POLITECNICO DI TORINO

DIMEAS – Department of Mechanical and Aerospace engineering

Master Degree

of Mechanical Engineering

Master Thesis

NUMERICAL MODELLING AND DESIGN OF FLOATING PLATFORMS FOR SEASTEADING

Supervisors

Prof. Giuliana Mattiazzo

Eng. Antonello S. Sirigu

Candidate

Domenico Castellano

278915

October 2022

Summary

Abstract

The offshore world has been growing over the years, the rise in sea levels and the increasingly intense demand to live near port centers pushes humanity to wonder what it would take to live on the sea. The aim of this thesis is to investigate the feasibility and design parameters (dimensions, materials and mooring) of a floating platform destinate to living, in order to obtain system's static and dynamic stabiity.

The floating platform will be installed inside the Venice's lagoon; considering the DNVGL-OS-E301 standard, the external environment is investigated: the 100-year return periods for waves and wind are obtained, and the 10-year return periods for the current. The data taken are from the CNR, subjected to a specific filtering and then used.

For the materials, since it's a new concept, similar types of constructions have been identified, from pontoons to everything regarding large, concrete marine constructions and the precautions for using it. Both material and material's construction precautions are documented.

Constraints and limits were identified to obtain appropriate comfort, specifically accelerations and displacements on the main degrees of freedom; both chosen after an analysis of the state of the art in the offshore marine world.

The overall system stability is investigated on the OrcaFlex software: different mooring's configurations are tested, to compare the mooring's influence on system's stability.

The thesis concludes with a chapter on a larger platform, for more intense sea states. And a study is proposed on the dynamic stability of the platform + superstructure system, iterating on ballast and mass distribution. The program used is Matlab with Nemoh extension.

Introduction

The rise in sea level and the massive demographic growth in coastal cities pushes to explore new solutions, thus the idea of creating livable spaces on the sea was born. To expand living areas in places unthinkable yet in front of our eyes. Once unlocked this "degree of freedom" the possibilities of what to do with this innovation are endless.

The idea of floating things on the water is one of the oldest, the same can be said for big platforms with basements built on water; also, the mix of them has been tried in the past: floating platforms with huge investments forced by the need of space not available elsewhere.

What's new is the modularity, that allows flexibility both financially and dimensionally. It's possible to start with one platform, and then add others at will. Or move the existing one elsewhere, change the system configuration; think of a city built on modular floating platforms (MFP): it would be possible to adapt the city needs with the growth of the city itself.

Of course, the engineering challenge is impressive: the sea has always been seen as indomitable and unpredictable; this study was created to verify that we finally have the engineering tools to make such a challenge possible, and to provide preliminary data to assess feasibility and convenience on the economic side.

Figure 1 concept design of a Modular floating platform

The concept

The platform will have a hexagonal shape, with the possibility of connectors on each side, and mooring on each vertex.

Anything can be built on top of the hexagonal structure: houses, public buildings, parks, wind turbines, solar panels and much more.

The platform must be so steady that to permit everyday life and must keep dry the superstructure.

Hexagonal shape and connectors allow a honeycomb modularity, so as to add platforms and grow at will. Other pros are the possibility of replacing the hexagonal module with an identical one, allowing freedom of configurations that normal cities do not allow.

The mooring possibility on each vertex allows the possibility to adjust to different configuration and sea state, in order to reuse the same platform for different applications.

The material chosen is the marine lightweight reinforced concrete, since it is reliable, common, well-known material. Many infrastructures dealing with sea have been built with it.

It is good to reserve a 10% of total mass as ballast, in order to level platforms with different superstructure's weight.

The case study

The main topic of this thesis is a group of three floating platform in the Venice lagoon. The idea is to create a prototype of "reduced" size started of 18 m (diameter of the circumscribed circumference).

It's a place where the sea condition is well known, optimal to test not only structural integrity but also the social acceptance, infarct it will be built in occasion of "La biennale di Venezia 2024".

The platform

To fulfill the object of this thesis the first order of business is to design the platform. From a first look on materials and derived constrains, followed by the actual design of the platform is presented in this chapter.

The reader will probably notice discrepancies on the dimensions of the examples and case studies: this is because the argumentations also want to stand for a future platform, much bigger than this prototype.

Materials

The material chosen for this type of application is the concrete, since it has very high durability hence low maintenance interventions and costs, it’s high density also lower the barycenter of the structure, optimal for stability. (RodrigoPérez Fernández 2013)

The two main candidates were the steel and the concrete, both famous for their reliability and characteristics. In general, large ships are made of steel, while large structures (floating and not) are usually made in concrete. The choice fell on the concrete because of the new tendency of using concrete for large application such as Offshore Wind Turbines. (Alexandre Mathern 2021)

Other material such as combination with EPS and concrete or composites (Eduardo Cejuela 2018) were considered but discarded, since too expensive or complex for this first application.

Follows a table describing characteristics and composition of the marine concrete CEM IV/B 32.5 R:

Table 1 concrete CEM IV/B 32.5 R density

MATERIALI		Miscela 1 kg/m³	Miscela 2 kg/m³
Cemento	Cem IV/A 42.5 R	380	-
	Cem IV/B 32.5 R	-	380
Acqua		165	165
Additivo		7,9	7,9
Aggregati ssa	Sabbia 0-3 bsaltica	783	586
	Sabbia silico calcarea 0-5	90	269
	Graniglia 10-16 basaltica	570	611
	Graniglia 16-25 basaltica	384	368
Aria (litri/m³)		20	14
Totale		**2380**	**2387**

Worth noticing that there are lighter marine concretes that goes down to density of 1800 kg/m3, more expensive. This chapter is to assess the feasibility of the construction, further details will be left to the executive and economic design phases.

Construction process

The discussion is still open on whether the construction must be made on site or pre casted, both having different pros and cons:

Construction System	Advantages
Construction Using Floating Dock	1. Long experience construction process 2. Floating factory: industrialized construction procedure, high quality standards, safety. 3. Decrease in execution schedule 4. Continuous process: no concrete joints. 5. Very low occupation of land, storage of caissons in dock. 6. Quick installation of equipment. 7. Easy transport of the floating dock (towed or on special ship).
Construction Using Conventional Equipments on Land	1. Construction structure on land: Traditional auxiliary means, less specialized personnel. 2. Cured with fresh water and set to 28 days. 3. Versatility in terms of dimensions and shapes. 4. Possibility of simultaneous construction of several caissons. 5. Lower initial investment

Table 2 Advantages of Floating Docks Contruction type and Conventional Equipment type

Construction System	Disadvantages
Construction Using Floating Dock	1. Curing with seawater is forbidden in many countries. 2. Limitation to floating dock dimensions, geometry for sliding formwork: difficulty for special caissons. 3. Logistics: supply of steel and concrete without interruptions. 4. Specialized workforce needed. 5. Investment in floating dock.
Construction Using Conventional Equipments on Land	1. Huge surface occupation. 2. Great means for launching caissons: dry dock or syncro-lift (less inconvenience if we take advantage of naval shipyards) 3. High term for assembly work facilities. 4. Using of climbing formwork: horizontal joints in the structure. 5. Slower process: several teams needed to work as fast as in the floating dock system.

Table 3 Disadvantages of Floating Docks Contruction type and Conventional Equipment type

The major disadvantage of the floating dock is the concrete curing, because in most countries it is forbidden to be made in seawater.

Possible construction sites are dry dock, floating barge and construction basin.

Figure 2 dry dock

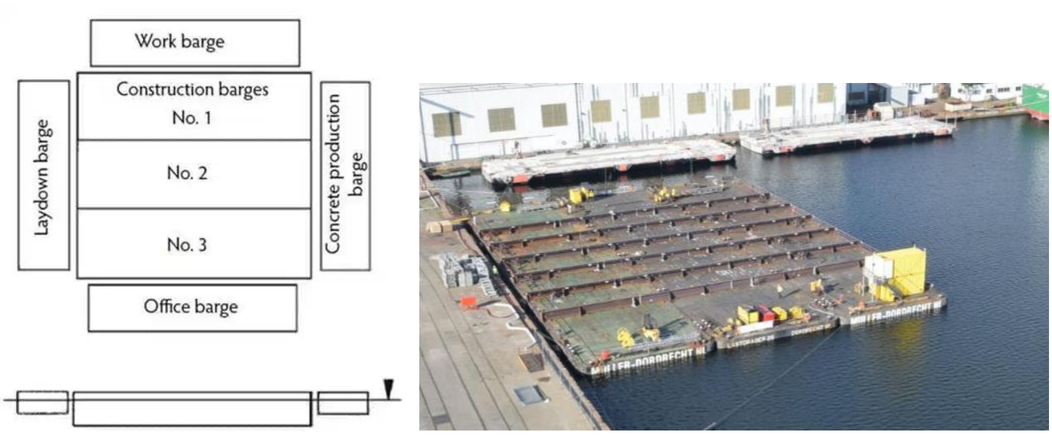


Figure 3 floating barge

Most critical factors are the eventual transportation and the soaking, since they are expensive processes, and an accurate analysis is what this problem deserve. For the moment it's possible to assess that construction of this type of big floating platform is possible. Therefore, the study can proceed.

CAD model

A cad model of the first prototype has been designed on Solidworks, taking into consideration the observation made during the study of the state-of-the-art similar constructions.

The mass of the entire structure has the upper limit of the Archimedes formula, from which the total weight a percentage must go to the superstructure, the more the better since it would mean lighter so cheaper platform. Also, at least 10% of the total mass should go to the ballast.

Another design constraint is the waterline, set to 1 m below the deck, higher than all waves.

Experts in the field were consulted to do a preliminary design of the internal structure: the concrete has better structural characteristic if walls have 90° angle between them; also, a very standard angle helps the construction phase keeping it cheaper. Typical thickness used for this type of construction range between 20-30 cm for the internal walls and 30-50 cm for screed and external walls. Usually, it's difficult to go below the 15 cm because of difficulties in placing the steel internal reinforcement.

The main punctual loads acting on the platform are mooring and connectors.

The CAD is then generated:

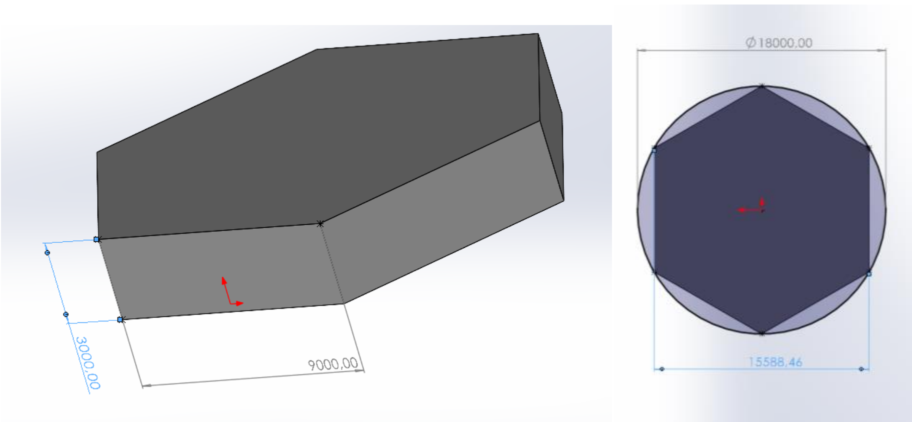


Figure 4 main dimensions

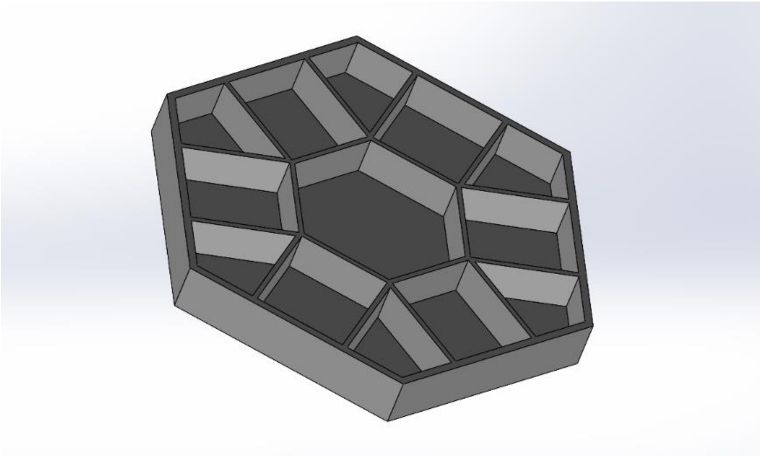


Figure 5 CAD section

The external walls have a hexagonal shape with a wall thickness of 40 cm; while the internal walls have thickness of 20 cm, placed in a way that most of the angles have 90°, so that it would be possible to prepare the rectangles and then assemble them during the final construction.

Furthermore, the internal configuration allows no design constrains for the connector and mooring joints, since they aren’t yet designed.

Mooring

The goal is to provide an analysis of the external conditions and a preliminary sizing of the mooring, in order to have an overview on the feasibility and costs of the work.

Standards

The reference standard used is the DNVGL-OS-E301, where it is described how to behave for the sizing of the mooring. A standardized mooring in designed on the return period of 100 years for waves and winds acting on the system, and 10 years return period for the currents.

The case study falls within the definition of mobile mooring, such as "anchoring at a specific location for a period less than 5 years" (Standards 2018), which allows a "Less detailed criteria may be acceptable for mobile moorings that are expected to be in consequence class 1 during extreme environmental conditions" (C. d. Venezia s.d.). Despite the mobile mooring option “soften” the physical constrains, the required return periods are still obtained.

Dataset

Figure 6 image of the data's locations

The data are taken from CNR (Centro Nazionale delle Ricerche) and ISMAR (Istituto di Scienza MARine) of Venice, who has a very vast dataset of lots of location of the internal and external lagoon. Image taken by (C. d. Venezia s.d.)

As declared by the CNR itself, the data "are published raw, i.e., without the controls and validation processes by the staff of the Center. [...] contain errors due to instrument malfunctions ".

The selected datasets are:

• Waves: location Punta Salute, 30-min time spaced discretization; containing significant wave height (Hs), medium wave period (Tp) and others.

• Wind: location San Giorgio, 1-hour time spaced discretization; containing average wind speed, gust speed, direction, and significant wave height.

• Current: location Malomocco, 30-min time spaced discretization; containing

The closest location to the real site is Punta Salute for waves; wind data were chosen that far because absent in closer datasets. current choice of Malomocco is conservative since it's in proximity of a port entrance.

Measurement tools

Screenshots taken by (C. d. Venezia s.d.)

Coordinate Geografiche (Rete GPS2000)	Sensori installati	Sensore	Altezza
Latitudine	Mareografo	t039 TIDROM	2.6 m
45° 20' 3.69" N	Sistema di acquisizione	DA9000	2.6 m
Longitudine			
12° 20' 29.54" E			

Altezza del caposaldo: 2.04 m

Figure 7 waves sensors

Coordinate Geografiche (Rete 2000)	Sensori installati	Sensore	Altezza
Latitudine	Barometro	t011d TBAR-IVS	12 m
45° 25' 42.27" N	Igrometro umidità aria	t003 TRH	12 m
Longitudine	Temperatura aria	t001 TTEP	12 m
12° 20' 46.55" E	Radiazione solare	t055 TPIR	12 m
	Sistema di acquisizione	DA9000	12 m
	Direzione vento	t033 TDV	14 m
	Velocità vento	t031 TVV	14 m

Figure 8 wind sensors

Coordinate Geografiche (Rete GPS2000)	Sensori installati	Sensore	Altezza
Latitudine	Ondametro	t021 TLU16	2.5 m
45° 25' 50.41" N	Mareografo	t039 TIDROM	2.8 m
Longitudine	Sistema di acquisizione	DA9000	2.8 m
12° 20' 10.99" E			

Altezza del caposaldo: 1.75 m

Figure 9 current's sensors

Data filtering

After a first look at the data, they've been cleaned and filtered since some measurements were physically impossible. By simply filtering the data from negative values and "NaN". For waves value the 98% of data from the cumulative have been considered.

