BellHandling System

Modification of clump weight

MASTER THESIS
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Main objectives and sub-objectives

The main objective is to find one or several possible solutions to straighten up the deployment angle of the clump weights so they are leveled in a horizontal position as the design specification instructed.

- The solution should be able to be installed by the Mechanical Dive Technicians onboard.
- The solution should not require load testing if possible.
- Simple to install, minimum costs

Sub-objectives

a) Analysis of the problem
b) Determine the consequences of the problem
c) Analysis of the solutions
d) Visualisation of the solutions
e) Make a detailed 3d drawing of the solutions

Project activities link to each sub-objective

a) Mathematical analyis and model test
b) Study the research made on wire rope
c) Mathematical analysis and model test
d) Make sketches
e) find limitations to the design

Limitations in depth and width

For this report I have been handed out 2D and 3D models in protected formats. It is possible create sketches based on the drawings, but I am not allowed to edit the files. (Parkburn has the copyright)

The mathematical analysis will be limited with simple calculations because the research of possible solution will be time consuming

Research methods

Model tests

Supervisors and advisors (UiS and Industrial company)

UiS:	R.M Chandima Ratnayake
Subsea 7:	Øystein Kleppestø,(Diving Technical Support Engineer)

Abstract

The dive support vessel Seven Havila is a new and top modern vessel with the most advanced dive system in the world. In 2011 she was awarded with the prestigious title “Support Vessel of the Year”. But modern design has their downsides, as a design often needs several versions before all the “child diseases” are gone.

Onboard Seven Havila a problem was encountered in the bell handling system. They are having a problem with the port and starboard bell clump weight deployment angle. The problem is that when the clump weight is deployed before the bell, the clump weight gets a tilt up to 60 degrees. Over a period of time this will cause the guide wires and bell frame bushes to wear and will increase the amount of maintenance.

The objective with this master thesis is to find possible solutions to straighten up the deployment/ recovery angle so they are sitting in the horizontal position as the design specification instructed.

As a research method, experimental trials with a clump weight model have been conducted. Studies of other clump weight designs were also an important part of the research. Simple calculations have been done to give an indication of the effect of the different solutions.

Several of the solutions will have a positive effect, but none of the solutions, except the use of two winches instead of one, will remove the tilt problem completely. The use of ballast weight to lower the CoG gave good results in the test trials, but because we are limited with the amount of weight we are allowed to add, we cannot expect the same effect. The use of support arms to act as a momentum counter to the tilt force gave the best results during the trials.

The final recommendation is to either:

1. Expand the diameter on the split bush and to add the allowable weight of 250 kg at the bottom of the clump weight. A lower COG will counter the tilt angle while the expanded diameter will allow for more free space and reduce the amount of friction caused by the bend.
2. Install supports arms and where the remaining weight is placed at the bottom of the clump weight.

The first option will require less work and is more cost effective than the second option, but the last option will give more tilt reduction.

Acknowledgements

First and foremost, I would like to thank professor Chandima Ratnayake at UiS for supervision, encouragement and support throughout the making of this thesis.

A special thanks should also be made to Øystein Kleppestø which has been a great support handing over helpful documents, he was halways happy to help whenever I had any questions regarding the dive system.

I will also thank engineers at subsea 7 which were happy to discuss the clump weight problem with me.

Michael Day, a former saturation diver, gave me a great insight in several types of dive systems, he also gave me a couple of tips to possible solutions. Thanks.

Jarle Kvåle Kolbeinsen

Stavanger, June 15th 2012

Contents

1 Introduction

During the summer of the 2011 I was working as a summer student for Subsea 7. I was lucky enough to be placed onboard the dive support vessel Seven Havila and got to assist the field engineer with various tasks. During this period I learned quite a lot about diving interventions and how the dive system worked. It was during this summer that I was told about the clump weight issue. Several engineers and experts had tried to find a solution to this problem. I found it quite interesting to see how a small part such as the clump weight can cause major problem to the rest of the system. By the end of the summer I was presented several problems they wanted me to write a theses about, but it was the bell handling system with the tilting clump weight which had caught my attention. This was a problem I really wanted to investigate.

The problem with the clump weight is due to the double fall system. One winch is used to deploy/ recover the clump weight. The clump weight is hold by the two sheaves inside the clump weight, the wire goes down from the winch through the sheaves and up to a fixed anchor point. The clump weight is designed to roll on the wire such that it always maintains a horizontal position. Resistance in the systems prevents the clump weight from rolling. It is not until the clump weight reaches an angle up to 60 degrees that the clump weight starts to roll. This causes major friction forces between the wire and the clump weight. This can lead to, over time, wear and fatigue of essential components.

For this thesis I have made a clump weight model where the mechanical behavior has been studied. The test model proved to be a helpful tool during the search of a perfect design.

The report is organized by following chapters:

Chapter 2 gives an introduction to diving operations in general and detailed description of the bell handling system onboard Seven Havila. This is presented so the reader can gain a better understanding of the complete system and to learn how the main components interact with each other.

Chapter 3 describes the clump weight problem in detail. Sequence of the operation is visualized with pictures and a sketch is made to show the problem in context with rest of the system.

Chapter 4 presents the analysis of the clump weight problem, with explanation of why the tilt is created. It also presents the risks and consequences associated with the problem.

Chapter 5 describes other clump weight designs, it also presents the limitations we have to our design.

Chapter 6 presents all the solutions which have been considered. This is to get a better argument for why the chosen solutions are considered to be the best option.

Chapter 7 presents the experimental trials on the clump weight test model. Several experiments were conducted, all of them with the objective to understand the behavior of the clump weight when we have a double fall system.

Chapter 8 investigates the effect and feasibility of the recommended solutions

Chapter 9 A final conclusions and recommendation is presented.

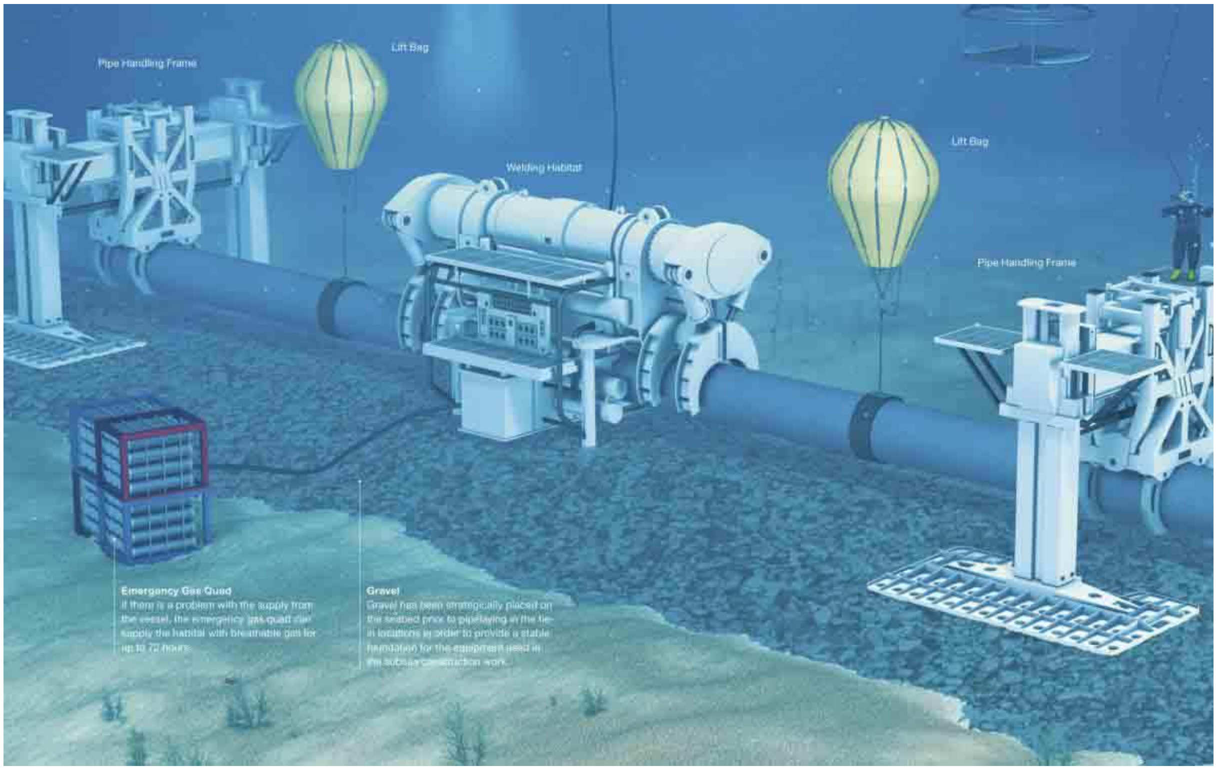
Last part of the reports describes the necessary work left before the recommended solutions can be implemented.

2. An introduction to Diving

The purpose of this chapter is to present the reader to the general context of which this report is written; tilting clump weights at the bell handling system. The most essential terms and expressions associated with diving operations are introduced, and a detailed description of the bell handling system onboard the DSV Seven Havila.

Diving Intervention

Diving Support Vessels operates on shallow water depths where human intervention is possible. Although the use of ROVs extensively provides remote eyes and hands for subsea operations, some tasks require human action. The applications of robot manipulators are limited, which calls for the more flexible abilities of a diver. Within reasonable water depths, divers are engaged in operations using the so-called saturation diving technique, which refers to the fact that the diver's tissues have absorbed the maximum partial pressure of gas possible for a given depth. Only being subjected to one compression and one decompression during each trip allows for the divers to live and work in pressurized environments for days or weeks at the time.



Figur 1 Diving Intervention, hyperbaric welding inside a habitat

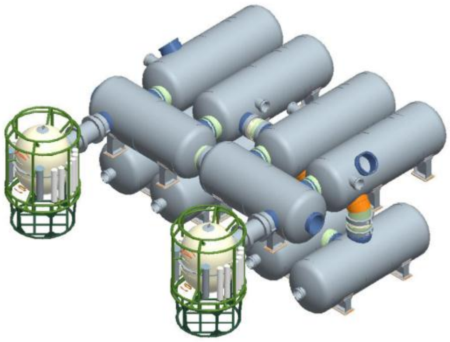
Figure 1 is an example of a typical dive operation; this is technique of hyperbaric welding inside a habitat (no water inside the habitat). The divers are transported to the sea bottom with a diving bell, for so to start the welding operation inside the habitat.

Dive System

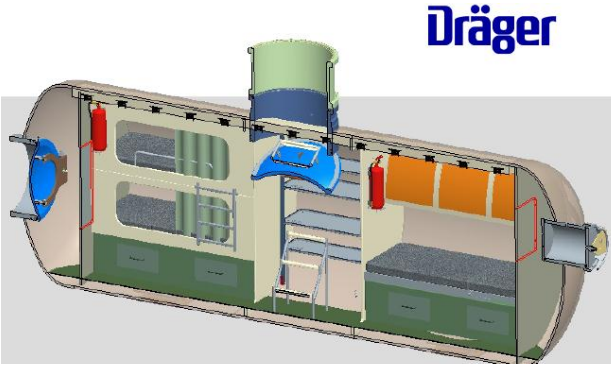
During non-working hours the saturation divers live in chambers. These chambers are pressurized equal the pressure at specified working depth. The divers are transported subsea using pressure-controlled diving bells. There are two main methods for launching of the diving bell is; either launched through a moonpool or over the side using an A-frame. A moonpool is well going through the ship.

Seven Havila is equipped with two separate diving bell moonpool deployment systems, located at mid ship.

The dive system onboard Seven Havila, which is manufactured by Draeger, can accommodate up to 24 divers. The system contains four living chambers, four sleeping chambers, two wet pots and two diving bells.



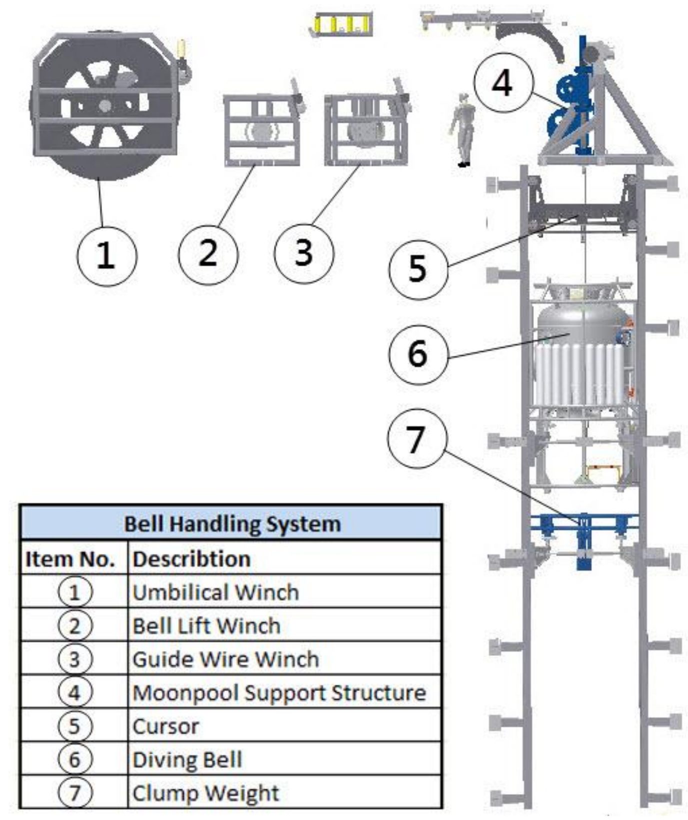
Figur 2 Saturation Chambers & Diving Bells



Figur 3 Inside a living chamber

Bell Handling System

The Diving Bell Handling System on the DSV Seven Havila comprises two independent systems. One located on starboard side, the other on port side.



Bell Handling System	
Item No.	Describtion
①	Umbilical Winch
②	Bell Lift Winch
③	Guide Wire Winch
④	Moonpool Support Structure
⑤	Cursor
⑥	Diving Bell
⑦	Clump Weight

Figur 4 Bell Handling system (Seven Havila)

Umbilical Winch

The Umbilical Winch is used to deploy and recover the Diving Bell's Umbilical Cable

Bell Lift Winch

The Diving Bell Lift Winch is used to deploy and recover the Bell Lift Wire, which is attached to the Diving Bell.

Guide Wire Winch

The Guide Wire Winch is driven by two independent electric motors. Each motor has an independently operated, spring-applied electrically released brake. The Guide Wire Winch is designed such that the Diving Bell can be lifted and braked on any single motor and brake in the event of the other drive unit failure. The brakes are configured such that even if an electric motor is faulty and coasting, the braking unit will still operate at full duty.

