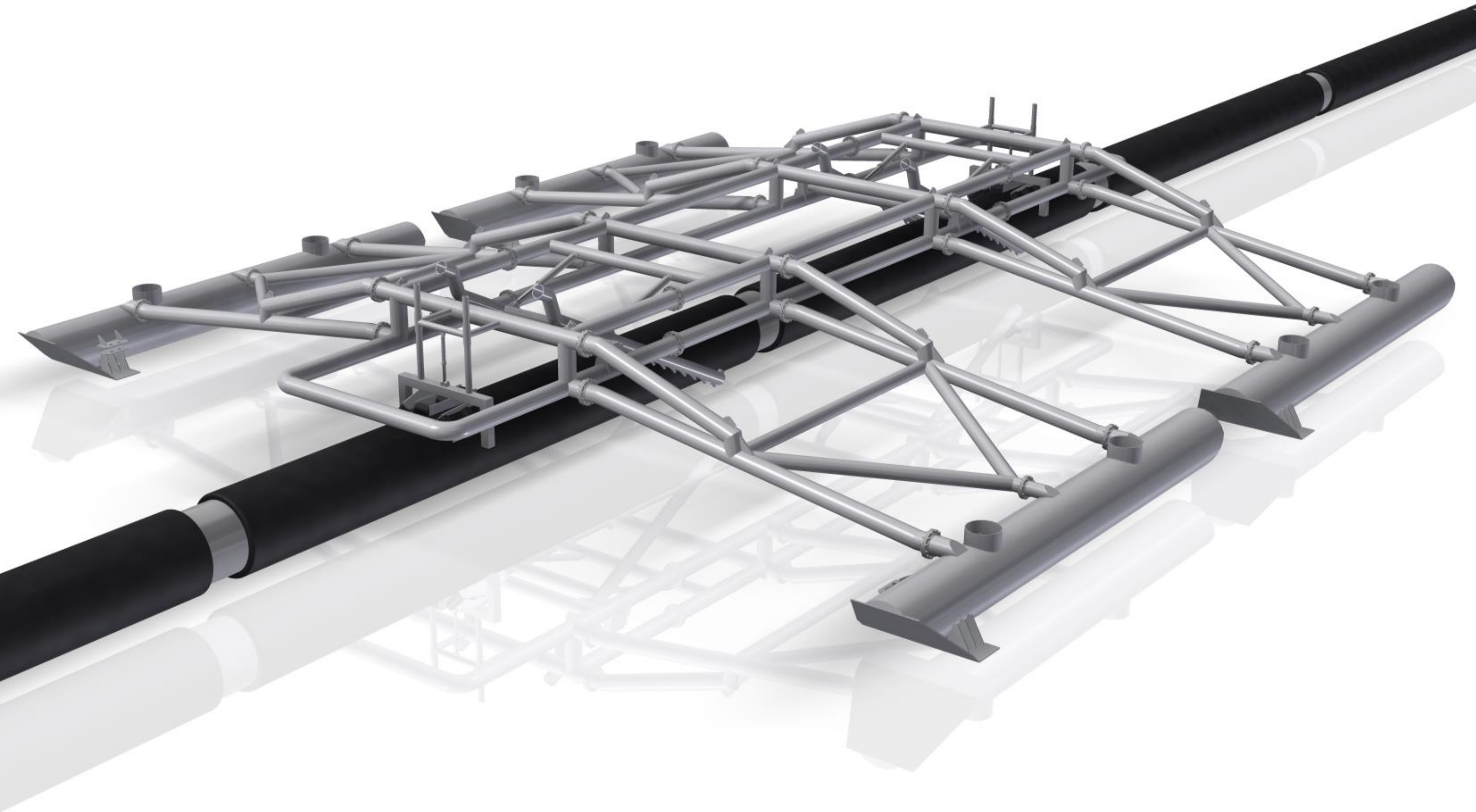
Design of Trencher Main Structure

Bachelor thesis, Mechanical Engineering



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PREFACE

This thesis is the final result of my graduation period at Allseas Engineering B.V., for the final stage of the study Mechanical Engineering at The Hague University of Applied Sciences. For a period of 17 weeks I have been working on the structural part of the new trencher, *Jet Sled III*. During my period at Allseas I improved my engineering skills and gained more knowledge about the offshore industry.

This thesis is intended for the examiners of The Hague University and the engineers of the Innovation and Structural Units of Allseas Engineering.

I want to thank all the engineers of the innovation and structural department, who provided me help and information during my project. Special thanks to my supervisors Alexander Vermeulen and Otto Kooy, who guided me along the project and provided me feedback to improve my work. I have learned a lot from both and had a great time with them. I want to thank Mr. Brilleman for guiding me during my project and providing me feedback when needed.

Finally but not least I want to thank my family, friends and girlfriend who supported me during my graduation, which helped me a lot.

Dylan Rasidin
Delft, December 2016

ABSTRACT

When a pipeline is laid on the seabed it can be exposed to hazards of ship anchors, large fishing gear or ice keels. To prevent the pipeline of being damaged, the pipeline can be trenched. Trenching is a technique where the pipeline will be buried in the seabed to a certain depth. This can either be done before or after the pipe lay process.

For the upcoming project in de Gulf of Mexico, Allseas has to trench a 49-inch pipeline to two different depths. One part has to be buried to a depth of ½ times the overall outer diameter of the pipe, measured from the bottom of the pipe. The other part has to be buried to a depth of 1.0-meter, measured from the top of the pipe to seabed. Since the already existing trenchers of Allseas are not capable to meet these requirements, a new trencher needs to be build.

The new trencher will make use of a jetting configuration, where the soil underneath the pipeline will be fluidized. This will be done with the so called Jet Swords. These are swords which are equipped with multiple nozzles and lower along both sides of the pipeline. When the soil is fluidized the pipeline will lower into the soil due to the higher density of the pipeline compared to the fluidized soil.

This graduation project *'Design of trencher main structure'* contains the design and development of the complete structure of the new trencher. This structure has to meet the requirements for both trenching depths and needs to be strong enough to hold different equipment.

A modular structure is developed which can be adapted for both scopes. Pipe profiles of DIN Ø273*6.3-mm are used for the complete structure. The structure exists of a main frame, skid frames and skids. These components are connected to each other with the use of welded slip-on flanges. The main frame exists out of two frames for the small structure and three frames for the large structure when a middle frame is added. The increased length is needed to install two jet swords. The second jet sword will keep the soil fluidized for a longer time, giving the pipeline more time and distance to lower into the trench. The two structures have the following dimensions:

- ½ times Overall Outer Diameter = 10 * 10.3 (length * width) [meter]
- 1.0-meter Top Of Pipe = 20 * 17.3 (length * width) [meter]

The small structure is supported by two skids and two skid frames, and the large structure with four skids and four skid frames. For the large structure the skids frames are wider, which increases the width of the structure. This is needed to overcome the width of the trench which can collapse during trenching. For the inner pipe profiles of the skid frames a profile of DIN Ø2191.1*8-mm is used.

An Inventor model is made to see the interaction between the structures and the installed equipment. The complete structure is modelled including the jet swords, guidance frames and all the flange connections. By this, a parts list for both structures is made. The list is used as a weight-input for the FEM analyses and calculations.

Besides the Inventor model a 3D-print is created to get a physical touch of the structure. Only the large structure is printed and the installed equipment is removed. The model is printed on a scale of 1:111.

Different load cases have been made to determine the loads which the structures are subjected to. The worst case scenario is when the structure is deployed by the crane underwater and the heave compensation will fail. This causes the structure to accelerate with the same motions as the tip of the vessels crane of which the trencher is deployed with. Besides the extra acceleration, water drag will occur. This will increase the loads on the structure.

FEM analyses have been made for both structures above and under water. For the small structure an extra weight of four tonnes is added to simulate the weight of submerged pumps in case they will be used. For the large structure a weight of eight tonnes is added, since there are two jet swords. The results show that the maximum stresses will stay below the allowable stress in all the load cases. For the longer skid frames an extra stiffener is added to keep the stresses acceptable.

Hand calculations have been made to check the FEM results. They confirm that the stresses will be acceptable and show that the bending stress in the large skids frames will be too high without stiffener. This confirms the need for a stiffener in the intern connections of the large skid frames.

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LIST OF ABBREVIATIONS

BOP = Bottom Of Pipe
CJ = *Calamity Jane*
FEM = Finite Element Method
FMEA = Failure Mode and Effects Analysis
ID = Inner Diameter
MCA = Multiple Criteria Analysis
OOD = Overall Outer Diameter
OD = Outer Diameter
TOP = Top Of Pipe
VO = *Volstad Oceanic*
WT = Wall Thickness

1.0 INTRODUCTION

In this chapter an introduction of the company and project will be given. The company and project will be described, which will lead to the objective of this project. The approach and scope of work will follow after.

1.1 Company

Allseas is an offshore pipe lay company which operates worldwide. The company is based in Switzerland and has three offices located in the Netherlands. Besides the Dutch offices Allseas has three yards located in Rotterdam, IJmuiden and Heusden (the Netherlands). The company owns six vessels which are capable of pipe lay, pipe lay support, trenching support or offshore platform removing/installing.

Their new vessel the *Pioneering Spirit* is a dynamic positioned vessel which is capable of installing pipelines up to 68" and removing offshore platform top sides up to 48,000 metric tonnes (Mt). It is the largest construction vessel in the world with a length of 382 meters and a width of 124 meters. The vessel was built in South-Korea by *Daewoo* and arrived in Rotterdam for final outfitting in January 2015. (Allseas, October 2016).

1.1.1 Innovations, Geotechnical

The student will carry out the project for the Geotechnical unit, part of the Innovations department. This division is responsible for development and improvement of technologies and activities within Allseas. The Innovation division is part on five core departments: Heavy Lift, Industrial Automation, Innovations, Naval Architecture and Structural; each responsible for the design, analysis and development of solutions that improve the performance of Allseas' vessels and equipment, or support offshore installation activities undertaken by Allseas.

The Geotechnical unit is a part of the core department Innovations. This unit is responsible for all Geotechnical challenges within pipe lay and heavy lift projects. The development of the new trencher for a larger pipeline is a challenging project where four engineers of the geotechnical unit are involved.

1.2 Project

For a future pipe lay project along the Mexican and U.S. coast a pipeline of 49" has to be laid and trenched. The in-house built trencher *Digging Donald* can trench pipelines up to 48" and is therefore not capable of trenching the pipeline. For this reason a new trencher has to be designed which meets the requirements of the new project.

For the project *Design of trencher main structure* the student has to develop and design the main structure for a new trencher. The new trencher, also known as the *Jet Sled III* within Allseas, has to be operational for the above mentioned project. The pipeline that has to be trenched has a maximum overall outer diameter (OOD) of 49". Due the Jones Act in the U.S. part of the project it is not allowed to make use of a mechanical way of trenching (Patrizia, 2002). This means that the soil may not be physically touched or moved by the trencher. This restriction leads to the use of jetting equipment, where the soil is moved by contact with the water, which is not a component of the trencher.

The project exists of two main requirements concerning the trenching depth. The pipeline has to be trenched to a depth of ½ times its overall outer diameter measured from the bottom of the pipe (½*OOD BOP). In the other parts the pipeline has to be trenched to a depth of 1 meter depth measured from the top of the pipe to seabed level (1-m TOP). The pipeline is made from single joints, with a length of ± 12.3 meter. The joints are welded to each other to create the pipeline, this welded area is called the field joint. The field joint is coated to protect the weld from seawater. The length of a field joint is ± 770 mm.

1.3 Objective

*'Develop and design the main structure of the new trencher which is capable of trenching the ½*OOD BOP and 1-m TOP scope'*

The new main structure will be modelled in Autodesk Inventor 2016 and analysed in the finite element method program Femap. Besides the FEM analysis, hand calculations will be done to check the FEM results. Aspects which has to be taken in account during designing of the main structure:

- Strength
  The main structure will be subjected to different loads, which it has to withstand.
- Modularity
  A modular system is preferred to be applicable for both trenching depths.
- Handling
  Handling of the trencher has to be taken in account due limited deck space on the vessel.

1.4 Methodology

In this section the methodology of this project will be discussed. Here it is explained how the project will be executed and which methods will be used.

Research
To get more information and knowledge of the project where the trencher will be built for, different data has to be reviewed. Project meetings will be joined to get more information. To get a clear view of the requirement for the main structure, different studies has to be done. The first requirements will come directly from the two project scopes (depths). The requirements from Allseas have to be known, which will be obtained by the meetings. Codes and regulations will demand requirements for the structure and allowable stresses. A set of requirements will be made which contains all the requirements from the above mentioned studies.

A function analysis will be made to determine the different parts of the main structure. This is important to know for the start of the design stage, where solutions have to be made for these functions. An Failure Mode Effect Analysis (FMEA) will be done to see where the weak spots are expected to be. When this is known, these risks can be eliminated during the engineering of the structure.

Design
During the design stage, different concepts will be made. The project is focussed on the main structure of the new trencher. The installed equipment of this structure will not be designed, this will be decided by Allseas. Although these decisions have to be taken in account, due the fact that the structure needs to fit this equipment.

Before starting with generating concepts, different options will be investigated for the functions found in the function analysis. When these are known, concepts can be generated. The concepts will be made based on a design vision. The concepts will be ranked on the criteria with a multiple criteria analysis (MCA). Based on the outcome of these concepts, it will turn out which one will be chosen. This can either be one concept, or a combination of different concepts.

Engineering
When a concept is chosen in the design stage, it will be further engineered. Different load cases will be made of situations where the structure will be exposed to different loads. Based on these load cases the structure will be dimensioned to withstand the loads. A FEM analysis will be made to see how high the stresses will be, and hereby if the structure will hold the loads. The structure will be modelled in Inventor to show the working and interactions with the installed equipment. After this, different conservative hand calculations will be made to check if the FEM results are realistic. Furthermore a lifting and towing arrangement will be made to show the handling of the structure.

To confirm that the structure meets all the requirements, it will be tested to the set of requirements afterwards. The risk point which came out of the FMEA analysis will be reviewed to explain how these risks are eliminated.

1.5 Scope

- Student starts on 29th of August 2016, until 23th of December.
- A study to existing trenchers will be done, to gain more knowledge about trenching techniques. (Dredging an rock dumping will be excluded)
- A study to norm and regulations will be done; relevant norms and regulations will be documented and used during designing of the main structure.
- Different load cases of situations will be made to determine the loads on the main structure.
- The load case of crossing the splash-zone is beyond the scope of work.
- A CAD-model of the main structure will be made in Autodesk Inventor. Equipment which will be installed on the trencher does not have to be modelled. The skids and jet swords will be modelled to get a vision of the interaction with the frame, they will not be modelled in detail.
- A FEM-analysis on the main structure will be made in Femap. Different load cases will be analysed.
- Different hand calculations will be done to check the FEM-analysis results, and vice versa.
- A cost estimation of the main structure will not be made. (This is proposed and determined with Ing. Kooy, has been approved by Ir. Brilleman and Ir. Van Kampen during the assessment on 22-06-2016)
- During designing of the main structure the following subjects will be detailed: Material, profiles, modularity (connections), lifting, loads and stresses.
- Conservative calculations will be made for the load of the jet swords and skids to determine the generated friction.

1.6 Boundary conditions

- Allseas has to provide sufficient resources, soft-/hardware and assistance during the graduation period of the student. The student is not responsible for the consequences when the above mentioned points can't be provided and the student will be limited or delayed during his graduation project.
- The Hague University of Applied Sciences has to provide sufficient supervising, information and assistance during the graduation period of the student. The student is not responsible for the consequences when the above mentioned points can't be provided and the student will be limited or delayed during his graduation project.

1.7 Set of requirements

In Table 1.1 the set of requirements is given. Each requirement will be tested at the end of the project to see if it is met. Besides the requirements, criteria are made. These are requirements which can be met in a certain level. By this way, the concepts can be weight up against each other, and the strong aspects of each concept will be resulting out of the multiple criteria analysis.

Table 1.1 Set of requirements

	Requirement	Test method	Requirements	criteria
Operational requirements	Trenching pipelines with max. 49" OD [1244.6 OD mm] (42" + 3.5" coating)	CAD drawing must prove if requirement is met	✓	
	Trencher main structure should withstand all forces during operational conditions	FEM-analysis and calculations must prove if requirement is met	✓	
	Trencher main structure has to be adjustable for the 0.5*OOD BOP and 1.0-m TOP jetting configuration	CAD drawing must prove if requirement is met	✓	
	No mechanical trenching allowed (part of project)	CAD drawing must prove if requirement is met	✓	
	The unprotected field joint may not be touched	CAD drawing must prove if requirement is met	✓	
	The trencher must be able to move on a seabed of 3 kPa	Calculations must prove if requirement is met	✓	
Structural requirements	Trencher must fit on the deck of *Volstad Oceanic* (VO)	CAD drawing must prove if requirement is met	✓	
	Trencher may have a maximum weight of 90 tonnes (lifting capacity of deck crane VO at maximum reach)	CAD drawing must prove if requirement is met	✓	
	Distance between jet swords, eductors and rollers to be adjustable	CAD drawing must prove if criterion is met		✓
	Trencher needs to be dissembled for transport	CAD drawing must prove if criterion is met		✓
	Underwater weight of the main structure has to be reduced	CAD drawing and calculations must prove if criterion is met		✓
	Possibilities for mounting extra equipment on the trencher	CAD drawing must prove if criterion is met		✓
	Main structure should be able to hold the loads of extra equipment	FEM-analysis and calculations must prove if criterion is met		✓
	Main structure needs to be resistance against unexpected loads	FEM-analysis must prove if criterion is met		✓

2.0 RESEARCH

In this chapter different studies will be shown. The purpose of these studies is to gain more basic knowledge. The information found in these studies provides a basis for the design phase of the main structure.

2.1 Trenching techniques

To get a clear vision of the nowadays subsea trenching techniques a trenching study has been done. A short description of the two trenchers of Allseas will be given. The following techniques will be discussed:

- Mechanical Digging
- Jetting
- Ploughing
- Eductor

Dredging and rock dumping are also techniques to protect the pipeline of hazards but will both not be discussed because it cannot be done by a trencher.

2.1.1 Mechanical Digging

With mechanical digging the soil will be removed by use of cutting or sawing techniques, see Figure 2.1. This technique is often used on harder soils like very dense sand, clay and even rocks. The cutting will be done by digging arms provided with large chain saws. These saws will cut the soil underneath the pipeline and transfers the loose soil to seabed level, where the soil is often deposited next to the trencher with the use of eductors. After the trenching is done this loose sand of clay can be used to backfill the trench and protect the pipeline.

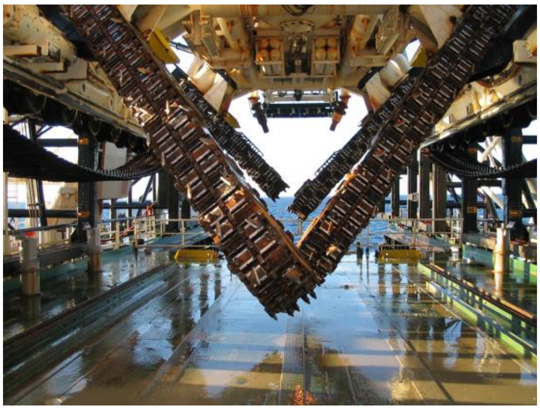


Figure 2.1 Mechanical arms *Digging Donald* (Allseas, 2016)

Most trenchers which make use of mechanical digging are equipped with tracks to maneuver around the seabed. These tracks will give the trencher more stability and control during trenching. However tracks can only be used in harder soils to prevent sinking in the seabed.

Allseas' in-house developed trencher *Digging Donald* makes use of mechanical digging and jetting. The trencher is equipped with 4 digging arms which work in pairs to generate a V-shape trench. The trencher is capable of trenching pipelines up to 48" with jetting and up to 36" with the mechanical arms.

Trencher dimensions [meters]

Length	: 17.3
Width	: 9.7
Width between tracks	: 6.5
Height	: 6.7

Trencher weight [metric tonnes]

Dry weight	: 145
Submerged weight	: 85
Dry weight with backfill blades	: 165
Submerged weight with backfill blades	: 105

2.1.2 **Jetting**

By jetting, the soil gets fluidized and the water-soil mixture gets a lower density. The density of the pipeline is higher than the mixture, as a result the pipe lowers in the trench. Jetting is often used for sand of soft clay. Sand is a non-cohesive material, therefore is gets easily fluidized. Clay is a cohesive material and requires more energy. In case of jetting clay the soil will be cut instead of fluidized. The amount of jetting power depends on the clay strength. The water pumps which deliver the pressured water can be installed on a support vessel as well as on board of the trencher.

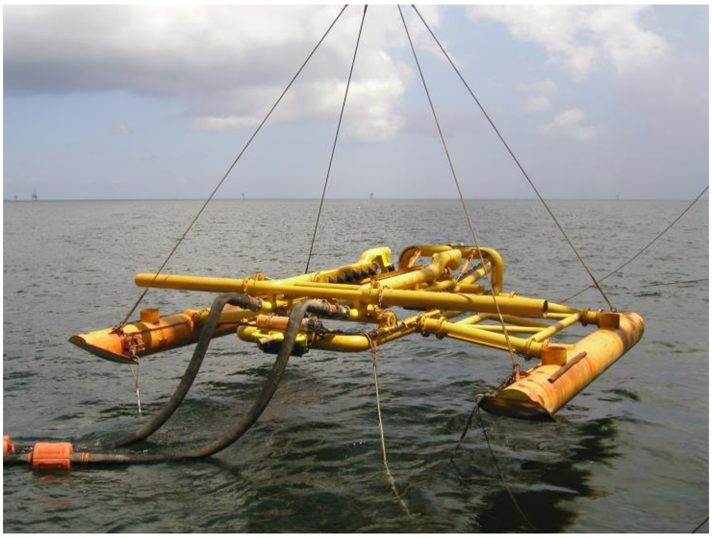


Figure 2.2 Deploying of the old *Jet Sled* (Allseas, 2016)

Allseas' in-house trencher *Jet-Sled* makes use of jetting swords to generate the trench. The trencher is equipped with one set of jetting swords to fluidize the soil, and one guiding arm on the back equipped with rollers. The guiding arm makes sure that the trencher stays positioned on the pipe, so that the trench in exactly underneath the pipe.

Trencher dimensions [meters]

Length overall	: 11.7
Width overall	: 12.7
Height when folded	: 2.7
Height when deployed	: 5.3

Trencher weight [metric tonnes]

Dry weight	: 22
Fully submerged weight	: 3

2.1.3 Mass excavating

Mass excavating is a way of jetting using a high volume stream of water under low pressure. By this way the water blows de soil underneath the pipeline away creating a trench. This method is not used by Allseas yet. An example of a mass excavating tools is the T8000 from Rotech, see Figure 2.3. Their tool exists of a T shaped pipe structure with two impellers on both top inlets. They can generate a vertical water stream of 10 m/s, with a volume stream of 8 m^3/s. (Rotech_T8000_Spec, 2008)

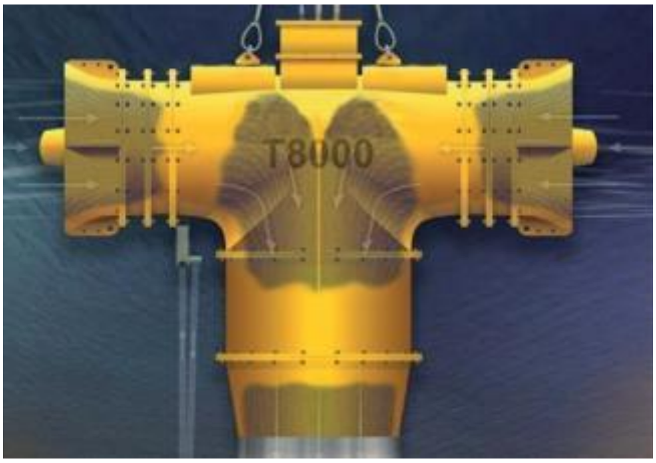


Figure 2.3 Rotech T8000 (Rotech_T8000_Spec, 2008)

2.1.4 Ploughing

Ploughing is like mechanical digging a way of trenching where the soil is mechanically transferred. Only a plough does not require direct power to cut the soil but stays static in the same position and is towed. Ploughing requires a lot of energy to force the soil to fail. It is a fast trenching method and can reach depths to 5-6 meter. Allseas does not have a trencher which is capable of ploughing.

2.1.5 Eductors

When a trench is made by use of mechanical digging or jetting, the loosened soil has to be removed in some cases. This can be done by sucking the loosened soil out of the trench. To do this, the trenchers can be equipped with eductors. Eductors are pumps which generate a under pressure (vacuum) which creates a stream, see Figure 2.4. In most cases this will be jet pumps which pumps which are robust and often already installed for the jetting installation. The *Digging Donald* and *Jet Sled* are both equipped with eductors.

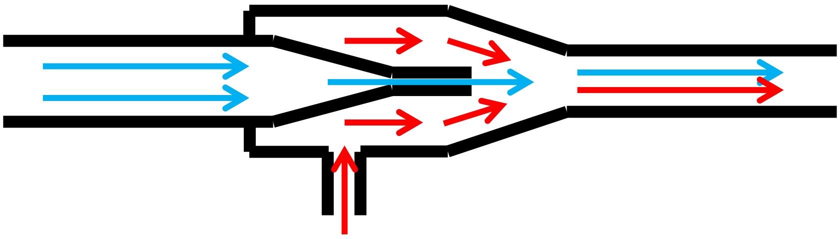


Figure 2.4 Eductor based on jet pump principle

2.2 Function analysis

In this section a function analysis will be given. This analysis has been done to clarify the components of the *Jet Sled III*. The trencher is divided in multiple design boxes, each having their own function. For this project the design box 'Structural' will be developed.

