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DELTA-BERENIKE

A semi-submersible type central-well, ballasted, self propelled platform

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ABSTRACT

We describe the surface vessel operational requirements needed for the construction, deployment and retrieval of a deep sea neutrino telescope. These impose stringent design criteria for the surface vessel. We propose an innovative solution and we describe the hydrodynamic behaviour, drag studies and the construction of such a vessel, the DELTA-BERENIKE, with the assorted host of deck equipment. Finally, we describe schematically its principal uses.

1.1 Introduction

Low Energy Neutrino Astronomy was born following the spectacular Supernova 1987A neutrino detection and the Solar Neutrino Deficit problem, now resolved with the 2002 Nobel Prize. However High Energy Neutrino Astronomy was a “no man's land”. High energy neutrinos should be produced in the most violent, cataclysmic processes in the Cosmos but there were no reliable flux calculations. The experimental techniques for high energy neutrino detection have been known to the community of elementary particle physicists since the 1960s. The Physics Laboratory of the University of Athens started in the early 90s, a pioneering and ambitious project, namely to build the World's first High Energy Neutrino Telescope, in the deepest part (5200 m) of the Mediterranean in the Oinouise trench, near Pylos and Methoni in the SW corner of the Peloponnesos. The telescope has to have gigantic size, i.e. a sensitive volume of several Cubic kilometres and room to grow in order to follow the Physics. There were two equally important components in this endeavour:

1) A lengthy programme, of detailed studies of the environmental parameters that affect the performance and longevity of the telescope such as, water transmissivity (absorption and scattering) in the visible part of the spectrum, sedimentation present and past rates, long term behaviour of underwater currents, sea bottom morphology and past history that affects the sea bottom, e.g. avalanches, earthquakes, long term detailed records of wind and sea state conditions, etc..

2) A lengthy programme to develop the necessary technology “(Anassontzis E.G. & Koske P., 2003)” and master the acquired know-how for such an undertaking where there is no experience internationally, except for the deep sea oil industry albeit at a much smaller depth and an essentially limitless budget compared to Science project funding in Greece.

A two step approach was taken:

I) concentrate on building modular smaller scale prototypes and getting experience with the hope that Nature might be kind and the neutrino flux is high and

II) operate the prototypes at a depth of 4500 m, judged to be acceptable for cosmic ray background reduction. This made operations easier because it is about 20nm closer to the sea port of Methoni than the area with the 5200 m depth.

The early part of this programme is referred to as NESTOR, this eventually evolved into KM3NeT (Cubic Kilometre size Neutrino Telescope) which was one of the two dozen large scale projects in the first list (2006) of ESFRI (European Strategy Forum for large scale Research Infrastructures) as a result of which the EU funded the Design Study and the Preparatory Phase of KM3NeT.

The basic unit of the NESTOR (Neutrino Extended Submarine Telescope with Oceanographic Research) neutrino telescope is a star like hexagonal “floor”. One can stack floors in the vertical, building thus a “tower”. Placing towers a few hundred metres apart one can also detect neutrinos which transverse the volume between towers, increasing thus many fold the sensitive volume of the telescope “(Resvanis L. K. (Ed). 1992)”, “(Resvanis L. K. (Ed.) 1993)”, “(Resvanis L.K. 2003)”, “(Aggouras G. et al. 2005a)”, “(Aggouras G. et al. 2005b)”, “(KM3NeT CDR)” and “(KM3NeT TDR)”.

The floor is basically a rigid frame on which one can mount photomultiplier tubes “(Anassontzis E.G. et al. 2002)”, along with the necessary electronics, to detect the photons of the Cherenkov radiation emitted by the charged particles that are produced whenever a neutrino interacts with the nucleons of sea water. The density of these photomultipliers is defined by the particular Physics one is investigating. For a general survey experiment as is NESTOR, a density of two, back to back, 13inch photomultipliers in the centre and the apexes of a 16 m radius hexagon suffice. The stacking of the hexagons every 30 m up to a Physics specified number, eg 12 hexagons in this case, in the vertical, completes the construction of a tower. Lengths of thin ropes, between floors, keep their relative orientation fixed. We note that the radius, the number of floors and the interfloor vertical distance are also defined by the specific Physics one is investigating. The whole mechanical construction forms a rigid platform onto which one can attach the number of photomultiplier tubes which is required by the Physics under investigation.



Fig. 1.1a. The titanium floor constructed out of titanium alloy pipe lattice trusses



Fig. 1.1b. The aluminium floor, constructed out of aluminium alloy pipes

The expected lifetime of the telescope is several decades and this means that the hexagons must be constructed from corrosion resisting metal alloys. Figure 1.1, shows two variants which were constructed: Fig. 1.1a, its 5 m long lattice trusses are constructed out of titanium alloy pipes (of 30 mm diameter frames, and 18 mm diameter struts), and Fig 1.1b its 5 m long aluminium alloy pipes of 70 mm diameter. In the centre of either hexagon, a 1 m diameter titanium alloy sphere (rated for a depth down to 7500 m) provides ample housing for the floor electronics and the inter floor connections, as well as for the deep sea electro-optical cable which provides electrical power via its Cu conductor (power return is achieved via the seawater, thus saving the cost of the second conductor), data/commands are transferred

to/from shore via monomode fibres. The Photomultiplier tubes are protected from the hydrostatic pressure by Benthos spheres (17 inch glass housing, 15 mm thick, rated for 6700 m depth). Electrical power, control commands and data are transmitted via special 7 pins connectors mounted on the Benthos sphere protective housing and on the Ti sphere electronics housing. The mass of each fully equipped floor is 1200 kg for the titanium and 1400 kg for the aluminium. The mass of a typical single armoured 12 monomode fibre light armour telecommunications cable is about 900 kg/km (about 6 kN/km weight in water). Since no Bathyscaph/Remotely Operated Vehicle was available, one had to retrieve the end of the underwater cable, make connections to the scientific payload in the air and redeploy to the bottom of the sea. Given the 4500 m depth, the cable catenary is circa 6-7km with a weight of circa 40 kN to be added to the in the water weight of the floors.

In the early stages of the experiment, the floors were assembled and fully tested in the bay of Navarino and then they were towed floating, or on a barge, to the deployment site, where a barge with a crane would lift them off the water to line them up with the electro-optical cable and the other floors. This proved to be a rather cumbersome as well as dangerous operation because effectively a pendulum (see Figs. 1.1a and 1.1b) was formed with an oscillating mass of more than 1000 kg and was oscillating even in calm seas because of the sea swell, subject to resonances. At the same time one had to handle the more than 40 kN weight of the electro-optical cable. It became obvious that the floors should never be lifted high off the water and the cable weight should be handled by an independent hoisting system and in such a way as not to introduce catastrophic oscillations while the tower was in the water, lowered to the sea bottom with the electro-optical cable hanging underneath.

Further, the deployment vessel should hold station (for days at a time) on the water surface using a Differential Dynamic Positioning System which should be coupled to an Acoustic Positioning System in order to deploy accurately (within a few metres) the towers on the sea bottom.

It soon became obvious that a semi-submersible type vessel with a central well was required. This vessel would be used:

- 1) To deploy/retrieve the telescope and its components
- 2) Connect/disconnect the telescope with the umbilical electro-optical cable that transfers power/data/commands from/to the shore station at Methoni
- 3) To suspend the telescope for a few days at a time for test purposes, with the telescope hanging underneath the vessel. The vessel's generators would provide power, while data and commands will be processed in a small "counting room" on the vessel. So, the vessel should be able to deploy/retrieve an electro-optical cable of a maximum length of 6km (note that the maximum depth is 5200 m).

The working crews would be transferred by speed boat from Methoni (20nm away). Only the Captain, the Chief of Operations and the Principal Scientist would be provided with live aboard accommodation.

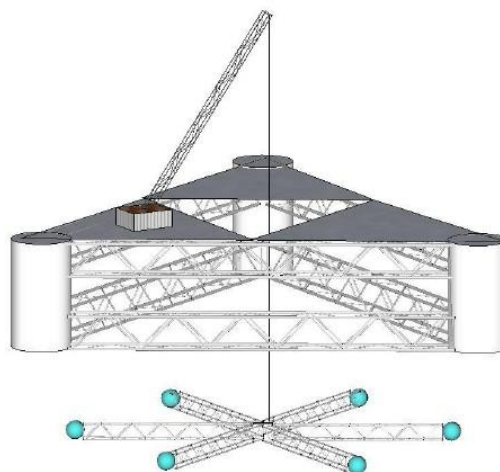


Fig 1.2. Graphical presentation of the prototype idea of a deployment platform. The load (a NESTOR star/floor) is shown.