Moonpool Support Structure

The Handling System Top Structure supports the Shock Absorber Swivel Sheave, the Swivel Sheave Assembly and the Cursor Maintenance Winch. The Structure is designed to take the full design load of the Diving Bell in Air.

The shock absorber, which operates in conjunction with the diving bell lift winch, is used primarily during the bell transition from air to water. This is to prevent slack wire leading to snatch loads.

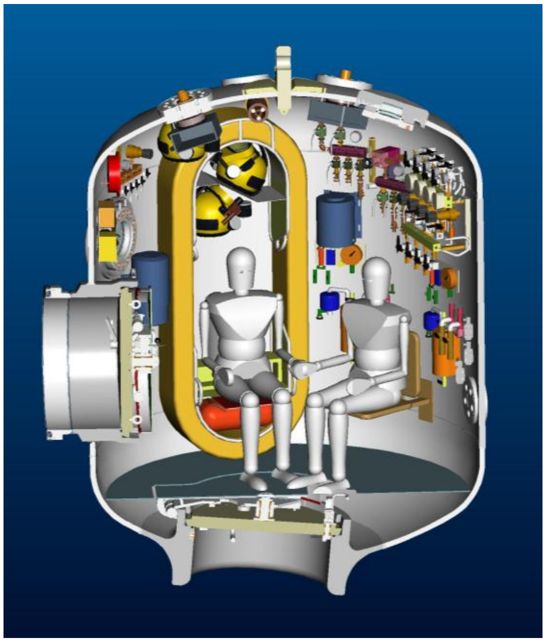
The main purpose of the Cursor Maintenance Winch is to maneuver the Cursor to its storage position to allow maintenance to be performed on the upper area of the Diving Bell.

Cursor

The Cursor is used to move the diving bell up and down the moon pool guide-rails and provides support in both transverse and longitudinal directions.

Diving Bell

The diving bell is used to transport the saturation divers to and from work. Each bell can accommodate 4 men. The horizontal trunk is connected with the chambers inside the diving bell. The bottom trunk is used as an entrance when subsea.



Figur 5 Inside the diving bell (Seven Havila)

Bell Lift Winch

The bell lift winch complete with wire is used to deploy and recover the diving bell. It is driven by four electrical motors, and is designed to work with any combination of two failed motors. The active heave compensator reduces the effect from the heave motion on the vessel by keeping a constant tension of wire and preventing any potential snatch loads.

The Clump Weight

The main objective with the clump weight is to maintain the diving bell in a vertical attitude during working operations. The second and equally important purpose is to act as an emergency lift of the diving bell in case of failure of the bell lift winch.

Figur 6 Clump Weight

Main Data Clump Weight	
Wire rope diameter	34mm
D/d ratio	18:1
Sheave diameter	612mm
Bearing type	Plain
Weight (approximate)	3500kg

Guide wire

The guide wire runs from a fixed point adjacent to the side of the bell in its pre-launch position, through the two sheaves, one attached to each side, and then back to the surface sheave giving a lead to the guide wire winch creating a double fall arrangement.

It has a diameter of 34 mm and is of the type Dyform 34LR. The guide wire is designed to take the full load of the clump weight and the diving bell. It has a SWL of 13.5 Te.

Figur 7 Guide wire leading up to the winch

Main Data Guide Wire	
Wire rope diameter	34 mm
Type	Dyform 34LR
Grade	1960
MBF	1060 kN
Mass	5.74 kg/m
SWL	13500 kg
Design Temp	-10°C to + 55°C
Finish	Galvanised

Benefits with Dyform 34LR (Bridon 2012, viewed April 12) :

- Low rotation
- Recommended for high lifting operations
- High strength
- Reduced rope sheave wear
- Accurate diameter, recommended for multi-layer coiling
- Suitable for single part and multi-part reeving
- Long service life
- Crush resistant
- Reduced down time

Figur 8 cross section of Dyform 34LR (Bridon)

3. Problem Description

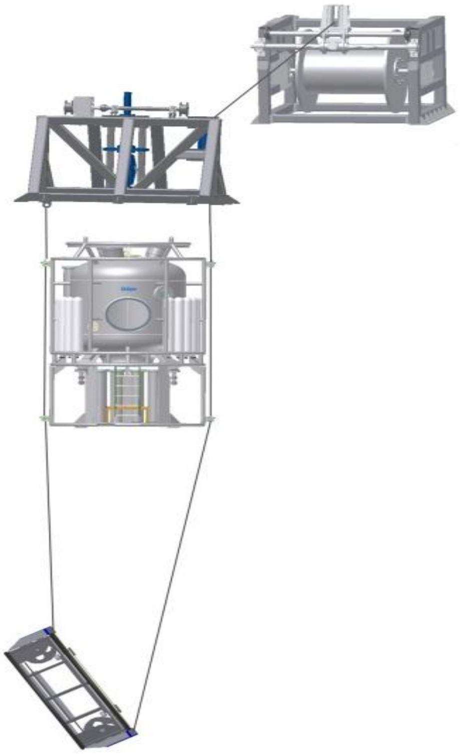
The clump weight is designed to be deployed and recovered in such a way that it lies on a horizontal level. The problem is that the clump weight rotates and creates a tilting clump weight during the lift and lowering of the guide wire. The magnitude of the tilt angle is largest during deployment and can reach up to 60 degrees at worst.

The main problem with the clump weights appears to be compounded by the use of a fixed anchor point with one guide wire winch. When lifting the clump weight, the sheave which is located at the same side as the guide wire winch is dragged upwards while the other winch still stands in same position. The same thing happens when lowering the clump weight, except that it goes downwards. The clump weight can reach up to 60 degrees before the sheaves starts to rotate. The figure to the left illustrates the problem during deployment of the clump weight.

Seven Havila is equipped with a state of the art bell handling system, as a consequence of a new design is that unexpected problems often appears.

A consequence of the tilt angle is that wire and split bushes will wear, leading to a higher requirement of maintenance and the availability of the diving bells will be reduced. Since the vessel is specialized in diving operations, it is essential the diving bells are in operational state at all times. High downtime of the diving bells will lead to a big cost implication.

On the two following pages the reader can view the detailed description of the clump weight operation



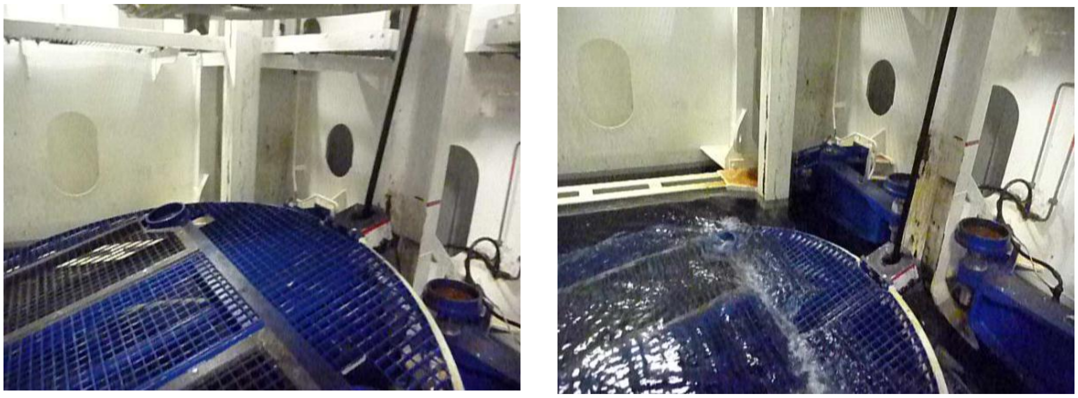
Figur 9 Bell Handling System with tilting clump weight

Parked Position

Figur 10 Clump weight inside the moonpool

The clump weight is locked in a parked position inside the moonpool. The clump weight is resting on a clamp system during standby, this makes it possible to release the tension in the wire. On the picture above we can see the bottom part of the diving bell which is parked just above the clump weight. the gap between the clump weight and the diving bell is 15-20 cm and makes it possible to lift the clump weight free from the clamps. The guide wire winch is placed on the left side on the picture while the fixed anchor point is fitted on the right side.

Deployment of clump weight



Figur 11 a & b deployment of clump weight

As the guide wire winch gives out wire for deployment of the clump weight, only the left side starts moving downwards, the right side is still placed in parked position. When the left side is lowered to a certain point, the right side starts to follow. The guide frame inside the moonpool prevents the tilt to be fully developed. When the clump weight has been lowered free from the guide frame, the tilt grows larger. At this point the clump weight can reach up to 60 degree tilt.

Recovery of clump weight

Figur 12 a & b Recovery of clump weight

During recovery of the clump weight, the lift side tilts upwards. The left side is leading up to the guide wire winch. Left side reaches parked position before right side (marked with red on the guide frame).The maximum tilt angle during deployment reaches a few degrees less than the deployment angle.

Parking the clump weight

Figur 13 a & b Parking the clump weight

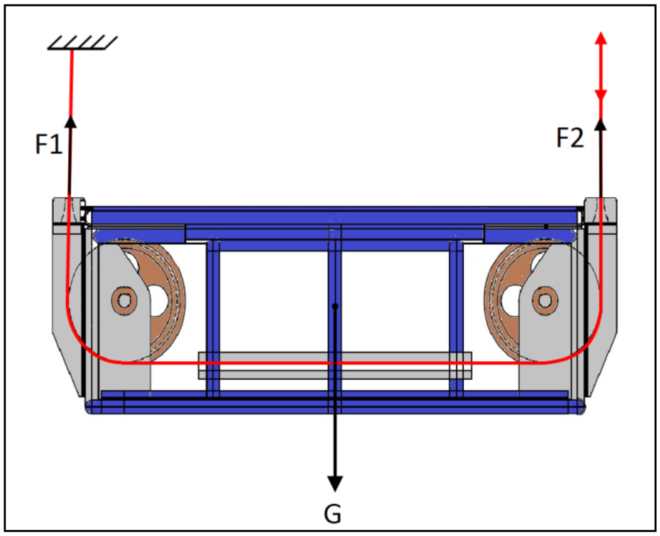
In order to park the clump weight, it has to be lifted above the clamps. To get the right side of clump weight to parked position, the left side needs to be lifted higher. When the right side is locked in park, the left side can lowered back to park position. Due to the tilt, the space between the clump weight and the diving bell is essential for this operation.

4 Analysis

In the first part of this chapter, the objective is to gain a better understanding of the different factors leading to this problem. We need to find the root of the problem before we can find a solution to the problem. In the second part, the consequences of the problem are investigated

Root Cause Analysis

Clump Weight in parked position



Figur 14 leveled clump weight

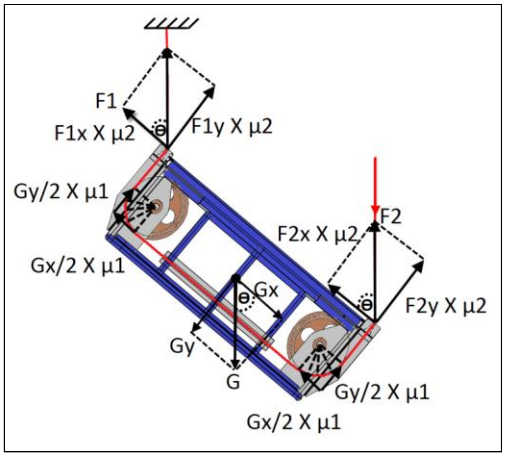
When the clump weight is in parked position, the weight of the clump weight (G) is held by the double fall arrangement. The two ropes (F1 & F2) are holding the clump weight with equally large forces.

F1 = F2 and F1 + F2 = G.

The weight of the clump weight is held by two sheaves mounted on the clump weight.

Deployment & Recovery

During initiating of the deployment, the clump weight tilt angle (ϴ) grows up to 60 degrees before it starts moving downwards.



Figur 15 Deployment

$0° < ϴ < 60°$

In order for the sheaves to rotate, an external force is needed.

This can be compared with a car standing on a flat ground; the car will stand still if no forces are applied in the horizontal direction. But if the car is placed in a steep hill, the gravity will act as force and the car will start moving. This force is dependent of how steep the hill is; the angle of the hill.

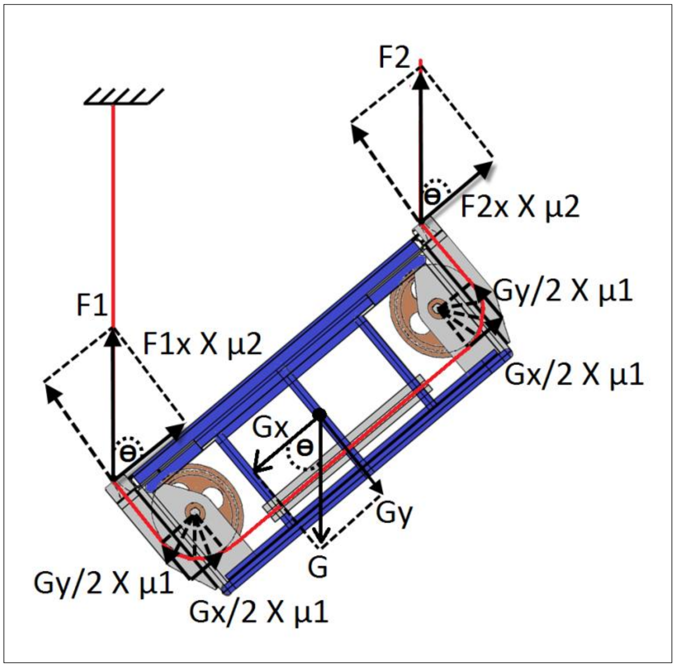
The same applies for the clump weight. The force applied

$Gx = G* \cos(\Theta)$

The external force required for the sheaves to rotate can be expressed as:

$Gx = G \times \cos 60$

At first it is only friction force from the two sheaves (µ1) which acts as a counter force to Gx, but as the tilt grows larger, a new source of friction appears; friction force from the split bushes (µ2). This friction will grow in line with the growing tilt. The split bushes will thus contribute, together with the sheaves, to hold the weight of the clump weight.



$G = F1 + F2 = mg$

$Gx = G \times \cos \Theta$

$Gy = G \times \sin \Theta$

µ1 = Friction force from sheave

µ2 = Friction force from split bushes

$F2x = F2 \times \cos \Theta$

$F1x = F1 \times \cos \Theta$

$0 \leq \Theta \leq 60$

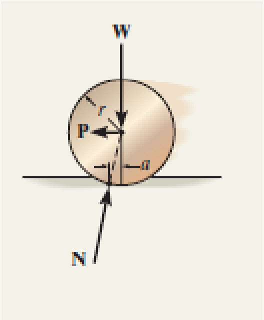
Figur 16 Recovery

When the wire rope is lifted/ lowered, the sheaves on the clump weight needs to rotate at the same speed as the wire rope. But in order for the sheave to rotate a force needs to be present; the sheave is dependent on an external force. In this case, the external force is created by the gravity Gx.

The force Gx must be large enough to overcome the resistance of friction at the contacting surface in order to cause rotation in the two sheaves. When the clump weight is levelled, all forces are acting in Gy direction. As the guide winch gives out wire, the tilt grows larger and the force Gx grows with the tilt. It is not until the tilt reaches an angle of 60 degrees that the force Gx is larger than the resistance of friction.

If we have two sheaves with the same mass but different sizes, the sheave with largest diameter requires more force to rotate compared with the smaller sheave; it has a larger moment of inertia.

The mass moment of inertia is defined as ‘a property of a body that measures its resistance to a change in its rotation. It is defined as the “second moment” of the mass element of the body about an axis.’(Hibbeler, 2010 ,Page 558)



Figur 17 Rolling Resistance (Hibbeler)

The mass moment of inertia (*I*) of a disk is calculated with following formula (Hibbeler, 2010):

$I = 1/2m*r^2$

Where “m” is rated as the mass and “r” is the radius of the disk (in this case the sheave).

The resistance of a wheel to rolling over a surface is caused by a localized deformation of the two materials in contact. This causes the resultant normal force acting on the rolling body to be inclined so that it provides a component that acts in the opposite direction of the applied force P causing the motion. This effect is characterized using the coefficient of rolling resistance, a, which is determined from experiement.(Hibbeler 2010, page 451

$P = (W*a) /r$

In order to determine the rolling resistance between the sheave and the wire rope we need to know the coefficient of the rolling resistance, which is determined for experiments. From the formula above we can see that larger radius gives less rolling resistance. It can be indicated that rolling resistance with a light load is less compared with a heavy load when the conditions are the same (Hibbeler, 2010)

A bearing is placed the center of the sheave. It is the bearing that makes it possible for the sheave to rotate, but the contact surface between the bearing and the sheave creates a friction. The rotation force in the sheave must be larger than the rolling resistance.

Consequences

What’s important to investigate for this problem can be summarized with two questions:

1. Does the tilt cause any operational implications?
2. Will the problem cause any fatigue to the components in the system?

Operational consequences

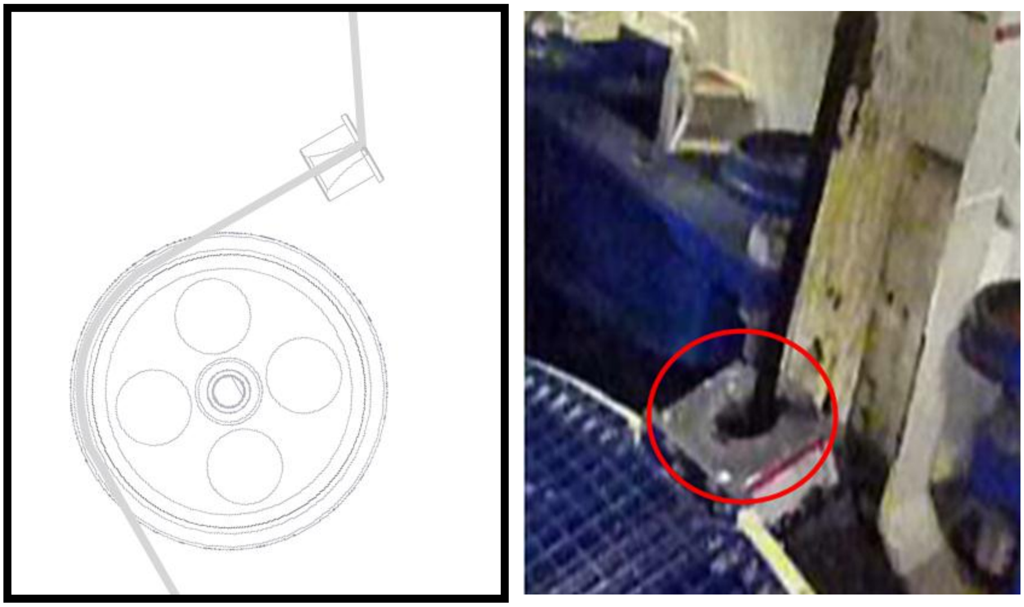
What the author investigated was whether or not this would affect the clump weights main objective, which is to maintain the diving bell in a vertical attitude and to act as a secondary recovery method. The main concern was how the clump weight was fitted under the diving bell during preparation for the recovery. But this was not a problem at all (Kleppestoe, personal communication, 15 March). The clump weight straightens up and fits the diving bell perfectly.

The clump weight rests on a clamp when it’s parked in the moonpool. Prior to launching, the clump weight has to be lifted up a couple of centimeters just enough to remove the clamp. Due to the tilt, it requires more lift to get the whole clump weight free from the clamp. The launch and recovery operation will therefore be slightly longer with a tilting clump weight compared with a non-tilting clump weight. But because it’s just a couple of minutes extra, the operation time alone cannot justify any modifications. It can only be regarded as a minor delay, which at worst can cause annoyance for the operator.

Wear of components

The main components which are exposed to additional wear as a result of the clump weight tilt are the split bushes, diving bell bushes and the guide wire rope.

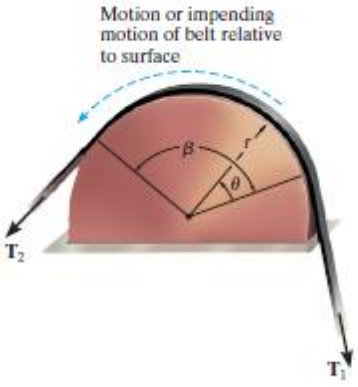
The split bushes are fitted on the clump weight, one on each side. When the clump weight reaches a tilt of 60 degrees a great part of the weight will be held by the guide bushes. This will again cause substantial friction between the wire and guide bushes. It also creates an unfortunate bend to the wire.



Figur 18 a & b wear of guide wire and split bushes

The tilt is causing larger friction forces between the wire rope and the two split bushes. The split bushes are pulling the guide wire out of position which creates a bend on the wire. In order to determine the consequence caused by the contact between the rope and the split bushings, we need to know:

- Friction between the rope and the split bushes
- Amount of bend
- Rope performance



Figur 19 Rope friction (Hibbeler)

The friction between the rope and the guide bush can by calculated with the formula (Hibbeler 2010, page 422):

$T2= T1e^{\mu\beta}$

Where;
T2, T1= rope tension
μ = friction coefficient
β= angle of rope to surface
e = 2.718

In order to determine the friction force acting between the guide bushing and the rope we need to know the tension in the wire rope, the angle of the surface and the friction coefficient.

Figur 20 Bell frame bushes

When the diving bell is recovered with the clump weight, this should contribute to an even greater tilt. But the frame bushes are preventing the tilt. The diving bell weighs 6.5 Te in the seawater. Since the frame bushes have to support this weight at the same time as the bell is moving upwards, we can expect a major friction force which wears both the bushes and the guide wire.

Split bushes

The split bush is designed to act as a guide for the wire rope and to stabilize the clump weight. But due to the tilt, a much greater force is applied to the bushings. But after approximate 6 months with vessel operation there are still no signs of wear on the bushes(Kleppestø, personal communication, 30 April 2012) Fatigue inside the material however is more difficult to detect.

But even if the any of the bushings should be damaged, they are designed for easy access, and can be changed out quickly. To avoid any major vessel delays, a spare part should be available onboard Seven Havila.

Guide wire

If the rope should break, it's most likely to happen when the maximum load is applied; during recovery of the diving bell. This can lead to major consequences for the divers inside the bell, death at worst. Due to this, it's vital to avoid any unexpected accidents. We need to know expected wire rope lifetime.

A method to determine the rope lifetime for ropes with cyclic bend over sheaves, a rope lifetime factor is often used (Gibson 1980, Vennemann 2008):

$$\mathrm{SF} \cdot \frac{\mathrm{D}}{\mathrm{d}} \text{ or } \frac{\mathrm{MBL}}{\mathrm{WL}} \cdot \frac{\mathrm{D}}{\mathrm{d}}$$

This method, however, does not account for rope size and rope constructions. The estimated lifetime can at best give information about the most probable retirement point however bending fatigue test using the actual rope size and construction are unavoidable in order to increase the degree of confidence. (Vennemann 2008)

‘The D/d Ratio is the ratio of the diameter around which the sling is bent divided by the body diameter of the sling.’ (Unirope 2010, viewed April 12 2012). The D/d ratio between the clump weight sheaves and the guide wire rope is 610mm/34mm = 18. Higher D/d ratio gives longer life time.

But it’s not only the D/d ratio which affects the wire rope performance. Other factors such as tensile load, the bending length of the rope (Muller 1961, Feyrer 1981, Vennemann 2008) and the wrap angle over the sheave (Muller 1961, Venneman 2008) are important parameters when we determine the rope degradation.

If we find the D/d for the rope bend over the spilt bush, we can get some indications on the expected rope wear, but as Venneman stated (2008) a bending fatigue test with the same conditions is the best way to determine the expected lifetime.

5 Design research

There are several Dive Support Vessels worldwide with different clump weight designs. To gather some ideas of how we can find a solution to our problem, the author found it quite helpful to see what other vessels have done with their clump weights and if they have the same problem with tilting. For this research, online video clips and pictures of different bell handling systems was very helpful. Discussions with a former saturation diver, Michael Day, gave me some great insight to several types of systems.

A common problem

Michael Day has worked on several Dive Support Vessels worldwide, and many of these vessels had a similar clump weight problem as on Seven Havila (personal communication, 5 May). The main reason for this is probably due to the use of the double fall system, with one guide wire winch and a fixed anchor point at the other end.

Figur 21 Tilting Clump weight (CCC Pioneer)

The picture above is a screen grab from a video taken on the multipurpose Dive/ ROV Support Vessel CCC Pioneer which M Day gave me. As we can see on the picture, the left side is much lower than the right side.

On some of the vessels they didn't do any changes to the clump weights, as the tilt only caused minor implications, i.e. no wearing of guide bushes or wires. On the clump weights which were more critical, more weight was added at the bottom. This lead to a lower CoG and created a counter force to the tilt. Another solution was to insert long steel tubes along the wires to act as a reaction force to tilt.

Support Arms

On the photos beneath we have two different clump weights with similar design. Both of the clump weights have two vertical arms along the guide wire. The arms seem to have a double function were one of the functions is to lift the bell (secondary lift system) and the other function is to act as a stabilizer working against the tilt. On the yellow clump weight, only the arms are located above the sheaves. Most of the mass is concentrated below the sheaves, giving a low center of gravity. The horizontal beam between the vertical arms can be used as a step for the diver and to support the vertical arms when subjected to horizontal loads.

Figur 23 DSI Diving & ROV Services (Youtube)

Figur 22 HSE Closed Bell commercial diver training.avi Youtube)

Design Limitation

Before we come up with suggestions for how to get the clump weight in a leveled position, we need to know our main limitations. This will regard maximum allowed weight, space and, because we are operating in seawater, choice of material is an important factor.

Maximum allowed weight

Weight Description	Weight (Kg)
Total weight of Diving Bell in Air	19300
Total weight of Diving Bell in Water	6500
Clump Weight	3500
Cursor Weight	3200
800 meter Guide Wire @ 5.74 kg/ m	4592
40 meter Guide Wire @ 5.74 kg/ m	230

Guide Wire Winch & Guide Wire Performance	
Minimum Safe Working Load of Winch	12618 kg
Rated Safe Working Load of Winch	13000 kg
Safe Working Load Wire	13500 kg

The maximum load applied on the guide wire winch occurs when the diving is lifted in air, inside the moonpool. It is rated with a SWL of 13000 kg. But the maximum lifting requirement reported to DNV, which has been tested and certified, is 12618 kg. Due to minor changes in the bell system the total weight of equipment has been reduced with 250 kg. This means that 250 kg can be added to the clump weight without needing renewal of certificates.

Space Limitations

As the bell is launched through a moonpool, the space regarding width is limited and we cannot extend the diameter of the clump weight.

The vessel has 1 meter lower freeboard than it was designed for, one of the consequences this has led to is higher water level in the moonpools. The bottom part of the two clump weights are therefore submerged during standby. This is not a desirable situation and we should avoid extending the clump weight in a downward direction.

The top of the clump weight is designed to mate with the diving bell for the secondary recovery method. The only place where we can extend the clump weight in vertical directions is from the split bushes and along the guide wires. Here we can extend the clump weight by 20 cm before bumping into the guide bushes attached to the bell frame. But this space is currently needed for parking of the clump weight due to the tilt.

Figur 24The narrow space in the moonpool gives restrictions to the modifications

6 Alternative Solutions:

The objective with this chapter is to present all considered solutions, this is to give the reader a better understanding of why the final recommendations is considered as the best option.

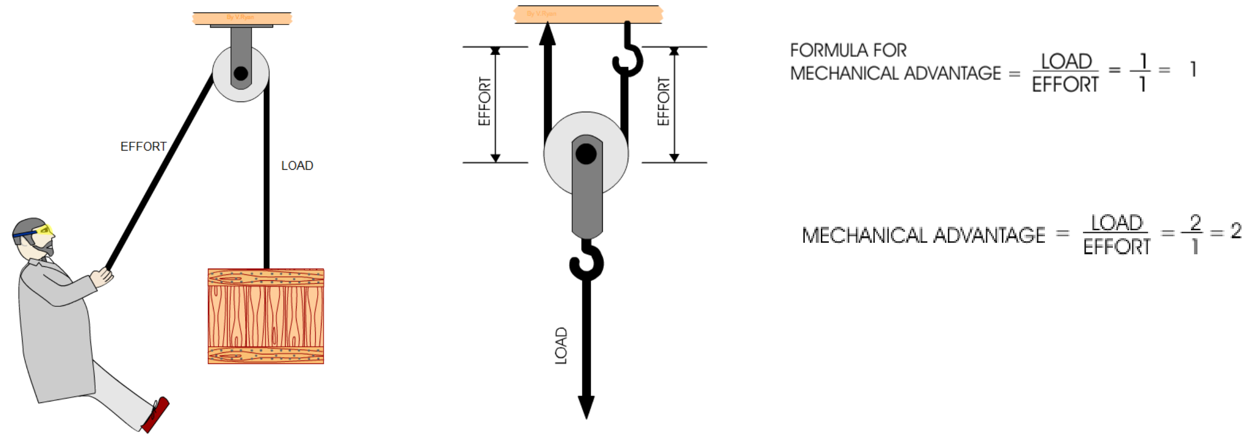
Use two winches or double drum winch

By using two winches or one double drum winch, we will never get a problem with a tilting clump weight. But as I will explain in this section, it’s a solution difficult to implement and is not recommended.

As for lifting points on the clump weight, we could remove both sheaves and install two pad eyes on top of the clump weight instead.

Winch size & capacity

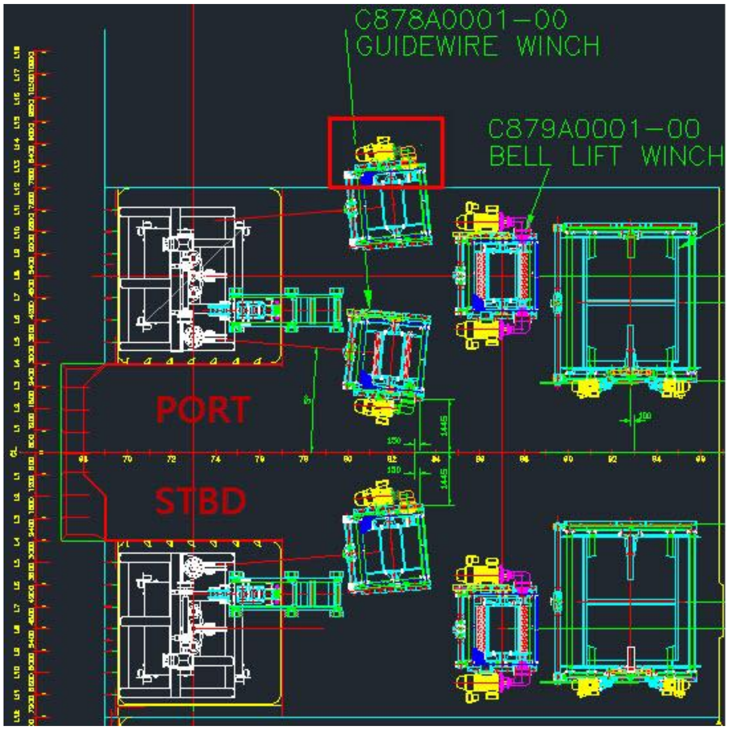
By changing out the winch system we will lose the mechanical advantage of single pulley system. This means that instead of having one winch with a certain maximum lifting capacity, we need two winches where each of them needs to have the same lifting capacity as the existing winch.



Figur 25 Pulley system (technologystudent 2012)

As we can see on the figure above, the double pulley system can reduce the effort by half compared with the single pulley system. This shows that the reason for only having one winch instead of two, it’s not only to save money and space but it also has a mechanical advantage.

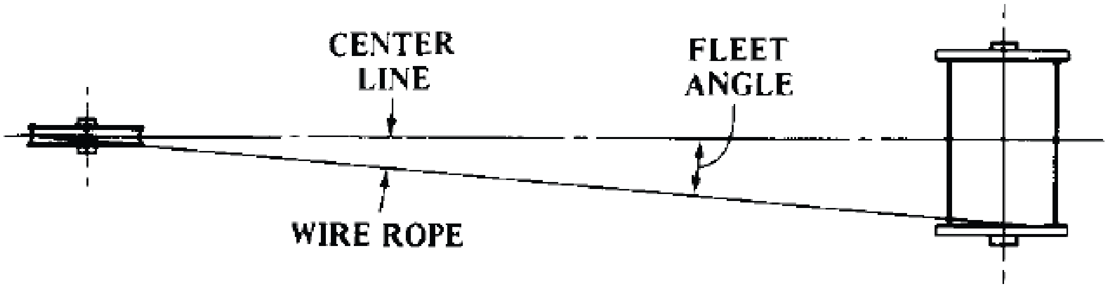
The “new” winch would need the same capacity as the existing winch due to loss of the double fall effect. The figure below shows us the arrangement of the winches for the bell handling system. On starboard side (bottom part) of the figure we can see how it is arranged today. The port side however I have put in one additional winch. The challenge will be to find a suitable winch(es) that meets the requirements as lifting capacity, speed and size. In addition we need to route the wires on each side of the diving bell.



Figur 26 Additional Winch

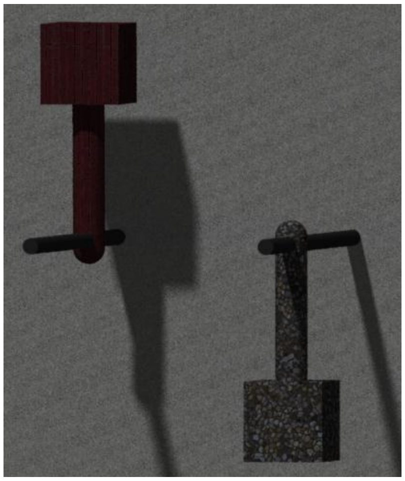
For installation of a new winch, the so called "fleet angle" must be taken into account. The fleet angle can be explained as the angle between the rope as it stretches from drum to sheave and an imaginary center-line passing through the center of the sheave grove and a point halfway between the ends of the drum. The maximum angle should not exceed one and a half to two degrees. Not exceed one and a half to two degrees. The drum and lead sheave should be aligned properly to prevent wear. (Oberg, Jones, Horton & Ryffe, 2004)

The guide wire winch installed on Seven Havila has a drum diameter of 648 mm. A new winch should not be installed with a smaller drum than what's already installed, as this can reduce the wire rope lifetime.



Figur 27 Fleet Angle (Oberg, Jones, Horton & Ryffe 2004

COG Effect



Figur 28 Lift point vs CoG

On the figure above, we have two items attached to a pole. The brick has a COG above its lifting point while the concrete has a COG below the lifting point. If we had tried to push the items to one of the sides, the brick would swing 180 degrees and ended up with the COG below its lifting point. The concrete on the other hand would swing back to the original position. This is logic sense, because we know that the gravity will work downwards.

The same effect will work on the clump weight. If the COG is above the lifting point, the gravity force will try to turn the clump weight 180 degrees. If the clump weight is below the lifting point, the gravity force will try to maintain the clump weight at a leveled position.

The distance between lifting point and COG determines how large the force is. Large distance will give more force than a shorter distance. (Moment = arm * force)

Support Arm

The diving bell is a good example of support arms. On the diving bell, four guide bushes are attached to the bell frame. When the clump weight is used as a recovery method, the guide bushes prevent the clump weight from tilting. If we add vertical arms to the clump weight, we can get the same effect as for the bell.

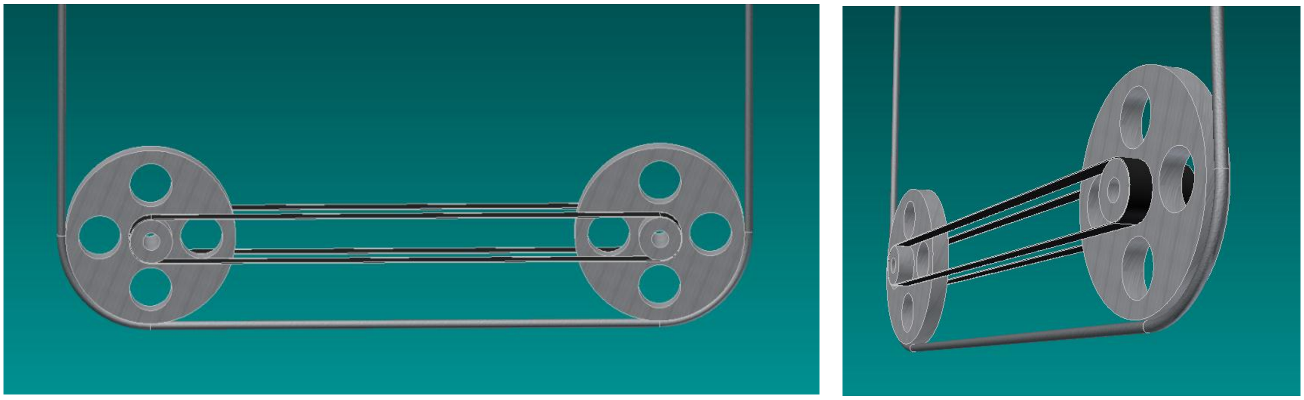
The arms work as a counter momentum to the tilt. A longer arm gives more momentum.

M = F * a, where “F” is the force and “a” is the arm length.

Use of chain

Use two chains in order to get the wheels to work simultaneously.

The theory behind this solution is that only one of the sheaves is rotating during the tilting phase. If the theory is correct, we can use a chain to force the other wheel to rotate, and hence we get a lift without any tilt.

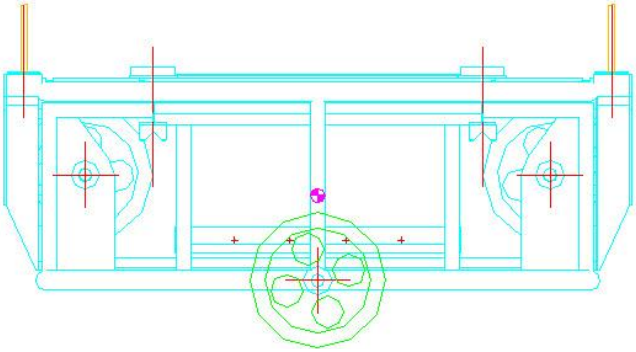


Figur 29 Solution option with chains

The cost of the parts is low and does not require any extensive work. The concern of this solution is the design, whether or not it can withstand the environmental loads. It has to be designed to prevent "jumping off" the wheel during deployment and it will also need to have a long life time with low requirements of maintenance. This is a typical "wear and tear" part, when it in addition is to be exposed to seawater, the life time will probably be further reduced.

Add a third sheave

Øystein Kleppestø, the Vessel Equipment Superintendent onboard Seven Havila, worked on an idea to add a third sheave on the clump weight(personal communication, 6 February). The thought behind this solution was to transfer the lifting point to the center of the guide weight, instead of the side. The side wheels would then act as a support to stabilize the clump weight.



Figur 30 Add a third sheave option (Kleppestø 2011)

But this suggestion was neglected due to several reasons. First off, the sheave would need to be fitted at a lower level than the existing sheaves in order to get any effect. Due to limited vertical space we would need to rebuild the bottom part of the clump weight.

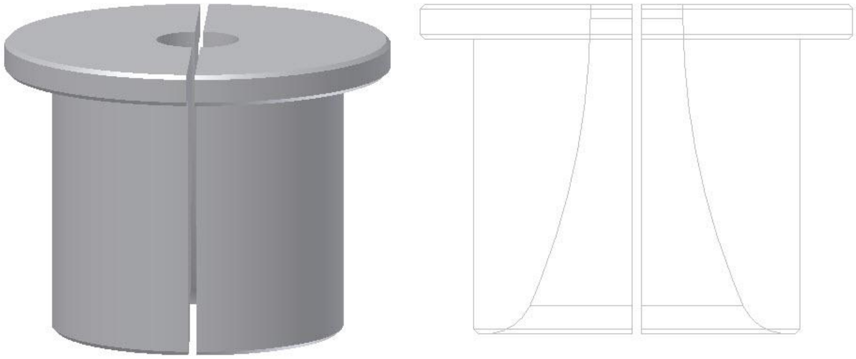
The central sheave would have to be designed to take the full load of the cursor, diving bell and the clump weight itself since the clump weight is used for secondary bell recovery. The structure and sheave required for these forces would most likely weigh much more than 250kg, which is the limit to what we can add to the clump weight before exceeding the SWL requirements from DNV.

The impact on the guide wire would also be greater. Instead of distributing the impact forces on two sheaves, the whole load would rest on the center sheave.

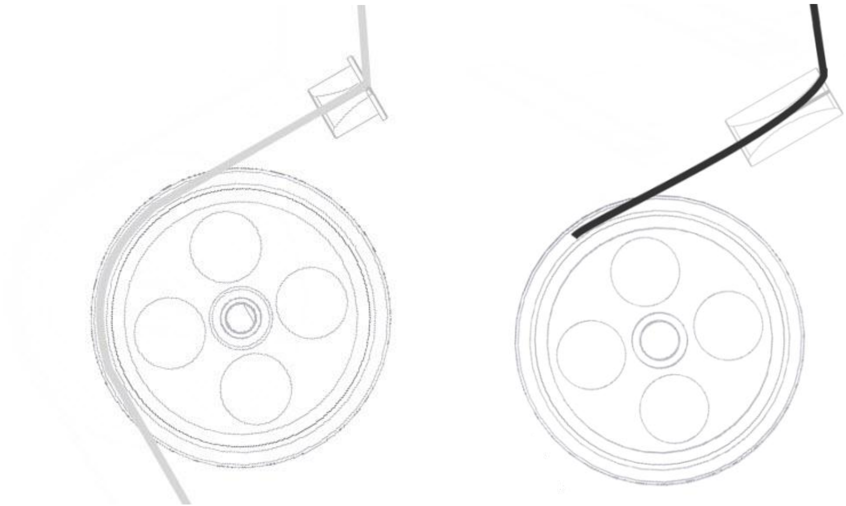
An alternative to meet the maximum weight requirements is that the two side sheave can be changed out with two smaller sheaves. This would remove a lot of weight from the sides, which could be used for the center sheave instead. But it requires extensive work to rebuild the clump weight and would also need to be proved that the sheave soulution will remove the tilt problem.

Adapt for tilting

Another solution is to adapt the design for tilting. The spilt bushes are designed for the wire rope to exit straight up along the bush axis. But due to the tilt, the wire exits the bush axis with an angle up to 60 degrees. This gives the wire rope a severe bend which most likely shortens the wire rope lifetime.



Figur 31 Split Bush



Figur 32 If we replace the split bush with a large bending radius, we can reduce wire rope bend.

The purpose of the split bushes is to guide the wire in to the sheaves. During the deployment through the splash zone the wire rope tension could get some slack due to the displacement. Heave motion will increase the effect. Too much slack can lead to the wire "jumping" off the sheave. It is therefore important to have some clamping effect in split bush, and we must keep the diameter inside bush.

Reduce rolling resistance

When the wire goes through the two sheaves, a friction force from the bearings will work against the sheave rotation and prevents the clump weight from going back to a leveled position. The sheaves are rotating with help from the bearings. The friction between the bearing and the sheave determines how much force is required in order to start the rotation.

The bearings used for the clump weight sheaves are of the plain bearing type. Some of the advantages with a plain bearing compared with roller/ antifriction bearing are greater rigidity, lower costs and a lifetime which is not limited by fatigue. The main disadvantage on the other hand is that the plain bearings have higher frictional properties, which again requires more force to get the sheaves to rotate (Oberg, Jones, Holbrook, Horton, Ryffel, 2010)

For journal bearings, the bearing friction torque M_r is found by following formula (roymech, 2009):

$M_r = P*f*(D/2)$

Where;

- P= Radial force (N/mm)
- F = coefficient of friction of rolling bearing (N)
- D = Diameter of the bore of the bearing (shaft diameter)(mm)

A research of different plain bearing types would reveal if we can reduce the friction without compromising the strength and maintenance requirements.

A bearing with less friction would definitely reduce the tilt angle. But due to higher maintenance requirements (Kleppestø, personal communication, 15 May) and reduced strength capacity it’s not recommended to change out the plain bearings with roller bearings.

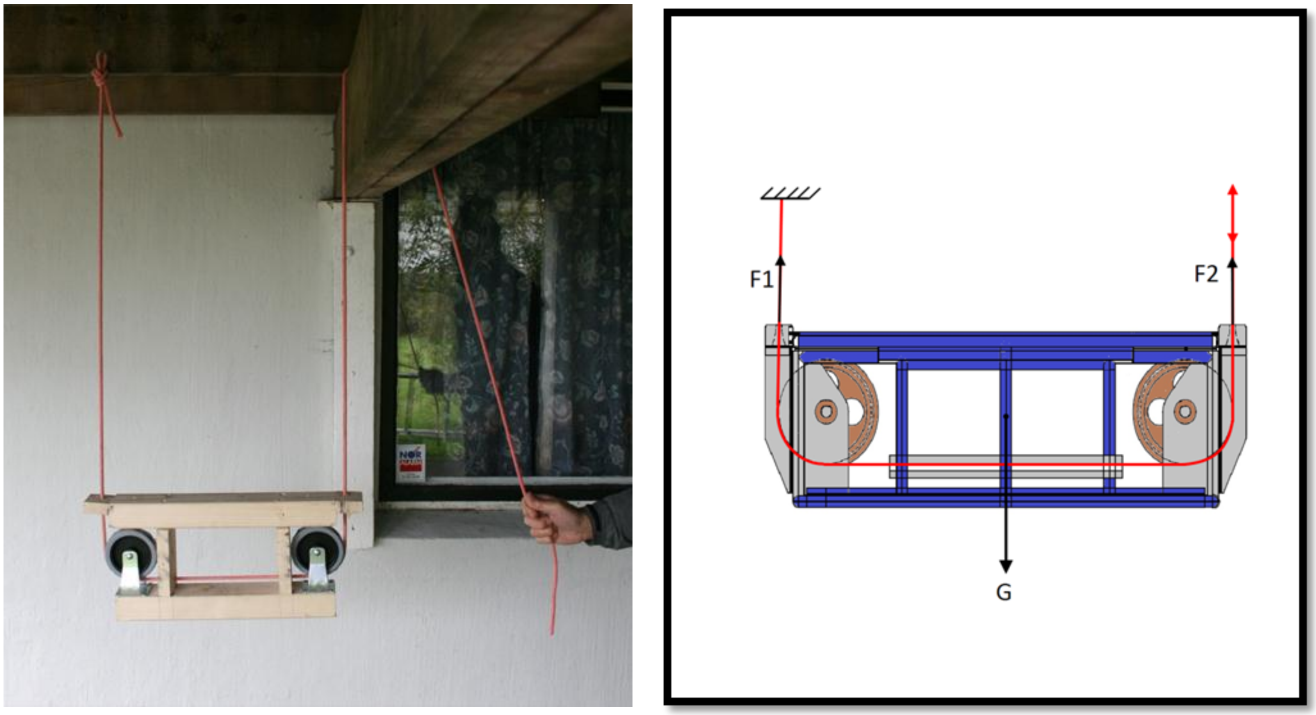
7 Model Test

The objective with the tests was to gain a better understanding of the mechanical behavior of the lift system, and to test out the different ideas on how to keep the clump weight in a leveled position during both deployment and recovery.

The test model is not a true copy of the original clump weight. But the mechanical principals are retained; a rope is attached to a fixed point, from the fixed point the rope runs vertical down to the clump weight, through a guide bush and continues through the two sheaves, and up vertical via a guide bush to a new sheave which guides the rope into the winch. The winch in the model test was an arm pulling the rope.

In order to achieve accurate results from a model test, the whole system should be a duplicate of the original design. The benefits with a smaller model, is that it’s easy to make changes. For the author, this was highly appreciated when new ideas came up.

Description of test model	
Dimensions	400 mm (l) x 70 mm (w) x 240 mm (h)
Center of Gravity	200 mm (l) x 50 mm (w) x 120 mm (h)
Weight	1 kg
Sheave diameter	100 mm
Rope diameter	10 mm
Distance between bottom and lift point	70 mm



Figur 33 Clump weight as designed

Possible parameters which can cause deviations from the actual clump weight are:

- Stiffness in the guide wire
- Diameter of the sheave
- Distance between the sheaves.
- Weight of the clump weight

Several tests have been conducted and the full test can be found in Attachment 1. The main ideas which have been thoroughly tested, is the use of support arms and a clump weight with lower CoG.

Results

Test No	Model Description	Recovery (degree)	Deployment (degree)
1	As designed	40	45
2	With arms	8	10
3	With arms + 1.5kg ballast	3	7
4	With arms + 3kg ballast	2	6
5	Lower COG (1.5kg ballast)	11	15
6	Lower COG (3kg ballast)	8	10
7	Increased weigth (3kg)	25	45
8	Higher COG (3kg at top)	65	70
9	Without guide bush	70	65
10	Without guide bush +1.5 kg ballast	17	10
11	Only bottom support	13	18
12	Only bottom support + 3kg ballast	3	7

Green color indicates satisfactory results, while results highlighted with red color indicated large tilt angle.

Tests No#1 - As designed

The objective of the as built model was to prove that the tilt problem for deployment & recovery was not only a problem on Seven Havila, but a problem caused by the mechanical design. It's also an evidence of validity of the test model; by achieving similar behavior as reported onboard Seven Havila.

The clump weight had a maximum angle between 40 to 45 degrees. On Seven Havila it has been reported a tilt angle up to 60 degrees.

What was noticed during the tests is that the angle is not constant. The clump weight reaches its maximum angle and the wheels starts moving. This accelerates the clump weight and the tilt angle decreases. Gradually the speed slows down until the wheels stops moving, before it again starts increasing. This behavior happens in fixed periods for both deployment and recovery.

Test No#2 – With Arms

Figur 34 Arm versus original design

The idea behind the support arms is that these will give a counterforce to the tilt. The arm will use the wire to hold back the position of the clump weight and prevent tilt. The longer the arms are the greater momentum is created.

As the figure on the right shows, the arms are reducing the tilt angle to an acceptable level. The maximum angle measured was 8 degrees for recovery and 10 degrees for deployment. This gives a tilt reduction of 32 and 35 degrees compared with test no#1 – as designed.

Test No# 5 & 6 –Lower COG

Figur 35 Lower CoG versus original design

The thought behind the idea of lowering CoG, is the same as for the support arms; to create a momentum which has a counter reaction to the tilt. The way the original clump weight is designed, the CoG is above the lifting points. By placing the CoG below the lifting points, the gravity will act as counterforce to the tilt instead of acting together with the tilt.

In the first test, a 1.5 kg ballast weight was placed at the bottom of the clump weight. This gave a maximum tilt angle of 11 and 15 degrees. By increasing the weight, with a total ballast weight of 3kg (test no# 6) the maximum tilt angle reached 8 and 10 degrees.

1.5 kg ballast gave a tilt reduction of 29 and 30 degrees, while the 1.5 kg ballast resulted in 32 and 35 tilt angle reduction.

A result of the reduced tilt angle was a smooth lift. There were no friction forces trying to stop the lift.

Expressed mathematically:

We can find the new CoG with following formula:

$h_{new} = \sum(m*h) / \sum m$

Test No#5:

$h = ((1kg*120mm) + (1.5kg*0mm)) / (1kg+1.5kg) \rightarrow h = 48mm$

The distance between the lifting point P and the CoG can be found by following formula:

Distance y = P-h

Test No#5 : y = 70mm – 48mm = 22mm

With a ballast of 1.5 kg, the new CoG is calculated to be 48mm high from the bottom of the clump weight. The distance between the CoG and the lift point, which can be defined as the moment arm, is 22mm. with 3kg of ballast; the CoG is 27 mm high with a moment arm of 43 mm.

Without any ballast, the moment arm will have a length of 50 mm above the lift point, i.e. the arm will act together with the tilt.

The magnitude of the moment depends on the tilt angle. Maximum moment occurs when we have a tilt angle of 90 degrees (sin (90) = 1).

Moment is calculated by following formula:

$M = m*g*y*\sin(\Theta)$

Test#5: Moment= $2.5\ \text{kg} * 9.81\text{m/s}^2 * 0.022\text{m} * \sin(\Theta) = 0.54 * \sin(\Theta)$ N/m

Test#6: Moment = $4.5\ \text{kg} * 9.81\ \text{m/s}^2 * 0.043\text{m} = 1.9 * \sin(\Theta)$ N/m

Test#1: Moment = $1\text{kg} * 9.81\ \text{m/s}^2 * 0.050\text{m} = 0.49 * \sin(\Theta)$ N/m

As we can see from the results, it's difficult to achieve a fully leveled clump weight by lowering the CoG only. But the rope bend at the guide bushes are much less dominating. It is therefore reason to believe that a lower CoG will have a positive effect for the rope lifetime.

On the original design, we can only add 250kg and we cannot add this weight lower than the lowest point of the clump weight itself. This means that we are not able to move the COG as low as on the model. The effect will therefore be much less than for the test model.

Additional tests

For test no#7 the objective was to investigate the effect of a heavier clump weight and still retain the CoG. This was done by adding 1.5 kg on both the top and the bottom of the clump weight. For the recovery the maximum angle reached 25 degrees and 45 degrees for the deployment. A simple solution for this result could be that the weights were placed uneven, but this was cross checked several times. No good explanations were found for this result.

Test no#8-higher CoG, was conducted to prove the effect of unbalanced clump weight. When the CoG is higher than the lift points, we will have an unbalanced situation. The distance between the lift point and the CoG will act as the moment arm to the moment acting together with the tilt. Effect of the moment depends of the length of the arm and the weight of the clump weight. And as expected; the maximum tilt angle was 65 and 70 degrees for the recovery and deployment.

As one of the ideas to mitigate the tilt problem was to expand inner diameter of the guide bushings, a test were conducted without any guide bushes at all. As a result the clump weight reached a maximum tilt angle of 65 degrees for the recovery and 70 degrees during deployment. Another observation was that the clump weight was much more unstable. It tipped over several times and the lift was difficult to perform. By adding a ballast weight on the bottom of the structure it gained stability and the maximum tilt angle was much less.

Test Summary

As a summary we can conclude that there are correlations between CoG and lifting points. If the CoG is above the lifting point we will have an unstable situation where the gravity will increase the tilt angle. If the CoG is below, the clump weight will be more stable and the weight of the clump weight will act as a counter force to the tilt. Distance and total weight are important parameters.

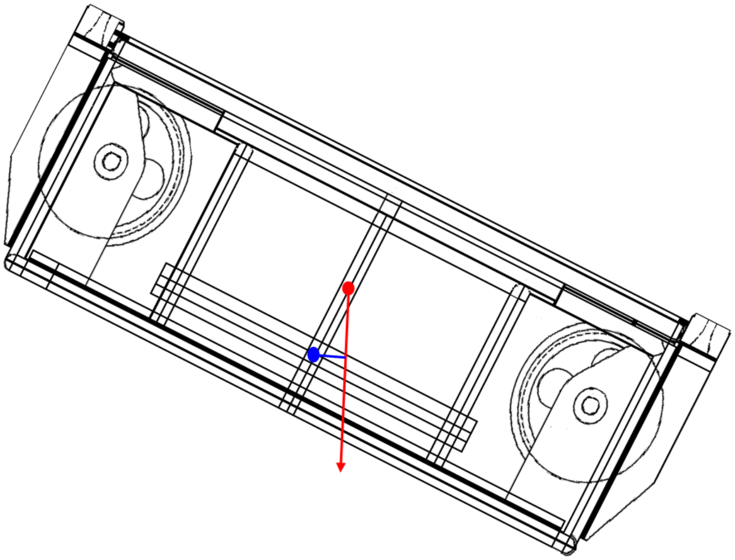
Support arms along the guide wire will stabilize the clump weight and act as counter force to the tilt. Length of the arms determines the total moment. Friction between the arm bush and the rope depends on the total force required to hold the clump weight in a stable situation. As force is found by moment divided by arm, the length of the arm determines the amount of friction. Longer arms will give less friction.

Another observation made for all the tests was that the deployment angle reached a few degrees larger than the recovery angle. This might be explained by the friction between the rope and the sheaves; when the clump weight is lowered the rope moves together with the gravity, while during lifting the rope moves upwards against the gravity.

8 Recommended Solutions

The objective with this chapter is to present the best solutions and to show the effect of these.

Changing the center of gravity



Figur 36 CoG is above the lifting point

There are two ways to improve the unstable situation. We can either place the lifting points higher, or we can lower the center of gravity by adding a ballast weight at the bottom of the clump weight.

Due to limited space inside the clump weight, we are unable to place the sheaves any higher without rebuilding the clump weight. When the clump weight is parked inside the moonpool there is a gap of 15 to 20 cm between the top of the clump weight and the bottom of the diving bell. This space is necessary as the clump weight is lifted to free the clamps prior to deployment. The freeboard on the vessel is currently 1 meter lower than vessel design specifications. A consequence of this is that the bottom half of the clump weight is submerged when resting on the clump weights. This is an unfortunate situation, and the clump weight should not be extended in the downwards direction. As a conclusion; it's not possible to relocate the sheaves/ lifting points.

This leads us to the last possible solution, to lower the CoG by adding ballast weight on the Clump weight. During model testing this proved to be an effective solution, but the effect is dependent of the amount of load added and distance between the lifting point and the new CoG.

The clump weight has weight of 3500 kg, which is 250 kg below SWL. This means that we can add 250kg on the clump weight. To get the most out of the 250 kilograms we need to use a metal with high density.

In order to determine the current CoG, we need to now the weight and CoG of all the parts installed. This is information the author was unable to get. It is therefore assumed that the CoG is located in the center of the clump weight.

The lifting point is located 286 mm above the bottom of the clump weight. The total height of the clump weight is 1133 mm, the CoG is thus assumed to be 566.5 mm above the bottom of the clump weight. This gives and distance of 280.5 mm. We define this distance as moment arm and call it y.

The moment which will act together with the tilt can be calculated as:

$M = m*g*y*\sin(\Theta)$

$M= 3500kg*9.81m/s^2*0.2805m*\sin(\Theta) = 9631 *\sin(\Theta)$ N/ m

If we add 250 kg ballast, the new CoG can be calculated as:

$\sum (m*h) / \sum m$

$CoG_{new} = ((3500kg*566.5mm) + (250kg*0)) / (3500kg + 250kg) = 528.73$ mm

$Y_{new} = 528.73 – 286 = 243mm$

$M_{new} = 3750kg*9.81m/s^2*0.243m*\sin(\Theta)= 8940 * \sin(\Theta)$ N/ m

By adding a ballast weight of 250kg, we can reduce the moment force by 7 %. In order reduce the moment force by 100 % we need to add 3570 kg on the bottom of the clump weight. The model test no#8 (Attachment 1) shows how much a high CoG impacts the amount of tilt. Even though an addition of 250 kg only reduces the moment by 7%, it will defiantly reduce some of the tension between the wire rope and guide bushings.

With the current design of clump weight, the COG is located in center. The lifting points, the two sheaves, are below the COG. This means that as soon as we get a tilt, the weight of the clump weight will work together with the tilt. I.e. it contributes to an even greater tilt. By reducing the distance we can reduce the moment force which helps creating the tilt.

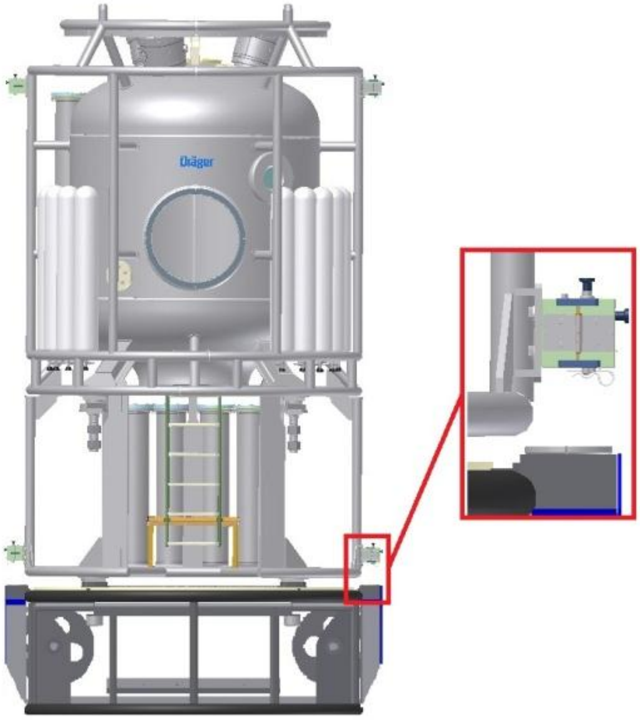
Support Arms

The model test (Attachment 1) showed that this is an effective way to straighten up the clump weight. But we still need to find out if this solution is feasible. One of the concerns is whether or not if we have the necessary space available. We also need to determine the expected loads acting on the arms. The main points which need to be questioned before we can install the righting arms are:

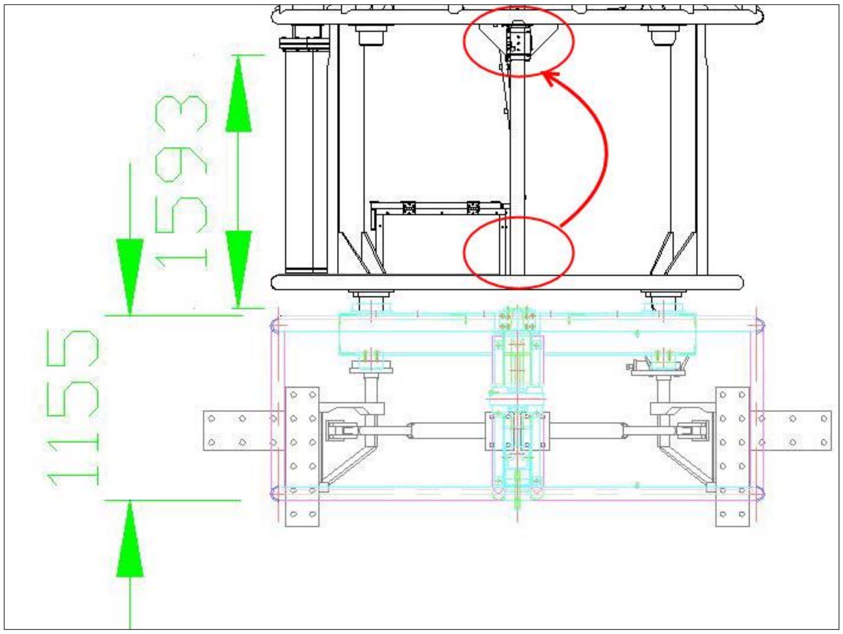
Arm length

The arms can't extend 150 (l) x 150(w)mm due to space limitations inside the moonpool. Tthe height is limited to 255 mm due to the bottom bell bushes.

Outside the bell frame, the wire is guided through two guide bushes on each side. The lowest guide bushes are situated at the bottom of the bell frame. The distance between the top of the clump weight and bottom of the bell bushes is 255 mm. In order to get any effect from the arms, they need to be longer than 25 cm. The alternative is to move the frame bushes higher up at the bell frame.



Figur 37 Bell frame bush needs to be relocated



Figur 38 Bell frame bush relocated

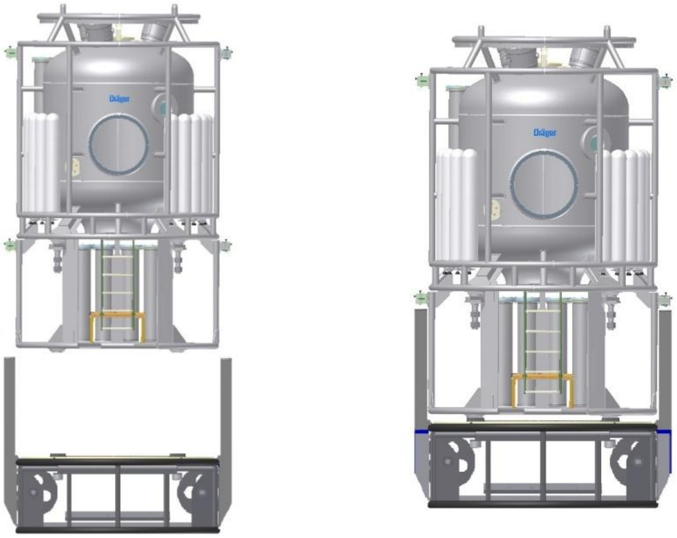
By moving the two bottom bell bushes up to the next level of “support area” we are free to insert arms extending 1.5 meters from the top of the clump weight.

Figur 39 bell frame bush needs be relocated

On the picture to the left, the blue part is the guide bush on the clump weight. Above is the bottom guide bush which needs to be moved higher up.

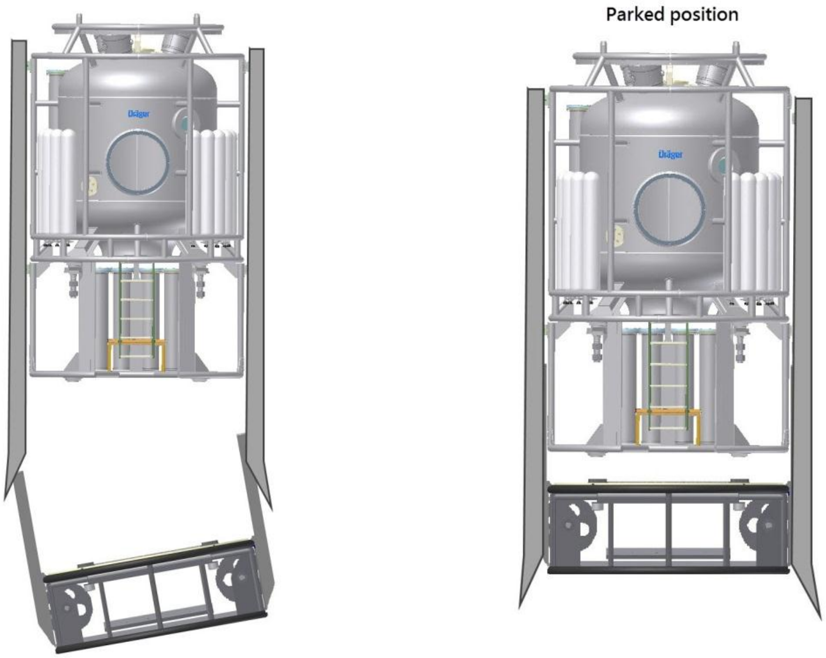
Clump weight with support arms

The pictures below show the clump weight with implemented support arms. The bell frame bushes are moved higher which makes it possible to increase the arm length.



Figur 40 support arms

If the clump weight still creates a tilt angle, the guide frame inside the moonpool will guide the clump weight in a leveled position.



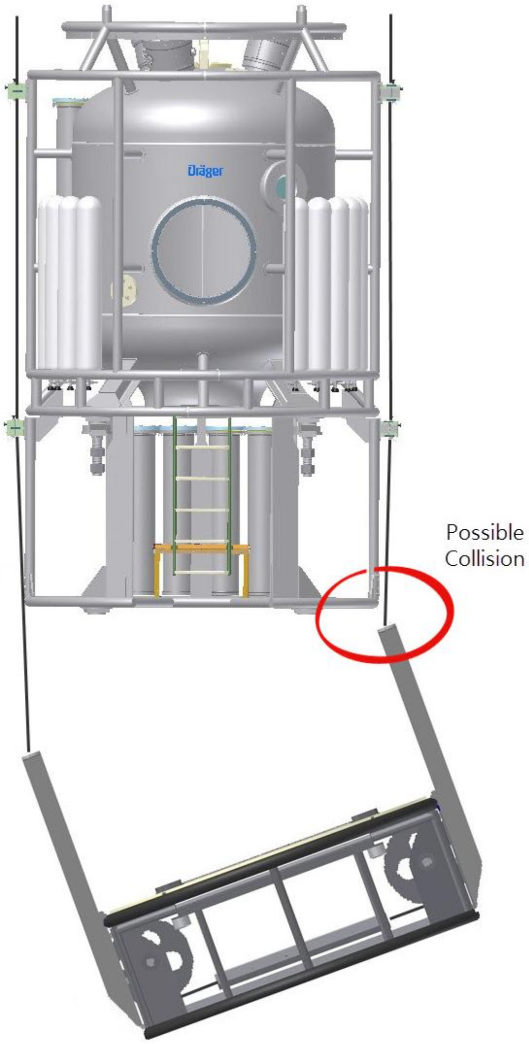
Parked position

Figur 41 Deployment/ recovery sequence inside the moonpool

Secondary recovery method

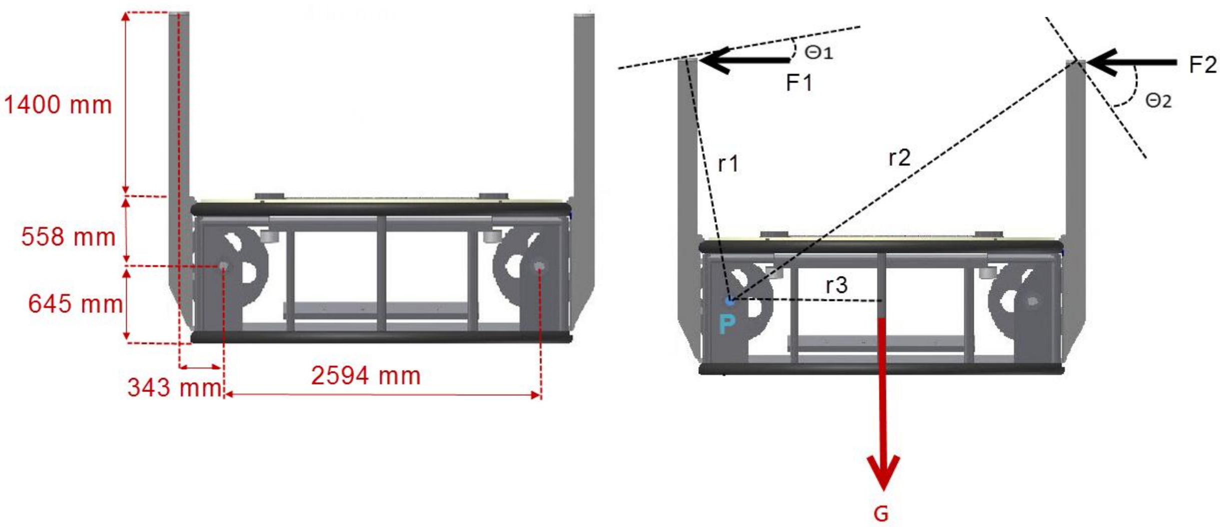
The purpose with the clump weight arms is to prevent the clump weight from tilting to the side. But as risk mitigation the arms should be designed for a possible collision with the bell frame. As the figure illustrates, the clump weight could collide with the bell frame during secondary recovery of the diving bell. The probability for this to happen is unlikely, but could cause major problems if the arm gets stuck under the bell frame.

During normal conditions, the divers could guide the arms outside the bell frame and would only cause minor operational delays. This delay however could be a major problem if there is an emergency situation onboard the vessel. The divers would then have to be transported back to the chambers in order to reach the hyperbaric lifeboats.



Figur 42 Tilt can cause a collision during secondary recovery

Arm Analysis



Figur 43 Momentum analysis

The big question regarding the righting arms is whether or not we are able to build arms strong enough to withstand the horizontal forces. As we could see on figure xx, this clump weight had a horizontal beam between the two arms. This beam acts as a support to the two vertical arms and will prevent the arms from bending. This horizontal beam cannot be used on Seven Havila, as the bell will rest on the clump weight when using the secondary recovery method.

In order to determine if we can build arms strong enough we need to find the expected loads.

In this analysis the objective is to determine the forces that will act on the two arms. The two arms will create a momentum working opposite to the momentum created by the gravity. In order to achieve equilibrium, the total momentum needs to be zero. In this case we are looking at the clump weight during deployment. Due to the similarity, this can be applied for both deployment and recovery.

$G = mg = 3500kg*9{,}81m/s^2$ P= Rotation axis $r1 = 1988mm$ $r2 = 3530mm$ $r3 = 1297mm$

$\Theta 1 = 9.94°$ $\Theta 2 = 56.31°$

$\mathbf{\sum M_P = 0}$

$M_G - M_{F1} - M_{F2} = 0 \rightarrow M_G = M_{F1} + M_{F2} \ (M_{F1} = M_{F2})$

$\mathbf{M_G} = G*r3 = \mathbf{44532.5\ Nm}$

$M_{F1} = ½ M_G \rightarrow F1 = (½ M_G) / (r1*\cos(9.94))$

F1= 11371 N

$M_{F2} = ½ M_G$ → $F2 = (½ M_G) / (r2*\cos(56.31))$

F2 = 11371 N

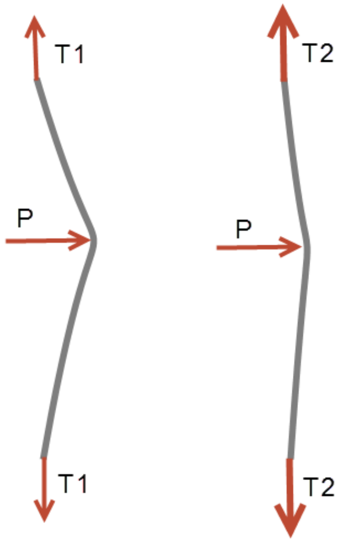
With arm lengths of 1.4 meters, the required end force at each of the two arms will be 11.4 kN. If we choose not to relocate the bell bushes, and install arms with a length of 0.2m, the required force will be 29.4 kN on each arm. That is 3 times the force compared with the 1.4 meter long arm.

NB: Momentum caused by the sheave resistance has not been taken into account. This force will act counter to the arm.

Amount of tilt

What determines the tilt of the clump weight is the guide wire's ability to withstand the force applied from the arms. If the load gets too big, the wire will give in and a bend will be created at the load point. The arms will follow the wire until enough reaction force is created, i.e. the tilt angle grows with the wire bend. A short arm will therefore create a larger tilt angle compared with a long arm.

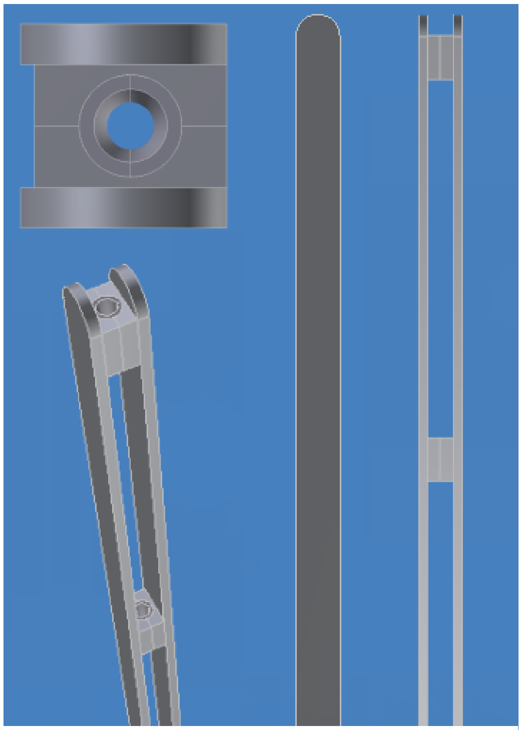
The wire's ability to withstand the perpendicular load depends on the axial tension in the wire. The tilt will therefore be reduced even more with a heavier clump weight.



Figur 44 Tension in wire determines amount of tilt

T1<T2, T2

Arm design



Figur 45 Possible arm design

Suggested arm design consisting of two flat beams connected by two guide bushes. The upper guide bush will act as counter force to the tilt, while the lower bush will guide the wire rope into the sheaves. The guide bushes should be of the split type.

The design makes it easy to install and replace parts as it wears out.

There are several criteria's which need to be fulfilled when designing the support arm, one of them is appropriate material. The material must be suitable for the same temperatures as the bell handling system, which is between -10°C to +50°C. It should also be corrosion resistance due to the marine environment.

9 Conclusion

Optimizing bearing type will have little or no effect on the tilt. Changing out bearing types with less friction will require much more maintenance as these will need to be greased at regular intervals.

Use of chain will not have any effect on the tilt, as the sheaves starts rotating at the same time. The idea of that sheave on the winch side would start moving as the wire started to move was proved wrong during the model test.

Addition of a third sheave requires extensive work on the clump weight and has not been proven to reduce the tilt angle.

The simplest solution and least costly is to expand the split bush diameter. This will cause the clump weight to tilt even more, but there will be less bending in the wire caused by the split bush. As the wire bending and surface friction between the rope and the split bush is believed to shorten the wire rope lifetime, this could be a good option to remove the friction. There are no major operational problems with a tilting clump weight; it is the additional wear that is causing a problem. By removing the source of wear the tilt will not cause any implications

The effect using ballast weight to lower the CoG is limited due to the restriction of the 250 kg that we are allowed to add. 250 kg gives a moment reduction of 7%. It requires over 3500 kg of ballast weight to get a 100 % moment reduction, and even more weight is needed to get the CoG beneath the lifting point. 250 kg of ballast weight will have a positive effect for the amount of wear, but it’s not enough to remove the tilt.

By using arms, we can reduce the tilt by 40 to 50 degrees. This will therefore remove the problem with a tilting clump weight, but a new source of wear will be added; the contact surface between the arms and the guide wire. But this is believed to be smaller than the wear from the split bushes. By having a rolling surface where the arm is in contact with the wire rope, the wear will be less compared with a non-rolling surface. The use of arms requires a relocation of the two bottom bell frame bushes.

The solution of using support arms will only help during deployment and recovery of the clump weight. It will not have any effect for the secondary recovery method of the diving bell. The guide bushes on the bell frame will take over for the support arms. This means that the clump weight will still be leveled, but the wear of the bell frame bushings will not disappear.

In order to get a leveled clump weight with no additional wear, the best solution seen from a mechanical perspective is to add an additional guide wire winch. This will also remove the friction caused during secondary recovery of the diving bell. But changing out the winch with two winches or one winch with double drum is quite expensive and will require several days of installation. This means longer down time I.e. higher costs. In addition we will require more powerful winches as we don’t get mechanical advantage of the pulley system. The cost and required workload on the other hand, makes this to a not desirable solution.

The final recommendation is to either:

3. Expand the diameter on the split bush and to add the allowable weight of 250 kg at the bottom of the clump weight. A lower COG will counter the tilt angle while the expanded diameter will allow for more free space and reduce the amount of friction caused by the bend.
4. Install supports arms where the remaining weight is placed at the bottom of the clump weight.

The first option will require less work and is more cost effective than the second option, but the last option will give more tilt reduction.

10 Further Work

For the arm solution a final design needs to be made. The strength of the beam/ arm has to be confirmed to be larger than the load acting at the top of the arm. An optimization between weight and strength should be conducted; as low weight benefits the effect of a low CoG. The weld between the arm and the clump weight must also be confirmed to be strong enough.

The analysis made in this report was to give indications only. In order to determine with accuracy the amount of tilt reduction and the friction acting in the system, following parameters should be included:

- Tension in wire
- Bend resistance in wire
- Rolling resistance in the sheaves
- Friction coefficient between sheave and the wire rope and
- Friction coefficient between the wire rope and the arm bush

The effect caused by relocation of the bell frame bushes needs to be investigated prior to an installation of support arms.

For ballast weight solution, the effect of placing 250 kg should be calculated. A material with high density should be chosen to get the CoG as low as possible.

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Attachement 1

Model Test

(12 pages)

Attachment 1

Model Test

Test No#1

Model as designed


Objective:

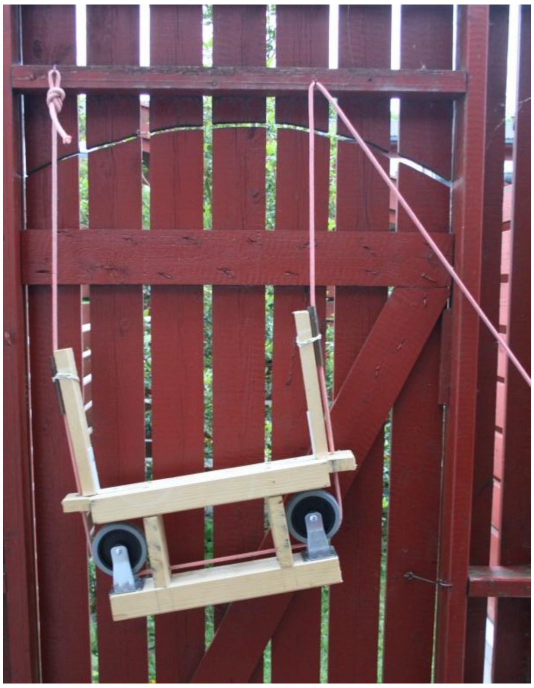
Prove the test model's validity

Results

- Behavior of the model are in accordance with the described situation onboard Seven Havila
- Maximum recovery angle (left picture) : **40°**
- Maximum deployment angle (right picture): **45°**

Test No#2

Model with arms (a)



Figur 1 Recovery Test No#2

Figur 2 Deployment Test No#2

Objective:

Determine the effect of support arms

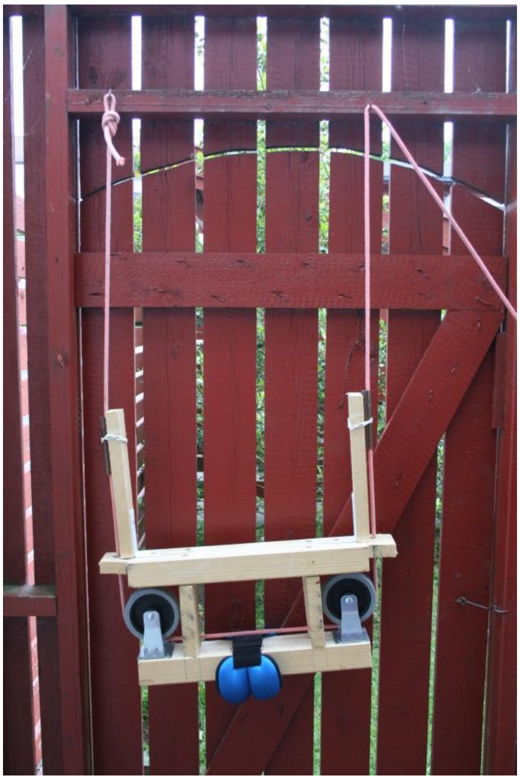
Results:

- Maximum recovery angle: **8°**
- Maximum deployment angle: **10°**

Test No#3

Model with arms (b)

1.5 kg are added to the bottom of the clump weight.



Objective:

Determine the effect of support arms with lower COG

Results:

- Maximum recovery angle: **3°**
- Maximum deployment angle: **7°**

Test No#4

Model with arms (c)

3kg are added to the bottom of the clump weight.

Objective:

Determine the effect of support arms with lower COG

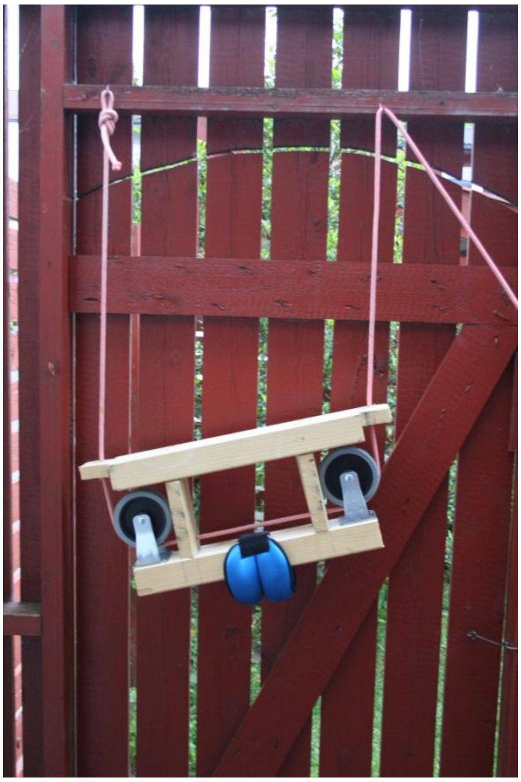
Results:

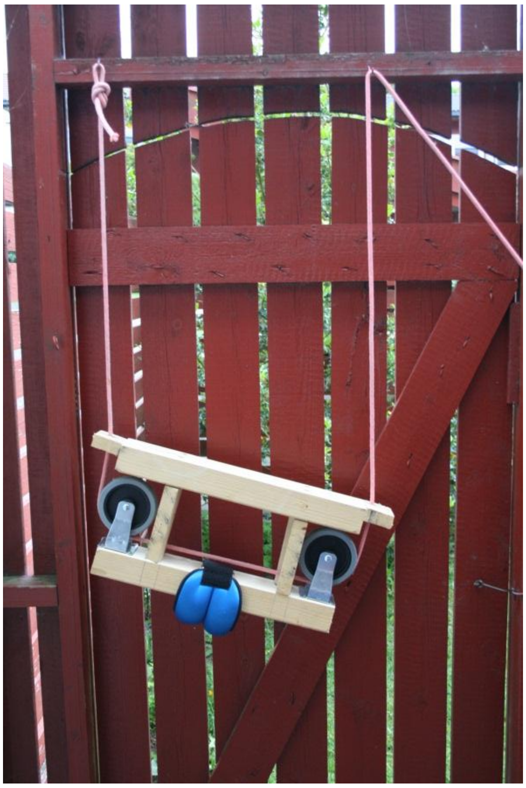
- Maximum recovery angle: **2°**
- Maximum deployment angle: **6°**

Test No#5

Model with lower COG (a)

1.5 kg are added to the bottom of the clump weight





Objective:

Determine the effect of lower COG

Results:

- Maximum recovery angle: **11°**
- Maximum deployment angle: **15°**

Test No#6

Model with lower COG (b)

3 kg are added at the bottom of the clump weight

Objective:

Determine the effect of support arms with lower COG

Results:

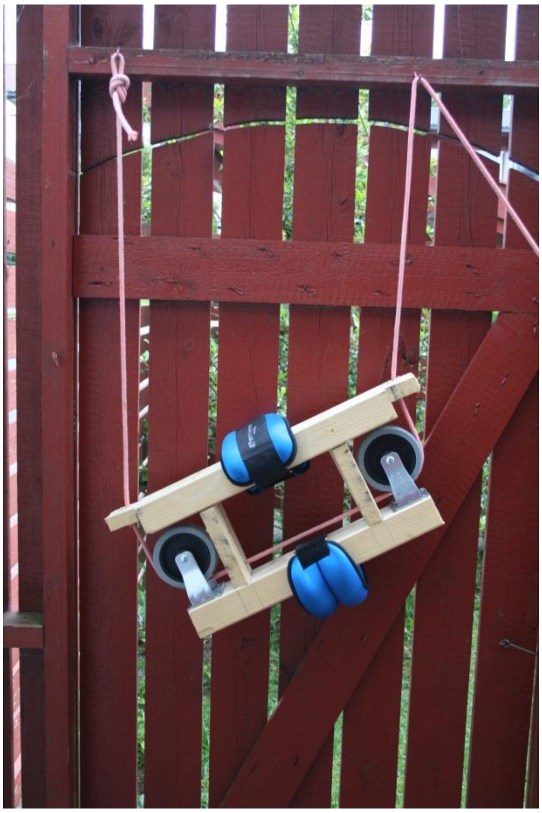
- Maximum recovery angle: **8°**
- Maximum deployment angle: **10°**

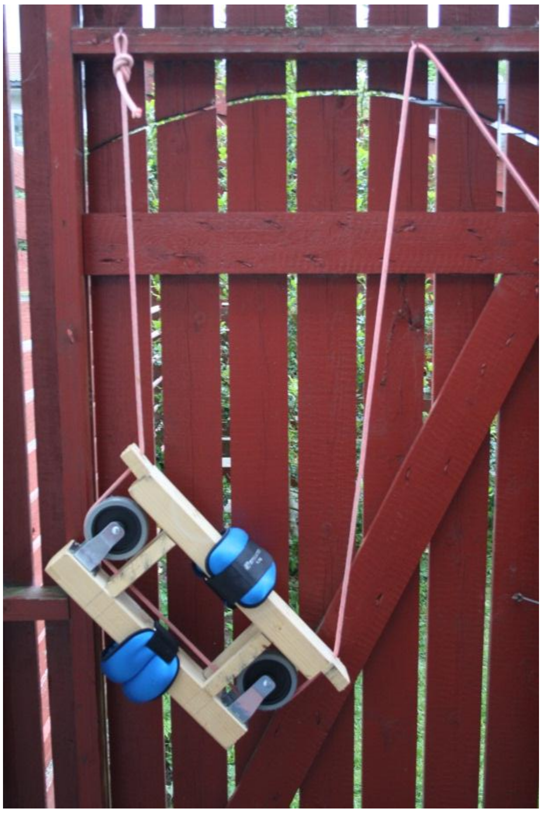
Test No#7

Increasing the weight

1.5 kg are added at the bottom of the clump weight, and

1.5 kg are added at the top of the clump weight.





Objective:

Determine whether or not the weight of the clump weight has any effect of the tilt angle.

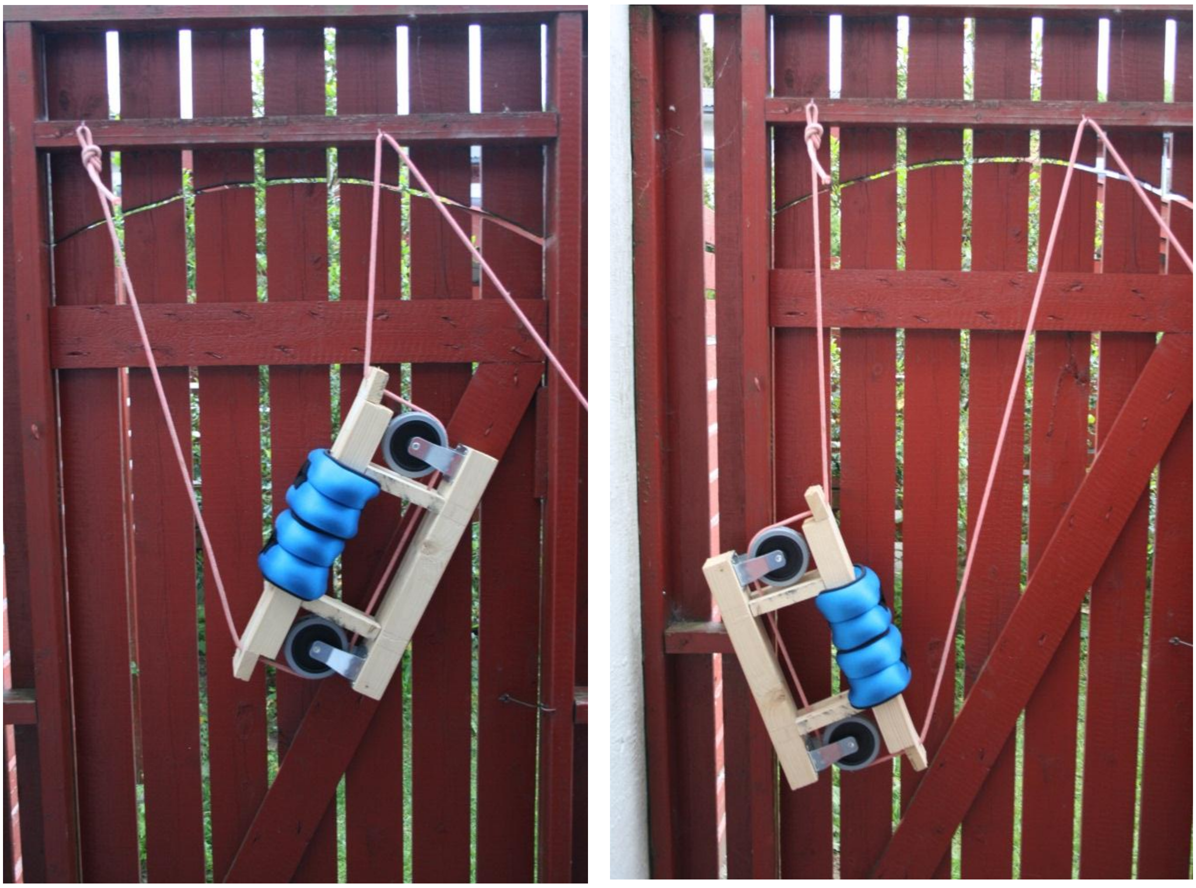
Results:

- Maximum recovery angle: 25°
- Maximum deployment angle: 45°

Test No#8

Higher COG

3kg are added at the top of the clump weight



Objective:

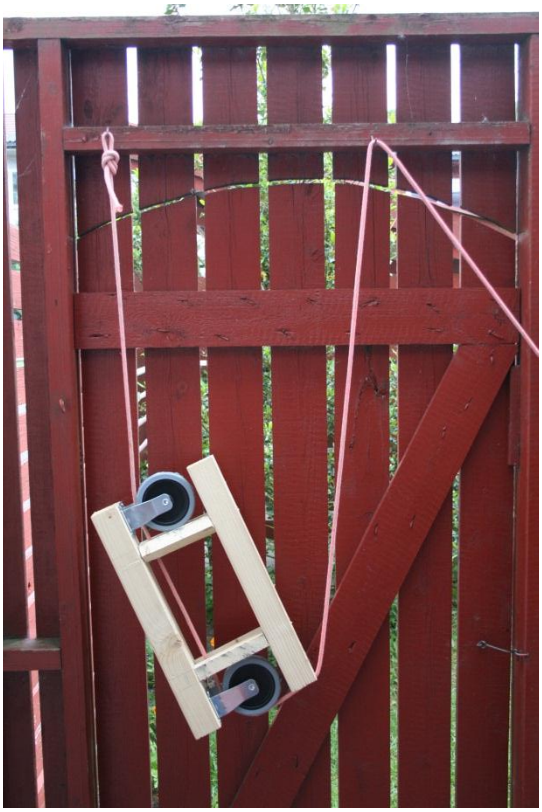
Prove that a top heavy clump weight (COG above lifting points) will increase the amount of tilt angle

Results:

- Maximum recovery angle: **65°**
- Maximum deployment angle: **70°**

Test No#9

Clump weight as designed, without guide bush



Objective:

Determine whether or not the weight of the clump weight has any effect of the tilt angle.

Results:

- Very unstable, tipped over several times.
- Top of the clump weight prevents the clump weight angle to grow larger

- Maximum recovery angle: **70°**
- Maximum deployment angle: **65°**

Test No 10#

Clump weight without guide bush, lower COG

1.5 kg are added at the bottom of the clump weight.

Objective:

Determine the influence of the guide bushings

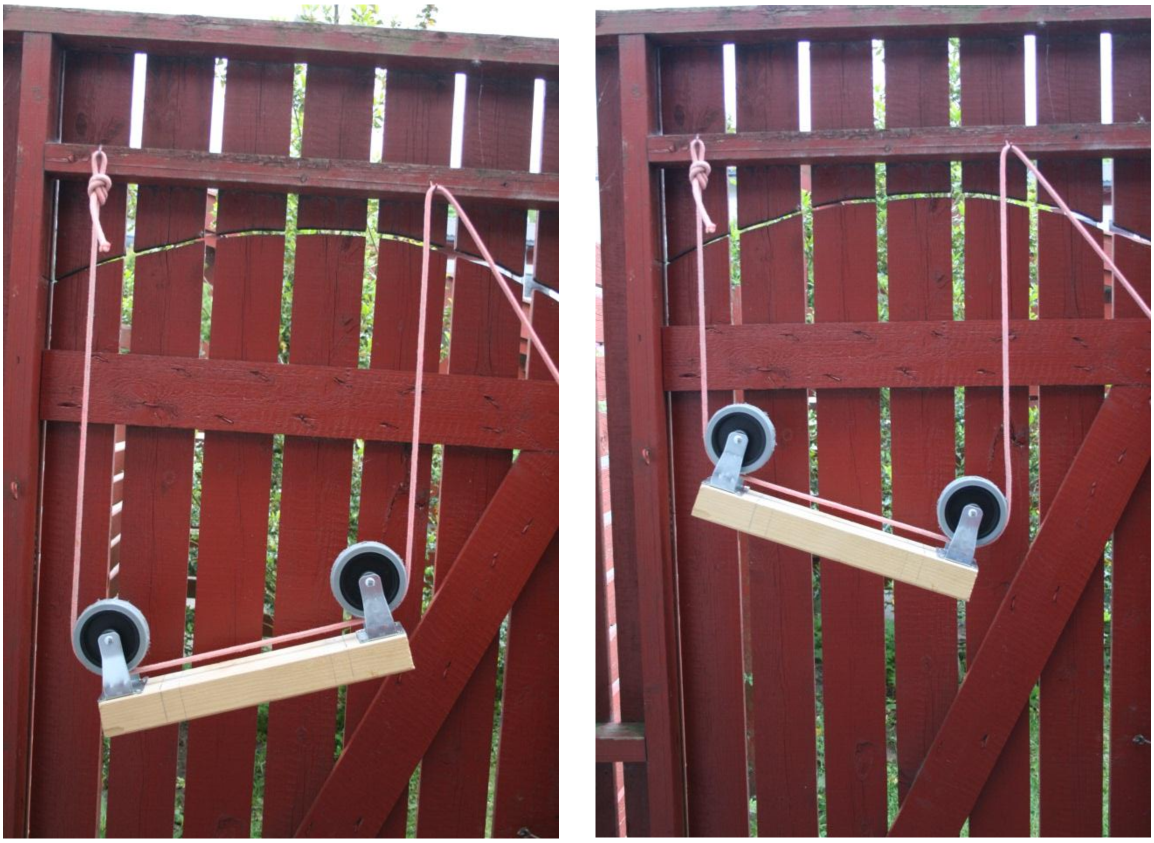
Results:

- Much more stable compared with test no#9
- Only the sheaves are in contact with the rope.

- Maximum recovery angle : **17°**
- Maximum deployment angle: **10°**

Test No#11

Clump weight with bottom support only



Objective:

Prove that a clump weight with COG lower than the lifting points gives a more leveled and stable position.

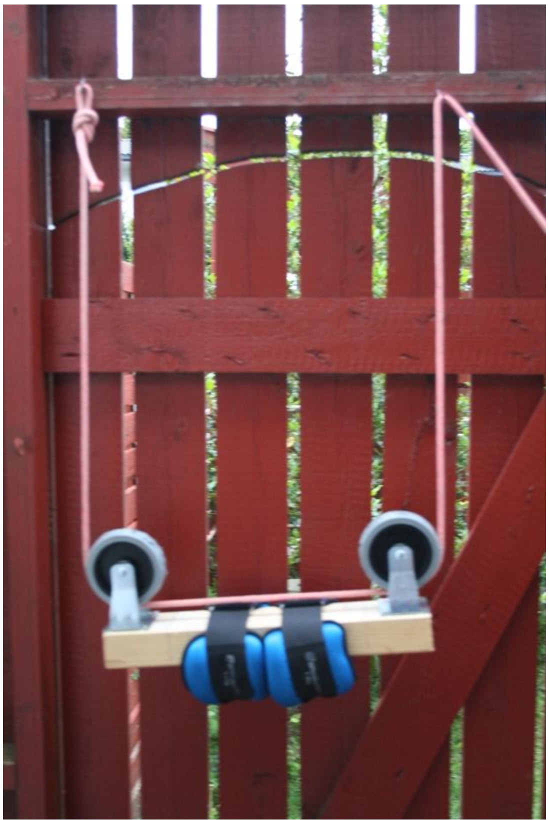
Results:

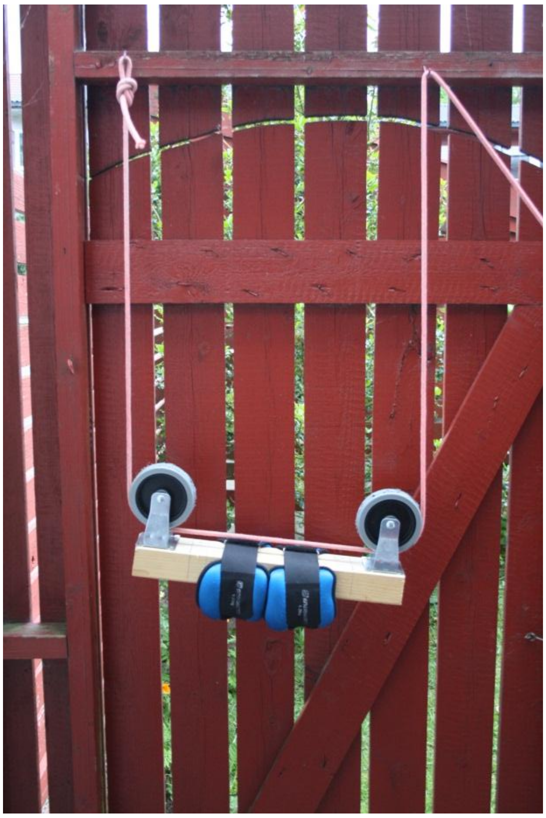
- Maximum recovery angle: **13°**
- Maximum deployment angle: **18°**

Test No# 12

Clump weight with bottom support only

3 kg are added at the bottom support





Objective:

Determine how the mechanical lift system can be lifted without creating a tilt angle

Results:

- Maximum recovery angle: **3°**
- Maximum deployment angle : **7°**

Test Summary

Test No	Model Description	Recovery (degree)	Deployment (degree)
1	As designed	40	45
2	With arms	8	10
3	With arms + 1.5kg ballast	3	7
4	With arms + 3kg ballast	2	6
5	Lower COG (1.5kg ballast)	11	15
6	Lower COG (3kg ballast)	8	10
7	Increased weigth (3kg)	25	45
8	Higher COG (3kg at top)	65	70
9	Without guide bush	70	65
10	Without guide bush +1.5 kg ballast	17	10
11	Only bottom support	13	18
12	Only bottom support + 3kg ballast	3	7