The characteristic of the sea change slowly, so small time step shows similar characteristic. Since the Environmental Contour is strongly dependent by the tail trend, it is important to choose an appropriate time step and distribution that better fit the data.

Since the Environmental Contour it's due to extreme event, an appropriate threshold is set. A threshold too high could generate a conservative EC, if it's set too low the problem can become bad conditioned since statistical uncertainty increases.

100y return theory: NATAF method

The return period is a probabilistic criterion used to measure and communicate the random occurrence of geophysical events such as floods in risk assessment studies. (M. Mehdi Bateni 2022)

For both wind and waves, the problem is described as a bivariate return period, with the two variables called x_1 and x_2.

For each set of data, a distribution should be chosen, the best the distribution fit the normal cumulative the best the EC will be obtained.

Once obtained, to evaluate the correlation factor in the Gaussian space, a Nataf transformation is performed. Then the inverse of the standard CDF Φ^{-1} is obtained to consider the correlation between the two variables x_1 and x_2, since now they have comparable values associated to the cumulative probability.

Correlation factor:

$$y_1 = \Phi^{-1}(x_1)$$

$$y_2 = \Phi^{-1}(x_2)$$

The Pearson correlation matrix is then obtained through a MATLAB function (corrceff):

$$R = \begin{bmatrix} 1 & \rho_{12} \\ \rho_{12} & 1 \end{bmatrix}$$

Then, the radius beta of the Gaussian space is obtained:

$$\beta = -\Phi^{-1}\left(\frac{1}{T_r\, N_e}\right)$$

It's a function of the number of events N_e and the return period T_r.

u_1 and u_2 are components of the circumference, obtained as follow:

$$u_1 = \beta \cos\theta$$

$$u_2 = \beta \sin\theta$$

$$0 < \theta < 2\pi$$

Finally, contours can be evaluated performing the inverse CDF of the related distribution function used to model the data set:

$$Contour_{x1} = F_{x1}^{-1}(\Phi(u_1))$$

$$Contour_{x2} = F_{x2}^{-1}\left(\Phi\left(u_2\sqrt{1-\rho_{12}^2} + \rho_{12}u_1\right)\right)$$

In case of a mono-dimensional EC, like the case with the current, $u_1 = u_2 = \beta$. And the contour is a constant straight line.

100y return period: Waves

In this case the x_1 variable is the significant wave height H_s and the x_2 variable is the Wave medium period T_p.

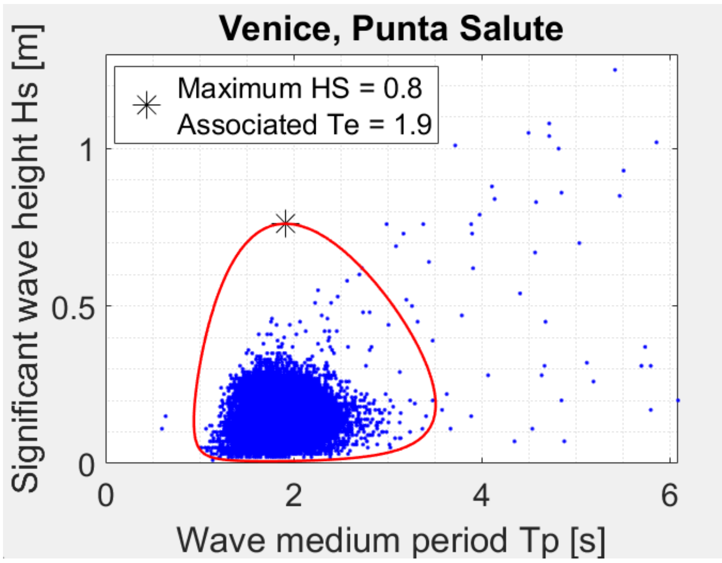


Figure 10 Environmental countur and 100y return period for waves

Despite various attempts to fit the distribution, the EC has a different shape than the usual "leaf" one, this could be because the model implemented is made for sea waves and not suitable for lagoon waves. Another theory blames the impurities of the dataset.

Anyway, for this work the values considered reasonable. It's still under investigation and left to further works the correct model for lagoon waves 100y return.

100y return period: Wind

In this case the x_1 variable is the Wind speed V_w and the x_2 variable is the Guts speed V_g.

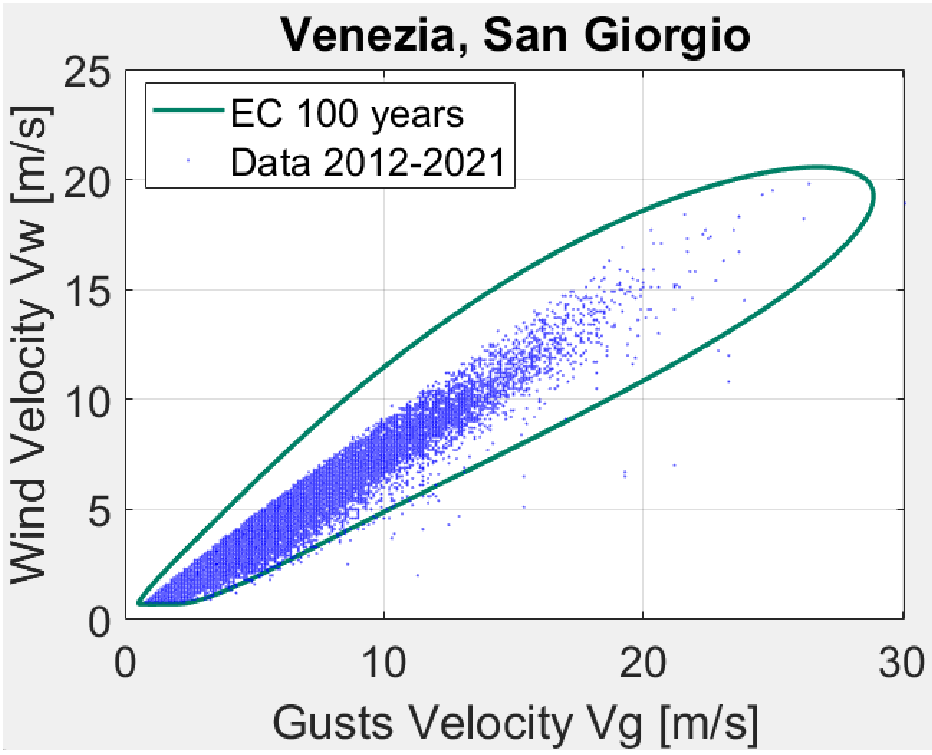


Figure 11 Environmental counter for wind

It's been used the Gamma distribution and the fit is suitable.

The 100y return profile is obtained and the 100y return value is the maximum wind velocity of the profile.

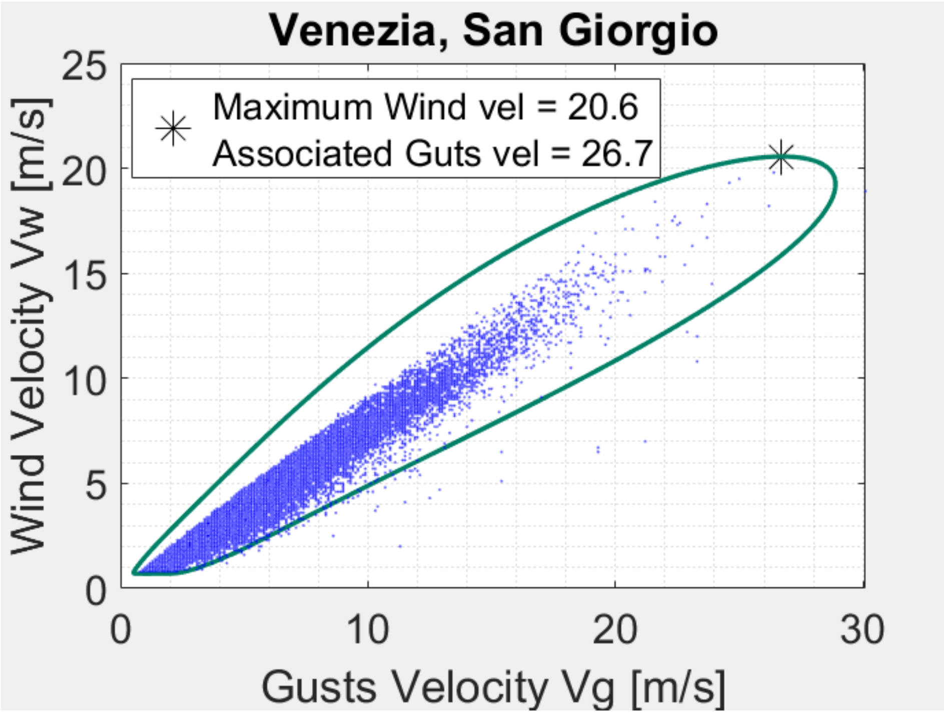


Figure 12 100y return period for wind

10y return period: Current

This is the case of mono-dimensional return period, in which the only variable of interest is the velocity of the current. The dataset contains the Average speed on vertical projected along axis channel [m/s], direction and wave height. The values used to obtain the discretization was obtained through the following relation:

$$C_u = C \times \cos\theta$$

With:

- C_u current velocity unidirectional.
- C the Average speed on vertical projected along axis channel [m/s].
- θ the direction of the current.

Normal distribution was used to fit the data.

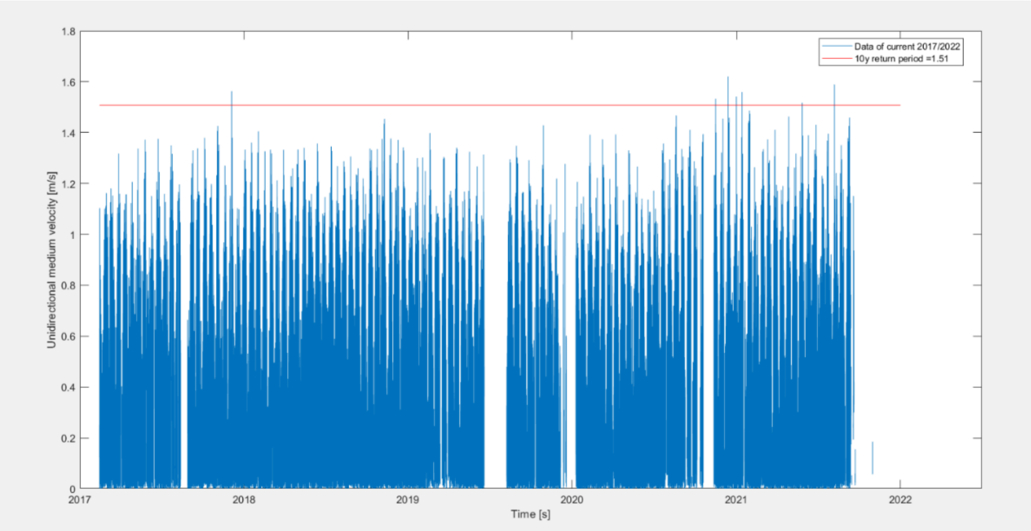


Figure 13 current data Cu and 10y return period

As it can be seen from the figure, the 10y current return period is equal to 1,51 m/s. the values that exceed it are statistically invalid.

Mooring configuration

A symmetrical and distributed mooring configuration was sought, with the aim of balancing the forces involved both between any future connections and on the mooring lines.

The configuration is shown in the figure: 8 mooring lines placed following the straight-circumference intersection, so that the load is supported on the direction by the internal section. For simplicity of calculation and global symmetry mooring lines' length it's the same for each line, in this way it's easier to deal pretensions and static loads.

Platform characteristic

Values for each platform:

Mass	431	Tons
Diameter	18	m
Draft	2	m
Freeboard	1	m

	X	Y	Z
Moment of inertia tensor [tons*m^2]	10,91e3	0	0
	0	10,91e3	0
	0	0	15,27e3
Radius of gyration [m^2]	25,31	25,31	35,43
Center of Gravity [m]	0	0	0,9
Center of Buoyancy [m]	0	0	-1

Mooring layout (Polyester 8-strand Multiplait):

Bathymetry	15	m
Distance vertex-anchor	17,20	m
Anchor Radius	26,20	m
Geometric length	17,20	m
Distance vertex-anchor (XY plane)	10	m
Distance vertex-anchor (Z axis)	14	m

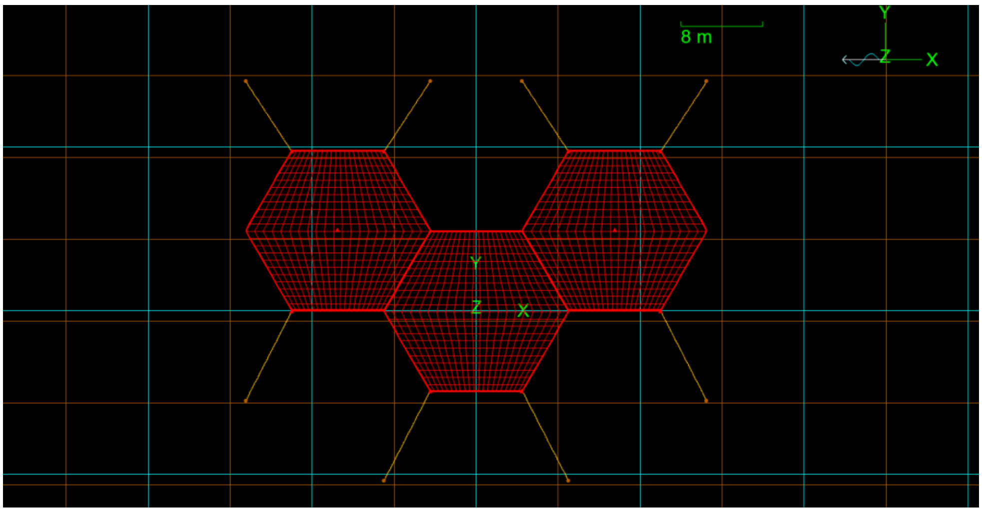


Figure 14 mooring layout, mooring lines in yellow

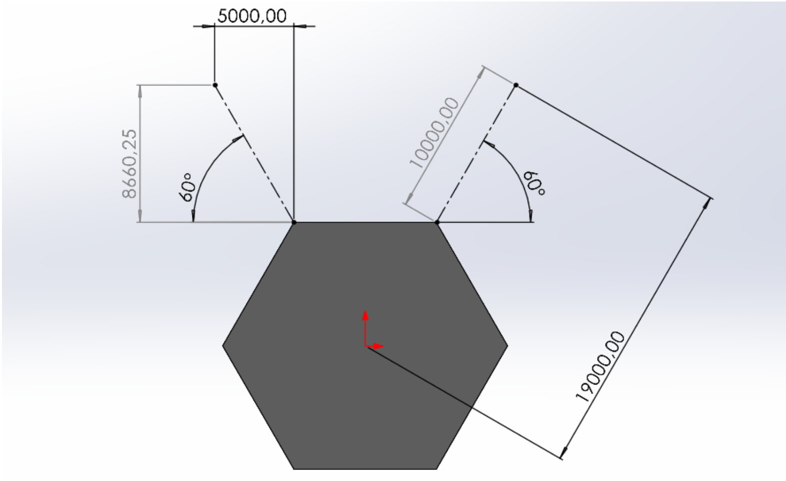


Figure 15 mooring geometries, top view; mooring line in dashed line

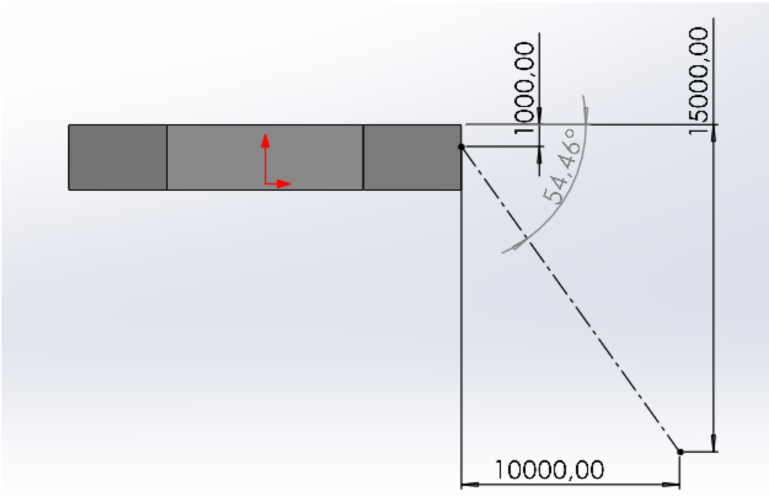


Figure 16 mooring geometries, side view; mooring line in dashed line

Analysis

The software used to investigate the system with moorings' design are:

- Nemoh, an open-source Boundary Element Methods (BEM) code dedicated to the computation of first order wave loads on offshore structures (added mass, radiation damping, diffraction forces). (Nemoh 2022)
- Orcawave, a diffraction analysis program which calculates loading and response for wet bodies due to surface water waves via potential flow theory. (Orcawave 2022)
- Orcaflex, performs global static and dynamic analysis of a wide range of offshore systems, typically including boundary conditions such as vessels, buoys, etc., as well as finite element modelling of line structures. (Orcaflex 2022)

Nemoh

To obtain the mesh the Nemoh code was run on MATLAB, the code automatically generates the mesh nodes' coordinates with as input the number of panels, panels coordinates and a parameter called "$nfobj$" (useful to choose the number of mesh elements, and so the mesh density).