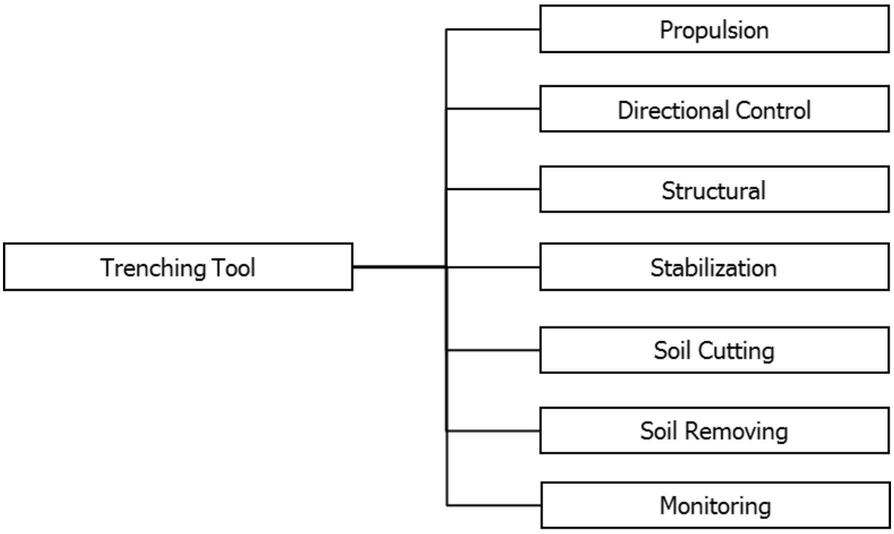


Figure 2.5 Function analysis *Jet Sled III*

The project *Design of trenching main structure* belongs to the structural box. The choices which are made by Allseas for the other boxes can be found in Appendix A – Component research. A different function analysis is made for this project. The below figure shows the different components of the structural box. Not every component will be developed but they will be leading in the dimensioning of the structure.

- The jet swords will not be designed, instead the old jet swords will be used. Therefore the dimensions of the old jet swords will be leading for the width of the main frame. Also the weight and loads of the jet swords will be analysed.
- A concept for the guidance system will be made. The complete engineering of this system will not be done, but the interaction with the frame and the resulting stresses on the frame will be analysed.

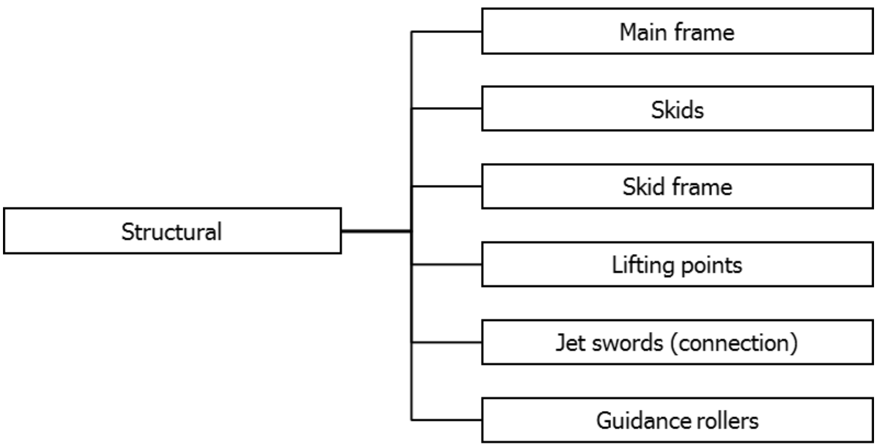


Figure 2.6 Function analysis structural

2.3 Dimensions

The main structure will be restricted to two dimensions, the vessel and trench. During trenching a part of the soil will get fluidized, this result in a weak spot in the ground. Due to this weak spot the 'walls' of the trench may collapse and turn into slopes. The width of these slopes is leading in the minimum width of the trencher, so that the trencher will not slide into these slopes. The minimum skid-to-skid distance for both scopes is shown in Appendix I – Trench dimensions. This results to the following width:

- ½ * OOD BOP scope -> ± 8 meters
- 1.0 meter TOP scope -> ± 17 meters

The trencher will be deployed from the *Volstad Oceanic,* one of the newest vessels of Allseas. The vessel has a large deck space to store equipment which makes it ideal for the new trencher. The maximum dimensions of the trencher, width and length, will be limit by the available deck space. The maximum width and length of the trencher can be 25 * 52 meters (space on deck). Due to the crane house on deck the width of 25 meters is only possible up to a length of 23 meters, see Appendix C – Deck lay-out *Volstad Oceanic* for the available deck space.

The height of the structure will be determined by the size of the pipe. A 49" pipe has a diameter of 1244.6 mm. To prevent contact between the structure and the pipeline a clearance is desirable, although the guidance frame will prevent this. A clearance of 250 mm between the top of the pipe and frame is used at the old *Jet Sled*, this will result in the following clearance.

$$Clearance = 1244.6\ (49") + 250 = 1494.6\ mm$$
$$Clearance = 1500\ mm$$

Table 2.1 Dimensions structure

Dimension	Value	Unit
Width	> 8000/17000	[mm]
Height	> 1500	[mm]
Length	< 52500	[mm]

2.4 Failure Mode Effect Analysis

In this chapter a failure mode and effects analysis (FMEA) will be done of the potential failure risks. During the analysis the operational load cases of the trencher will be inspected. By doing this, risks can be remarked and excluded. A table including all the risks can be found in Appendix D – FMEA.

2.4.1 **Process description**

When a subsea pipeline is installed the pipeline has to be buried sometimes. This prevents anchors and fishing nets to damage to pipeline. Burying the pipeline can be done by a trencher. With the use of high pressure water jets the trencher fluidizes the ground underneath the pipeline which causes the pipeline to lower into the seabed due a higher density than the soil mixture. The jetting system exists of jetting swords which are equipped with multiple nozzles. These swords will lower in pairs into the soil around the pipeline. The swords can be lowered to a certain depth to ensure that the pipeline sinks to the required depth. The trencher will be equipped with skids to rest on the soil. With the use of a towing wire the trencher will move along the pipeline.

2.4.2 **FMEA boundaries**

Only the components within the scope will be analysed on potential risks. This includes; main frame, skids, skid frame, jetting arms (excluding nozzles), rollers. Potential risks of these components will be examined and excluded by finding a solution.

2.4.3 **Risks**

Points 4.1, 5.2 and 5.4 have a high risk (RPN > 100) and need to be considered. During the design process these risks has to be taken in mind to prevent them.

- Jet swords

The Jet Swords have a high risk to collide with an unseen rock or object in the soil. When this situation occurs the swords can be damaged or break. To prevent this situation the swords will be retracted with the use of hydraulic cylinders when a collision with a hard object is monitored. The monitoring will be done by load sensors on the Jet sword. In this case the load on the sword can never be overloaded and damage will be prevented or limited.

- Rollers

The rollers will guide the trencher along the pipeline and in the trench. In many cases the rollers will be submerged in the soil-water mixture and being at risk to get locked. This will be caused by soil which gets in between the bearings. When this occurs the roller can get locked and will scratch the pipe during trenching. If this is not monitored in time a lot of damage can be made. To prevent this risk bearing of the rollers has to be well sealed, so that no soil can get in.

- Complete structure

When the trencher is deployed from the vessel in rough sea conditions the vessel will undergo accelerations due the weather. These accelerations will be felt in the structure due the lifting wires. However, when lifting the heave compensation is active. This ensures that the influence of the vessels motions on the structure will be limited. In case of a heave compensation fail the trencher will accelerate with the same motions as the crane tip. This will lead to large accelerations underwater, including a load from the water drag. The structure needs to withstand all these loads.

3.0 CONCEPTS

Research has been done for different solutions for the structural components, which can be found in Appendix A – Component research. This research is mainly focussed on which kind of profiles are suitable and the configuration of the structure. Out of the different options, two concepts have been generated. Appendix E – Concepts contains more figures and information of both concepts.

Due the restrictions as a result of multiple aspects, both the structure will be based on the old *Jet Sled*, and upgraded to the new requirements. These aspects are as follows;

- The old jet swords will be used, therefore the main frame has to be adapted to the width of the old jet swords. This results in the same frame width as the old *Jet Sled.* The jet swords have a width of 3500-mm and are suspended by steel blocks which will be welded onto the frame.
- The spacing between the skids needs to be large enough due the slopes of the trench. To overcome this width, skid frames are needed. See section 2.3 for the needed spacing between the skids.
- Due the soft soil it is not possible to use tracks, they will be too heavy and not be able to get grip in the loose soil. Therefore the structure must be equipped with skids.

The challenge for the new trencher is to overcome the large width of the trench and making the structure modular for both scopes. For the following components a new design has to be made:

- Main frame; The frame which suspends the jet swords and all the equipment which will be installed on the trencher.
- Skid frame; The connection between the skids and the main frame which has to be strong enough to hold the complete weight of the main frame.
- Skids; The part of the structure which has to hold the complete weight of the structure, to rest on the soil.

3.1 Concept 1

Concept 1 is based on the old *Jet Sled* and is upgraded to the new requirements. The main structure will be demountable so it can be adjusted for the small and large scope. The small structure has a main frame consisting out of two sections, and can be extended with an extra main frame for the large structure. For the large structure there are four wider skid frames needed to overcome the spacing between the skids of 17 meters. The used profiles for the main frames are: DIN Ø273*10. In Figure 3.1 the top view of the two structures can be found.

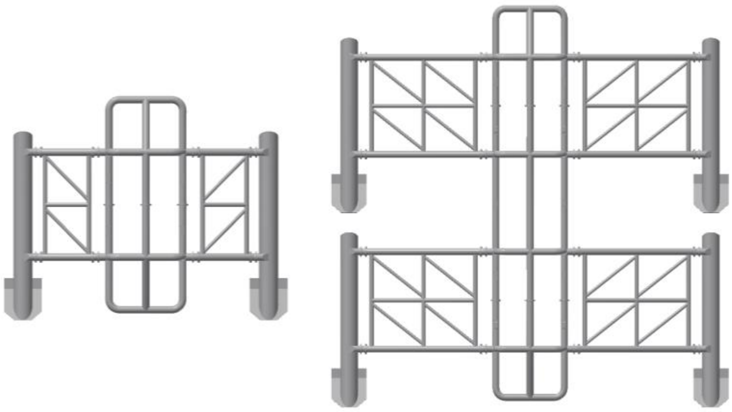


Figure 3.1 Concept 1 small and large structure

Table 3.1 Concept 1 components

Material	- S235
Main frame	- Pipes welded together in the old *Jet Sled* configuration with extra reinforcement. - Connection of separated sections and skid frame with flanges.
Skids	- Pipe to provide buoyancy, reinforced to withstand pressure. - Connection to skid frame with flanges.
Skid frame	- Pipes welded together in trusses configuration to withstand the load. - Connection to skid and main frame with flanges.
Rollers	- Roller frame which lowers around the pipe around an axis, same principle as the jet swords.

3.2 Concept 2

Concept 2 is like concept 1 based on the configuration of the old *Jet Sled* with extra reinforcement. The main difference with concept 1 is the use of I-beams instead of pipes, the used I-beams are: ANSI 250*32.7. Concept 2 has the same set up as the first concept, where the small structure exists out of two frames and the large structure out of three frames. The middle section can be removed to connect the two outer sections. In Figure 3.2 the top view of the two structures can be found.

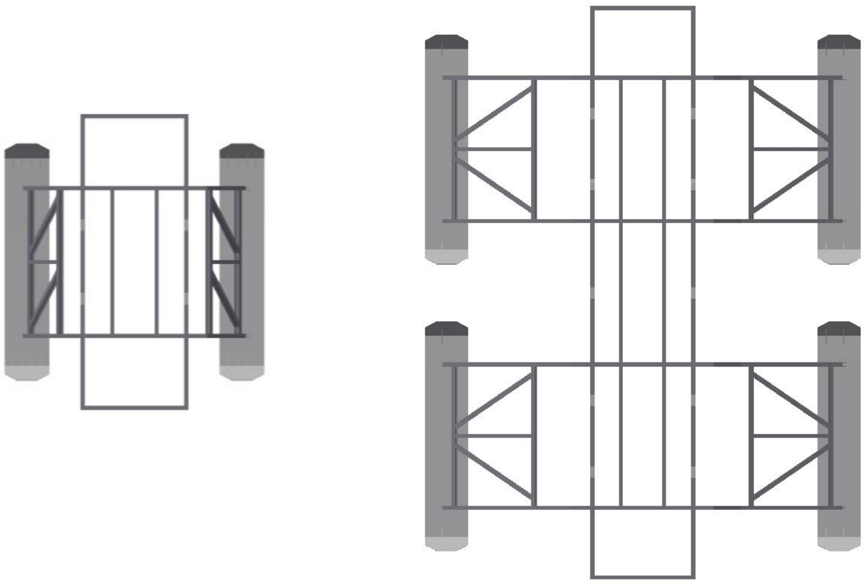


Figure 3.2 Concept 2 small and large structure

Table 3.2 Concepts 2 components

Material	- S355
Main frame	- I-beams welded together in the old *Jet Sled* configuration with extra reinforcement. - Connection of separated sections and skid frame with plates.
Skids	- Plate for maximum contact surface to decrease pressure. - Connected to skid frame with plates;
Skid frame	- Frame made of I-beams with trusses, welded together. - Connection to skids and main frame with plates.
Rollers	- Roller frame which lowers vertically on the pipe with the use of a cylinder, and guided by two tubes.

3.3 Multiple criteria analysis

The two concepts will be weight up against each other, with the use of a multiple criteria analysis (MCA). The set of requirements is divided in requirements and criteria. Both the concepts must meet all the requirements, and will be ranked to the criteria. To determine the importance of the different criteria, priority factors will be assigned. The following criteria will be ranked:

1. Distance between jet swords, eductors and rollers needs to be adjustable.
2. Trencher needs to be demountable for transport.
3. Underwater weight of the main structure has to be reduced.
4. Possibilities for mounting extra equipment on the trencher.
5. Main structure should be able to hold the loads of extra equipment.
6. Main structure needs to be resistance against unexpected loads.

Table 3.3 Criteria ranking

Criterion	1	2	3	4	5	6	Total	Priority factor, PF (1-3)
1	-	1	0	0	0	0	1	1
2	0	-	0	0	0	0	0	1
3	1	1	-	1	1	0	4	3
4	1	1	0	-	1	0	3	2
5	1	1	0	0	-	0	2	2
6	1	1	1	1	1	-	5	3

Now the priority factors of the criteria are known, the concepts can be weight up against each other. Both the concepts will be tested to the criteria on a scale from 1-3. The score will be multiplied with the priority factor of the specific criteria. This will result in a total score.

Table 3.4 Concept ranking, ranking 1-5

#	Criterion	Concept 1	Concept 2	Priority factor per criterion, *PF*
1	Adjustable equipment distance	3	3	1
2	Demountable for transport	3	3	1
3	Underwater weight reduction	4	2	3
4	Mounting of extra equipment	3	4	2
5	Hold loads of extra equipment	4	3	2
6	Resistance against unexpected loads	4	2	3
	Total score (score * PF)	**44**	**32**	-

Concept 1 has a higher ranking, this comes due the use of pipe profiles instead of I-beams. They give an advantage in multiple ways. The below section will explain the ranking, and the configuration of the final concept.

3.3.1 Configuration final concept

To optimize the main structure different components of both concepts will be combined, in this way the final concept scores high on all criteria. In the below sections the ranking of the different criteria is substantiated.

1. *Distance between jet swords, eductors and rollers to be adjustable.*
   Concept 1: 3 **Concept 2: 3**

   The jet swords will be the same as on the old *Jet Sled*, and will have the same suspension. Both the concepts use the same solution for distance between the jetting swords, eductors and rollers. The suspension of the jet swords can be welded on different places. Therefore they both score 3 points in the ranking. The final concept will make use of the same suspension.

2. *Trencher needs to be demountable for transport.*
   Concept 1: 3 **Concept 2: 3**

   Both the concepts are made of three sections for the two different scopes. The middle section can be removed so that the two outer sections can be attached to each other. Therefore the two concepts both score 3 points in the ranking. The final concept will make use of this principle.

3. *Underwater weight of the main structure has to be reduced.*
   Concept 1: 4 **Concept 2: 2**

   The underwater weight will influence the stress in the structure when standing on the sea floor. Concept 2 scores better due the use of pipe profiles. The profiles can be (partially) filled with air, which makes the underwater weigh less than above water weight. The final concept will be made of pipes to generate buoyancy.

4. *Possibilities for mounting extra equipment on the trencher.*
   Concept 1: 3 **Concept 2: 4**

   For the current project and future projects extra equipment might need to be installed. Connecting extra equipment on I-beams is easier than on pipes, because of the flat surface. Concept 2 makes use of two longitudinal I-beams at the top of the main structure, which gives more possibilities for mounting equipment. Therefore concept 2 scores higher than concept 1.

   The disadvantage of I-beams is the strength in different directions. An I-beam is only high resistance against a load around the X axis (moment of inertia). This makes it unpractical for equipment which will generate loads around the Y axis. A pipe profile has the same resistance in X and Y direction.

   The final concept will make use of the same 'two longitudinal profiles' principle of concept 2 in combination with pipes. By this way the concept makes use of both advantages.

5. *Main structure should be able to hold the loads of extra equipment.*
   Concept 1: 4 **Concept 2: 3**

   Concept 1 scores higher due the use of pipes instead of I-beams. As described in the above section pipes will have a higher resistance against loads in different directions. Because it is unclear which equipment will be installed in the future, loads in all the directions has to be taken in account. Therefore the final concept will make use of two pipes in the longitudinal direction.

6. *Main structure needs to be resistance against unexpected loads.*
   Concept 1: 4 **Concept 2: 2**

   This comes due the use of pipes in concept 1. Pipe profiles have the same resistance in both X and Y direction, which makes them ideal for unexpected loads. As already mentioned in the upper sections, the structure will be made of pipes.

3.3.2 Components summary

Table 3.5 Final concept summary

Components	Final concept
Material	S355
Main frame	Based on old *Jet Sled* configuration from three sections made of pipe profiles.
Skids	Pipes (partially) filled with air for buoyancy
Skid frame	Two frames for small/large scope made of pipe profile
Lifting points	Pad eyes
Jet sword connection	Multiple points, old *Jet Sled* connection
Rollers	U shaped roller frame with two rows of rollers

4.0 FINAL CONCEPT

In this chapter the final concept will be detailed. In section 4.1 the design will be described. In section 4.2 the different load cases of the structure will be described, they will serve as an input for the FEM analysis. In section 4.3 the results of the FEM analysis will be described, where it is shown that the maximum stresses are below the allowable stresses. Section 4.4 contains the calculations checks, which are made for the areas where the highest stresses will occur.

4.1 Design

The final concept is based on a modular system, where two outer sections of the main frame can be connected with an extended frame between to increase the length. By this the structure is adaptable for both scopes and therefore modular. The large structure needs more length to install two jet swords. The second jet sword is used to keep the soil longer fluidized, giving the pipeline more time and distance to lower into the trench.

4.1.1 Structure properties

- **Material**

The complete structure is made of Lloyd's grade material S355J2, with a specified minimum yield strength of 355 MPa. J2 stands for the absorption of a notch impact at a temperature of -20°C. Offshore temperatures can reach below 0°C and therefore special steel is required.

- **Profiles**

The structure is made out of pipe profiles with two different dimensions. The diagonal and longitudinal pipes in the skid frames are made of a smaller pipe. The stiffeners on the skid frame are made of plate material. Properties of the pipes and plates are shown in Table 4.1 and Table 4.2.

Table 4.1 Pipe properties

Dimensions [Ø * Wall thickness] [mm]	[Inch]	Weight [kg/m]	Steel
DIN 273 * 6.3	10.75	41.4	S355J2
DIN 219.1 * 8	5.625	41.6	S355J2
DIN 914 * 16	36	354	S355J2

Table 4.2 Plate properties

Thickness [mm]	Weight [kg/m²]	Steel
20	157	S355J2
30	235.5	S355J2

- **Skid bottom surface on seafloor**

The structure will rest with its skids on the seafloor. The total weight of the structure will be divided over the surface which will touch the soil. Assuming that the front plate and a certain part of the pipe profile will touch the soil the total contact surface per skid is as follows:

Table 4.3 Skid surface

Section	Surface [mm²]	Surface [m²]
Surface pipe section	8000 * 100 = 800.000	0.8
Surface front plate	1800 * 500 = 900.000	0.9
Total surface	800.000 + 900.000 = 1.700.000	1.7

- Connections

Flanges

The main frame, skid frame and skids are connected with slip-on flanges. The flanges are welded on the pipe and are mutually connected with bolts. The flanges are both from the inside and outside welded with a fillet weld. Since the flanges are not exposed to high pressures, a 150 class flange is chosen. Figure 4.1 shows the interface between the pipe and flange, and welding points.

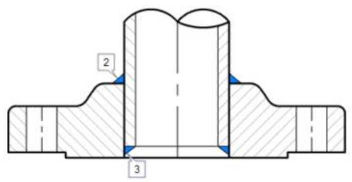


Figure 4.1 Cross section flange/pipe (Wermac, 2016)

Figure 4.2 ASME B16.5 Slip-on flange

The following flanges are used:

- ASME B16.5 class 150 8"
- ASME B16.5 class 150 10"

Welds

The pipes are welded together with a full penetration V weld. The thumb rule of 1.5 times the thickness of the material will be used to make sure that the weld is strong enough. The welds of the stiffeners are made with a full penetrated bevel weld.

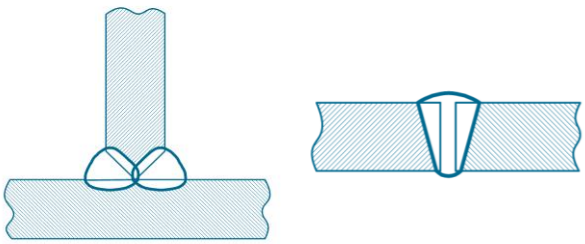


Figure 4.3 Welds examples (Concept draw, 2016)

- Guidance frame

The rollers are installed on a U-shaped construction which can lower vertically on the pipeline. Nine rollers are installed divided over three rows. The centre spacing between the rollers is 450 mm to make sure that one row of rollers will always stay in contact with the pipe when crossing a field joint. The spacing between the two frames is 6600/16600 mm (small/large structure). By this the two guidance frames can never cross a field joint at the same time. (Length of pipe is ±12300 mm, see section 1.2)

Figure 4.4 Guidance frame

- **Skids**

The skids have the same dimensions as the old skids and are based on the same principle. The skid is reinforced by steel plates on the inside. Besides the reinforcement they also function as chambers. These chambers can be (partially or completely) filled with air to make the skids weigh less underwater. Each chamber has two openings on top to add/remove water/air. One opening is provided with a small pipe which lowers to the bottom of the chamber to pump the water out. Both the openings are closed with a bolt. A drawing of the skids with general dimensions can be found in Appendix F – Inventor model.

- The skid is made of a DIN Ø914*16 mm pipe.
- All plate material on the skids has a thickness of 20 mm.

4.1.2 **Lifting**

The structures will be lifted with the use of steel wire ropes, also called slings. These slings will be connected to the pad eyes with shackles. Appendix K – Lifting/towing arrangement shows the configuration of the slings for both structures during lifting. The following slings will be used:

Large structure - 6*7 IWRC, ultimate strength 1770 N/mm2, DIA 18 mm, M.B.L. 190 kN
- 6*7 IWRC, ultimate strength 1770 N/mm2, DIA 36 mm, M.B.L. 761.58 kN

Small structure - 6*7 IWRC, ultimate strength 1770 N/mm2, DIA 18 mm, M.B.L. 190 kN

For the large structure a spreader bar is needed to prevent the construction of bending in the longitudinal direction. The spreader bar needs to have a length of 10 meters and the same SWL as the connected lifting appliances plus its own weight (Codes for lifting Appliances in a marine Environment, 2016).

4.1.3 **Towing**

The structures will be towed to move along the pipeline. The towing wires will be connected to the front skids and the vessel. To prevent the towing wires of lifting the structure, the maximum angle of towing may be 5°. A clump weight is needed to generate the towing load out of the connection with the vessel. Appendix K – Lifting/towing arrangement shows the towing configuration including the clump weight.

Weight clump weight = 14.8 Tonnes

4.1.4 Small structure

The small structure is made for the smaller scope of 1/2*OOD BOP. Therefore only one set of jet swords is installed, because of the limited trenching depth. On both ends a guiding frame is installed to make sure that the jet sword will not touch the pipe and will be guided along the pipe. These can adjust in height so that the rollers always touch the pipeline, and hereby the distance to the pipe can constantly be measured. See Figure 4.5 and Figure 4.6 for an impression of the structure. In Appendix F – Inventor model more figures of the construction are available.

Table 4.4 Overall dimension small structure [mm]

Length	10000
Width	10300
Height*	1547.5

* Distance from ground surface to bottom of main frame.

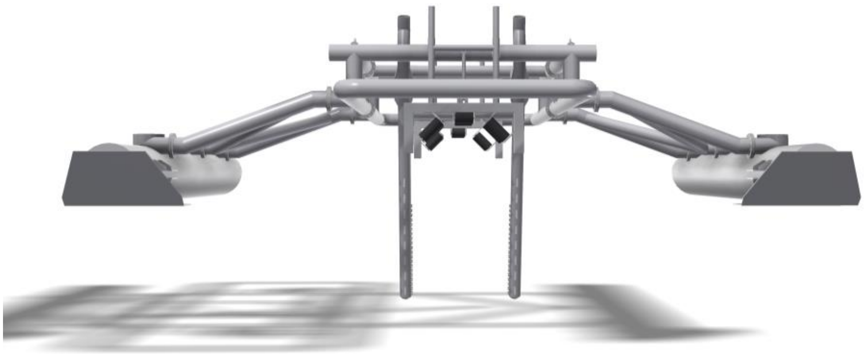


Figure 4.5 Small structure front view

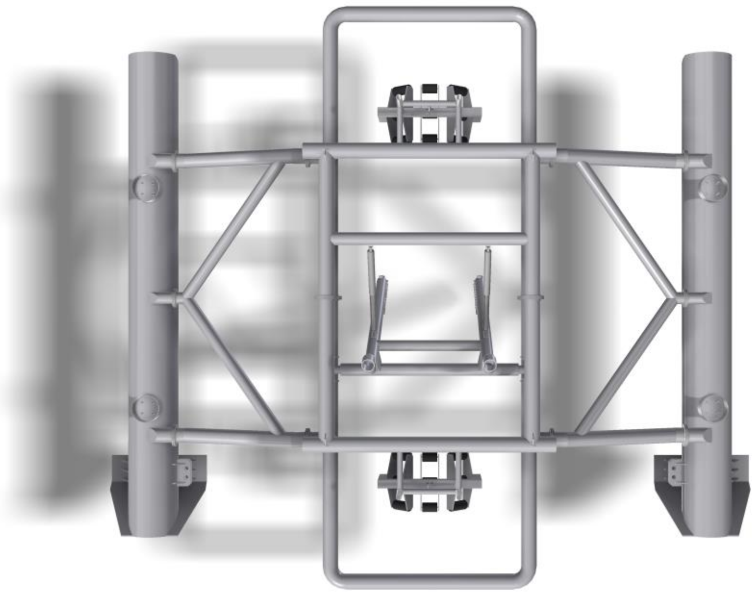


Figure 4.6 Small structure top view

- **Above water weight of structure**

The structure has a weight of around 13700 kg above water. This includes the weight of the guiding frames, skids and jet sword. See Table 4.5 for a parts overview of the small structure.

