NTNU – Trondheim
Norwegian University of
Science and Technology

SUBSEA RECEIVER STATION FOR COMMUNICATION WITH DOWN WELL SENSORS

Undervanns mottakerstasjon for
kommunikasjon med brønnhull sensorer

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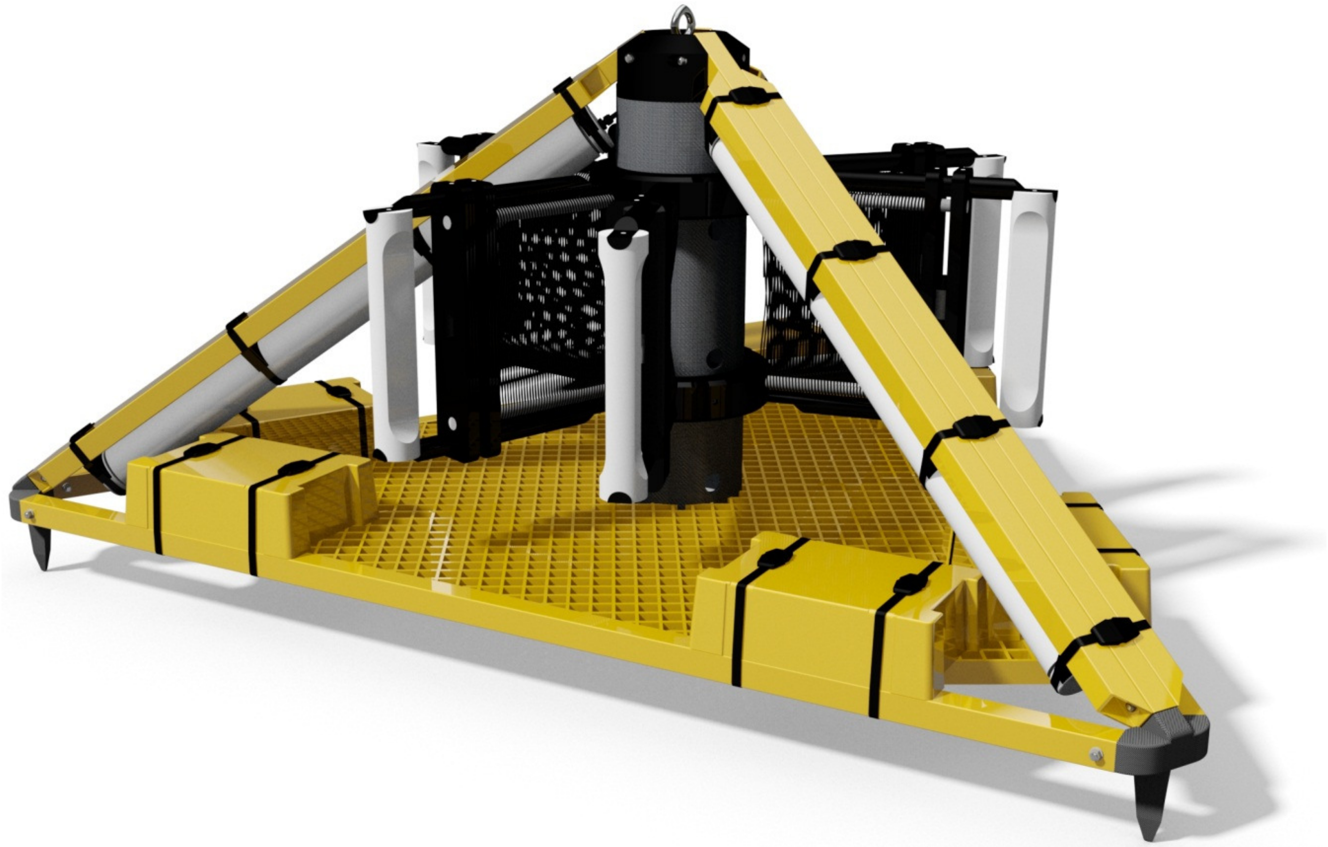
SUBSEA COMMUNICATION SYSTEM

MASTER THESIS - TMM4901
Stud. Techn. Jarl André Fellinghaug, BSc
NTNU 2013
DEPARTMENT OF ENGINEERING DESIGN AND MATERIALS



WiNS
Wireless Instrumentation Systems

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Innovation and Creativity

MASTER THESIS - TMM4901

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Sammendrag

Omfanget av dette prosjektet var å utvikle en spesialutformet kommunikasjonsplattform for Subsea applikasjoner. Wireless Instrumentation Systems (WINS) AS har et pilotprosjekt med Statoil ASA på produksjons feltene Gullfaks og Åsgard. WINS vil installere ettermonterbare autonome brønn sensorer som vil overføre data trådløst fra brønnen på havbunnen.
Dette prosjektet følger utviklingsfasen av dette kommunikasjonssystem som for den "siste kneika" av signaloverføring fra havbunnen til Topside plattform eller produksjon senter.

Den største bekymringen for denne plattformen er de undersjøiske strømninger som kan indusere vibrasjoner til ramme strukturen. Dette vil ødelegge plattformens evne til å motta signaler fra brønn sensorer siden prinsippet for kommunikasjon er svært svake elektromagnetiske bølger. For å motta disse signalene, er brukes hyper sensitive magnetometre i et 3D-array. Som et forsøksprosjekt vil WINS også teste signal mottak prinsippet ved å måle elektrisk potensial på havbunnen ved bruk av elektroder. Et system for distribusjon disse elektrodene må inngå i designet.

Flere konsepter ble unnfanget og forkastet da de ikke klarte kravspesifikasjonen under analysen. Men disse dataene ga kunnskap til å utforme det endelige konseptet.

Det endelige konseptet har en meget stiv ramme struktur av et tetraeder form. Alle materialer er ikke-magnetisk, da dette ville ødelegge signalmottaket. En sammenkoblet trykktank system inneholder magnetometrene og datainnsamling enheten. Hver magnetometer er godt festet til den stive rammestrukturen for å unngå vibrasjoner. Elektrodene vil bli utplassert ved hjelp av spesialbygde kabelspole rammer, som vil bli utført av en fjernstyrt miniubåt (ROV).

Denne rapporten beskriver i detalj de integrerte konsepter av det endelige produktet og hvordan det løser kravspesifikasjon gitt av WINS og Statoil ASA.

Abstract

The scope of this project was to develop a purpose designed communication platform for subsea applications. The company Wireless Instrumentation Systems (WINS) AS has a pilot project with Statoil ASA on the production fields Gullfaks and AAsgard. WINS will install retrofit autonomous well-sensors that will transmit data wirelessly from the well to the seabed.
This project outlines the development phase of this communication system providing the “last mile” of signal transmission from the seabed to the topside platform or production center.

The main concern for this platform is the subsea currents as they might induce vibrations to the frame structure. This will disable the platforms ability to receive signals from the well-sensors as the principle of communication is very weak electromagnetic waves. To receive these signals, hypersensitive magnetometers are used in a 3D array. As a pilot project WINS will also test the reception principle of measuring electric potential on the seabed by the use of electrodes. A deployment system for this must be incorporated in the design.

Several concepts were conceived and discarded as they failed the requirement specifications during analysis. However, this data gained knowledge to design the final concept, with success.

The final concept has a very rigid frame with a tetrahedron shape. All materials are non-magnetic as this would distort the signal reception. An interconnected pressure vessel system contains the magnetometers and the data acquisition unit. Each magnetometer is firmly attached to the rigid frame structure to avoid vibrations. The electrodes will be deployed by the use of purpose built cable spool frames, which will be performed by a Remotely Operated Vehicle (ROV).

This report describes in detail the integrated concepts of the final product and how it addresses the requirement specifications given by WINS and Statoil ASA.

Preface

This report is the result of 4 months of hard work and many late nights at the office. This project had a rather turbulent start as the task description changed from the Autonomous Underwater Vehicle (AUV) project which was meant for supplying power and communication to the Subsea Communication System (SCS) to actually develop the SCS itself.
The reason for this was a strategic change in Wireless Instrumentation Systems (WINS) product portfolio resulting in that the SCS will be placed near subsea infrastructure on offshore productions sites, making the need for an AUV obsolete.

Initially the idea was to use an electromagnetic receiver from the company EMGS AS, named RX4. This receiver however, was designed to operate subsea for up to 2 week at the most, while the design life for the WINS application is 5 years. The task of modifying this and the other disadvantages made the development of a purpose built Subsea Communication Station more appealing.

The leading goal for the SCS design was to make the frame structure so stiff that the first mode of resonate frequency (Eigen frequency) would be as high as possible, reducing the risk of vibration. Structure vibration will make the SCS useless as the main technology used for signal reception is magnetometers. The signals from these are so weak that the slightest movement will distort the signals severely.

The requirements from WINS AS and Statoil ASA were not 100% complete until late May, and this delayed the manufacturing process. It has been a very high focus on lead time for this project and a constant chase to meet the production end date. However, this led to a very agile development team with frequent meetings and high flow of internal information which resulted in a thoroughly designed product.

Great appreciation is forwarded to the key personnel in the development team Frode, Yingkang and Arvid. Also huge thanks to Atle Hjertenæs, WINS CEO, which has been very flexible in terms of facilitating to make this Master Thesis possible.

Jarl André Fellinghaug

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1 Abbreviations

WINS	Wireless Instrumentation Systems
WIPC	Wireless Instrumentation Power and Communication
SCS	Subsea Communication System
NORSOK	Norsk Sokkels Konkuranseposisjon
ROV	Remotely Operated Vehicle
EDS	Electrode Deployment System
EPVS	Electronics Pressure Vessel System
EPV	Electronics Pressure Vessel
ERM	Electronics Rack Mount
MPV	Magnetometer Pressure Vessel
GFRP	Glass Fiber Reinforced Plastic
FEM	Finite Element Method
CFD	Computional Fluid Dynamics
VS	Vortex Shedding
VIV	Vortex Induced Vibrations
TBD	To Be Determined

2 Introduction

This report is the Master Thesis for André Fellinghaug performing a rapid development project for the company Wireless Instrumentation Systems (WINS).

WINS is a technology company that addresses a major problem for the oil and gas industry; when production wells are made, they are usually completed with permanent pressure and temperature sensors. These sensors are used by the process engineers to control the production for optimal results. However, most of these sensors die out in a short period of time, and a recompletion is often not economic or practical. As a result of that, periodic logging operations of pressure and temperature are performed by an intervention tool. This is a costly and time-consuming task.

WINS solves this problem by making a Wireless Instrumentation Power and Communication (WIPC) tool, see Figure 3-1 WIPC tool, to take these measurements and transfer the data wirelessly. For this application WINS needs a communication station placed on the seabed to receive signals from the WIPC and relay these signals up to the platform.

This report covers the development of the Subsea Communication System (SCS) hardware and presents the concept in production level details.

3 WINS technology

WIPC tools utilize the oil stream in the well to spin a internal turbine. The turbine is connected to a generator which produces electricity. The WIPC has onboard pressure and temperature sensors and derive the oil stream flow velocity from the turbine rpm. These three data points are packed in files and transmitted by electromagnetic (EM) waves [1] through the earth formation. EM signals conducts well in earth formation, but poorly in water conditions. Thus a communication station between these two domains of earth and water is necessary.

The SCS will be placed on the seabed to receive the EM signals from the WIPC by magnetometers [2] and electrodes [3]. This is a redundancy configuration that WINS wants on the first pilot systems. The best technology, magnetometer or electrodes, will be used on SCS version 2.0.

The SCS will collect data from several WIPC tools and relay the data through the seawater to the topside platform or production center by hydro acoustic [4] or a cabled connection. See Figure 3-2 WINS Application overview

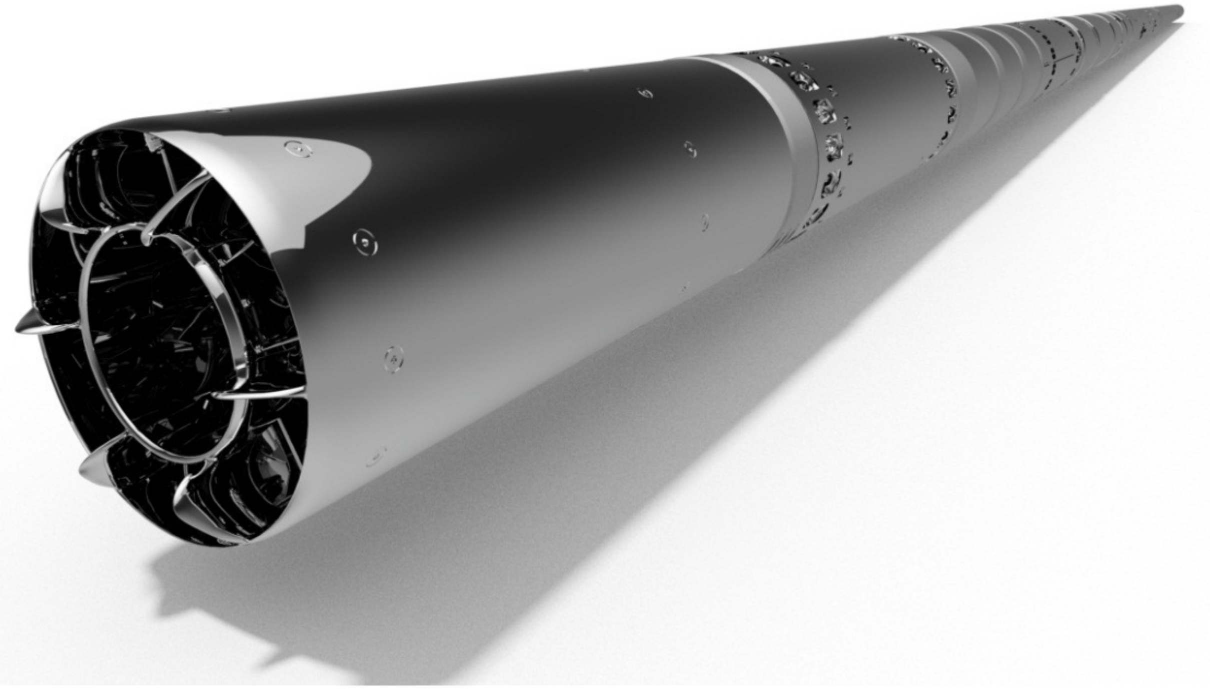


Figure 3-1 WIPC tool

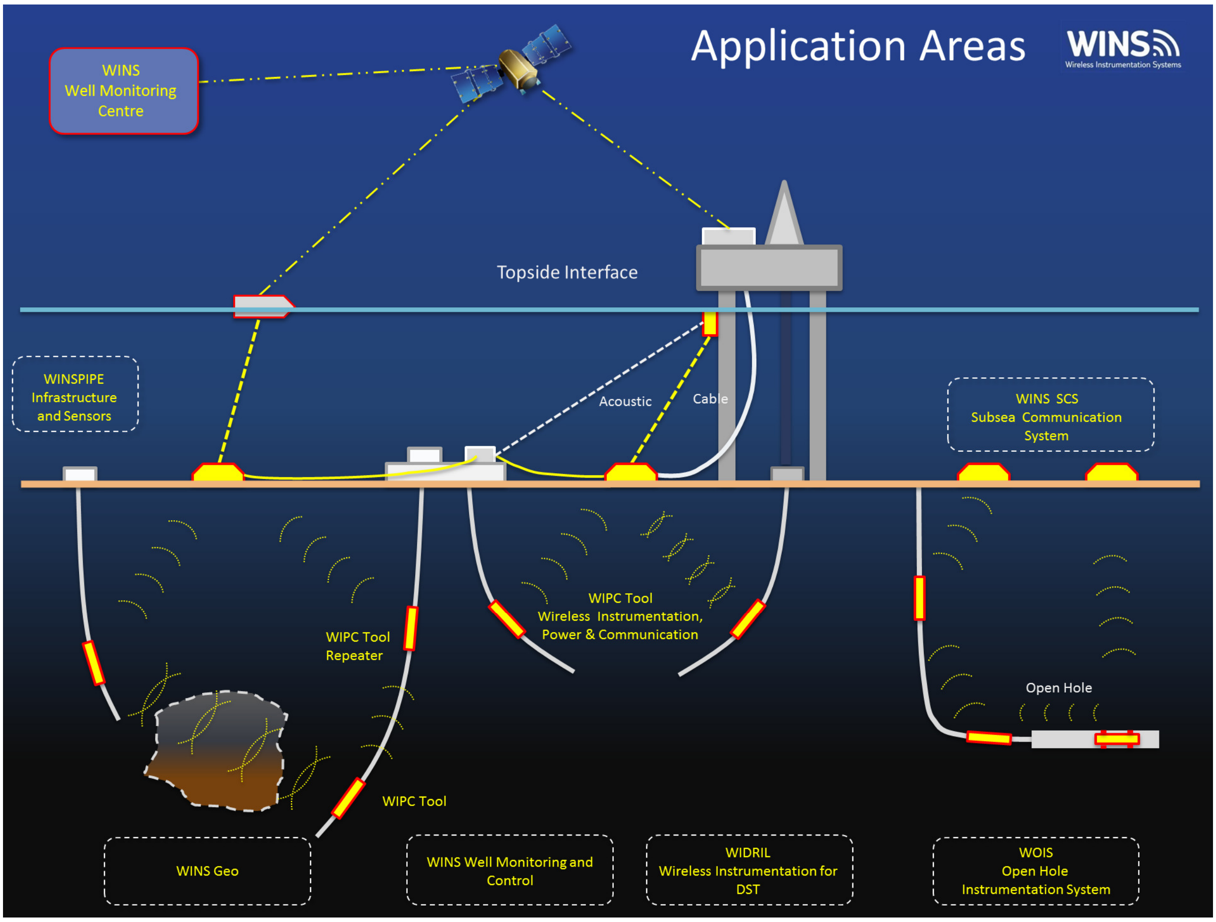


Figure 3-2 WINS Application overview

4 Task description

Wireless Instrumentations Systems (WINS) need a communication station placed on the seabed to receive and relay the signals from the well sensors to the topside platform. The production of the receiver station must be started within Q2 2013.

The work should generate a production ready design of the system, including drawings and material specifications. Detailed renderings of the system for marketing purposes may also be included.

All development and design must be based on the requirement specifications from Statoil and WINS.

WINS own all rights on the produced design material from this project.

5 Requirements specification

The requirements applying to the hardware development of the SCS are listed in Table 5-1 Requirement specification. This is an excerpt from the document "SCS_Statoil Specifications" in the appendix issued by Statoil ASA and WINS.

Table 5-1 Requirement specification

Number	Name	Requirement
R1.2	Operational period	The operational period is 5 years.
R1.3	ROV handling	Subsea interactions with SCS shall be handled with a Remote Operated Vehicle (ROV). At least two ROV are required. One for observations and one for working. (NORSOK standard U-102.)
R1.4	Size	To Be Determined (TBD).
R1.5	Weight	On land/ in sea. Tension changes in lift wire through splash zone are critical.
R2.1	Depth	Down to 500m, to be extended later.
R2.2	Temperature range	Operation range from -5 to 30 degrees Celsius.
R2.5	Sea current	Less than 0.75 m/s (approx. 1.5 knots).
R5.1	Magnetometers	TBD. Using 3 magnetometers.
R5.2	Electrodes	TBD. Possible solution: 4 cables turns, each containing up to 100m cable, unwind by working ROV.
R5.3	Data Acquisition Unit (DAU)	Low power consumption.
R6.1	Protection	Trawl protection and protection against falling objects. (NORSOK standard U-001). Trawl protection is not necessary if equipment is close to platform or other places where trawling is not allowed.
R6.2	Materials	Non-magnetic. (NORSOK standard M-001).
R6.3	Corrosion countermeasures	As required.
R6.4	ROV operations	Direction indicators.
R6.5	Weight	Sufficient ballasting.
R6.6	Hoisting points	Provisions for ROV assisted attach/release of hooks.
R6.7	Stability at sea floor	The construction must be stable on sea bed and not induce any movements on EM sensors.
R6.8	Stability through splash zone	Open bottom construction.
R7.1	Lifting	NORSOK R-002, R-003, R-005.
R7.2	Deployment	By vessel crane and ROV.
R7.3	Sea state	Hs=4 m (Significant wave height).
R7.4	Orientation	Recorded after deployment.
R7.5	Recovery	By vessel crane and ROV.
R7.6	Hoisting speed	TBD.
R7.7	Hoisting points	ROV adapted.

6 Work methods

Product developments [5] and analysis are performed in close companion to key personnel at WINS, see chapter 19 Key personnel, with basis on the requirements specifications in Table 5-1 Requirement specification and Table 7-1 Secondary requirements.

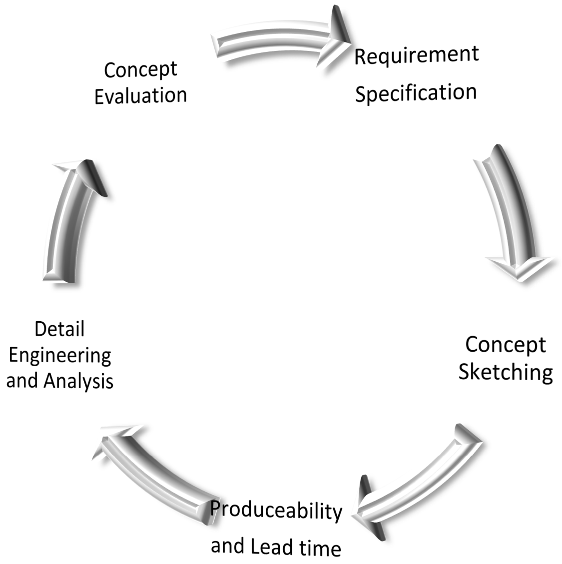


Figure 6-1 Product development methodology

7 Secondary requirements

Secondary requirements added during the product development phase are listed in Table 7-1 Secondary requirements.

Table 7-1 Secondary requirements

Number	Name	Requirement
SR1.1	Size	Footprint must be less that 4 x 4 [m] and height under 2,8 [m] to fit in WINS assembly hall.
SR1.2	Magnetometers type	Install 3 x LEMI 120 magnetometers [2].
SR1.3	Electrode type	Install 6 x Polyamp electrodes with 6x50 [m] cable [3]
SR1.4	Data Acquisition Unit (DAU)	Install "Beckhoff EL2004" and 3 " Beckhoff EL 3602) listed in the appendix.
SR1.5	Subsea infrastructure connector	BENNEX Penetrator interface [6]
SR1.6	Structure Eigen frequency	Above 60 Hz, as this will not affect the sampling frequency of 48 Hz. Determined by Statoil ASA.
SR1.7	Max acceleration during lifting /hoisting operations	3G acceleration determined by Statoil as a conservative value.
SR1.8	Transportation	Must pack for robustness and fit within a standard ISO container.

8 Evolutionary concepts

Along the evolutionary path of product development, several concepts were conceived and discarded. However, it was established on an early stage to use Glass Fiber Reinforced Plastic (GFRP) and the most accessible materials shapes is square beams and grating panels.

All concepts are designed from materials and technology which can be delivered or made in a few weeks' notice. By this approach, the project can ensure fast production and short lead time.

The first concept, a pyramid shaped frame, failed the Eigen frequency [1] requirement (SR1.6 in Table 7-1), and had a relatively high signature. This will give a lot of sideways drag forces [7] from oncoming sea currents (R2.5 in Table 5-1) which may cause the frame structure to tumble [8].

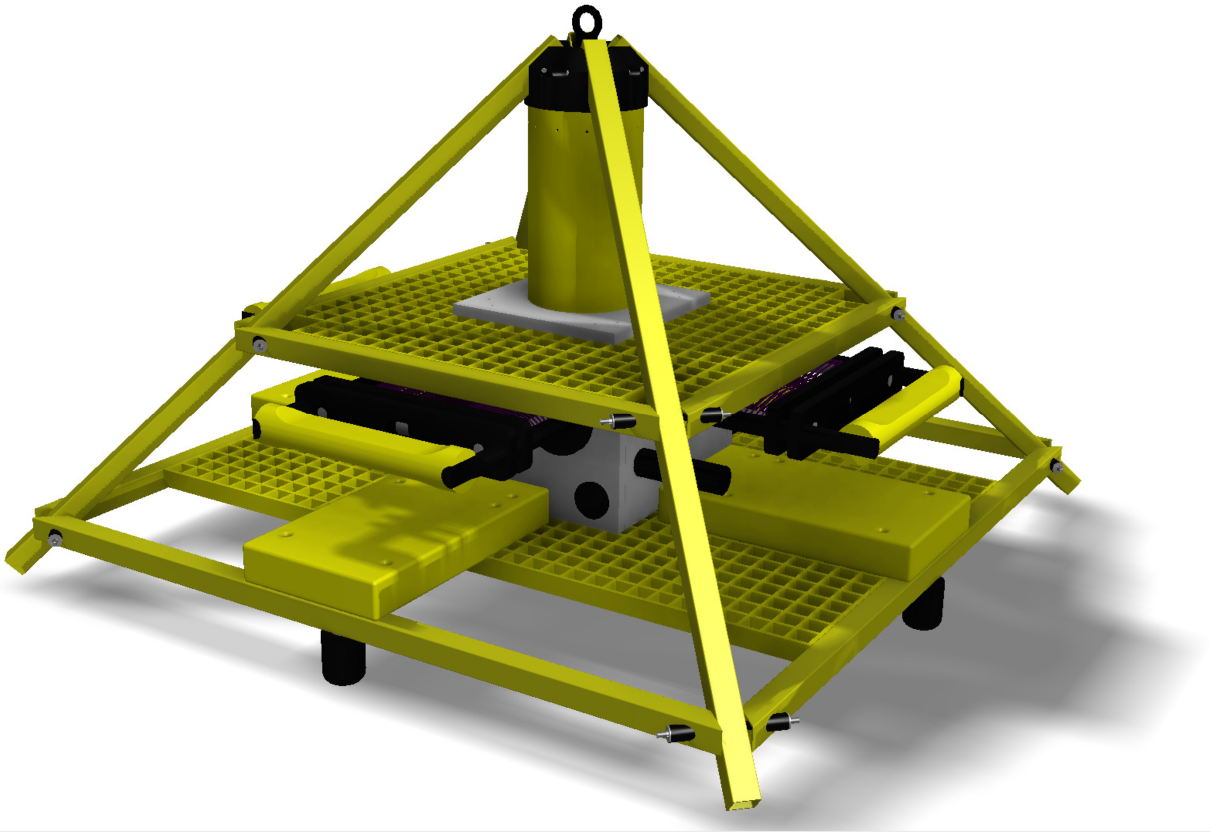


Figure 8-1 First concept, square frame composite material

The second concept, a tetrahedron shaped frame, fulfills the Eigen frequency requirement (SR1.6 in Table 7-1). However, it has too many complex parts in the foot joints and beam connections. It also needs a robust fastening solution for the weights and the sensors.

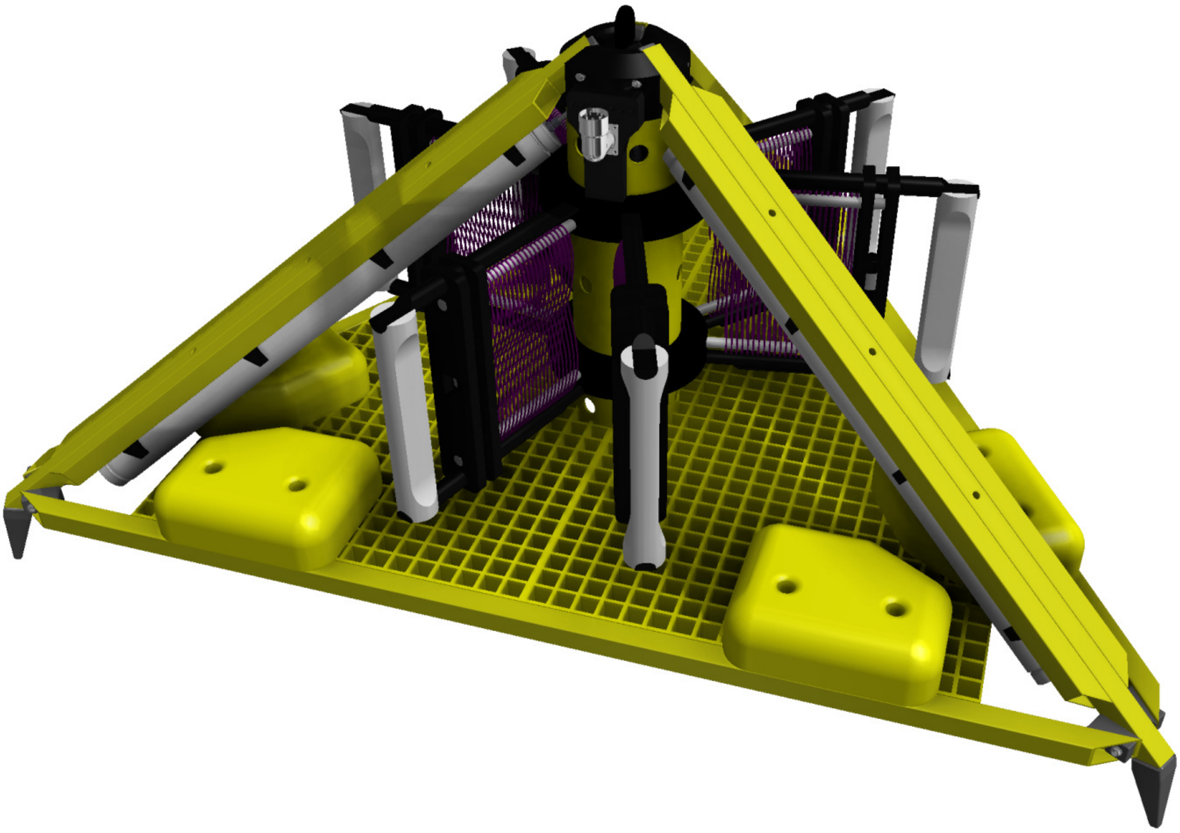


Figure 8-2 Second concept, tetrahedron frame

The basic outline for the final product is achieved. With further product development [5] the final concept is conceived.

9 Final concept

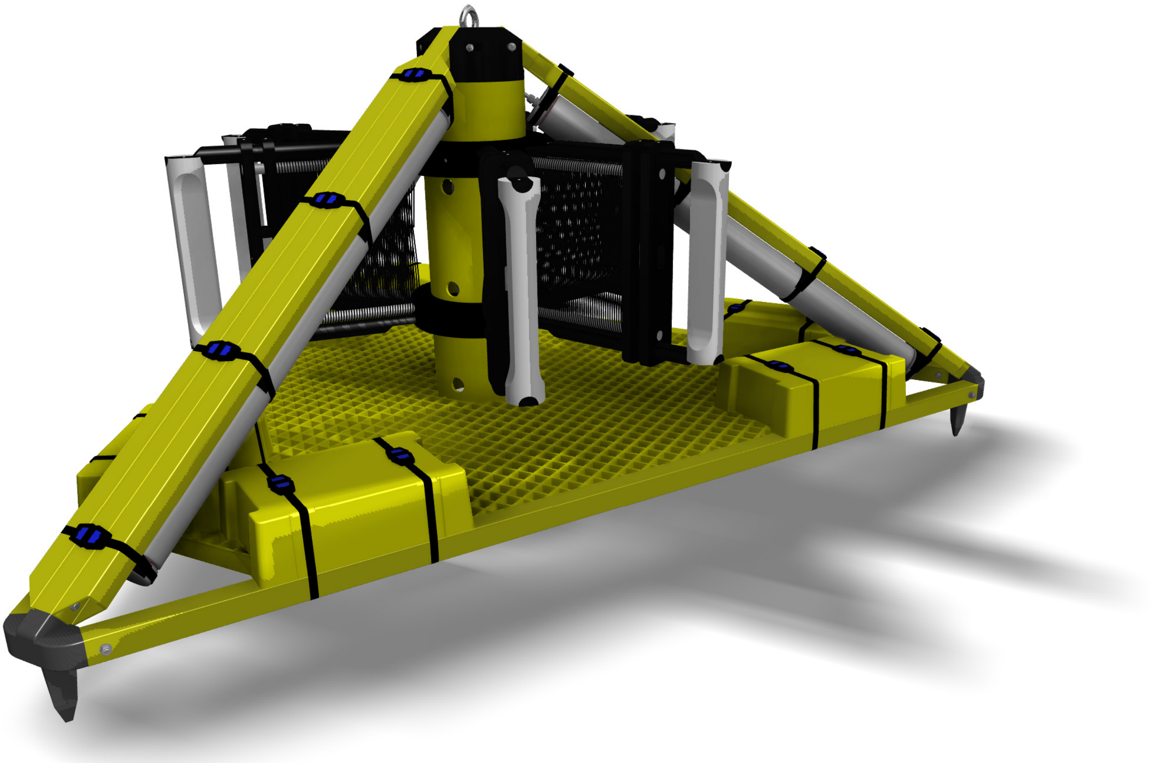


Figure 9-1 Final concept, Subsea Communication System (SCS)