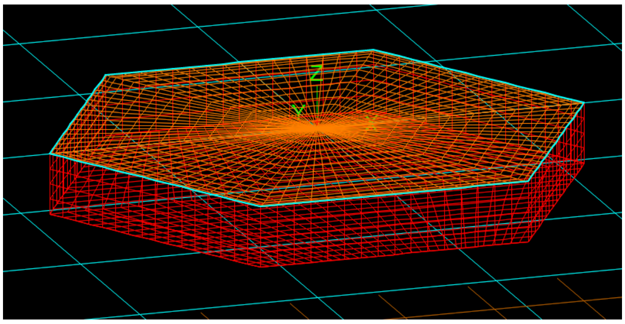


Figure 17 mesh of the platform on the Orcawave's Mesh view

Worth notice that the Mesh code works with symmetry on the xz plane, so that only half of the object's panel coordinates must be inserted. Also, quite useful to give the correct CoG of the object simulated, to better communicate with following programs.

Being the platform shape basically a cylinder with hexagonal base, only 5 panels (3 for the side and 2 for the base, that was split since each panel have 4 vertices) were used and with parameter $nfobj = 750$.

Orcawave

The mesh file generated by the Nemoh code is then upload into the software Orcawave. The software calculates all the hydrodynamic characteristics and solve the Response Amplitude Operators (RAOs).

For the simulation parameters are set:

- Mesh, a $.dat$ file format generated by Nemoh code, xz symmetry, triangulation method.
- Mass and inertias of the system platform superstructure were taken by Solidworks' CAD.
- Environment: 144 periods, going from $0\ to\ 51\ s$, with denser discretization for lower periods; with 12 wave heading direction, $from\ 0°\ to\ 330°$.

To compute the system RAOs three equal platforms were created, placed setting each center of the mesh position. Although there was the possibility to constrain each platform to the others, it was chosen to set them free but attached to each other; this because it better communicates with the following program Orcaflex, without effecting the results.

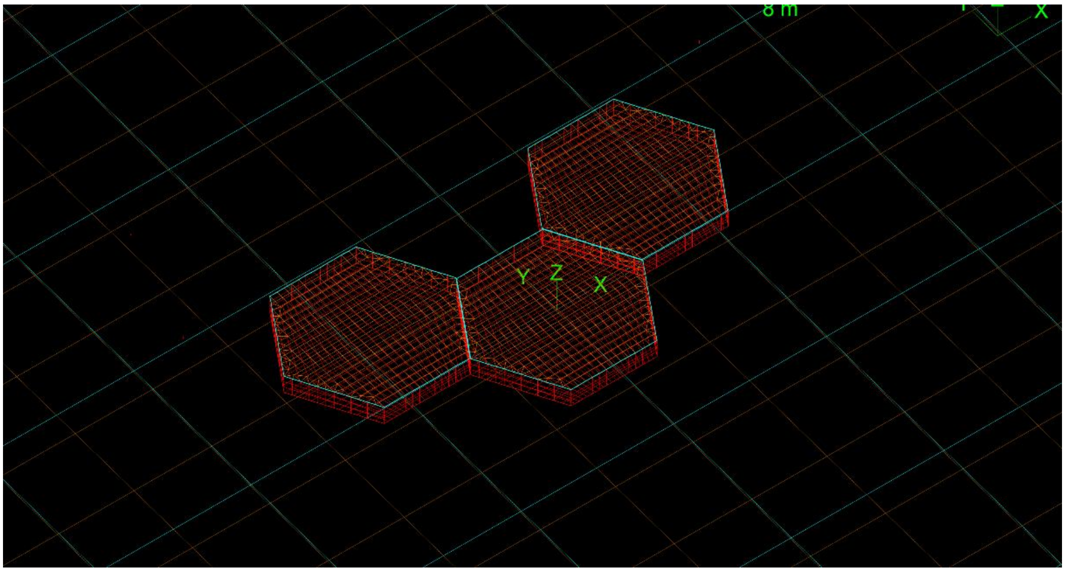


Figure 18 system with the three platforms

The results show a homogeneous behavior for all 3 platforms, the two lateral platforms display the same graphs, since the problem is symmetric.

The few differences between central and the two lateral platforms are due to the hydrodynamic interferences they have on each other.

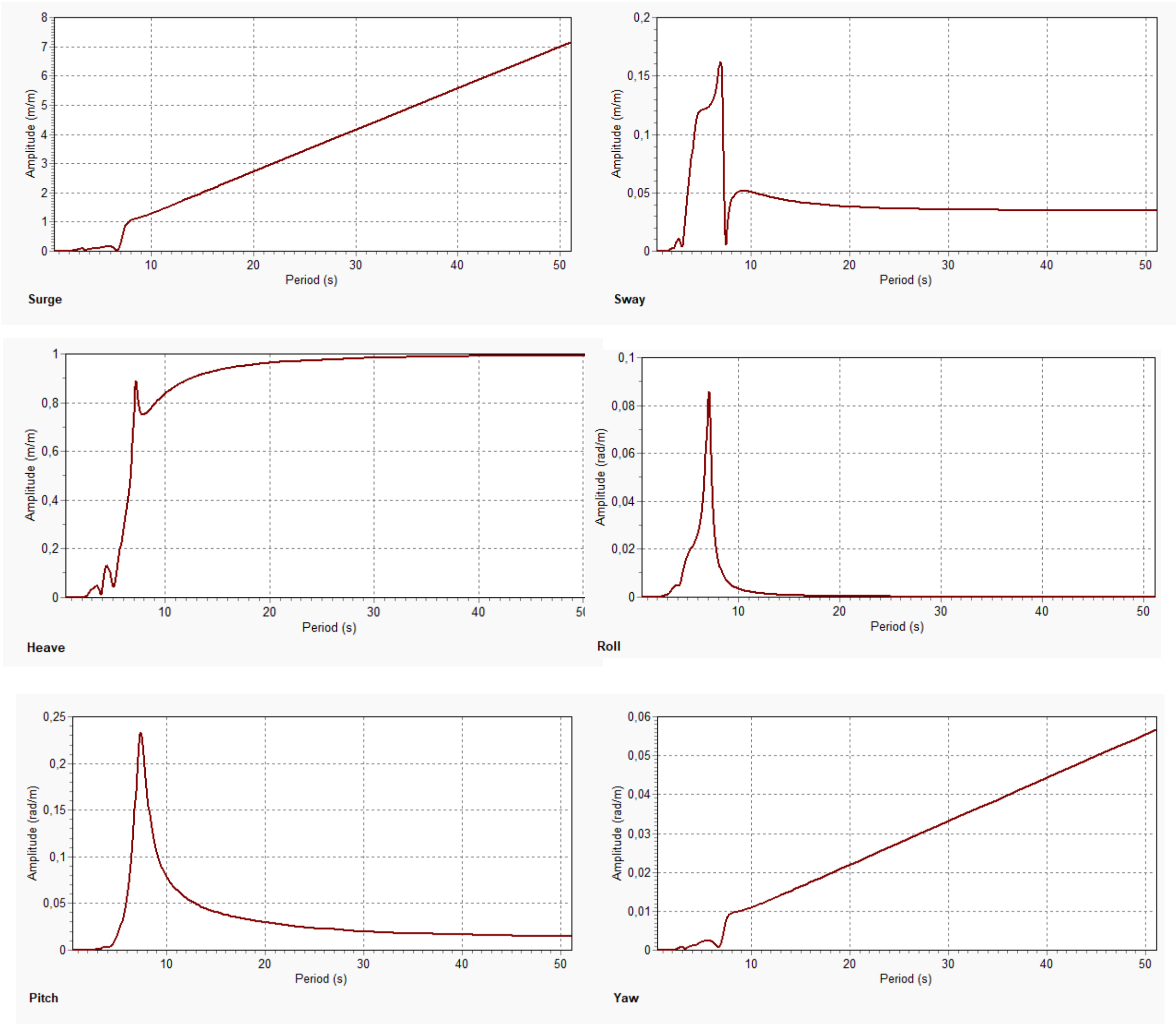


Figure 19 displacement RAOs for the central platform, wave heading 0°

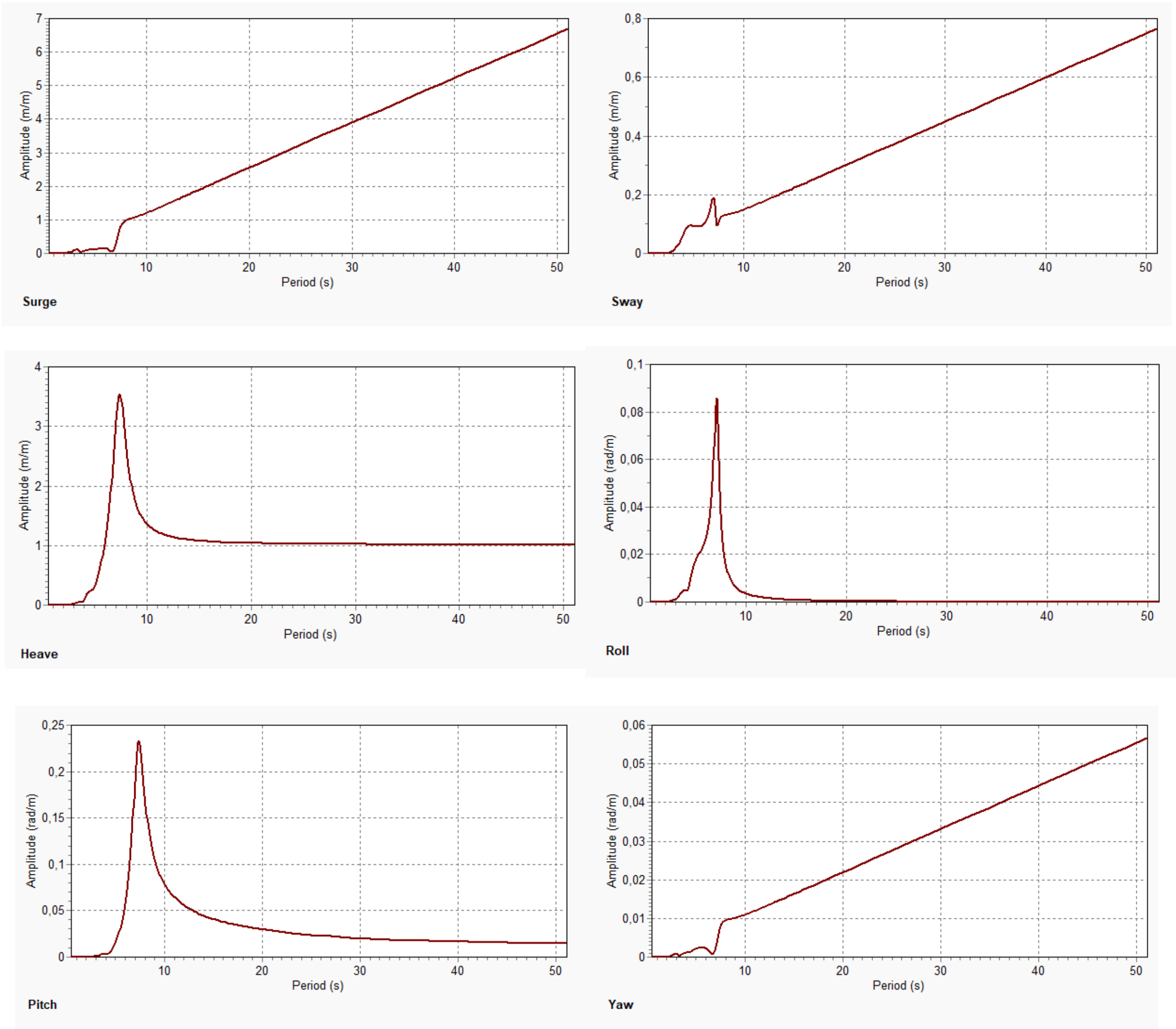


Figure 20 displacement RAOs for both lateral platforms, wave heading 0°

Orcaflex

Mooring lines, constrains, and environmental conditions were set directly on the software Orcaflex.

The three platforms are finally set in place, only the centered one is set free, while the other two are constrained to the centered. The result is a system of platforms that works as a single rigid body since there are no data on connectors. Further model development would be changing the platforms constrains and lock only some degrees of freedom, to better model the connectors.

Mooring lines are then defined, each with the previous mentioned characteristics. The line is fixed to the platform and anchored to the ground, the line element size is 0.5 m.

For the following analysis all 6 dof will be considered by the program with the 2nd order wave drift load, since the problem has 2nd order load effects that cannot be neglected.

Static analysis

The software allows to compute both static and dynamic simulation, it's very useful since the first thing to do is to detect the optimal mooring line length and diameter, iterating on the pretension values obtained. To do so, an iterative approach on static analysis has been made, the results are shown in the table below.

lunghezza linea			16 m	16,5 m	16,8 m	17 m
diametro linea	8 cm	pretensione [m/m]	7%	4%	2%	1%
		tension Tot media [kN]	198,9	44,0	2,4	1,7
		tension Tot media [tons]	20,3	4,5	0,2	0,2
		pretensione [tons/tons]	13%	3%	0%	0%
	10 cm	pretensione [m/m]	7%	4%	2%	1%
		tension Tot media [kN]	268,6	60,0	3,1	2,7
		tension Tot media [tons]	27,4	6,1	0,3	0,3
		pretensione [tons/tons]	17%	4%	0%	0%
	12 cm	pretensione [m/m]	7%	4%	2%	1%
		tension Tot media [kN]	332,6	74,1	3,8	2,9
		tension Tot media [tons]	33,9	7,6	0,4	0,3
		pretensione [tons/tons]	21%	5%	0%	0%

Figure 21 lines' pretension values for each combination of line lenght and diameter

A good pretension value doesn't exceed 5% [tons/tons]: bigger pretension value is not suggested since it increase the draft reducing the available superstructure's weight; on the contrary, lower pretension values is not optimal since the system become almost free to move.

The line length chosen is the $16,5\ m$. Follows the dynamic analysis both with line diameter of $8\ cm$ and $10\ cm$. Each configuration will be tested under two types of analysis: Design Analysis and Comfort Analysis. Each analysis, by standards, must last at least 3 h (Standards 2018).

Dynamic analysis: design approach

It consists in detecting the worst-case scenario, to check the mooring integrity under the standards procedure.

- 100-year wave return period: significative wave height $0{,}8\ m$; wave period $1{,}9\ s$.
- 100-year wind return period: wind speed $20{,}56\ m/s$.
- 10-year current return period: $1{,}51\ m/s$.

Waves, wind, and current loads direction is set to 180° since it's the most loaded case due to mooring configuration.

Wind and current load origin were set in the Center of Pressure of each component.

