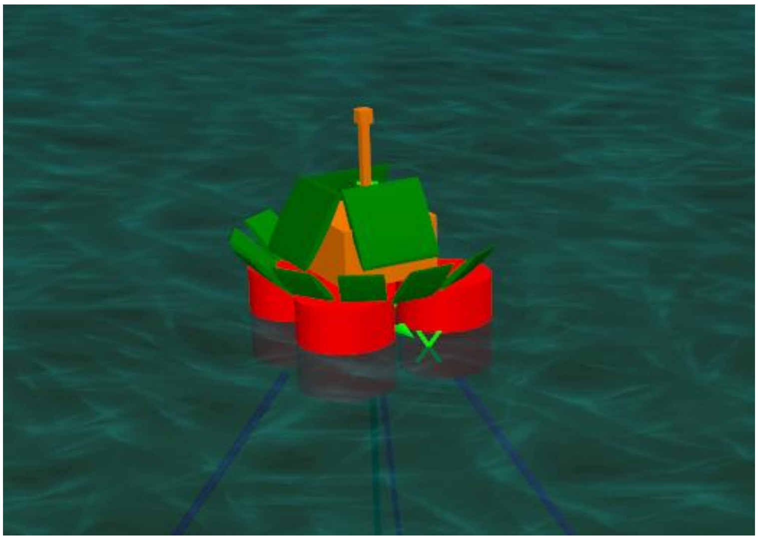
case	Rotation (deg)					
	X min	X max	Y min	Y max	Z min	Z max
1	-5.6	9.7	-10.6	5.6	-0.2	1.0
2	-5.0	8.7	-8.8	5.1	-0.1	1.3
3	-4.9	9.9	-9.8	5.1	-0.2	1.8
4	-4.9	12.6	-12.8	4.5	-0.2	3.1
5	-3.9	10.7	-10.7	4.3	-1.0	3.6
6	2.0	12.6	-15.1	-5.0	-2.6	3.8
7	1.9	12.2	-14.8	-5.6	-0.6	3.4

The acceleration at the top of the shelter are (in g):

case	Acceleration (g)					
	X min	X max	Y min	Y max	Z min	Z max
1	-0.3	0.4	-0.3	0.4	-0.3	0.2
2	-0.2	0.3	-0.2	0.3	-0.5	0.4
3	-0.3	0.3	-0.3	0.3	-0.5	0.4
4	-0.4	0.4	-0.4	0.4	-0.6	0.5
5	-0.4	0.3	-0.4	0.3	-0.6	0.5
6	-0.3	0.2	-0.3	0.3	-0.5	0.4
7	-0.3	0.2	-0.3	0.2	-0.4	0.3

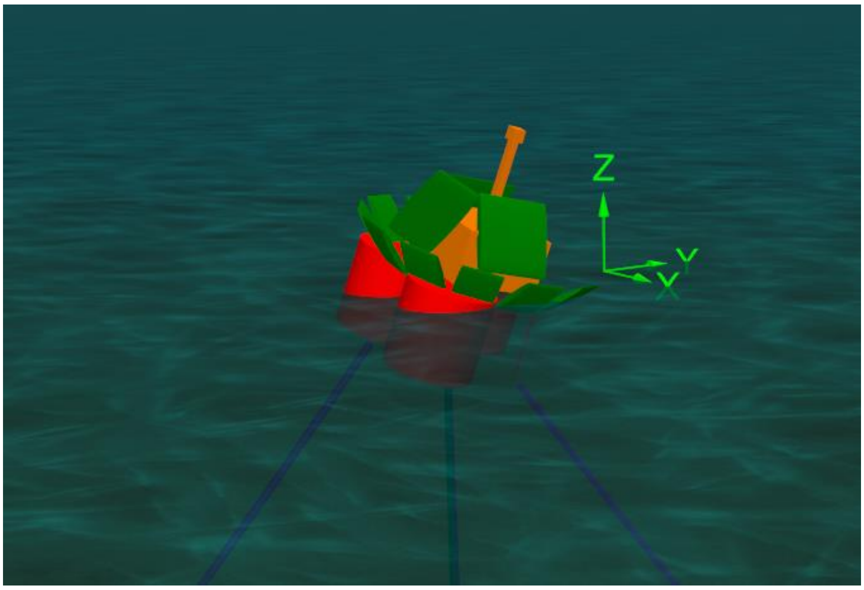
7.5. Damaged stability

In order to analyze the loss of buoyancy in one compartment, the buoy has been discretized in 4 equivalent buoys (with ¼ of buoy weight and volume).



To simulate the loss of buoyancy, the volume of one buoy is set to 0.

The declination angle of the buoy with one compartment breached is 19 deg with a mean draft of 2.5m.



APPENDIX A. EQUIPMENT LIST AND MTO

Equipements		Nombre	Masse unitaire (kg)	Volume unitaire (m3)	Masse totale (kg)	Volume total (m3)
Génération d'énergie	Panneaux photovoltaïques LG 370WC Neon R monocristallin	20	19	0.07	380	1.40
	Batterie solaire plomb gel 12V 130Ah SONNENSCHEIN	14	38	0.012	525	0.16
	Régulateur Victron Smartsolar MPPT 250-60	1	5	0.02	5	0.02
	Convertisseur BT/HT	1	30	0.02	30	0.02
Gestion des capteurs	COSTOF2	1	25	0.047	25	0.05
	Pupitres	2	30	0.25	60	0.50
	Enceintes diverses	3	20	0.04	60	0.12
Communication	Modem 4G	1	5	0.02	5	0.02
	Antenne 4G	1	10	0.04	10	0.04
	Modem Wifi	1	5	0.02	5	0.02
	Antenne Wifi	1	10	0.04	10	0.04
Signalisation	Boitier AIS McMurdo	1	1	0.01	1	0.01
	Antenne AIS McMurdo	1	1	0.04	1	0.04
	Feux de signalisation	1	10	0.04	10	0.04
Météo	Récepteur météo GILL MaxiMet	1	5	0.02	5	0.02
	Capteur météo GILL MexiMet	1	10	0.04	10	0.04
Total					1142	2.54