Table 4.5 Part list small structure

#	Part	Amount	Weight [kg]	Total weight [kg]
1	Main frame - outside	2	1045	2090
2	skid frame - small	2	538	1076
3	guidance frame - including cylinders	2	385	770
4	Jet sword - including cylinders	1	1250	1250
5	Jet swords cylinder support	1	115	115
6	Jet sword support	2	115	230
7	skids	2	3740	7480
8	skid connections	6	18	108
9	skid pad eyes - towing	2	50	100
10	lifting pad eyes	4	4	16
11	M24 Bolt 90 mm - (12 per flange)	144	0.443	63.8
12	M24 Nut - (12 per flange)	144	0.129	18.6
13	M22 Bolt 90 mm - (8 per flange)	16	0.372	6
14	M22 Nut - (8 per flange)	16	0.105	1.7
15	ASME B16.5 slip-on flange 8"	4	12	48
16	ASME B16.5 slip-on flange 10"	24	16.3	391.2
			Total weight	13764.2
				13800 kg

- **Under water weight of structure**

The structure weighs less underwater as a result of the underwater weight of steel and the buoyancy of the skids. The normal density of steel is 7850 kg/m³, when underwater the water density must be subtracted from the steel density. This results in an underwater weight of;

$$7850 - 1025 = 6825\ kg/m^3.$$

Weight of structure underwater;

$$\frac{13800}{7850} * 6825 = 11998\ kg$$

When the skids are filled with air, they will provide buoyancy and are therefore assumed to be weightless. The skids have an underwater weight of;

$$\frac{3740}{7850} * 6825 = 3250\ kg$$

This will make the underwater weight of the small structure;

$$11998 - (2 * 3250) = 5498\ kg$$

With a contact surface of 1.7 m² per skid (Table 4.3 Skid surface) the total ground pressure will be;

$$5498 * \frac{9.81}{2 * 1.7} \approx \mathbf{15900\ N/m^2}$$

4.1.5 Large structure

The large structure is made for the 1.0-m TOP scope, and has two jet swords installed. The reason for this is the depth of the trench. Usually for a 1.0-m TOP scope the pipeline has to be trenched two times for reaching its desired depth, which is called a second pass. With two jet swords installed on the structure the 'second pass' can be done in one pass. This will save a lot of time and thereby a lot of money. The length between the first and second jet sword is around 10 meters in the actual design. This can be adjusted by increasing the length between the swords. A reason for this is keeping the soil in suspension for a longer period, in case the touch-down point of the pipe is further. Figure 4.7 and Figure 4.8 give an impression of the structure.

Table 4.6 Overall dimensions large structure [mm]

Length	20000
Width	17300
Height*	1597.5

* Distance from ground surface to bottom of main frame.

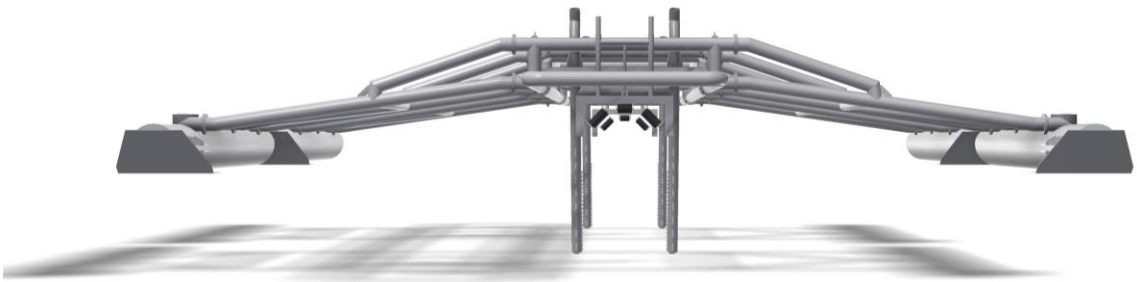


Figure 4.7 Large structure front view

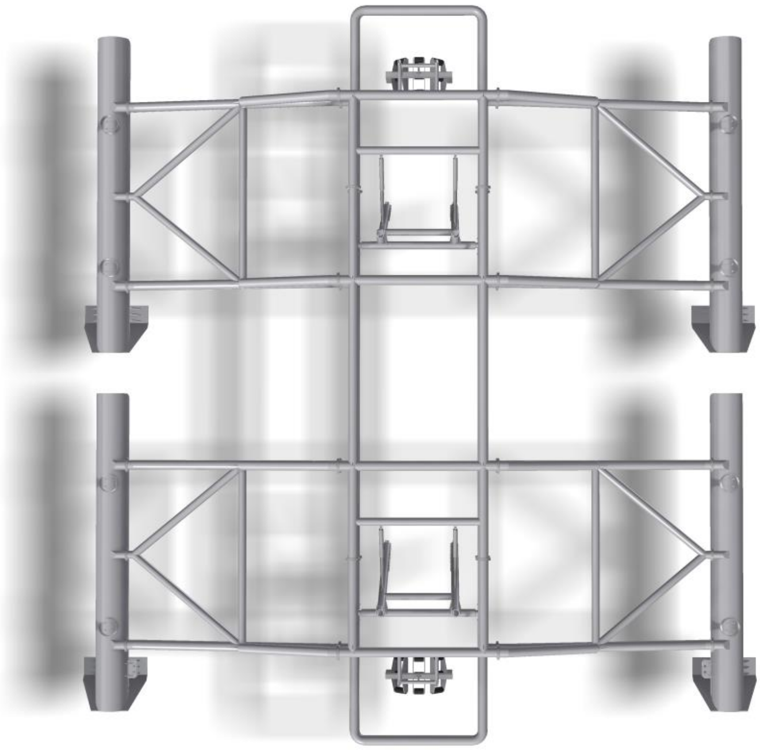


Figure 4.8 Large structure top view

To reduce the stresses at some pipes of the skid frames, stiffeners are welded against the corners of the pipe connections, see Figure 4.9. The stresses in the skid frame of the small structure do not exceed the allowable stresses and are therefore not reinforced with stiffeners.

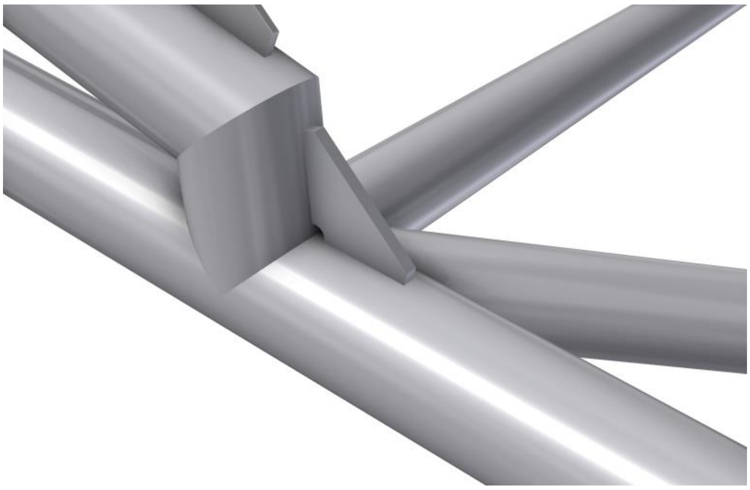


Figure 4.9 Stiffener at pipe connection

- **Above water weight of structure**

The large structure has more components than the small structure and is therefore heavier, in Table 4.7 a list of all the parts and total weights can be found.

Table 4.7 Part list large structure

#	Part	Amount	Weight [kg]	Total weight [kg]
1	Main frame - outside	2	1045	2090
2	Main frame - inside	1	2240	2240
3	skid frame - large	4	1400	5600
4	guidance frame - including cylinders	2	385	770
5	Jet sword - including cylinders	2	1250	2500
6	Jet swords cylinder support	2	115	230
7	Jet sword support	4	115	460
8	skids	4	3740	14960
9	skid connections	12	18	216
10	skid pad eyes - towing	2	50	100
11	lifting pad eyes	8	4	32
11	M24 Bolt 90 mm - (12 per flange)	384	0.443	170.1
12	M24 Nut - (12 per flange)	384	0.129	49.5
13	M22 Bolt 90 mm - (8 per flange)	32	0.372	11.9
14	M22 Nut - (8 per flange)	32	0.105	3.4
12	ASME B16.5 slip-on flange 8"	8	12	96
13	ASME B16.5 slip-on flange 10"	64	16.3	1043.2
			Total weight	30572.1
				31000

- Underwater weight of structure

With same theory as described in section 4.1.4, the underwater weight and ground pressure can be calculated.

Weight of structure underwater;

$$\frac{31000}{7850} * 6825 = 26952\ kg$$

When the skids are filled with air, they will provide buoyancy and are therefore weightless. The kids have an underwater weight of;

$$\frac{3740}{7850} * 6825 = 3250\ kg$$

This will make the underwater weight of the large structure;

$$26952 - (4 * 3250) = 13952\ kg$$

With a contact surface of 1.7 m² per skid (Table 4.3 Skid surface) the total ground pressure will be;

$$13952 * \frac{9.81}{4 * 1.7} \approx \mathbf{20100\ N/m^2}$$

4.1.6 **3D print model**

A 3D-model is printed to visualize the concept. The model is printed with the in-house 3D printer from Allseas, and has a length of 180 mm and a width of ± 165 mm. See Figure 4.10 to get an impression of the print.

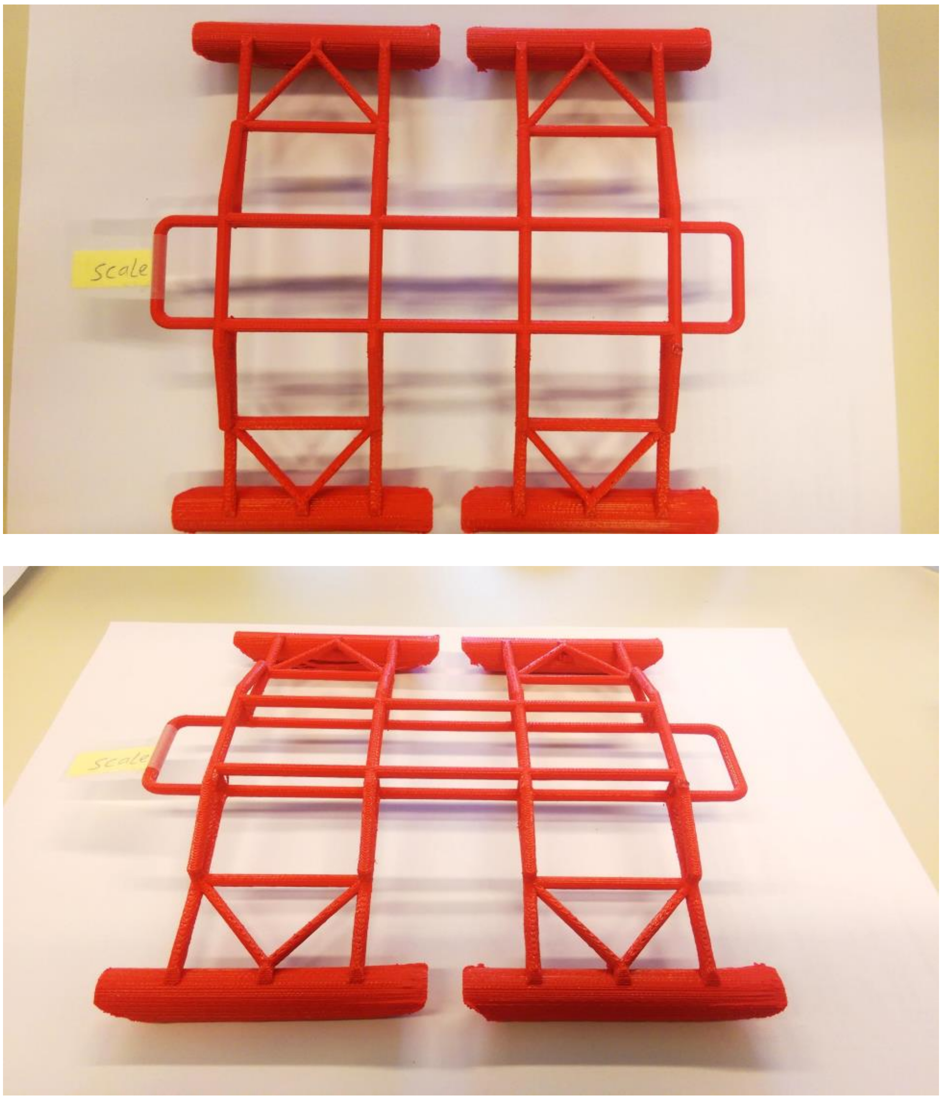


Figure 4.10 3D printed model (scale 1:111)

4.2 Load cases

In this chapter the different load cases are described. A more detailed description of the load case can be found in Appendix G – Load cases. In section 4.2.1 the allowable stresses are shown.

4.2.1 Allowable stresses

The allowable stresses are given by different rules, codes and standard in the offshore industry. For this project the following codes and standards are used:

- [REG1] - Lloyd's Register of Shipping (July, 2016). Codes for lifting Appliances in a marine Environment.
- [REG2] - Allseas Engineering B.V. (November, 2002). Stand criteria for lifting Appliances.

Table 4.8 S355J2 properties

Material	Yield strength [N/mm²]	Ultimate tensile strength [N/mm²]	σ_Y/σ_U
S355J2	355	510	0.7

$$\sigma_a = F * \sigma_y$$

σ_a = allowable stress
F = stress factor
σ_Y = failure stress

The stress factors, F, for steels in which $\sigma_y/\sigma_u \leq 0,85$.

Table 4.9 Load cases and stress factors, *F*

Load case	**1**	2	3 and 4
Stress factor, *F*	**0.67**	0.75	0.85

Load case 1 is for operational conditions, and therefore used in the calculations.

$$\sigma_a = 0.67 * 355$$
$$\sigma_a = 238\ [N/mm^2]$$

Table 4.10 Allowable stresses

Mode of failure	Symbol	Failure stress	Allowable stress [N/mm²]
Tension	σ_t	$1.0 \cdot \sigma_a$	238
Compression	σ_c	$1.0 \cdot \sigma_a$	238
Shear	τ	$0.58\ \sigma_a$	138
Equivalent stress	σ_e	$1.1\ \sigma_a$	261

For components subjected to combined stresses, the following allowable stress criteria are to be used:

(a) $\sigma_{xx} \leq \sigma_a$
(b) $\sigma_{yy} \leq \sigma_a$
(c) $\tau_o \leq \tau_a$
(d) $\sigma_e = \sqrt{{\sigma_{xx}}^2 + {\sigma_{yy}}^2 - \sigma_{xx} * \sigma_{yy} + 3 * {\tau_o}^2} \leq 1.1 * \sigma_a$

Where:

σ_{xx} = applied stress in X direction
σ_{yy} = applied stress in Y direction
τ_o = applied shear stress

4.2.2 Load case structure in air

For the situation where the structure is in the crane the following load cases are made, see Table 4.11. For more information about the load cases Appendix G – Load cases can be consulted.

Table 4.11 Load cases in air (P=7850 kg/m³)

LC	Load case	Description	Parameters
1	Standing on deck	Trencher is resting on skids	a = 9,81 m/s²
2	Deploying in air	Trencher is connected at pad eyes	a = 9,81 m/s²
3	Heave compensation fail in air	Extra acceleration from ship motion, plus water drag	VO; a = 2,54 m/s² v = 2.79 m/s CJ; a = 2,71 m/s² v = 2.98 m/s

1. Standing on deck

When the structure is standing on its skids a gravitational acceleration of 9.81 m/s² is felt. This generates stresses in the pipes as a result of its own weight.

2. Deploying in air

When the trencher is deployed in the air, a gravitational acceleration of 9.81 m/s² will be felt and stresses will occur as results of loads in de lifting points. For the small structure the lifting points are placed at the top of the main frame. For the large structure the lifting point are placed in de middle of the skid frame, at the end of the upper pipe.

3. Heave compensation fail in air

When the structure hangs in the crane the heave compensation is operating. By this way the ships motions are dampened in the lifting cable and the load. In the worst case scenario when the heave compensation will shut down, the structure will accelerate with the motions of the ship (in this case the motions of the tip of the crane). The structure will be deployed with the knuckle boom crane of the *Volstad Oceanic (VO),* the motions of the tip of the crane are known and shown in Table 4.11, and obtained from the motion reports given in Appendix J – Motion reports.

In case that the trencher is deployed from the *Calamity Jane (CJ)* the motions will be different, these different motions will also be taken in account during the FEM analysis. Both the motion reports are made for a significant wave height of 3.5 meters. These are extreme weather conditions in which trenching is already impossible. It could be the case that the trencher will be retrieved when this wave height is expected, for this reason this is taken as worst case scenario.

4.2.3 Load case structure submerged

When the structure is submerged in the water, different load cases will be made. Due the water, the steel density 'decreases' which makes the structure weigh less. In Table 4.12 the load cases for underwater conditions are shown.

Table 4.12 Submerged load cases (P=6825 kg/m³)

LC	Load case	Description	Parameters
4	Standing on seafloor	Trencher is resting on skids	a = 9,81 m/s²
5	Deploying submerged	Trencher is connected at pad eyes	a = 9,81 m/s²
6	Heave compensation fail submerged *	Extra acceleration from ship motion, plus water drag	VO; a = 2,54 m/s² v = 2.79 m/s CJ; a = 2,71 m/s² v = 2.98 m/s
7	Towing	Friction of skids + jet sword(s)	v = 300 m/hr = 0,08 m/s
8	Guidance frame	Load from guidance frame on main frame	a = 0.5 m/s²
9	Hydrostatic pressure	Depth of max 120 meters	*p* = 12 bar = 1,2 N/mm²
10	Splash zone **	Crossing the splash zone	a = 9.81 m/s²

* maximum winch velocity of the crane is 100 m/min = 1.67 m/s, if load case 5 meets the requirements normal condition will stand the load.

** Load case of crossing the splash zone lies beyond the scope, and will therefore not be analysed.

4. Standing on seafloor

In this load case the structure will stand on its skids and will be influenced by the gravitational acceleration. Due the reduced weight the stresses will be less than above water.

5. Deploying submerged

When the structure is deploying submerged, the complete weight of the trencher will be hanging in the pad eyes. The weight underwater is less than above water due the underwater density and the buoyancy of the skids.

6. Heave compensation fail submerged

When the structure is deployed by the crane and fully submerged, the complete weight of the structure will hang in the pad eyes. In the worst case the heave compensation of the crane will fail and the structure will accelerate with the same acceleration of the ship. Besides the extra acceleration, a load as a result of the water drag will increase the stresses.

7. Towing

During towing of the structure skids will undergo friction with the soil. The towing force in the steel towing wires needs to overcome the resultant load of these frictions. The towing wires will be connected to the skid frame, as this will generate the least stresses on the complete frame.

8. Guidance frame

During trenching the structure will be guided along the pipe by the guidance frames. When the pipeline makes a bend these frames will align the structure along the bend, resulting in a load of the guidance frames onto the main frame. When the structure is lowered on the pipeline and the guidance frame touches the pipe first, loads in the frame can occur due horizontal movement of the structure. These loads will be completely felt in the guidance frames.

9. Hydrostatic pressure

The trencher will operate in shallow waters at a maximum depth of 120 meters. This will result in a hydrostatic pressure on the structure, which it has to withstand. The hydrostatic pressure will only influence the pipes, since they are pressurised at 1 bar (atmospheric pressure).

10. Splash zone

Crossing the splash zone is the moment when the structure will go from above water to under water. During this operation, unexpected loads can occur and generate large stresses in the structure. The exact loads are not known and require a separated study. Therefore this load case lies beyond the scope and will not be analysed.

4.2.4 Skids

The skids will be analysed on two load cases. The first one is carrying the weight of the complete structure and the second one is the load of the towing wires.

4.3 Femap analysis

In this chapter the results of the FEM-analysis will be shown. The different load cases mentioned in the previous section are analysed. In the Femap analyses different stresses will result. These stresses have to be known to make sure that they stay below the allowable stresses which are given by the Lloyd's register. At the end, the reason to know these stresses is to make sure if the structure is strong enough to be operational and survive the expected stresses. The following stresses will be obtained:

- Axial stress : $\sigma_{axial} = F/A$
- Principal stress : resulting stress of tensile/compression loads in all three dimensions.

4.3.1 Units

FEM:

Length: [mm]
Mass / Weight: [kg], [tonne] = 1000 [kg]
Time: [s]
Force: [N]
Angle: [°] (non-SI unit)
Vessel speed: [kN] (non-SI unit)
Stress: [MPa or N/mm2]

4.3.2 Constants

g = gravitational acceleration = 9.81 [m/s²]

4.3.3 Small structure

Layout of FEM model

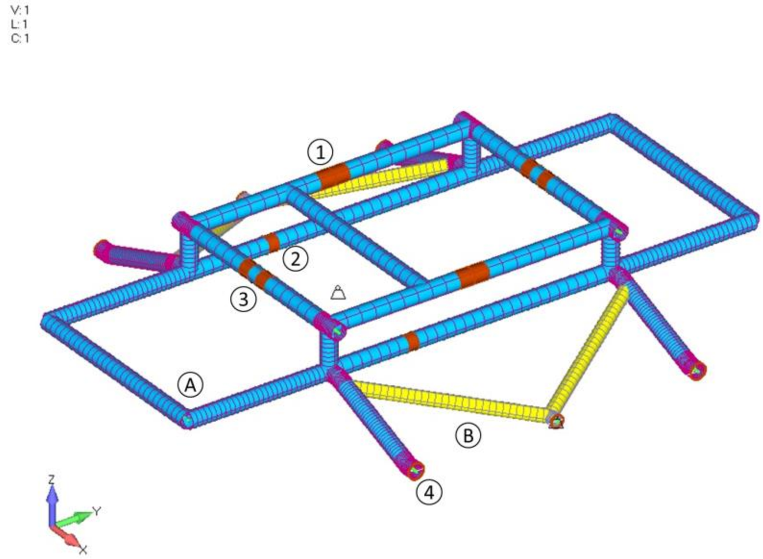


Figure 4.11 Layout of small structure FEM model

Elements

The model exists of beam elements combined with non-structural mass regions. These regions add extra mass to the model where equipment is constraint.

A. Pipe Ø 273 * 6.3 W.T [complete frame, A = 5279 mm²]
B. Pipe Ø 219.1 * 8 W.T. [inner pipes of skid frame]
1. Extra weight of equipment [2000 kg per side]
2. Weight of jet swords [625 kg per side]
3. Weight of guidance frame [385 kg per side]
4. Weight of skids [3740 kg per side, divided over three ends]

Stress evaluation in air

For the stress results the envelop function FEMAP is used. When using this function the maximum and minimum stresses of all load cases are shown in one output. The maximum and minimum combined stresses are shown and can be presented as the maximum and minimum principal stresses. For the different load cases the following stresses can be found:

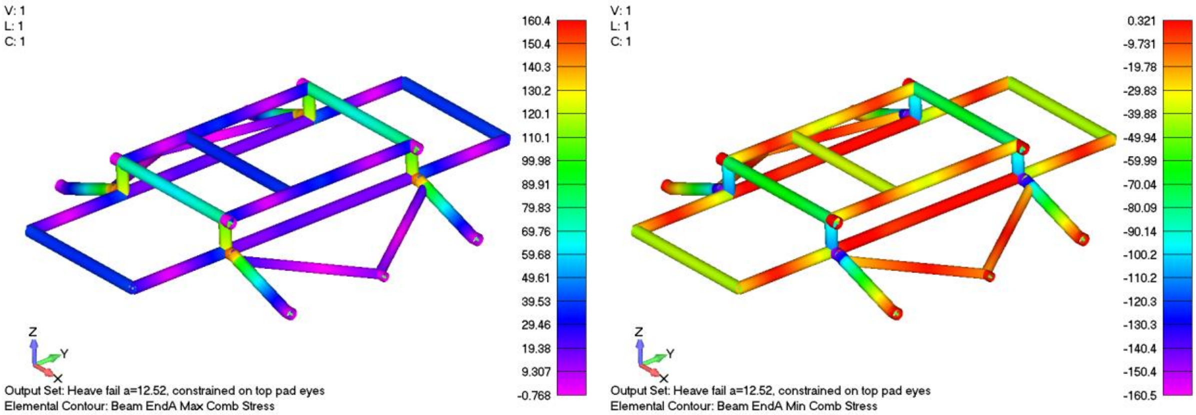


Figure 4.12 Max. and min. principal stress small structure, LC 4 in air (max. allowable ±238 MPa)

Table 4.13 FEM results small structure in air

#	Description	Maximum axial force [N]	Maximum principal stress [MPa]
1	Standing on deck	60396	90.12
2	Deploying in crane	30085	125.8
3	Heave compensation fail, VO	37875	158.3
4	Heave compensation fail, CJ	38396	160.5

For all the load cases the highest stresses can be found at the connection of the skid frames to the main frame. This can logically be explained by the weight of the skids which generate a moment around this point. The stresses are at its highest in load case 4, where an extra acceleration of 2.54 m/s^2 is felt on top of the gravitational acceleration. The maximum principal stress of 160.5 MPa, see Figure 4.12, is below the allowable stress and therefore acceptable.