	X	Y	Z	
Wind load origin	13,5	7,89	1,0	m
Current load origin	0	0	0	m

To compute the loads acting on the system's components the program needs drag coefficients, taken from bibliography.

Superstructure's buildings drag coefficient

It was made reference to the standards "Azione del vento secondo le NTC 2018 – Circolare 2019" (NTC 2018): depending on the building's material and on its geometries there are drag coefficient tables.

To simplify the problem, assumption of wind acting only on lateral translation was made.

In the figure below the table for concrete, the material assumed for the buildings:

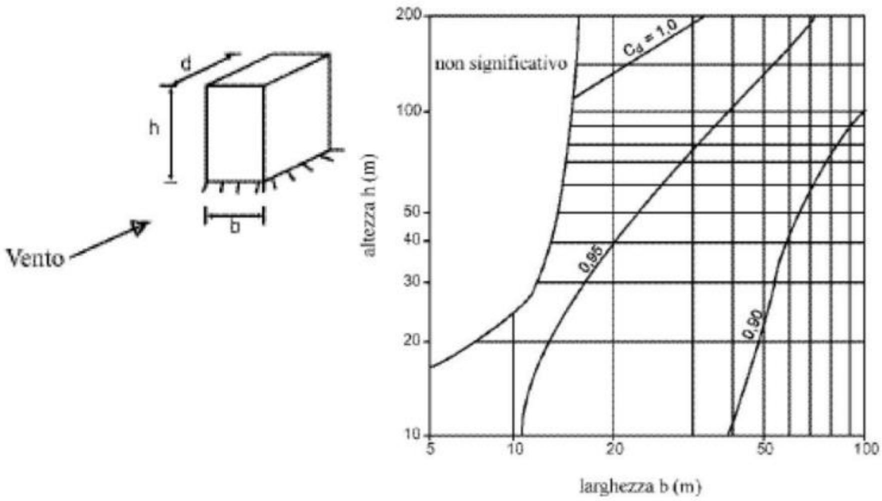


Figure 22 concrete building drag coefficient, function of its geometries

A standard building of about $5\,m \times 10\,m$ was chosen, the resulting drag coefficient is $C_D = 0{,}95$.

The program also asks areas and drag coefficient dependency on directions. It was assumed a cosine interpolation from direction 0° to 90°.

Areas and area moment:

Surge area (m^2)	Sway area (m^2)	Heave area (m^2)	Roll area moment (m^3)	Pitch area moment (m^3)	Yaw area moment (m^3)
54,0	54,0	0,0	0,0	0,0	0,0

Load coefficients:

Directions: 4

View coefficients

Direction	Surge	Sway	Heave	Roll	Pitch	Yaw
0,0	0,95	0,0	0,0	0,0	0,0	0,0
30,0	0,82	0,47	0,0	0,0	0,0	0,0
60,0	0,47	0,82	0,0	0,0	0,0	0,0
90,0	0,0	0,95	0,0	0,0	0,0	0,0

Figure 23 wind drag coefficients and areas

The areas and coefficient of heave, roll, pitch, and yaw are null because of the assumption made about lateral translation load.

Platform's underwater drag coefficient

It was made reference to an academic study "Modelling of flow around hexagonal and textured cylinders" (Karampour 2018). The study obtains drag coefficient function of the Reinold number. It also underlines differences depending on the hexagonal orientation:

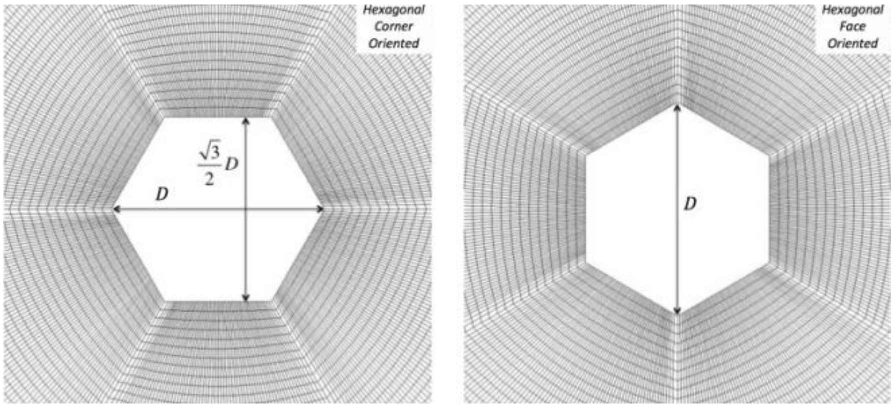


Figure 24 different hexagonal orientation, direction of flow from the right side

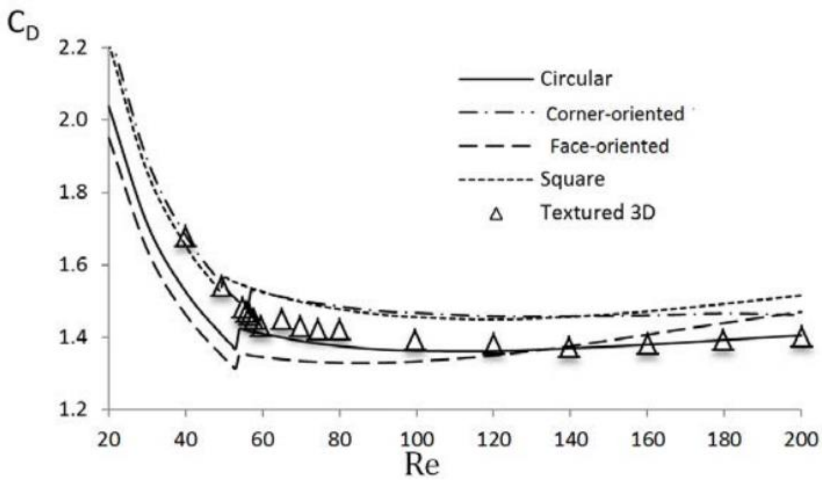


Figure 25 drag coefficient function of Re, for different geometries

The case at hand is a corner-oriented hexagon with a $100 < Re < 150$, that gives a $C_D = 1{,}55$.

The program also asks areas and drag coefficient dependency on directions. It was assumed a cosine interpolation from direction 0° to 90°.

To simplify the problem, assumption of current acting only on lateral translation was made.

Cosine interpolation from direction 0° to 90° was assumed:

Current load data for draught Draught1

Areas and area moment:

Surge area (m^2)	Sway area (m^2)	Heave area (m^2)	Roll area moment (m^3)	Pitch area moment (m^3)	Yaw area moment (m^3)
31,18	36,0	0,0	0,0	0,0	0,0

Load coefficients:

Directions: 4 View coefficients

Direction	Surge	Sway	Heave	Roll	Pitch	Yaw
0,0	1,55	0,0	0,0	0,0	0,0	0,0
30,0	1,34	0,78	0,0	0,0	0,0	-0,06
60,0	0,78	1,34	0,0	0,0	0,0	-0,06
90,0	0,0	1,55	0,0	0,0	0,0	0,0

Figure 26 current drag coefficients and areas

The areas and coefficient of heave, roll, pitch, and yaw are null because of the assumption made about lateral translation load.

Dynamic analysis: comfort approach

It is the most frequent case scenario, it was chosen the most frequent wave, detected by developing the scatter plot of the dataset.

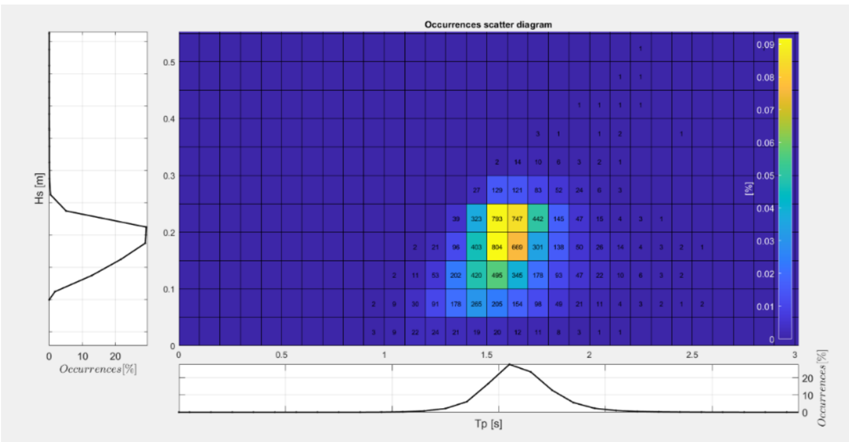


Figure 27 waves scatter plot. Location Punta Salute, Venice

The most frequent wave case has significative wave height $0{,}175\ m$ and wave period $1.55\ s$.

Constrains

Design analysis constrains: Minimum Breaking Load

The design analysis is conducted to check the structural integrity of the lines, under the worst condition loads. Then compare the max force reached by each line with the minimum breaking load (MBL), that is function of material and diameter of the line. In the case of Polyester 8-strand Multiplait line the MBL is:

- diameter 8 mm: 1090,99 kN.
- diameter 10 mm: 1704,67 kN.

The values have been taken from the Orcaflex Software's database (OrcinaOrcaflex s.d.), that returns the minimum breaking load as a function of the line diameter.

Comfort analysis constrains: Accelerations, Displacements, Inclinations

Since there are still no standards about a floating platform designed for living comfort, constraints were taken from a similar study: Space@sea (Space@Sea s.d.). They considered acceleration and inclination limits of standards for office work on container ships, and lower by an acceptable value those limits:

- Vertical acceleration: 0,15 $m/s2$
- Horizontal acceleration: 0,3 $m/s2$
- Max overall inclination: 1°

They also made good considerations on inclination limits between more platforms and others. (Julius Schay 2017)

Results

Design approach results

Physical constrains are respected since the MBL is not exceeded in both configurations. Here reported the effective tension of the most loaded lines for the configuration with $10\ cm$ diameter, $16{,}5\ m$ length on a $3\ h$ timeline. Other data and configurations can be found in Appendix A.

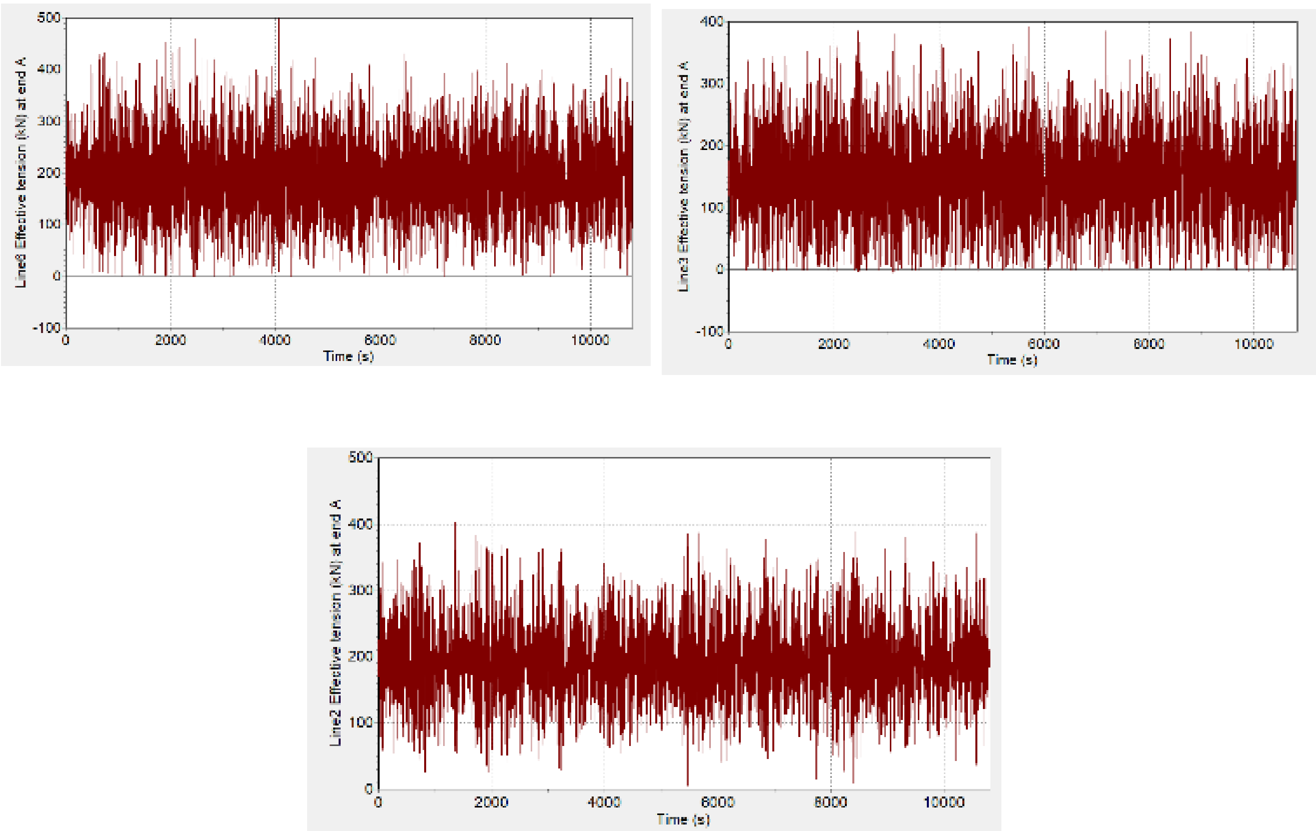


Figure 28 effective tension over time of line 8, line 3 and line 2

The maximum effective tension (MET) reached by the most loaded line is $489\ kN$, reached by line 8. The safety coefficient, defined as:

$$S.C. = \frac{Min\ Breaking\ Load}{Max\ Effective\ tension} = 3{,}48$$

The other configuration, with MET $= 451\ kN$, has a $S.C = 2{,}41$.

Comfort approach results

Comfort constrains are satisfied in both configurations, here reported the most significative data of the 8 cm diameter configuration. Other data and configurations can be found in Appendix B.

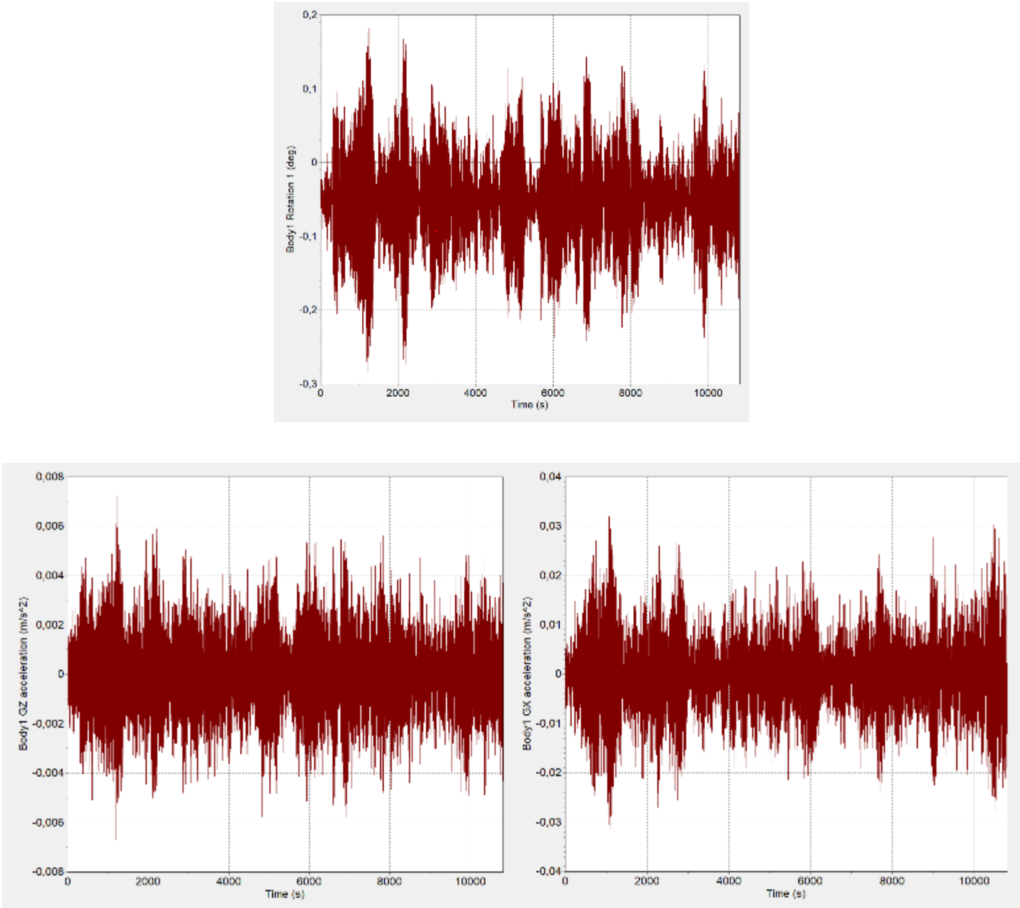


Figure 29 inclination, vertical and horizontal accelerations of the configuration 8 cm diameter and line lenght 16,5 m, most frequent case scenario

Rotation 1 (rotation around x axis) reaches the highest degree inclination up to 0,18° < 1° of the constrains.