1.2 The DELTA-BERENIKE

After several brain storming sessions, a simple but ingenious solution was presented to the Director of the NESTOR Institute by a civil engineer, the late Demetres Papanikolaou, based on off shore oil rig designs. Namely a 50 m long equilateral triangle, made from latticed steel beams, resting on three cylinders, one on each of the triangle apexes for buoyancy. This platform, equipped with loading cranes operating through the central well, would provide the required stability for the deployment of the neutrino telescope components, minimising the yawing, pitching, rolling etc. motions during deployment (fig.1.2).

This idea was presented to Prof. Th. Loukakis, then the Director of EANT (Society for the Development of Marine Technology). He was soon succeeded by Prof. V. Papazoglou who took charge of the design and asked Prof. S. Mavrakos of the National Technical University of Athens to help with the design by doing the necessary hydrodynamic simulations. In the meantime he and George Katsaounis started the engineering calculations and produced the drawings required for its production. The final design is shown schematically in Figs 1.3, 1.4, 1.5. Following the advice of Prof. Loukakis, she was constructed at the Elefsis Shipyards and named DELTA-BERENIKE. The geometrical size constraints of the yard's dry dock forced the modification of the original equilateral triangle idea to that of an isosceles.

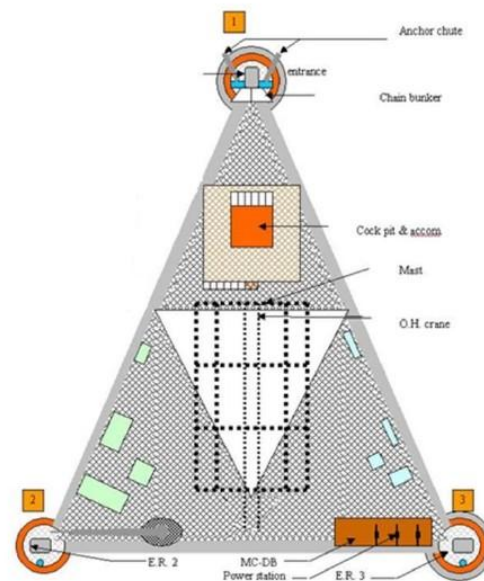


Fig 1.3. Schematic, top view of the DELTA-BERENIKE

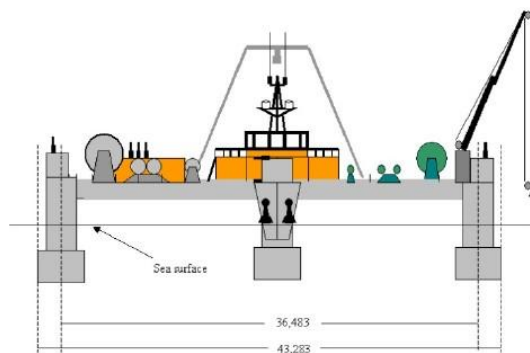


Fig 1.4. Schematic, front (bow) view of the DELTA-BERENIKE (lengths in metres)

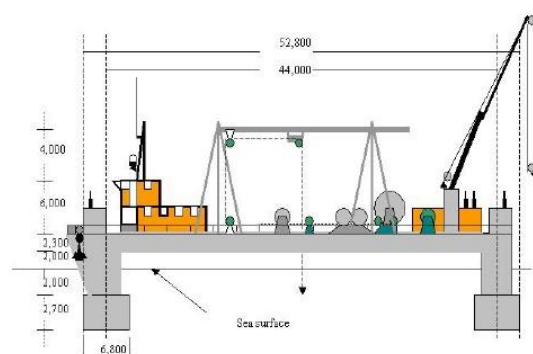


Fig 1.5. Schematic, side (port) view of the DELTA-BERENIKE (lengths in metres)



Fig 1.6. The triangle structure and reinforcements after construction (mosaic of a couple of photographs due to the large size).



Fig 1.7. The cylinders after construction



Fig 1.8. Welding a cylinder to the triangle

The DELTA-BERENIKE, is a semi-submersible type central-well, ballasted platform (Figures 1.3, 1.4 and 1.5). The deck is an isosceles triangle about 44 m on the sides and 36.5 m at the base (deck dimensions, i.e. excluding the cylinders). The triangle sides are made with three tube-like Main Beams of 2.3 m (height) by 1.25 m (width) of orthogonal cross section (fig.1.6). Between the Main Beams, special steel reinforcement beams are welded. The design is such that the lower edge of the sides of the platform floats about 2 metres above the sea surface. This is a key requirement in order to allow floors to be moved, while floating, from the outside to under the platform's central well. Three identical compound cylinders (fig. 1.7), each located at the apexes of the triangle (1, 2 and 3 in fig.1.3.) provide the required buoyancy to keep the triangular body and the platform infrastructure about 2 m above the sea surface



Fig 1.9. Ready to be painted and launched



Fig 1.10. A model of DELTA-BERENIKE

(fig. 1.5, 1.8). Each concentric double cylinder has a total height of 9.3 m. The upper part is a 4.4 m diameter cylinder and the lower part is a 6.8 m diameter (with height of 6.3 m and 3.0 m respectively). The large diameter cylinders lie below the sea surface providing additional flotation and damping the oscillations caused by wave action, as well as lowering the heave resonant frequency of the platform to approximately 0.9 rad /s.



Fig 1.11a. Ready to install the ancillary equipment. Insert: The central opening is clearly shown.



Fig 1.11b. Painted and ready to install the ancillary equipment

Each of the three cylinders houses a CATERPILLAR 322 BHP diesel motor coupled to a steerable water pumpjet, SCHOTTEL SPJ57RD jet, which can rotate a full 360°. Using the combined power and thrust direction of these engines, the DELTA-BERENIKE can sail the required course, or hold position in the open sea. Diesel, ballast tanks, pumps and fans, as required, are also installed inside each cylinder.

Most of the triangular structure is covered with decking metal sheets leaving in the middle a isosceles triangular opening, about 18 m side length, for equipment deployment (fig. 1.6, 1.9, 1.10 and 1.11). The platform is equipped with assorted cranes, winches, sheave blocks etc to be used as required.

The platform is also equipped fully with navigational and naval ancillary equipment. The DELTA-BERENIKE is a platform designed to be used in the open sea up to a sea state and including 4 Beaufort¹ in order to deploy large structures of complex geometry. Simulation studies have shown that the hydrodynamic behaviour of the DELTA-BERENIKE² and the available power is adequate up to this sea state while holding position. However, if the weather conditions worsen the

1 A sea state at the upper end of 4 on the Beaufort scale is characterised by winds up to 30 km/h with small waves (up to 1 m) and fairly frequent white caps. Weather records taken over the last 50 years, show that in the general area of operations (SW Peloponnese) one can expect clusters of three contiguous days at a sea state of less or equal 4 on the Beaufort scale 50% of the time.

2 See part 2, below

deployment operations should be suspended and the DELTA-BERENIKE should heave to until the weather conditions allow the resumption of operations or return to Pylos.

The Differential Dynamic Positioning System, augmented by various sensors (wind speed metres, current metres, etc.), automatically acquires real-time information concerning the platform's position and orientation, as well as wind force and direction etc. The data are fed to the Dynamic Positioning Computer (DPC), processed through appropriate filters (usually a Kalman filter), compared to the programmed position and generate the appropriate commands to the Schottel pumpjets and main engines in order to make the required corrections and move the DELTA-BERENIKE to the predefined position³. The position of the DELTA-BERENIKE is acquired using the Global Positioning System data. The accuracy of the system for keeping position is expected to be 2 to 5 m.

The main ancillary equipment the DELTA-BERENIKE is equipped with, is a bridge crane⁴ which is built using a main beam (Fig. 1.12) having of a total length of 18 m supported by two pairs of supporting columns of inverted V shape at a height, above deck, of approximately 9 m (built by 2 π TECHNOLOGIES S.A.). Two main deployment sheaves, of diameter about 800 mm are hanging below a "trolley". The position of the trolley and the winch/hoist feed rate could be automatically adjusted according to DELTA-BERENIKE's attitude to create an effective heave compensation system. The bridge crane has a working load of 100 kN.