The maximum axial which is found in the structure is as follows;

$$Maximum\ axial\ stress: \frac{60396}{5279} = 11.44\ MPa$$

The maximum stress which is found in the complete structure leads to the following unity check;

$$\boldsymbol{Unity\ check}: \frac{\mathbf{160.5}}{\mathbf{238}} = \mathbf{0.67}$$

Stress evaluation submerged

For the submerged analysis the non-structural regions of the skids are disabled due the buoyancy capacity of the skids, therefore they are assumed to be weightless. In the heave compensation fail load cases an extra load is applied at the end of the skid frames to simulate the drag of the skids.

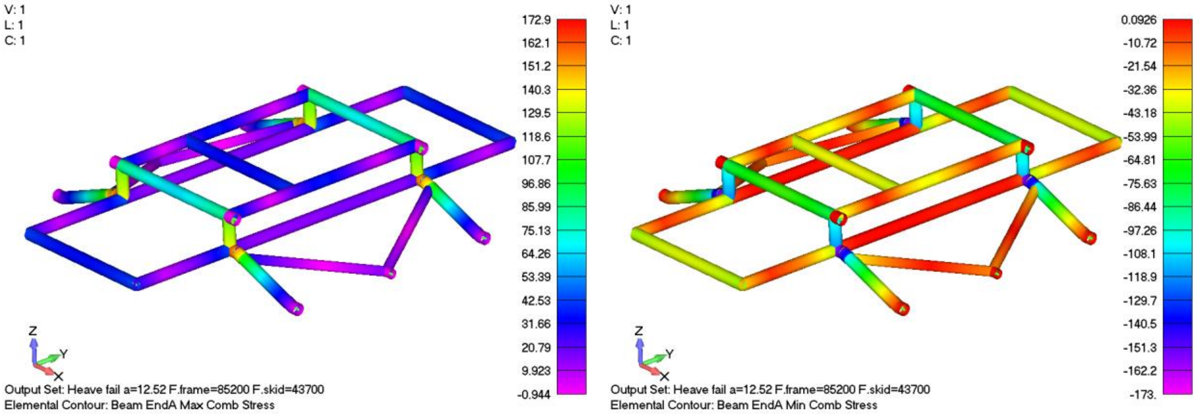


Figure 4.13 Max. and min. principal stress small structure, LC 4 submerged (max. allowable ±238 MPa)

Table 4.14 FEM result small structure submerged

LC	Load case	Maximum axial force [N]	Maximum principal stress [MPa]
1	Standing on seafloor	40506	60.7
2	Deploying submerged	12830	32.15
3	Heave compensation fail submerged VO	40334	144.2
4	Heave compensation fail submerged CJ	46886	173
5	Towing	60410	71.89
6	Guidance frame	21225	157.1

The maximum stress can be found at the skid frame connections to the main frame, where a moment is generated as result of the skids. The highest stresses can be found in load case 4, where the extra acceleration as result of the heave compensation is added. The maximum principal stress of 173 MPa is found in the skid frame connection, see Figure 4.13. They stay below the allowable stress and are therefore acceptable.

The maximum axial which is found in the structure is as follows;

$$Maximum\ axial\ stress: \frac{60410}{5279} = 11.44\ MPa$$

The maximum stress which is found in the complete structure leads to the following unity check;

$$\boldsymbol{Unity\ check}: \frac{\mathbf{173}}{\mathbf{238}} = \mathbf{0.73}$$

4.3.4 Large structure

Layout of FEM model

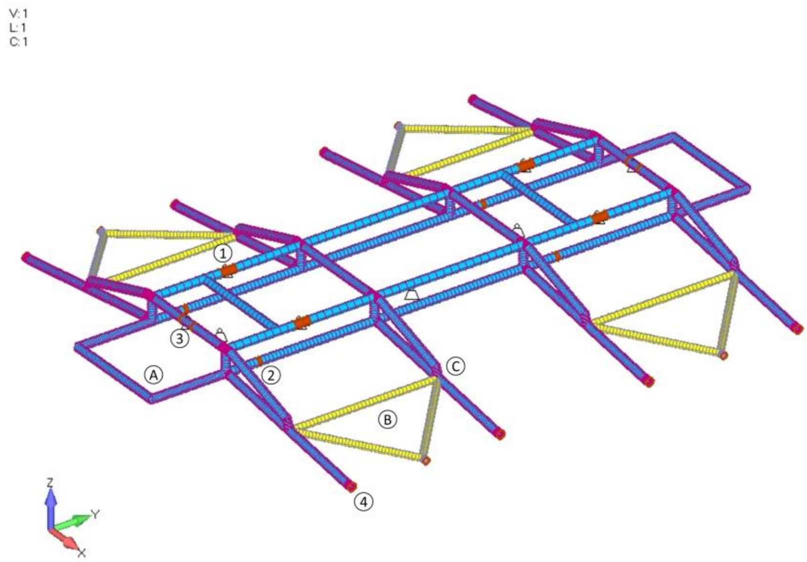


Figure 4.14 Layout of large structure FEM model

Elements

The model exists of beam elements combined with non-structural mass regions. These regions add extra mass to the model where equipment is constraint.

A.	Pipe Ø 273 * 6.3 W.T	[complete frame, A = 5279 mm²]
B.	Pipe Ø 219.1 * 8 W.T.	[inner pipes of skid frame]
C.	Plate PL6	[stiffener in frame]
1.	Extra weight of equipment	[2000 kg per side]
2.	Weight of jet swords	[625 kg per side]
3.	Weight of guidance frame	[385 kg per side]
4.	Weight of skids	[3740 kg per side, divided over three ends]

Stress evaluation in air

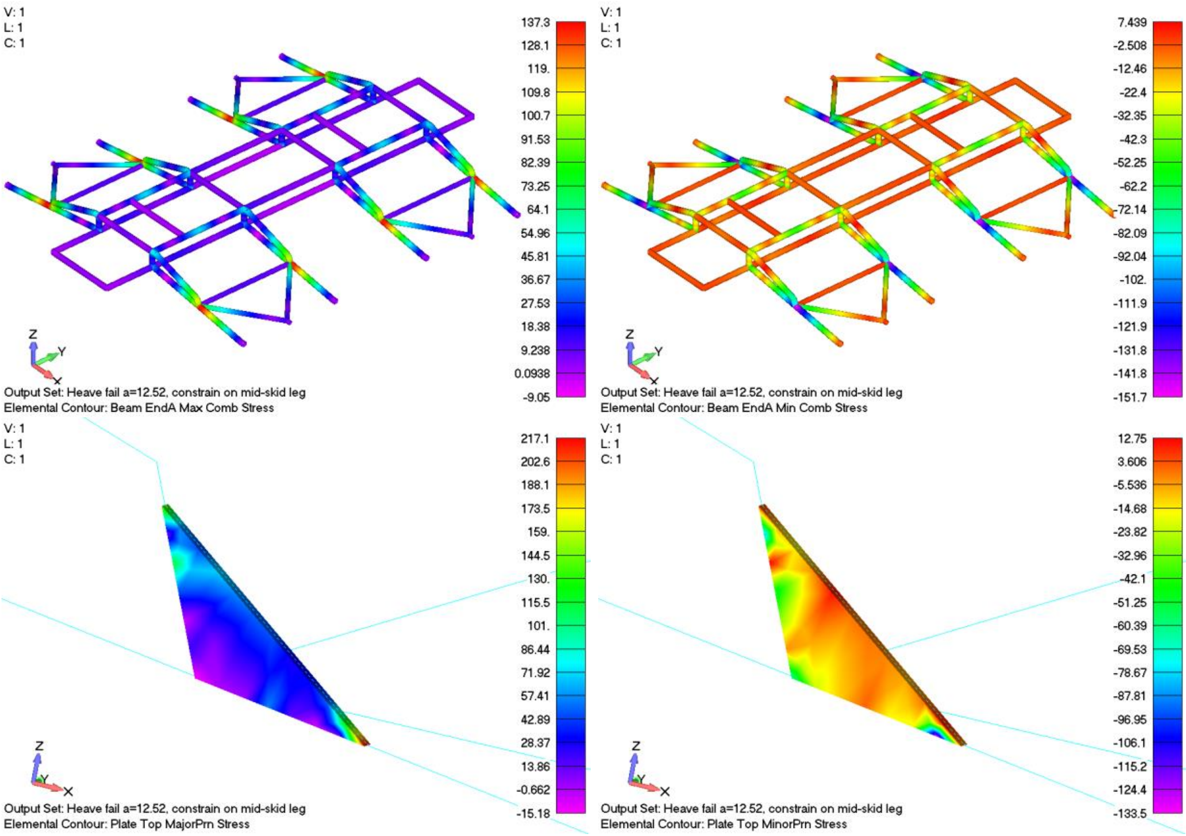


Figure 4.15 Max. and min. principal stress large structure, LC 4 in air (max. allowable ±238 MPa)

Table 4.15 FEM result large structure in air

#	Description	Maximum axial force [N]	Maximum principal stress [MPa]
1	Standing on deck	96984	pipe= 87.21 plate= 93.48
2	Deploying in crane	55387	pipe= 118.9 plate= 170
3	Heave compensation fail, VO	69727	pipe= 149.7 plate= 214.1
4	Heave compensation fail, CJ	70687	pipe= 151.7 plate= 217.1

The maximum stresses can be found in de middle section of the skid frames. This can be explained due the fact that the structure is rigged at the pad eyes above these points. Therefore the weight of the skids will generate a moment around this point. To reduce the stress at the pipe connection, a stiffener plate is added, this plate reduces the bending stress between the pipes and therefore the maximum principal stress. The maximum stress of 151.7 MPa in the pipe and 217.1 MPa in the stiffener plate stay below the allowable stress and are therefore acceptable, see Figure 4.15.

The maximum axial which is found in the structure is as follows;

$$Maximum\ axial\ stress\!: \frac{96984}{5279} = 18.37\ MPa$$

The maximum stress which is found in the complete structure leads to the following unity check;

$$\boldsymbol{Unity\ check}\!: \frac{\mathbf{217.1}}{\mathbf{238}} = \mathbf{0.91}$$

Femap only shows the shear stress and Von Mises stress in plate elements. These stresses in the stiffener plate are as follows:

Table 4.16 Shear and Von Mises stress large structure in air

Stress	Maximum stress [MPa]	Unity check
Max. shear stress	110	110/138 = 0.8
Max. Von Misses stress	218.6	218.6/261 = 0.84

Stress evaluation submerged

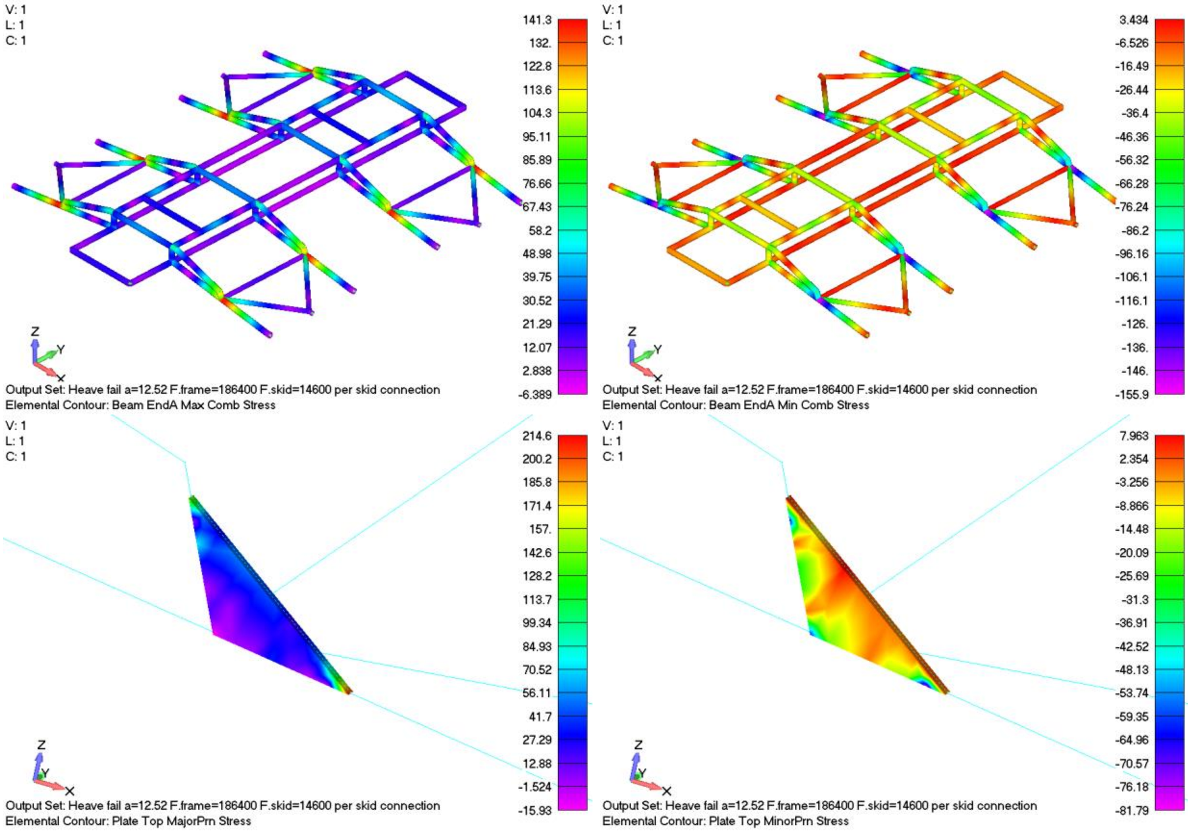


Figure 4.16 Max. and min. principal stress large structure, LC 4 submerged (max. allowable ±238 MPa)

Table 4.17 FEM result large structure submerged

LC	Load case	Maximum axial force [N]	Maximum principal stress [MPa]
1	Standing on seafloor	82238	pipe= 73.42 plate= 185.7
2	Deploying submerged	46995	pipe= 98.18 plate= 19.71
3	Heave compensation fail submerged VO	57170	pipe= 129.9 plate= 175.8
4	Heave compensation fail submerged CJ	71297	pipe= 155.9 plate= 214.6
5	Towing	103591	pipe= 95.12 plate= 250.7
6	Guidance frame	48660	pipe= 95.92 plate= 17.23

The maximum stresses can again be found in the middle section of the skid frames. Due the water drag and extra acceleration on the skids a moment is generated on this point. The stiffener plates will prevent the stresses in the pipe to exceed the allowable stress. The maximum stress of 155.9 MPa is found in the pipes and 250.7 MPa in the stiffeners, see Figure 4.16. The maximum stress in the plate material exceeds the allowable stress. Section 2.17.8 in Lloyd's register tells that the allowable stress may be multiplied with 10% in case of a structural analysis by means of a finite element model.

The maximum axial which is found in the structure is as follows;

$$Maximum\ axial\ stress: \frac{103591}{5279} = 19.6\ MPa$$

The maximum stress which is found in the complete structure leads to the following unity check;

$$\boldsymbol{Unity\ check}: \frac{\mathbf{250.7}}{\mathbf{238 * 1.1}} = \mathbf{0.96}$$

The maximum shear stress and Von Misses stress found in the skid plates are as follows:

Table 4.18 Shear and Von Mises stress large structure submerged

Stress	Maximum stress [MPa]	Unity check
Max. shear stress	124.1	121.4/138 = 0.88
Max. Von Misses stress	249.4	249.4/261 = 0.96

4.3.5 Skids

The skids need to withstand the load of the complete structure. They are therefore also analysed in Femap and the results are shown below. The three connection points are modelled at the top of the skid where the load of the structure will be applied. The towing load will be applied at the square surface on the side. The maximum weight on top of one skid is 31000/4 = 7750 kg.

Figure 4.17 Skid lay-out

Stress evaluation skids

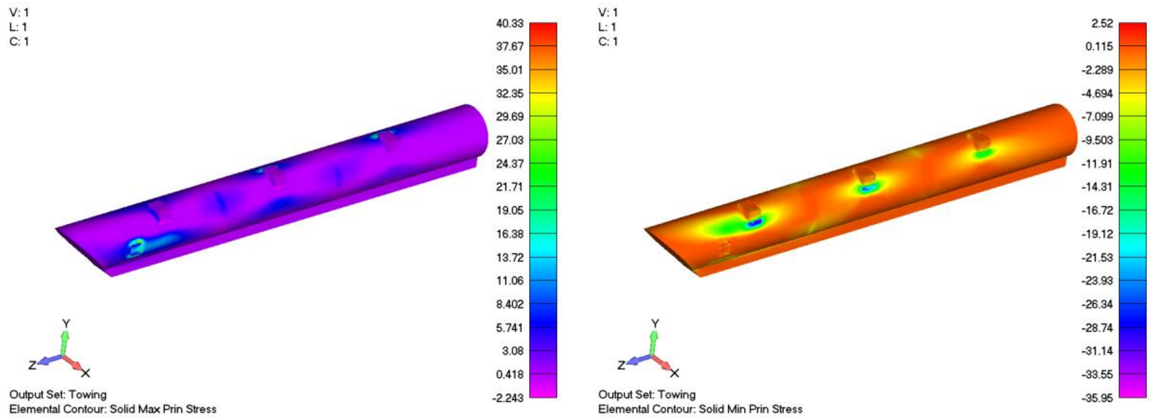


Figure 4.18 Max. and min. principal stress skid (max. allowable ±238 MPa)

Table 4.19 FEM results skids

LC	Load case	Maximum principal stress [MPa]	Minimum principal stress [MPa]
1	Weight of structure	19.66	25.02
2	Towing load	40.33	35.95

The maximum principal stress can be found around the pad eye during towing. The minimal principal stress is found around the skid frame connections. The highest stress is 40.33 MPa which is below the allowable stress and therefore acceptable, see Figure 4.18.

$$\boldsymbol{Unity\ check}: \frac{\mathbf{40.33}}{\mathbf{238}} = \mathbf{0.17}$$

The maximum shear stress and Von Misses stress found in the skid is as follows:

Table 4.20 Shear and Von Mises stress skid

Stress	Maximum stress [MPa]	Unity check
Max. shear stress	19.25	19.25/138 = 0.14
Max. Von Misses stress	33.81	33.81/261 = 0.13

4.3.6 **Maximum stresses**

The FEM results show that the highest stresses occur when the heave compensation will fail. These stresses are seen at the connection of the skid frames at the small structure and the in the middle of the skid frames of the large structure. In both structures these are the places close to the lifting pad eyes. These areas are exposed to the highest loads due the load of the lifting wires and the moment which will occur around this area as a result of the weight of the main frame and skids.

4.4 Calculations check

To check the FEM result different calculations have been done. The calculations are made for the pipes where the highest stresses are expected. The calculations are conservative and have therefore different results compared with the FEM analysis.

Appendix H – Calculations contains the calculation sheets. For each structure two load cases have been calculated:

- Standing on skids
- Deploying with the crane

4.4.1 **Small structure**

For the load case illustrated in Table 4.21 the following results have been found:

Table 4.21 Stresses small structure [stress in MPa]

Small structure on skids				
Pipe	**Stress**	**Value**	**Allowable**	**U.C.**
1=2	Axial	10.5	238	0.04
1=2	Bending	121.0	238	0.51
3=4	Axial	2.3	238	0.01
3=4	Bending	113.3	238	0.48
5	Axial	19.7	238	0.08

Small structure in crane				
Pipe	**Stress**	**Value**	**Allowable**	**U.C.**
1=2	Axial	1.4	238	0.01
1=2	Bending	134.3	238	0.56
3=4	Axial	2.0	238	0.01
3=4	Bending	134.3	238	0.56
5	Axial	23.3	238	0.10

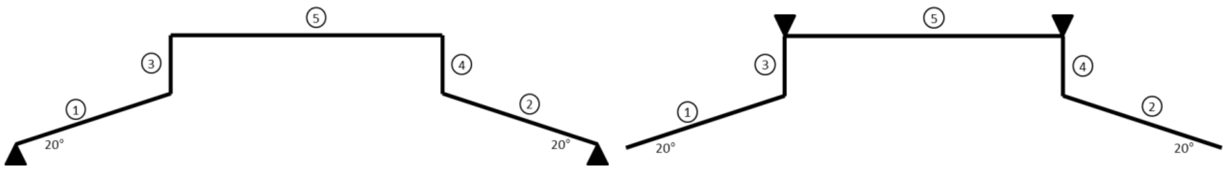


Figure 4.19 Constrains small structure

4.4.2 Large structure

Table 4.22 Stresses large structure

Large structure on skids				
Pipe	**Stress**	**Value**	**Allowable**	**U.C.**
1=2	Axial	0.8	238	0.003
1=2	Bending	267.3	238	1.123
3=4	Axial	36.6	238	0.154
5=6	Axial	1.1	238	0.005
7	Axial	21.4	238	0.090

Large structure in crane				
Pipe	**Stress**	**Value**	**Allowable**	**U.C.**
1=2	Axial	0.6	238	0.002
1=2	Bending	173.1	238	0.727
3=4	Axial	18.8	238	0.079
5=6	Axial	1.1	238	0.005
7	Axial	1.1	238	0.005

Pipe 1 and 2 will exceed the allowable stress as seen in the above table, for this reason a stiffener is added at the connection of pipe 1 and pipe 3. By this the stress stays below the allowable stress, as seen in chapter 4.0 section 4.3.4.

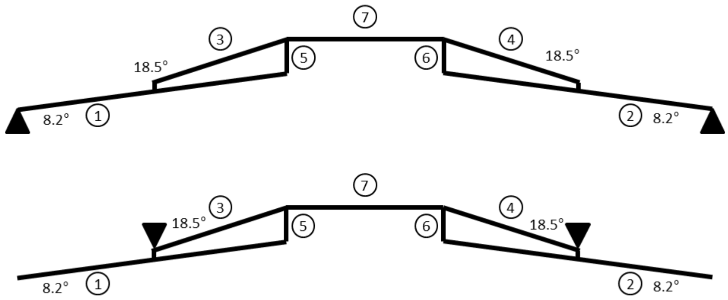


Figure 4.20 Constrains large structure

5.0 FEEDBACK

5.1 Test set of requirements

To prove that all the requirements are met, the complete set of requirements will be tested by explaining how each requirement is met.

- **Trenching pipelines with max. 49" OD [1244.6 mm] (42" + 3.5" coating)**
  Clearance between ground and main frame > 1500 mm, 49" (1244.6 OD mm) pipe fits underneath. The structure is modular for both the scopes and can trench to the desired depth, see chapter 4.0.

- **Trencher main structure should withstand all forces during operational conditions**
  FEM results proves that the structures can withstand all the load cases and stresses stay beneath the allowable stresses, see chapter 4.0 section 4.3.

- **Trencher main structure has to be adjustable for the 0.5*BOP and 1.0-m TOP jetting configuration**
  The structure is modular due the middle frame which can be placed between the two outer frames with flange connections. This makes the structure adjustable for both scopes, see chapter 4.0.

- **No mechanical trenching allowed (part of project)**
  The trencher makes use of jet swords from the old *Jet Sled*, hereby the trencher does not make use of mechanical trenching and does not conflict with the Jones Act, see chapter 4.0.

- **The unprotected field joint may not be touched**
  The field joint has a length of ±770 mm. The centre spacing of the two outer rows of the guidance frame is 900mm, which makes sure that one row of rollers will always touch the pipe. Preventing the other rollers of entering the field joint. See chapter 4.0 section 4.1.1.

- **The trencher must be able to move on a seabed of 3 kPa**
  The small structure has a ground pressure of 15.9 kPa, the large construction 20.1 kPa. This means that a part of the weight has to be lifted by the crane where the soil is softer than these values, see chapter 4.0 section 4.1.4 and 4.1.5. This requirement is partially met, because the structure cannot stand on its complete own weight in all soil conditions. To make this possible the skids need to have a larger surface, this leads to more material and more friction during towing. This would lead to an unrealistic large skid, and an too high load on the structure. Therefore this problem is mitigated by assuming that a part of the weight will be lifted by the vessels crane in areas where the soil is too soft.

- **Trencher must fit on the deck of Volstad Oceanic (VO)**
  The trencher has the maximum dimensions of 20* 17.3 m (length*width) and fits thereby on the stern deck of the *Volstad Oceanic* which has a width of 25 meters with a length of 23 meters, see chapter 4.0 section 4.1.5.

- **Trencher may have a maximum weight of 90 tonnes (lifting capacity of deck crane VO at maximum reach)**
  The large structure has a weight of 31000 kg (31 tonnes), and can therefore be lifted by the crane. See chapter 4.0 section 4.1.5.

- **Distance between jet swords, eductors and rollers to be adjustable**
  The jet swords are suspended by steel blocks which can be placed along the main frame. The cylinders can be attached to multiple pipes on the top, as well that the current cylinder support pipe can be replaced to fit the jet swords. See chapter 4.0 section 4.1. Eductors are not installed on the current trencher, but might be installed for future project. In this case they will be combined with the jet swords, to remove the soil right after it is been loosened.

The requirement for adjustable rollers was based on the old *Jet Sled* where the rollers where placed in the same supports of the jet swords. The current guidance frames are placed to never cross a field joint at the same time, so that one guidance frame will always be completely in touch with the pipe. Also the rollers on the frame have a spacing of 450 mm, so that one set of rollers will always touch the pipe. By this it is not needed to adjust the distance between the guidance frames, and therefore the rollers.

- **Trencher needs to be dissembled for transport**
  The structure is divided in multiple parts and connected with flanges, these flanges can be dissembled to change the configuration or dissemble the complete structure for transport. See chapter 4.0 section 4.1.1.

- **Underwater weight of the main structure has to be reduced**
  The skids are made of pipe profiles and provide buoyancy when filled with air. This makes the structure weigh less underwater. See chapter 4.0 section 4.1.4 and 4.1.5.

- **Possibilities for mounting extra equipment on the trencher**
  On top of the main frame there are possibilities to mount extra equipment such as submersible pump. Depending on the size, it has to be located not to clash with other equipment, see chapter 4.0 section 4.1 and appendix E.

- **Main structure should be able to hold the loads of extra equipment**
  During the FEM analysis an extra weight of 4 tons is applied on top of the small structure and 8 tons on top of the large structure. The stresses stay all below the allowable stresses, see chapter 4.0 section 4.3.

- **Main structure needs to be resistance against unexpected loads**
  A worst case scenario of the heave compensation fail is made in the FEM model, the resulting stresses stay all below the allowable stress, see chapter 4.0 section 4.3.