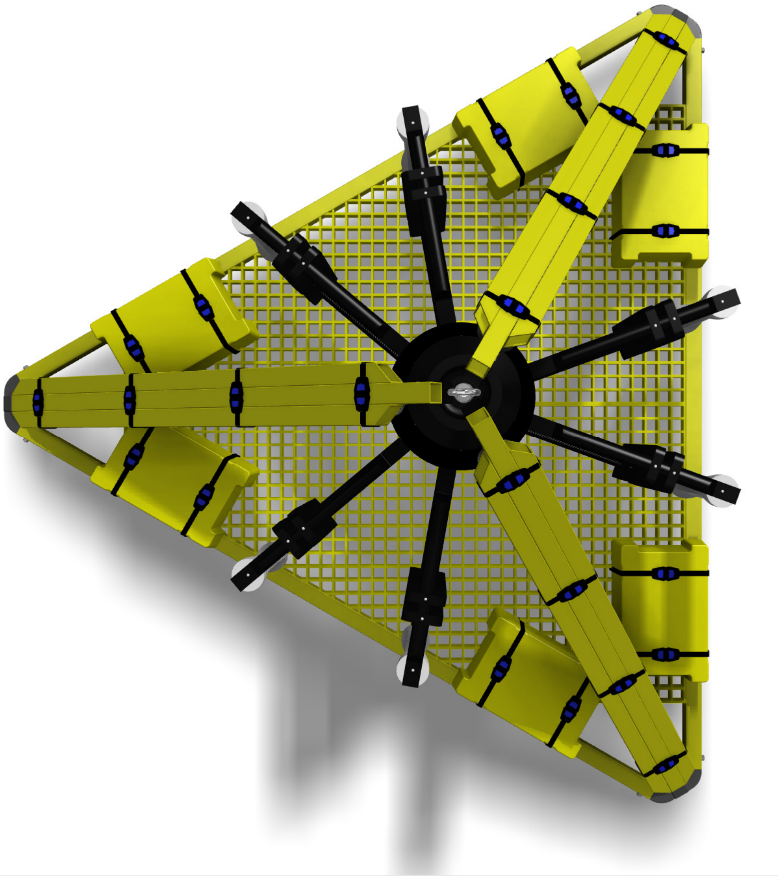


Figure 9-2 SCS, top view

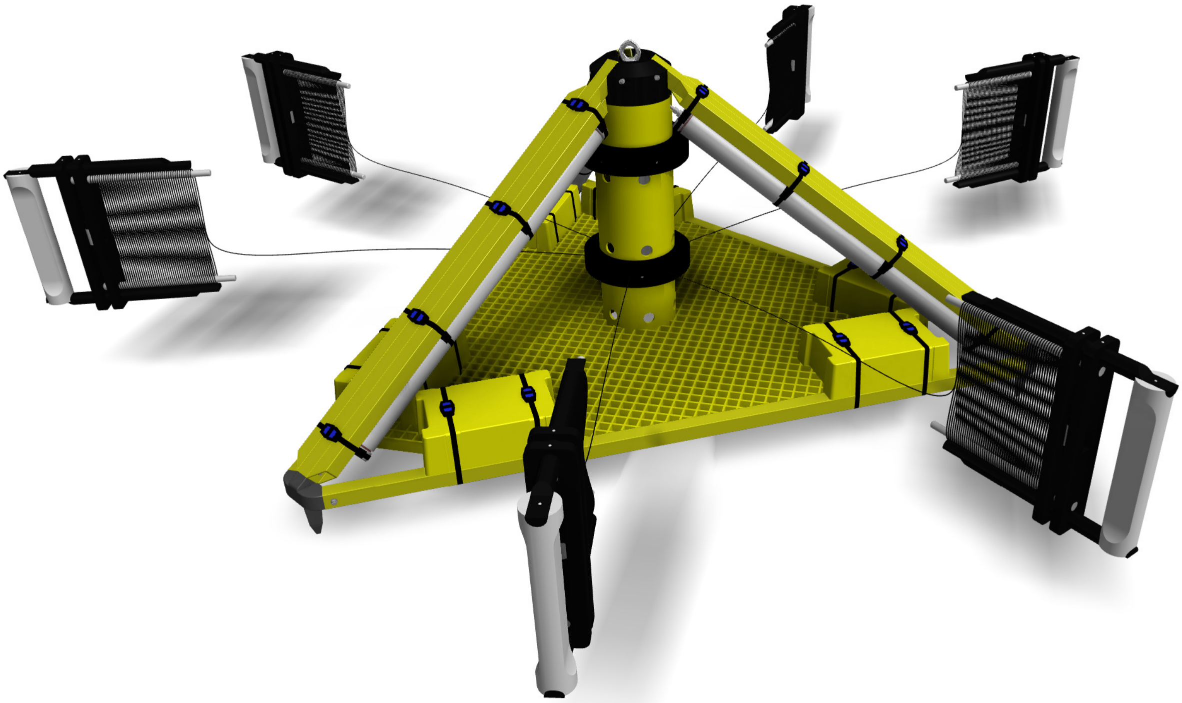


Figure 9-3 SCS, electrode deployment system released

Figure 9-4 SCS in ISO shipping container

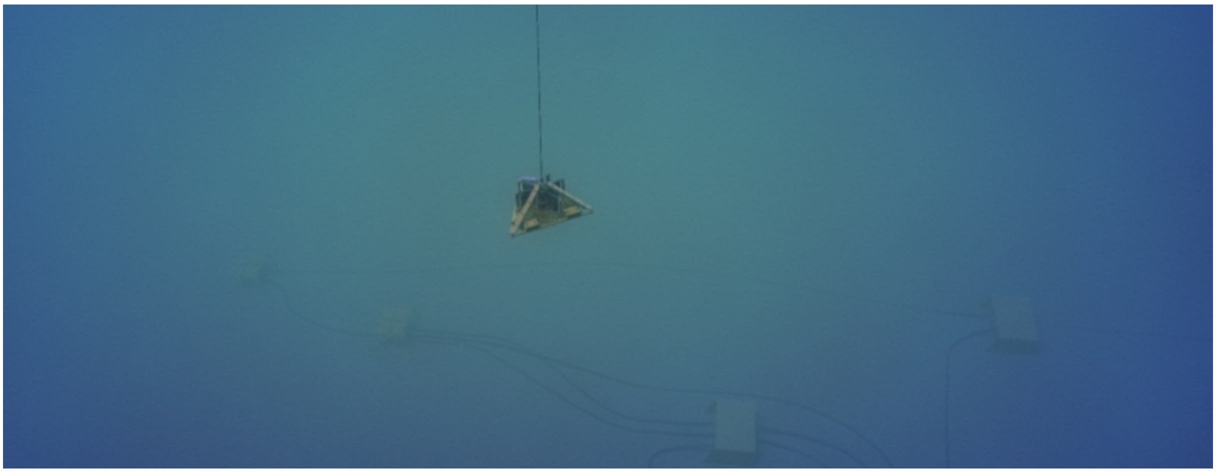


Figure 9-5 SCS, view during decent to seabed

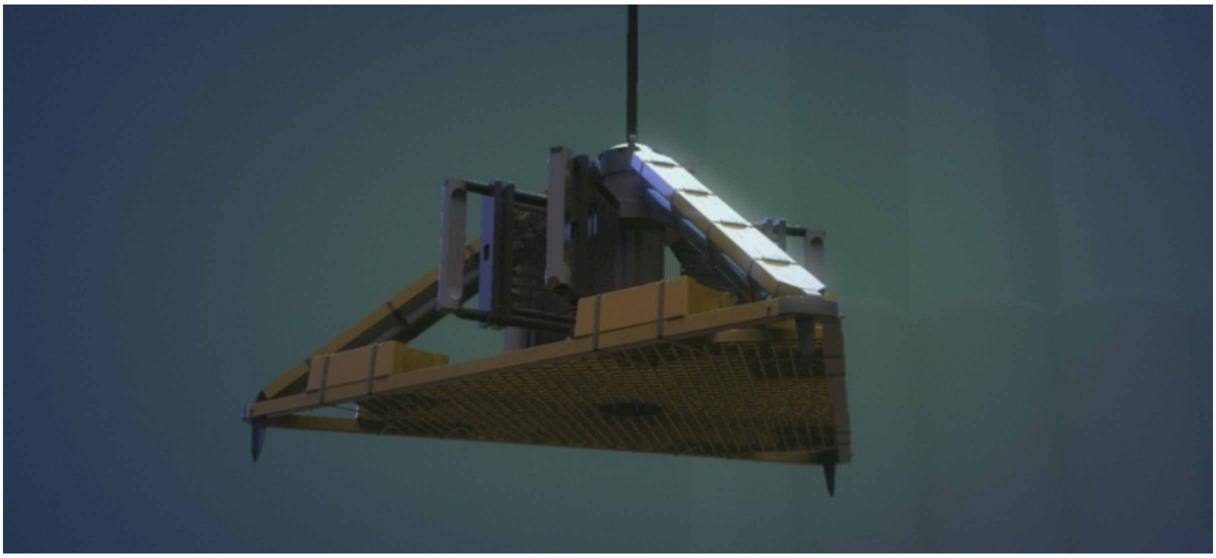


Figure 9-6 SCS, close up view during decent

Figure 9-7 SCS, view during ROV deployment

10 Concept architecture

The final concept is built on a subset of concepts. The different concepts are divided into separate chapters. See Figure 10-1 Concept architecture for reference.

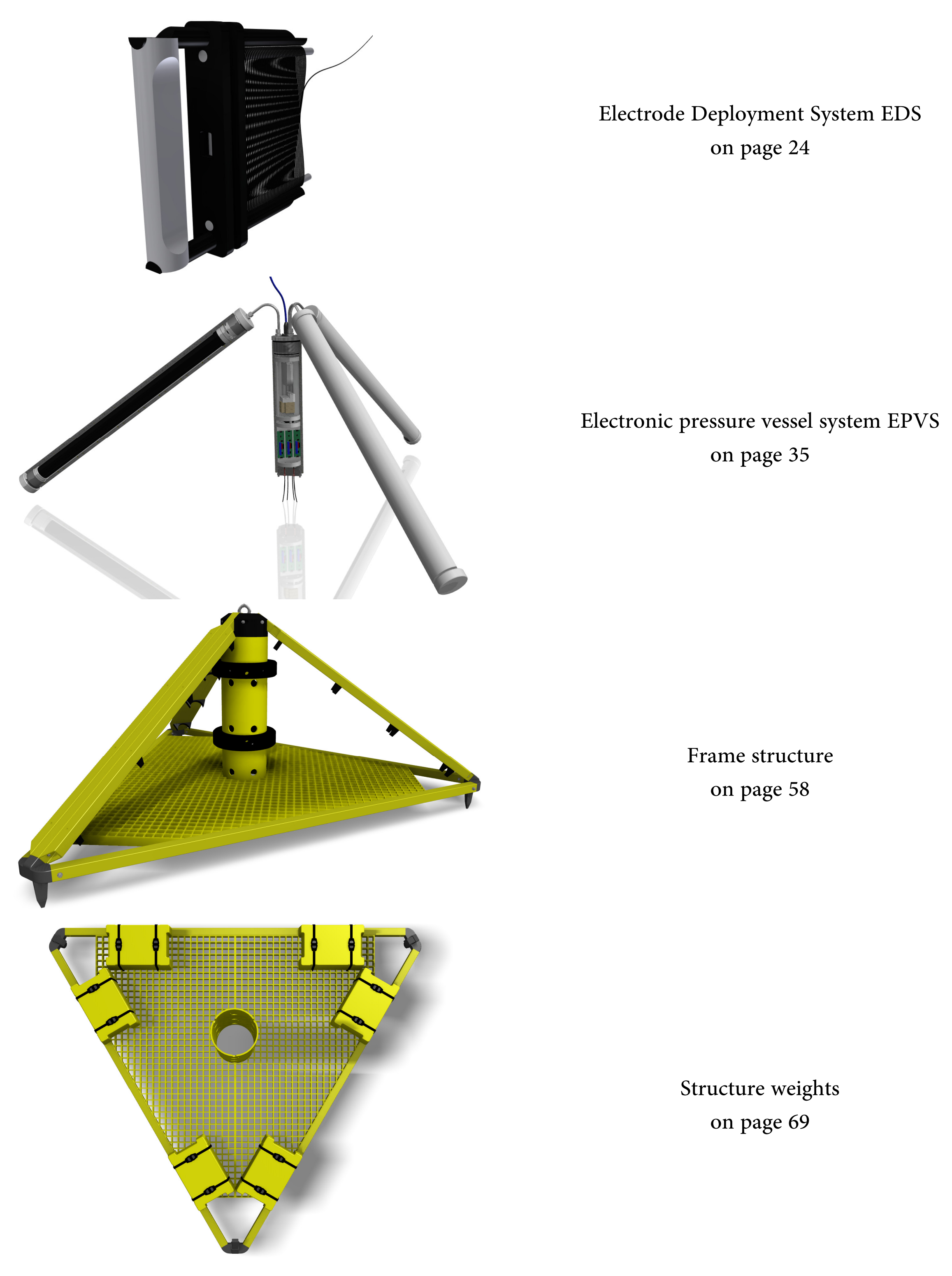


Figure 10-1 Concept architecture

11 Electrode Deployment System EDS

11.1 EDS requirements

The following elaborated requirements are separated in to functional, material and geometrical requirements which must be fulfilled to ensure high level of integrity for the final product.

11.1.1 Functional requirements

The Electrode Deployment System (EDS) must be designed to be operated by the use of a ROV (R1.3 in Table 5-1). The proposal for this system should also be discussed and reviewed with an experienced ROV pilot. The EDS must be securely attached during transportation and deployment (SR1.7 and SR1.8 in Table 7-1).

11.1.2 Material requirements

All materials must be qualified and approved by the customer (R6.2 in Table 5-1). The materials used in the EDS must withstand the corrosive [9] and hydrostatic pressure [1] conditions (R2.1 in Table 5-1) or otherwise be protected (R6.3 in Table 5-1). The use of engineering polymers and Glass Fiber Reinforced Plastics (GFRP) should be considered as these materials will not affect the magnetic fields [1] and oblique the above needs [9].

11.1.3 Geometrical requirements

The frame work must be large enough to contain the necessary length of the electrode cable and at the same time provide protection of the electrodes [3] (SR1.3 in Table 7-1). The width and length of the frame must be within the geometric constrains of the frame structure to provide protection of the EDS, during transport and deployment.

11.2 EDS concept

The EDS concept is a cable spool frame and an enclosure for the electrode [3]. Combining the spool and electrode enclosure, removes the need for a separate observation ROV (R1.3 in Table 5-1). The working-class ROV can control the unspooling of cable and deploy the electrode in the same operation. The ROV will grab and hold the EDS handle while backing away from the SCS. The electrode cable will unspool from the EDS successively as the ROV moves away. The cable is spooled up by the figure 8 method and pinched on to both spool bars to prevent tangle. When the cable is fully unspooled the ROV places the EDS on the seabed and the deployment is complete.

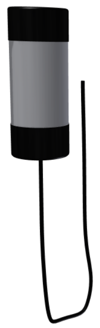


Figure 11-1 Electrode

Figure 11-2 Electrode capsule in EDS

Figure 11-3 EDS

11.2.4 EDS Function

The electrode is exposed to seawater and act as a measuring point for voltage [3]. The SCS Data Acquisition Unit (DAU) will measure the potential between all 6 electrodes located in a hexagonal shape with the frame structure in center. The electrode cable length is 50 [m], giving the effective span of 100 [m] between a pair of electrodes.

11.2.5 EDS materials

All parts of the ESD are PET polymer material; refer to “PET Rochling-MDS” in the appendix.

11.2.6 EDS manufacturing and assembly

The frame is slotted together and locked with press fit lock pins. This design requires a certain level of machining tolerances as raw extruded polymer bolts are used with varying outer diameters. To reduce production time, all tolerances are located on the holes and not axles, meaning the mating axle is measured and holes are drilled to tolerance [10]. Refer to Table 11-2 EDS drawing reference.

The disadvantage from this method is that all parts must be machined to fit simultaneously.

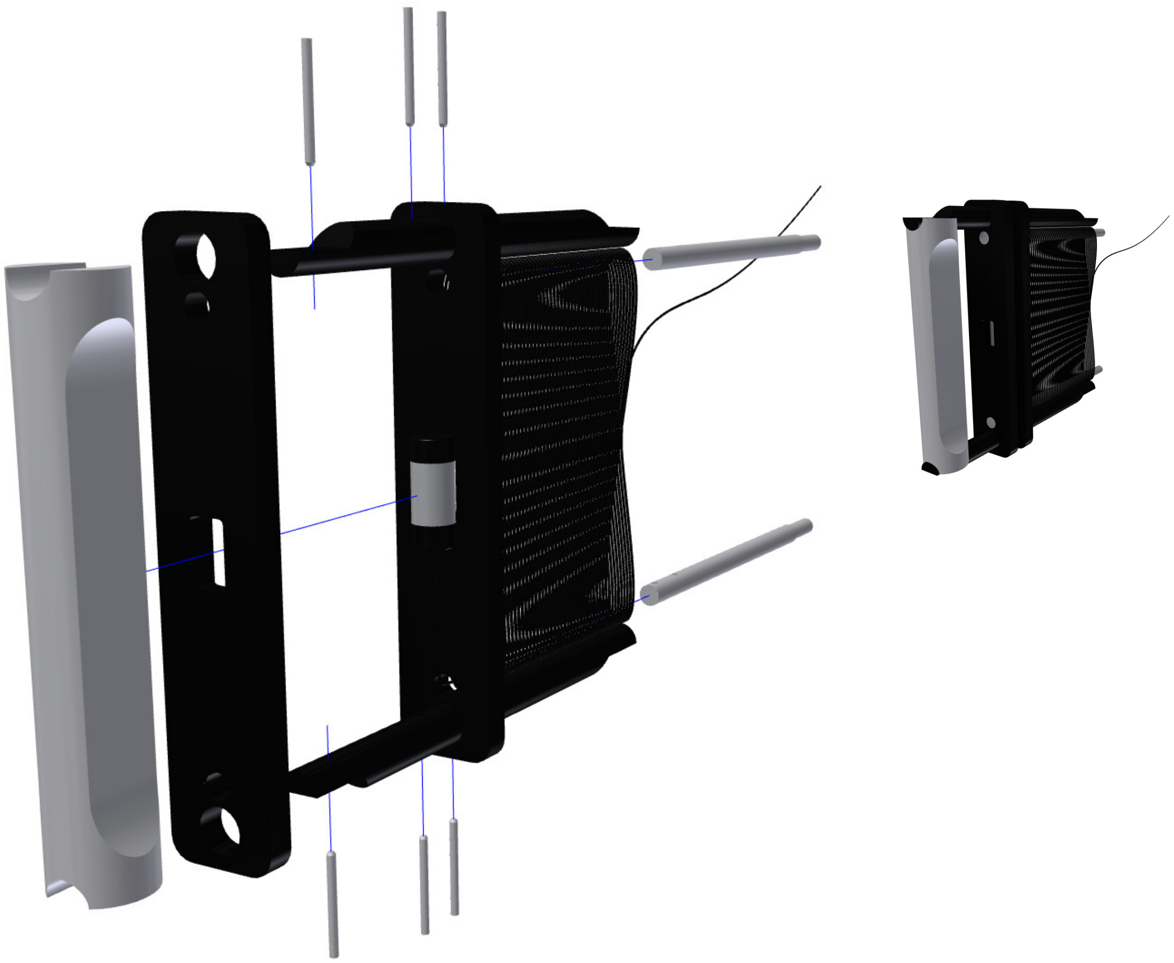


Figure 11-4 EDS assembly exploded

11.2.7 EDS dimensions and weight

Refer to Figure 11-5 EDS dimensions EDS dimensions. Refer to Table 11-1 EDS weight for EDS weight.

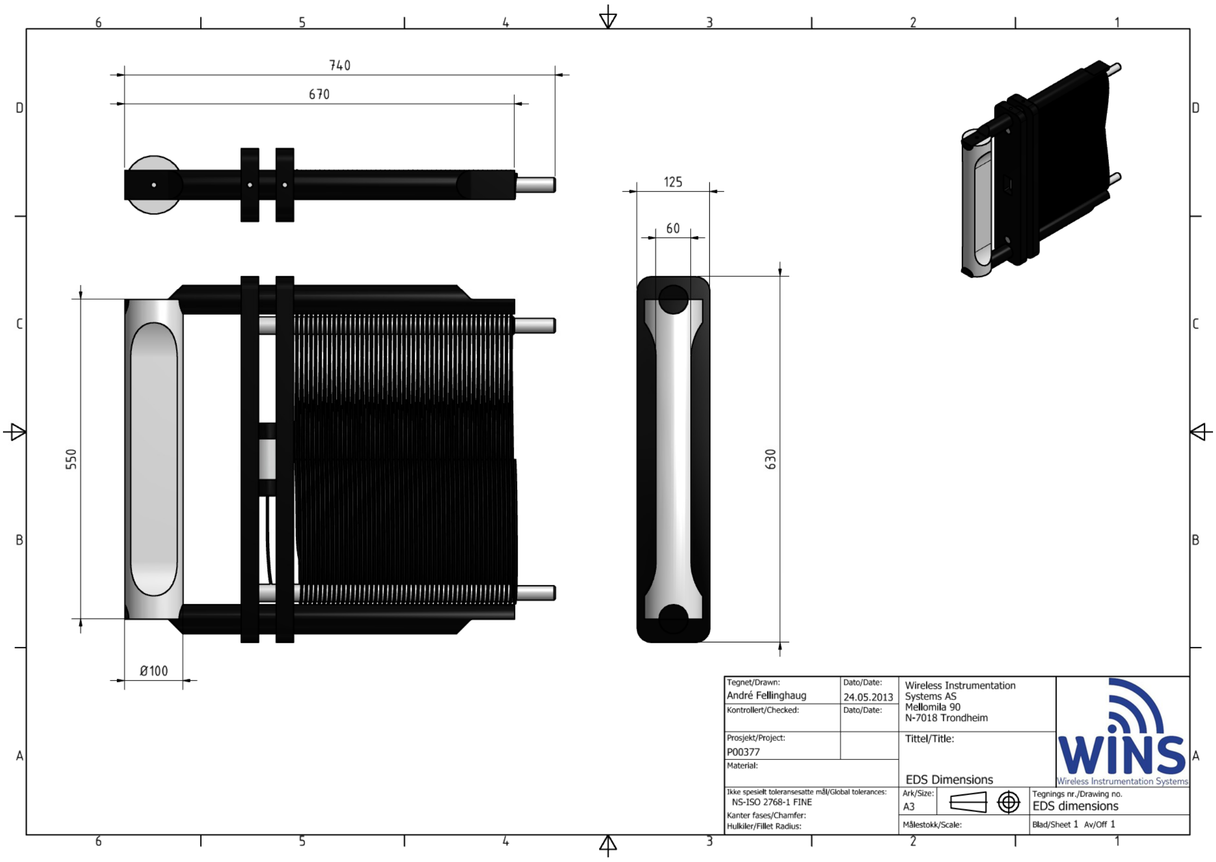


Figure 11-5 EDS dimensions

Table 11-1 EDS weight

Part	Weight @ air	Weight @ water
EDS	16 [Kg]	5 [Kg]

11.2.8 EDS drawing reference

All EDS parts have drawing files in the appendix. See Table 11-2 EDS drawing reference

Table 11-2 EDS drawing reference

Part	Reference in appendix DWG
EDS Assembly	Assembly, EDS
ROV handle	ROV handle, EDS
Lock bar	Lock bar, EDS
Cable shield	Cable shield, EDS
Spool bar	Spool bar, EDS
Lock pin	Lock pin, EDS

11.3 EDS FEM analysis

EDS can be subjected to various loads and accelerations during deployment (SR1.7 in Table 7-1). Stress analysis is performed to verify the design integrity, Failure criteria is Max Von Mises < Material Yield strength @ Table 11-3 EDS simulation input. This is a conservative design criterion which can be applied for ductile and isotropic materials. [11] [12]

Table 11-3 EDS simulation input

Property	Value	Reference
Hoist acceleration (SR1.7)	3[G]	(SR1.7 in Table 7-1)
Cable mass	3 [Kg]	[3]
Earth's gravitational acceleration	9,81 [m/s^2]	[1]

The assembly model is simplified to a shrinkwrap model. Treathing the assembly as a shrinkwrap is analog to setting all contact surfaces as bonded [11].

Figure 11-6 EDS simplified FEM model

The model is meshed with tetrahedron elements with local mesh control on stress concentrated grooves and corners. Refer to “EDS FEM Report” in the appendix for mesh settings.

Figure 11-7 EDS meshed model

Frictionless constraints are set on the cable spool bars and on the stoping surface of the lowest lock bar to simulate the EDS installed in the EDS bracket. See deformation in Figure 11-13 EDS Max deflection.

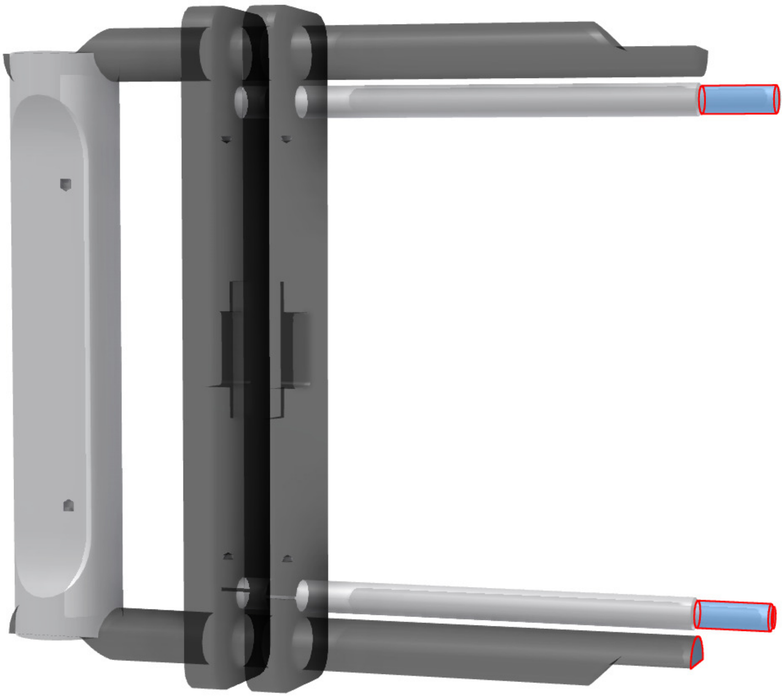


Figure 11-8 EDS frictionless constraint

Acceleration load and remote mass are applied according to Table 11-3 EDS simulation input.

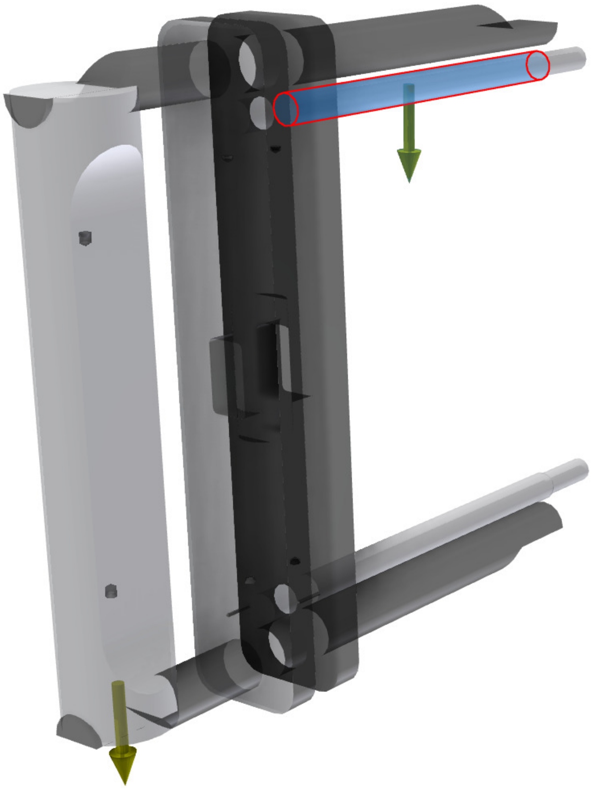
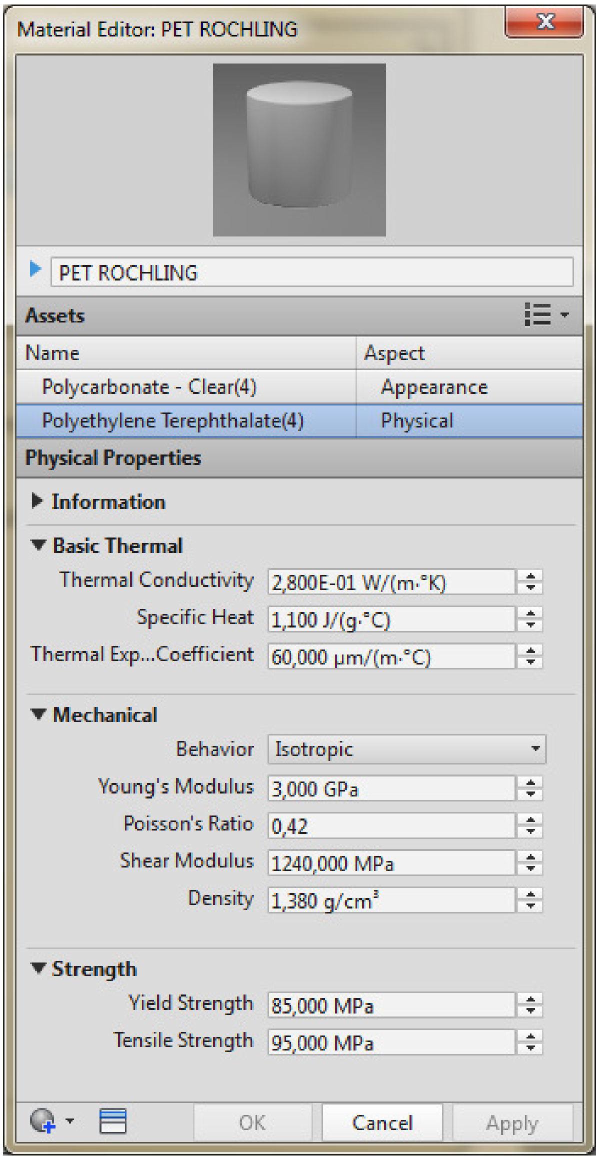


Figure 11-9 EDS loads

Material specifications are applied in accordance with chapter 11.2.5 EDS materials.



Material Editor: PET ROCHLING

PET ROCHLING

Assets

Name	Aspect
Polycarbonate - Clear(4)	Appearance
Polyethylene Terephthalate(4)	Physical

Physical Properties

Information

Basic Thermal

Thermal Conductivity 2,800E-01 W/(m·°K)
Specific Heat 1,100 J/(g·°C)
Thermal Exp...Coefficient 60,000 µm/(m·°C)

Mechanical

Behavior Isotropic
Young's Modulus 3,000 GPa
Poisson's Ratio 0,42
Shear Modulus 1240,000 MPa
Density 1,380 g/cm^3

Strength

Yield Strength 85,000 MPa
Tensile Strength 95,000 MPa

Figure 11-10 EDS material specification

11.3.9 Results EDS FEM

EDS FEM analysis stress distribution is diplayed in Figure 11-11 EDS stress distribution and the results are listed in Table 11-4 EDS analysis results.

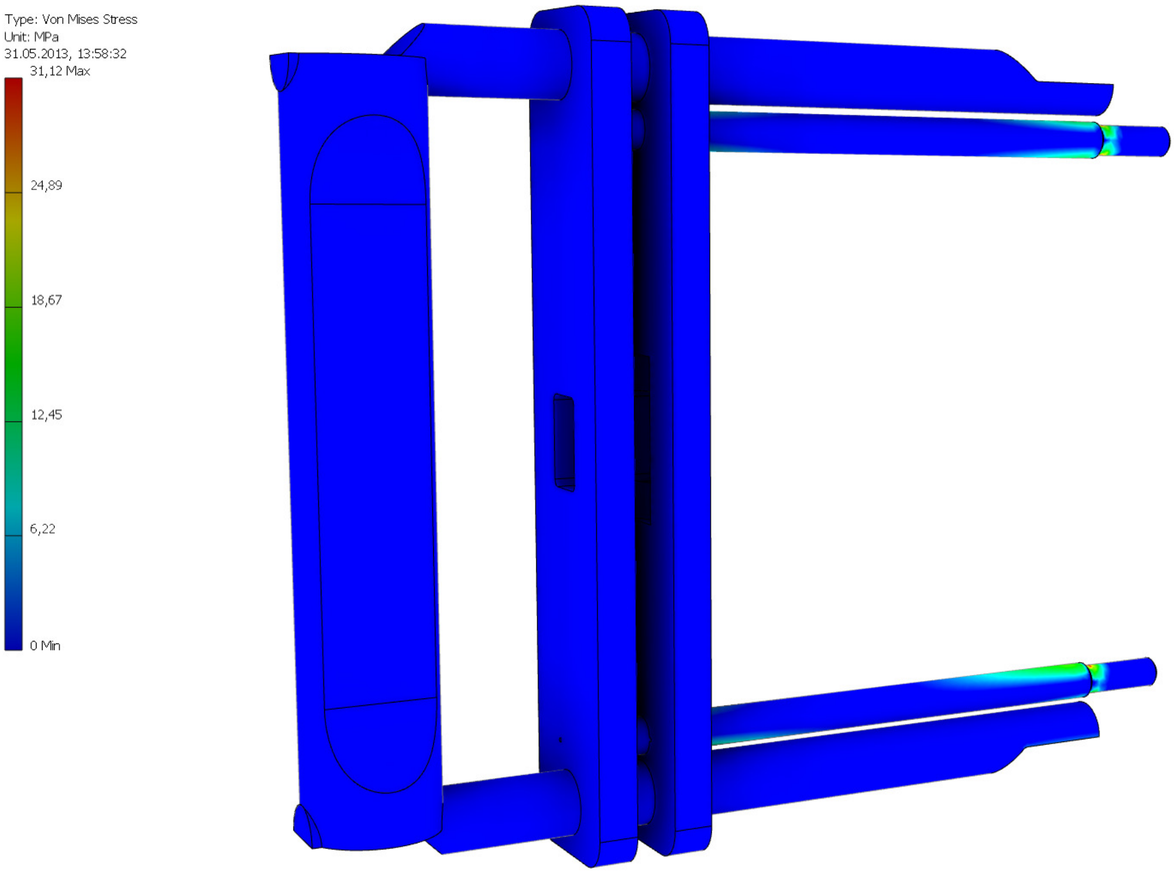


Figure 11-11 EDS stress distribution

Table 11-4 EDS analysis results

Results	Value	Figure reference
Max Von Mises Stress	31,1 [MPa]	Figure 11-12 EDS Max Von Mises Stress
Max deflection	23,8 [mm]	Figure 11-13 EDS Max deflection
Minimum safety factor of yield	2,7	Figure 11-14 EDS Minimum safety factor