The cables from the winches on the deck of the DELTA-BERENIKE (described in the next paragraph) are guided via direction changing sheaves over the main deployment sheave on the trolley. As the trolley is free to move along the beam of the Bridge Crane and the sheave wheel can rotate freely, the main deployment cable remains vertical: movement of the load suspended in the water due to the heave motion of the DELTA-BERENIKE is strongly damped. The trolley can move by +/- 6 metres from its nominal central position. A hydraulic mechanism damps the trolley movement: this can be operated manually with pushbuttons or automatically via load sensors. Full compliments of 1.8m diameter pulleys were constructed to accommodate the electro-optical cables when/if it had to be retrieved/deployed. The sheave diameter was determined based on the minimum bending radius of 0.80 m for standard telecom elector-optical cable (fig. 1.17).

Two hydraulic winches, with appropriate spools for storing deployment cable (and/or rope), are located on the DELTA-BERENIKE deck. Using these winches, with a cable/rope deployment speed between 0.1 m/s and 1 m/s, a load measuring system with 1 kN accuracy and the Bridge Crane payloads can be deployed to depths of 5200 m (the maximum sea depth in the area of operations).

The Main Winch (fig. 1.14) is a 100 kN winch (built by G. Tzenakis, Aerohydraulic S.A.), has a pair of traction drums of 1.8 m diameter and a 2 m wide storage drum with automatic spooling by controlled movement of the storage drum that ensures that the wire/rope is always at right angles to the drum.

The Secondary Winch (fig.1.15) is a 40 kN winch, has a pair of traction drums of 0.9 m diameter and a storage drum with automatic spooling by controlled movement the wire/rope along the drum and keeping always the wire/rope at right angles to the drum; the drum is 1 m wide. We thank our colleagues from the University of Hawaii for contributing this winch to the NESTOR programme (this winch was refurbished by G. Tzenakis, Aerohydraulic S.A.).

³ The system was designed and built by Prof. E. Papadopoulos, School of Mechanical Engineering, National Technical University of Athens

⁴ The system was designed by Prof. P. Makris, School of Mechanical Engineering, National Technical University of Athens



Fig. 1.12 Mechanical drawing of the Bridge Crane of the DELTA-BERENIKE



Fig. 1.13 The SORMEC M62/2S nautical crane of the DELTA-BERENIKE



Fig. 1.14. The Main Winch



Fig. 1.15 The Secondary Winch



Fig. 1.16. Accommodation and power station housings.
Insert: Pilot House, side view.



Fig. 1.17. Sheave suitable for electro-optical cable, 1.8 m diameter.

An auxiliary crane, called the ship's crane in this text, is a SORMEC M62/2S nautical crane (fig. 1.13), with a boom length up to 24 m and working load of 50 kN at 14 m boom and 15 kN at 24 m boom, is mounted on the deck of the DELTA-BERENIKE. This is a general

purpose crane to transport equipment, deployment of ancillary hardware, tender boats etc.; it is positioned so it can be also used as a working crane for lifting and lowering equipment to and from the working deck.

The power station of the DELTA-BERENIKE, consists of three generators and a control unit, located in a housing on DELTA-BERENIKE deck. The rating of the generators are: two LEROY SOMER 140kVA-220/380V-50HZ-3PH-4W+E generator, each powered by water-cooled DEUTZ (BF6M 1013-128kW) diesel engine each and one LEROY SOMER 30kVA-220/380V-50HZ-3PH-4W+E generator, powered by an air-cooled DEUTZ (F3L912-28kW) diesel engine.

The DELTA-BERENIKE is equipped with a bridge fully equipped with the required navigation and control instrumentation. Moreover, an accommodation area is provided to be used as a counting room to house the data acquisition instrumentation plus a general purpose accommodation room is available. The housings were built by NESTOR AVIET S.A..

Because of the close proximity of the theatre of operations to the shore station at Methoni the accommodation area (fig. 1.16) was limited to just four people since it is expected that the deployment crew will be transferred to/from shore for each shift.

The DELTA-BERENIKE is also equipped with the marine safety, fire fighting and signalling instrumentation, as required by the regulation.

2. THE CONSTRUCTION

2.1 The hydrodynamic behaviour study of DELTA-BERENIKE

For the evaluation of the hydrodynamic characteristics of the three – cylinder configuration, the computer software HAMVAB (Hydrodynamic Analysis of Multiple Vertical Axisymmetric bodies) “(Mavrakos S.A. 1994)” has been used, which has been developed at the Laboratory for Floating Structures and Mooring Systems, NTUA. The hydrodynamic interactions among the cylinders of the multi – body configuration have been accounted for through the use of the physical idea of multiple scattering “(Mavrakos S.A. & P. Koumoutsakos 1987)” and “(Mavrakos S.A. 1991)”. Hydrodynamic exciting wave forces, hydrodynamic parameters, shear forces and motions at structurally critical elements of the DELTA-BERENIKE, as well as its motion components have been parametrically computed for various loading conditions and wave headings.

Fig. 2.1 and 2.2 show the horizontal and vertical wave exciting forces per unit of wave amplitude, plotted over the wave frequency for three wave headings. Moreover, the response amplitude operator in heaving motion is given in Fig. 2.3, whereas Fig. 2.4 is devoted to the response amplitude operator of the shear force per unit wave amplitude in longitudinal direction at the location of the connection of first cylinder with the structural bracings.