5.2 FMEA feedback

In this section feedback will be given on the three risks which came out of the FMEA.

- Jet swords

The jet swords will be lowered in the seabed to fluidize the soil. A collision with an unexpected object in the soil can occur which can result in an increasing cylinder load. To prevent the jet swords and cylinder of damage, the cylinder will retract when a load of 5000N is monitored. The FEM analysis shows that the structure can withstand the load of 5000N and therefore the risk limited.

- Rollers

The rollers will guide the structure along the pipeline and will always stay in touch with the pipe. When a roller bearing gets stuck the roller might lock, which can result in damaging the concrete pipe coating. To prevent this situation the rollers are placed on top of the pipe in a 'V' shape. This will prevent the rollers of passing through the soil mixture, as long as the pipe is still on top of the seabed. Besides this action the roller bearings need to be well sealed and the rollers themselves need to be flushed to prevent the soil of entering the bearings.

- Complete frame

The complete frame will undergo high loads when the heave compensation will fail. Especially the large structure will undergo high loads when accelerating with the ships motions, due the longer skid frames. To make sure that the stresses stay below the allowable stress as a result of the extra acceleration and water drag, stiffeners are added to the mid-connections of the skid frame. The FEM results show that the appearing stresses are acceptable.

6.0 CONCLUSION

The aim of this project was to design and develop the main structure of the new *Jet Sled III*, for the upcoming pipe lay project in the Gulf of Mexico. The new design must meet all the requirements demanded by the pipe lay project and Allseas. The three important aspects which have to be taken in account are;

- Strength
- Modularity
- Handling

The structure is based on the old *Jet Sled* and upgraded to the new requirements. A new frame is developed with reinforcements. The structure is made of pipe profiles with the following dimensions; DIN Ø273*6.3 and DIN Ø2191.1*8. The skids are made of DIN Ø914*16 pipe profiles and can be filled with air to provide buoyancy and hereby decreasing the underwater weight. The main frame, skid frames and skids are connected with flanges so that the structure can be dissembled for the other scope or storage.

Strength
Different load cases have shown the loads on the structures. When the heave compensation fails during deploying with the *Calamity Jane* the stresses are at its highest as a result of an extra acceleration of 2.54 m/s^2 The FEM results show that both the structures are strong enough to hold the loads. The maximum load that has been found is 155.9 MPa in the pipe structure and 250.7 MPa in the stiffeners.

Modularity
The construction is modular for both the scopes, by removing or installing the extended main frame between de two outer main frames. This makes it possible to trench the 1.0-m TOP scope in one pass, instead of executing a second pass. Also the soil will be longer suspended, giving the pipeline more time and distance to lower into the trench.

Handling
The structures will be handled with slings connected to the pad eyes on the structure. Four connections are made on top of the main frame of the small structure, eight connections on the middle of the skid frames on the large structure. For the large structure a spreader bar is needed to prevent the structure of bending in longitudinal direction during lifting. The structure will be towed by use of a towing wire connected to the front skids. The towing arrangements contains a 14.8 tonnes clump weight to make sure that the trencher will be towed forwards and not be lifted upwards at the front.

7.0 DISCUSSION

The results of the FEM analyses have shown that the stresses will stay below the allowable stress. Only the stresses in the skid frames will exceed the allowable stress. Therefore stiffeners are added to these points. This has led to a significant drop in the stresses.

The FEM analyses are made of 'beam' elements in Femap. This means that the model in Femap is based on a line-geometry where the program applies the pipes around. At the connections of two different pipes it is seen that the pipes interact. This seems incorrect at first sight, however this will not influence the results.

All the Femap models were checked by a structural engineer of Allseas when they were finished. She checked the configuration of the structures and reviewed the results. She concluded that the stresses in the connections of the pipes might be lower when the structure will be modelled in plate-element compared to modelling with beam-elements. However, modelling the complete structure in plate elements requires a lot of work and is not needed, since the structural engineers at Allseas also model with beam elements for Lloyd's certificates. Furthermore, the file would be significantly large which can result in very large process times.

The stresses in the load cases where the trencher will stand on the seafloor will be expected to be less in the real situation. This can be explained due the fact that a part of the structures weight will be lifted by the crane and the rest of the weight will rest on the soil. During the analyses it is assumed that the structure is completely filled with water to simulate the worst case scenario. When the pipes will be filled with air, the underwater weight will be lower due the buoyancy which will result in lower stresses.

Due the soft soil the trencher needs to be partially lifted by the vessels crane. In some parts of the trenching scope the soil has a strength of 3 kPa, which results in a large weight that has to be lifted by the crane in order to not let the structure sink in the soil. Looking at this fact it might not be the ideal solution to use such a large structure for this project since the soil is not stiff enough in some areas to hold the weight of the structure. The constant tension in the vessels crane, and hereby constant use of heave compensation is neither the ideal situation, because this will cause a lot of wear.

8.0 RECOMMENDATIONS

Splash zone

For the stress analyses different load cases have been worked out, except the crossing of the splash zone. This load case needs to be investigated to see what kind of loads will appear. Special software is available on the market which calculates and simulates the crossing of the splash zone. By using this, the loads can be better estimated and seen if the stresses stay under the allowable stress.

Towing

The structures will be towed with the same vessel as it will be deployed. This will be done with a towing wire including a clump weight. The clump weight makes sure that the trencher is pulled forwards and will not be lifted at the front side when towing. Due the large depth compared to the vessels length the configuration of this method will not be optimal. A large clump weight is needed and an extra wire to prevent the clump weight of touching the pipeline when the towing wire will hang slack.

A tug boat can be used to connect the towing wire to, this will increase the towing length compared to the depth. This can reduce the required weight for the clump weight to generate a horizontal towing force. When using this configuration, the distance between the deploying vessel and the tug boat needs to be fixed and constantly monitored.

9.0 REFERENCES

Allseas Engineering B.V. (October, 2016). *Pioneering Spirit*
http://allseas.com/equipment/pioneering-spirit/

Allseas Engineering B.V. (November, 2002). *Stand criteria for lifting Appliances*.
Retrieved from Allseas' database.

Concept Draw. (December 8th, 2016). *Welding symbols*
http://www.conceptdraw.com/examples/welding-symbols

Fianagusta. (October 26, 2016). *Pipe Wall Thickness Design*
http://fianagusta.blogspot.nl/2012/02/pipe-wall-thickness-design.html

Hibbeler, R.C. (2010). *Statica* (12th edition). Amsterdam, the Netherlands: Pearson Education

Hibbeler, R.C. (2012). *Sterkteleer* (8th edition). Amsterdam, the Netherlands: Pearson Education

Lloyd's Register of Shipping (July, 2016). *Codes for lifting Appliances in a marine Environment*.
Retrieved from Allseas' database.

Patrizia, C.A. (October 14, 2002). *Allseas Customs Letter Ruling Trenchsetter(v8).* [Letter]
Retrieved from Allseas' database.

Rotech (2008). *Rotech_T8000_Spec.* [specification sheet]
Retrieved from Allseas' database.

SWR (December, 2016). *Fibre Core Wire Rope Specification*
http://www.steelwirerope.com/WireRopes/Constructions/GeneralEngineering/6x7-fibre-core-wire-rope.html#.WFqpy1UrLct

Van Beest (2005). *VanBeest_Catalogue_Complete.* [Catalogue]
Retrieved from Allseas' database

Wermac. (December 8th, 2016). *Definition and Details of Flanges- Types of Flanges*
http://www.wermac.org/flanges/flanges_welding-neck_socket-weld_lap-joint_screwed_blind.html

10.0 APPENDICES

The following appendices are attached to this document:

- Appendix A – Component research
- Appendix B – Design boxes *Jet Sled III*
- Appendix C – Deck lay-out *Volstad Oceanic*
- Appendix D – FMEA
- Appendix E – Concepts
- Appendix F – Inventor model
- Appendix G – Load cases
- Appendix H – Calculations
- Appendix I – Trench dimensions
- Appendix J – Motion reports
- Appendix K – Lifting/towing arrangement
- Appendix L – Competentie verantwoording

Appendix A – Component research

In the component chart below the main components of the structural box are shown. For the different components a solution has to be found. However for some components there is only on suitable solution due the interface with installed equipment or due norms and regulations.

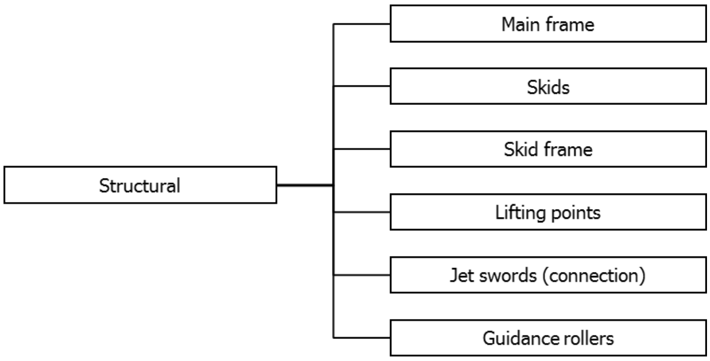


Figure 10.1 Structural design box

- **Material**

The trencher main structure will be build out of steel. The reason for this is the high quality demands for construction in the offshore industry. Due economic interests the quality has to be guaranteed. Steel is a material with a high strength and can withstand offshore conditions, if it is treated well.

The main structure will be built of construction steel. There are different kinds of construction steels on the market with different strengths (yield strength). The following grades are taken in consideration: S235, S355 and S460. The pros and cons of an increasing grade construction steel are shown below:

Pros higher construction steel	Cons higher construction steel
High strength, depending on yield strength	Welding and machining becomes more complicated when yield strength increases. Requires more pre-treatment, knowledge and qualified personnel.
Good weldability and machinability	Higher yield strength increases the price
Construction profiles are also made of higher construction steel	

- **Profiles**

The main frame and skid will be made of steel profiles. There are different steel profiles on the market each are specially made for different applications. For the trencher main frame the loads will mainly cause the profiles willing to bend and buckle. Therefore I-beams and pipes will be suitable.

Pros I-beams	Pros Pipes
High resistance against bending	Moment of inertia in both X/Y direction the same
Less weight per meter than pipes for same strength (under certain conditions, see appendix I)	Option to make the profiles buoyant

Cons I-beams	Cons Pipes
Moment of inertia in Y direction less than X direction	Heavier than I-beams for same strength

- **Configuration**

The configuration of the main structure can be separated in two kinds. The first is based on the old configuration of the Jet Sled, and the second is a different configuration. This can be any configuration possible.

- **Connections**

The profiles in the structure can be connected in different ways. The connection can be either fixed or demountable. The demountable connection can be divided in two, I-beam connection and pipe connection.

Pros Weld (Fixed)	Pros Plate/bold (demountable I-beam)	Pros Flanges/bold (demountable Pipe)
Strong connection, sometimes stronger than base material	Modularity	Modularity
	Frame parts easy to transfer	Frame parts easy to transfer

Cons Weld (Fixed)	Cons Plate/bold (demountable I-beam)	Cons Flanges/bold (demountable Pipe)
Heat affected zone (HAZ)	Extra weight on structure	Extra weight on structure
Not demountable, not modular		Heat affected zone (HAZ), connection of flange with pipe

- **Skids**

The skids can be made of two profiles, plate material or pipes. In case of the steel plates there has to be a reinforcement by use of an extra profile, for example an I-beam.

Pros steel plate	Pros Pipes
More support due larger surface	Option to make the profiles buoyant

Cons steel plate	Cons Pipes
Large volume of steel	Less surface to support
No buoyancy possibilities	
Requires extra reinforcements to strengthen the plate	

- **Lifting points**

For the handling and lifting of the trencher there will be multiple pad eyes be installed. These pad eyes are designed to withstand the load during lifting/handling and are dimensioned according to the Allseas standards. The dimensions of the pad eyes for different loads are given in the following document:

- Engineering Guideline, 'Standard Criteria for Lifting Appliances' Pad eyes from 001 – Lift Rev B'

- **Jet sword connection**

The design and layout of the Jet Sword are beyond the scope of this graduation project. However the connection of the Jet Swords has to be taken in account. The actual design of the new Jet Sword is not made yet. Therefore the Jet Swords of the old Jet Sled are used. These Jet Swords are made from pipes and are connected to the main frame with a roll based connection. Therefore the same connection will be used in the new Jet Sled design.

- **Guidance rollers**

The guiding of the structure can be done in two ways. The first way is to fix the rollers on the main frame, by this way they will not make constant contact with the pipe. The second way is to attach the rollers on the main frame with the use of an extra frame. This frame can adapt to the height of the pipe and thereby make constant contact.

Pros fixed configuration	Pros frame configuration
Less components	Constant contact with pipe
	Less chance of contact between frame and pipe

Cons fixed configuration	Cons frame configuration
No constant contact with pipe	Moving parts
	Extra weight

Appendix B – Design boxes *Jet Sled III*

For the different design boxes decisions are made by Allseas. Hereby the general configuration of the trenching tool is already known. The underneath paragraphs will explain the choices for the configurations of the other boxes.

Propulsion

The trenching tool will be propelled by the use of a towing wire connected to a support vessel. This wire will pull the trencher along the pipeline with a certain velocity. When using a towing wire, a clump weight is needed to keep the wire tensioned. In the underneath text it is explained why Allseas did not choose the other options.

- Tracks -> The soil is too soft to hold the weight and load of the tracks.
- Thrusters -> Not possible to get 8-10 tonnes pull force, thruster will be too large.
- Roller/track on pipe -> May cause damage on the pipe, is not possible when pipe is underneath the seabed.
- ROV -> Not possible to get 8-10 tonnes pull force.
- Archimedes screws -> No experience, ground may be too soft to absorb the load of the Screws.

Directional control

To guide the trencher along the pipeline there will be rollers installed on the trencher. These rollers will align the trencher in the right position. The rollers will not be driven, as they will not operate as propulsion. In the underneath text it is explained why Allseas did not choose the other options.

- ROV steering -> Trencher will not be propelled with a ROV, so therefore not be guided by the ROV.
- Thruster -> Will only be used for positioning during landing on seabed.
- Rudders -> No experience, no guarantee if it will work.

Stabilization

The trencher will be stabilized by the skids on the main frame. These skids will be filled with air to provide buoyancy during trenching. The amount of air in the skids can be adjusted to adapt the buoyancy for different soils/conditions. Also the rollers will stabilize the trencher in the horizontal plane. In the underneath text it is explained why Allseas did not choose the other options.

- Hovering -> Not stable enough for jetting with swords.
- Gyroscopes -> No experience, no guarantee if it will work.

Soil cutting

The trencher will make use of a jetting configuration to cut the soil. The reason for this is that a part of the project is excluded of mechanical digging to cut the soil. Therefore the choice is made to jet. The trencher will make use of jetting swords which can lower in the soil to reach the exact trenching depth. The jetting swords will be demountable to change the configuration of the trencher. By doing this the trencher can be adjusted for different projects and requirements.

- Mechanical digging -> Excluded from project by government of the project region.
- Mass excavating -> No experience with technique.

Soil removing

To remove the cut soil after trenching the trencher will be equipped with eductors. Just like the jetting swords the eductors are demountable to. If it is not needed to remove the cut soil out of the trench the eductors won't be needed, in that case they will not be installed on the trencher.

Monitoring

To monitor the position of the pipeline different sensors will be installed. These sensors will make use of sonar to detect the position and depth of the pipeline. Besides these sonars different load sensors will be installed on the trencher to monitor the loads of different components on the trencher.

Appendix C – Deck lay-out *Volstad Oceanic*

Deck lay-out of *Volstad Oceanic*, available deck space of ± 25*23 [m] (width*length). See Figure 10.2 for the deck lay-out. The top of the red area borders to the crane house, this is a distance of ± 23 meter.

- Top -> Bow
- Bottom -> Stern
- Right -> Portside
- Left -> Starboard

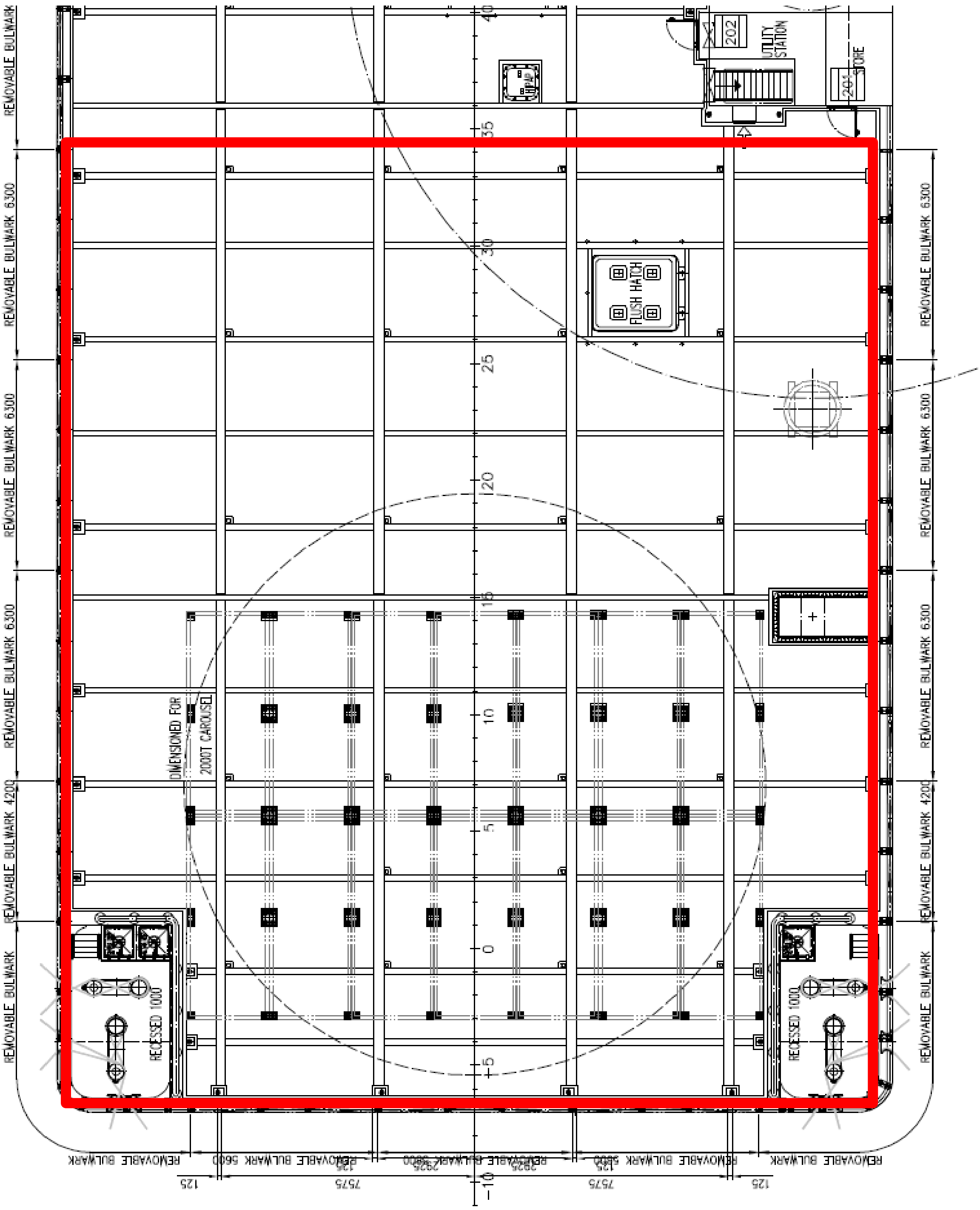


Figure 10.2 Deck lay-out Volstad Oceanic

Appendix D – FMEA

In the underneath table the FMEA analysis can be found. The three aspects which exceed the 100 RPN are mentioned in section 2.4.3.

Component	Function	#	Failure mode	Cause	Result	Detection method	Severity, E	Frequency, F	Chance of detection, D	RPN	RPN >100? Take action
Main frame	Holding the trencher together	1.1	Fracture	Overloading	Components break	Load sensor	8	2	2	32	no
		1.2		Collision with object	Components break	Load sensor	8	3	2	48	no
		1.3	Weld fracture	Overloading	Frame falls apart	Camera, visual	8	2	5	80	no
Skids	Providing stabilisation of trencher	2.1	Fracture	Collision with object	Leakage	Stability monitor, visual	6	3	5	90	no
		2.2	Weld fracture	Overloading, Collision with object	leakage, skids breaks	Stability monitor, visual	6	2	5	60	no
Pad eyes	Points to handel or lift the trencher	3.1	Fracture	Overloading	Pad eye breaks, trencher falls	Visual	9	2	2	36	no
		3.2	Weld fracture	Overloading	Pad eye breaks, trencher falls	Visual	9	2	2	36	no
Jet sword	Jetting of soil	4.1	Fracture	Collision with underground object	Jet arm breaks	Pressure drops, load sensor	8	4	5	160	yes
		4.2	Bending	Collision with object	Jetting swords bends	load sensor visual	6	4	4	96	no
Rollers	Guide de trencher over the pipeline	5.1	Failure	Overloading	Roller breaks	visual	6	3	4	72	no
		5.2	Roller locks	bearing locks	Roller locks, pipe damage	visual	8	3	6	144	yes
		5.3	FJC gets touched	Rollers are not well placed	FJC gets damaged	visual inspection	8	2	6	96	no
Complete frame	supports the trenching components	5.4	Fracture	Overloading due heave compensation fail	Components break	load sensor, visual	8	4	4	128	yes

Figure 10.3 FMEA

Appendix E – Concepts

To determine the size of profiles for both the concepts an estimation of the expected loads is made. The weights are based on the gross weight of the parts draws for the concepts.

Table 10.1 Weight estimations concepts

Large frame			**Small frame**		
jet sword,2	2200	Kg	jet sword,1	1100	kg
roller frame,2	900	Kg	roller frame,2	900	Kg
extra weight	2000	Kg	extra weight	2000	Kg
main frame large	5300	kg	main frame small	2600	Kg
total	10400	kg	total	6600	kg
	102024	N		64746	N
8 skid connections			4 skid connections		
load per skid connection	12753	N	Load per skid connection	16186.5	N
Load per 6 meter skid arm	12753	N	Load per 2.5 meter skid arm	16186.5	N

Assuming the following loads with distance:

Large -> 13000 N per skid -> 6000 mm skid width -> 7.8*10^7 [N/mm]
Small -> 16200 N per skid -> 2500 mm skid width -> 4.05*10^7 [N/mm]

W.needed-S355 = M.max/Allowable stress
= 7.8*10^7 / (355*0.67)
= 327938
= 330000 [mm^3]

W.needed-S235 = M.max/Allowable stress
= 7.8*10^7 / (235*0.67)
= 495395
= 330000 [mm^3]

Needed pipe dimensions (S235):
- Needed section modulus = 496395 [mm^3]
- Section modulus pipe Ø273*10 = 524109 [mm^3]

Needed I beam dimensions (S355):
- Needed section modulus = 330000 [mm^3]
- Section modulus I-beam 250*32.7 = 380000 [mm^3]

Concept 1

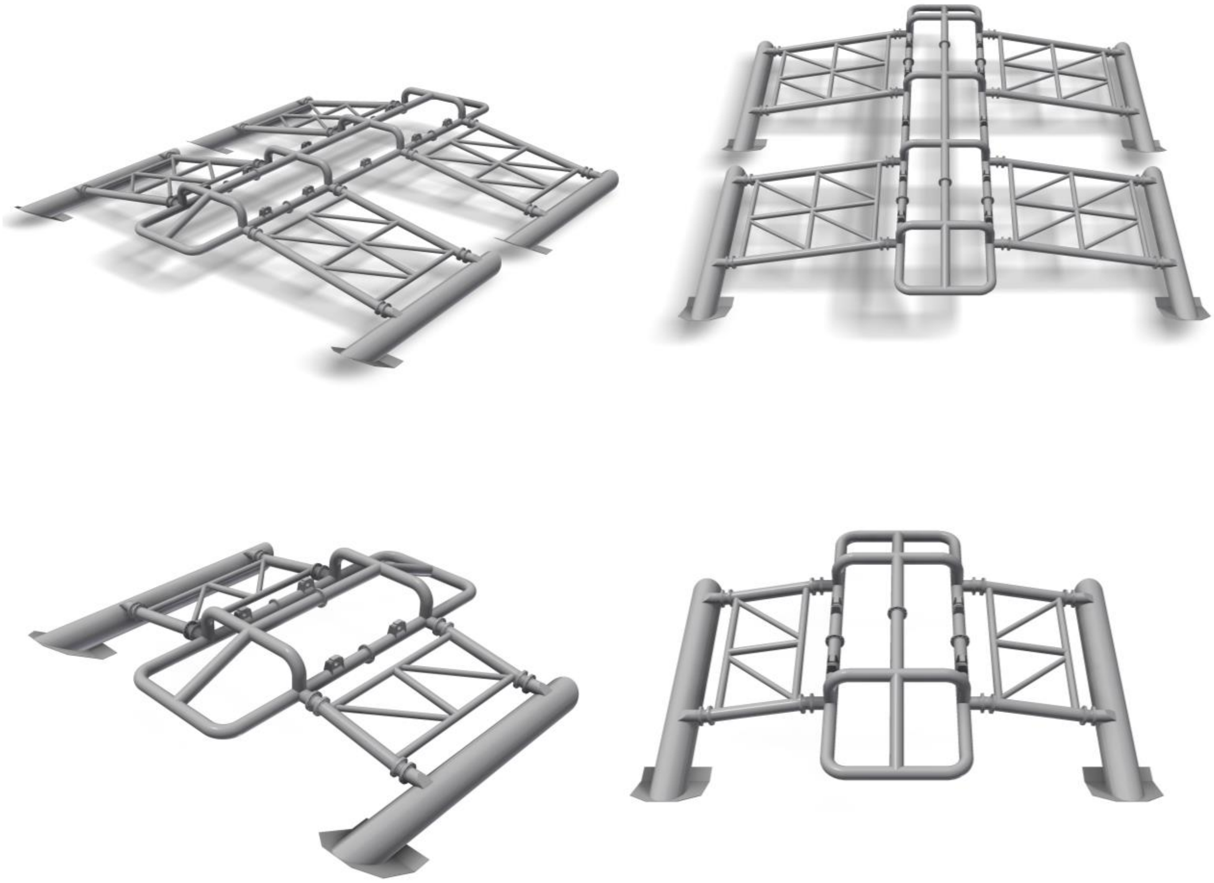


Figure 10.4 Concept 1 illustrations

The two outer section of the main frame have a length of 5 meters, and the middle section has a length of 10 meters. Hereby the total length of the small structure comes on 10 meters and the large structure at 20 meters.

The pipes are made of the same dimension as the old *Jet Sled* (DIN Ø273*10 mm WT, weight; 64.9 kg/m), only the main frame is reinforced to that more equipment can be mounted on. This is in particularly needed when the structure is equipped with the large skid frames.

To guide the trencher along the pipeline the structure will rest on air filled skids. Hereby the submerged weight can be reduced which results in less friction with the soil. Besides the skids guidance arms will be installed to make sure that the trencher stays aligned on the pipe. These arms are equipped with four sets of rollers which will be lowered around the pipeline. The reason for using four sets is the field joint coating which may not be touched. By using this set up the rollers cannot enter the field joint coating, because two sets will always stay in contact with the pipe when the other is above the FJC.

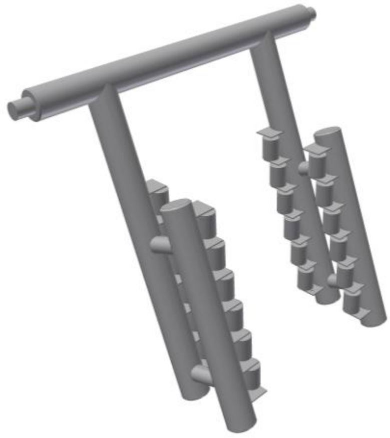


Figure 10.5 Guidance arms

Concept 2

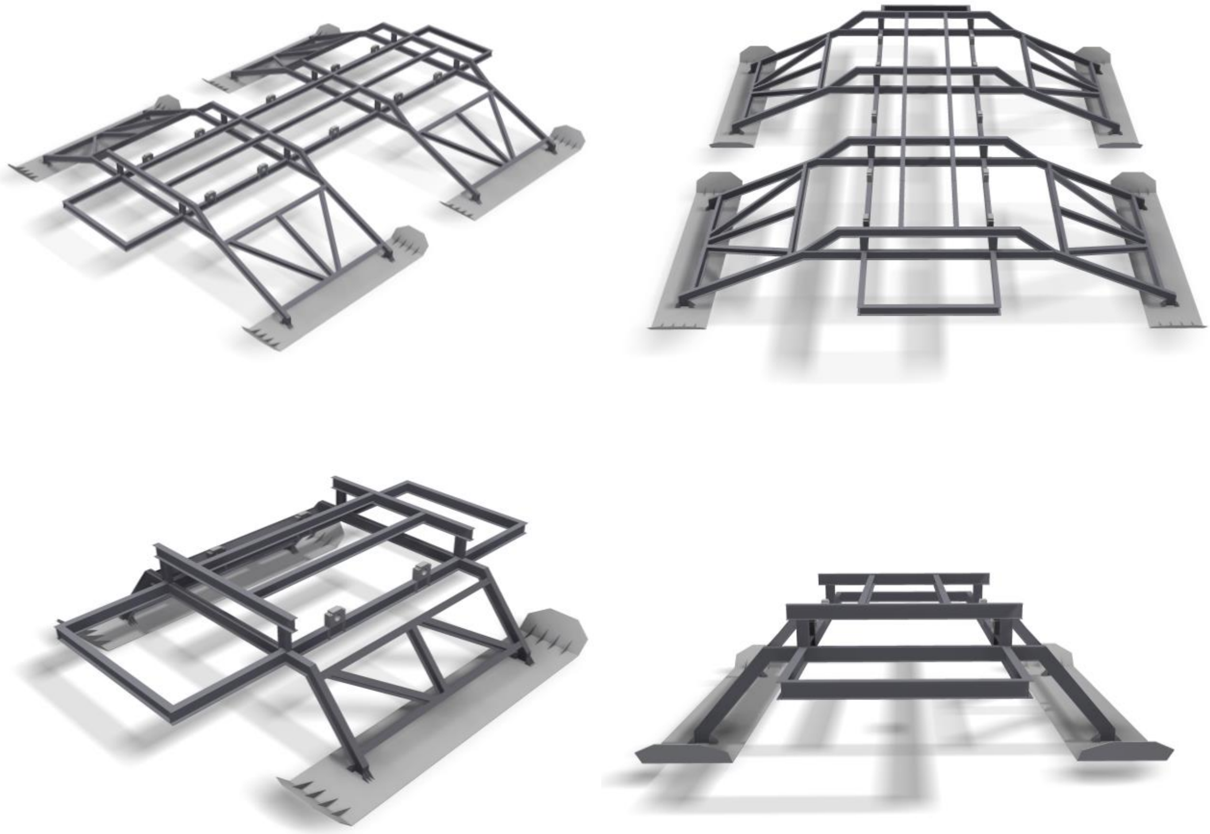


Figure 10.6 Concept 2 illustrations

Concept 2 has the same dimensions as concept 1, which are based on the requirements of Allseas. The main difference with concept 1 is the profiles. I-beams are used instead of pipe profiles. I-beam with the same section modulus weighs less than pipe profiles. This results in a lighter construction and therefore smaller loads as a result of its own weight. The I beams which are used are ANSI W250*32.7 beams, with a weight of 48.6 kg/m. This results in a lightweight construction.

The structure will rest on skids made of plate material. They weight significantly less than pipe shaped skids. They can have a larger contact surface with the soil, which results in a lower ground pressure. For preventing steel contact with the pipe a new guidance frame is designed. It is a U shaped frame with rollers on the inside, which can vertically lower onto the pipeline. A second set of rollers is placed behind the first one to prevent contact with the FJC.

Figure 10.7 Guidance frame

Appendix F – Inventor model

This appendix contains drawings of both the structures with the overall dimensions given in millimetres.

Small structure

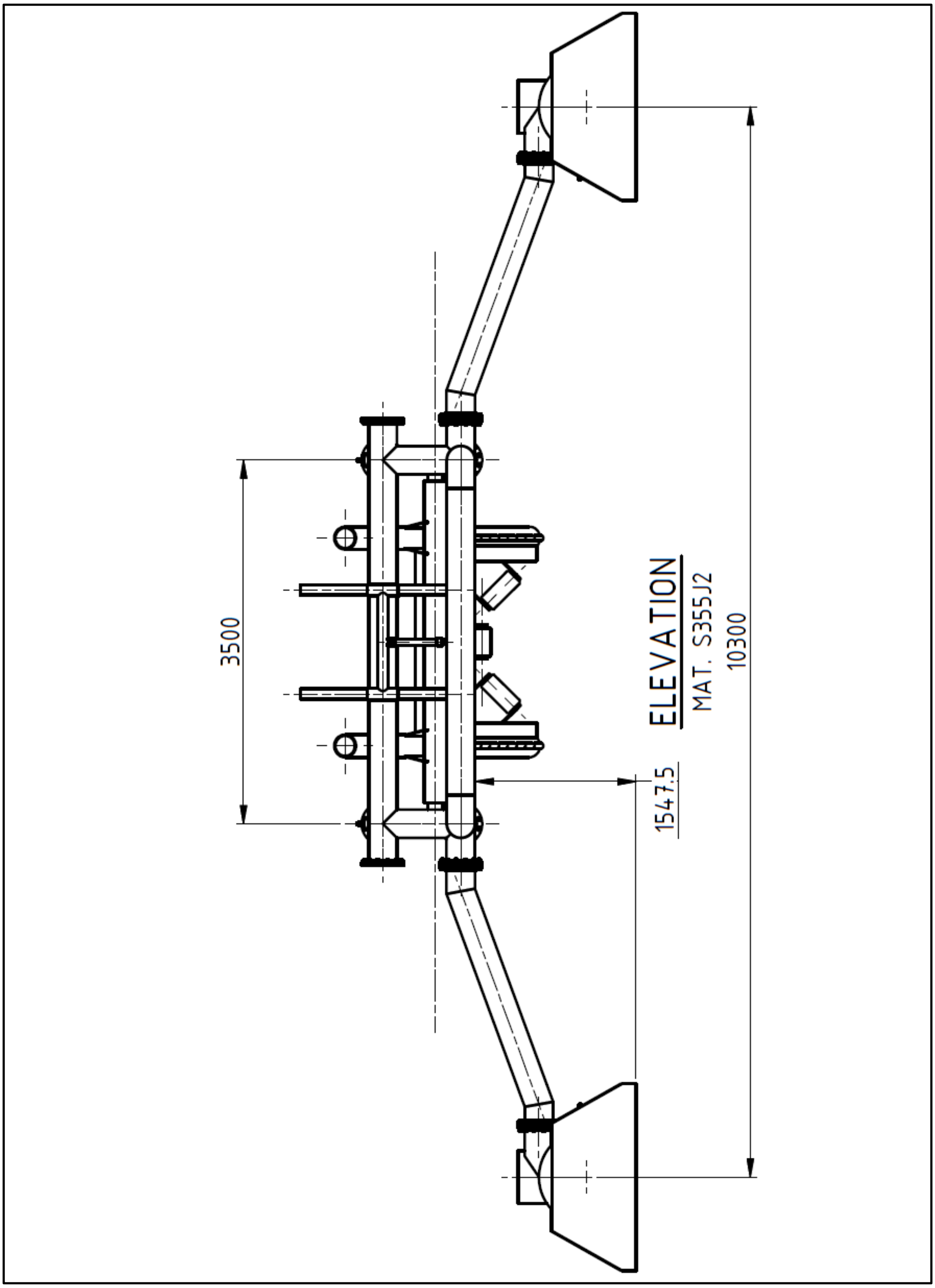


Figure 10.8 Small structure front dimensions

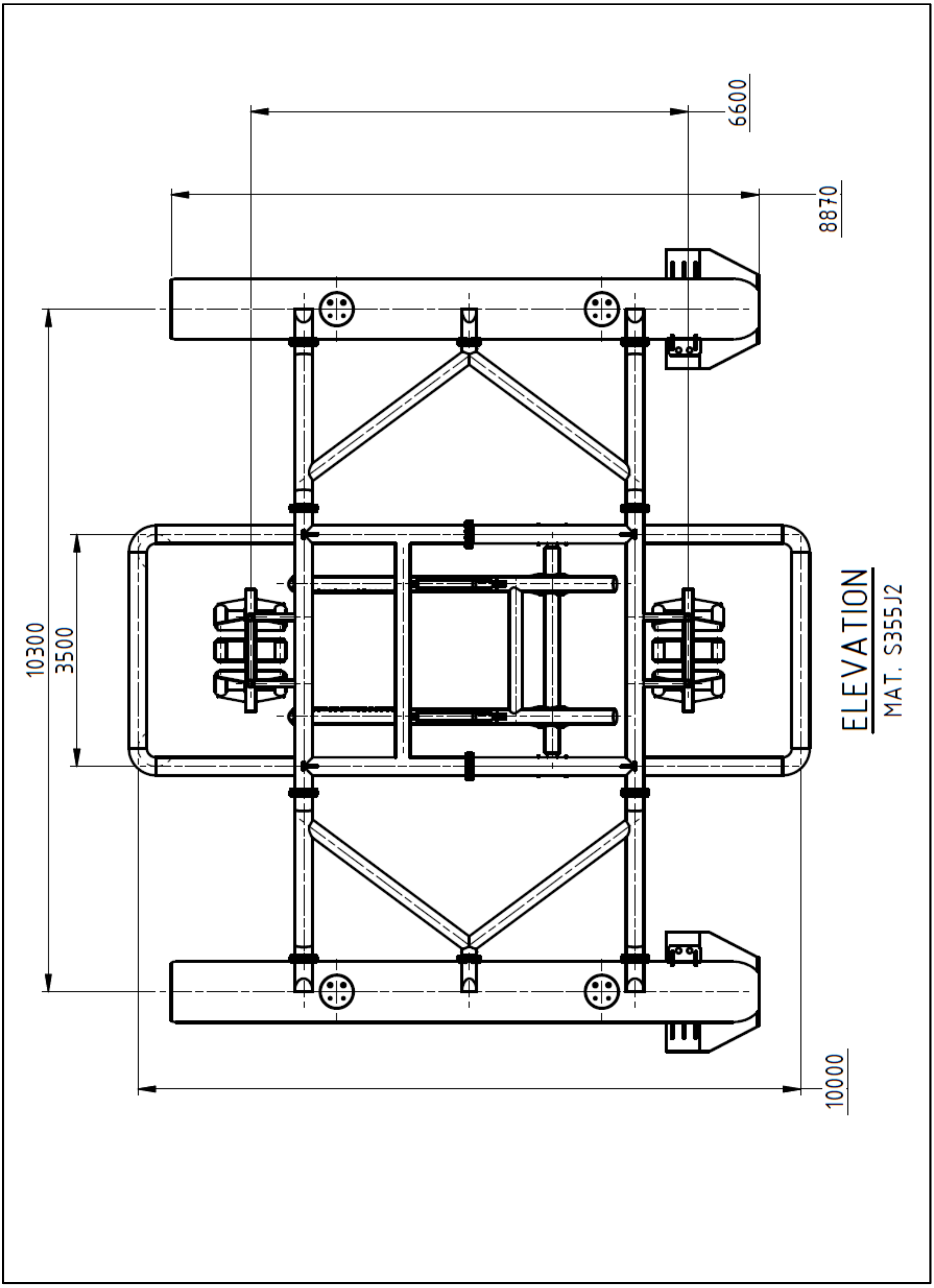


Figure 10.9 Small structure top dimensions

Large structure

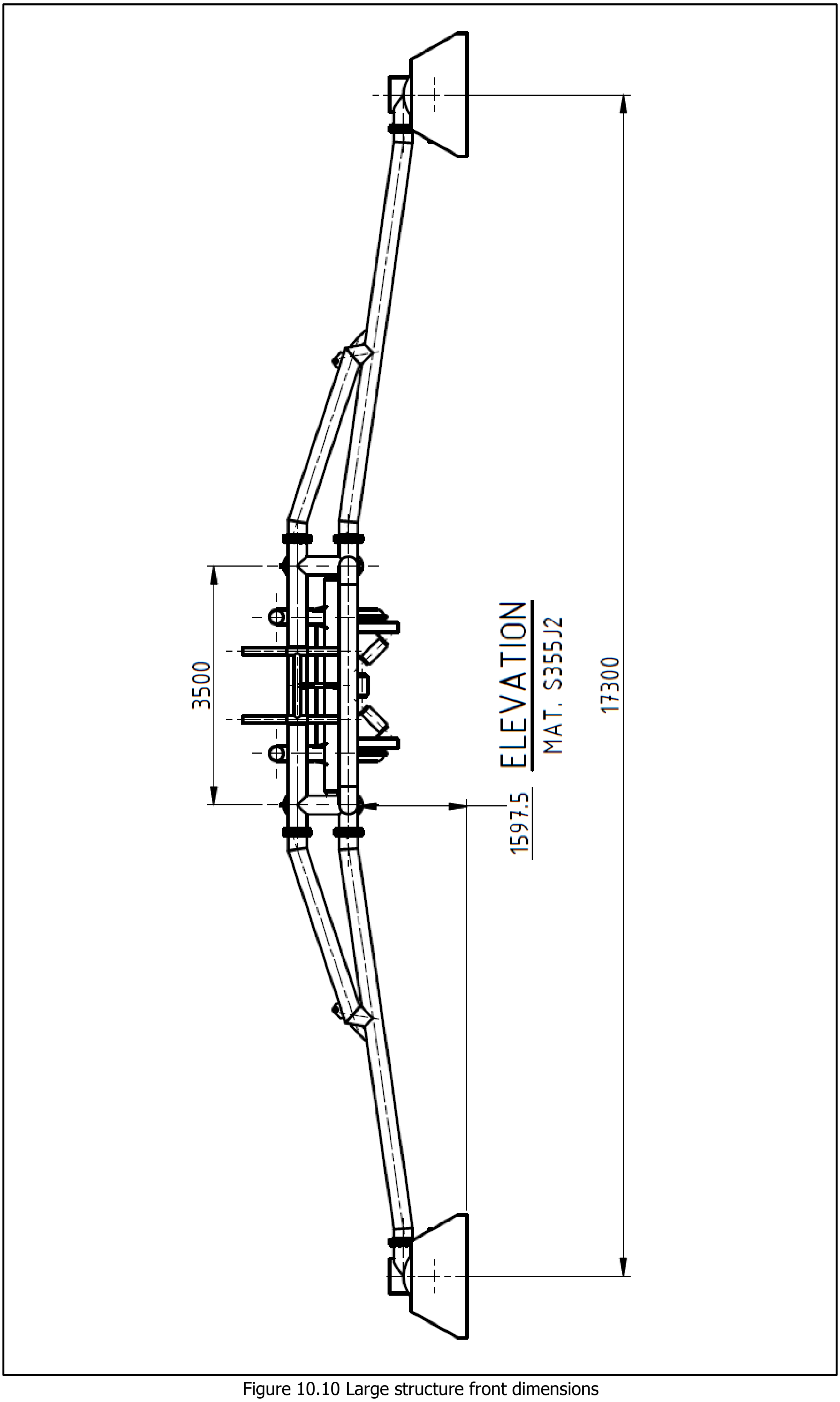


Figure 10.10 Large structure front dimensions

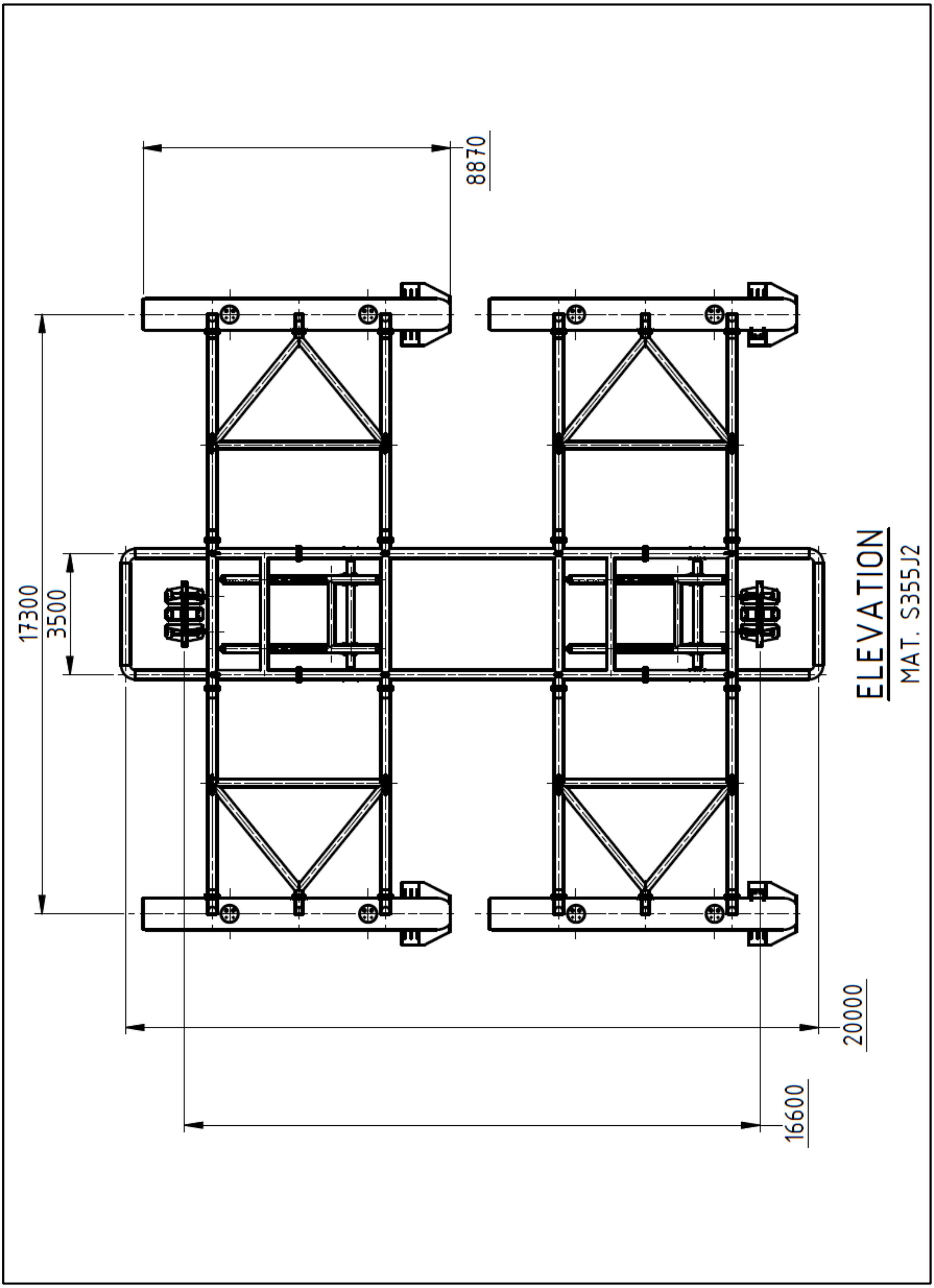


Figure 10.11 Large structure top dimensions

Skids

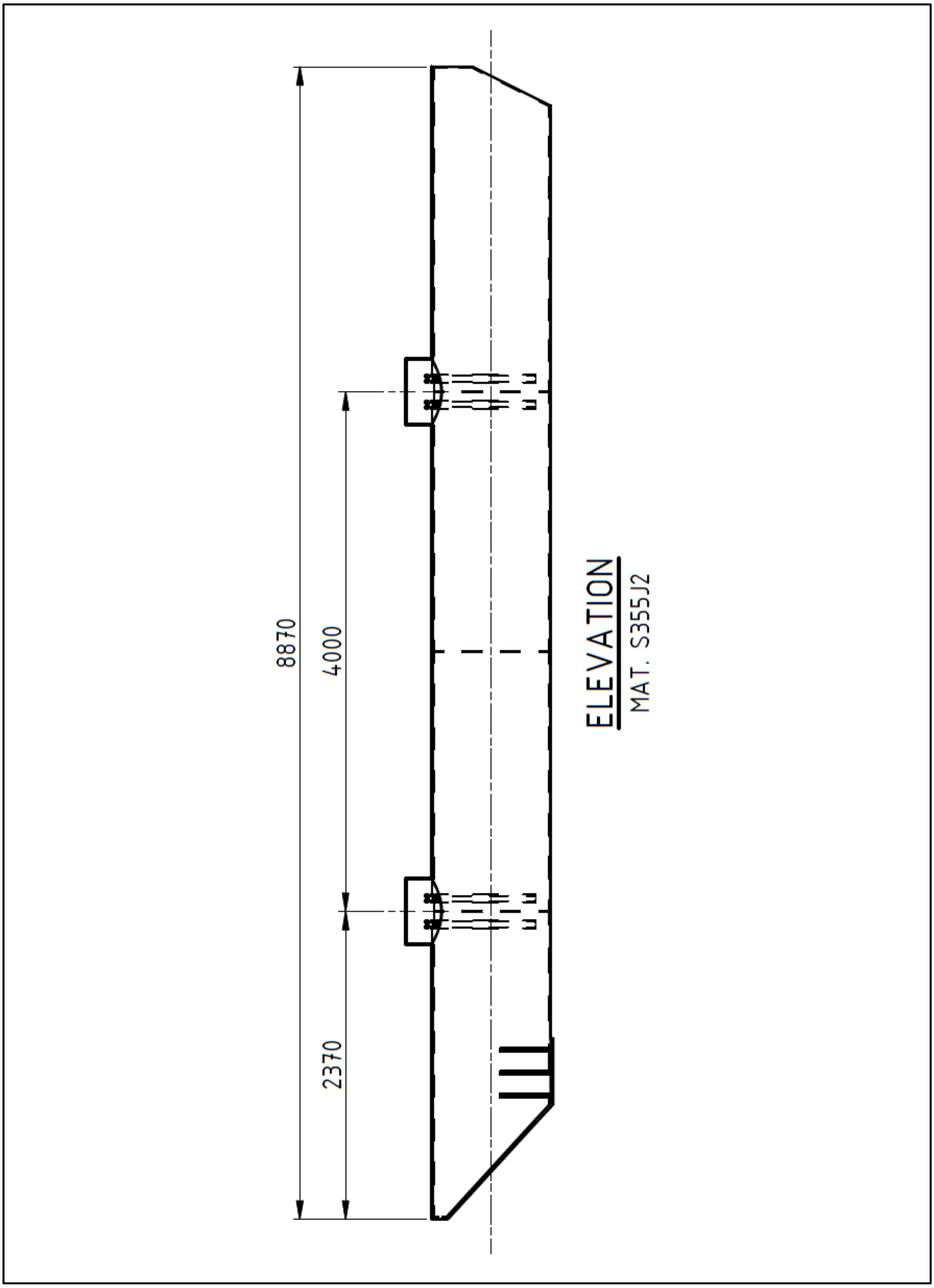


Figure 10.12 Skid dimensions

Appendix G – Load cases

In this chapter the load cases will be described. They will be divided in submerged and in-air load cases. The purpose of these load cases is to give a clear view of the loads which the trencher may undergo. These loads will serve as input for the FEM analysis. An overview of the load cases is given in the underneath tables.

Table 10.2 Load cases

LC	Load case	Description	Parameters
1	Standing on deck	Trencher is resting on skids	a = 9,81 m/s²
2	Deploying in air	Trencher is connected at pad eyes	a = 9,81 m/s²
3	Heave compensation fail in air	Extra acceleration from ship motion	a = 2,54 m/s² a = 2,71 m/s²

LC	Load case	Description	Parameters
4	Standing on seafloor	Trencher is resting on skids	a = 9,81 m/s²
5	Deploying submerged	Trencher is connected at pad eyes	a = 9,81 m/s²
6	Heave compensation fail submerged *	Extra acceleration from ship motion, plus water drag	VO; a = 2,54 m/s² v = 2.79 m/s CJ; a = 2,71 m/s² v = 2.98 m/s
7	Towing	Friction of skids + jet sword(s)	v = 300 m/hr = 0,08 m/s
8	Guidance frame	Load from guidance frame on main frame	a = 0.5 m/s²
9	Hydrostatic pressure	Depth of max 120 meters	*p* = 12 bar = 1,2 N/mm²

LC 1 Standing on deck

When the trencher is rigged on deck of the Volstad Oceanic the total weight will be resting on the skids. In this case only gravitational acceleration is taken in account, assuming that the rigging is strong enough to survive extreme conditions. An extra weight is added in case the pumps are placed on the structure.