Vertical and horizontal accelerations are far lower than the limit case described in the constrains. This means that the platform can be considered comfortable.

The same can be said for the other configuration, who's showed even lower values than this one (results in appendix B).

Final configuration

Despite both configurations passed the design and comfort analysis, the platform chosen for the prototype is the following one, since cheaper.

Lines	8	-
Material	Polyester 8-strand Multiplait	-
Diameter	8	cm
Min Breaking Load	1090,99	kN
Tot static effective tension	352,00	kN
Pretension	4 %	m/m
Pretension	3 %	Tons/tons
Length	16,5	m
Geometric length	17,20	m
Distance vertex-anchor (XY plane)	10	m
Distance vertex-anchor (Z axis)	14	m

Offshore platform

In the following are explored the dynamics of a future large floating platform farther from the coas, subjected to more extreme and larger sea conditions.

The concept is the same as the prototype describe in the previous chapter: a hexagonal floating platform, designed to live on it, with the same concept of modularity and scalability. This platform of about 57 m diameter, has to be designed for conditions at 2 km from the coast of Venice, in the Adriatic Sea (useful for the environmental data availability).

The chapter talks about the modeling of the system and its ideal configurations, without considering the influences of the mooring.

Ballast

Given the larger dimensions, it is also possible to implement a dynamic ballast system, which interact with the overall system's dynamics by adapting it to varying wave conditions and superstructure loads change. Influencing the inertial matrices of the system as it pleases.

Furthermore, the ballast allows the system to be raised and lowered at will, thus guaranteeing the same height to platforms close to each other.

Inside, the platform will be divided into several rooms, which will house the ballast tanks and chambers; seawater was chosen as the material for the ballast, both for its easy availability and for no transportation costs; also, it's easy to discharge it and recharge at will. Of course, it would be filtered to avoid discomfort due to excessive salinity, other organisms that could compromise or damage the internal walls and systems.

A centralized pump system will manage introduction, exchange of stagnant water, change of compartments to adapt to changes in weight and inertia of the superstructure. It is also possible to think of a system that adapts itself to changes in external stresses, dynamically with an immediate response (5-10 min).

CAD model

The 3d cad model was developed following the same guidelines described in the previous chapters, both on materials and design constrains.

Of course, the draft increases since the dimension change; also, the freeboard is raised to 2 m to face higher sea waves:

Mass	4600	Tons
Diameter	57	m
Draft	4	m
Freeboard	2	m

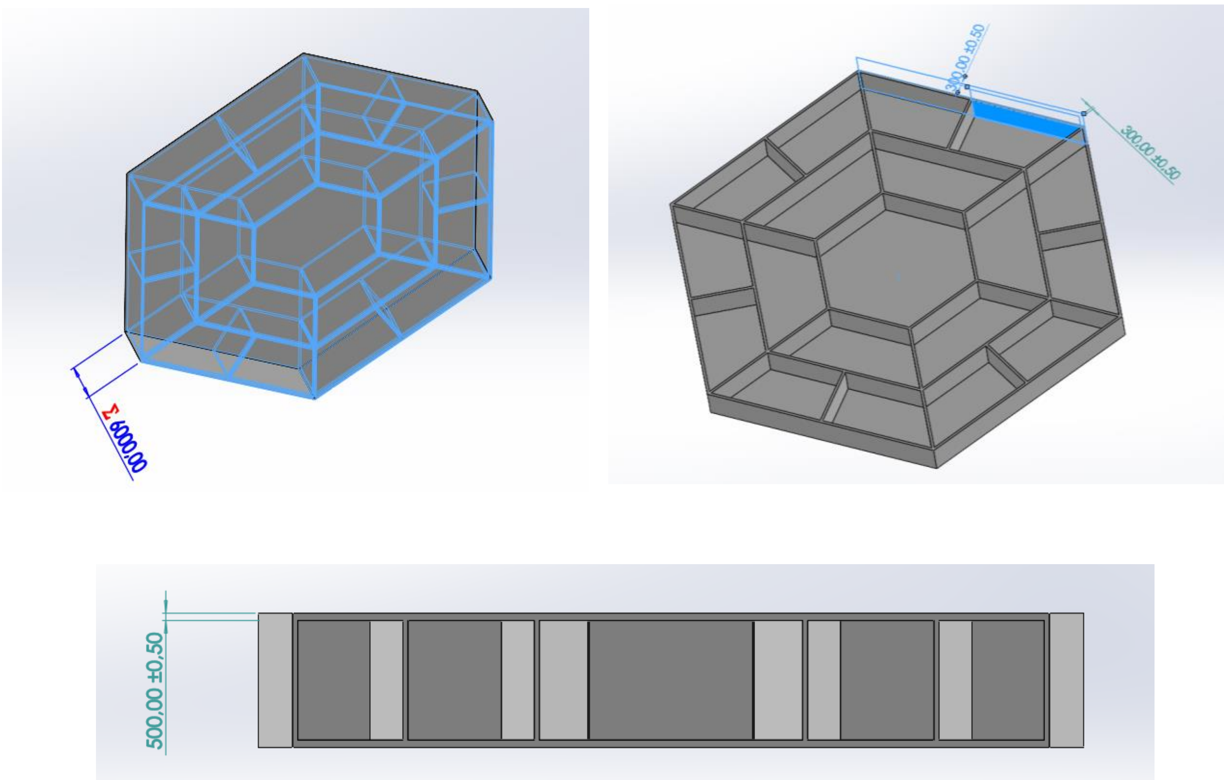


Figure 30 sections of the CAD design

The multiple chambers have both structural and ballast's house purpose.

MATLAB/Nemoh model

The Nemoh extension allows the creation of the mesh and takes care of the calculation of the hydrodynamic matrices, leaving the calculation of the RAOs to the user.

The geometry is then defined following the logic required by the program, which requires coordinates of the vertices of the panels since the case deals with a hexagonal-based cylinder, the fineness of the mesh is defined through the nfobj parameter; in order to calculate the hydrodynamic characteristics, the program also requires masses, inertias and center of gravity (calculated by SW).

Mesh convergence

To speed up the optimization process by decreasing the time required for each analysis, a convergence study was set up.

The same geometries were simulated with different mesh element sizes. Subsequently compared the hydrodynamic matrices of the simulations with the values of the hydrodynamic matrices of the simulation considered as reference since the element is below the threshold value 0.85 m.

For simplicity, only the different values of the Added Mass and of the external forcing are reported here.

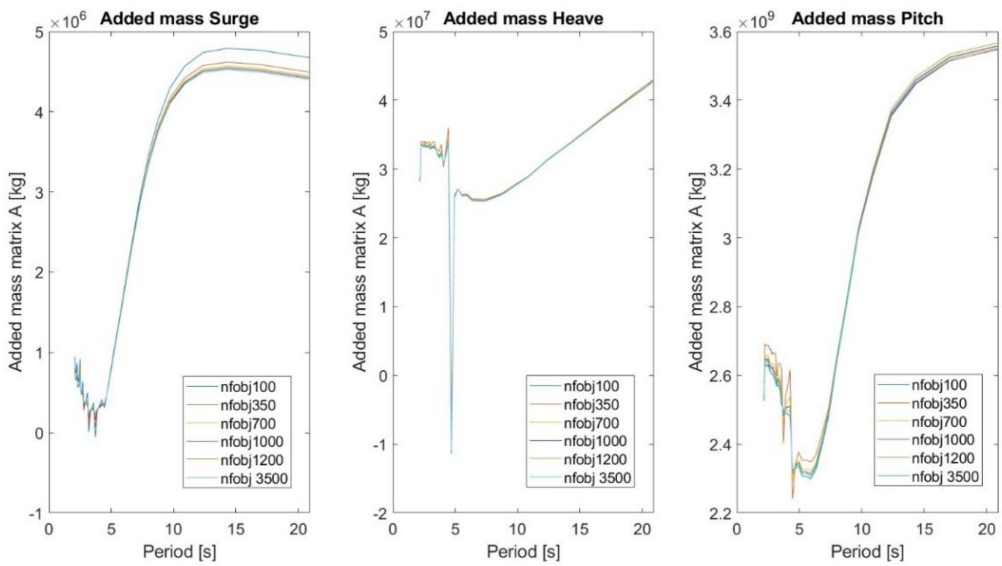


Figure 31 nfobj is a value Nemoh uses to target number of panels for Aquaplus mesh

It was therefore decided to proceed with analysis for nfobj of 700, obtaining a time saving of about 3 h per simulation, accepting an error of less than 2%.

$Nfobf$	Time [s]
100	4,14
350	36,3
700	165
1000	337
1200	437
3500 (riferimento)	1,08e4

Ballast iteration

The MATLAB model iterates on different ballast values, looking for the optimal configuration. A configuration is considered optimal when the peak pitch value is the lowest.

The ballast is modeled on its inertia, that can vary in both height and diameter, the approximation made is on a circular ballast instead on hexagonal. The radius of gyration adjusts external and internal radius constrained from the mass of the ballast, imposed to be 10% of the total mass.

The hollow cylinder mass moment of inertia formula:

$$I_x = I_y = \frac{1}{12} m(3(r_e^2 + r_i^2) + h^2)$$

$$I_z = \frac{1}{2} m(r_e^2 + r_i^2)$$

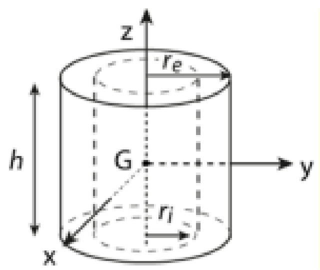


Figure 32 hollow cylinder

With:

- I_x $[kgm^2]$ inertia mass moment
- m $[kg]$ mass
- h $[m]$ cylinder height
- $r_e[m]$ and $r_i[m]$, external and internal radius

Environment

The dataset is collected from the ISMAR-CNR platform, located outside of the venetian lagoon, the platform host sensors for wind, waves, temperature, rain, and others. As declared by the CNR itself, the data "are published raw, i.e., without the controls and validation processes by the staff of the Center. [...] contain errors due to instrument malfunctions ".

Figure 33 ISMAR - CNR platform and its location

Once filtered the data, the scatter plot is obtained.

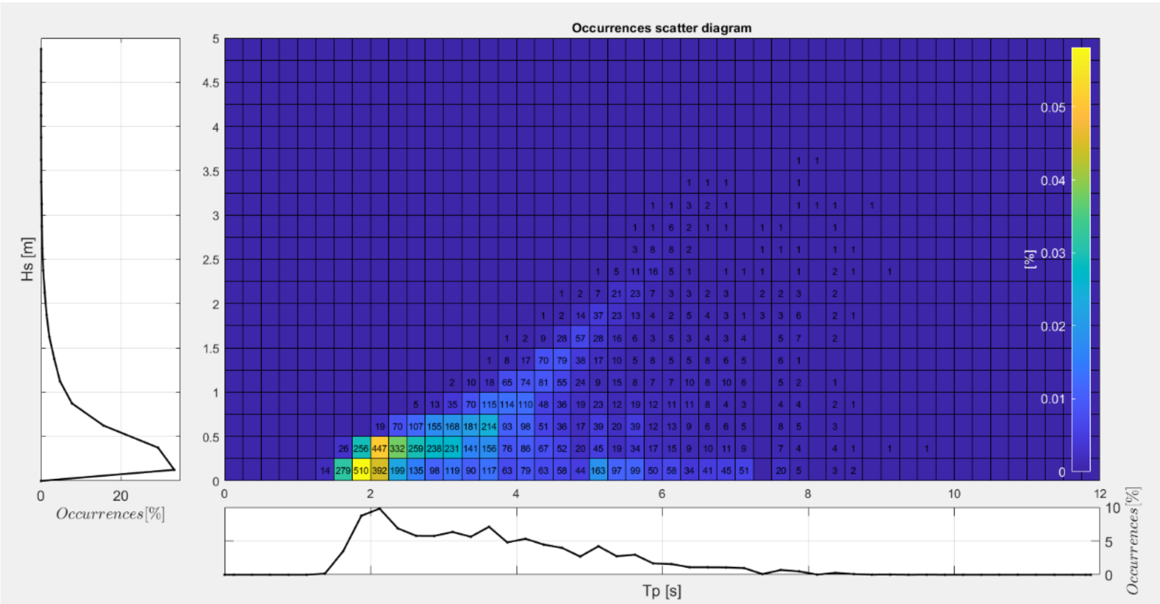


Figure 34 waves scatter plot, Venice, ISMAR-CNR platform

Results

Platform characteristics and RAOs are obtained.

Metacentric height roll	39,5	m
Metacentric height pitch	31,5	m
Heave hydrostatic stiffness	21200	kN/m
Roll hydrostatic stiffness	3,29e6	kN/m
Pitch hydrostatic stiffness	3,27e6	kN/m

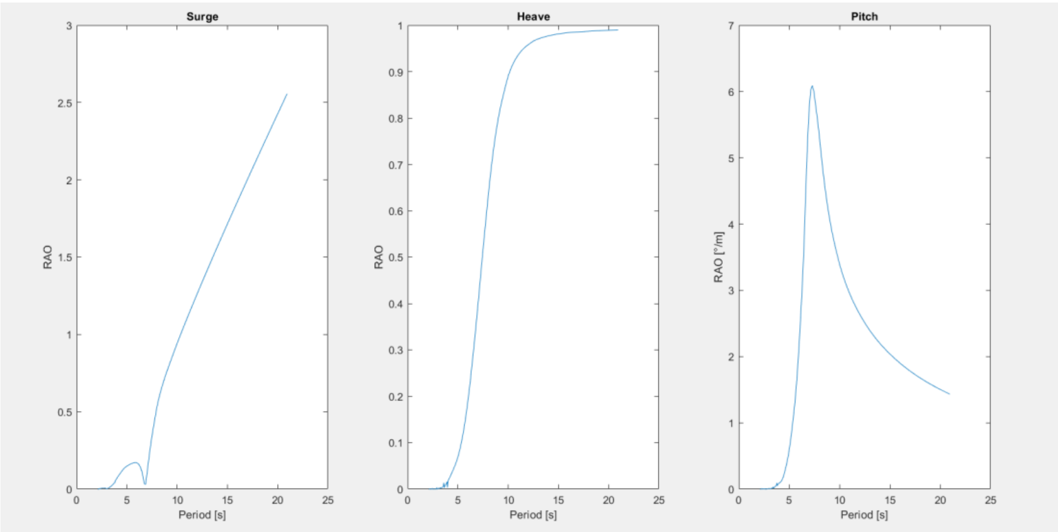


Figure 35 significant graphs of displacement RAOs of the platform

By comparing the results with the scatter waves plot there are waves with period comparable with the peak pitch period. The iteration ballast optimization is then run.