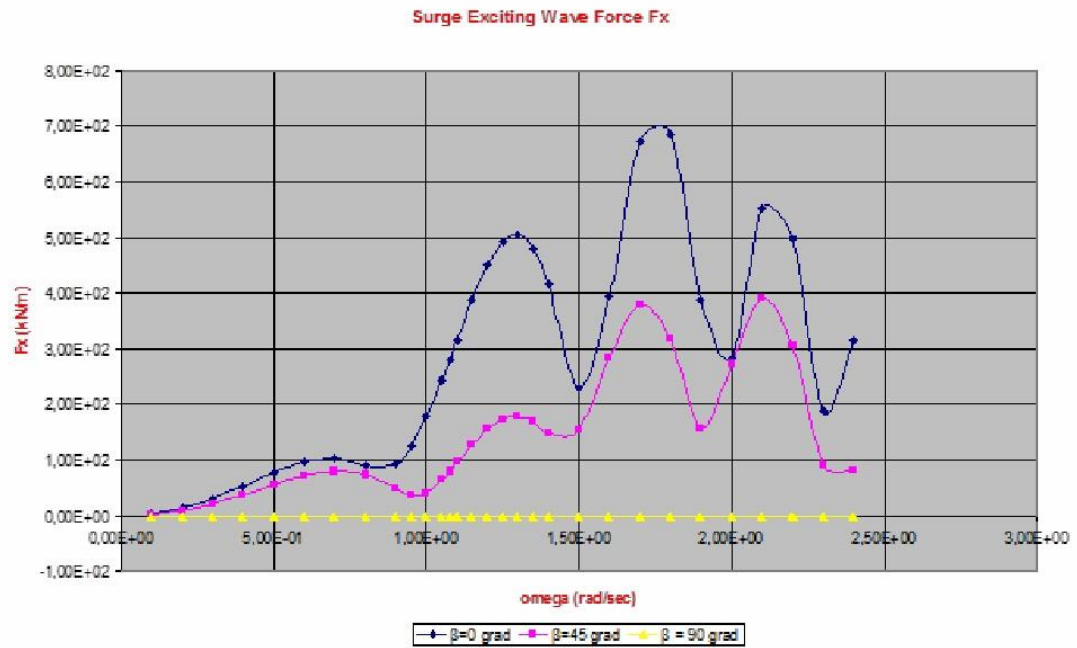


Fig. 2.1 Horizontal wave exciting force per unit wave amplitude

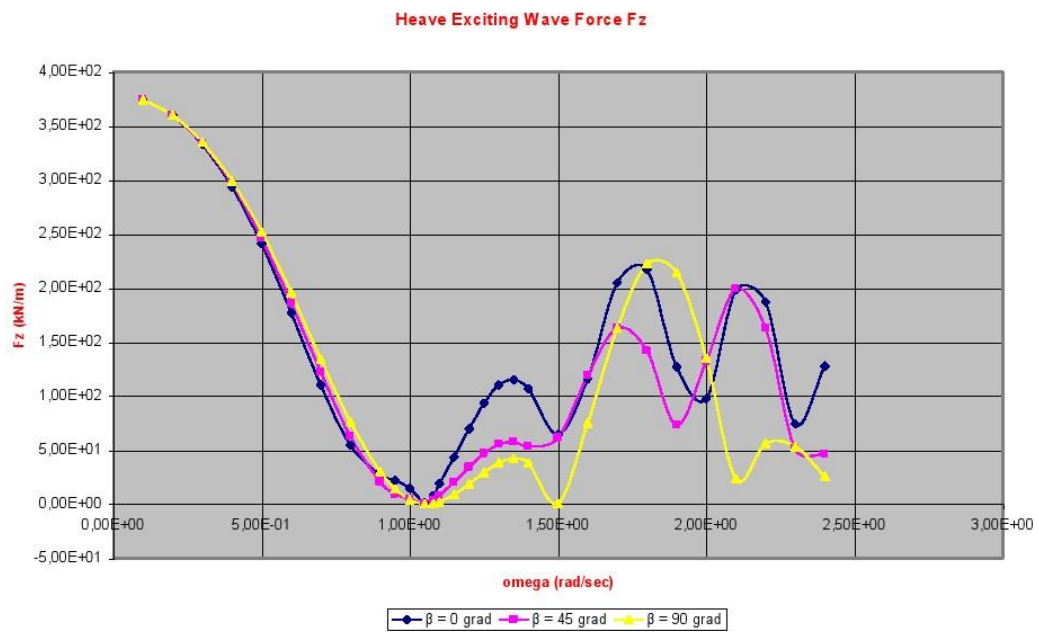


Fig. 2.2 Vertical wave exciting force per unit wave amplitude

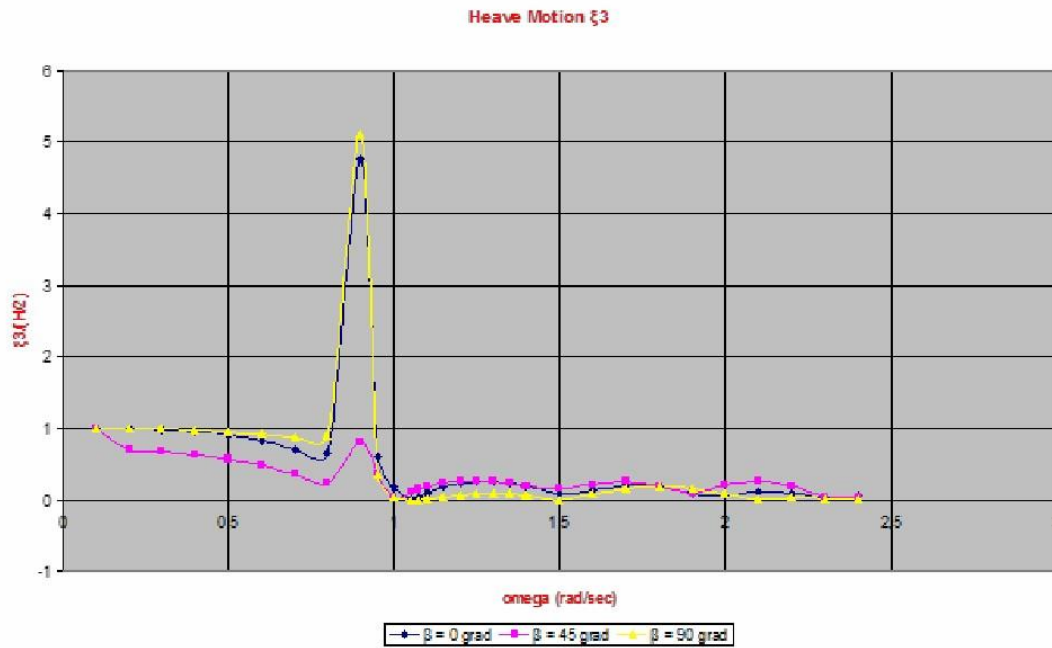


Fig. 2.3 Response Amplitude Operator in Heave motion of the DELTA-BERENIKE

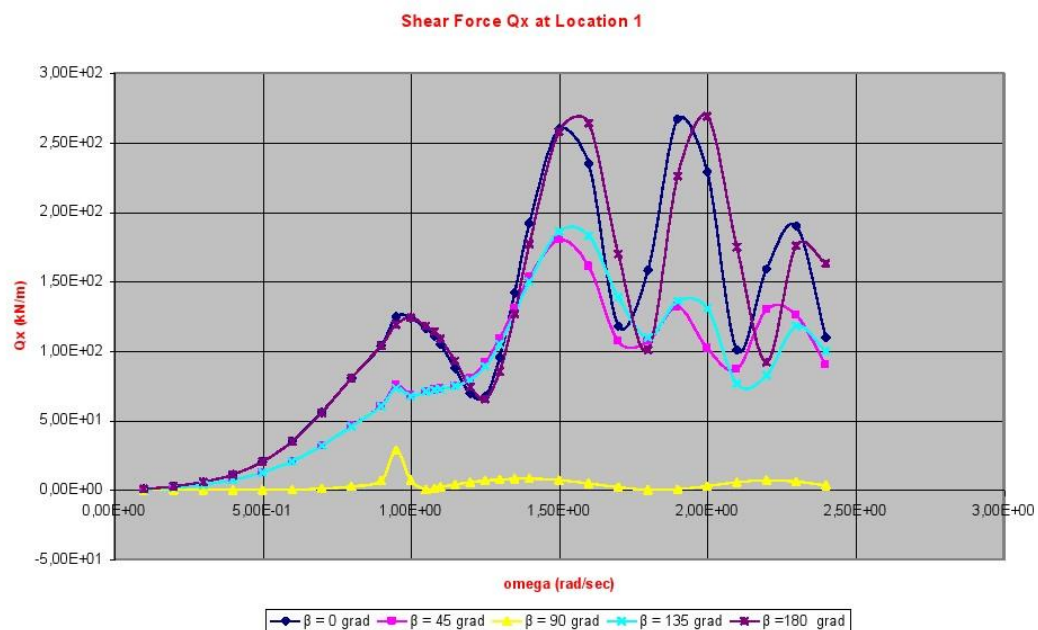


Fig. 2.4 Response Amplitude Operator of the shear forces per unit wave amplitude in longitudinal direction at the connection of the first cylinder of the DELTA-BERENIKE with the structural bracings.

2.2 The hydrodynamic drag study of the DELTA-BERENIKE

A further hydrodynamic study was carried out for the calculation of the drag force on the *DELTA-BERENIKE* when she is towed out of she is self – propulsing to her installation location offshore. It was assumed a parametric change of the *DELTA-BERENIKE* forward speed velocity between 1 – 5 knots with or without superimposing co-existent current. The drag force in the case of solely existence of sea current was varying between 8.31 kN, 33.24kN, 74.75kN, 132.93kN and 207.75kN for 1, 2, 3, 4 and 5knots current velocity, respectively. The corresponding drag force on the structure in the case of her forward speed without co-existent current was varying between 8.64kN, 34.58kN, 77.81kN, 138.34kN and 216.15kN for 1, 2, 3, 4 and 5knots structure's forward velocity, respectively. The corresponding drag forces for the case of the co-existent forward speed and wave current are shown in the following table.

Table 1: Drag force in kN on the DELTA-BERENIKE in the case of the combined action of various forward speed velocities of the floating platform and co-existent ambient current

Forward speed of the <i>DELTA-BERENIKE</i> (kn)	Current Velocity (kn)				
	0	1	2	3	4
1	8.64	33.91	75.79	134.24	209.42
2	34.58	76.80	135.64	211.02	303.18
3	77.81	136.98	212.77	305.10	414.22
4	138.34	214.46	307.20	416.47	542.56
5	216.15	309.23	418.93	545.13	688.19

Finally, the required power for achieving the set forward velocity of the *DELTA-BERENIKE* for various ambient current velocities is summarized in the next table.

Table 2: Required power in kW for achieving the set forward velocity of the DELTA-BERENIKE for various ambient current velocities

Forward speed of the <i>DELTA-BERENIKE</i> (kn)	Current velocity (kn)				
	0	1	2	3	4
1	4.32	17.12	38.27	67.79	105.75
2	34.92	77.56	137.00	213.13	306.21
3	117.88	207.52	322.34	462.22	627.54
4	279.44	433.20	620.54	841.27	1095.97
5	545.77	780.80	1057.79	1376.45	1737.68

2.3 The structural design and analysis of DELTA-BERENIKE

The main object of the structural design of the vessel was to provide the required space for the installation of the diverse equipment and a structural arrangement capable to withstand the operational and environmental loads. The main problem faced in the design was related to the size of the NESTOR stars. Their shape and dimensions dictated the joining of the cylindrical

floaters of the system by a connecting structure placed at height of the platform deck, without any other submerged members underneath. This arrangement requires the platform deck to be specially strengthened in order to exhibit increased bending and torsional stiffness.