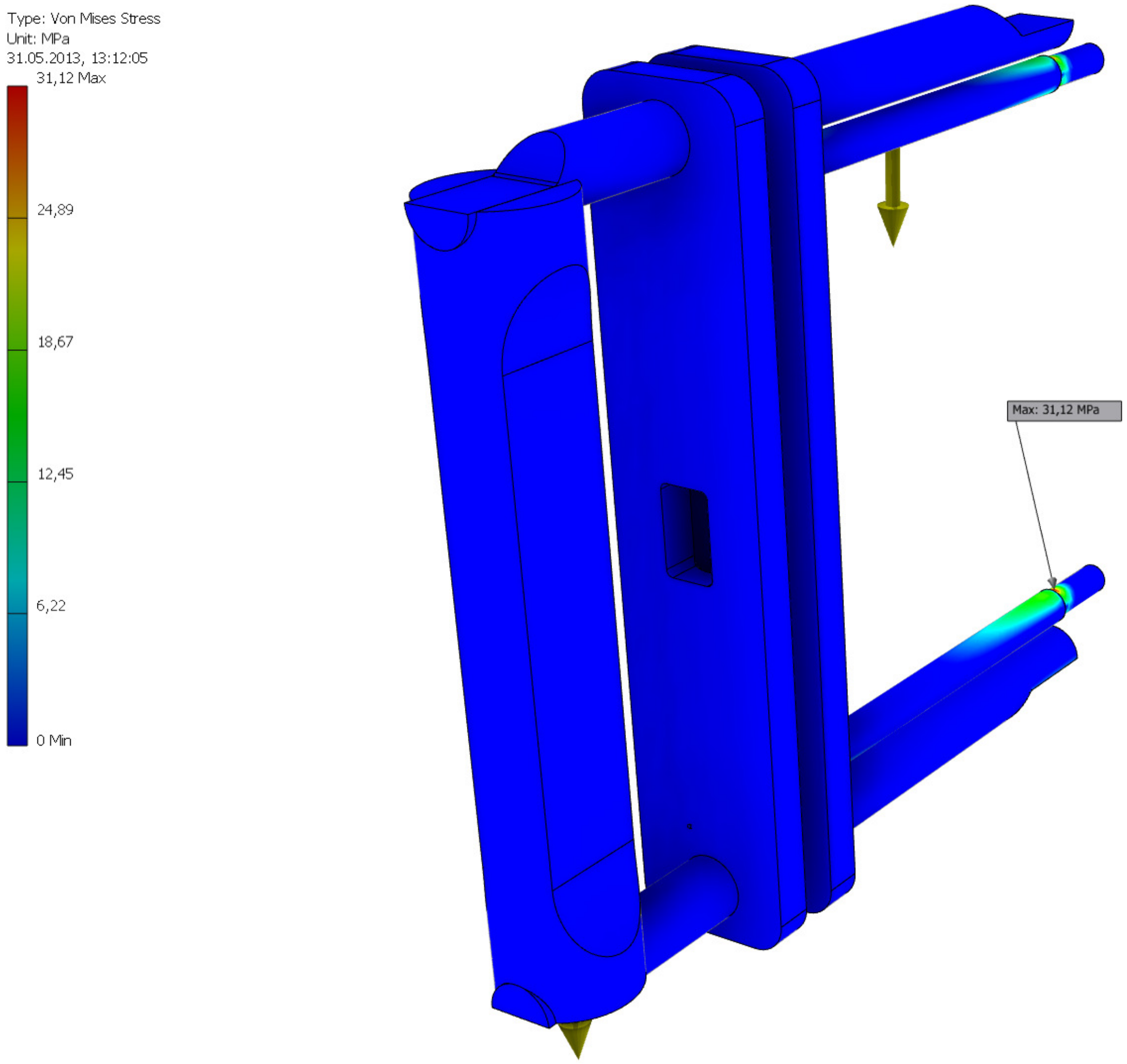


Figure 11-12 EDS Max Von Mises Stress

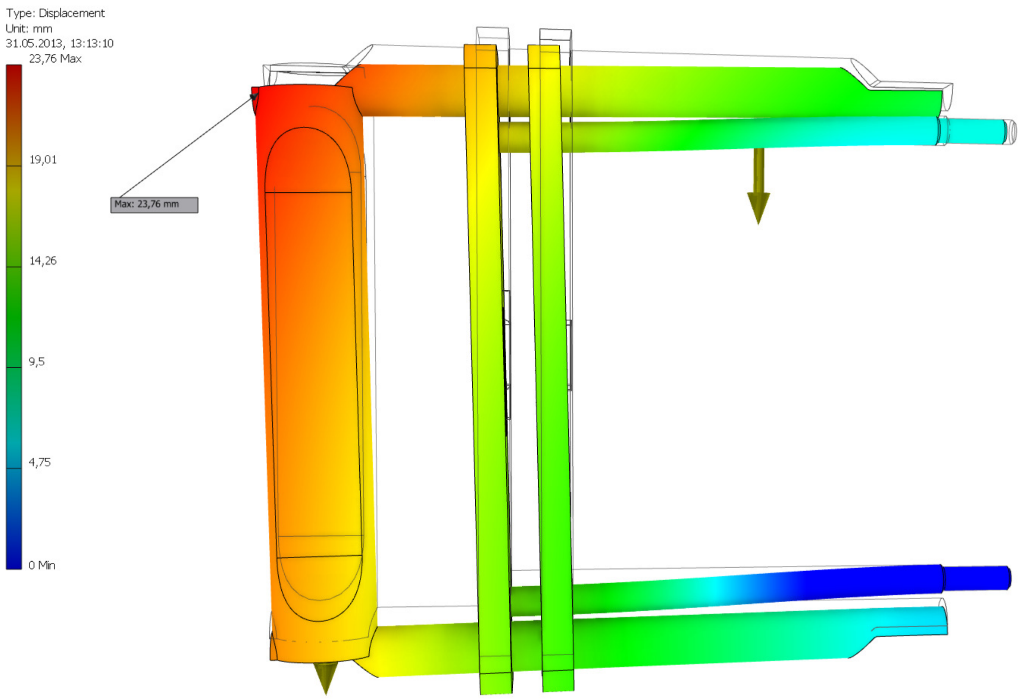


Figure 11-13 EDS Max deflection

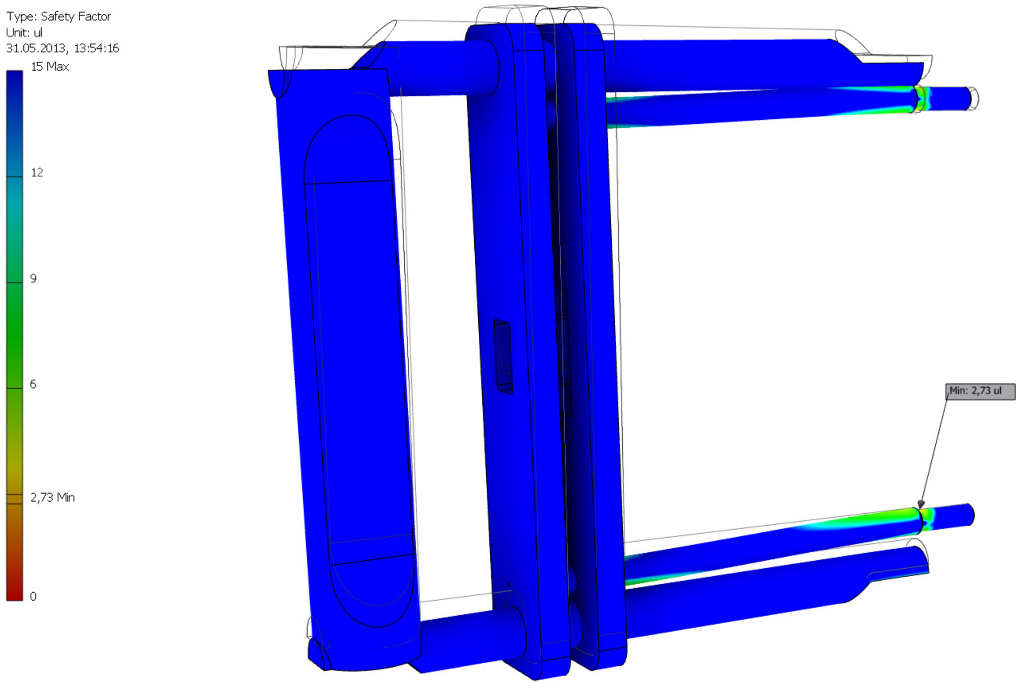


Figure 11-14 EDS Minimum safety factor of yield

11.3.10 EDS FEM conclusion

All stresses are within the material specification. Max Von Mises Yield < Material Yield.
The deflection is relatively large, but expected for this flexible frame.
See full report in “EDS FEM Report” in the appendix

12 Electronic pressure vessel system EPVS

12.1 EPVS requirements

The following elaborated requirements are separated into functional, material and geometrical requirements which must be fulfilled to ensure high level of integrity for the final product.

12.1.1 Functional requirements

The pressure vessel system must contain all electrical components (SR1.2, SR1.3, SR1.4, SR1.5 in Table 7-1) and give sufficient protection against seawater intrusion and hydrostatic pressure [1] (R2.1 in Table 5-1)

12.1.2 Material requirements

All materials must be qualified and approved by the customer (R6.2 in Table 5-1). The materials used in the EPVS must withstand the corrosive [9] and hydrostatic pressure [1] conditions (R2.1 in Table 5-1) or otherwise be protected (R6.3 in Table 5-1). For the vessel containing the Data Acquisition Unit DAU, there will be a benefit if the material conducts electricity [1]. This will reduce the induced electromagnetic noise on the magnetometers from the electronic components [13]. However, the material must be non-magnetic [1] (R6.2 in Table 5-1).

12.1.3 Geometrical requirements

The vessels must have capacity for all the electronic components (SR1.2, SR1.3, SR1.4, SR1.5 in Table 7-1)
The vessels must be firmly fastened to the structure frame, and its mass should not contribute to lowering the frames Eigen frequency [1] (SR1.6 in Table 7-1)
The geometrical measurements of the vessels must be within the frame structure to provide protection from falling objects and during transport and handling.

12.2 EPVS concept

The Electronic Pressure Vessel System (EPVS) is system consisting of 4 interconnected pressure vessels, 3 Magnetometer Pressure Vessel (MPV) and 1 Electronic Pressure Vessel (EPV).

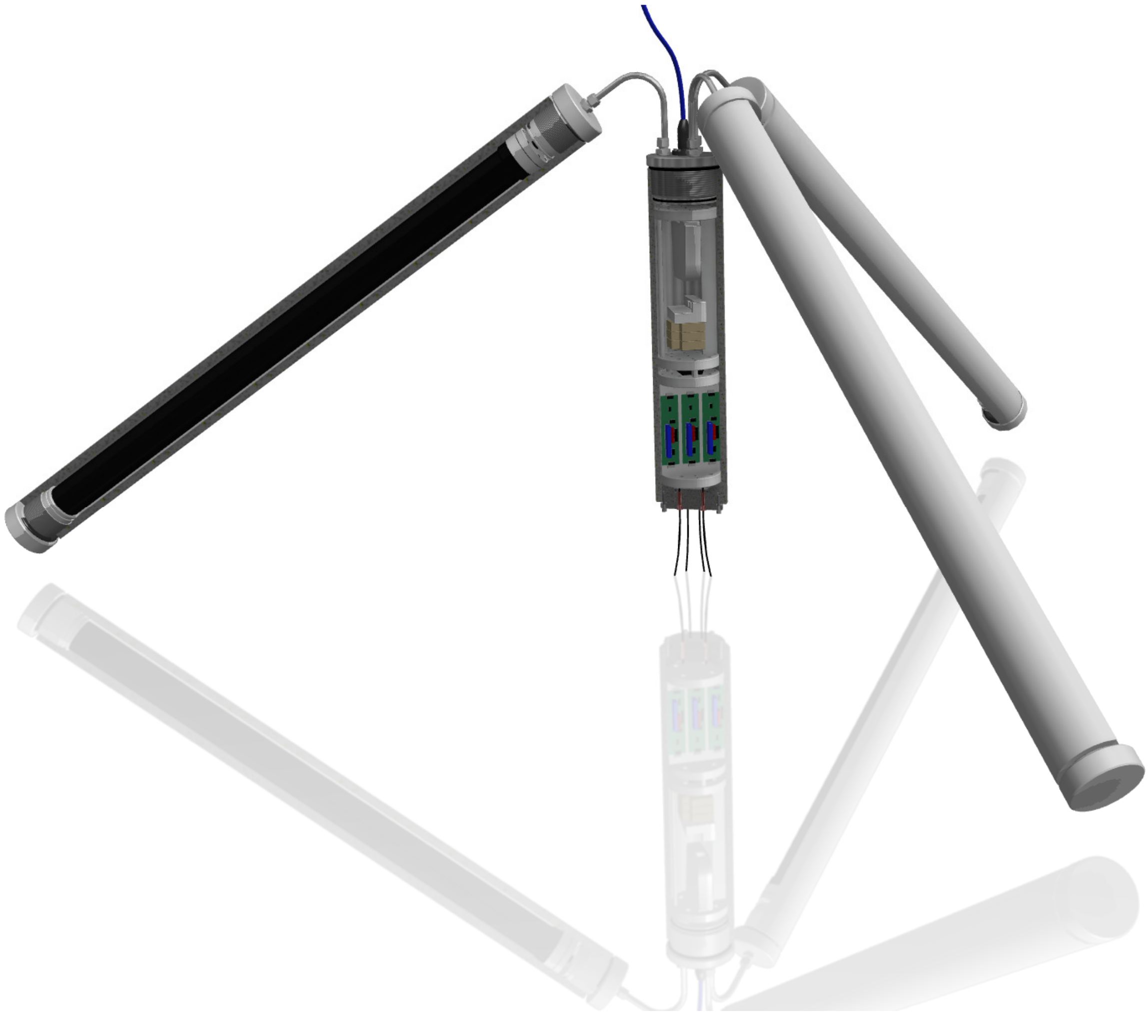


Figure 12-1 EPVS concept

The EPV is made of a steel [9] cylinder with connecting pressure tubes [14] on topside, see chapter 12.2.6 for reference. The lower part of the EPV will have a penetrator module, see chapter 12.2.7 for reference, which will feed through the 6 cables from the electrode sensors [3].

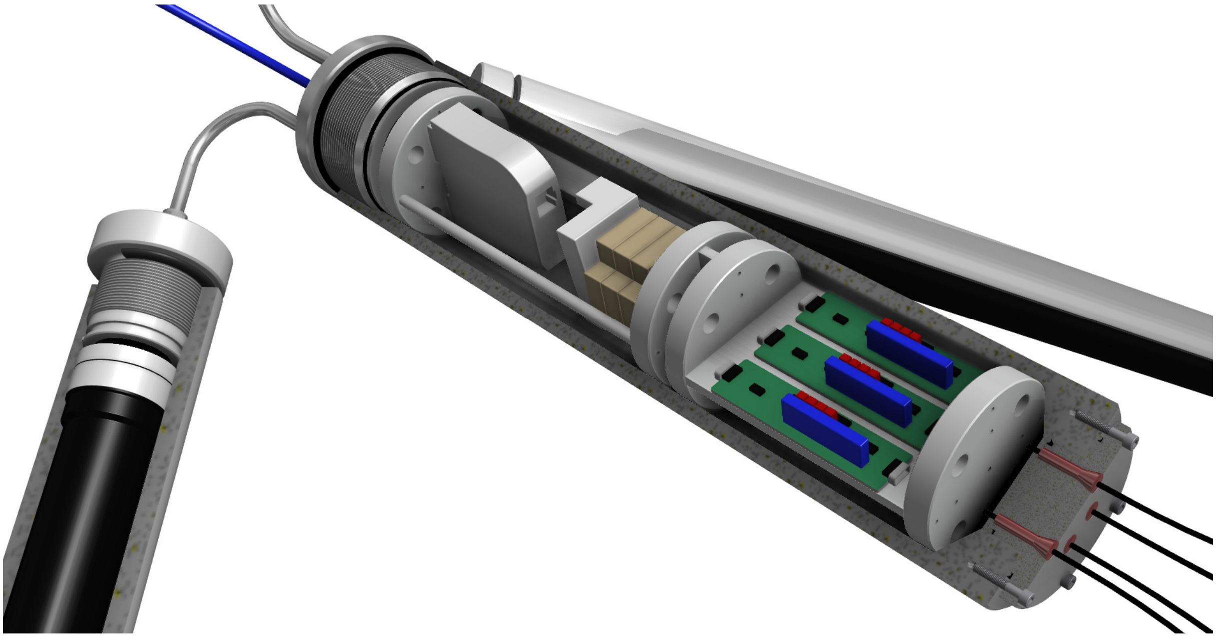


Figure 12-2 EVPS internal view

12.2.4 Electronics rack mount

All electronic components are fastened to an Electronic Rack Mount (ERM) which slides into the EPV cylinder tube. The sensitive components are separated from the noisy components to provide the best electromagnetic noise conditions [13].

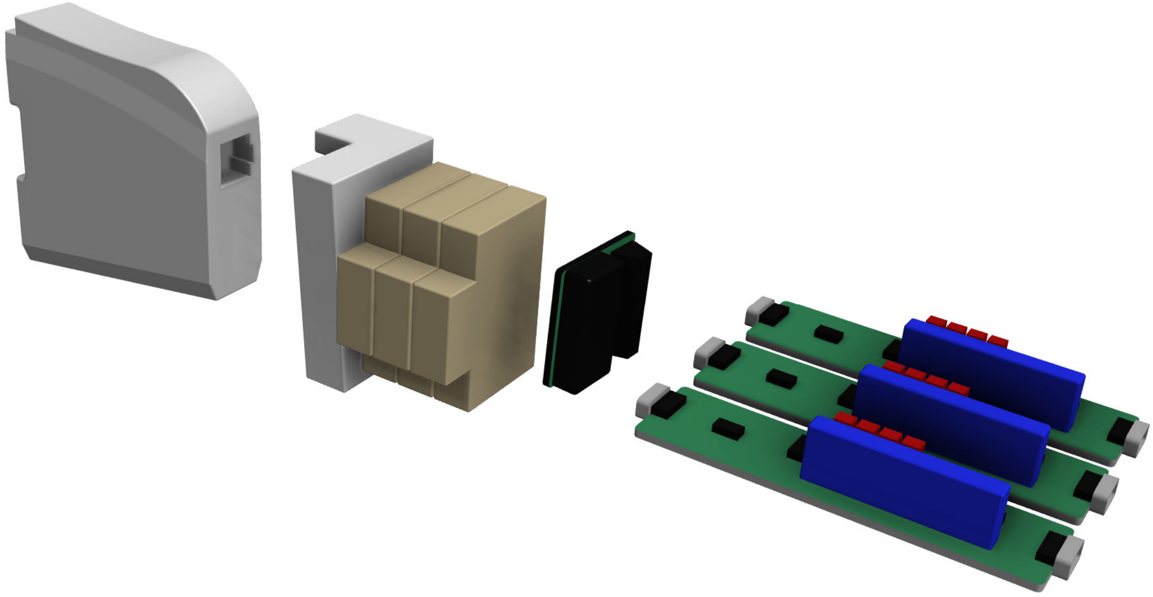


Figure 12-3 Electronic components

First chamber on the left, refer to Figure 12-4 Electronic Rack Mount, will house the noisy Ethernet modem and DAU (SR1.4 in Table 7-1) [13]. The middle chamber will contain a power supply unit. The last chamber will house 3 sensitive preamplifiers [3] (SR1.3 in Table 7-1) for the electrodes sensors. The internal wiring will be fed through bulk wall holes.

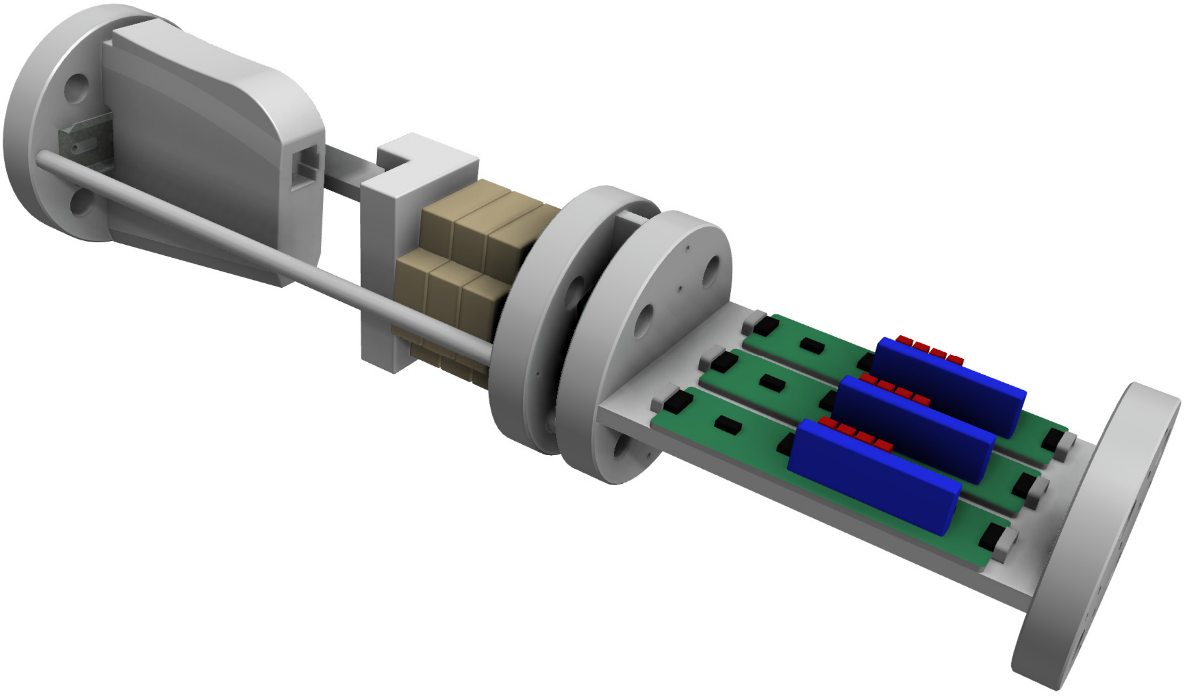


Figure 12-4 Electronic Rack Mount

The requirement for the ERM material is non-magnetic and electrically conductive to absorb electromagnetic noise [13]. The ERM is electrically connected to the EPV cylinder wall, thus creating 3 separate Faraday cages [1]

12.2.5 EPV tube

The ERM is inserted into the EPV cylinder tube. The ERM is mechanically supported by the EPV, providing electrical connection by the conductive metal surfaces [1].

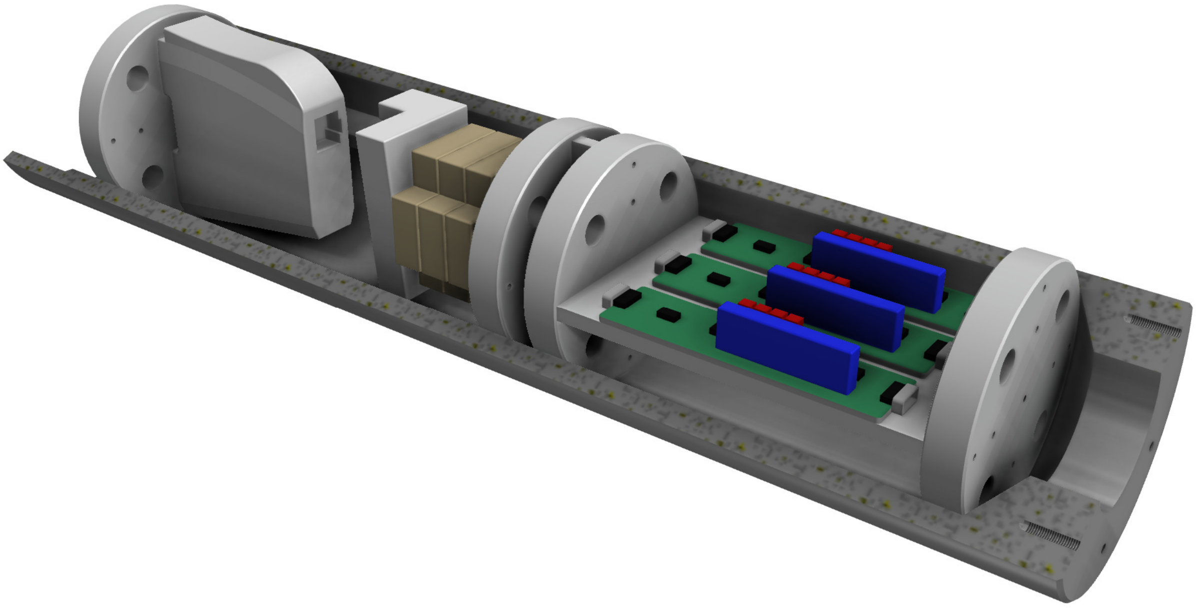


Figure 12-5 ERM inserted in to EPV

12.2.6 EPV topside lid

The Swagelok™ pressure tube fittings [15] are connected by NPT [16] threads in to the topside lid. A BENNEX penetrator [6](SR1.5 in Table 7-1) is inserted in the topside lid feeding through the power and communication from subsea infrastructure.

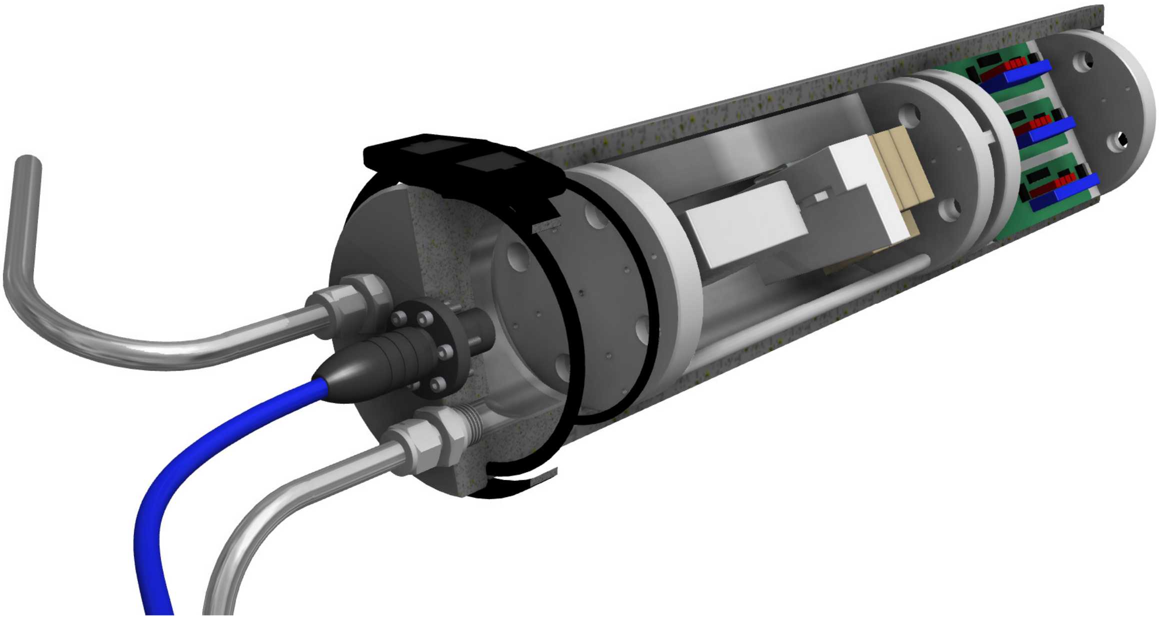


Figure 12-6 EPV topside lid

The topside lid is threaded on to the EPV cylinder and sealed with redundant O-ring seals. The lid will be mechanically secured by a SmartBand™ [17] to ensure stabile sealing pressure.

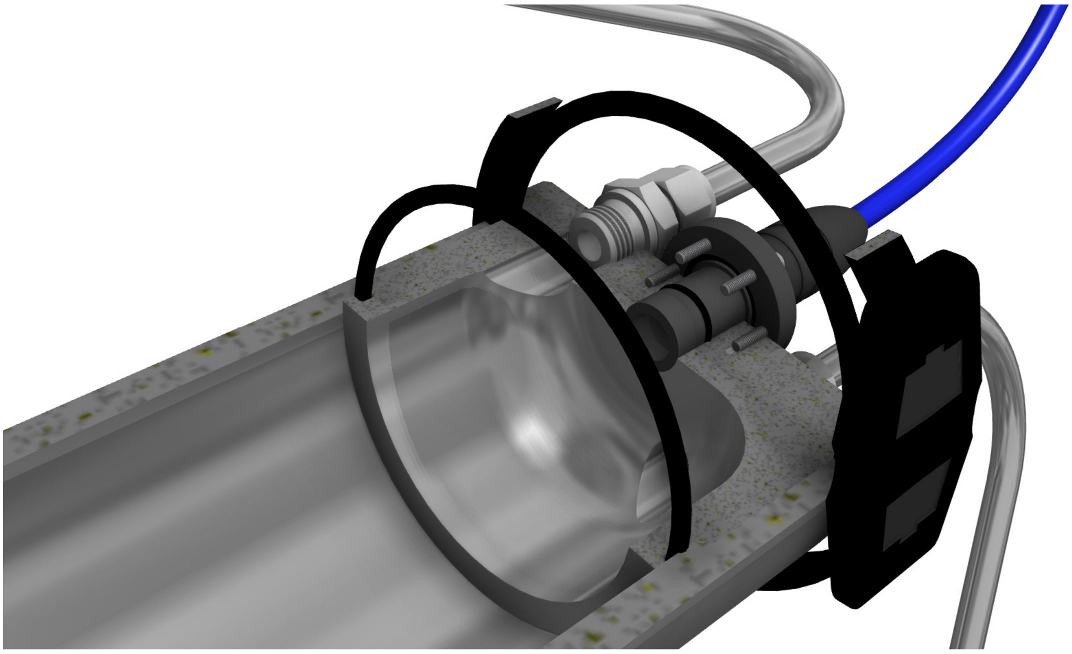


Figure 12-7 EPV topside lid, internal view

12.2.7 EPV penetrator module

The lower end of the EPV has a penetrator [6] module to feed thorugh the cables from the electrode sensors [3]. The penetrator flange has redundant o-ring sealings. The electrode cables are molded in with ScotchCAST™ [18] for submerged applications, see chapter 12.2.9 EVPS materials for reference.

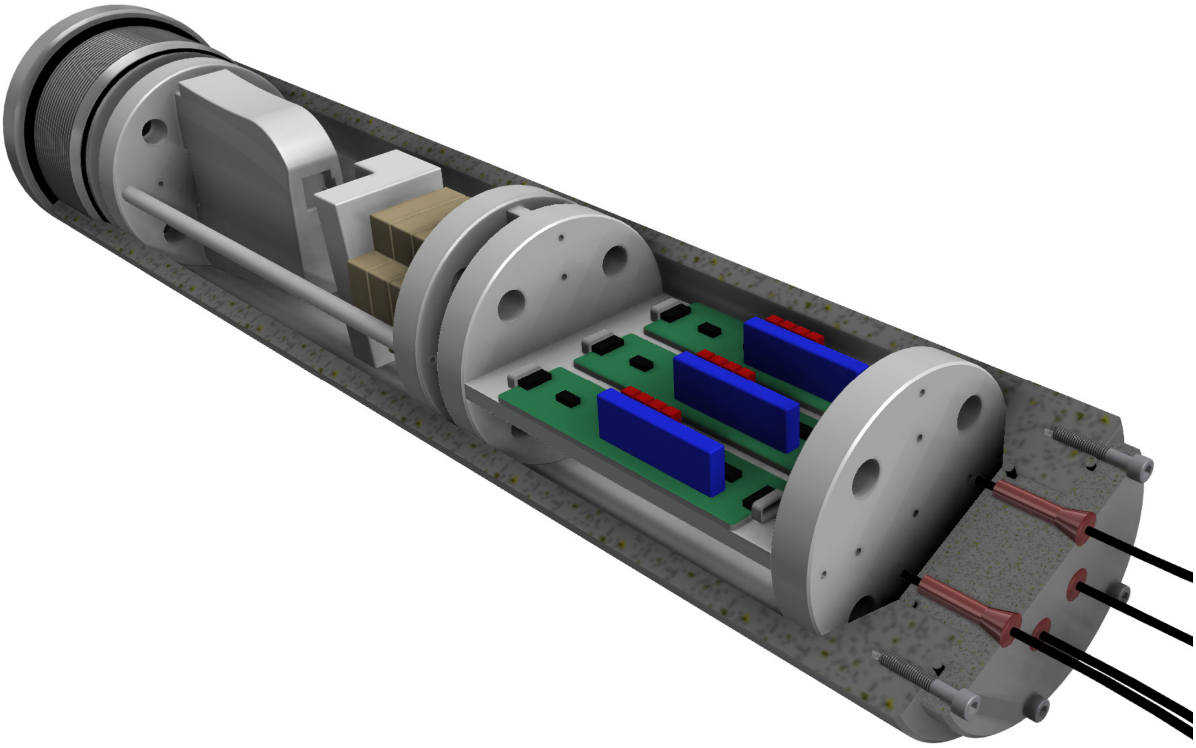


Figure 12-8 EPV penetrator module

The molded sealing shape utilizes the hydrostatic pressure [1] to increase the sealing pressure on the Neoprene cable [3].

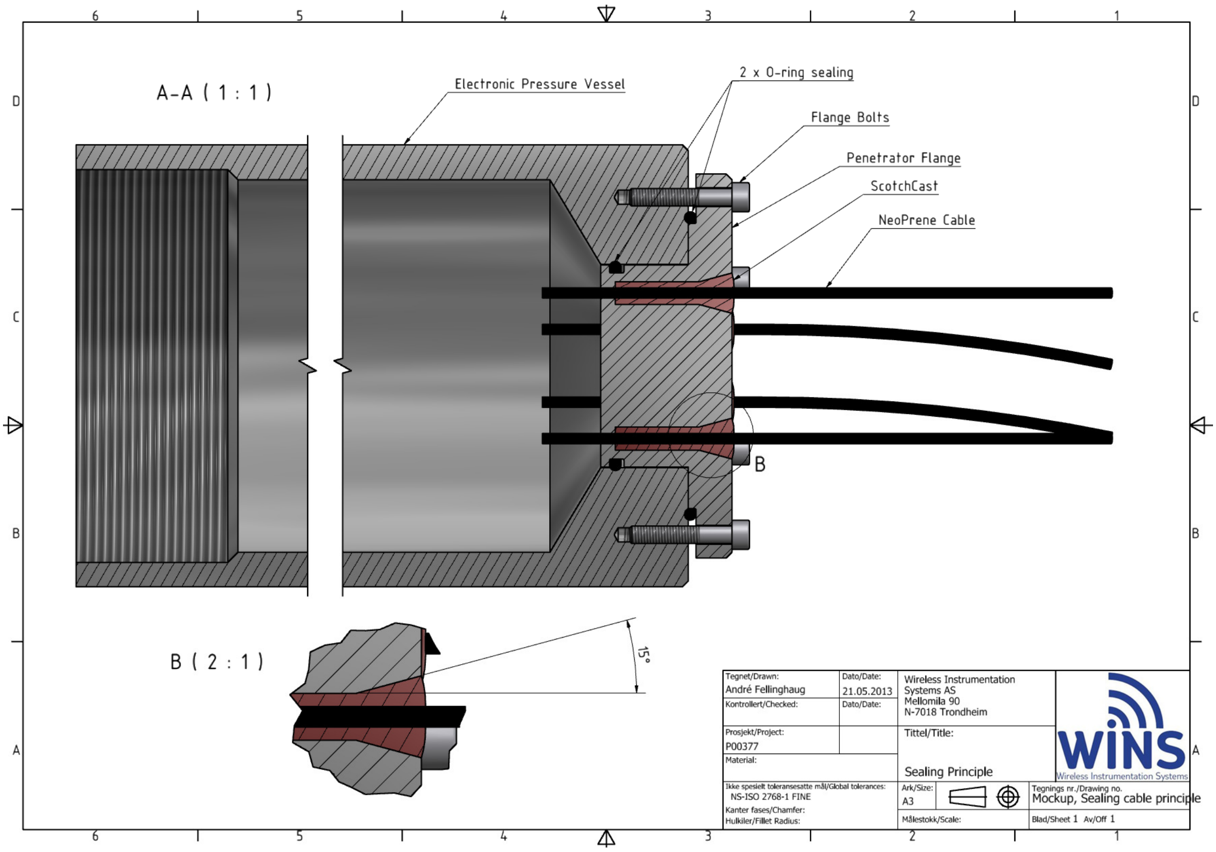


Figure 12-9 EPV penetrator flange cross section view

12.2.8 Magnetometer Pressure Vessel

The magnetometer (SR1.2 in Table 7-1) needs to be protected from seawater intrusion and hydrostatic pressure [1] conditions (R2.1 in Table 5-1) [2]

Figure 12-10 Magnetometer

The Magnetometer Pressure Vessel (MPV) is made of PET polymer see Table 12-1 EVPS Materials for reference. PET has excellent hydrolysis [9] resistance, is nonmagnetic [1] and has good mechanical strength.

Figure 12-11 Magnetometer Pressure Vessel

The magnetometer is inserted into a cylinder tube with threaded end lids. Same sealing principle is used for this as for the EPV with redundant O-ring seals. The topside lid has a NPT [16] thread connection to connect the pressure tube fittings [15] from the EPV. The signal cable from the magnetometer will be fed through this pressure tube [14].

Figure 12-12 MPV tube connection to EPV

12.2.9 EVPS materials

The materials in the EPVS are listed with respective appendix reference in Table 12-1 EVPS Materials.