Ballast iteration results

In the figure below are shown the peak pitch values, function of the ballast height and radius of gyration:

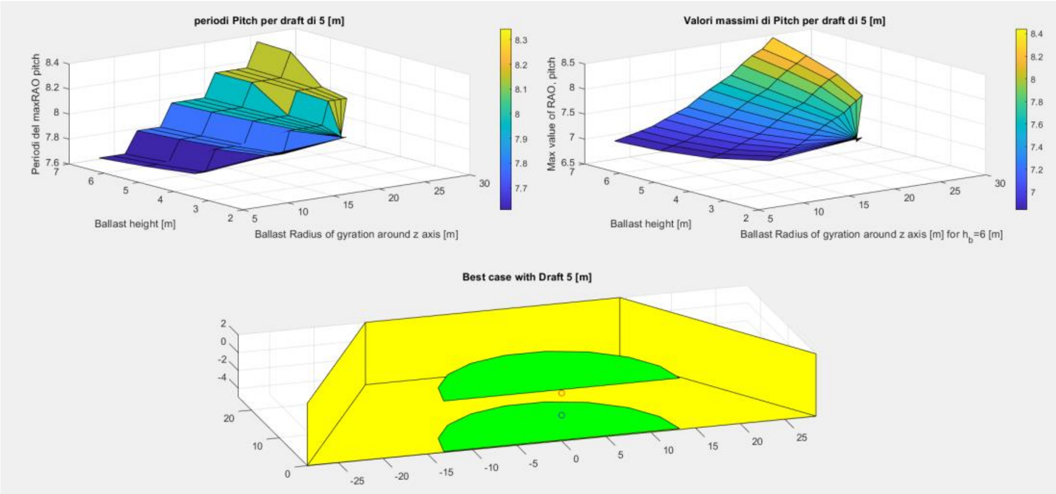


Figure 36 peak pitch values, function of the ballast height and radius of gyration; the green circle is the ballast configuration

The best case described by the iteration is with all the ballast mass close to the CoG; this is a counterintuitive behavior; it could be due to the superstructure massive influence (3000 tons with a CoG of about 1,5 m) or due to the fact that the system is not complete because the mooring is not included.

The model is still useful to find the parameters that most influence the system dynamic: it’s worth noticing how the system is not influenced by the ballast height, and mostly by its radius of gyration, and so the ballast radius.

Further work can be considering the mooring by a first approximation in the stiffness matrix, neglecting the damping effects. This could lead to an optimal system configuration, and then implement the software Orcaflex to detect and verify a real mooring configuration that mirror the modelized one.

CONCLUSION

The thesis work focused on the technical feasibility of creating 3 interconnected and floating platforms for the construction of an exhibition pavilion in Venice. It started with the CAD design, followed by the mooring and then the analysis of the entire system with the mooring, to check the system integrity and stability.

The platform modeled complies with the imposed limits: under the environmental condition found, the system of three floating platform of diameter 18 m, with the mooring design displaced as designed, is perfectly stable and optimal to be living on. The deck will remain stable with no sensible inclination and accelerations.

Also, the study of building process has not found huge obstacles; there are many reasons to believe it is feasible and possible.

The study of the bigger offshore platform found good basis for the development of it. Since the platform showed stable behavior even without the mooring, that could bring huge improvements on system's stability. On the other hand, few can be done for the deck to stay dry: a solution could be the implementation of breakwaters.

This thesis aimed also to give the row data and parameters for an economic assessment and a structural analysis. It was also useful to understand the loads on play, the inertias, the masses, the materials.

Further work can be made development of more advanced numerical methods for studying multibody dynamics and therefore designing the characteristics of the connectors; to understand how they affect the dynamic of the system further stabilizing it, rigid or flexible connectors? Also, a focus on the ballast system would be a good idea, is it worth implementing it on the prototype?

Bibliography

Alexandre Mathern, Christoph von der Haar, Steffen Marx. "Concrete Support Structures for Offshore Wind Turbines: Current Status, Challenges, and Future Trends." *MDPI*, 2021.

Eduardo Cejuela, Vicente Negro, Jose María del Campo, Mario Martín-Antón, M. Dolores Esteban. "Recent History, Types, and Future of Modern Caisson." *MDPI*, 2018.

Julius Schay, Clara Hüsken. "Space@Sea: Updated Requirements Formulation D 10.5." 2017.

Karampour, Hassan, Wu, Zhuolin, Lefebure, Julien, Jeng, Dong-Sheng, Etemad-Shahidi, Amir. "Modelling of flow around hexagonal and textured cylinders." *Proceedings of the ICE*, 2018.

M. Mehdi Bateni, Mario L. V. Martina, Marcello Arosio. "Multivariate return period for different types of flooding in city of Monza, Italy." *Natural Hazards*, 2022.

Nemoh, website. 2022. https://lheea.ec-nantes.fr/valorisation/logiciels-et-brevets/nemoh-running (accessed 2022).

NTC, Normativa. *https://studio-galimberti.com/.* 2018. https://studio-galimberti.com/carico-vento/ (accessed 2022).

Orcaflex, help. *Orcaflex help.* 2022. Orcawave help (accessed 2022).

Orcawave, help. *Orcawave help.* 2022. https://www.orcina.com/webhelp/OrcaWave/Default.htm (accessed 2022).

OrcinaOrcaflex. *Orcina.* n.d. https://www.orcina.com/orcaflex/ (accessed 2022).

RodrigoPérez Fernández, Miguel Lamas Pardo. "Offshore concrete structures." *Ocean Engineering*, 2013.

Space@Sea. n.d. https://spaceatsea-project.eu/ (accessed 2022).

Standards, Offshore. "DNVGL-OS-E301 Position Mooring." *Offshore Standards*, 2018.

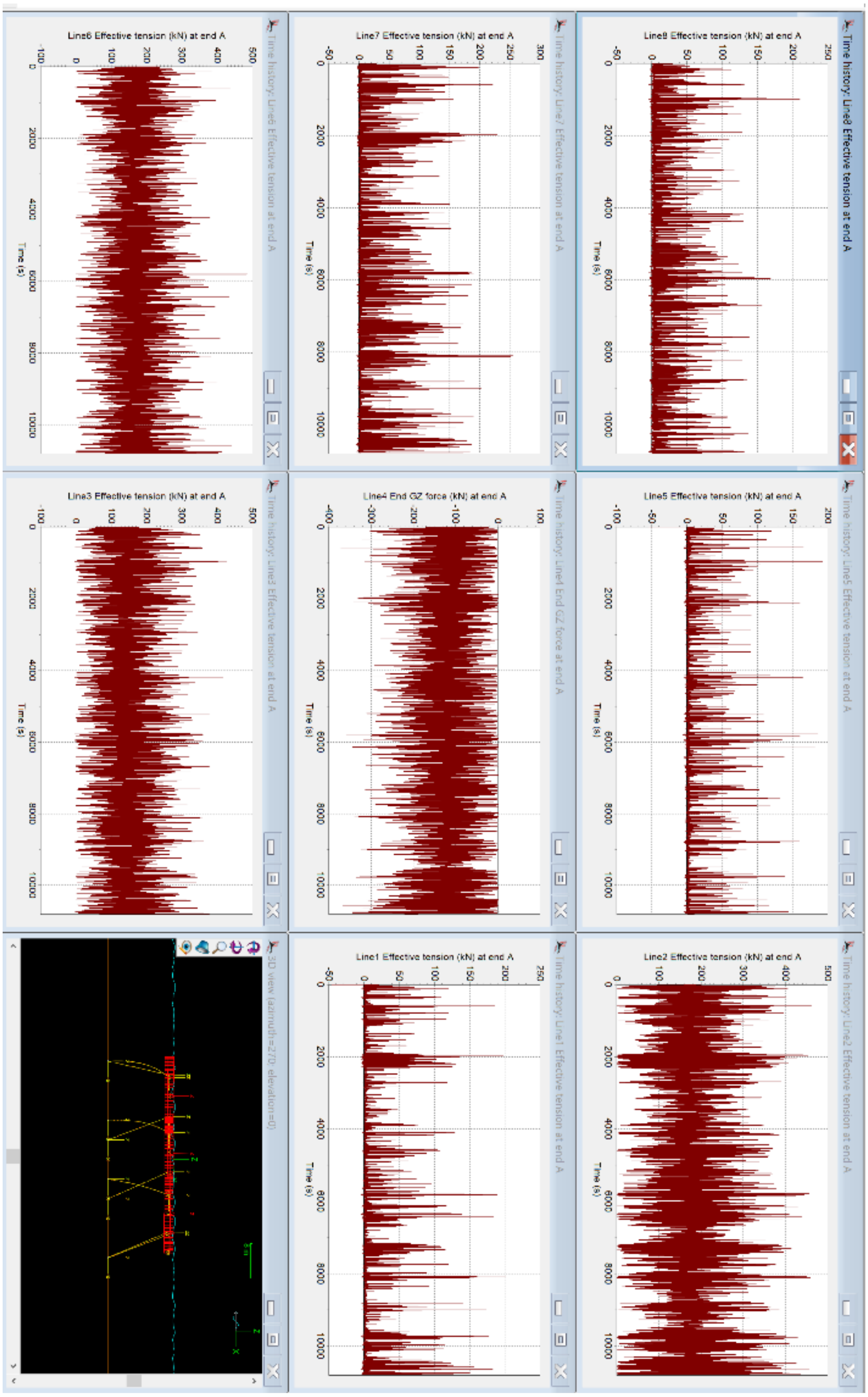
Venezia, Città di. *Città di Venezia.* n.d. https://www.comune.venezia.it/it/content/3-piattaforma-ismar-cnr (accessed Ottobre 2022).

Venezia, CIttà di. *Città di Venezia.* n.d. https://www.comune.venezia.it/it/content/dati-dalle-stazioni-rilevamento (accessed Ottobre 2022).

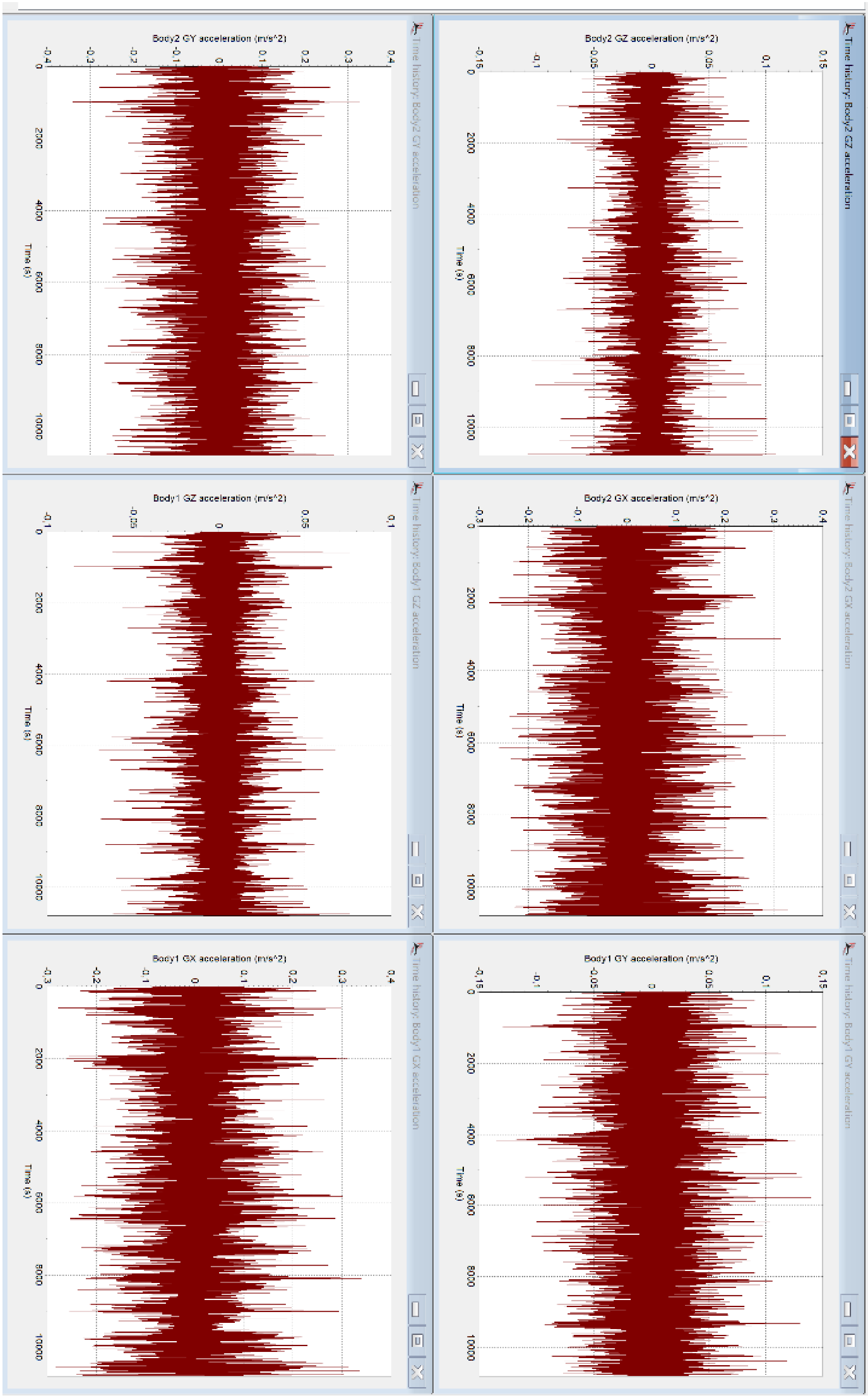
APPENDIX A

Design analysis. Configuration: line diameter 8 cm, length 16,5 m

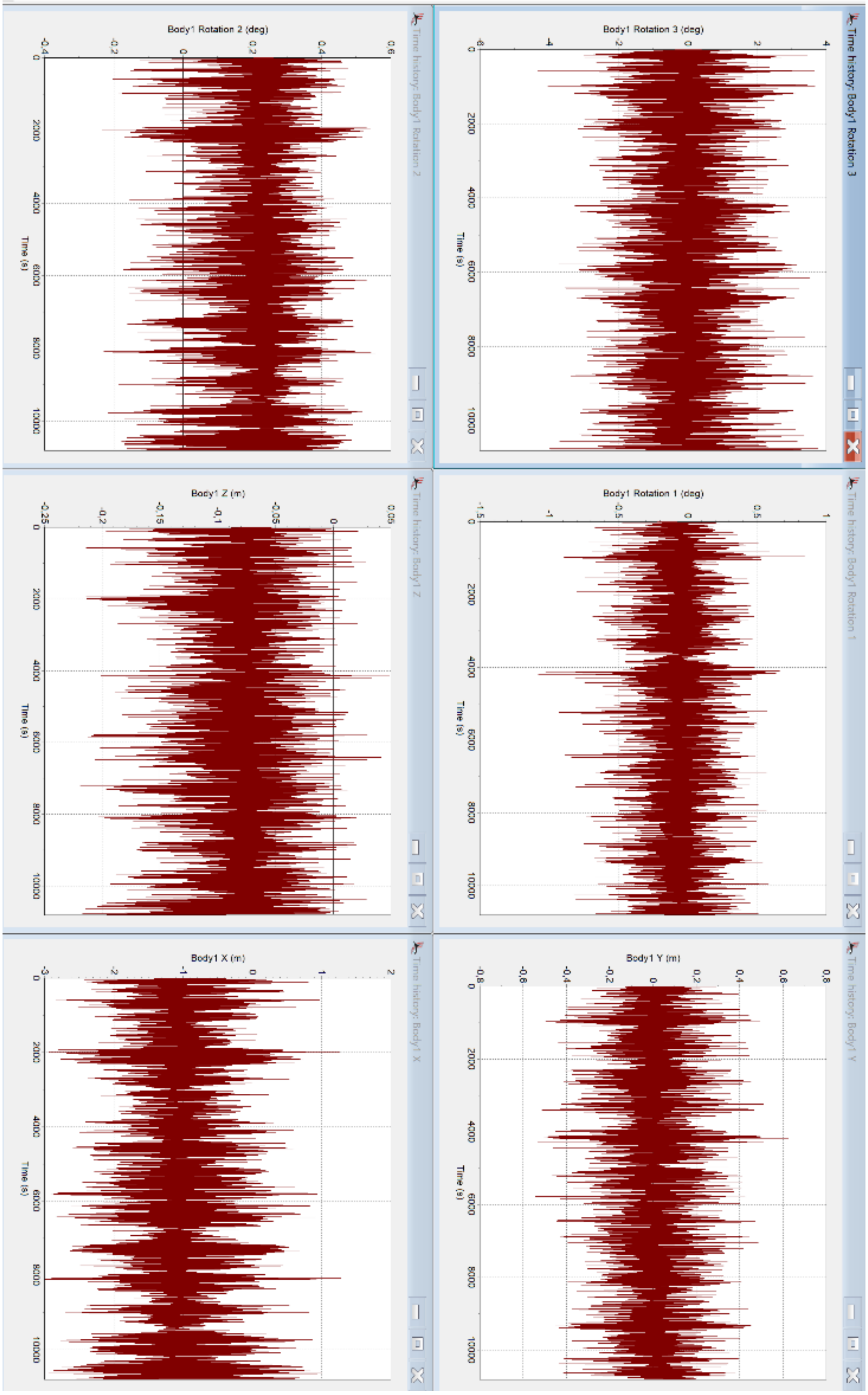
Effective tension temporal evolution of each line