The structure of the hull of the vessel, shown schematically in figure 2.5, can be divided into the following groups:

The main girders. These are box shaped girders, running along the edges of the main platform and serving as the main load carrying members. Their thin-walled transverse section offer the required bending strength to support the deck loads, while their closed shape exhibits enhanced torsional rigidity, necessary for the connection to the cylindrical buoyancy members. The girders have cross sectional dimensions of 2.30x1.25m and are internally reinforced by transverse webs for resistance against local buckling and shear loading. The longitudinal spacing of the webs is 2.5m. A more dense arrangement was selected for the middle length location, to support the joints with the secondary girders (fig. 2.6). The transverse webs have openings to facilitate the survey of the structure. The top, bottom and side plates of the girders are reinforced by longitudinal angle stiffeners, for strengthening against buckling and normal loads.

The secondary girders. These are again closed thin walled box girders, connecting the middles of the main girders and forming the internal triangular opening, facilitating in this way the operation of the main crane of the system and the deployment of the NESTOR stars. The secondary girders offer also a strong support for the mounting of the main crane legs.

The platform girders and plates. The platform deck area, has been covered by steel plating, supported by transverse girders and longitudinal stiffeners. These areas offer the required space for the installation of the winches of the system (main and secondary) and the remaining deck equipment.

The buoyancy cylinders located at the vertices of the main deck. Each of them is composed of two cylinders, the lower one having a diameter of 6.8m and the upper one, with a diameter of 4.4m. This compound shape results in a volume transfer well below the free surface and in a reduction of the hydrodynamic loading on the structure, as described in the previous section.

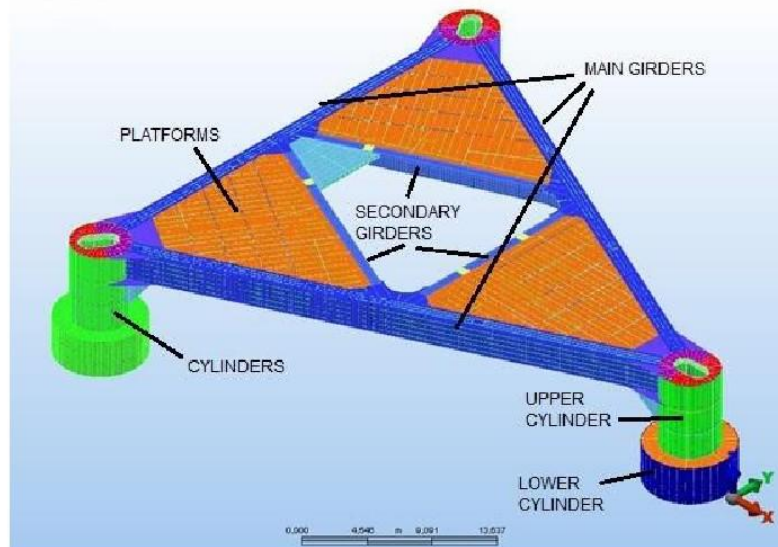


Fig. 2.5 The main structural components of the hull

The upper cylinder is structurally continued inside the lower cylinder, down to the bottom of the structure, acting in this way as a column, supporting the main triangular deck. The lower cylinder is structurally formed like a torus, surrounding the upper cylinder. It is divided into separate watertight compartments, which can serve as ballast tanks.

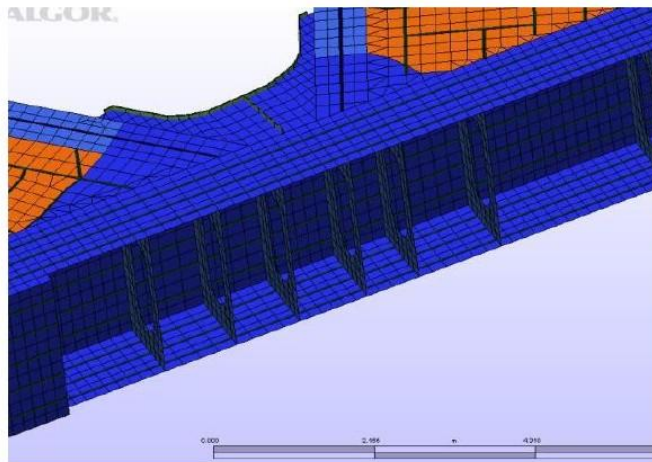


Fig. 2.6. Transverse web frames inside the main girders

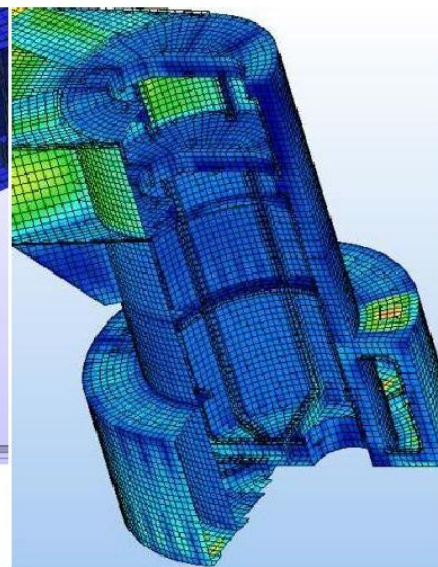


Fig. 2.7. Finite Element Model showing some of the internal construction details of the cylinders

At the bottom of the structure the propulsion machinery of the station keeping system is located, i.e. the pump-jet and the main engine. The steelwork includes proper elements for the formation of the pump well and the engine bed. The cylinders are stiffened vertically by longitudinal angle profiles and horizontally by stringer rings. Intermediate decks are placed inside the upper cylinder, equipped with stairs, to facilitate the service and the operation of the equipment (fig. 2.7).

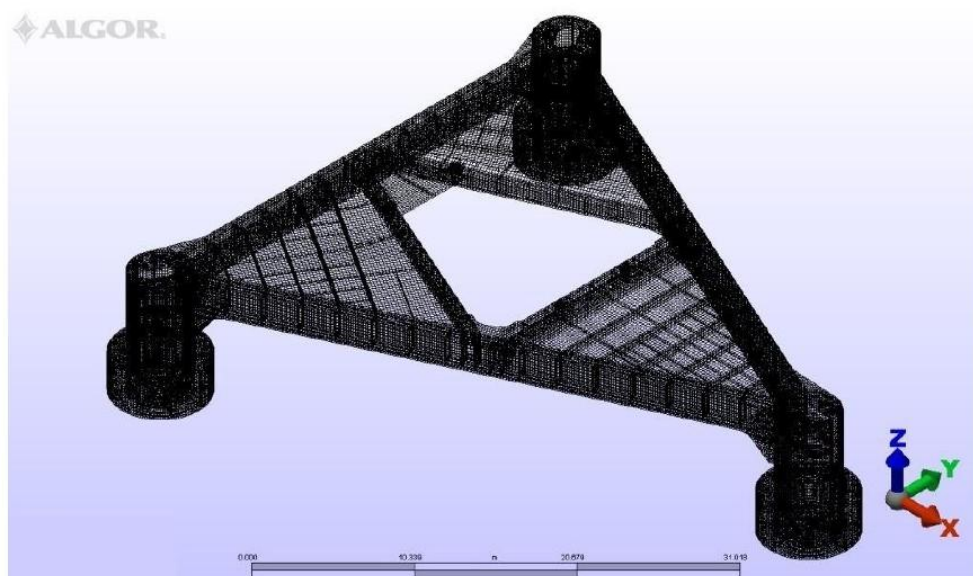


Fig. 2.8. The finite element mesh used in the analysis

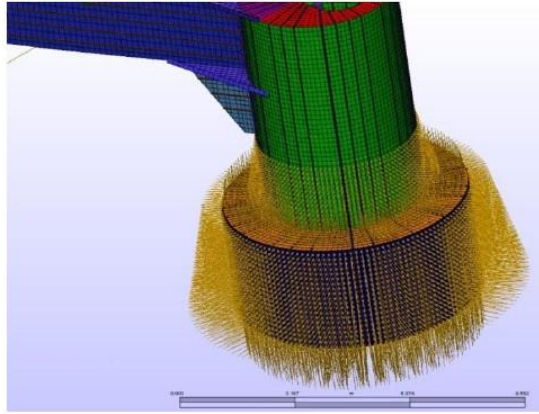


Fig. 2.9. Hydrostatic pressure loading

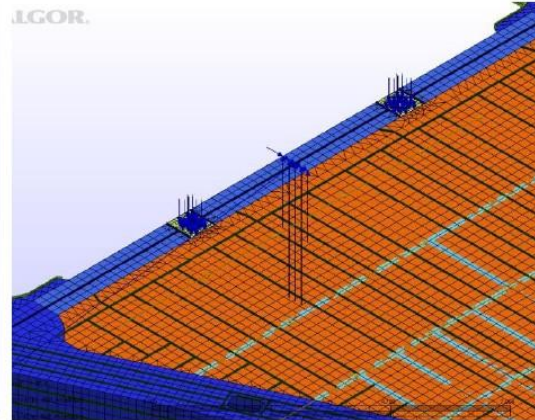


Fig. 2.10. Concentrated loads due to crane legs and sheaves

The structure was built in normal strength marine steel, having a minimum yield strength of 235MPa. The hull of the vessel has been built in the Elefsis shipyards under the supervision and according to the rules of the Hellenic Register of Shipping (HRS), which also approved the relevant construction plans and drawings.

Structural analyses. The structural analysis of the structure was investigated through the application of the finite element method. The FE model consists of approximately 115,000 shell elements, 27,800 beam elements and 650,000 degrees of freedom. It was developed using the ALGOR software package “(Autodesk Algor 2009)”. The adopted element mesh is shown fig. 2.8. The steel plating was modelled by 4-noded plate (shell) elements while the stiffeners were modelled by beam elements having sectional properties in accordance to the dimensions of the corresponding angle profile. Suitable eccentricity was given to the beam nodes, placing them away of the plate plane, in order to simulate the behaviour of the plate-stiffener assemblage. The overall modelling procedure follows the general methodologies

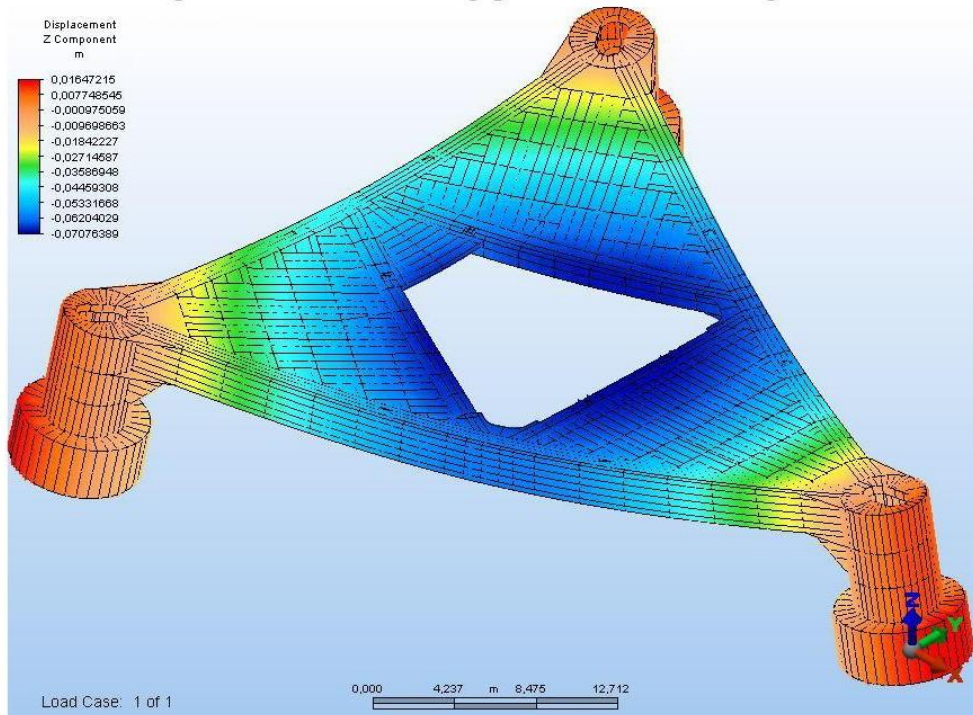


Fig. 2.11. Vertical displacement pattern

given by Hughes in “(Hughes O. F. 1988)”. The structure was subjected to the hydrostatic pressures on the wetted surface of the cylinders, as shown in fig. 2.9. The hydrodynamic loads correspond to a displacement of the structure at 430 tons salt water. Furthermore, the operational loads of the installed equipment were added as concentrated forces on the structure (e.g. the loads due to the crane legs and the sheave system, as shown in fig. 2.10) or as concentrated masses, for the case of massive equipment, like the main engines. In addition, loads due to hydrodynamic motions, examined in the previous paragraphs, were added as imposed horizontal or vertical accelerations of the structure. Results of such an analysis, with the structure being subjected to gravitational, operational and horizontal acceleration loads are shown in figures 2.11 to 2.13. The vertical deflections are shown in fig. 2.11. The larger values, having a level of 7 cm are found at the middle of the main girders that is at the middle of the unsupported span of platform deck.

Figure 2.12 shows the equivalent von Mises stresses, exerted at the plating of the structure. Stresses at a level of 85 MPa and some stress concentrations of 135 MPa are developed mainly at the upper and lower flange of the main girders. The most stressed area is located in their mid-span. Lower values, at a level of 50 MPa are depicted in figure 2.13, where a closer view of the connection between the platform deck and the cylinders is shown.

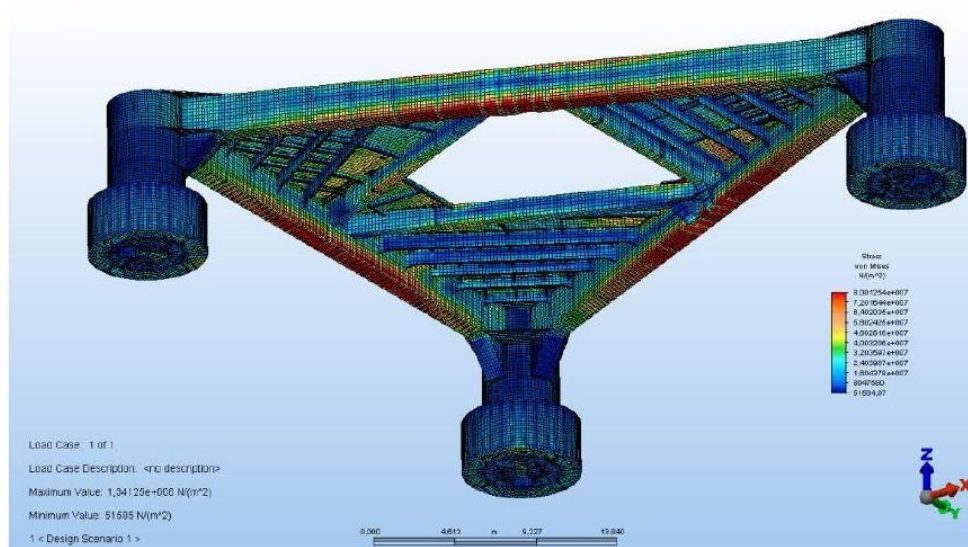


Fig. 2.12. von Mises mechanical stresses (entire structure)

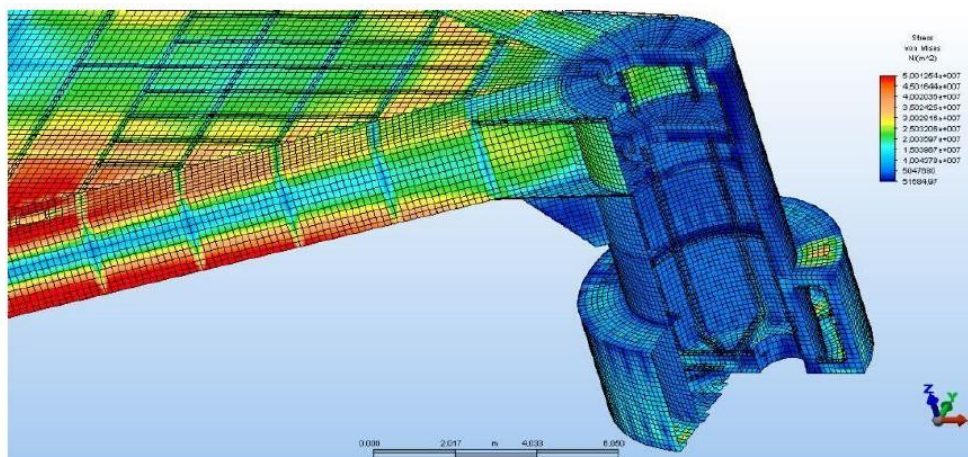


Fig. 2.13. von Mises mechanical stresses (detail near the cylinders)

The studies described above were followed by similar analyses performed by the HRS, for the examination of the compatibility of the design with the rules of the organization and the subsequent approval of the construction plans.

3. THE APPLICATIONS

3.1 Deployments

The DELTA-BERENIKE will be used for the deployment of the deep sea neutrino telescope, associated Oceanographic instrumentation and other massive instrumentation to the sea floor. Telescope units or more general, the detector units (DUs), will be transferred from the shore using transport vessels. The DELTA-BERENIKE has a flat deck to store temporarily several DUs before deployment. The crane will transfer the units to be deployed to the sea surface and the winch will lower them to the sea bed.

Each detector unit should be positioned with high accuracy on a predefined position on the sea bed. The DELTA-BERENIKE is equipped with a DGPS Dynamic Positioning System and communicates with a Long Baseline Acoustic Navigation System distributed on the sea bed at the deployment area (sec. 3.2). A counting room to monitor the deployment is provided. The deployment process is continually monitored using bathymetry measuring

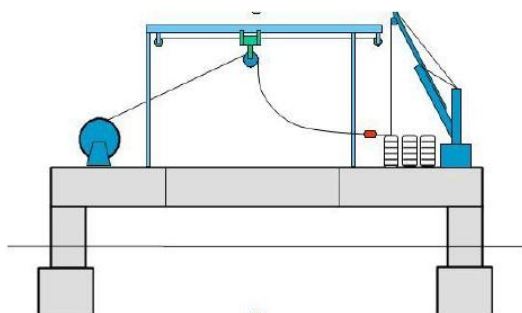


Fig. 3.1a. Preparation of the payload on the deck site of DELTA-BERENIKE for deployment

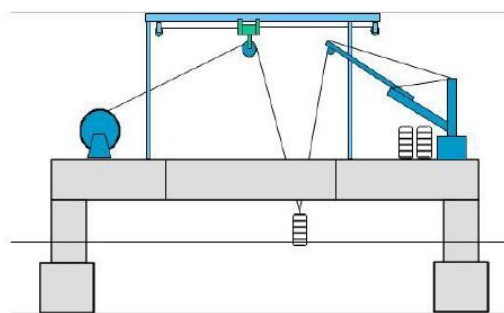


Fig. 3.1b. Payload transfer from the ship's crane to the Bridge Crane

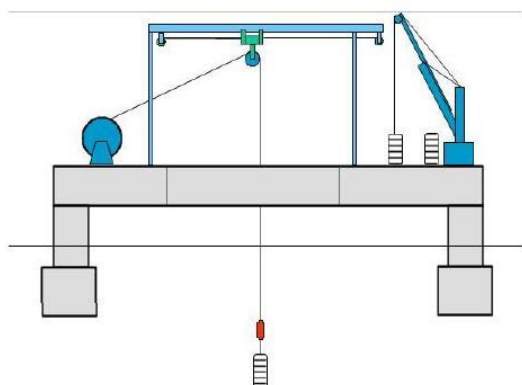


Fig. 3.1c. Lowering of the payload to the bottom of the sea. The acoustic release unit is shown in red.

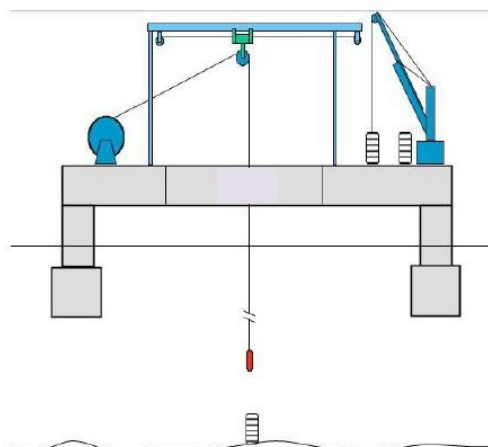


Fig. 3.1d. The payload has been deployed at the bottom of the sea and the deployment rope with the acoustic release device at its end is rewound to the surface

systems and monitoring sensors (tilt meters, accelerometers, compasses, acoustic systems etc.).

The deployment process itself is performed by the combined action of the installed equipment aboard DELTA-BERENIKE: the ship's crane, the Bridge Crane with its main beam, sheaves and the two winches. The payload to be deployed is usually stored on the deck of the DELTA-BERENIKE, after having been brought out to the deployment site by transport craft. The operation starts with the ship's crane lifting the payload off the deck and transferring it over the central well of the DELTA-BERENIKE. The payload has already been attached to the deployment rope, which runs through a sheave on the Bridge Crane to one of the winches. (Fig. 3.1a). Alternately, the trolley of the Bridge Crane will move towards the end of the bridge to load the payload directly from the deck.

By lowering the ship's crane, the deployment load is gradually transferred to the deployment rope-Bridge Crane-winch. This completes the transfer process and the load has been taken over by the winch through the sheave of the Bridge Crane (Fig. 3.1b), the connection to the ship's crane is removed and the lowering of the payload to the sea bottom with the winch commences (Fig. 3.1c) until the payload is a few metres above the sea bottom.

The DELTA-BERENIKE will execute fine manoeuvres with guidance from of the Long Baseline Acoustic Navigation System in order to ensure that the payload is positioned at the predetermined location. Then the acoustic release unit, at the lower end of the deployment rope, is activated, thus disengaging the payload. The rope is then recovered by pulling it up and storing it on the winch to be used again for the next payload deployment (Fig. 3.1d).

This schematic description of the deployment process with the DELTA-BERENIKE used the concept "payload" generically, without defining the specific payload to be deployed. It is clear with the process described, that the DELTA-BERENIKE can be used for all possible telescope configurations presently discussed or tested for the Kilometre Cube Neutrino Telescope (KM3NeT) design, these might include standard single strings, photomultiplier-sphere strings, bar towers, or hexagonal star/floor tower structures. With regard to open sea deployment activities, the DELTA-BERENIKE design is a universally usable and stable floating structure that is capable of delivering payloads to the sea floor with high accuracy..

The hardware on the DELTA-BERENIKE is tuned for the deployment of large detector components such as the KM3NeT towers or the NESTOR stars. In particular, the deployment of the NESTOR stars is extensively studied. In the following, a summary of this study is shown. By adding extra buoyancy, the stars are made neutrally buoyant in the water. The deployed tower is kept in position by a heavy anchor and kept taut in the vertical by a buoyancy unit. The anchor and the buoyancy unit are integral elements of the tower.

The first step in the mechanical deployment of a NESTOR tower⁵ consists of the assembly of 12 floors beneath the platform, with a vertical distance of 30 m between them.

The principal steps of this assembly process are shown in Figure 3.2 a – d.

⁵ One specific property of towers should be pointed out here: depending on the length of the arms and therewith the diameter of the star like floors the number of photomultipliers on each level is determined. The minimal number of photomultipliers per hexagonal floor is 7, 6 on the apexes and 1 in the centre; with longer arms it could be 12 or even more. Therefore one tower is equivalent to 7 or 13, etc. string arrangements (detection units)

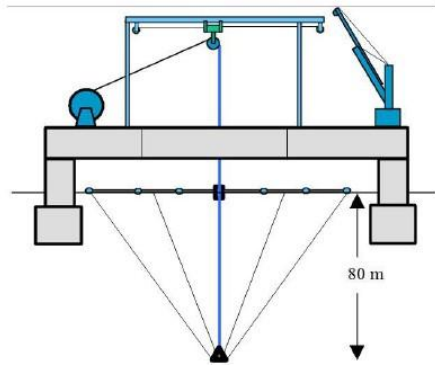


Fig. 3.2a. The Lower floor and the Bottom unit (anchor and tower junction box) are connected and deployed

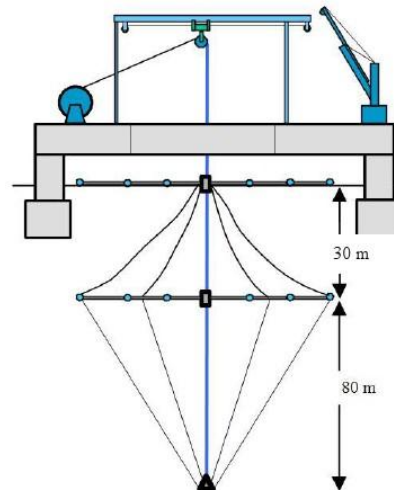


Fig. 3.2b. Second floor is arranged 30 m above the first one

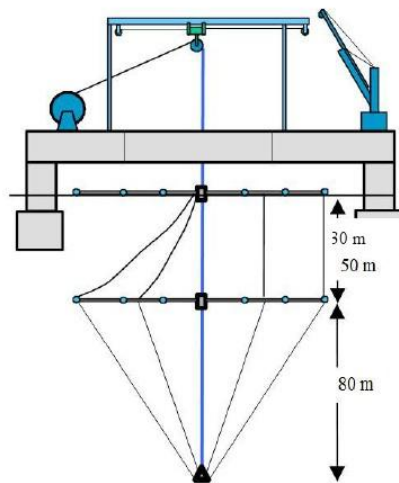


Fig. 3.2c. Second floor is partly connected to the first one

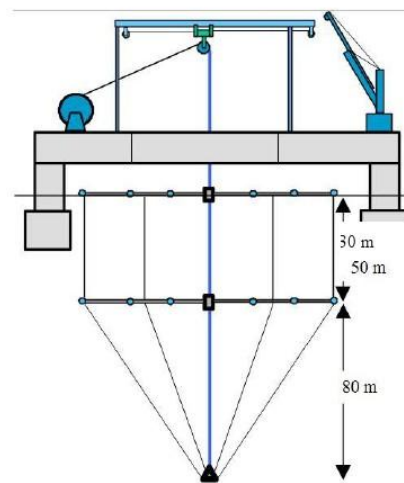


Fig. 3.2d. Second floor is connected completely to the first one

The so-called bottom unit, marked by a black triangle on the drawings, contains the anchor and the tower junction box to the umbilical cable. After the bottom unit has been lowered to a depth of about 80 m by a “mounting rope” via a sheave on the Bridge Crane, the first floor is deployed and connected to the bottom unit by six ropes which have been kept at the platform during the lowering of the bottom unit (Fig. 3.2a).

The mounting rope plays a central role in the assembly of the tower because it carries the full load of the tower, i.e. the bottom unit (and possibly an umbilical cable hanging underneath) since the floors are “weightless” in the water. By paying out the mounting rope the combined entity of bottom unit and first floor is then lowered by 30m, while six ropes for connection to the second floor are kept loosely at the surface (Fig. 3.2b). Figures 3.2c and 3.2d show stepwise the coupling between floor one and two.

In the same way all 12 floors are assembled and then the tower (or any D.U.) is kept taut in the vertical by adding the required deep sea buoyancy, at a vertical distance of about 100 m above the 12th floor. The buoyancy unit is attached to the topmost floor, with six ropes in the

same way as has been done with the floors. This completes the assembly of the tower in the water.

After the complete tower has been assembled and deployed in the water, one has to transfer the load from the “mounting rope” to the so called “deployment rope”. The deployment rope is long enough to lower the whole tower to the bottom of the sea. The deployment rope is attached to the buoyancy unit and runs through a second sheave at the Bridge Crane and is stored on a winch. After the deployment rope has taken over the load of the suspended tower in the water, the mounting rope is released and attached to the top of the buoyancy unit to be used later during recovery. Now the total weight of the tower in the water below the buoyancy unit is kept by the six connecting lines, running at the outer edge of the tower along the ends of the star arms all the way down the bottom unit. By lowering the deployment rope, the tower is deployed to a predetermined position on the sea bottom, and then the deployment rope is released acoustically and retrieved.

3.2 The Sea Bottom Positioning

To achieve accurate positioning of detection units of the underwater detector during deployment, a Long Baseline Acoustic Navigation System (LBNS) will be deployed when required, to monitor the position of the Telescope components and its anchor and to guide it to a predetermined position on the seabed. The LBNS is composed of several transponders deployed and positioned on the seabed, on the anchor of the detection unit and on the surface vessel.

A Long Baseline Acoustic Navigation System (LBNS) was evaluated with an appropriate transponder grid, composed of several transponders, a GPS receiver, the deck unit (the LBNS controller and the vessel transducer) and the appropriate navigation and calculation software (WINGFROG ver. 3.8). This system has undergone first field tests in the sea during the spring 2008. Three transponders were deployed and positioned on the sea bed, at a depth of around 4000 m. The distance between the transponders was about 1.2 nautical miles. The area where the test was performed was around the coordinates N36° 37'800 and E21° 35'000. Two procedures were tested: Transponder positioning and transponder manoeuvring. The transponders were recovered after the conclusion of the test. In summary, the performed tests have shown that by deploying several transponders on the sea-bed to make a grid in the area of interest, one can establish the positioning in absolute coordinates of the grid on the sea bottom, with accuracy better than 1 m. This could be further improved by deploying more fixed transponders. Thus, tracking a payload during deployment and placing it on a particular position on the seabed with metre like accuracy is possible with this acoustic system.

3.3 The Development of a concept for absolute angular calibration

The DELTA-BERENIKE surface area is $\sim 1000 \text{ m}^2$. If necessary this could be increased with outriggers. Equipped with elementary particle detectors like ‘muon’ chambers, it could form a large Air Shower Detector array “(Anassontzis E.G. et al. 2011)”.

Having an extended Air Shower detector array at the surface above the deep sea neutrino telescope would allow the detection and tagging of high energy muons that are produced by cosmic ray showers which also trigger the underwater telescope. Analysis of these coincidences would give a good indication of the angular accuracy response (both absolute and relative) of the underwater telescope. Such an analysis would complement studies of the telescope's angular response with atmospheric muons, internal calibration beacons and Monte-Carlo simulations.

The absolute pointing accuracy of the underwater telescope could be confirmed or corrected by the reconstruction of an event in the telescope back to the same shower which has also triggered the surface array. A surface array positioning error of 1 m would introduce a pointing error of 1 metre/4000 metre depth (~ 0.25 milliradian), essentially insignificant.

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Ο **Βασίλης Παπάζογλου** (1952-2014), καθηγητής της Σχολής Ναυπηγών Μηχανολόγων Μηχανικών του Ε.Μ.Π., αγάπησε και υπηρέτησε με πάθος το Πολυτεχνείο, τη διδασκαλία, τους φοιτητές του, τις ακαδημαϊκές βιβλιοθήκες και την τριτοβάθμια εκπαίδευση. Τα υπηρέτησε όλα με συνέπεια, ανιδιοτέλεια και υψηλό αίσθημα ευθύνης από το 1985 και μέχρι το τέλος από διάφορες θέσεις: ως καθηγητής, Πρόεδρος της Σχολής του, Αντιπρόεδρος της Επιτροπής Ερευνών Ε.Μ.Π., Πρόεδρος του Συνδέσμου Ελληνικών Ακαδημαϊκών Βιβλιοθηκών (Σ.Ε.Α.Β.), μέλος της Αρχής Διασφάλισης Ποιότητας στην Ανώτατη Εκπαίδευση (Α.ΔΙ.Π.), μέλος του Εθνικού Συμβουλίου Παιδείας (Ε.ΣΥ.Π.). Τέλος, ως Ειδικός Γραμματέας Ανώτατης Εκπαίδευσης του Υπουργείου Παιδείας Δια Βίου Μάθησης και Θρησκευμάτων, υπήρξε ο βασικός αρχιτέκτονας του νόμου 4009/2011.

Ο αφιερωμένος σ' εκείνον παρών Τόμος, περιέχει κείμενα συναδέλφων, συνεργατών και φοιτητών του από όλους τους χώρους της ευρύτερης ακαδημαϊκής κοινότητας όπου δραστηριοποιήθηκε, καθώς και επιστημονικά άρθρα σχετικά με τις επιστήμες του μηχανικού που υποβλήθηκαν ειδικά για την παρούσα έκδοση από συναδέλφους και συνεργάτες του. Το έργο αποτελεί μια ελάχιστη επιστροφή του χρέους που οφείλεται στον Βασίλη Παπάζογλου, ο οποίος με την ύπαρξη και τη σταδιοδρομία του τίμησε τον Άνθρωπο και την Παιδεία, σε ύψιστο βαθμό.



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