Table 12-1 EVPS Materials

Part	Material	Appendix reference
EPV, tube	AL-6XN	AL-6XN_Datasheet
EPV, topside lid	AL-6XN	AL-6XN_Datasheet
EPV, penetrator flange	AL-6XN	AL-6XN_Datasheet
EPV, flange bolts	AL-6XN	AL-6XN_Datasheet
EPV, cable sealing	Polyurethane (PU)	ScotchCast-MDS
ERM, plate	AL-6061	Alloy_6061-MDS
ERM, bulk wall	AL-6061	Alloy_6061-MDS
ERM, tube	316L	Swagelock-Tube-316L
ERM, fasteners	316L	sandvik-316-316l
EPVS, fittings	Alloy 400	Swagelock-1-8-Alloy400
EPVS, pressure tubes	254 SMO	Sandvik-254-SMO
EVPS, O-ring sealing	HABR	RU4-O-ring-MDS
MPV, tube	PET	PET Rochling-MDS
MPV, lids	PET	PET Rochling-MDS
MPV, lids	PET	PET Rochling-MDS
SmartBand™	PA11GF	SmartBand_Technical

This material composition may cause a galvanic potential large enough to subject the steel alloys to different types of corrosion. This might reduce the lifespan of the system if not protected. [9]

An independent corrosion analysis is conducted by Roe D. Strømmen PhD, former CEO of CorrOcean, refer to document “Memo-Corrosion-Alloys-april-2013” in the appendix.

“***Comments/conclusions*:**
There will always be uncertainty in a brief analysis or a brief literature survey like this one. There are uncertainties in the data, from one article to another. There is a well-known effect on electrochemical potentials of stainless steels in seawater, which takes time to show up; namely the effects of biofilms that may develop over time in natural seawater. However, the data observed are all reasonably in line with well-known data from other research institutions than those cited in attachments.
It is therefore recommended to go ahead and use the materials selected, without any extraordinary precautions, except for using good and well proven design practices.
Please observe that an inexpensive method to mitigate any corrosion risk in this case might be to use a sacrificial anode, e.g. of zinc. The size of such an anode for 5 year design life would be small, and inexpensive. In this case this is not considered necessary. It is recommended to test the present design without the use of sacrificial anodes.” [*19*]

12.2.10 EPVS drawing reference

All EPVS parts have drawing files in the appendix. See Table 12-2 EPVS drawing reference

Table 12-2 EPVS drawing reference

Part	Appendix reference
EPV assembly	EPV, ASSY
EPV, tube	Tube, EPV
EPV, topside lid	Topside lid, EPV
EPV, penetrator flange	Penetrator lid, EPV
ERM assembly	ERM, ASSY
ERM, plate	Plate, ERM
ERM, bulk wall	Bulk wall, ERM
EPVS assembly	EPVS, ASSY
MPV assembly	MPV, ASSY
MPV, tube	Tube, MPV
MPV, lids with tube connection	Lid_NPT, MPV
MPV, lid	Lid, MPV

12.3 FEM analysis pressure vessels

FEM analysis is carried out on simplified and symmetric models of the pressure vessels.
Failure criteria is Max Von Mises < Material Yield strength @ 2 x operational load. This is a conservative design criterion which can be applied for ductile and isotropic materials. [11] [12]

12.3.11 Hydrostatic pressure for simulation input

In order to find the pressure acting on the pressure vessels at the operational depth (R2.1 in Table 5-1), the hydrostatic pressure must be calculated.

Hydrostatic pressure is the pressure exerted by a fluid at equilibrium due to the force of gravity.
In hydrostatics, liquids are close to incompressible so the density can be assumed as constant [7]. For relatively small distances, in this case water depth of 500 [m] (R2.1 in Table 5-1), gravity is constant [7]. The hydrostatic pressure at any given water depth is expressed by the following equation: [1]

$$p = \rho g h + p_{atm}$$

Equation 1 Hydrostatic pressure

Where

p	Hydrostatic pressure
ρ	Seawater density
g	Gravitational constant
h	Seawater depth
p_{atm}	Atmospheric pressure at seawater surface

The ambient pressure inside the pressure vessels are atmospheric meaning $p_{atm} = 0$

Table 12-3 EPVS design properties

Property	Value	Reference
Water depth	500 [m]	(R2.1 in Table 5-1)
Water density, North sea	1,029 [Kg/m^3]	Given by Statoil ASA
Earth's gravitational acceleration	9,81 [m/s^2]	[1]

Applying input from Table 12-3 EPVS design properties to Equation 1

$$p = 1{,}029\left[\frac{Kg}{m^3}\right]\cdot 9{,}81\left[\frac{m}{s^2}\right]\cdot 500[m] = 5047[KPa] \approx 5{,}05[MPa]$$

Table 12-4 EVPS simulation input

Property	Operational load	2 x operational load
Hydrostatic pressure	5,05 [MPa]	10,1[MPa]

12.3.12 EPV FEM analysis

A simplified model of the EPV is cut into a symmetric model to reduce computational time. When symmetric models are used, friction less constraints is applied on the cut surface. [11]

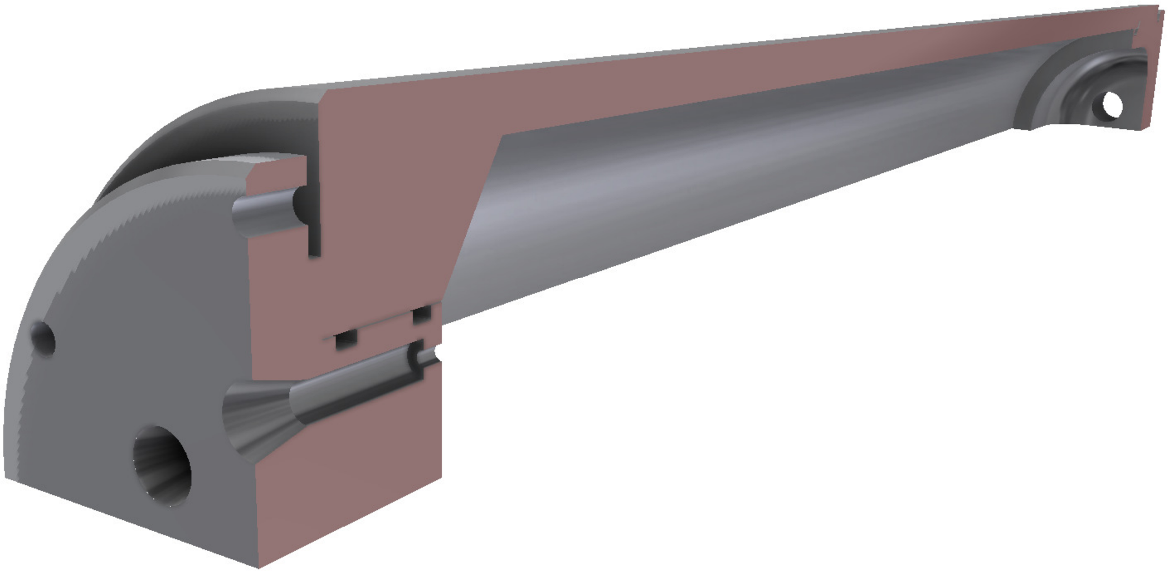


Figure 12-13 EPV symmetric model for FEM

The model is meshed with tetrahedron elements with local mesh control on stress concentrated corners and grooves. Refer to the full report “EPV FEM Report” in the appendix for mesh settings.

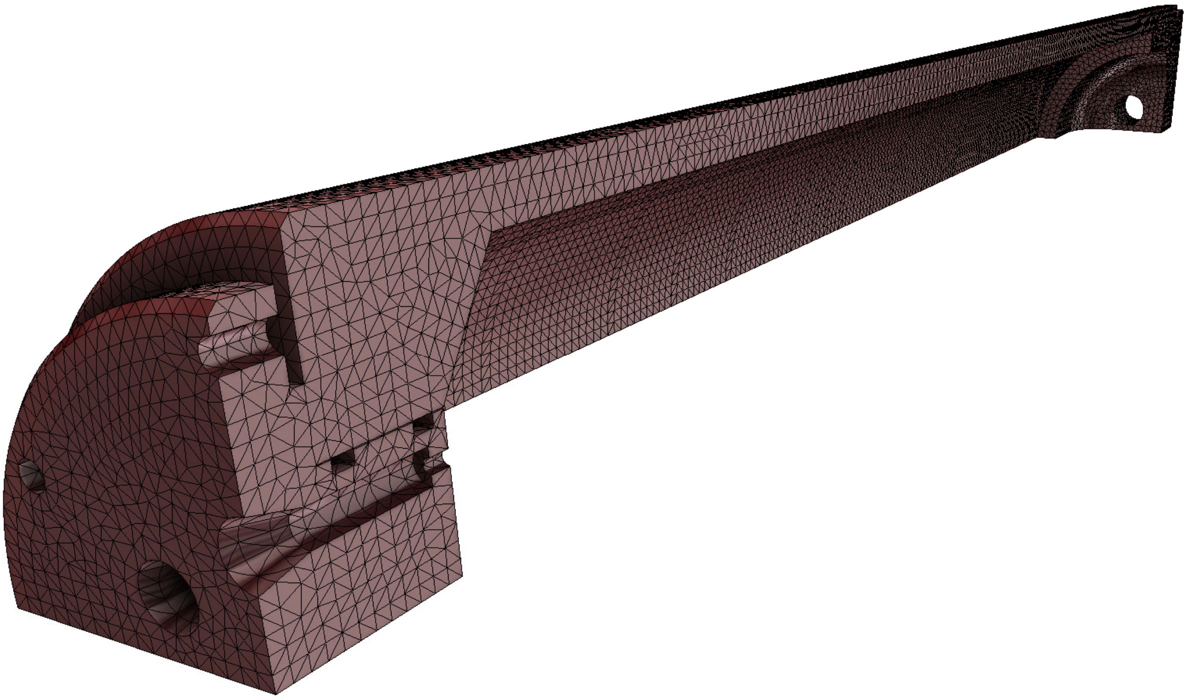


Figure 12-14 EPV meshed model

Frictionless constraints are set on the cut surfaces and on one lid surface to constrain movement along its longitudinal axis and allow for radial movement.

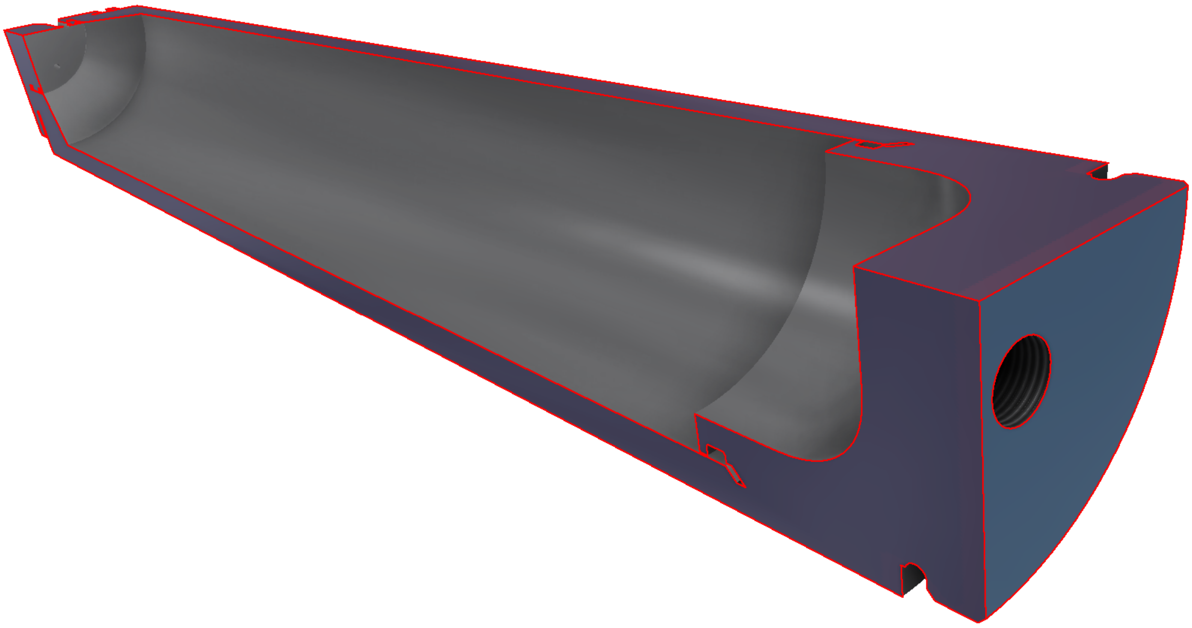


Figure 12-15 EPV Frictionless constraints

Pressure load is applied to all outer surfaces of the model according to Table 12-4 EVPS simulation input.

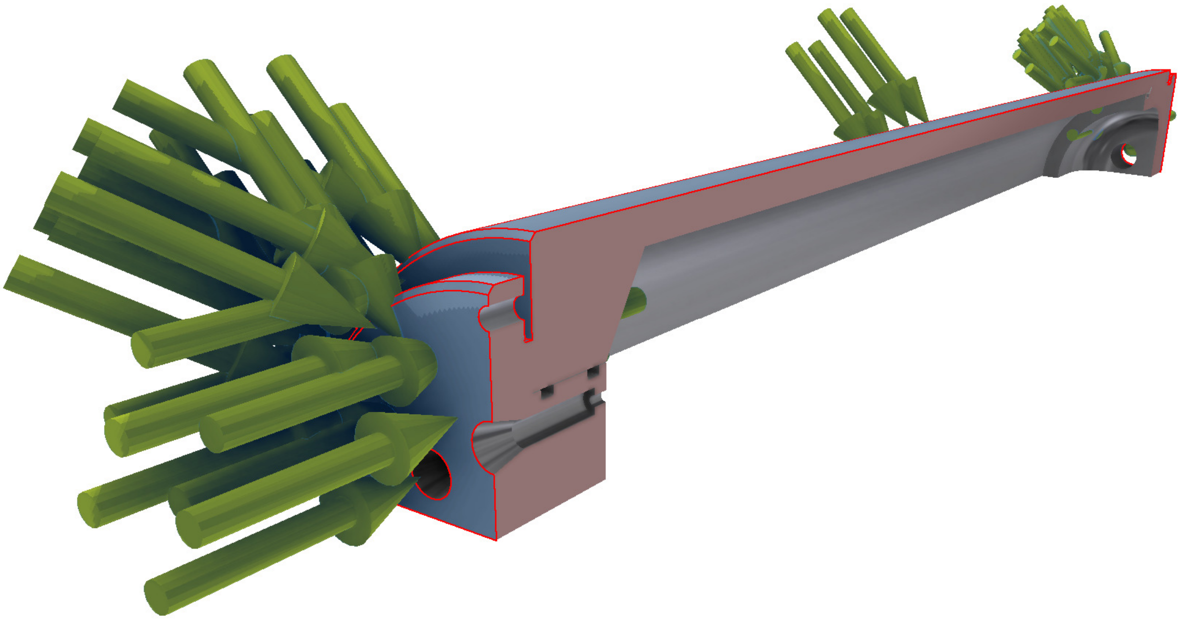
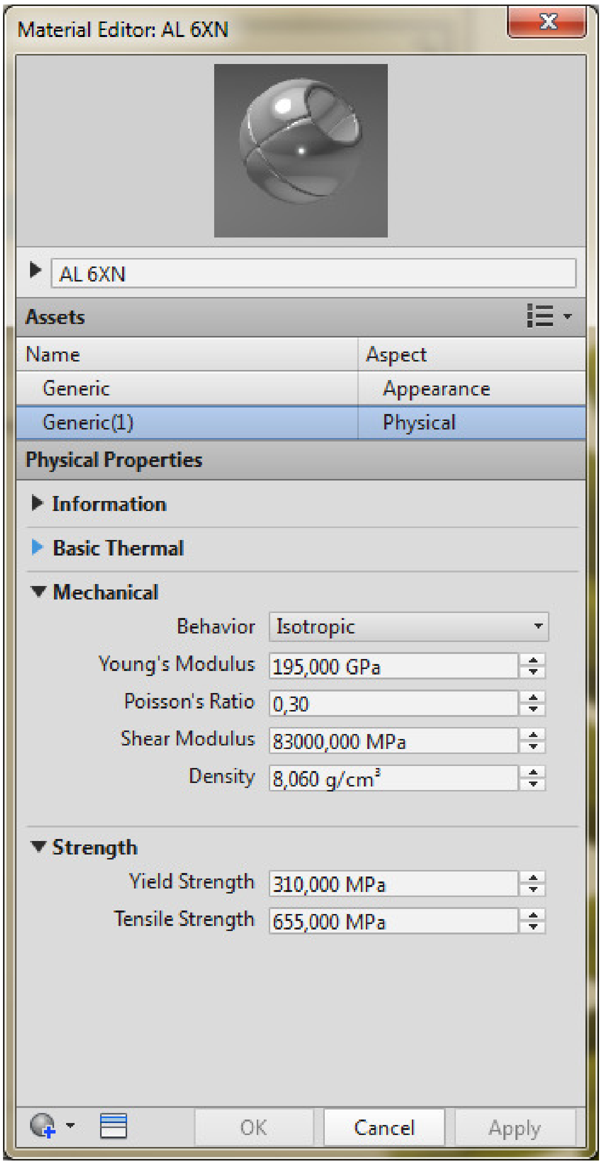


Figure 12-16 EPV Pressure load

Material specification is applied according to Table 12-1 EVPS Materials.



Material Editor: AL 6XN

AL 6XN

Assets

Name	Aspect
Generic	Appearance
Generic(1)	Physical

Physical Properties

Information

Basic Thermal

Mechanical

Behavior: Isotropic

Young's Modulus: 195,000 GPa

Poisson's Ratio: 0,30

Shear Modulus: 83000,000 MPa

Density: 8,060 g/cm³

Strength

Yield Strength: 310,000 MPa

Tensile Strength: 655,000 MPa

Figure 12-17 EPV Material specification

12.3.13 Results EPV FEM

EPV FEM analysis stress distribution is diplayed in Figure 12-18 EPV stress distribution and the results are listed in Table 12-5 EPV FEM analysis results.

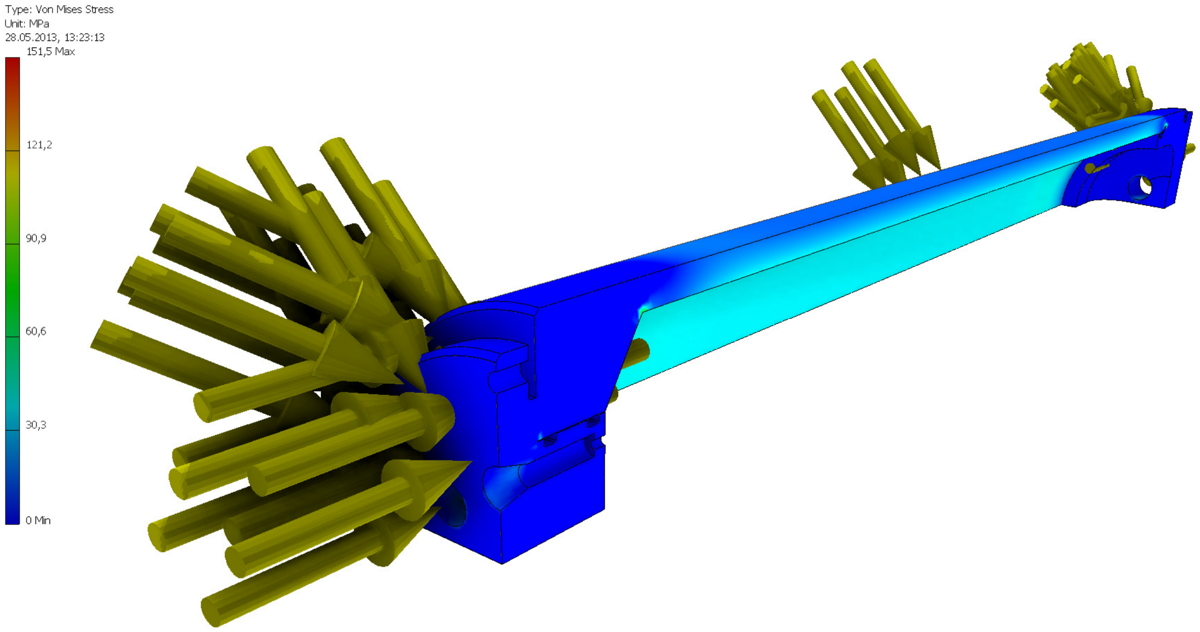


Figure 12-18 EPV stress distribution

Table 12-5 EPV FEM analysis results

Results	Value	Figure reference
Max Von Mises Stress	151,5 [MPa]	Figure 12-19 EPV Max Von Mises Stress
Max Radial decrease	0,02 [mm]	Figure 12-20 EPV Max Radial decrease
Minimum safety factor of yield	2,05	Figure 12-21 EPV Minimum safety factor

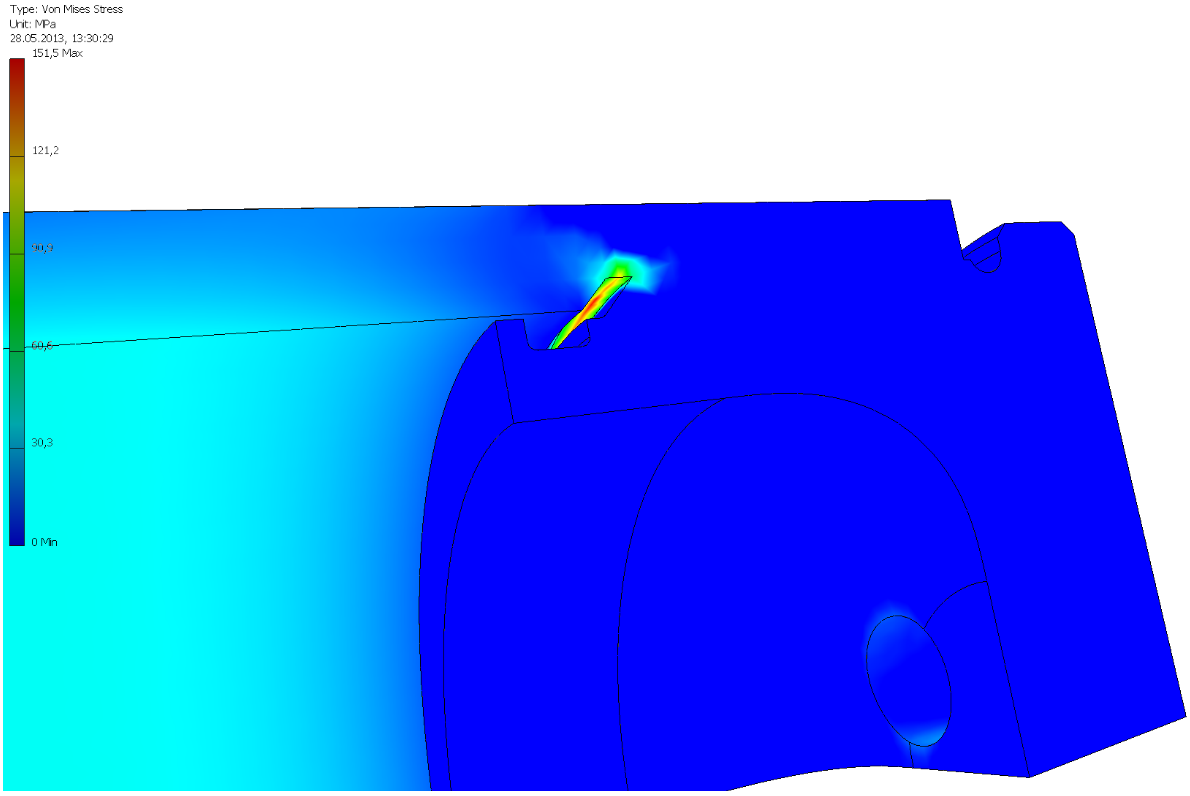


Figure 12-19 EPV Max Von Mises Stress

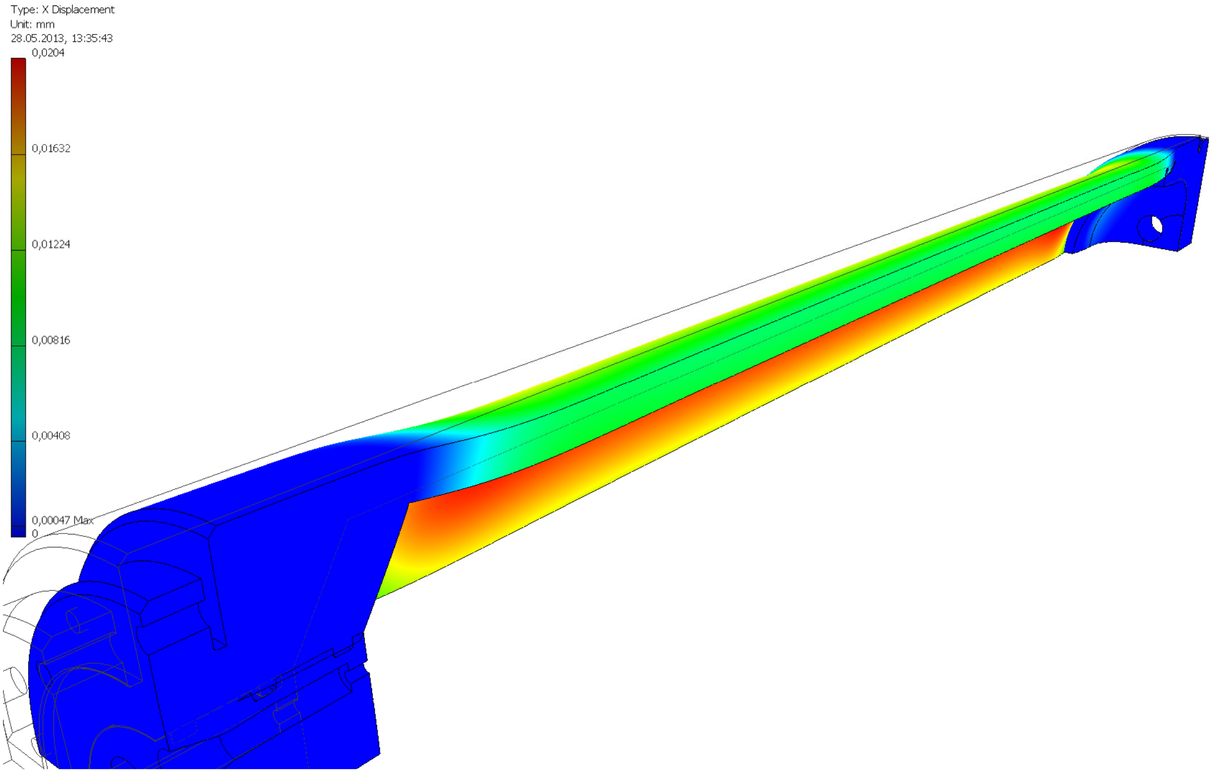


Figure 12-20 EPV Max Radial decrease (exaggerated)

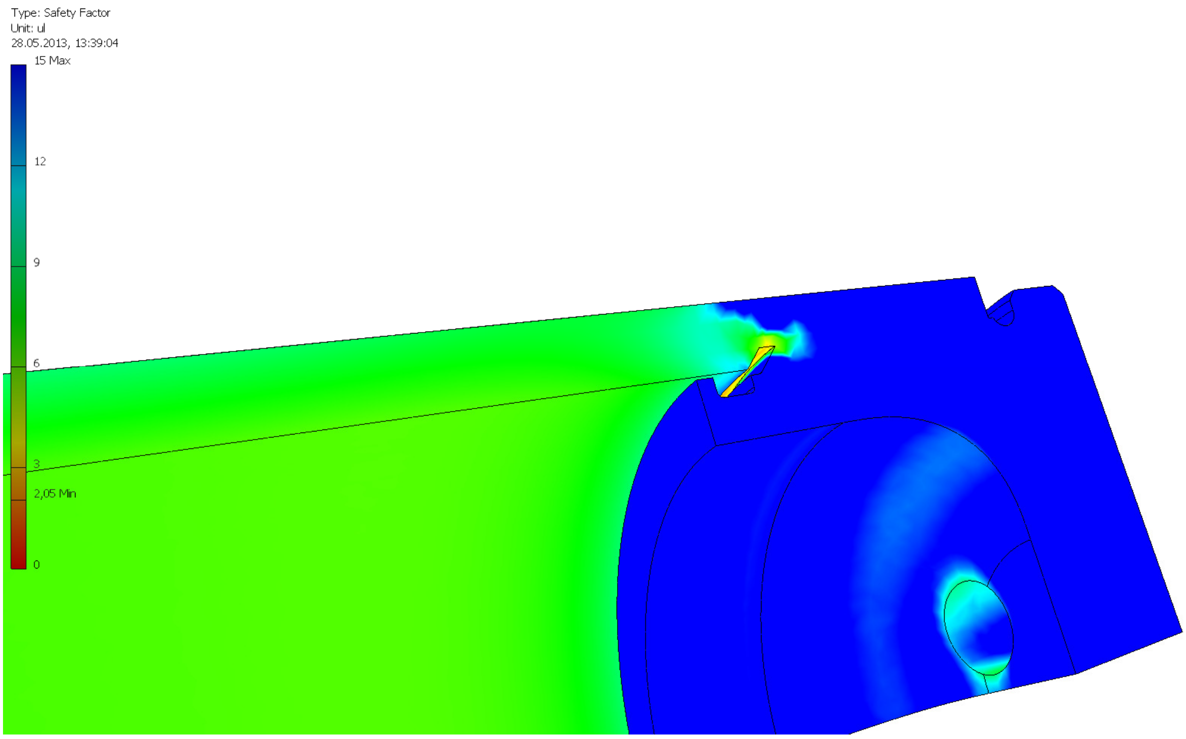


Figure 12-21 EPV Minimum safety factor of yield

12.3.14 EPV FEM conclusion

All stresses are well within the material specification. Max Von Mises Yield < Material Yield. The EPV design withstands the given loads.

See the full report “EPV FEM Report” in the appendix.

12.3.15 MPV FEM analysis

A simplified model of the MPV is cut into a symmetric model to reduce computational time [11]. When symmetric models are used, friction less constraints is applied on the cut surface [11].

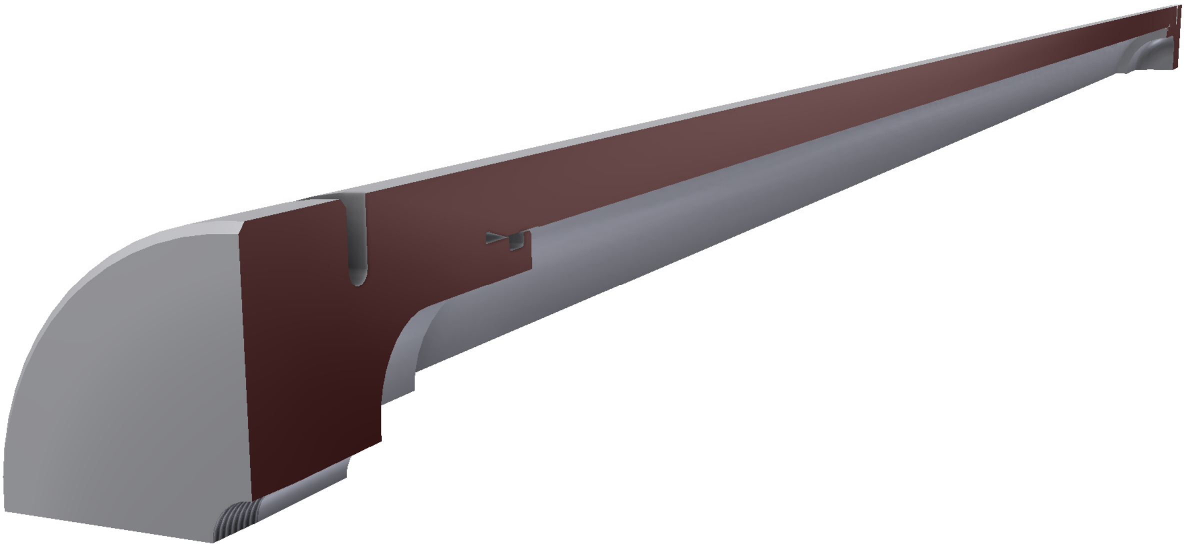


Figure 12-22 MPV symmetric model for FEM

The model is meshed with tetrahedron elements with local mesh control on stress concentrated corners and grooves. Refer to the full report "MPV FEM Report" in the appendix for mesh settings.

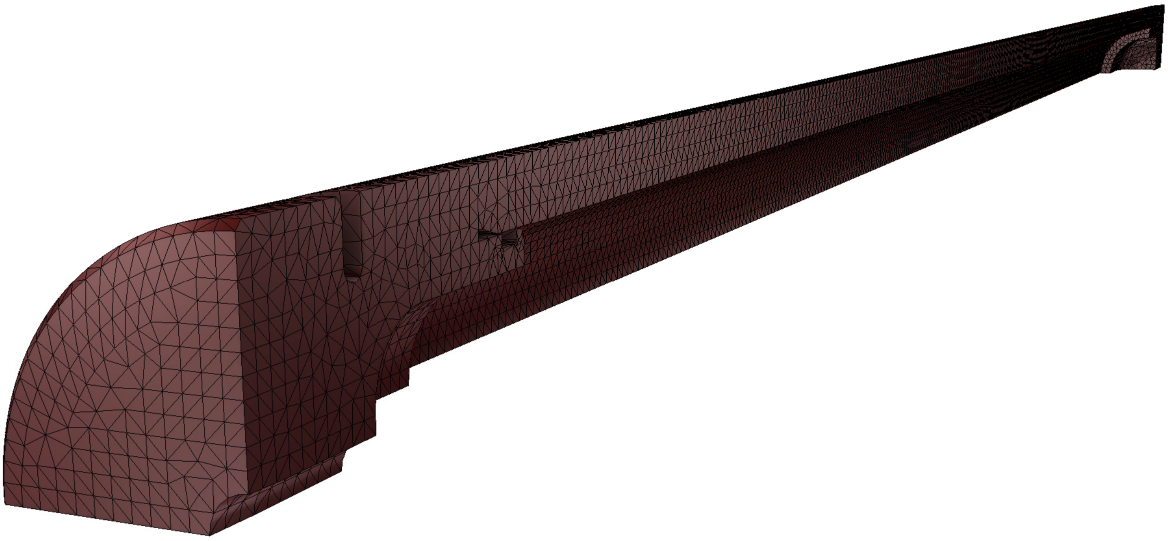


Figure 12-23 MPV meshed model

Frictionless constraints are set on the cut surfaces and on one lid surface to constrain movement along its longitudinal axis and allow for radial movement.

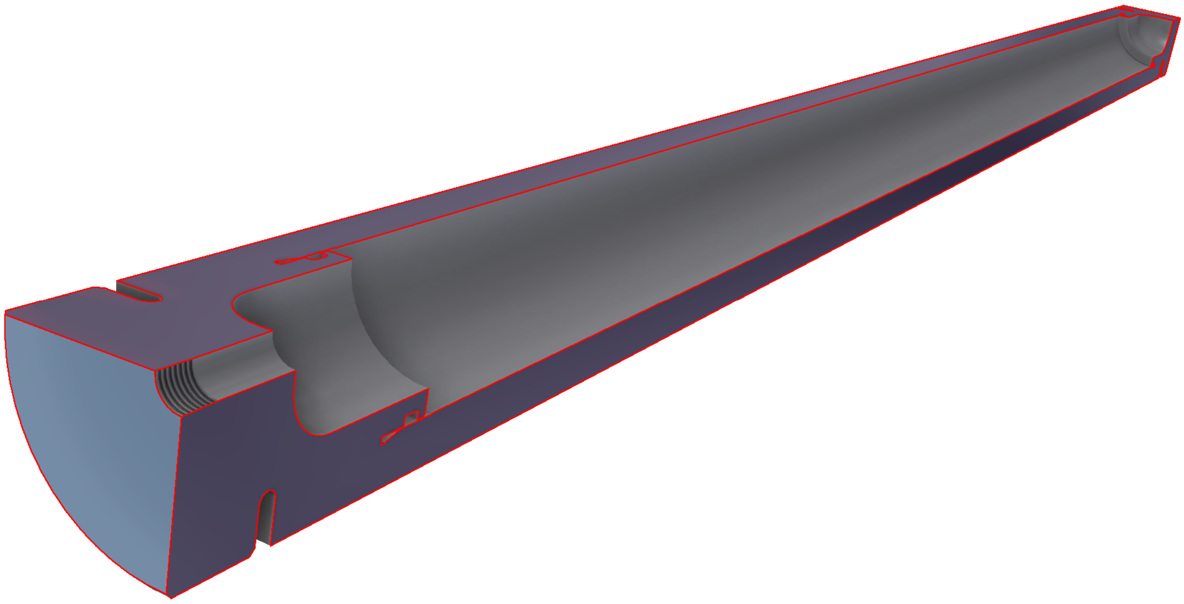


Figure 12-24 MPV Frictionless constraints

Pressure load is applied to all outer surfaces of the model according to Table 12-4 EVPS simulation input.

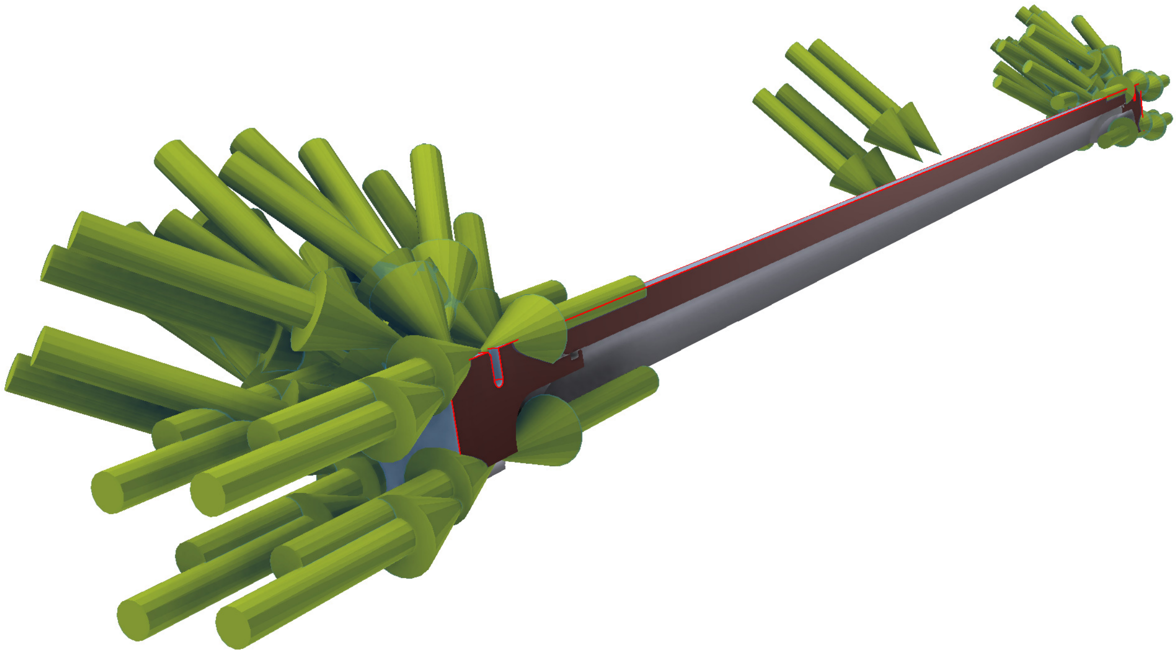
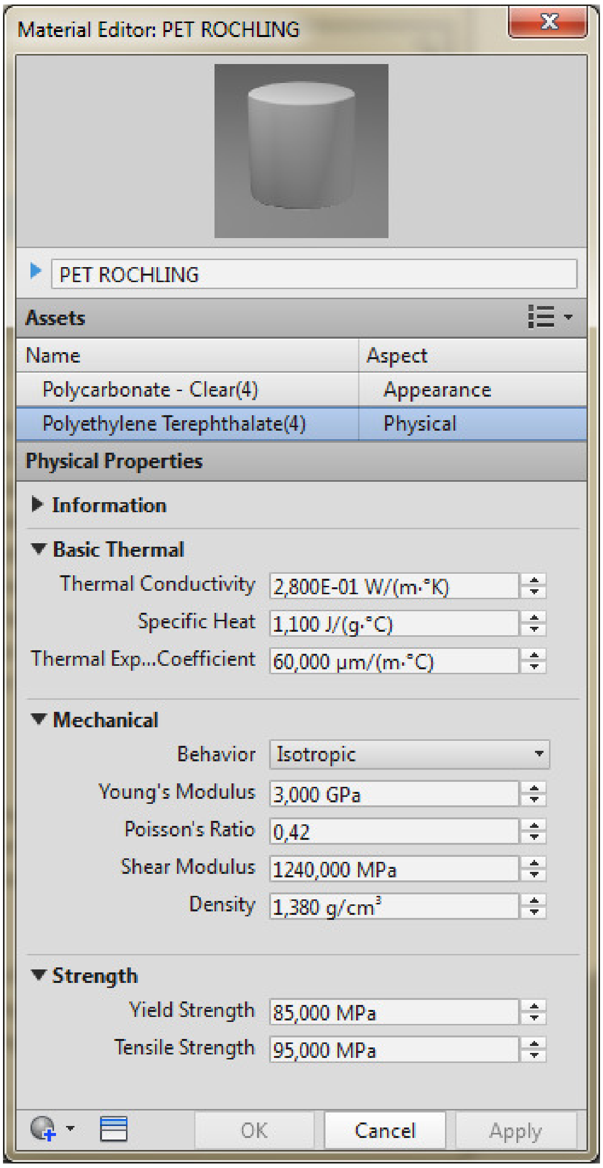


Figure 12-25 MPV Pressure load

Material specification is applied according to Table 12-1 EVPS Materials


Material Editor: PET ROCHLING

PET ROCHLING

Assets

Name	Aspect
Polycarbonate - Clear(4)	Appearance
Polyethylene Terephthalate(4)	Physical

Physical Properties

Information

Basic Thermal

Thermal Conductivity: 2,800E-01 W/(m·°K)

Specific Heat: 1,100 J/(g·°C)

Thermal Exp...Coefficient: 60,000 µm/(m·°C)

Mechanical

Behavior: Isotropic

Young's Modulus: 3,000 GPa

Poisson's Ratio: 0,42

Shear Modulus: 1240,000 MPa

Density: 1,380 g/cm³

Strength

Yield Strength: 85,000 MPa

Tensile Strength: 95,000 MPa

Figure 12-26 MPV material specification

12.3.16 Results MPV FEM

MPV FEM analysis stress distribution is diplayed in Figure 12-18 EPV stress distribution and the results are listed in Table 12-6 MPV FEM analysis results.

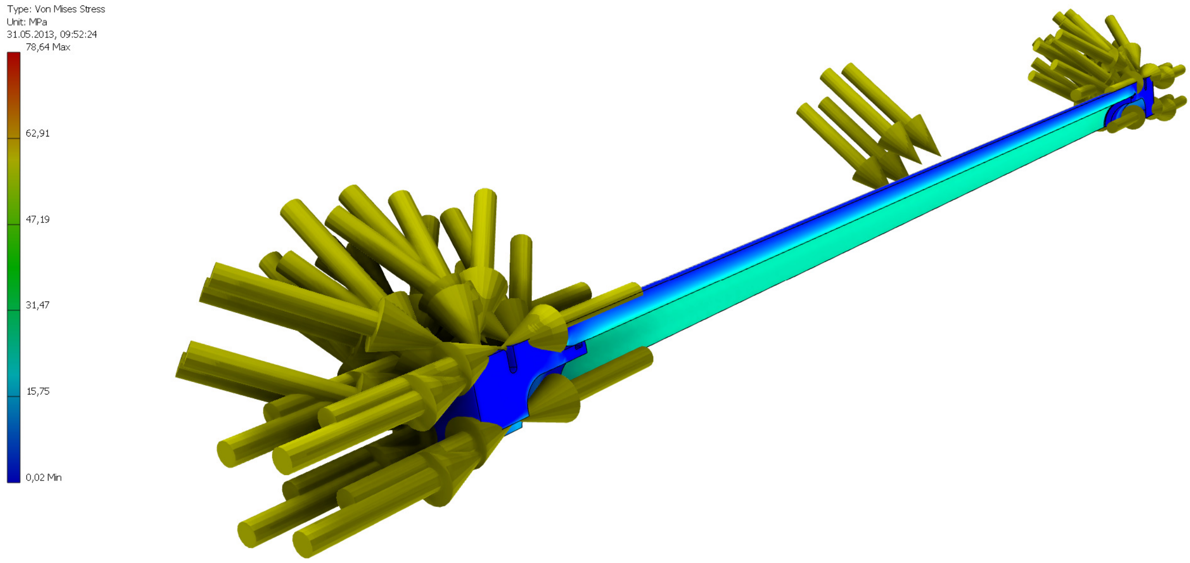


Figure 12-27 MPV stress distribution

Table 12-6 MPV FEM analysis results

Results	Value	Figure reference
Max Von Mises Stress	78,6 [MPa]	Figure 12-28 MPV Max Von Mises stress
Max Radial decrease	0,47 [mm]	Figure 12-29 MPV Max radial decrease
Minimum safety factor of yield	1,08	Figure 12-30 MPV Minimum safety factor

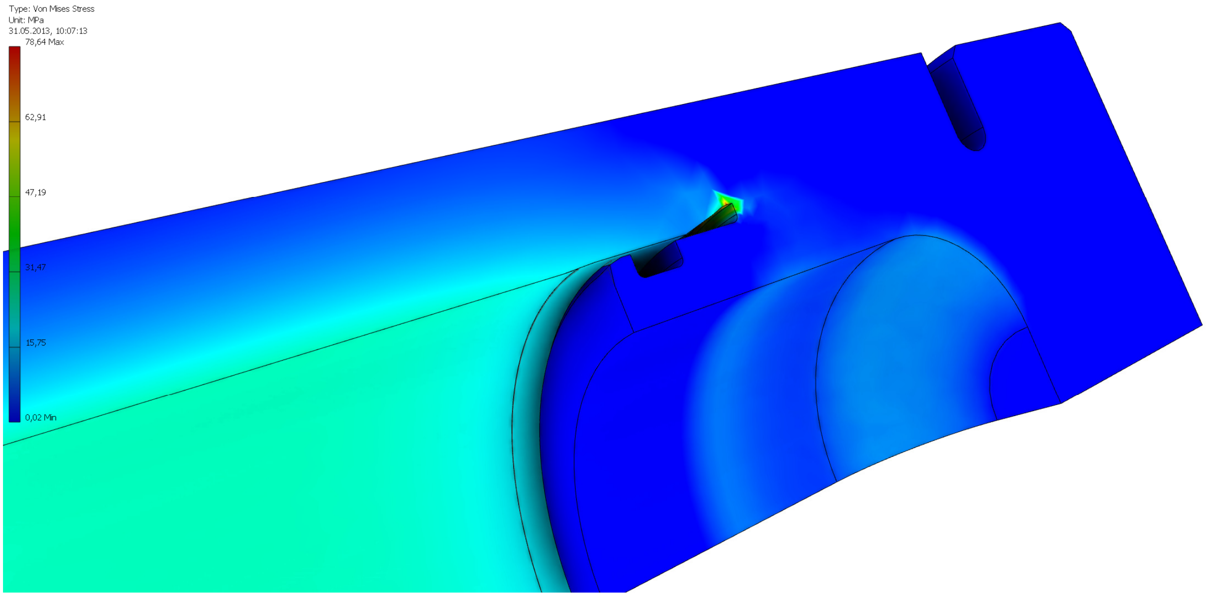


Figure 12-28 MPV Max Von Mises stress

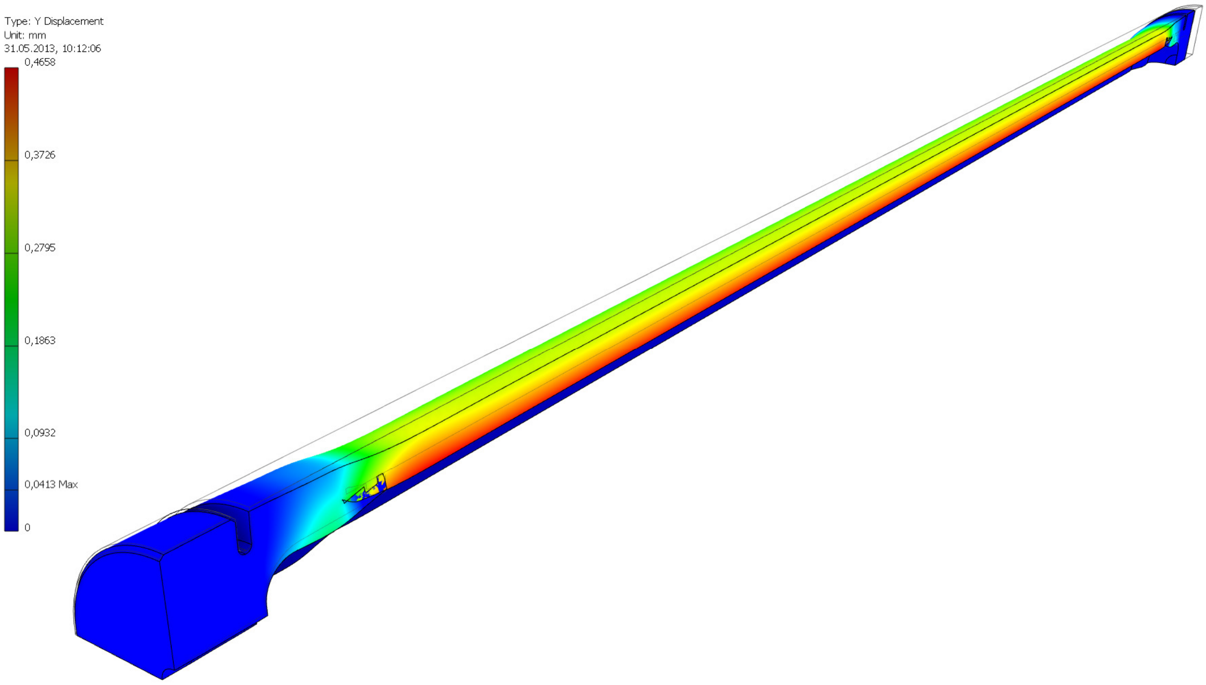


Figure 12-29 MPV Max radial decrease

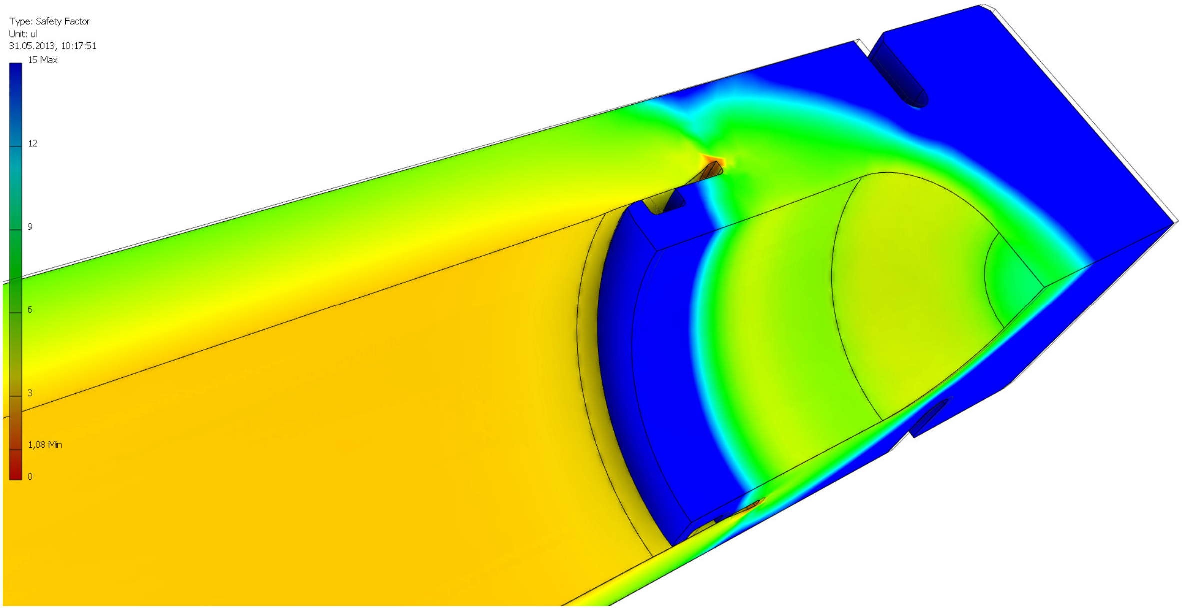


Figure 12-30 MPV Minimum safety factor

12.3.17 MPV FEM conclusion

All stresses are within the material specifications. Max Von Mises Yield < Material Yield. However a small plastic deformation can be expected if subjected to 2 x operational load, as Max von Mises Yield are close to Material Yield. The red/yellow field in Figure 12-28 MPV Max Von Mises stress is a stress concentration at the contact point between the MPV lid and the MPV tube. Increasing load further will surpass the Material Yield and harden the material locally by plastic deformation. This will harden further deformation until material collapse. To find this critical value, further analysis is necessary with non-linear solver and a true material flow curve model [12].

The MPV design withstands the given loads.
See full report in “MPV FEM Report” in the appendix.

13 Frame structure

This chapter will describe in detail the requirements and solutions provided to the structural frame for the SCS.

13.1 Frame structure requirements

The following elaborated requirements are separated into functional, material and geometrical requirements which must be fulfilled to ensure high level of integrity for the final product.

13.1.1 Functional requirements

The Eigen frequency [1] of the frame structure (SR1.6 in Table 7-1) should not be in the range of the Vortex Shedding (VS) frequencies [20] for the given ocean currents (R2.5 in Table 5-1) see chapter 15 Frame structure FEM analysis for reference. Nor should the frame structure have any modes of Eigen frequencies in the 48 [Hz] range which will be the sampling frequency (SR1.6 in Table 7-1) for the magnetometers [2]. The center of gravity should be low enough to prevent the structure from tilting or behave unstable during lifting operations (R6.5, R6.8 in Table 5-1).

All parts must have tolerances or operational space such that their functions will not be affected by the hydrostatic pressure [1] (R2.1 in Table 5-1) nor the underwater currents (R2.5 in Table 5-1).
The structure must withstand falling objects and critical parts must be protected (R6.1 in Table 5-1). The SCS should have an underwater visible color and direction markers to orientate the ROV pilot (R7.4 in Table 5-1). The structure must have good lateral anchoring to ensure stabile position at all times (R6.7 in Table 5-1)

13.1.2 Material requirements

All materials must be qualified and approved by the customer (R6.2 in Table 5-1). The materials used in the EPVS must withstand the corrosive [9] and hydrostatic pressure [1] conditions (R2.1 in Table 5-1) or otherwise be protected (R6.3 in Table 5-1). The use of engineering polymers and Glass Fiber Reinforced Plastics (GFRP) should be considered as these materials will not affect the magnetic fields [1] and oblique the above needs [9], see "GFRP_profiles-VINK" in appendix for reference.

13.1.3 Geometrical requirements

The structure must be large enough to contain all pressure vessels and electrode deployment systems.
The maximum width and height should be within the normal ISO container [21] sizes for easy transport offshore (SR1.8 in Table 7-1).

13.2 Concept introduction

This modular design is based on repetitive assembled parts made of Glass Fiber Reinforced Plastic (GFRP) machined POM and PET polymer, see chapter 13.2.9 for material reference. These composite and polymeric materials have great corrosion resistance [9] and provide the structure sufficient support. Vortex Induced Vibrations [20] (VIV) will not be a problem for this design as the Eigen frequency of the frame structure, refer chapter 15.1.2, is far above the VIV frequency range, see chapter 0 for reference. Polymer and ceramic material has no influence on the magnetic fields and are electromagnetic transparent [1].

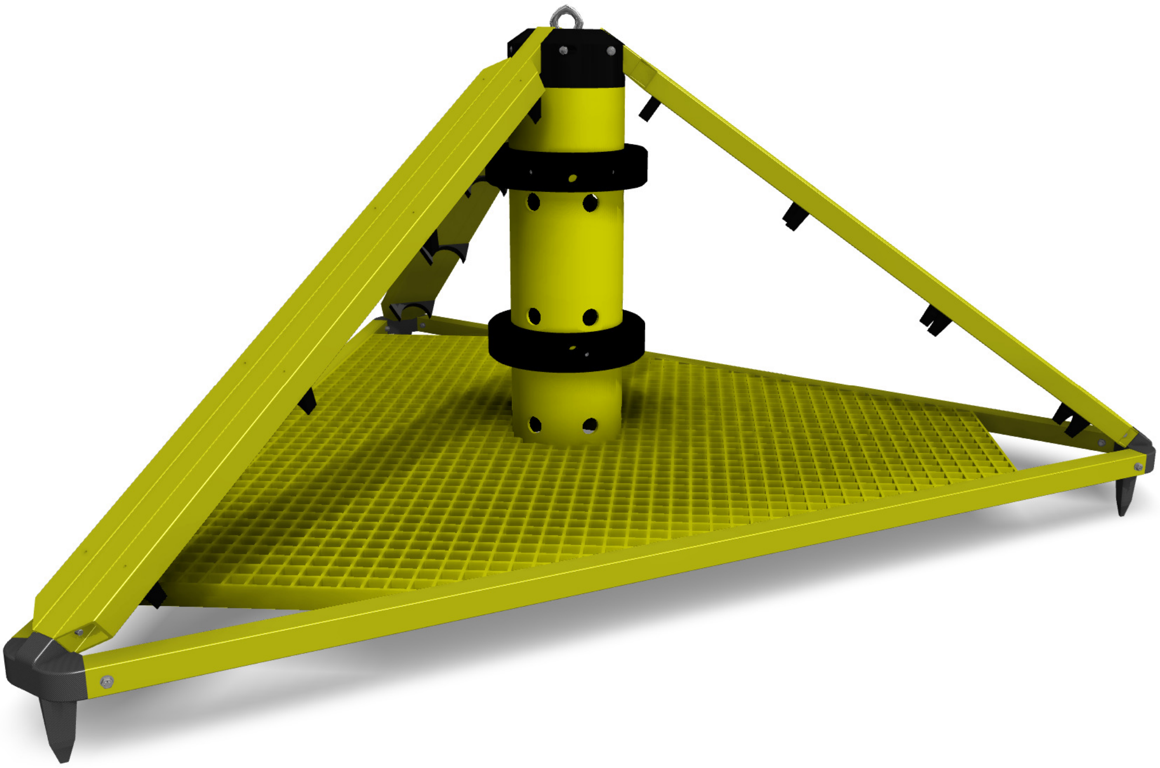


Figure 13-1 Frame concept introduction

13.2.4 Frame shape

The shape of the structure is a tetrahedron [22]. A tetrahedron consists of 4 triangles which by nature is rigid [23]. Building this with GFRP will give a high total stiffness, see chapter 15 for reference. The frame structure base has a tripod configuration which gives an inherently good stability on any surface terrain.

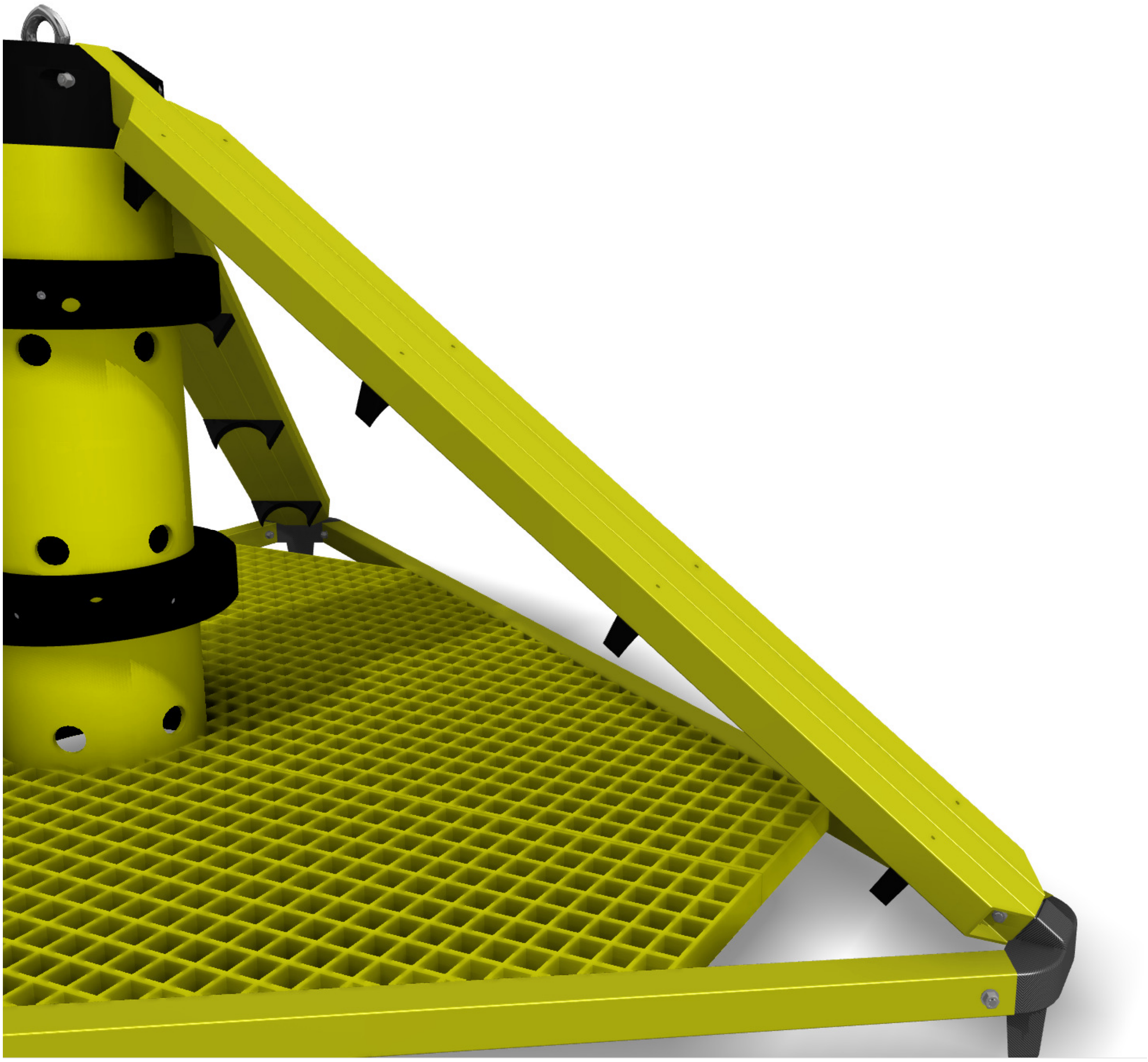


Figure 13-2 Frame shape, side view

By notation, a straight tetrahedron consists of 4 equal lateral triangles [22], but for this setup a 90° relationship [24] between the 3 magnetometers [2] is desirable. Thus leaving the angle relationship of 3 equally inclined triangles of 90°, 45°, 45° on an equal lateral base triangle of 60°, 60°, 60°. See Figure 13-3 Angular relations "Seabed Tool Design". [24]

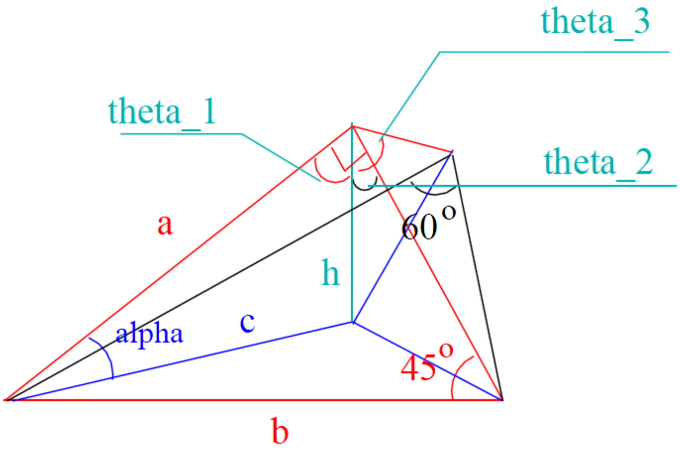


Figure 13-3 Angular relations "Seabed Tool Design" [24]

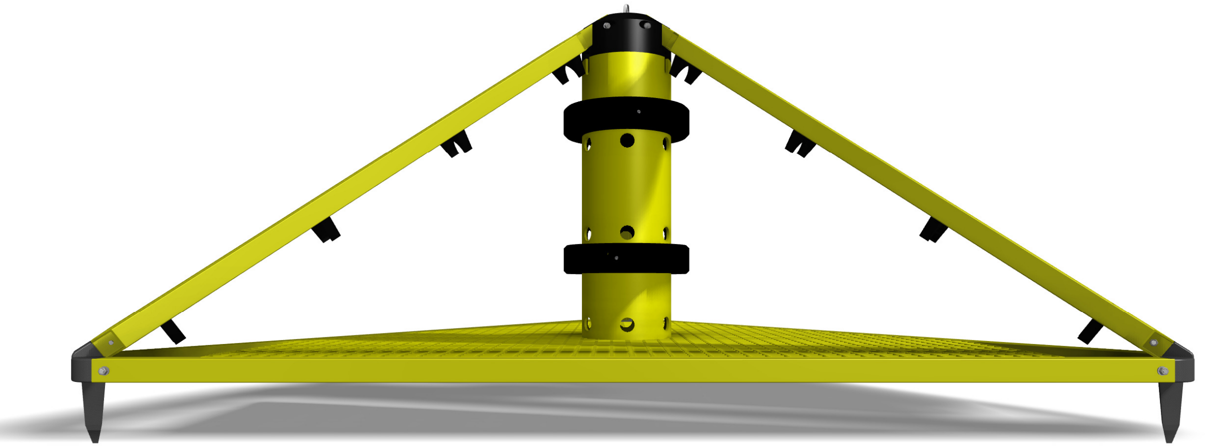


Figure 13-4 Frame shape, front view

The 3 upper square tubes are named “arm tubes” and the 3 lower square tubes next to the grating panels are named “base tubes”. Each arm tube consists of 3 bonded tubes side by side. This increases the Eigen frequency (SR1.6 in Table 7-1), see chapter 15.1 for reference.

13.2.5 Frame stability

This configuration gives a very low signature resulting in less drag forces from oncoming sea currents. A very low center of gravity is achieved with the weights placed on the base grating panel. The extended feet spears will protrude into the seabed ensuring good lateral anchoring. It will be advised to fill the grating pockets with seabed sand during deployment to enhance stability. This can be done with the ROV.

To ensure good spear protrusion the structure is loaded with 6 concrete weights, see chapter 14 “Structure weights” for reference. The weights are located as close as possible to the foot joint to avoid the suspended mass to lower the Eigen frequency [1].

The weights are secured to the base grating panel and base square tubes with SmartBand™ [17] straps.

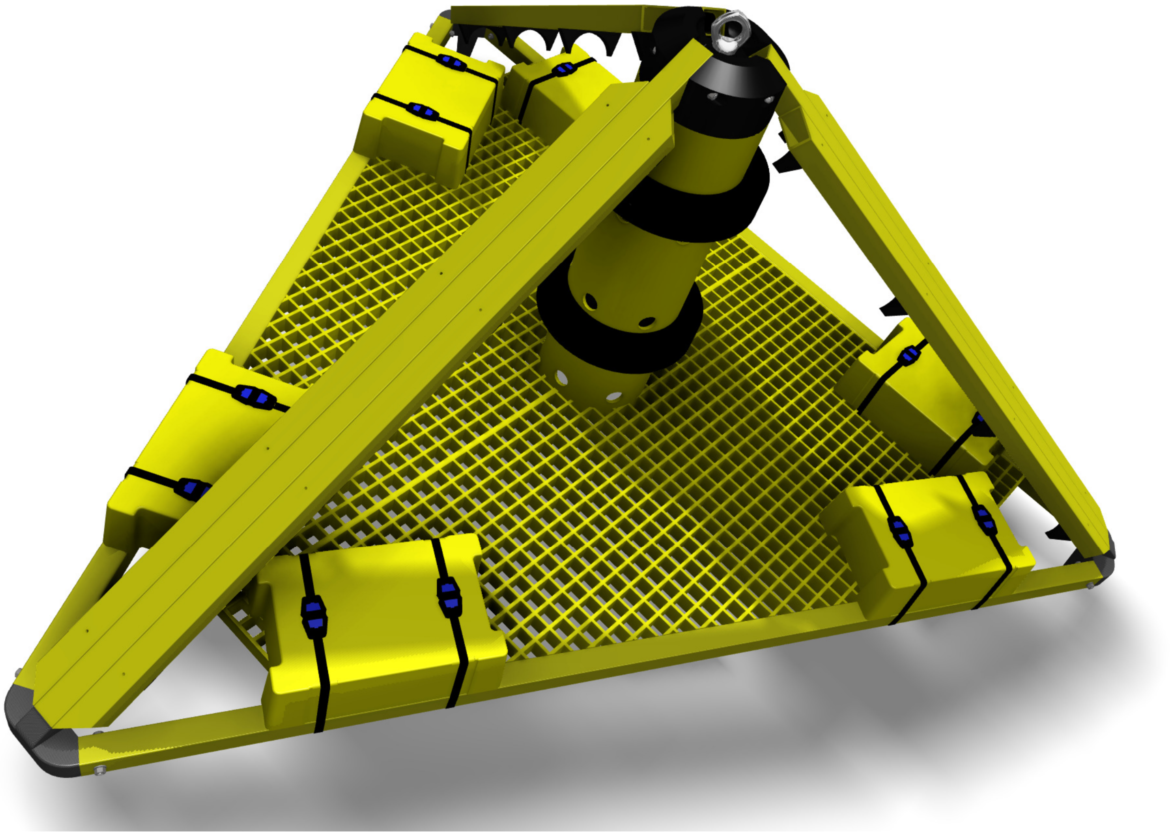


Figure 13-5 Frame with concrete weights

The grating panels offer great rigidity. The panels are glued with Araldite™ 2015 [25] in between the square tubes, see Table 13-2 Frame structure materials" for reference. This bonded connection increases the structure's overall stiffness.

The grating panel is glued to the center tube and ties the tetrahedron structure together as a cross beam [23].

The base grating will allow water to easily flow through during deployment. This will especially improve the splash-zone penetration (R6.8 in Table 5-1).

The low center of gravity combined with a wide base gives a very high maximum tilt angle see Figure 13-14 Weight distribution for reference. This will ensure stabile operation during lifting operations and maneuvering during deployment on the sea bed (R7.1 in Table 5-1).

13.2.6 Frame assembly

A complex molded fot joint is used to connect the square tubes together. This part is compression molded in HexMC® [26]. It serves several functions as connecting the square tubes and protruding in to the seabed with its spear, ensuring lateral anchronig (R6.7 in Table 5-1). A molded product also ensure good reproducability [5] with emphasis on the frame structure angels.

Figure 13-6 Foot joint

Figure 13-7 Foot joint, side view

There are 3 incoming square tubes on each corner of the frame structure, 2 base tubes and 1 arm tube. They are inserted into the foot joint pegs and bolted with double ended studbolts. The upper peg on the foot joint has a slip angle to ensure easy assembly/disassembly of the arm tube.

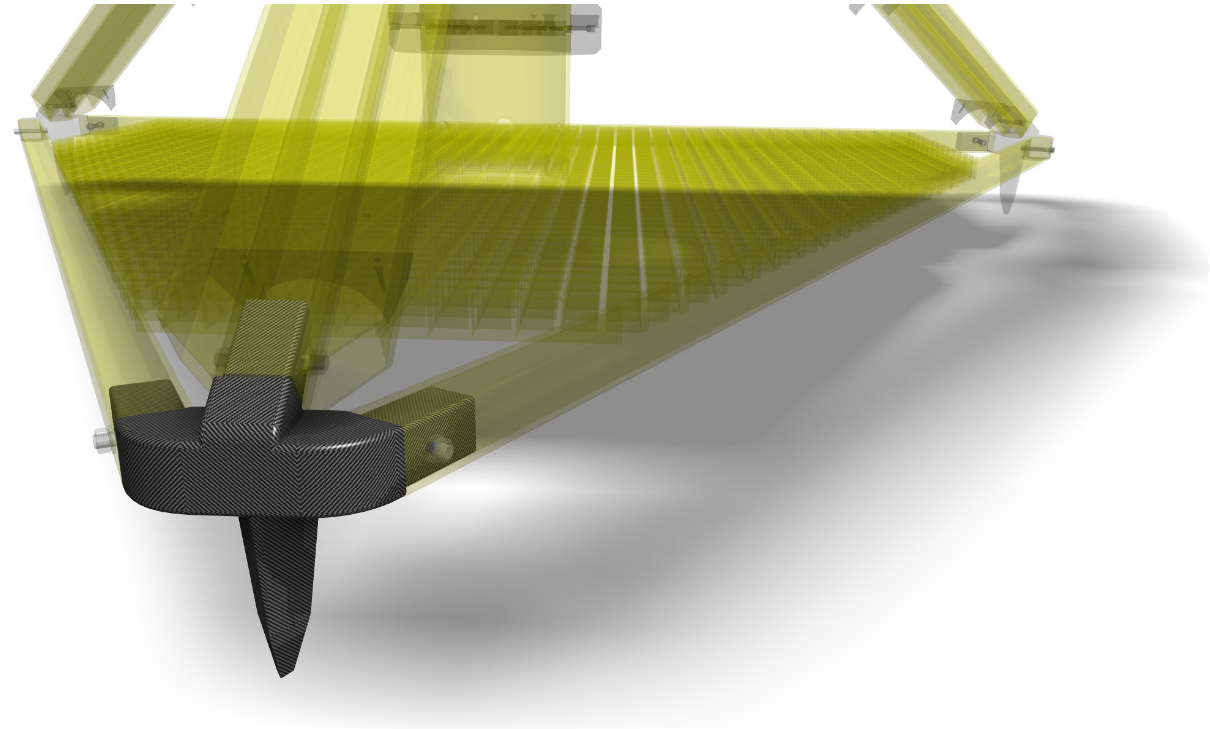


Figure 13-8 Foot joint in frame structure

A hub is mounted on top of the center tube named “top neck” which connects the 3 arm tubes to the center tube. The arm tubes are mounted in recessed grooves with throughfed studbolts. This pivot will allow some variations in the frame structure during manufacturing, which may be necessary provided most of the frame structure material is glassfiber products. Refer to Table 13-2 Frame structure materials.

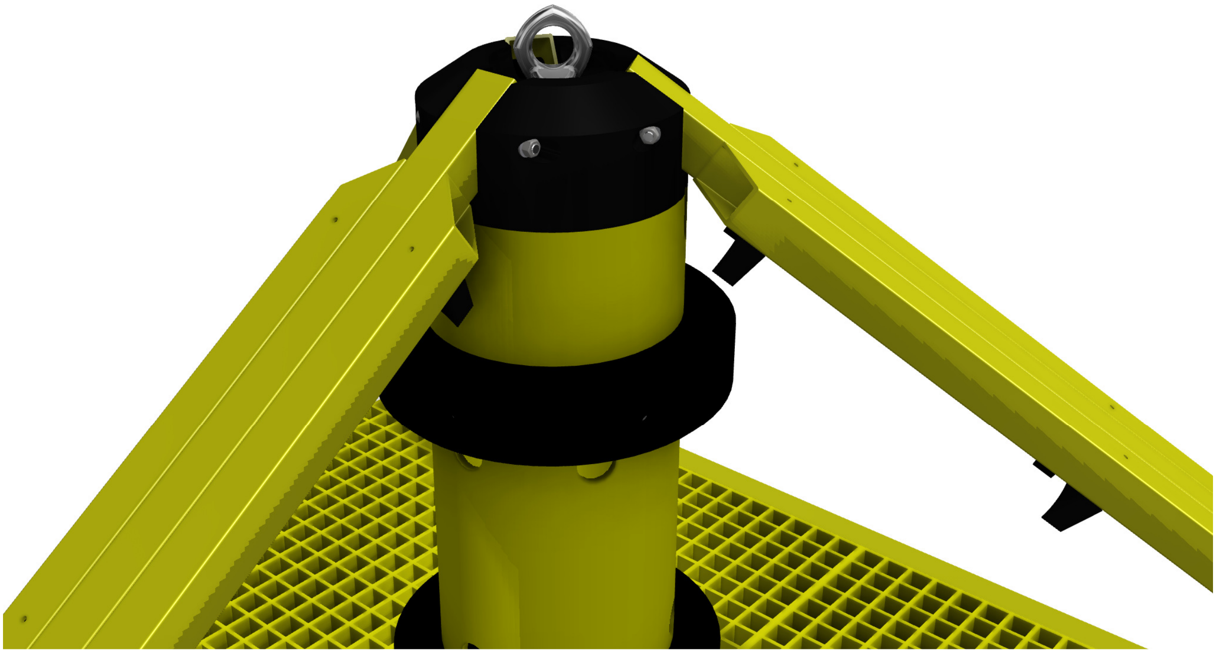


Figure 13-9 Upper arm tube connection

13.2.7 Frame brackets

The main purpose of the frame structure is to contain all sensors and the electronics. The Magnetometer Pressure Vessels (MPV) are suspended by semicircular brackets, named "MPV brackets" and tied in place by SmartBand™ [17] straps.

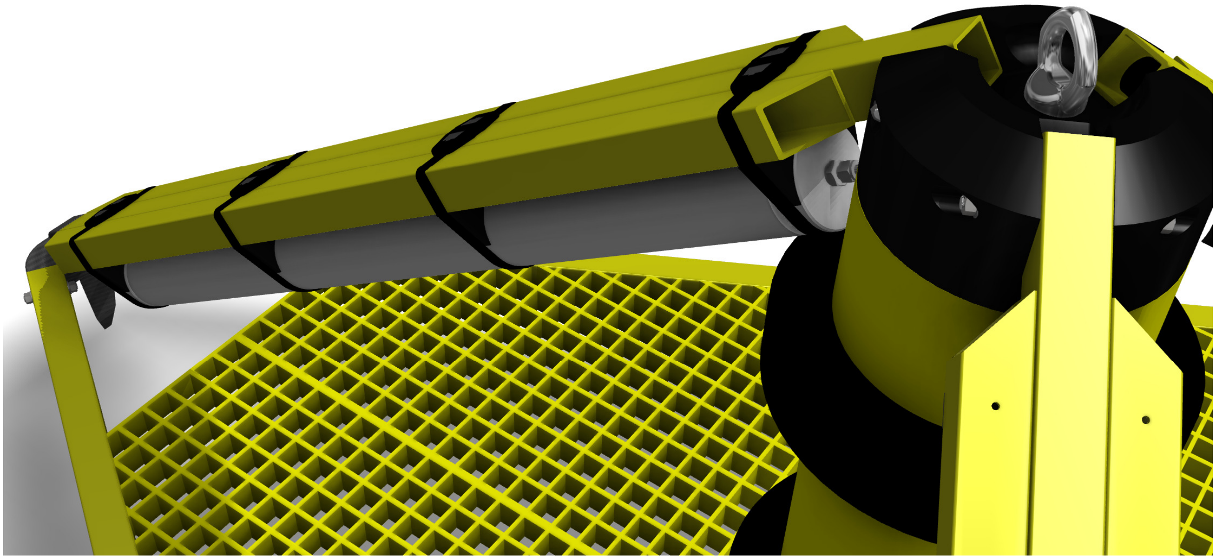


Figure 13-10 Magnetometer Pressure Vessel (MPV) brackets

The Electronics Pressure Vessel (EPV) is inserted into a shrouded bracket and fastened by setscrews. This bracket is named "EPV Bracket" and is mounted inside the center tube.

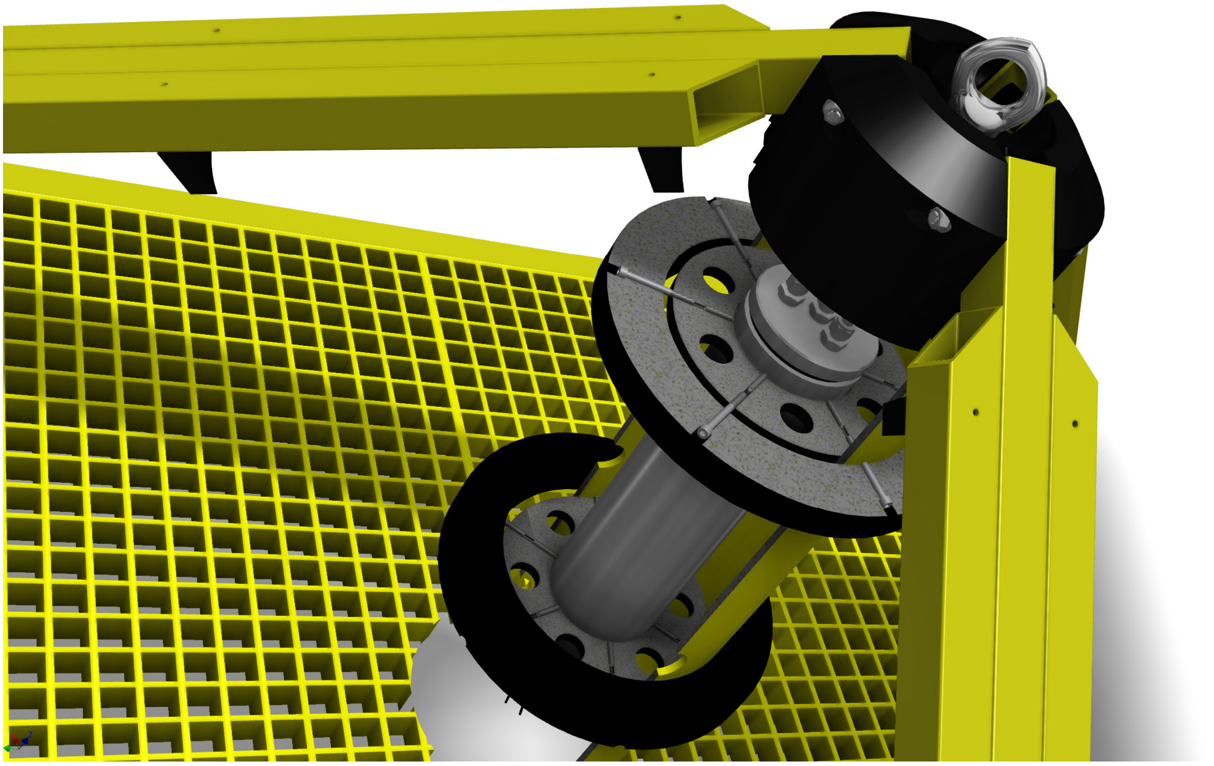


Figure 13-11 Electronics Pressure Vessel (EPV)) brackets

The Electrode Deployment System (EDS) is inserted in to mounting holes in the EDS bracket prior to subsea deployment. There is a press fit interface between the EDS spool bar and EDS bracket. This connection yields adequate friction to secure the EDS inside the frame structure during transport and deploying. The EDS bracket is bolted through the center tube with socket heads into the EPV bracket.

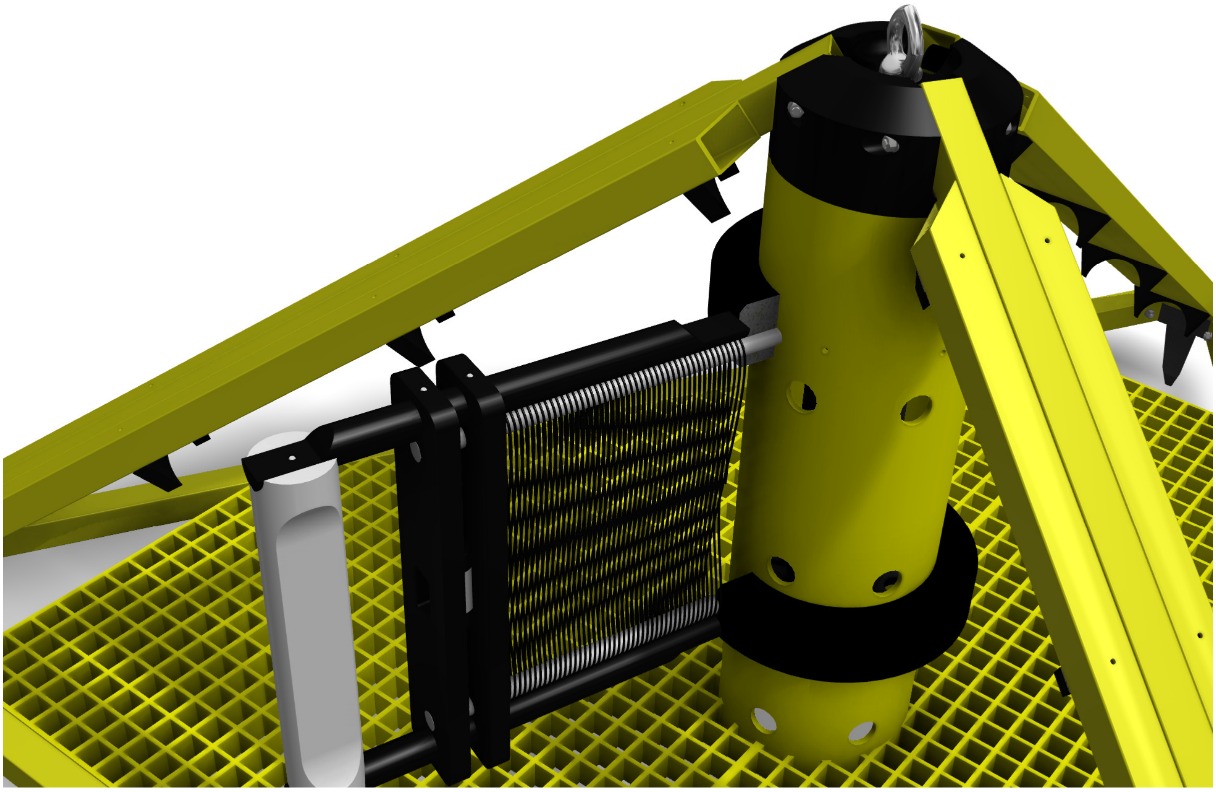


Figure 13-12 Electrode Deployment System (EDS) bracket

13.2.8 Frame structure weight and dimensions

The maximum outer dimensions of the frame structure is given in the Figure 13-13 Frame dimensions. The total weight is listed in Table 13-1 Frame structure weight and its distribution is displayed in Figure 13-14 Weight distribution.

Table 13-1 Frame structure weight

Part	Weight @ air	Weight @ water
Frame structure	205 [Kg]	78 [Kg]
Total system prior deployment	740 [Kg]	355 [Kg]
Total system post deployment	645 [Kg]	324 [Kg]

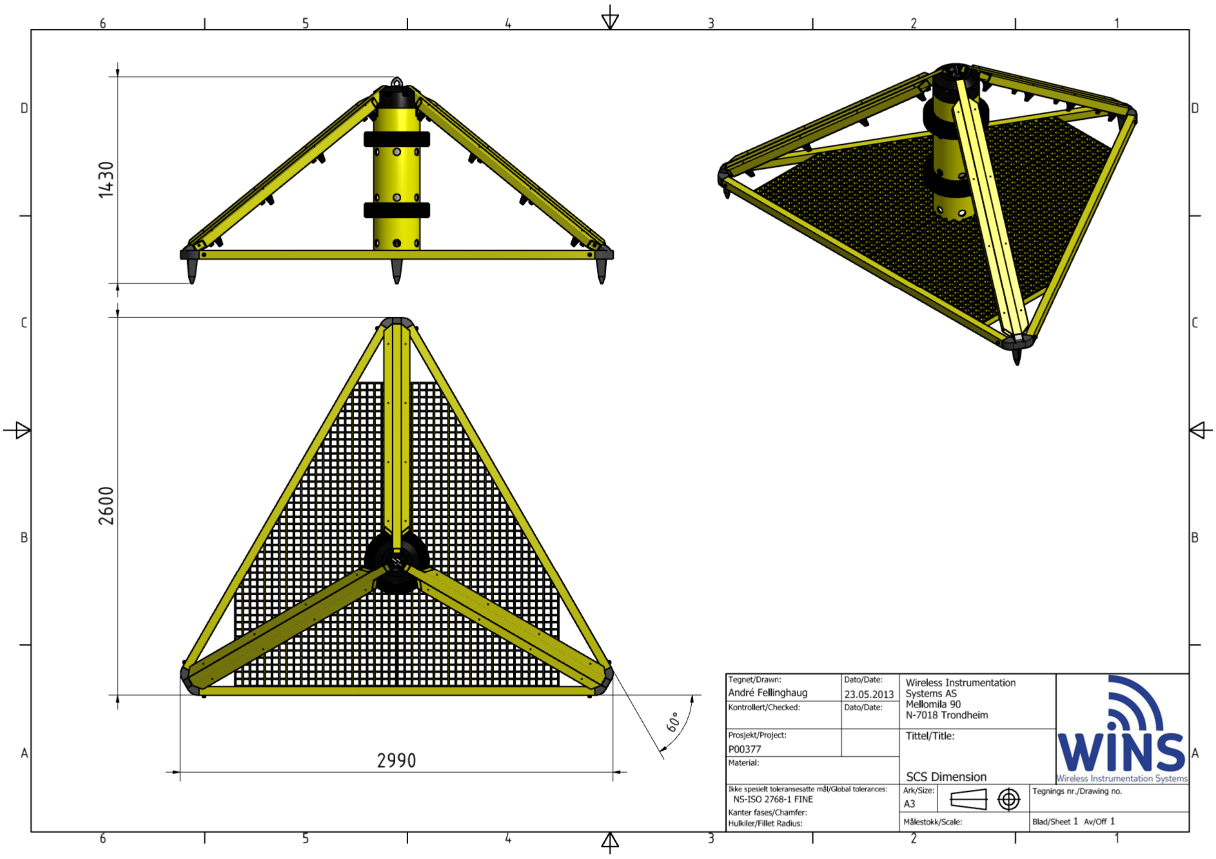


Figure 13-13 Frame dimensions

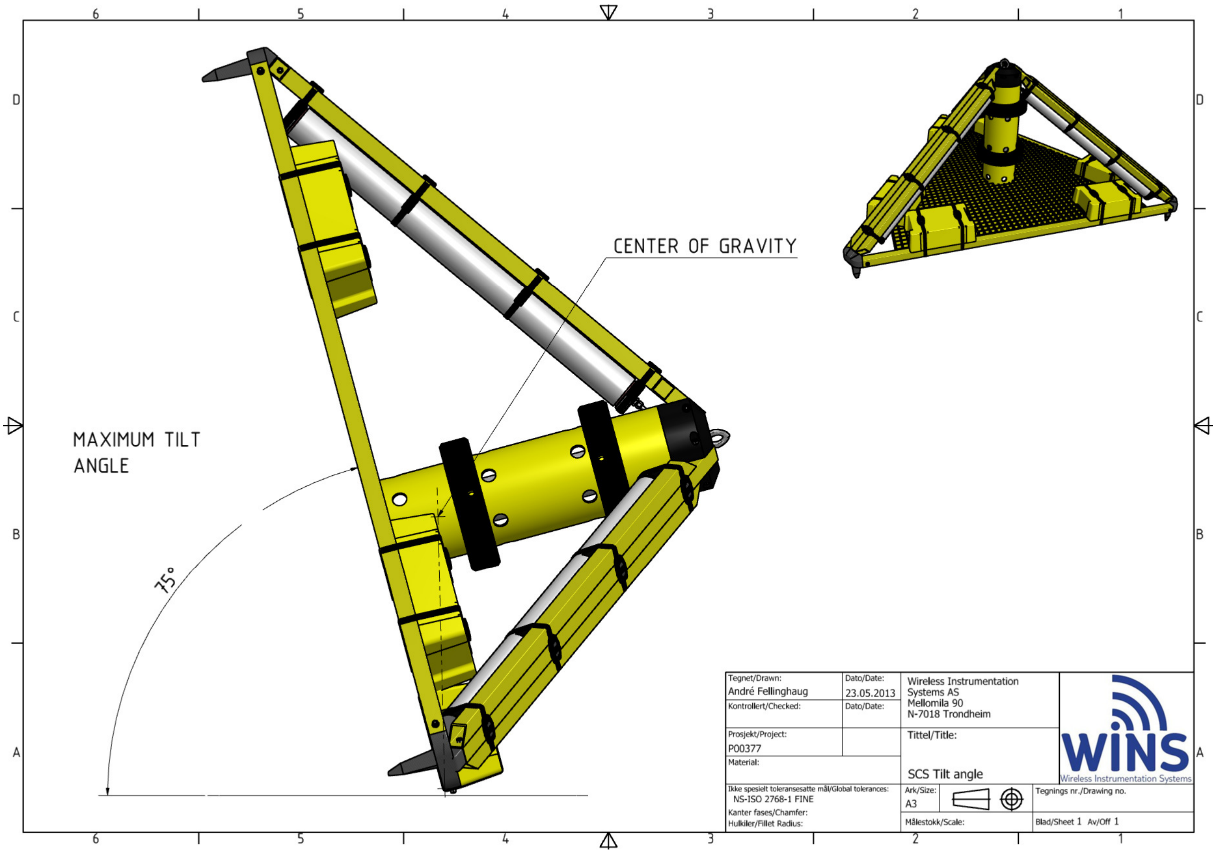


Figure 13-14 Weight distribution

13.2.9 Frame structure materials

The frame structure materials are listed with respective appendix reference in Table 13-2 Frame structure materials.

Table 13-2 Frame structure materials

Part	Material	Appendix reference
Base tube	GFRP	GFRP_profiles-VINK
Arm tube	GFRP	GFRP_profiles-VINK
Base grating	GFRP	GFRP_grating-VINK
Center tube	GFRP	GFRP_profiles-VINK
MPV bracket	PETP	PET Rochling-MDS
EDS bracket	PETP	PET Rochling-MDS
EPV bracket	PETP	PET Rochling-MDS
Top neck	POM-C	POM-C_VINK-MDS
Foot joint	HexMC	HexMC-MDS
Fasteners	AL-6XN	AL-6XN_Datasheet
Lifting eye	Super-Duplex	INOX-MDS
SmartBand™	PA11GF	SmartBand_Technical
Bonding glue	Epoxy	Araldite-2015-MDS

13.2.10 Frame structure drawing reference

All frame structure parts have drawing files in the appendix. See Table 13-3 Frame structure drawing reference.

Table 13-3 Frame structure drawing reference in appendix

Part	Appendix reference
Frame structure assembly	Frame structure, ASSY
Base tube	Base tube, frame structure
Arm tube	Arm tube, frame structure
Support tube, arm	Support tube, frame structure
Base grating panel	Base grating panel, frame structure
Center tube	Center tube, frame structure
MPV bracket	Bracket, MPV
EDS bracket	Bracket, EDS
EPV bracket	Bracket, EPV
Top Neck	Top neck, frame structure
Foot joint mold	Foot_Joint_mold, STEP file

14 Structure weights

14.1 Requirements

The following elaborated requirements are separated in to functional, material and geometrical requirements which must be fulfilled to ensure high level of integrity for the final product.

14.1.1 Functional requirements

Sufficient strain to the lifting wire is needed to ensure stabile conditions during hoisting operations (R1.5 in Table 5-1). To achieve stabile penetration through the splash zone, high weight combined with low buoyancy and open base configuration is desirable (R6.8 in Table 5-1).

14.1.2 Material requirements

All materials must be qualified and approved by the customer (R6.2 in Table 5-1). The materials used in the weights must withstand the corrosive [9] and hydrostatic pressure [1] conditions (R2.1 in Table 5-1) or otherwise be protected (R6.3 in Table 5-1). The use of electromagnetically transparent and non-magnetic [1] materials is critical as these weights will have a relatively large volume.

14.1.3 Geometrical requirements

The footprint of the weight should not be so large that it will significantly affect the penetration through the splash zone (R6.8 in Table 5-1). The weight must be firmly fastened to the structure and not contribute to lowering the Eigen frequency [1] of the frame (SR1.6 in Table 7-1). The geometrical measurements of the weight must be within the frame structure to ensure good protection during transport and deployment.

14.2 Structure weights concept

The frame structure of the SCS must be weighted down to ensure stability and high lateral friction on the seabed (R6.7 in Table 5-1). The concept is 6 evenly distributed concrete blocks coated in PuraCoate™ [27] and tied down to the base grating panel with 2 SmartBand™ [17] straps.

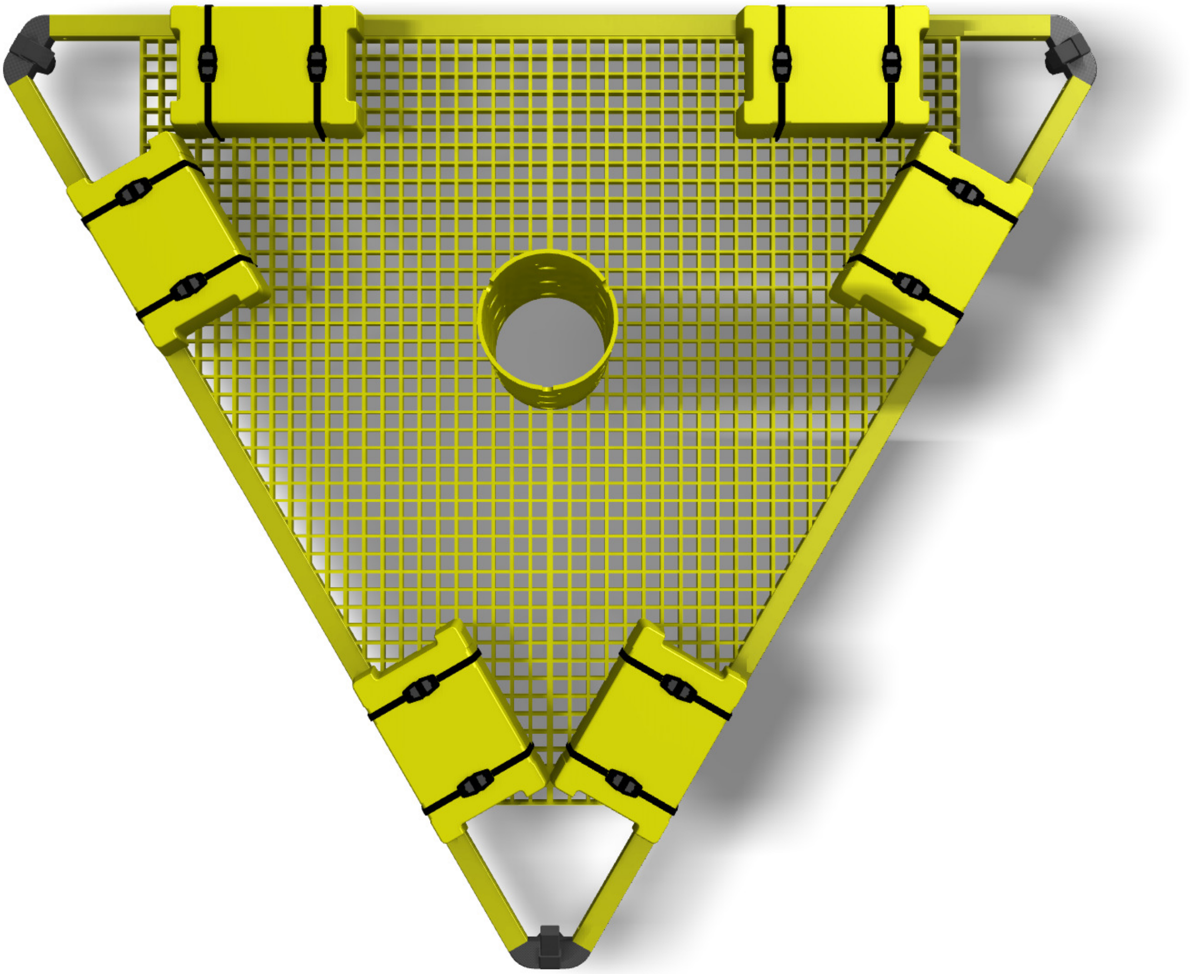


Figure 14-1 Structure weight concepts

14.2.4 Weights assembly

The weight blocks are placed on top of the grating panel and located as far out to the leg joints as possible to increase the Eigen frequency for the suspended mass [1]. A double set of SmartBand™ [17] is used to fasten the block to the frame for stability and redundancy.

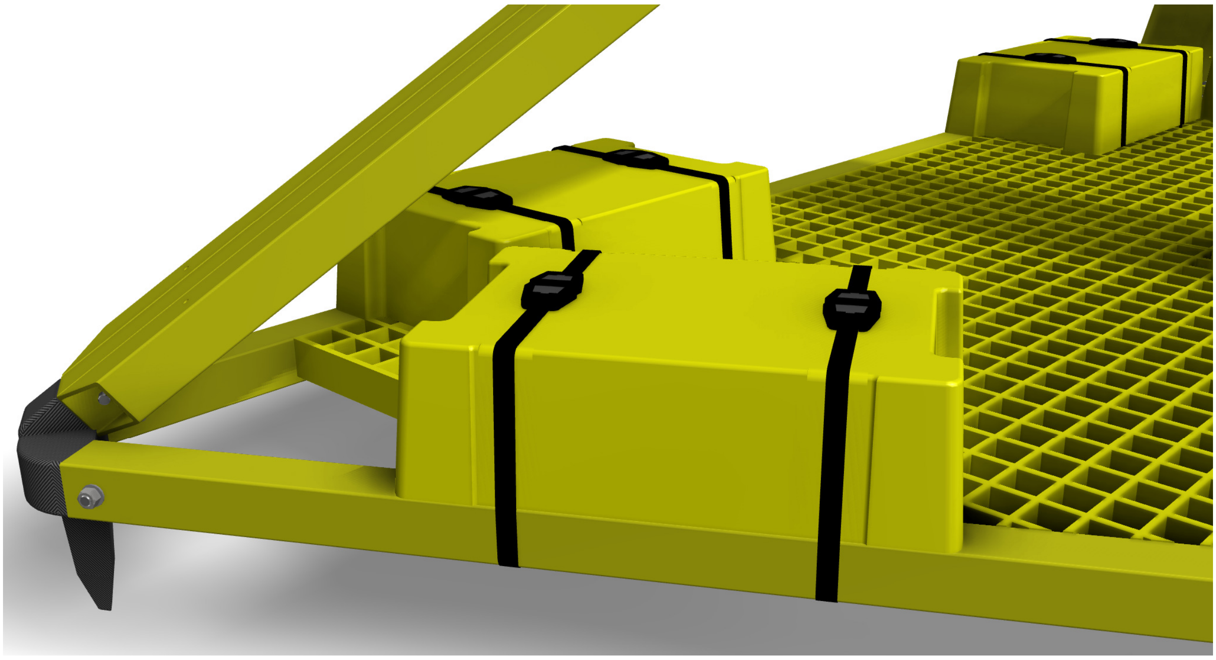
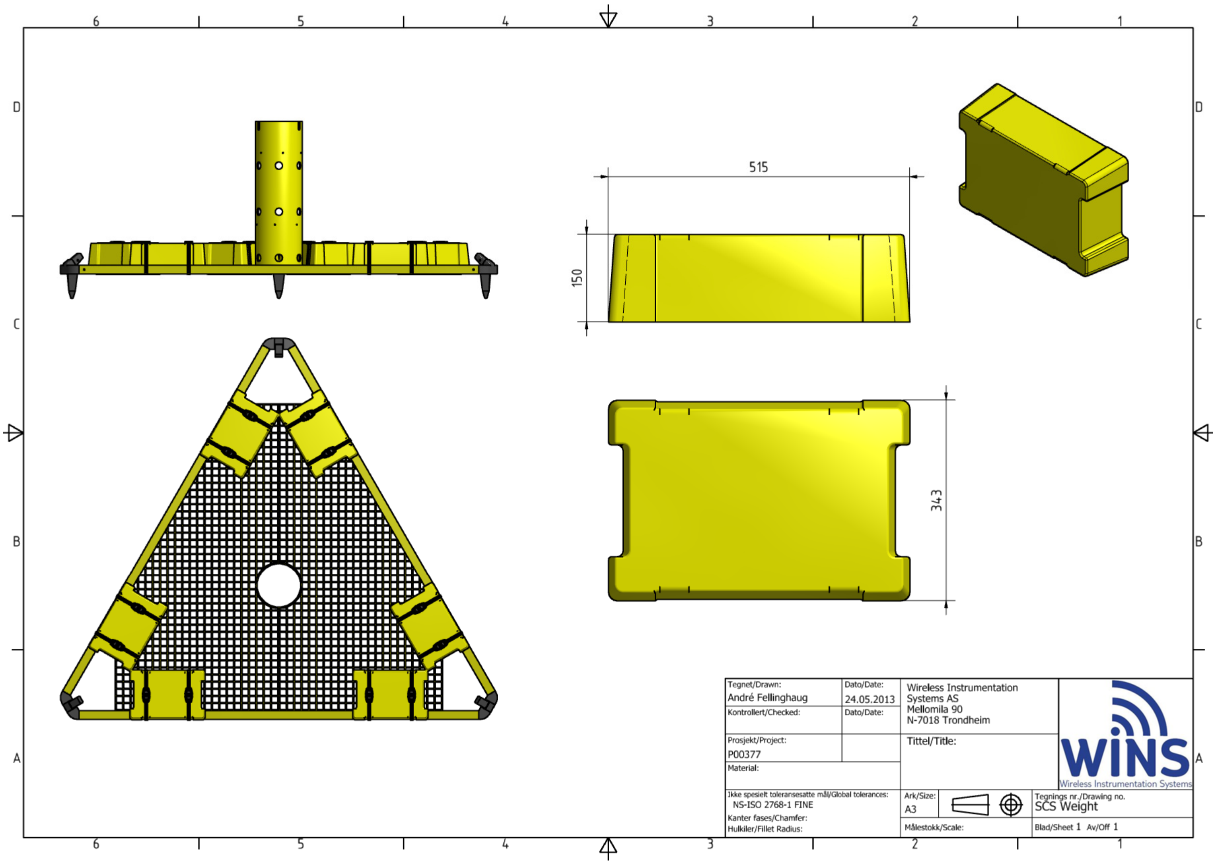


Figure 14-2 Weights assembly

14.2.5 Weight block dimensions and weight

The weight block dimensions is displayed in Figure 14-3 Weight block dimensions and weight in Table 14-1 Weight block weight.



Tegnet/Drawn: André Fellinghaug
Dato/Date: 24.05.2013
Kontrollert/Checked:
Dato/Date:
Wireless Instrumentation Systems AS
Mellomila 90
N-7018 Trondheim
Prosjekt/Project: P00377
Material:
Tittel/Title:
Ikke spesielt toleransesatte mål/Global tolerances: NS-ISO 2768-1 FINE
Kanter fases/Chamfer:
Hulkiler/Fillet Radius:
Ark/Size: A3
Tegnings nr./Drawing no. SCS Weight
Målestokk/Scale:
Blad/Sheet 1 Av/Off 1

Figure 14-3 Weight block dimensions

Table 14-1 Weight block weight

Part	Weight @ air	Weight @ water
Weight block	55 [Kg]	33 [Kg]

14.2.6 Weight materials

The weight material used is listed with respective appendix reference in Table 14-2 Weight materials.

Table 14-2 Weight materials

Part	Material	Appendix reference
Weight block	Standard concrete	DØNN-Concrete-MDS
Coating	PuraCoat™ PU	PURACOAT-MDS
SmartBand™	PA11GF	SmartBand_Technical

14.2.7 Weights drawing reference

All frame structure parts have drawing files in the appendix. See Table 13-3 Frame structure drawing reference.

Table 14-3 Weights drawing reference

Part	Appendix reference
Weight block	SCS Weight

15 Frame structure FEM analysis

An analytical approach is performed to find the frequency range of Vortex Shedding (VS) [7] caused by sea currents. These vortices may cause Vortex Induced Vibrations (VIV) [20] on the frame structure if this frequency range is in near proximity of the Eigen frequency of the frame [1]. However, this will be a rather rough estimate compared to a full Computational Fluid Dynamics (CFD) analysis [28] which should be performed to find the actual VS frequencies given by the frame geometry and the sea currents.

In fluid dynamics, Vortex Shedding (VS) is an unsteady oscillating flow that takes place when a fluid such as air or water flows past a blunt body. The oscillating frequency depends on the size and shape of the body and the fluid velocity [7].

Strouhal number St [20] is a dimensionless number given as the relation:

$$St = \frac{fD}{V}$$

Equation 2 Strouhal number

Where f is the VS frequency, D is the circular body diameter and V is the fluid velocity.
The St for a circular body is displayed in Figure 15-1. This number is given by experimental fluid analysis.

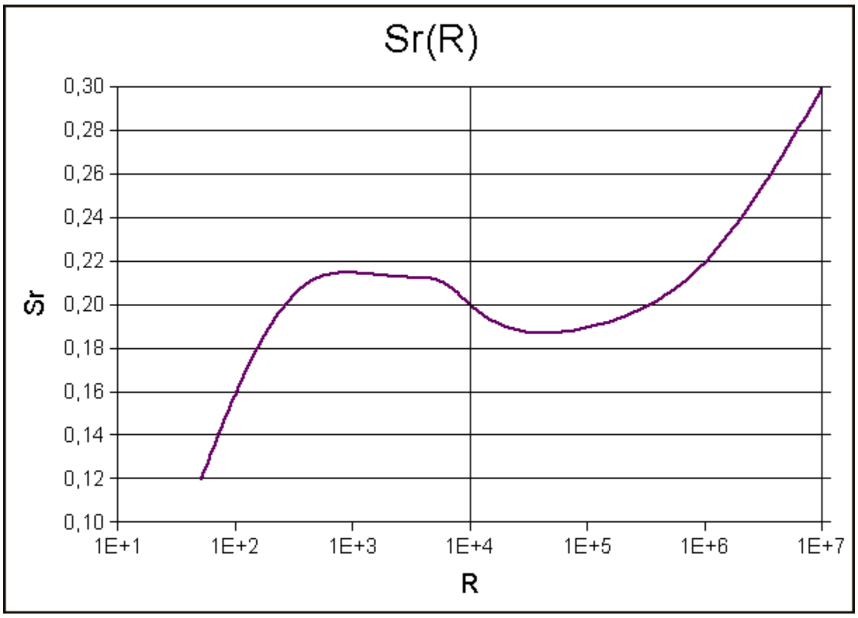


Figure 15-1 Strouhal number for circular bodies in 2D flow [20]

Rearrangeing Equation 2 for VS frenquency f:

$$f = \frac{St \cdot V}{D}$$

Equation 3 VS frequency

For most practical applications it can be assumed a Reynolds number between 10^3-10^6 [20] which corresponds to a Strouhal number ~0.2. Refer to Figure 15-1 Strouhal number for circular bodies in 2D flow.

The velocity V will vary from 0 to 0,75 [m/s] (R2.5 in Table 5-1) meaning there will be a VS frequency varying from 0 to VS @ Vmax.
Thus with an arm diameter of approx. 180 [mm] and the center tube diameter of 320 [mm] there will be a VS frequency range from 0 [Hz] to VSmax given by Equation 3 as a function of current velocity V.

$$f = \frac{St \cdot V}{D} = \frac{0.2 \cdot 0.75[\frac{m}{s}]}{0{,}180\ [m]} = 0{,}83\ Hz$$

Equation 4 VS frequency, Frame arm

$$f = \frac{St \cdot V}{D} = \frac{0.2 \cdot 0.75[\frac{m}{s}]}{0{,}320\ [m]} = 0{,}44\ Hz$$

Equation 5 VS frequency, Center tube

Table 15-1Vortex Shedding frequencies

Part	VSmax	Equation
Frame arm	0,83 [Hz]	Equation 4
Center tube	0,44 [Hz]	Equation 5

Thus to prevent the frame structure from resonating [1], the Eigen frequency must be over 0,83 [Hz]. None of the modal frequencies must be in close proximity to the sampling frequency 48 [Hz]. The Eigen frequency requirement for the frame structure is above 60 [Hz] (SR1.6 in Table 7-1) as a conservative value determined by Statoil ASA.

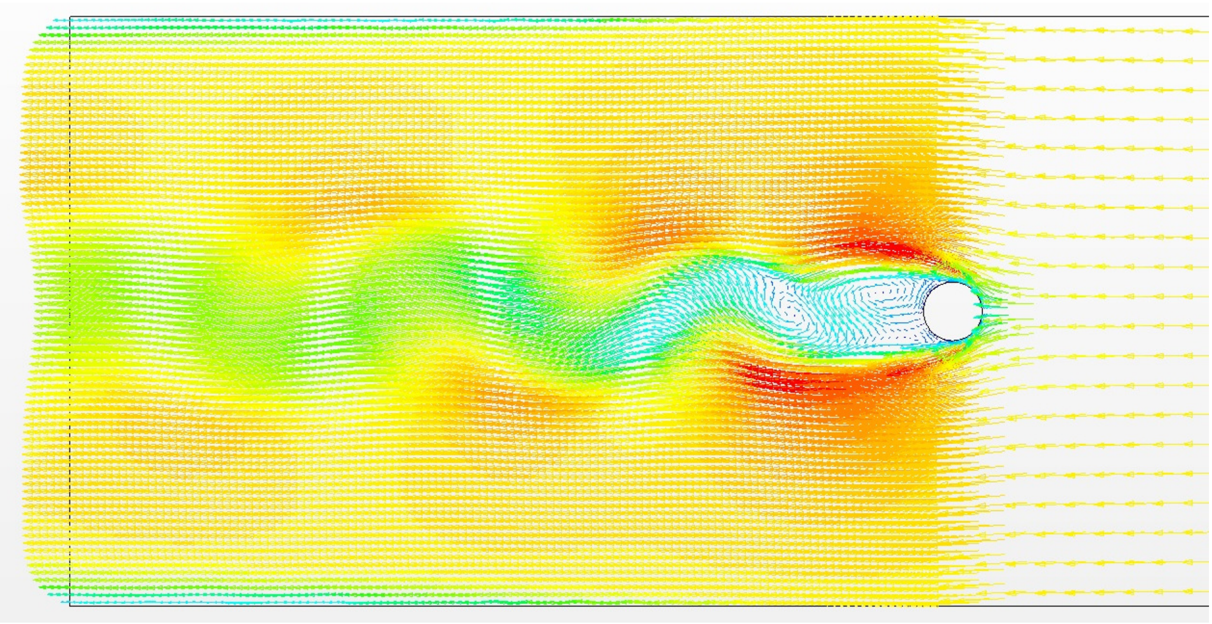


Figure 15-2 CFD image of Vortex Shedding for circular bodies in 2D flow

Table 15-2 Frame structure FEM analysis input

Property	Value	Reference
Hoist acceleration	3[G]	(SR1.7 in Table 7-1)
Earth's gravitational acceleration	9,81 [m/s^2]	[1]
Reaction force from EDS	521,4 [N]	"EDS FEM Report" in the appendix

15.1 Frame modal analysis

Modal analysis is preformed to ensure the first mode of Eigen frequency for the frame structure to be over 60 [Hz] (SR1.6 in Table 5-1). The frequency range of interest is 0-100 [Hz]

Note that this analysis occurs to the state after SCS deployment and the EDS are removed from the frame structure. To reduce the complexity of the frame structure a simplified model is used. The grating panel, EPV and MPV geometry is reduced to solid bodies with substituted mass and stiffness.

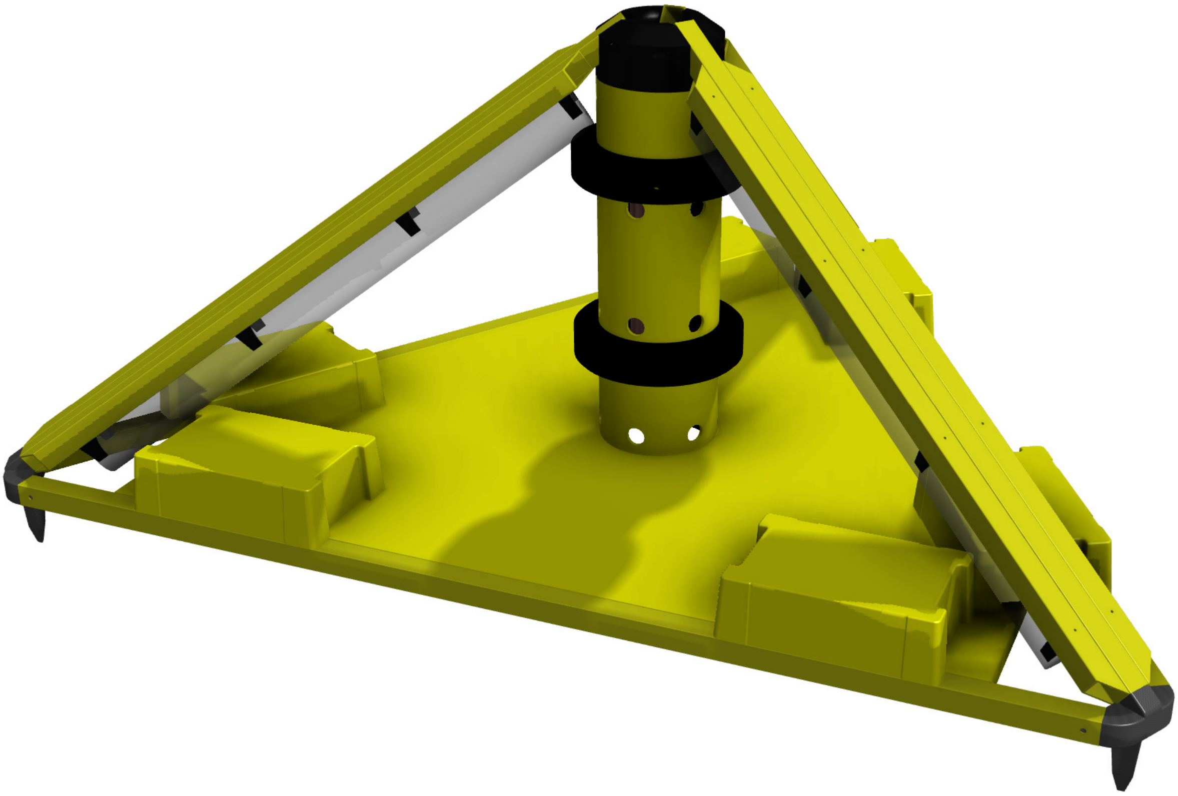


Figure 15-3 Frame modal analysis, simplified model

The square frame tubes are replaced with shell bodies in order to mesh the model with shell elements.

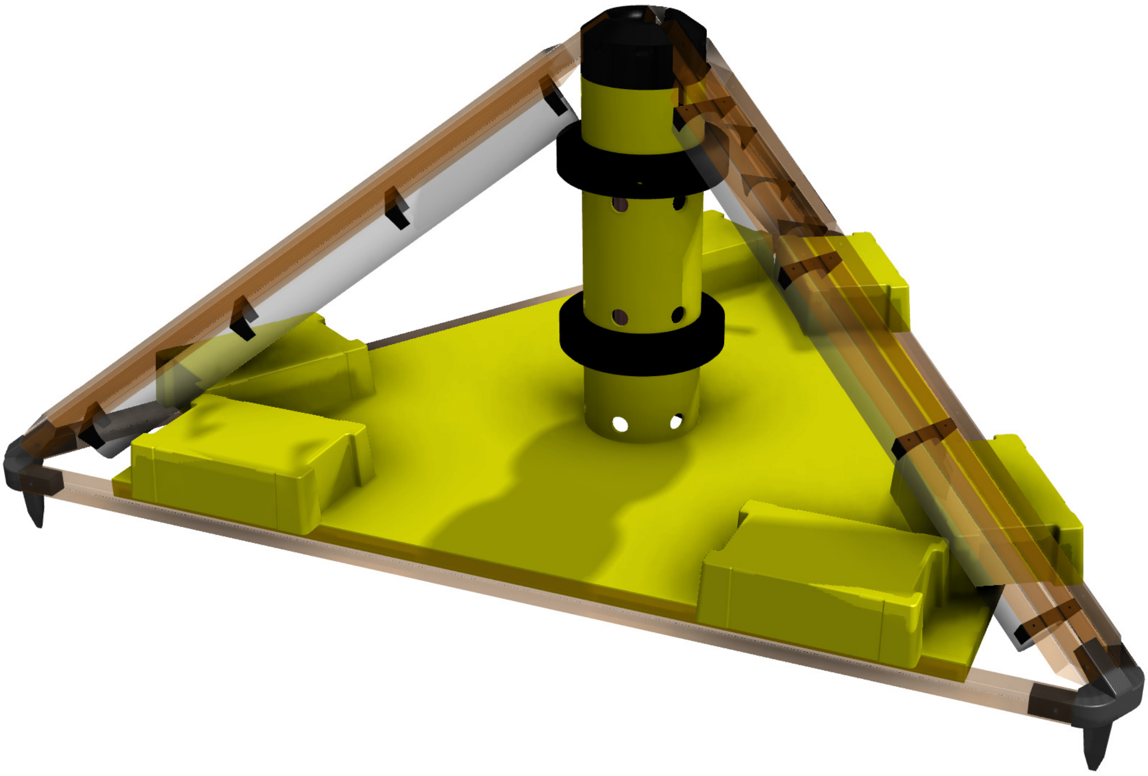


Figure 15-4 Frame model anlysis, shell bodies

All solids are meshed with fine tetrahedron elements. Refer to “Frame Structure Modal Analysis Report” in the appendix for mesh settings.

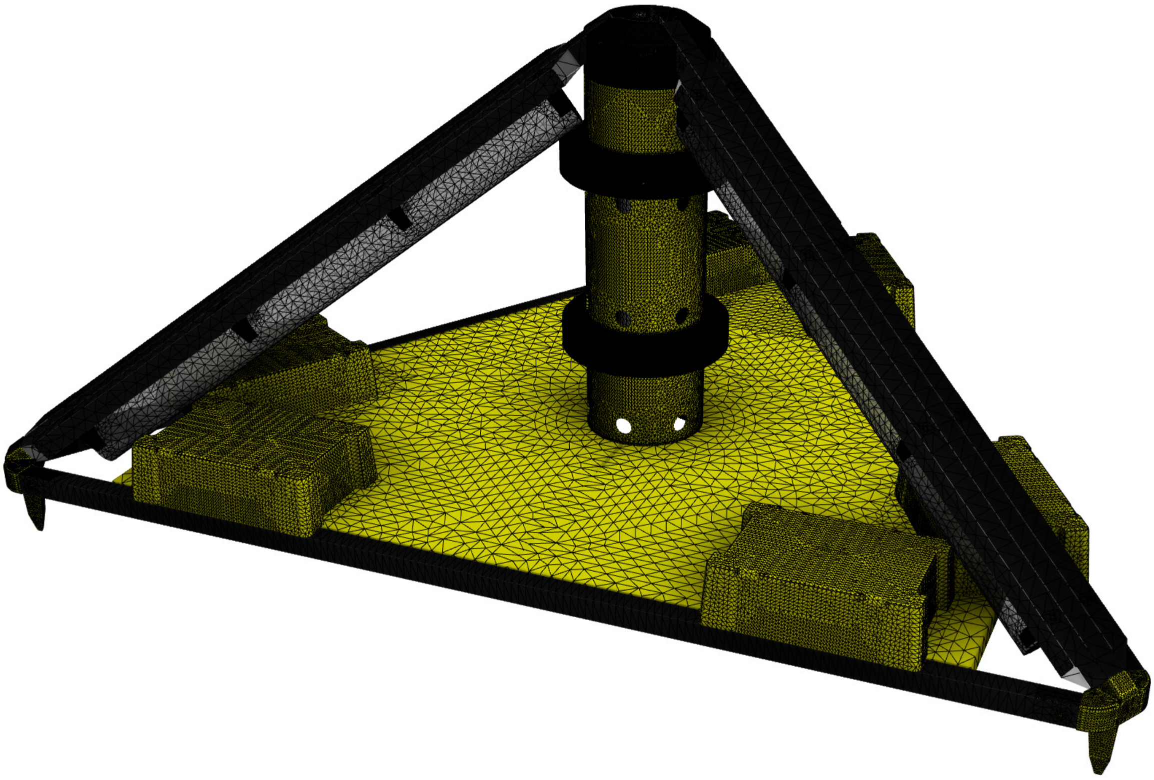
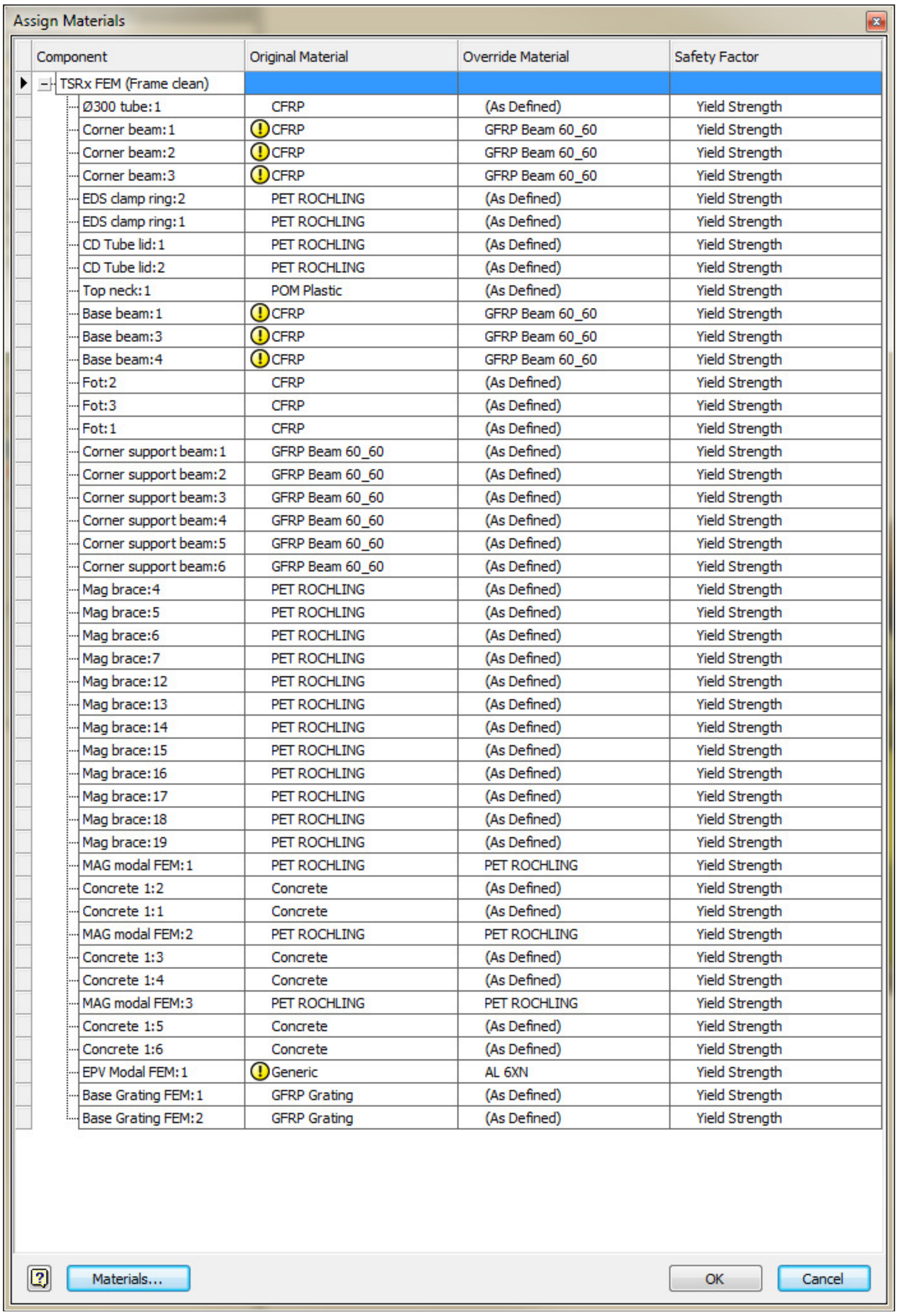


Figure 15-5 Frame modal analysis, meshed model

Materials are applied according to Table 13-2 Frame structure materials and Table 14-2 Weight materials



Component	Original Material	Override Material	Safety Factor
TSRx FEM (Frame clean)			
Ø300 tube:1	CFRP	(As Defined)	Yield Strength
Corner beam:1	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Corner beam:2	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Corner beam:3	⚠ CFRP	GFRP Beam 60_60	Yield Strength
EDS clamp ring:2	PET ROCHLING	(As Defined)	Yield Strength
EDS clamp ring:1	PET ROCHLING	(As Defined)	Yield Strength
CD Tube lid:1	PET ROCHLING	(As Defined)	Yield Strength
CD Tube lid:2	PET ROCHLING	(As Defined)	Yield Strength
Top neck:1	POM Plastic	(As Defined)	Yield Strength
Base beam:1	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Base beam:3	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Base beam:4	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Fot:2	CFRP	(As Defined)	Yield Strength
Fot:3	CFRP	(As Defined)	Yield Strength
Fot:1	CFRP	(As Defined)	Yield Strength
Corner support beam:1	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:2	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:3	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:4	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:5	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:6	GFRP Beam 60_60	(As Defined)	Yield Strength
Mag brace:4	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:5	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:6	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:7	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:12	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:13	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:14	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:15	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:16	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:17	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:18	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:19	PET ROCHLING	(As Defined)	Yield Strength
MAG modal FEM:1	PET ROCHLING	PET ROCHLING	Yield Strength
Concrete 1:2	Concrete	(As Defined)	Yield Strength
Concrete 1:1	Concrete	(As Defined)	Yield Strength
MAG modal FEM:2	PET ROCHLING	PET ROCHLING	Yield Strength
Concrete 1:3	Concrete	(As Defined)	Yield Strength
Concrete 1:4	Concrete	(As Defined)	Yield Strength
MAG modal FEM:3	PET ROCHLING	PET ROCHLING	Yield Strength
Concrete 1:5	Concrete	(As Defined)	Yield Strength
Concrete 1:6	Concrete	(As Defined)	Yield Strength
EPV Modal FEM:1	⚠ Generic	AL 6XN	Yield Strength
Base Grating FEM:1	GFRP Grating	(As Defined)	Yield Strength
Base Grating FEM:2	GFRP Grating	(As Defined)	Yield Strength

Figure 15-6 Frame modal analysis, material specification

All connection surfaces of the frame structure are set to bonded condition in order to simulate glued parts and friction fastened connections.

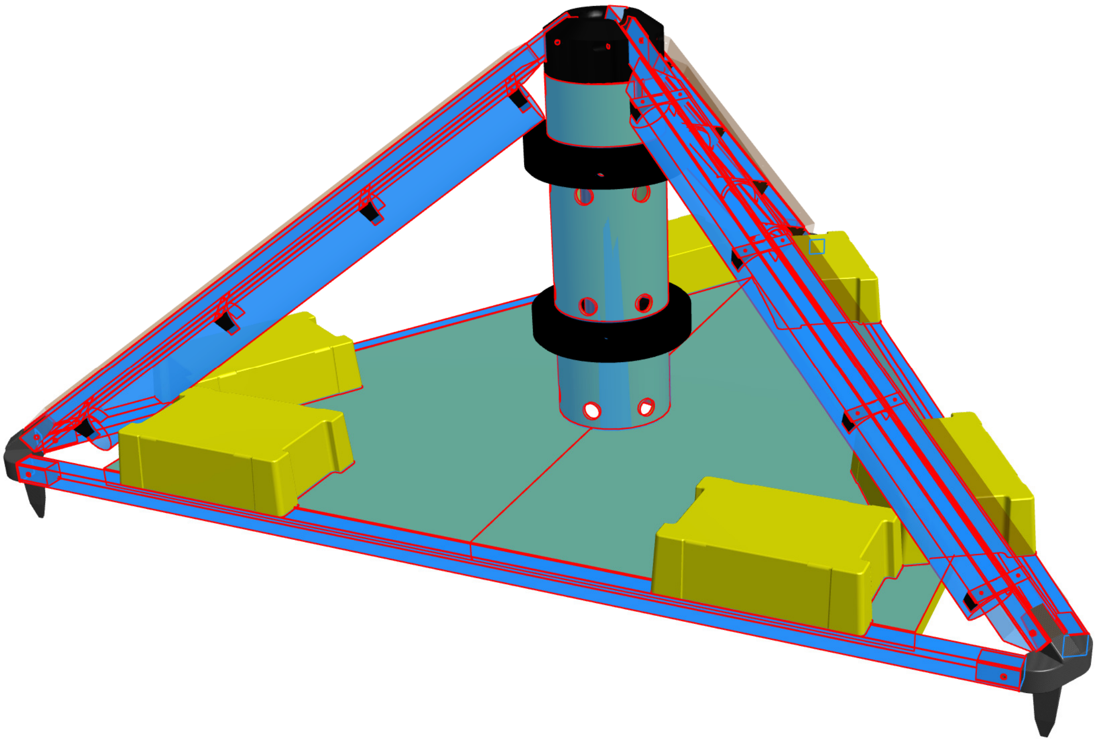


Figure 15-7 Frame modal analysis, surface connections

The spears on the foot joint are set to fixed constraints to simulate seabed penetration.

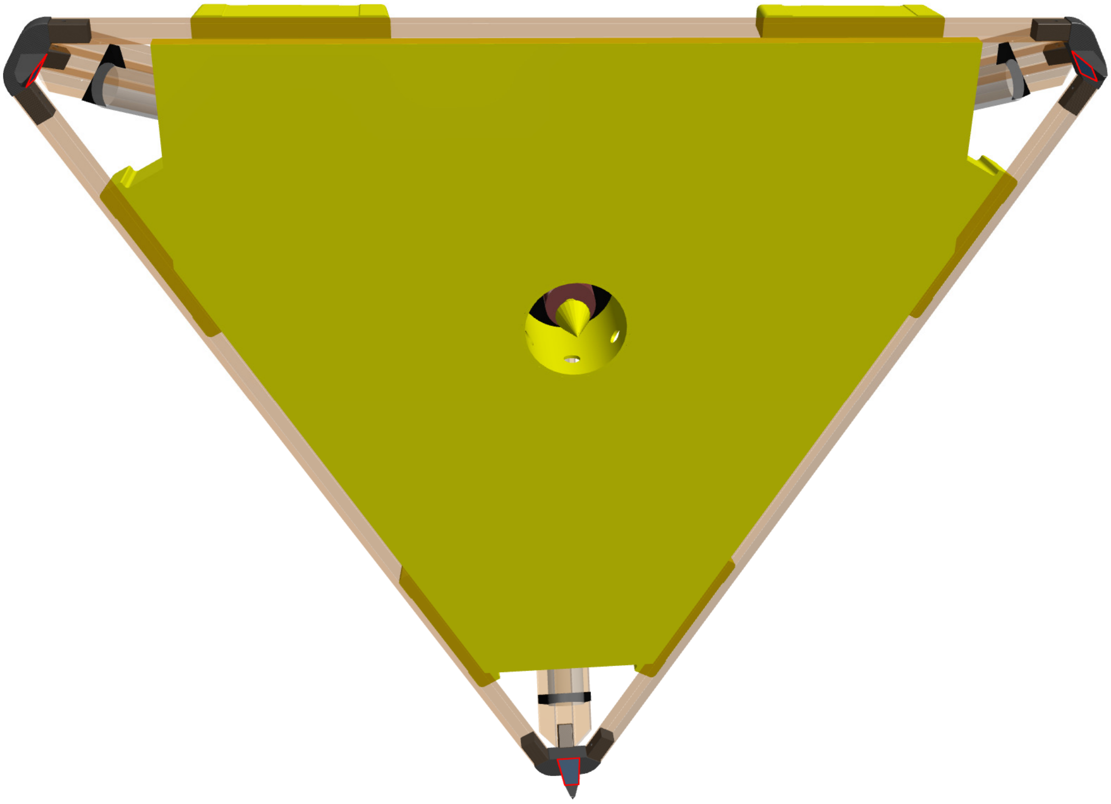


Figure 15-8 Frame modal analysis, fixed constraint on foot joint

The base grating panel is embedded on the seabed with sand filled grating pockets. Fixed constraints are applied to simulate good lateral anchoring.

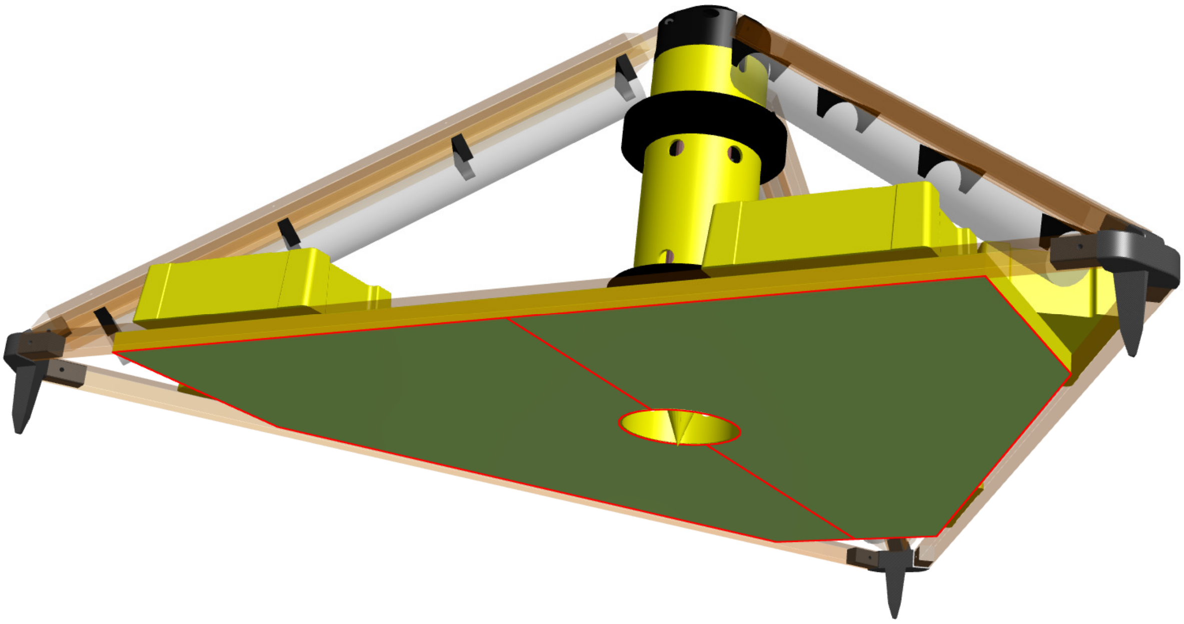


Figure 15-9 Frame modal analysis, fixed constraints on base grating

15.1.1 Results modal analysis

The first mode of Eigen frequency occure on the arms vibrating in a up and downwards motion, refer to Figure 15-10 Frame modal analysis first mode frequency. Refer to Table 15-3 Frame Modal results.

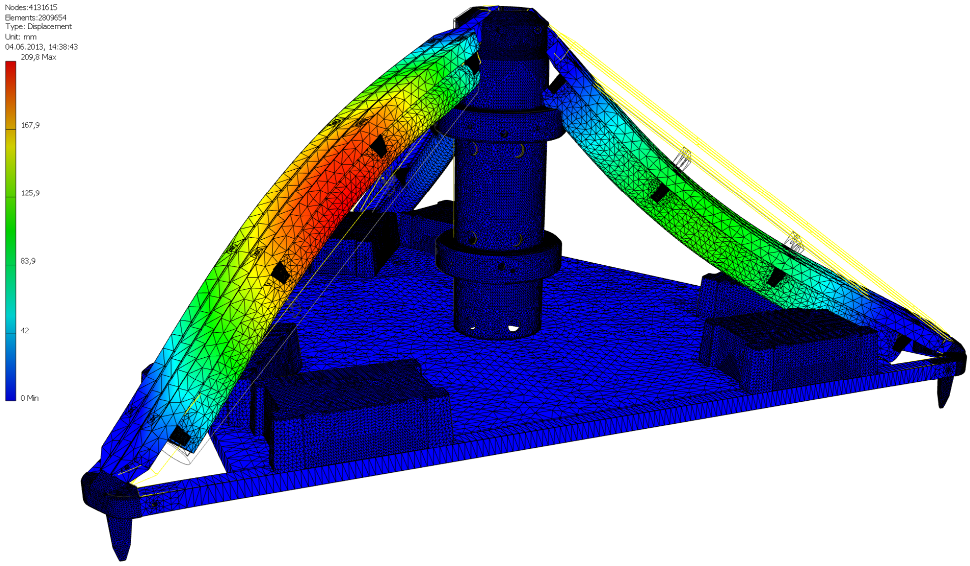


Figure 15-10 Frame modal analysis first mode frequency

The second mode occure at 85,3 [Hz]. The arm tubes will resonate in sideways motion, refer to Figure 15-11 Frame modal analysis second mode frequency.

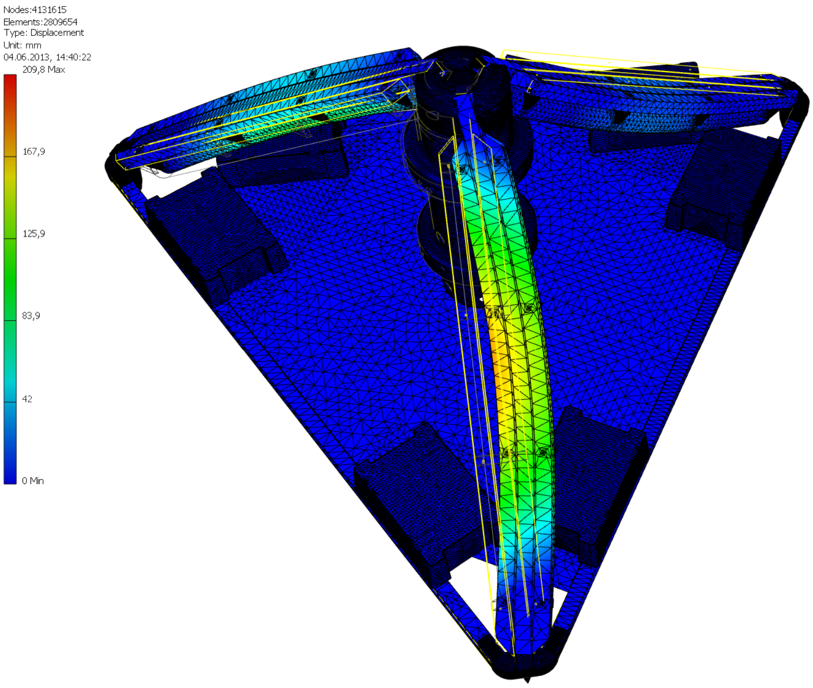


Figure 15-11 Frame modal analysis second mode frequency

Table 15-3 Frame Modal results

Results	Value	Figure reference
Mode 1 frequency	78,7 [Hz]	Figure 15-10 Frame modal analysis first mode frequency
Mode 2 frequency	85,3 [Hz]	Figure 15-11 Frame modal analysis second mode frequency

15.1.2 Modal analysis conclusion

The frame structure will not resonate under the specified Eigen frequency of 60 [Hz] (SR1.6 in Table 5-1). The analysis implies that the frame structure will not resonate with any vibration subceeding 78 [Hz]. Noteworthy is that the only vibrations apparent are the Vortex Shedding (VS) vibrations from the seacurrents. These will be in the region of 0.8 [Hz], see chapter 15 Frame structure FEM analysis for reference.

See full report in “Frame Structure Modal Analysis Report” in the appendix.

15.2 Frame stress analysis

A simplified model of the SCS is analyzed to ensure system integrity during hoist operations.

To reduce the complexity of the frame structure a simplified model is used. The grating panels are solid and the EPV and MPV are replaced with solid bodies with substitute mass and stiffness. The EDS reaction force is set to the EDS bracket mounting holes.

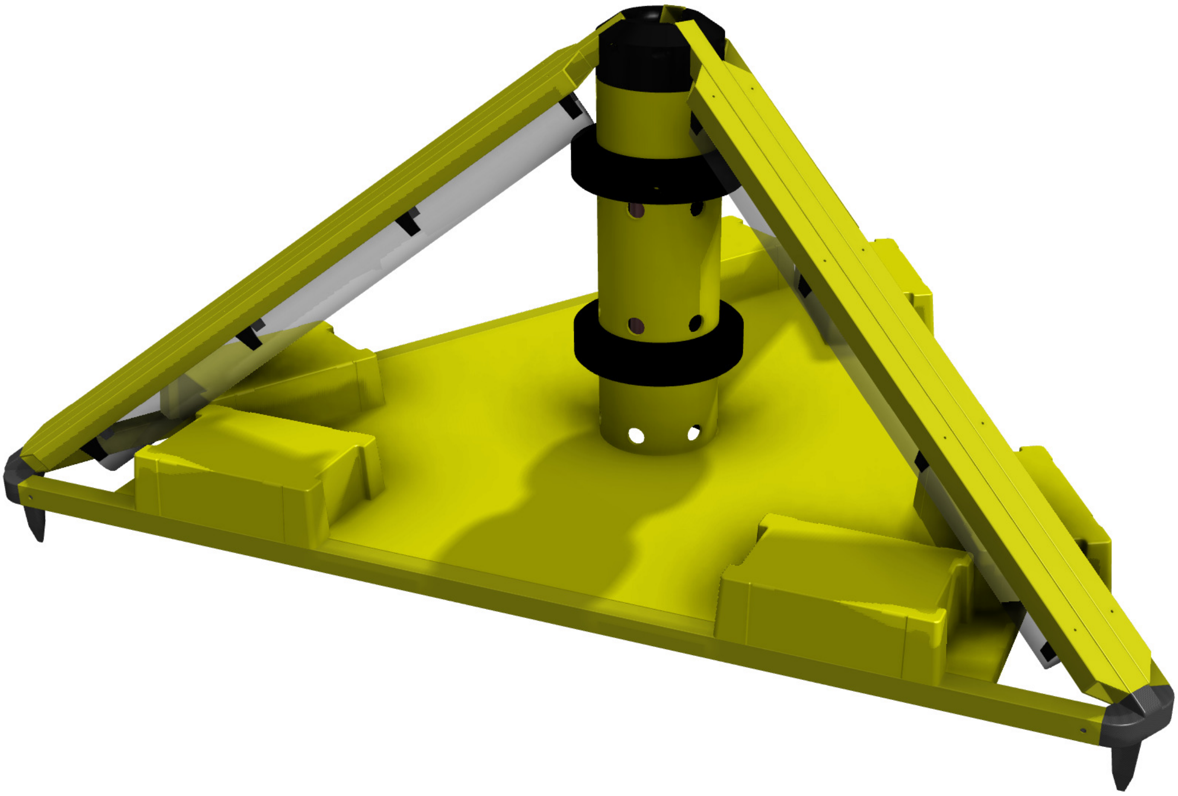


Figure 15-12 Frame stress analysis, simplified model

The square frame tubes are replaced with shell bodies in order to mesh the model with shell elements.

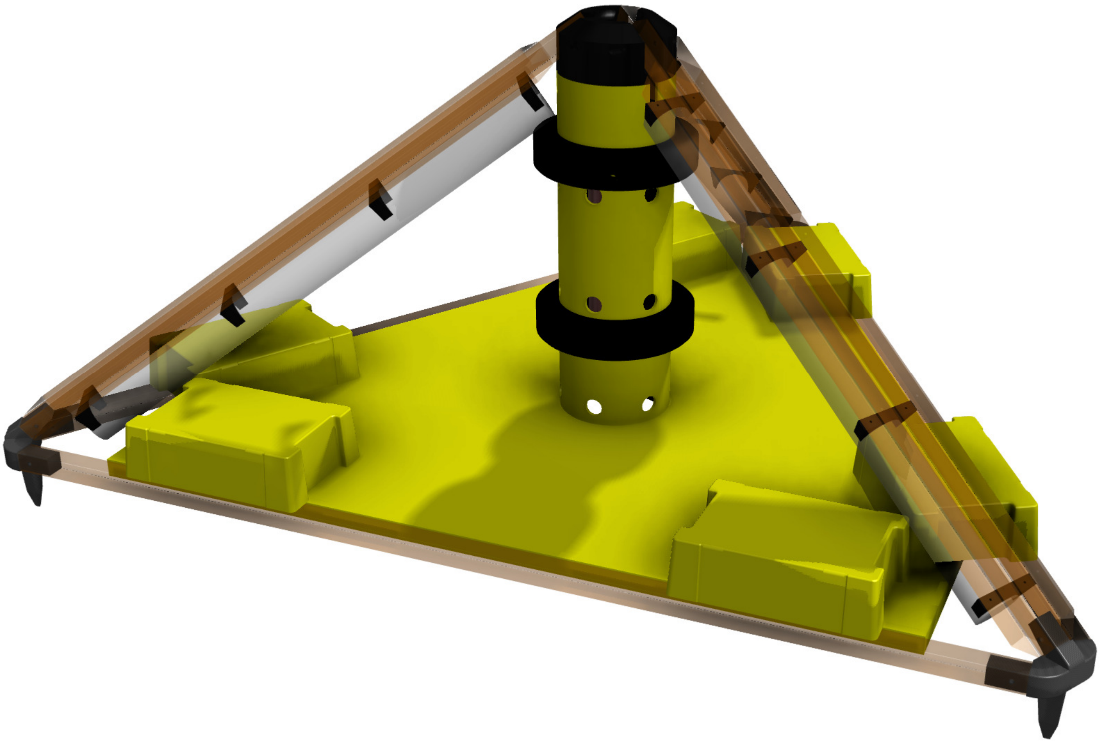


Figure 15-13 Frame stress analysis, shell bodies

All solids are meshed with fine tetrahedron elements. Refer to “Frame Stress FEM report” in the appendix for mesh settings.

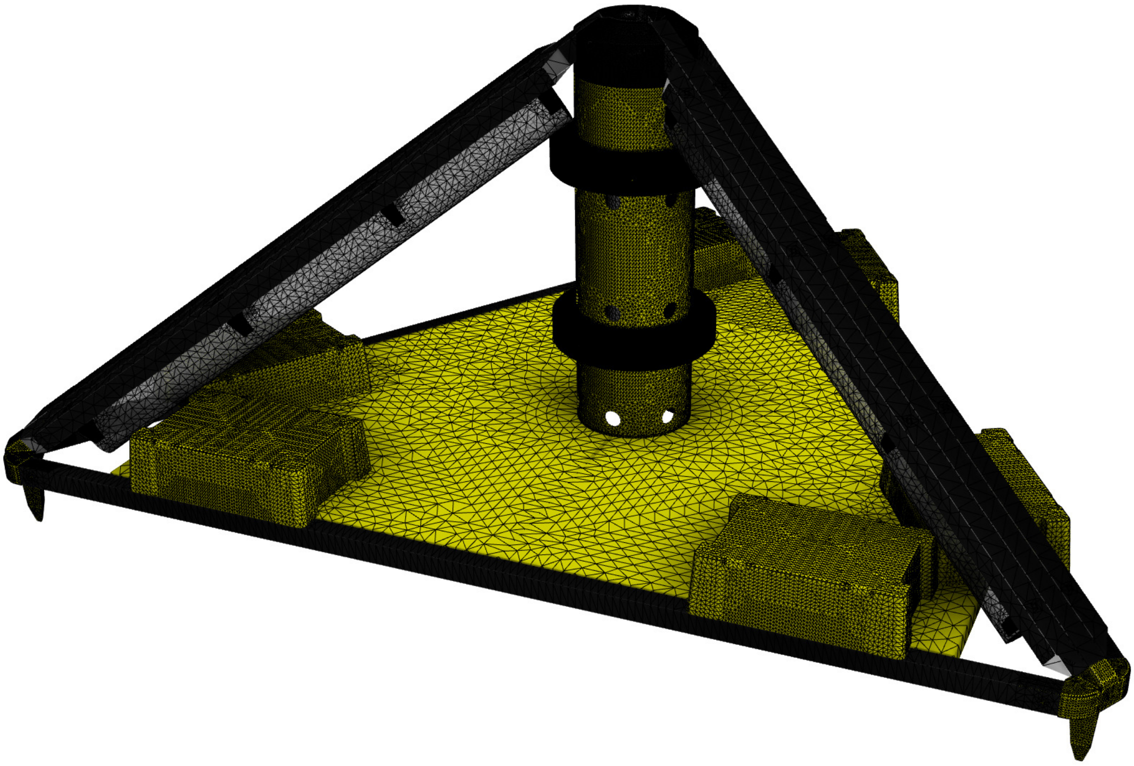
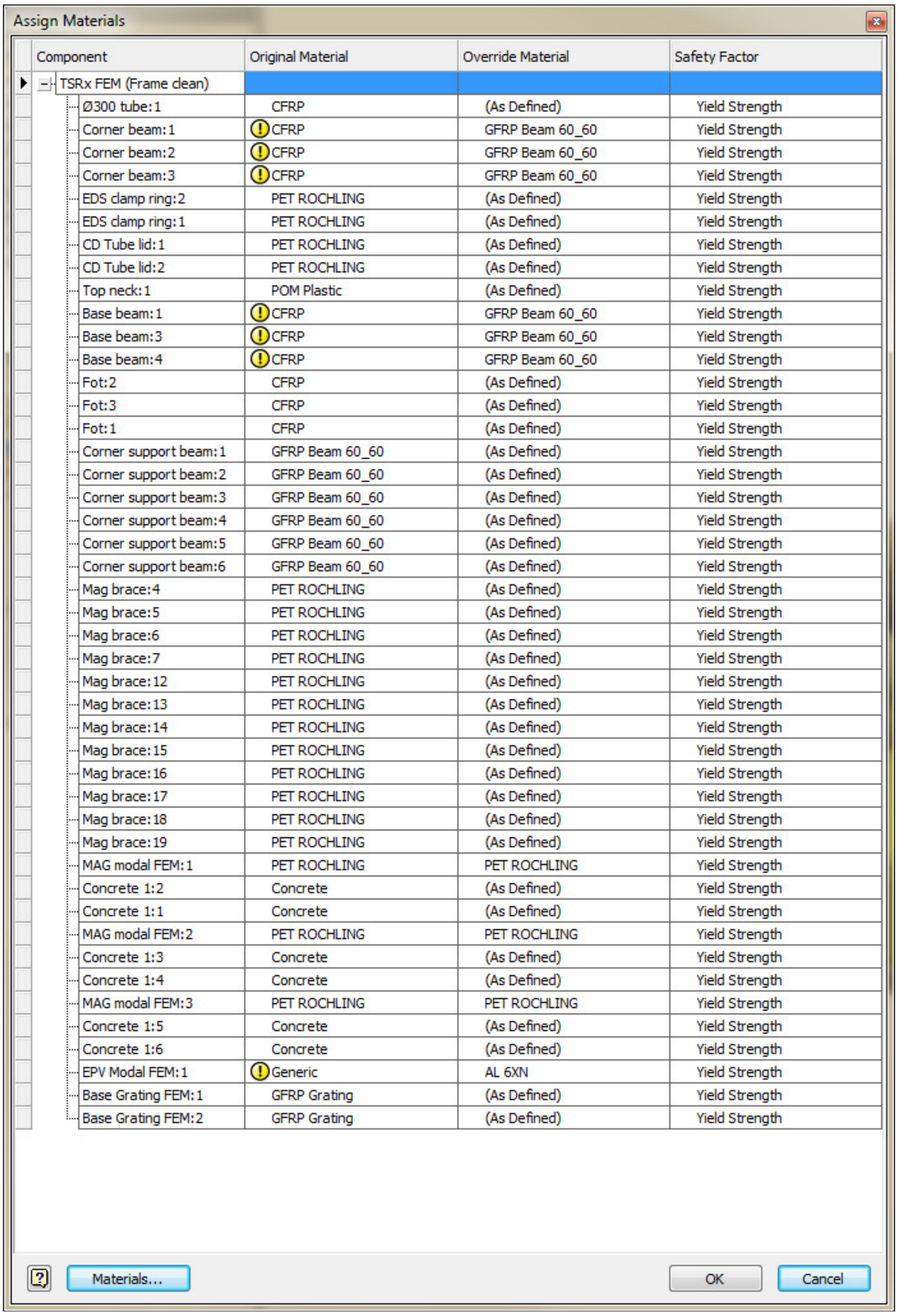


Figure 15-14 Frame stress analysis, meshed model

Materials are applied according to Table 13-2 Frame structure materials and Table 14-2 Weight materials



Component	Original Material	Override Material	Safety Factor
TSRx FEM (Frame clean)			
Ø300 tube:1	CFRP	(As Defined)	Yield Strength
Corner beam:1	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Corner beam:2	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Corner beam:3	⚠ CFRP	GFRP Beam 60_60	Yield Strength
EDS clamp ring:2	PET ROCHLING	(As Defined)	Yield Strength
EDS clamp ring:1	PET ROCHLING	(As Defined)	Yield Strength
CD Tube lid:1	PET ROCHLING	(As Defined)	Yield Strength
CD Tube lid:2	PET ROCHLING	(As Defined)	Yield Strength
Top neck:1	POM Plastic	(As Defined)	Yield Strength
Base beam:1	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Base beam:3	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Base beam:4	⚠ CFRP	GFRP Beam 60_60	Yield Strength
Fot:2	CFRP	(As Defined)	Yield Strength
Fot:3	CFRP	(As Defined)	Yield Strength
Fot:1	CFRP	(As Defined)	Yield Strength
Corner support beam:1	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:2	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:3	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:4	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:5	GFRP Beam 60_60	(As Defined)	Yield Strength
Corner support beam:6	GFRP Beam 60_60	(As Defined)	Yield Strength
Mag brace:4	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:5	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:6	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:7	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:12	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:13	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:14	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:15	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:16	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:17	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:18	PET ROCHLING	(As Defined)	Yield Strength
Mag brace:19	PET ROCHLING	(As Defined)	Yield Strength
MAG modal FEM:1	PET ROCHLING	PET ROCHLING	Yield Strength
Concrete 1:2	Concrete	(As Defined)	Yield Strength
Concrete 1:1	Concrete	(As Defined)	Yield Strength
MAG modal FEM:2	PET ROCHLING	PET ROCHLING	Yield Strength
Concrete 1:3	Concrete	(As Defined)	Yield Strength
Concrete 1:4	Concrete	(As Defined)	Yield Strength
MAG modal FEM:3	PET ROCHLING	PET ROCHLING	Yield Strength
Concrete 1:5	Concrete	(As Defined)	Yield Strength
Concrete 1:6	Concrete	(As Defined)	Yield Strength
EPV Modal FEM:1	⚠ Generic	AL 6XN	Yield Strength
Base Grating FEM:1	GFRP Grating	(As Defined)	Yield Strength
Base Grating FEM:2	GFRP Grating	(As Defined)	Yield Strength

Figure 15-15 Frame stress analysis, material specifications applied

All connection surfaces of the structure are set to bonded condition in order to simulate glued parts and friction fastened connections.

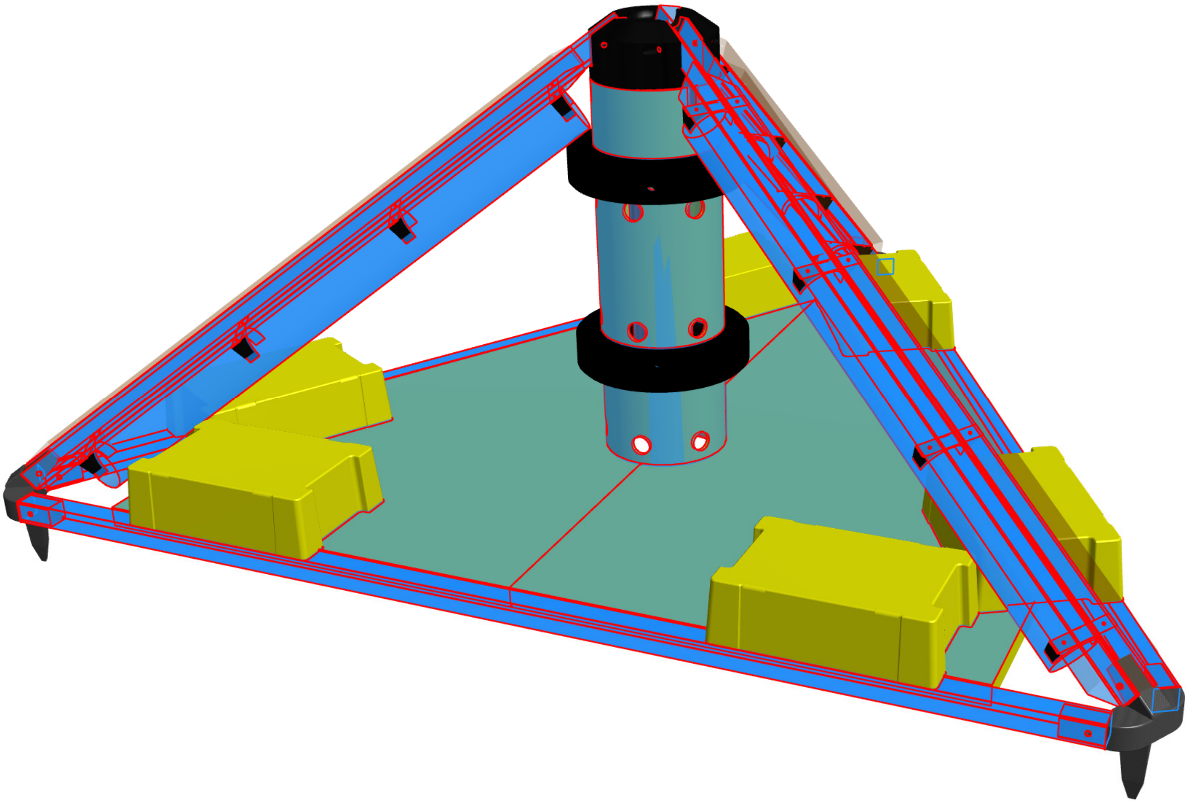


Figure 15-16 Frame structure stress analysis, connection surfaces applied

Fixed constraint is applied to the connection surface for the lifting eye to simulate hoisting.

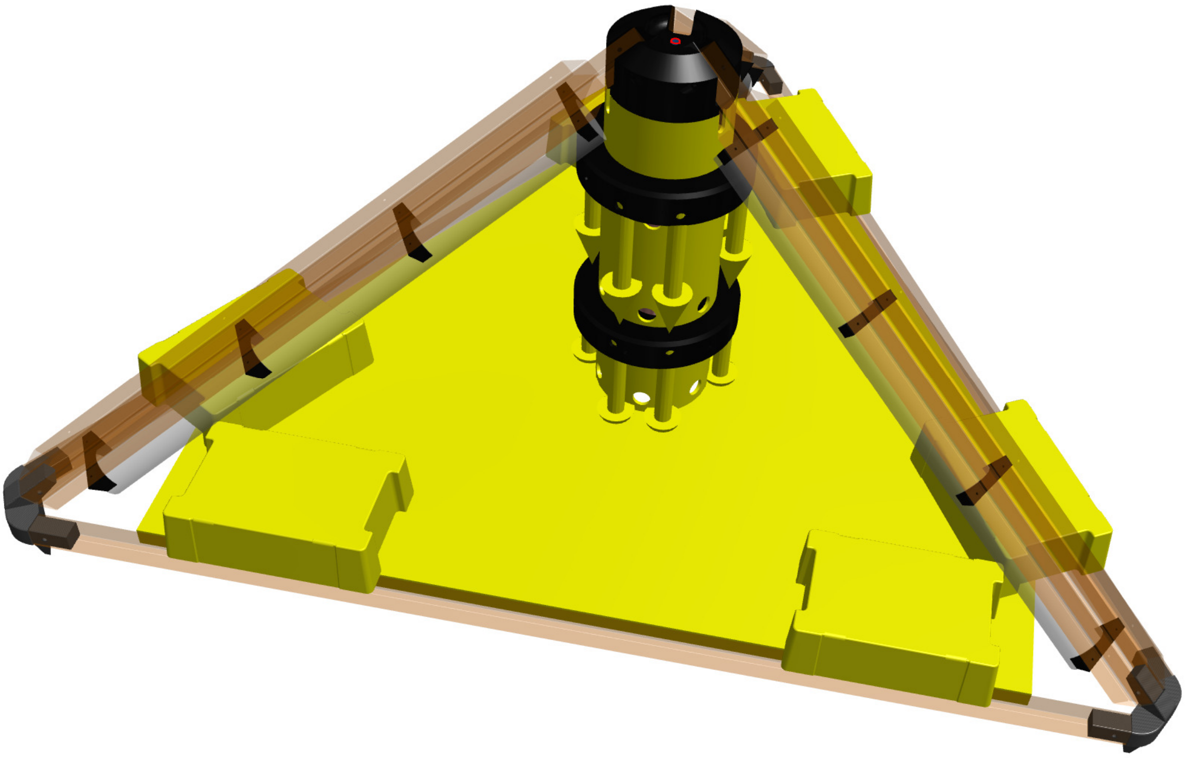


Figure 15-17 Frame structure stress analysis, constraints applied

A force load is applied to the EDS bracket holes and acceleration to the model according to Table 15-2 Frame structure FEM analysis input.

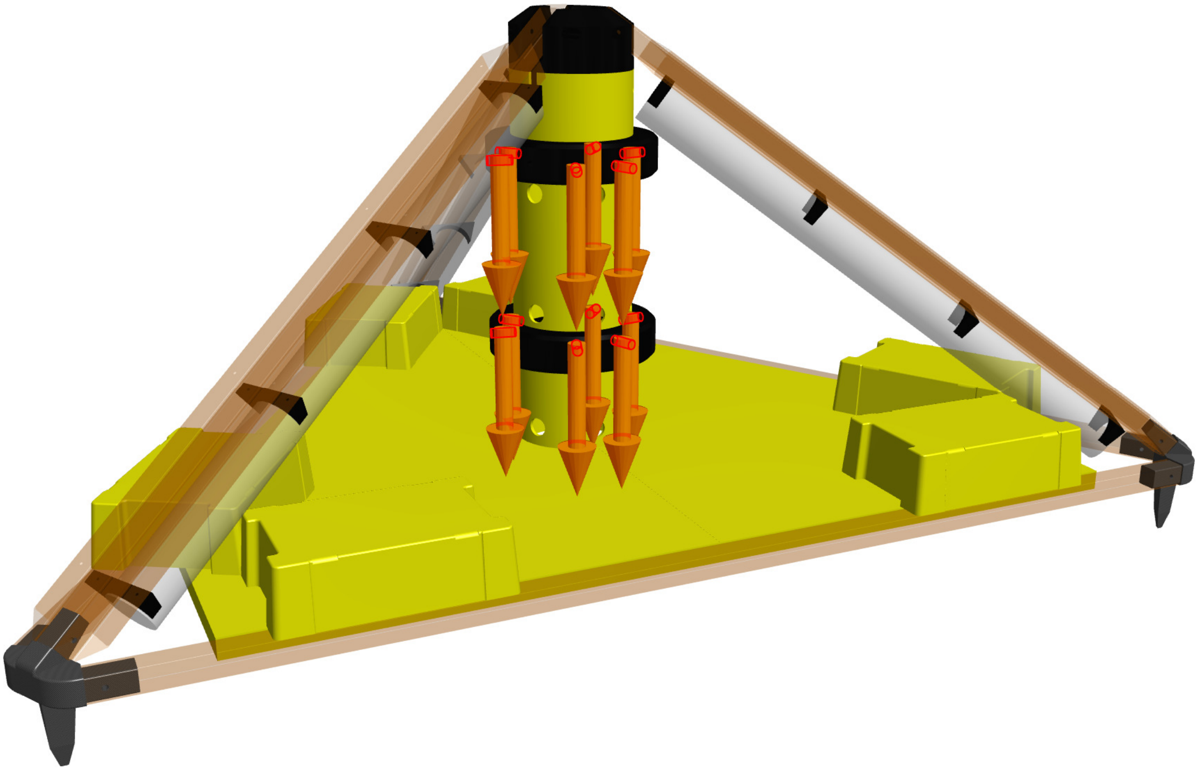


Figure 15-18 Frame structure stress analysis, loads applied

15.2.3 Results Stress analysis

The stress distribution is displayed in Figure 15-19 Frame structure stress analysis, Von Mises stress and the maximum deflection of the frame is displayed in Figure 15-20 Frame structure stress analysis, max deflection. Refer to Table 15-4 Frame structure stress results for FEM results.

Table 15-4 Frame structure stress results

Results	Value	Figure reference
Max Von Mises Stress	14,6 [MPa]	Figure 15-19 Frame structure stress analysis, Von Mises stress
Max deflection	0,23[mm]	Figure 15-20 Frame structure stress analysis, max deflection

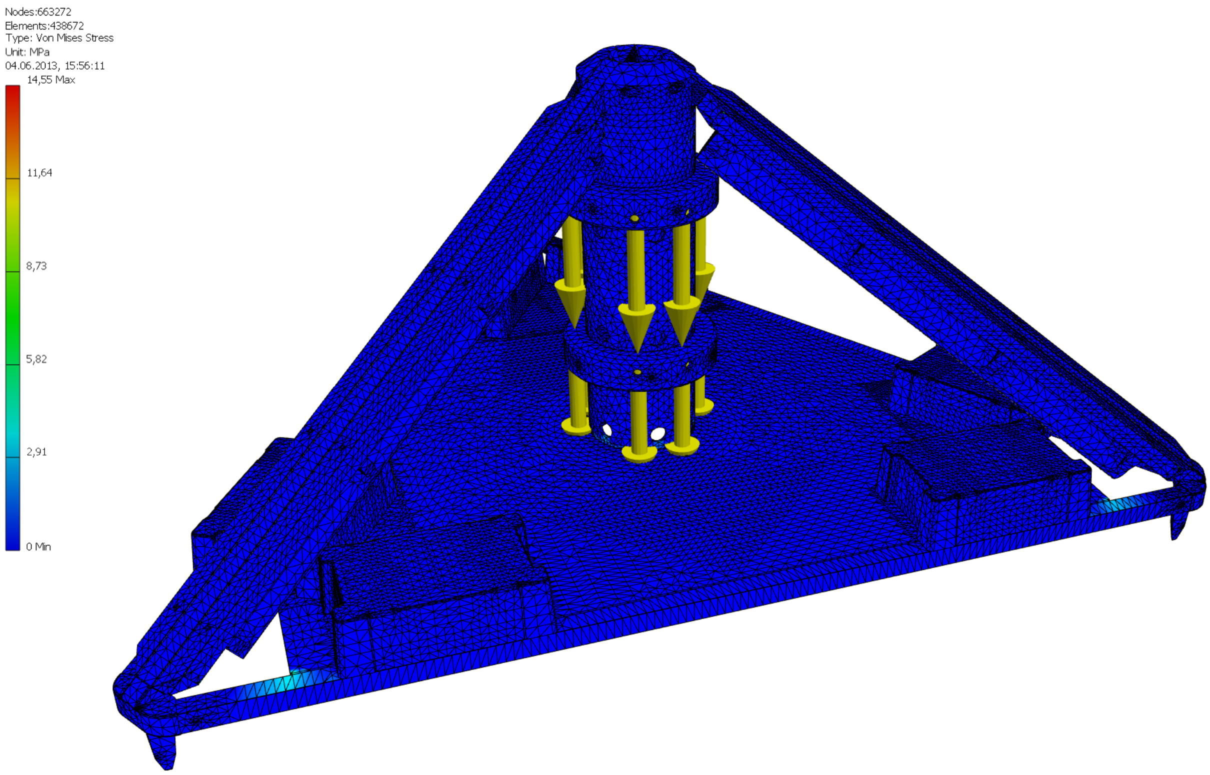


Figure 15-19 Frame structure stress analysis, Von Mises stress

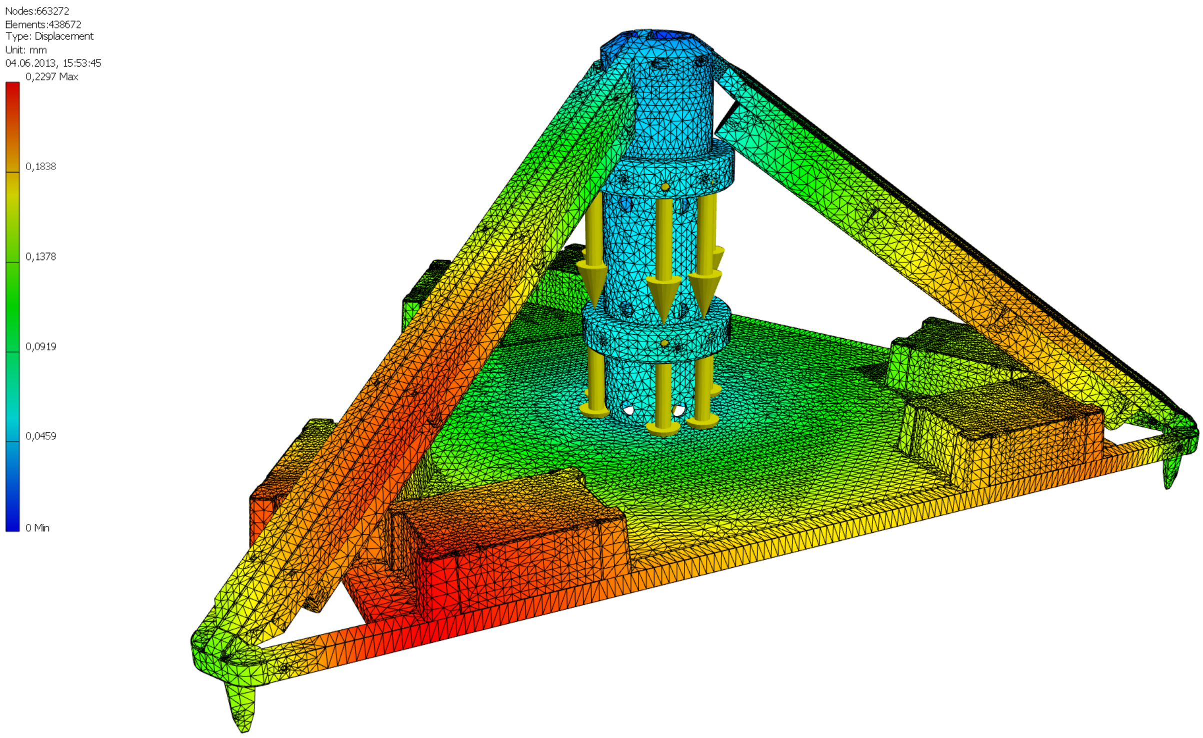


Figure 15-20 Frame structure stress analysis, max deflection

15.2.4 Frame structure stress analysis conclusion

The frame structure withstands the maximum loads and the deflection is small. All stresses are within the material specifications. Max Von Mises Yield < Material Yield.

See full report in “Frame Stress FEM report” in the appendix

16 SCS concept summary

The SCS concept is a result of several iterations of product development, see chapter 6 Work methods for reference. The evolving path was led by the chase of increasing the stiffness of the frame structure and simplification to the manufacturing processes in order to reduce the production time.
The end result is a robust, yet flexible solution that meets WINS current and possible future needs. All requirements given in Table 5-1 Requirement specification and secondary requirements given in Table 7-1 Secondary requirements has been included and resolved in the final product.
The production of a pilot model started the 1st of May 2013 and is scheduled to be completed on July 15th 2013.

17 WINS feedback

Key personnel at WINS have been involved in the complete process and are very satisfied with the end-result. This product meets the requirements and gives a versatile platform for future products.
The SCS is due for installation at Statoils ASA Gullfaks field in late November 2013 and at Aasgard early February 2014.

WINS has gained a lot of knowledge on subsea and non-metallic materials design during this project.

18 Project conclusion

From start to finish this have been a high priority project as delivery time has been the main controlling parameter. Many iterations and redesigns are done because of changes in hardware specifications like sensors and electronics. This has delayed the production start-up. However, production start-up date was due within Q2 2013. This was achieved with the help of late nights at the office.

WINS as a development team is now much more agile and coherent, as methodology from the book “Product Design and Development” [5] has been widely used.

Lessons to be learned are to invest more time in the early stages of planning and setting up the requirement specifications in full detail. This will allow the product development phase to flow better, and keep the project progression on track.

19 Key personnel

The following personnel contributed during the development phase of the Subsea Communication System.

Ying Kang Wei, PhD	WINS, Electrical Engineer
Frode Haugen	Dynamica, Electrical Engineer
Arvid Ophaug	Purapipe, CEO
Peter S Aronstam	PSA inventions, Owner
Atle Hjertenæs, PhD	WINS, CEO
Roe Strømmen, PhD	Araco, Owner

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