- **Small structure** (mass excluding skids, 2)

Mass	= m	=	6.800	[kg]
Extra mass	= m_{extra}	=	4.000	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]

$$F = m * a$$
$$F = (6.800 + 4.000) * 9{,}81 = 105.948\ N$$
$$\boldsymbol{F = 106.000\ N}$$

- **Large structure** (mass excluding skids, 2)

Mass	= m	=	17.000	[kg]
Extra mass	= m_{extra}	=	8.000	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]

$$F = m * a$$
$$F = (17.000 + 8.000) * 9{,}81 = 245.250\ N$$
$$\boldsymbol{F = 245.250\ N}$$

LC 2 Deploying in air

When the trencher is lifted in the air, all the weight will hang in the pad eyes. A gravitational acceleration of 9.81 m/s² is assumed. An extra weight is added in case the pumps are placed on the structure.

- **Small structure**

Mass	= m	=	13.800	[kg]
Extra mass	= m_{extra}	=	4.000	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]

$$F = m * a$$
$$F = (13.800 + 4.000) * 9{,}81 = 174.618\ N$$
$$\boldsymbol{F = 175.000\ N}$$

- **Large structure**

Mass	= m	=	31.000	[kg]
Extra mass	= m_{extra}	=	8.000	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]

$$F = m * a$$
$$F = (31.000 + 8.000) * 9{,}81 = 382.590\ N$$
$$\boldsymbol{F = 382.600\ N}$$

LC 3 Heave compensation fail in air

When the heave compensation will fail, the acceleration of the tip of the crane in Z-direction will be added to the gravitational acceleration. The trencher will be deployed by the Volstad Oceanic and the Calamity Jane is considered for future projects. The extra acceleration of the crane tips at worst sea state conditions is as follows:

- Volstad Oceanic = 2,54 [m/s²]
- Calamity Jane = 2,71 [m/s²]

- **Small structure**

Mass	= m	=	6.800	[kg]
Extra mass	= m_{extra}	=	4.000	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]
Crane tip acceleration	= a	=	2,54/2,71	[m/s²]

$$F = m * (g + a)$$
$$F = (6.800 + 4.000) * (12{,}35\ or\ 12.52) = 133.380\ or\ 189.052\ N$$
$$\boldsymbol{F = 186.500\ or\ 189.100\ N}$$

- **Large structure**

Mass	= m	=	31.000	[kg]
Extra mass	= m_{extra}	=	8.000	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]
Crane tip acceleration	= a	=	2,54/2,71	[m/s²]

$$F = m * (g + a)$$
$$F = (31.000 + 8.000) * (12.35\ or\ 12{,}52) = 481.650\ or\ 488.280\ N$$
$$\boldsymbol{F = 481.700\ or\ 488.300\ N}$$

LC 4 Standing on seafloor

When the trencher is standing on the seafloor the total weight will be resting on the skids. When submerged, the density of steel can be assumed lower due the surrounding water. This results in the following density.

$$P_{steel} - P_{water} = P_{submerged\ steel}$$
$$7.850 - 1.025 = 6.825\ [kg/m\hat{}3\ ]$$

- **Mass small structure**

Mass	= m	=	6.800	[kg]
Extra mass	= m_{extra}	=	4.000	[kg]
Density steel	= P_{steel}	=	7.850	[kg/m³]
Density submerged steel	= $P_{steel\ subermerged}$	=	6.825	[kg/m³]
Total mass submerged	= $m_{submerged}$	=	$\frac{10.800}{7.850} * 6.825 = \mathbf{9.390\ kg}$	

- **Mass large structure**

Mass	= m	=	17.000	[kg]
Extra mass	= m_{extra}	=	8.000	[kg]
Density steel	= P_{steel}	=	7.850	[kg/m³]
Density submerged steel	= $P_{steel\ subermerged}$	=	6.825	[kg/m³]
Total mass submerged	= $m_{submerged}$	=	$\frac{25000}{7.850} * 6.825 = \mathbf{21.735\ kg}$	

- **Small structure**

Total mass submerged	= $m_{submerged}$	=	9.390	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]

$$F = m * a$$
$$F = 9.390 * 9{,}81 = 92.116\ N$$
$$\boldsymbol{F = 92.100\ N}$$

- **Large structure**

Total mass submerged	= $m_{submerged}$	=	21.735	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]

$$F = m * a$$
$$F = 21.735 * 9{,}81 = 213.220\ N$$
$$\boldsymbol{F = 213.200\ N}$$

LC 5 Deploying submerged

When the trencher is resting in the crane (submerged), the total weight off the trencher will hang in the pad eyes. The skids will be partially filled with air so that they will be buoyant. Therefore the weight of the skids will not be taken in account. The resulting load will be the same as in load case 4, only the weight will be led to the pad eyes.

- Small structure, F = 92.100 [N]
- Large structure, F = 213.200 [N]

LC 6 Heave compensation fail submerged

When the heave compensation will fail when the trencher is submerged, an extra acceleration will be felt. Besides the extra acceleration, the water drag will increase and generate a large load.

- **Small structure**

Mass	= m	=	9.390	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]
Crane tip acceleration	= a	=	2,54/2,71	[m/s²]

$$F = m * (g + a)$$
$$F = 9.390 * (12{,}35\ or\ 12.52) = 115.966\ or\ 117.562\ N$$
$$\boldsymbol{F = 116.000\ or\ 117.600\ N}$$

Top view area:

Main frame:	8.2	[m²]
Skid frames:	6.0	[m²]
Extra equipment:	1.8	[m²]
Total:	**16**	[m²]

The water drag will lead to the following load:

- Density water	= P_{water}	=	1.025	[kg/m³]
- Velocity VO	= V_{VO}	=	2,79	[m/s]
- Velocity CJ	= V_{CJ}	=	2,98	[m/s]
- Drag coefficient	= C_d	=	1,17	[-]
- Area structure	= A	=	16	[m²]

$$F = 0.5 * P * v^2 * C_d * A$$
$$F = 0.5 * 1.025 * (2{,}79^2\ or\ 2{,}98^2) * 1.17 * 16 = 70.459\ or\ 85.199\ N$$
$$\boldsymbol{F = 70.500\ or\ 85.200\ N}$$

- **Large structure**

Mass	= m	=	21.735	[kg]
Gravitational acceleration	= a	=	9,81	[m/s²]
Crane tip acceleration	= a	=	2,54/2,71	[m/s²]

$$F = m * (g + a)$$
$$F = 21.735 * (12.35 \; or \; 12,52) = 268.427 \; or \; 272.122 \; N$$
$$\boldsymbol{F = 268.400 \; or \; 272.100 \; N}$$

Top view area:

Main frame:	17.5	[m²]
Skid frames:	13.9	[m²]
Extra equipment:	3.6	[m²]
Total:	**35**	[m²]

The water drag will lead to the following load:

- Density water	= P_{water}	=	1.025	[kg/m³]
- Velocity VO	= V_{VO}	=	2,79	[m/s]
- Velocity CJ	= V_{CJ}	=	2,98	[m/s]
- Drag coefficient	= C_d	=	1,17	[-]
- Area	= A	=	35	[m²]

$$F = 0.5 * P * v^2 * C_d * A$$
$$F = 0.5 * 1.025 * (2.79^2 \; or \; 2.98^2) * 1.17 * 35 = 154.130 \; or \; 186.372 \; N$$
$$\boldsymbol{F = 154.100 \; or \; 186.400 \; N}$$

- **Skids**

The water drag will lead to the following load:

- Density water	= P_{water}	=	1.025	[kg/m³]
- Velocity VO	= V_{VO}	=	2,79	[m/s]
- Velocity CJ	= V_{CJ}	=	2,98	[m/s]
- Drag coefficient	= C_d	=	1,17	[-]
- Area	= A	=	8,2	[m²]

$$F = 0.5 * P * v^2 * C_d * A$$
$$F = 0.5 * 1.025 * (2.79^2 \; or \; 2.98^2) * 1.17 * 35 = 36.110 \; or \; 43.664 \; N$$
$$\boldsymbol{F = 36.000 \; or \; 43.700 \; N}$$

LC 7 Towing

During trenching the skids and jet swords will generate friction. The towing force needs to overcome this friction. The friction is calculated as follows.

- **Jet swords**

Figure 10.13 Jet sword

To determine the friction of the jet swords, the force per nozzle needs to be known. Assuming that each jet pipe with nozzles is attached to a separated pump of 900 m³/hr @ 7.3 bars. According to the jet calculation sheet of Allseas the following forces will be generated by the three different nozzles.

Table 10.3 Nozzle loads

Backwards nozzle; 1	D	92	mm	(A-X nozzle)	1026	mm
	F nozzle	9637	N	M	9887.56	N/m
	Total F	9.64	kN			

Downwards nozzles; 8	D	33	mm	(A-Y nozzle)	940	mm
	F nozzle	1170	N	M	-8798.4	N/m
	Total F	9.36	kN			

Inside nozzles; 40	D	16	mm	(A-Z nozzle)	2750	mm
	F nozzle	199	N	M (around X-axis)	21890	N/m
	Total F	7.96	kN			

The backwards (X) and in downwards (Y) nozzle will generate a load on the cylinder which lowers the swords, see below figure. They will generate a momentum around point A which has to be hold by the cylinder. The load in the cylinder is as follows:

$$M_a: 9887.56 - 8798.4 - F * 2.75 = 0$$
$$F = 396\ N$$
$$F_{cyl} = \cos(16) * 396 = 381\ N$$

In case the swords get stuck behind an object in the soil, the cylinder must retract to prevent damage to the swords. Therefore the cylinders will be programmed to retract when a load of 5000 N is felt.

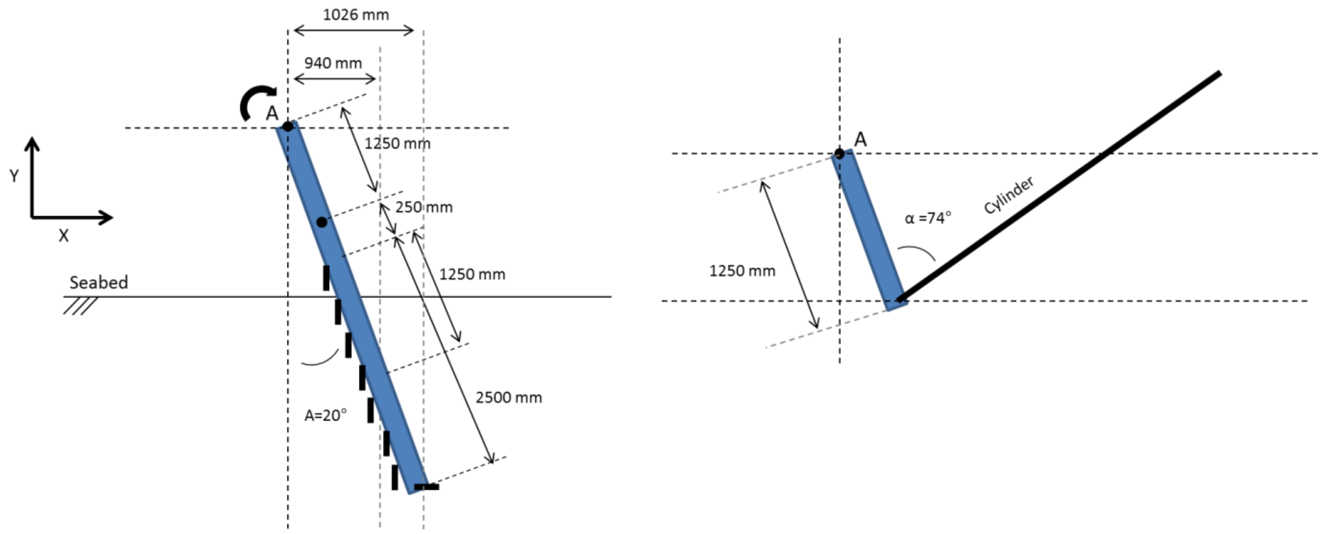


Figure 10.14 Nozzle configuration jet sword

- **Skids**

Table 10.4 Soil data skid calculation

Soil data			
Parameter	**symbol**	**Value**	**Unit**
Friction factor	μ	0.43	-
Length of skid	L1	9000	mm
Maximum mass of trencher per skid	M	5500	kg
Maximum unit weight clay	γ	19.43	kN/m³
Maximum shear strength clay	Cu	30	kPa
Maximum effective unit weight sand	γ'	11	kN/m³
Angle of friction sand	ϕ	35	°
Depth of plate in soil	Z	0.2	m
Length of plate in soil	L2	0.4	m
Width of plate in soil	W	1.4	m

Friction of front plate in clay

$$F_{clay} = \left(\frac{1}{2} * \gamma * Z * L + 2 * C_u * L\right) * W$$

$$F_{clay} = \left(\frac{1}{2} * 19.43 * 0.2 * 0.4 + 2 * 30 * 0.4\right) * 1.4 = 34.7\ kN$$

Friction of front plate in sand

$$K_p = \frac{1 + \sin(\varphi)}{1 - \sin(\varphi)}$$

$$K_p = \frac{1 + \sin(35)}{1 - \sin(\varphi 35)} = 3.69$$

$$F_{sand} = \left(\frac{1}{2} * K_p * \gamma' * Z * L\right) * W$$

$$F_{sand} = \left(\frac{1}{2} * 3.69 * 11 * 0.2 * 0.4\right) * W = 2.27\ kN$$

This results in the following maximum frictions:

Table 10.5 Skid resistance

Small structure		
Max load per skids	34.7	kN
	3536.0	kg
	3.5	Tonnes
2 skids	69.4	kN
	7072.0	kg
	7.1	Tonnes

Large structure		
Max load per skids	34.7	kN
	3536.0	kg
	3.5	Tonnes
4 skids (2 back skids will get half the load)	104.1	kN
	10608.0	kg
	10.6	Tonnes

The towing force of the old *Jet Sled* was varying from 7-10 tonnes of towing load. This situation is similar with the small structure because they both use two skids. The new jet swords are equipped with nozzles facing down and backwards. At the old jet swords the nozzles where facing to the front, which generated extra friction and therefore a higher towing load.

LC 8 Guidance frame

For the load resulting from the guidance frame the following conservative calculation will be assumed. Because it is unclear what horizontal velocity the trencher will undergo, perpendicular to the pipeline, an acceleration of 1 m/s² is assumed.

LC 9 Hydrostatic pressure

Reference:
(http://fianagusta.blogspot.nl/2012/02/pipe-wall-thickness-design.html, October 2016)

Table 10.6 Pipe pressure properties

Parameter	Symbol	Value	Unit
Outside press	Po	1.3	N/mm²
Inside press	Pi	0.1	N/mm²
Poisson	V	0.3	-
Yield	S	355	N/mm²
E. Modulus	E	210000	N/mm²
Load factor	γ	0.67	-

- Formulas:

$$P_c = \frac{P_y * P_e}{\sqrt{{P_y}^2 * P_e}}$$

$$P_y = 2 * S * \left(\frac{t}{D}\right)$$

$$P_e = 2 * E * \frac{t/_{D^3}}{1 - V^2}$$

$$P_o - P_i \leq \gamma * P_c$$

- Unity check pipes

D	273	mm
t	6.3	mm

Py	16.38	N/mm²
Pe	5.67	N/mm²
Pc	5.36	N/mm²

Po-Pi	γ * Pc
1.2	3.59

D	219.1	mm
t	8	mm

Py	25.92	N/mm²
Pe	22.47	N/mm²
Pc	16.98	N/mm²

Po-Pi	γ * Pc
1.2	11.38

D	914	mm
t	16	mm

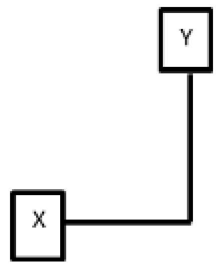
Py	12.43	N/mm²
Pe	2.48	N/mm²
Pc	2.43	N/mm²

Po-Pi	γ * Pc
1.2	1.63

Appendix H – Calculations

- **Pipe properties**

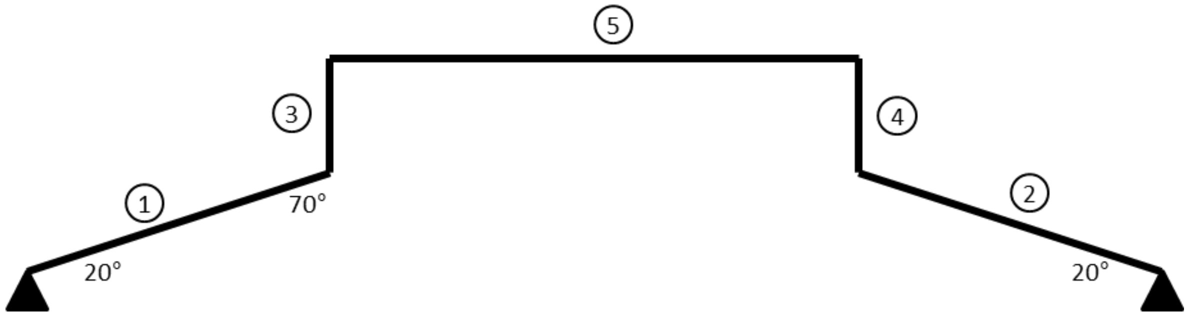
Table 10.7 Pipe calculation properties

OD	273	mm	
WT	6.3	mm	
ID	260.4	mm	
Radius outside	136.5	mm	
Radius inside	130.2	mm	
Surface	5279	mm^2	
Moment of Inertia Ix=Iy	46958234	mm^4	
Section modulus, W	344016	mm^3	
E module	210000	N/mm^2	

Formulas

$$\sigma_{axial} = \frac{F}{A}$$

$$\sigma_{bending} = \frac{M * C}{I}$$



Total weight (without skids, incl. 4000 extra weight)	10500	kg
Total load	103005	N
Skid arms	4	-
Reaction load per constrain	25751	N

- **Pipe 1=2**

40.5 meter pipe, 41.4 kg/m	1665	kg
Weight of jets + guidance frame	2050	kg
Weight of equipment	4000	kg
Total weight	7715	kg
Total load	75684	N
Load per pipe	18921	N
Y load on pipe 1 (cosine)	70	°
Load in pipe	55321	N
σ axial (pressure)	**10.5**	**MPa**

40.5 meter pipe, 41.4 kg/m	1665	kg
Weight of jets + guidance frame	2050	kg
Weight of equipment	4000	kg
Total weight	7715	kg
Total load	75684	N
Load per pipe (4 pipes)	18921	N
Bending length ±	2200	mm
Moment	41626283	N*mm
σ bending	**121**	**MPa**

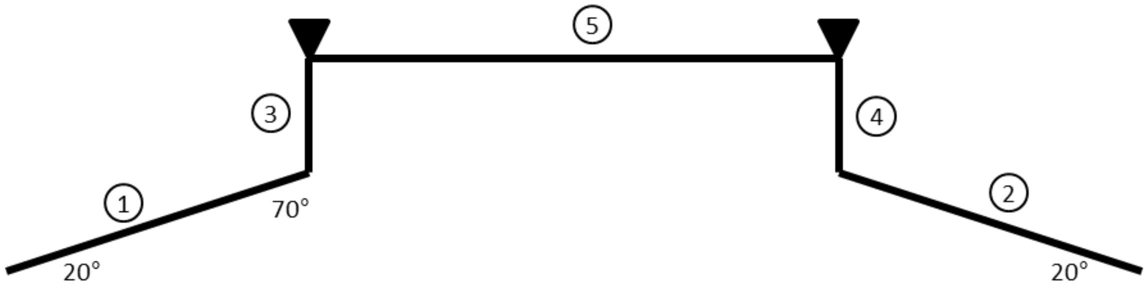
- **Pipe 3=4**

21 meter pipe, 41.4 kg/m	869	kg
Weight equipment	4000	kg
Total top weight	4869	kg
Total load	47769	N
Load per pipe (4)	11942	N
σ axial (pressure)	**2.3**	**MPa**

X load from pipe 1/2	51985	N
Bending length ±	750	mm
Moment	38988842	N*mm
σ bending	**113**	**MPa**

- **Pipe 5**

Load in pipe 1	55321	N
Angle	20	°
Axial load from pipe 1 (cosine)	51985	N
Total load in pipe (from pipe 1+2)	103970	N
σ axial (pressure)	**19.7**	**MPa**



Weight (with skids, incl. 4000 extra weight)	17800	kg
Total load	174618	N
Lift points	8	-
Load per constrain	21827	N

- **Pipe 1=2**

Weight skids	3740	kg
Weight of skid frame	540	kg
Total weight	4280	kg
Total load	41987	N
Load per pipe (2 pipes)	20993	N
Load in pipe 1	7180	N
σ axial (tension)	**1.4**	**MPa**

Weight skids	3740	kg
Weight of skid frame	540	kg
Total weight	4280	kg
Total load	41987	N
Load per pipe (2 pipes)	20993	N
Bending length ±	2200	mm
Moment	46185480	N*mm
σ bending	**134**	**MPa**

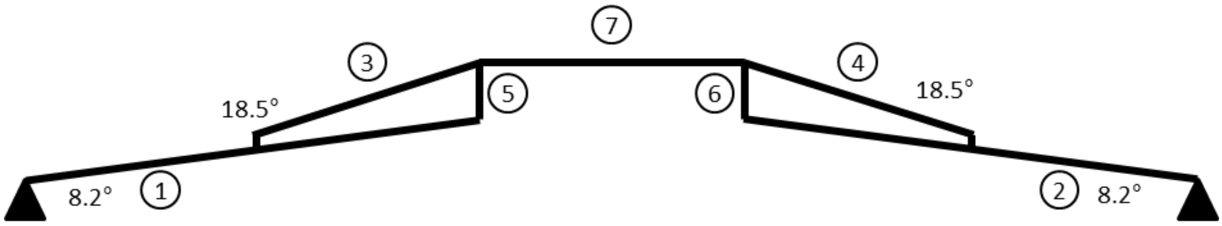
- **Pipe 5**

Weight skids	3740	kg
Weight of skid frame	540	kg
Total weight	4280	kg
Total load	41987	N
Load per pipe (2 pipes)	20993	N
Bending length ±	2200	mm
Moment	46185480	N*mm
Bending length pipe 3	750	mm
Load pipe 5	61581	N
Load from both sides	123161	N
σ axial (tension)	**23.3**	**MPa**

- **Pipe 3=4**

Weight skids	3740	kg
Weight of skid frame	540	kg
Total weight	4280	kg
Total load	41987	N
load per pipe	10497	N
σ axial	**2.0**	**MPa**

bending length	750	mm
Load pipe 5	61581	N
Moment	46185480	N*mm
σ bending pipe	**134**	**MPa**



Weight (without skids, incl. 8000 equipment)	25000	kg
	245250	N
Skid arms	8	-
Load per constrain	30656	N

- **Pipe 1=2**

reaction load	30656	N
Angle (cosine)	81.8	°
Load in pipe	4372	N
σ axial	**0.8**	**MPa**

reaction load	30656	N
arm	3000	mm
moment	91968000	N*mm
σ bending	**267**	**MPa**

- **Pipe 3=4**

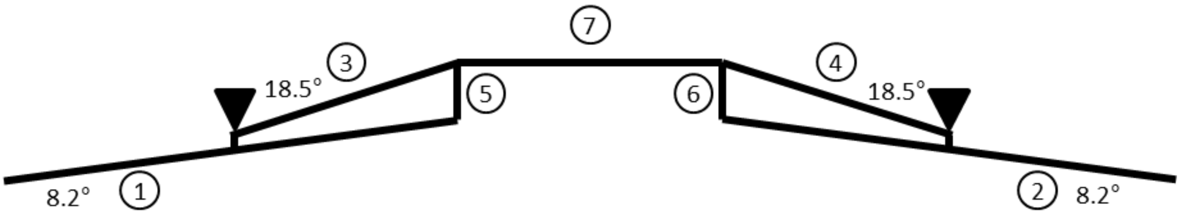
Reaction load	30656	N
Arm	6000	mm
Moment	183936000	N*mm
Arm pipe 3	3000	mm
Load	61312	N
Angle (cosine)	71.5	°
Load in pipe	193228	N
σ axial	**36.6**	**MPa**

- **Pipe 5=6**

51 meter pipe, 41.4 kg/m	2111	kg
Weight of jets	2500	kg
Total top weight	4611	kg
	45238	N
Load per pipe (8)	5655	N
σ axial	**1**	**MPa**

- **Pipe 7**

length C.O.G. to constrain	8650	mm
Load	30656	N
Moment	265176563	N*mm
Y length pipe 7 to constrain	2350	mm
load in pipe	112841.09	N
σ axial	**21**	**MPa**



Weight (with skids, incl. 8000 equipment)	31000	kg
Total load	304110	N
Skid arms	8	-
Load per constrain	38014	N

- **Pipe 1=2**

Weight of skids	3470	kg
Weight of half skid frame	866	kg
Total weight	4336	kg
Weight per pipe (2 pipes)	2168	kg
Load	21267	N
Angle (sine)	8.2	°
load in pipe	3033	N
σ axial	**0.6**	**MPa**

Weight of skids	3470	kg
Weight of half skid frame	866	kg
Total weight	4336	kg
Weight per pipe (2 pipes)	2168	kg
Load	21267	N
Length of pipe	2800	mm
Moment	59547877	N*mm
σ bending	**173**	**MPa**

- **Pipe 3=4**

Weight of top construction	4306	kg
Weight of extra weight and jets	10500	kg
Total weight	14806	kg
Total load	145243	N
Load per side	18155	N
Angle (cosine)	71.5	°
Load in pipe	5761	N
σ axial	**1.1**	**MPa**

- **Pipe 5=6**

51 meter pipe, 41.4 kg/m	2111	kg
Weight of jets	2500	kg
Total top weight	4611	kg
	45238	N
Load per pipe (8)	5655	N
σ axial	**1.1**	**MPa**

- **Pipe 7**

weight of top construction	4306	kg
Extra weight and jets	10500	kg
Total weight	14806	kg
Total load	145243	N
Load per side (8 sides)	18155	N
Bending length C.O.G. ±	3000	mm
Moment around point	54466101	N*mm
Distance point-pipe 7 (vertical)	1100	mm
Load in pipe 7	49515	N
Load from both sides	99029	N
σ axial	**18.8**	**MPa**

References for calculations:

- Hibbeler, R.C. (2010). *Statica* (12th edition). Amsterdam, The Netherlands: Pearson Education
- Hibbeler, R.C. (2012). *Sterkteleer* (8th edition). Amsterdam, The Netherlands: Pearson Education

- **½ * OOD BOP**

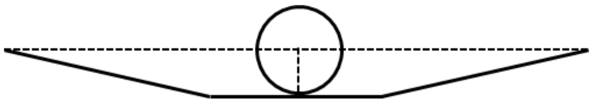
The 0.5*OD BOP scope will result in the following trenching depth:

$$depth\ trench = 0.5 * \text{OD pipe}$$
$$= 1244.6 * \frac{1}{2} = 622\ mm$$

Width of 0.5*OD BOP trench (20° slope angle):

$$W = Bottom\ width + \frac{trench\ depth}{\tan(slope\ angle)} * 2$$
$$W = 2519 + \frac{622}{\tan 20} * 2$$

$$W = \mathbf{5937\ mm}$$



The distance between the skids needs to be at least 5937 -> 6000 mm. This leads to a clearance between the centre spacing of the skids of 8 meters.

- **1.0-m TOP trench**

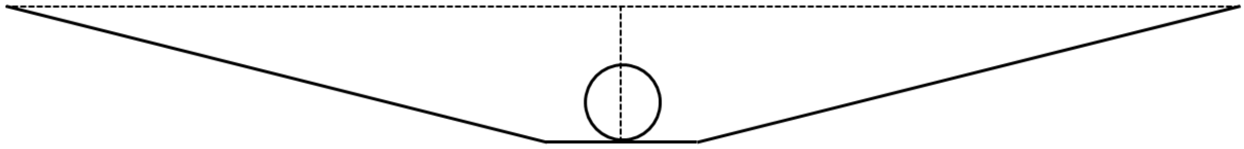
For the 1.0-m TOP scope the depth of the trench is as follows:

$$depth\ trench = OD\ pipe + 1000mm$$
$$= 1244.6 + 1000 = 2245\ mm$$

Width of 1.0-m TOP trench:

$$W = 2519 + \frac{2245}{\tan 20} * 2$$

$$W = \mathbf{14855\ mm}$$



The distance between the skids needs to be at least 14855 -> 15000 mm. This leads to a clearance between the centre spacing of the skids of 17 meters.

Appendix J – Motion reports

Motion report *Calamity Jane* – Knuckle boom crane

Motion Response Calculator - results form

General			
Date	26-Oct-2016		
Project	Deploying Trencher		
Specification	Design of trencher deploying system		
Originator	HBG		
Revision	1		
Vessel	*Calamity Jane*		[-]
Draft	*7.63*		[m]
AQWA *.lis file	*ALCJ3_15DEG.LIS*		[-]
Water depth	1000		[m]
Operational / survival condition	Operational		[-]
Wave spectrum	Jonswap		[-]
Wave directions	[0:15:345]		[deg]
Peakedness factor (γ)	DNV notation		[-]
Significant wave height	[3.5]		[m]
Wave period	[5:0.5:15]		[s]
Wave period type	Tp		[-]
Wave height reduction applied?	yes		[-]
Location of interest*			
	x-Coor [m]	y-Coor [m]	z-Coor [m]
Knuckle boom	37.80	20.50	32.37
Remarks			

*Coordinate system
- positive x-axis points from the APP towards the bow
- positive y-axis points from CL towards PS
- positive z-axis points from the keelline orthogonal upwards
- 0 degree wave direction coming form the stern, positive defined anti-clock wise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**		x	y	z	rx	ry	rz	Hs [m]	Tp [s]	γ [-]	Wave Dir. [deg]
Surge	[m]	1.96	0.98	2.70	2.15	4.82	1.74	3.5	7	4.3	120
Sway	[m]	0.51	3.99	4.44	7.09	1.76	0.93	3.2	14.5	1.0	255
Heave	[m]	0.95	3.46	4.93	7.23	2.83	1.46	3.5	15	1.0	300
Roll	[deg]	0.64	3.74	2.84	7.30	1.73	0.87	3.2	15	1.0	75
Pitch	[deg]	1.96	0.98	2.70	2.15	4.82	1.74	3.5	7	4.3	120
Yaw	[deg]	1.69	1.38	3.00	2.14	4.59	1.87	3.5	8	2.3	120

Velocity**		x	y	z	rx	ry	rz	Hs [m]	Tp [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s]	1.80	0.77	2.03	2.00	4.05	1.42	3.5	6.5	5.0	120
Sway	[m/s]	0.37	1.94	2.14	2.97	1.44	0.68	3.2	14	1.0	255
Heave	[m/s]	1.53	1.06	2.98	1.19	3.40	1.33	3.2	7	4.3	105
Roll	[deg/s]	0.62	1.67	1.27	3.16	1.93	0.90	3.5	15	1.0	60
Pitch	[deg/s]	1.80	0.85	2.36	1.99	4.33	1.54	3.5	7	4.3	120
Yaw	[deg/s]	1.63	0.95	2.42	1.90	4.11	1.56	3.5	7.5	3.1	120

Acceleration**		x	y	z	rx	ry	rz	Hs [m]	Tp [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s^2]	2.46	1.02	2.09	1.89	3.94	1.40	3.5	7	4.3	120
Sway	[m/s^2]	0.50	2.05	1.18	1.41	1.10	0.50	3.2	15	1.0	255
Heave	[m/s^2]	2.09	1.01	2.71	1.22	3.23	1.33	3.2	7	4.3	105
Roll	[deg/s^2]	2.15	1.29	0.82	2.27	3.61	1.23	3.5	6.5	5.0	60
Pitch	[deg/s^2]	2.46	1.02	2.09	1.89	3.94	1.40	3.5	7	4.3	120
Yaw	[deg/s^2]	2.12	0.80	1.70	1.56	2.92	1.59	3.2	5.5	5.0	105

**Remarks
- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

Motion report *Volstad Oceanic* – Knuckle boom crane

Motion Response Calculator - results form

General			
Date	26-Oct-2016		
Project	Deploying Trencher		
Specification	Design of trencher deploying system		
Originator	HBG		
Revision	1		
Vessel	*Oceanic*		[-]
Draft	*6.19*		[m]
AQWA *.lis file	*XshipRao_damped_r6.mat*		[-]
Water depth	1000		[m]
Operational / survival condition	Operational		[-]
Wave spectrum	Jonswap		[-]
Wave directions	[0:15:345]		[deg]
Peakedness factor (γ)	DNV notation		[-]
Significant wave height	[3.5]		[m]
Wave period	[5:0.5:15]		[s]
Wave period type	Tp		[-]
Wave height reduction applied?	yes		[-]
Location of interest*			
	x-Coor [m]	y-Coor [m]	z-Coor [m]
VO crane damped	30.50	-22.50	37.50
Remarks			

*Coordinate system
- positive x-axis points from the APP towards the bow
- positive y-axis points from CL towards PS
- positive z-axis points from the keelline orthogonal upwards
- 0 degree wave direction coming form the stern, positive defined anti-clock wise.

3 hours maximum, single amplitude motions and corresponding environmental conditions

Position**		x	y	z	rx	ry	rz	Hs [m]	Tp [s]	γ [-]	Wave Dir. [deg]
Surge	[m]	2.31	0.77	2.90	1.69	4.08	2.10	3.5	7	4.3	120
Sway	[m]	0.87	4.33	4.26	5.97	2.90	1.88	3.5	14	1.0	240
Heave	[m]	0.97	2.26	4.82	6.10	2.64	1.66	3.5	14	1.0	300
Roll	[deg]	0.92	2.23	2.78	6.13	2.55	1.61	3.5	14.5	1.0	60
Pitch	[deg]	2.21	1.02	3.19	1.99	4.13	2.16	3.5	7.5	3.1	120
Yaw	[deg]	2.09	1.37	3.41	2.28	4.06	2.17	3.5	8	2.3	120

Velocity**		x	y	z	rx	ry	rz	Hs [m]	Tp [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s]	2.14	0.74	2.30	1.32	3.50	1.84	3.5	6.5	5.0	120
Sway	[m/s]	1.00	2.18	2.26	2.94	2.09	1.24	3.5	13.5	1.0	120
Heave	[m/s]	0.63	1.59	2.79	2.42	1.81	1.00	3.2	11	1.0	285
Roll	[deg/s]	0.62	1.21	1.44	3.05	1.82	1.09	3.5	13.5	1.0	60
Pitch	[deg/s]	2.12	0.70	2.54	1.49	3.66	1.90	3.5	7	4.3	120
Yaw	[deg/s]	2.12	0.70	2.54	1.49	3.66	1.90	3.5	7	4.3	120

Acceleration**		x	y	z	rx	ry	rz	Hs [m]	Tp [s]	γ [-]	Wave Dir. [deg]
Surge	[m/s^2]	2.69	0.88	2.18	1.30	3.35	1.80	3.5	6.5	5.0	120
Sway	[m/s^2]	1.21	2.07	1.52	1.58	1.61	0.91	3.5	13.5	1.0	120
Heave	[m/s^2]	1.95	0.90	2.54	1.38	2.46	1.61	3.2	7	4.3	105
Roll	[deg/s^2]	0.88	1.07	1.20	1.83	1.49	0.59	3.5	5.5	5.0	60
Pitch	[deg/s^2]	2.69	0.88	2.18	1.30	3.35	1.80	3.5	6.5	5.0	120
Yaw	[deg/s^2]	2.14	0.70	1.89	1.62	2.35	2.14	3.2	5	5.0	105

**Remarks
- listed values for motions,velocities and accelerations are single amplitudes
- all values are related to 3 hours maxima
- for a complete description of the model and calculation method see the motion report.
- the gravity contribution [g*sin(phi)] is incorporated in all affected values
- Motion analyzer rev. 11

Appendix K – Lifting/towing arrangement

- **Towing arrangement**

In this appendix the lifting arrangement will be shown for both structures.

Reference for slings:
http://www.steelwirerope.com/WireRopes/Constructions/GeneralEngineering/6x7-fibre-core-wire-rope.html#.WE6SC9UrLcs

Sling dimensions large structure

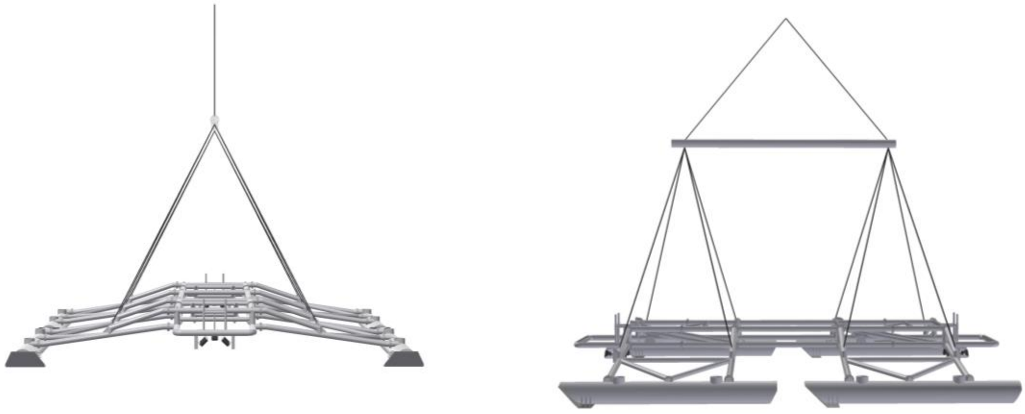


Figure 10.15 Large structure lifting arrangement

Lower slings

Total load	=	31000*9.81 = 305 [kN]
Load per sling	=	305/8 = 38.125 [kN]
Load factor γf	=	1.3
Consequence factor γc	=	1.3
Reduction factor γr	=	1.33
Wear factor γw	=	1.00
Material factor γm	=	1.35
Load distribution factor	=	1.5
Nominal safety factor γsf	=	1.3*1.3*1.33*1*1.35 = 3.03
Load distribution factor	=	1.5 (75%-25%)
M.B.L. sling required	=	Load*γsf = 38.125*3.03*1.5= 173.3 [kN]
Sling	=	6*7 IWRC, ultimate strength 1770 N/mm², 1.1 kg/m DIA 18 mm, M.B.L. 190 kN > 173.3 kN satisfies

Top slings

Total load	=	31000*9.81 = 305 [kN]
Load of slings	=	± 85.8*1.1 = 94.3 [kg] = 925 [N]
Load of spreader bar	=	± 2000*9.81 = 19620 [N]
Total load	=	305+0.925+19.620 = 325.545 [kN]
Total load per sling	=	325.545/2 = 162.8 [kN]
Nominal safety factor γsf	=	3.03
Load distribution factor	=	1.5 (75%-25%)
M.B.L. sling required	=	Load*γsf = 162.8*3.03*1.5= 740 [kN]
Sling	=	6*7 IWRC, ultimate strength 1770 N/mm², 4.47 kg/m DIA 36 mm, M.B.L. 761.58 kN > 740 kN satisfies

Sling dimensions small structure

Figure 10.16 Small structure lifting arrangement

Load	=	13800 * 9.81 = 136	[N]
Load per sling	=	136/4 = 34	[kN]
Load factor	=	1.3	
Consequence factor	=	1.3	
Reduction factor	=	1.33	
Wear factor	=	1.00	
Material factor	=	1.35	
Nominal safety factor γsf	=	1.3*1.3*1.33*1*1.35 = 3.03	
Load distribution factor	=	1.5 (75%-25%)	
M.B.L. sling required	=	Load*γsf = 34*3.03*1.5= 154.53 [kN]	
Sling	=	6*7 IWRC, ultimate strength 1770 N/mm², 1.1 kg/m DIA 18 mm, M.B.L. 190 kN > 154.53 kN satisfies	

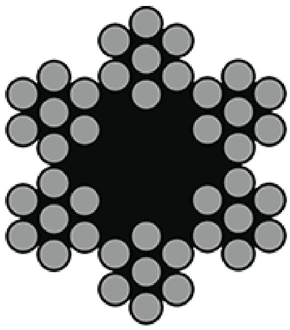


Figure 10.17 6*7 IWRC sling (6 bundles of 7 individual wires)

Shackles

Reference for shackles:
VanBeest_Catalogue_Complete

The slings will be attached to the pad eyes with the use of shackles. These shackles are standard product from a supplier of Allseas and are dimensioned as follows. Assuming that the shackles will be loaded under an angle of maximum 45°, the allowable load will be 70% of its working load limit, see Figure 10.18. The shackle needs to have the same safe working load as the sling to which it is attached.

Load angle	Reduction for side loading New Working Load Limit
0 °	100% of original Working Load Limit
45 °	70% of original Working Load Limit
90 °	50% of original Working Load Limit

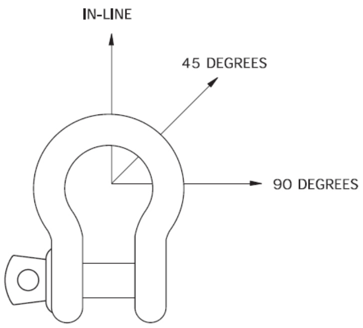
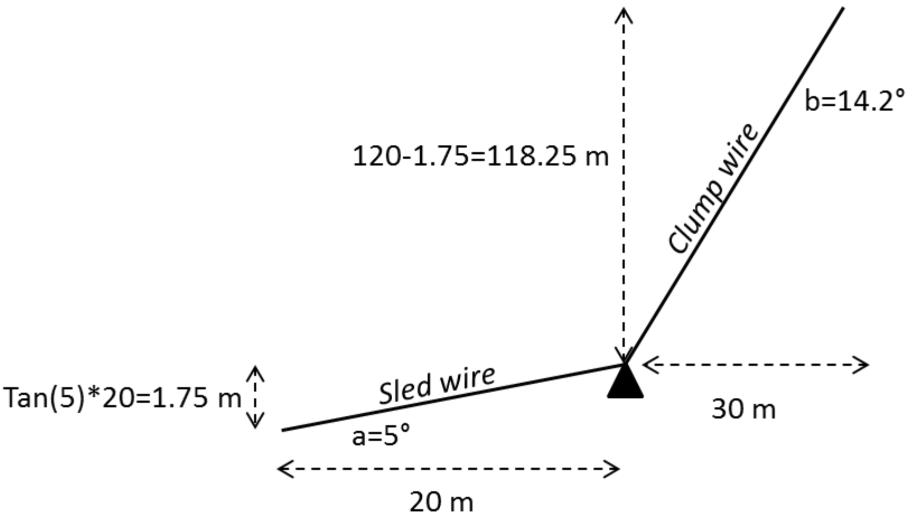


Figure 10.18 Working load limit shackle

Shackle selection:

- 173.3 kN / 0.7 / 9.81 = 25.2 tonnes -> 25 tonnes G-4163 shackle
- 740 kN / 0.7 / 9.81 = 107.8 tonnes -> 120 tonnes P-6036 shackle
- 154.53 kN / 0.7 / 9.81 = 22.8 tonnes -> 17 tonnes G-4163 shackle

- **Towing arrangement**



Distance trencher – crane	=	20 meter
Distance crane – clump wire connection	=	30 meter
Angle of towing, trencher	=	5°
Required towing load	=	105 kN

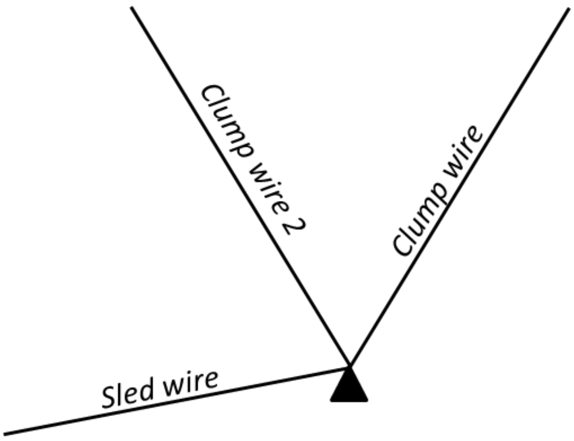
$$Fsled\ wire_x = 105\ kN$$
$$Fsled\ wire = 105 * cos(5) = 104.6\ kN$$
$$Fsled\ wire_y = 105 * tan(5) = 9.2\ kN$$

$$b = tan^{-1}\left(\frac{30}{118.25}\right) = 14.2°$$

$$Fclump\ weight_x = 105\ kN$$
$$Fclump\ weight = \frac{105}{\cos(90 - 14.2)} = 428\ kN$$
$$Fclump\ weight_y = 105 * \tan(90 - 14.2) = 415\ kN$$
$$M_{clump\ weight} = \frac{145}{9.81} = 14.8\ tons$$

When the trencher is towed and the vessel will slow down or come to a stop, the clump wire will hang slack. If this occurs, the clump weight will drop and swing forward, resulting in hitting the pipeline. To prevent this from happening a second clump wire is added.

The second advantage of a second clump wire is that the trencher cannot increase in velocity when the clump wants to swings forward. Hereby the quality of the trench will be maintained.



Appendix L – Competentie verantwoording

In dit hoofdstuk worden de behaalde competenties verantwoord. Dit wordt gedaan met behulp van verschillende deelcompetenties te beschrijven. Aan het begin van de afstudeerstage zijn de volgende drie competenties benoemd waarin de student zich gedurende zijn afstudeerperiode in heeft ontwikkeld:

- Professionaliseren
- Analyseren
- Ontwerpen

1. Analyseren

"Het analyseren van een engineeringvraagstuk omvat de identificatie van het probleem of klantbehoefte, de afweging van mogelijke ontwerpstrategieën / oplossingsrichtingen en het eenduidig in kaart brengen van de eisen / doelstellingen / randvoorwaarden. Hierbij wordt een scala aan methoden gebruikt, waaronder wiskundige analyses, computermodellen, simulaties en experimenten. Randvoorwaarden op het gebied van o.a. (bedrijfs) economie & commercie, mens & maatschappij, gezondheid, veiligheid, milieu & duurzaamheid worden hierbij meegenomen."

Niveau:	3
Aard van de taak:	complex, ongestructureerd, verbetert methoden en past normen aan de situaties aan
Aard van de context:	onbekend; complex, multidisciplinair in de praktijk
Mate van zelfstandigheid:	zelfstandig

Deelcompetentie 1d;

"Zelfstandig opstellen van een programma van (onbekende en complexe technische & niet-technische) eisen in een multidisciplinaire context en dit vast kunnen leggen."

Verantwoording:

Aan het begin van het project heeft de student door middel van onderzoek en communicatie het pakket van eisen moeten vaststellen waaraan het ontwerp moest voldoen. Dit pakket van eisen is gedurende het project uitgebreid en aangepast, als gevolg van project veranderingen of onderzoeksresultaten. Hierbij heeft de student aangetoond dat hij aan de deelcompetentie voldoet.

Deelcompetentie 1e;

"Zelfstandig modelleren van een bestaand onbekend(e) en complex(e) product, proces of dienst in een multidisciplinaire context."

Verantwoording:

Voor het starten van het ontwerpen van het nieuwe frame heeft de student zich moeten verdiepen in de werking van een trencher. Om een ontwerp te kunnen maken wat bestand is tegen verschillende krachten, moeten eerst de krachten bekend zijn. Hiervoor heeft de student het trenching-proces geanalyseerd en verschillende load cases opgesteld waarin de trencher aan krachten wordt blootgesteld. Deze loadcases zijn zowel gebaseerd op operationele als niet operationele situaties.

Na het ontwerpen van de constructie heeft de student de hiervoor opgestelde load cases toegepast met het programma Femap. Hierbij zijn de verschillende frames geanalyseerd op de situaties die tijdens verschillende condities voor kunnen komen. Met de FEM-modellen is onderzocht waar die piek spanningen voorkomen, om deze vervolgens te kunnen optimaliseren met als doel de piekspanningen te verlagen. Hiermee heeft de student aangetoond een ontwerp te kunnen modelleren en analyseren om zo tot resultaten te komen.

2. Ontwerpen

"Het realiseren van een engineeringontwerp en hierbij kunnen samenwerken met engineers en niet-engineers. Het te realiseren ontwerp kan voor een apparaat, een proces of een methode zijn en kan meer omvatten dan alleen het technisch ontwerp, waarbij de engineer een gevoel heeft voor de impact van zijn ontwerp op de maatschappelijke omgeving, gezondheid, veiligheid, milieu, duurzaamheid (bijv. cradle-to-cradle) en commerciële afwegingen. De engineer maakt bij het opstellen van zijn ontwerp gebruik van zijn kennis van ontwerpmethodieken en weet deze toe te passen. Het te realiseren ontwerp is gebaseerd op het programma van eisen en vormt een volledige en correcte implementatie van alle opgestelde eisen."

Niveau:	3
Aard van de taak:	complex, ongestructureerd, verbetert methoden en past normen aan de situaties aan
Aard van de context:	onbekend; complex, multidisciplinair in de praktijk
Mate van zelfstandigheid:	zelfstandig

Deelcompetentie 2a;

"Zelfstandig in staat zijn om vanuit de opgestelde eisen een onbekende en complexe concept-oplossing (architectuur) te bedenken en te kiezen in een multidisciplinaire context."

Verantwoording:

Het pakket van eisen is samengesteld door voorafgaand onderzoek door de student en er is een constructie ontworpen welke is getest aan verscheidene loadcases tijdens operationele en niet-operationele condities. Daarnaast is het systeem modulair gemaakt om zo twee scopes of work te kunnen uitvoeren met het aanpassen van het systeem. Dit resulteert in materiaal besparing en dus kosten. Bovendien wordt hiermee ruimte aan dek van het schip bespaart tijdens de operatie. Hiermee heeft de student aangetoond een concept-oplossing te kunnen ontwerpen en hiermee te voldoen aan de deelcompetentie.

Deelcompetentie 2f;

"Zelfstandig opstellen van de documentatie ten behoeve van het complexe product, de complexe dienst of het complexe proces in een onbekende of multidisciplinaire context."

Verantwoording:

De student heeft de resultaten van het onderzoek verwerkt in een rapport volgens de eisen die aan een structural rapport worden gesteld binnen Allseas. Op basis van dit rapport worden ontwerpen gekeurd door Lloyd's register. Hiermee heeft de student kunnen aantonen dat hij voldoet aan de deelcompentie.

8. Professionaliseren

"Het zich eigen maken en bijhouden van vaardigheden die benodigd zijn om de engineering competenties effectief uit te kunnen voeren. Deze vaardigheden kunnen ook in breder verband van toepassing zijn. Dit omvat onder meer het hebben van een internationale oriëntatie en het kunnen plaatsen van de nieuwste ontwikkelingen, bijvoorbeeld in relatie tot maatschappelijke normen, waarden en ethische dilemma's."

Niveau:	3
Aard van de taak:	complex, ongestructureerd, verbetert methoden en past normen aan de situaties aan.
Aard van de context:	onbekend; complex, multidisciplinair in de praktijk
Mate van zelfstandigheid:	zelfstandig

Deelcompetentie 8b;

"Zich zelfstandig flexibel opstellen in uiteenlopende onbekende en complexe beroepssituaties in een multidisciplinaire context."

Verantwoording:

De student heeft tijdens het afstuderen onder anderen in een team gewerkt en deelgenomen aan vergaderingen waarbij gezamenlijk naar oplossingen voor technische problemen werden gezocht. Daarnaast is de student zelfstandig aan het werk gegaan met zijn afstudeeropdracht. Hiermee heeft de student aangetoond dat hij flexibel aan het werk kan gaan in een team.

Deelcompetentie 8f;

"Zelfstandig kunnen gebruiken van diverse onbekende en complexe communicatievormen en –middelen om effectief te kunnen communiceren in het Nederlands en Engels in een multidisciplinaire context."

Verantwoording:

Tijdens het afstuderen heeft de student in een multicultureel team gewerkt waar voor het grotendeels in Engelse taal wordt gecommuniceerd. Alle documentaties zijn Engels talig, door middel van een Engels scriptie heeft de student aangetoond dat hij over deze competentie beschikt.