Platform 1 and platform 2 accelerations:

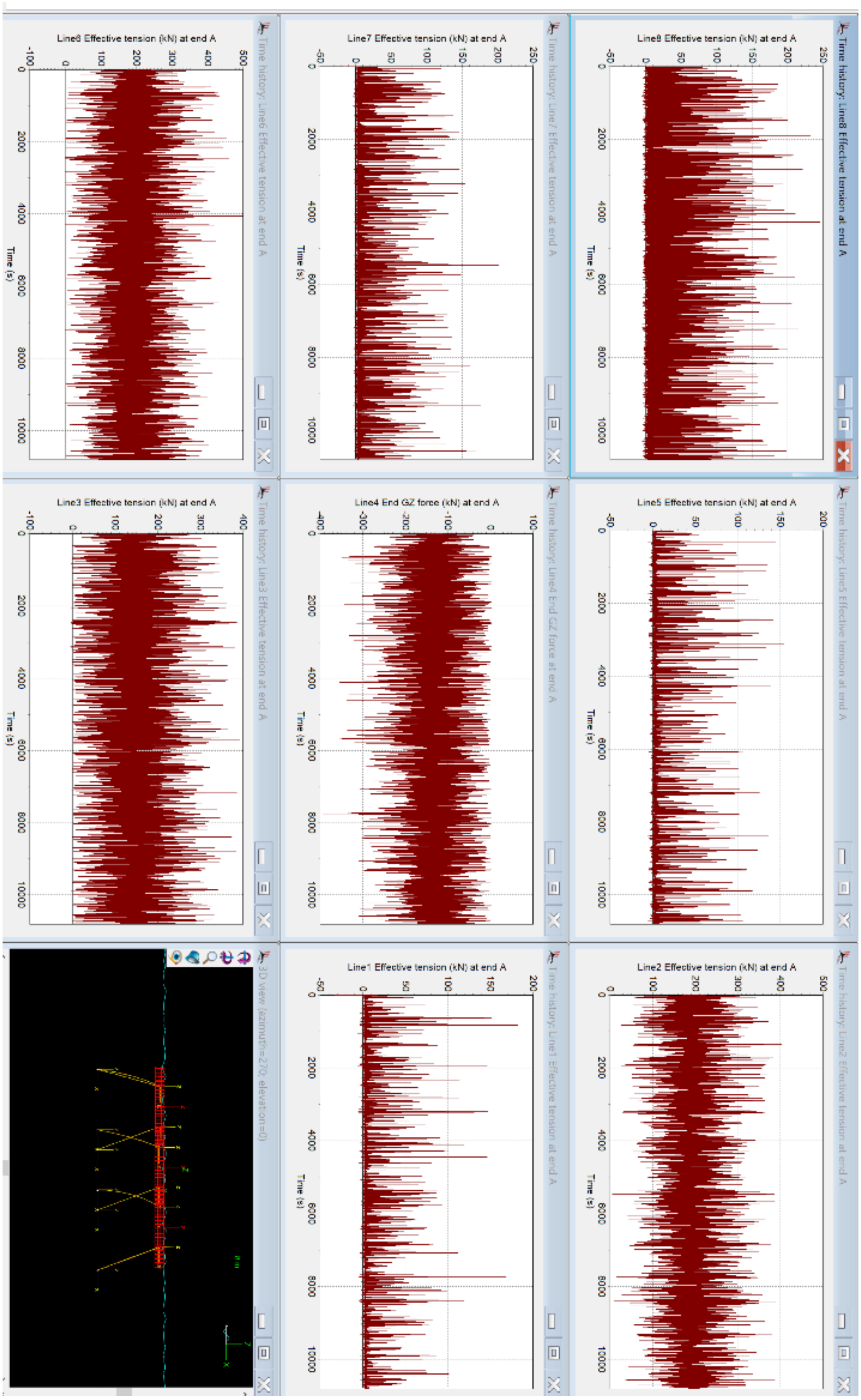


Rotation and displacements

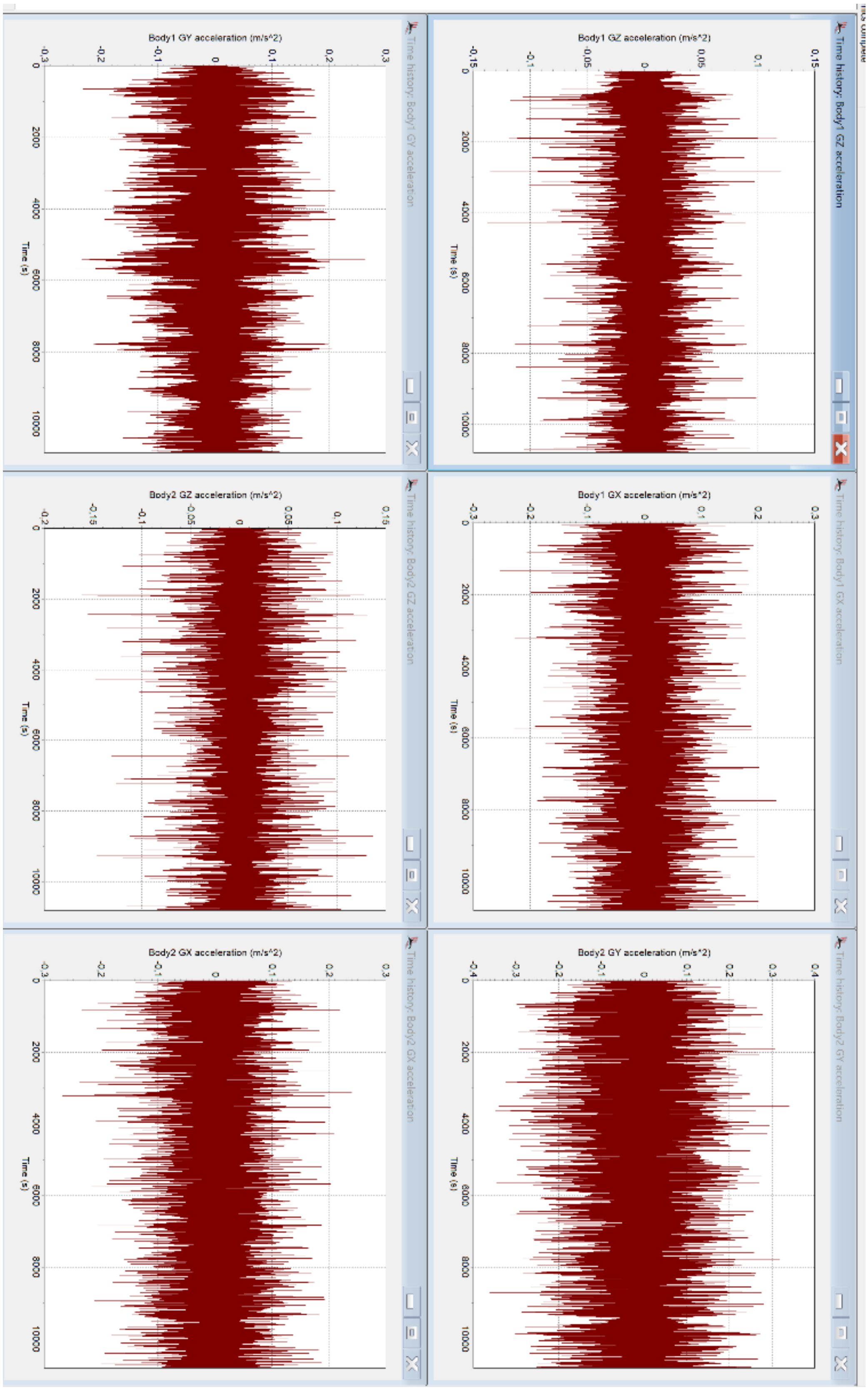


Design analysis. Configuration: line diameter 10 cm, length 16,5 m

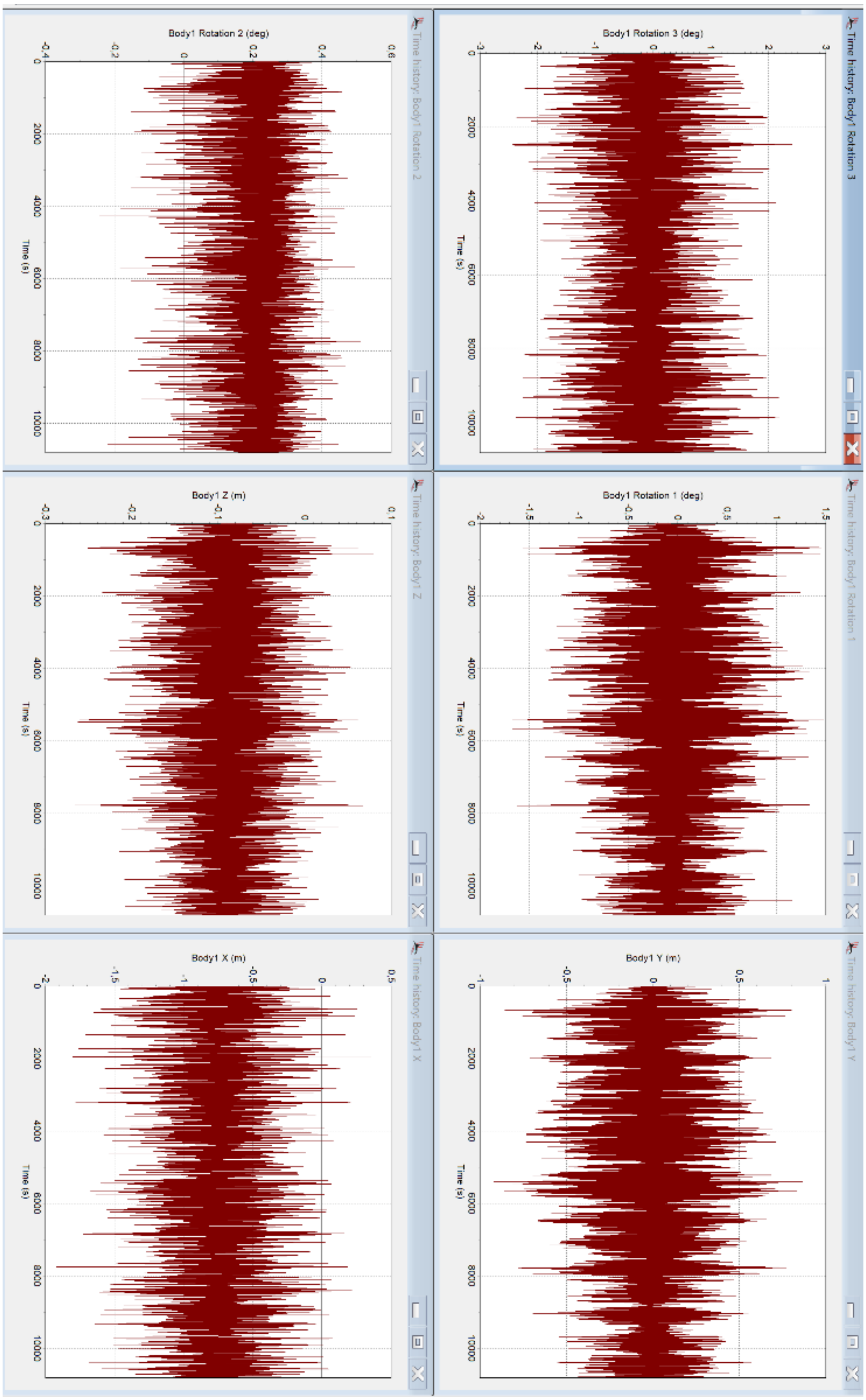
Effective tension temporal evolution of each line



Platform 1 and platform 2 accelerations:



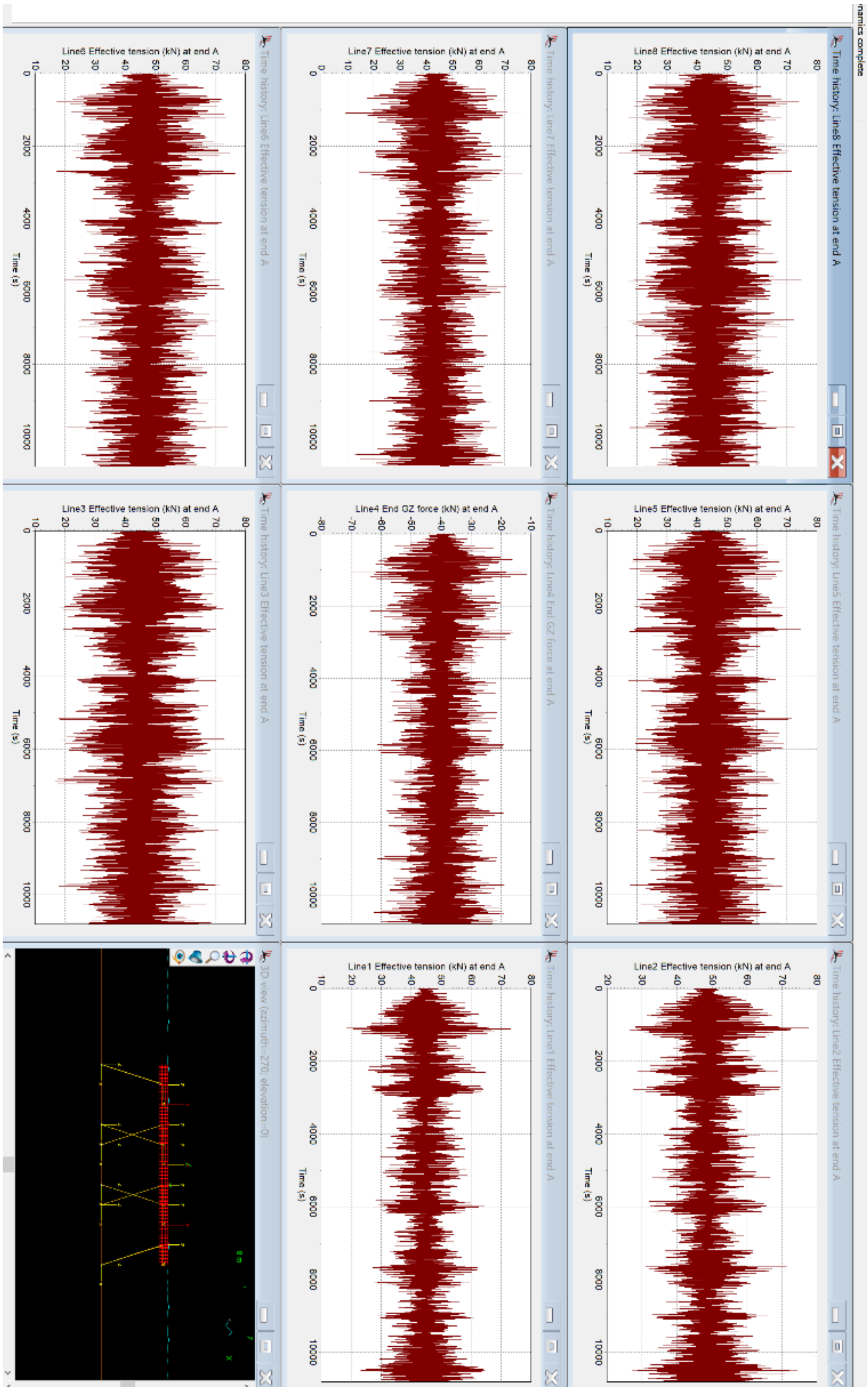
Rotation and displacements:



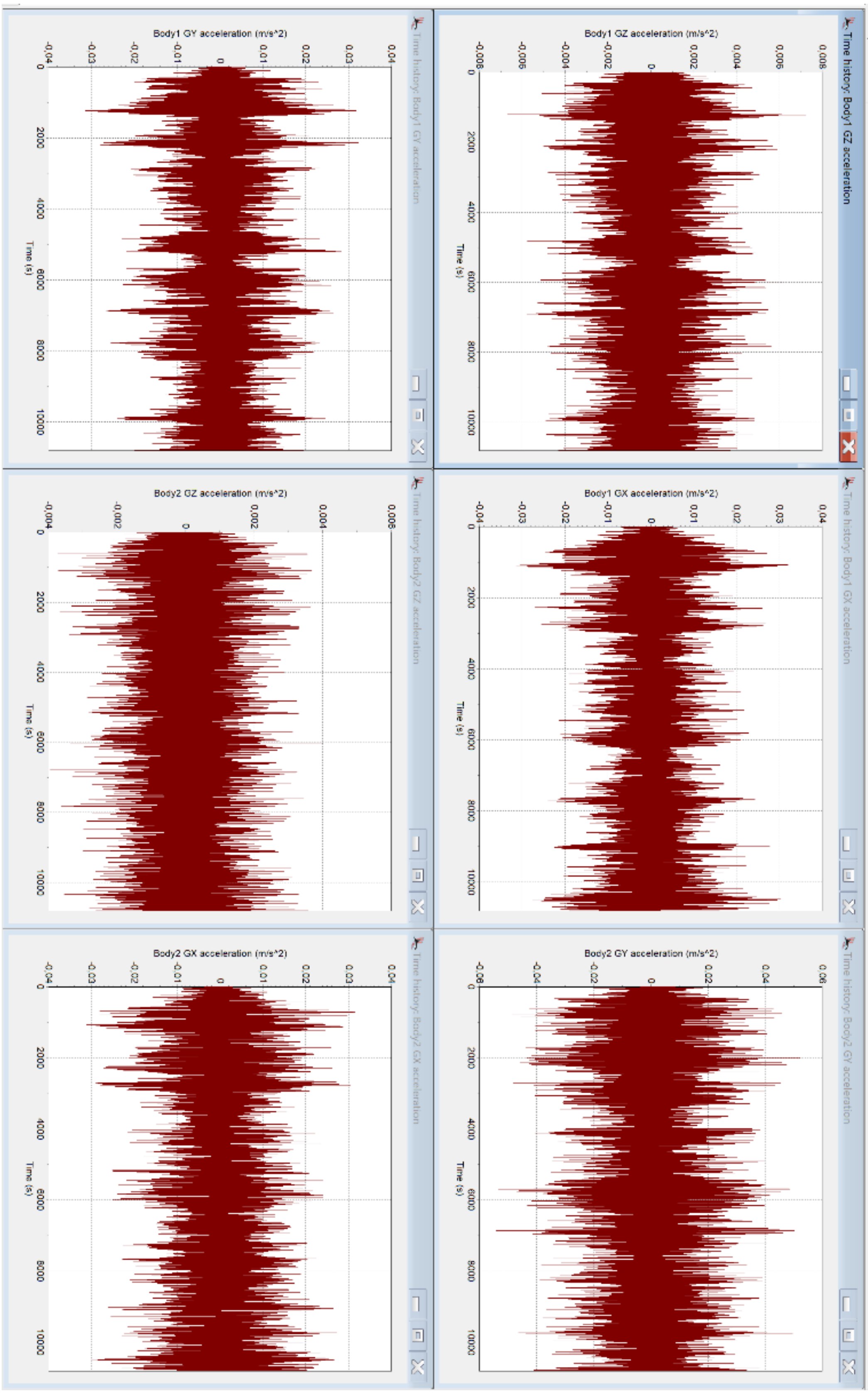
APPENDIX B

Comfort analysis. Configuration: line diameter 8 cm, length 16,5 m

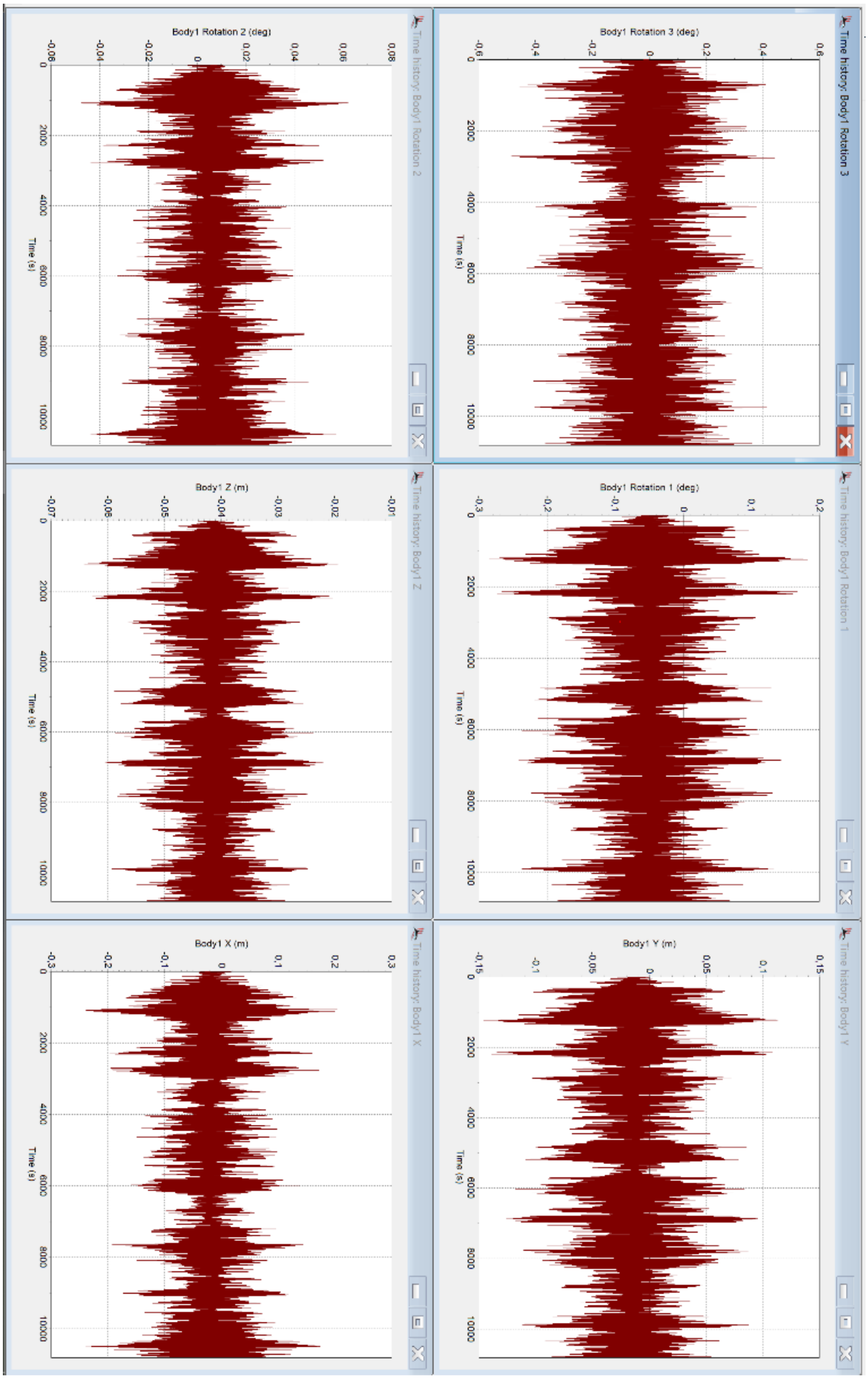
Effective tension temporal evolution of each line:



Platform 1 and platform 2 accelerations:

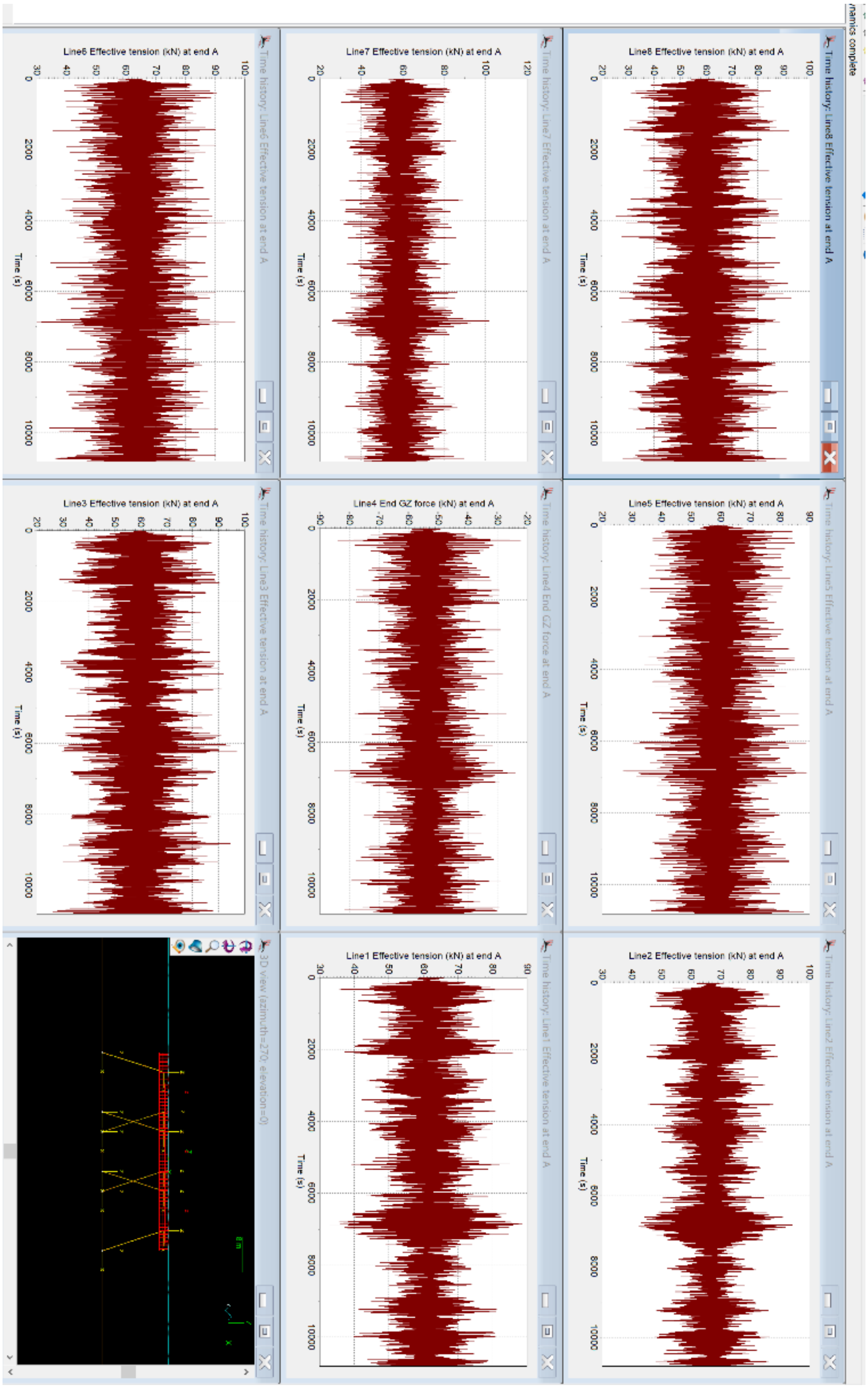


Rotation and displacements:

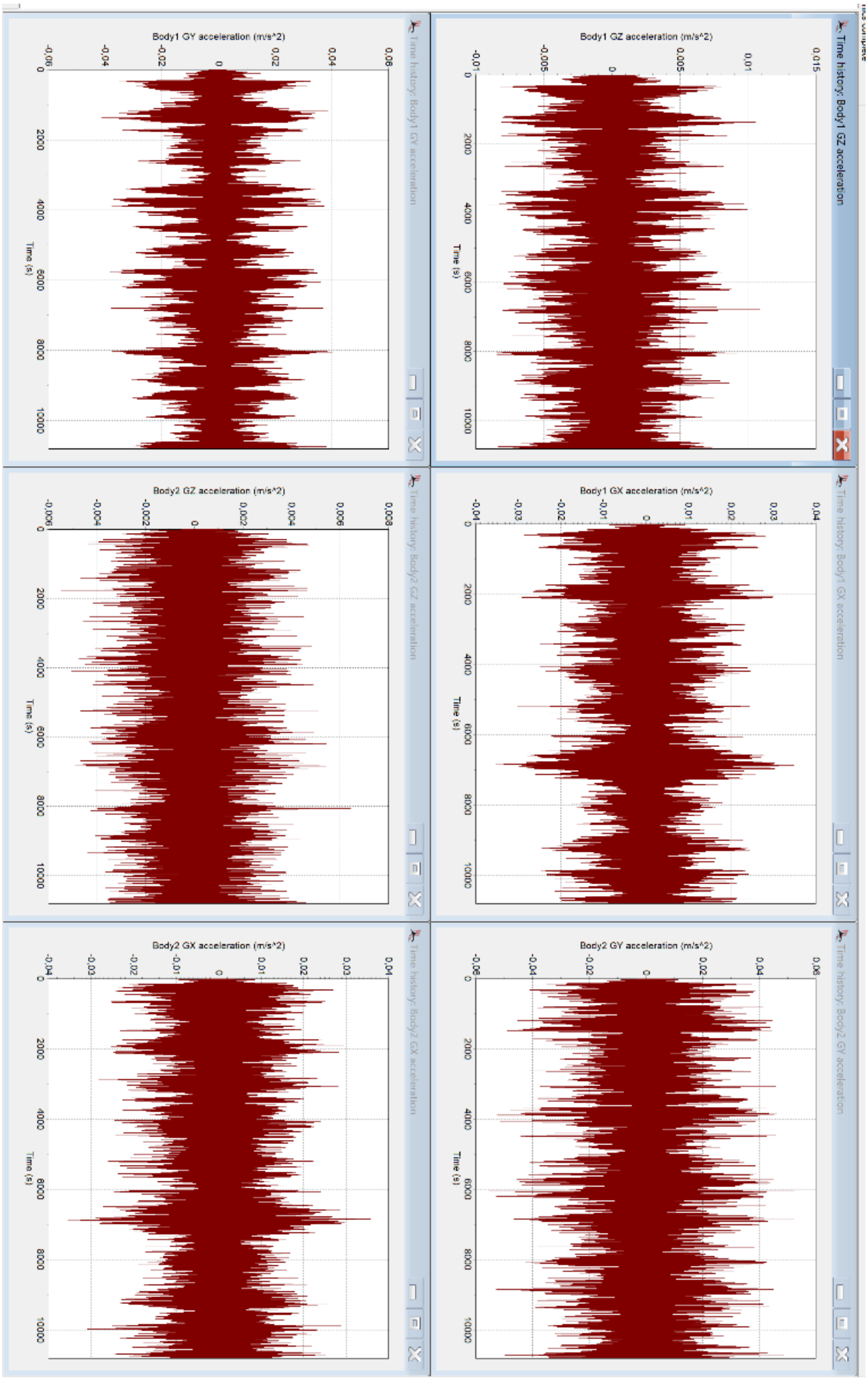


Comfort analysis. Configuration: line diameter 10 cm, length 16,5 m

Effective tension temporal evolution of each line:



Platform 1 and platform 2 accelerations:



Rotation and displacements: