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ABSTRACT

The size of semi-submersible drilling rigs has tripled over the past 50 years, with corresponding increase in cost. In order to change the direction of this development, the size of the rigs has to be challenged. Utilizing new technologies is the key for succeeding. By reducing the required variable deck load (VDL), existing rigs could increase their capacity, and the size of the future rigs could be reduced without jeopardizing their operational capacities.

This thesis presents a parametric study of the VDL where the objective is to identify technologies that can reduce the required VDL, and attempt to quantify reduction potentials for key contributors of the required VDL. Theoretical background for the semi-submersible drilling rigs and VDL is presented. The identified technologies are presented and their reduction potential is established and discussed, as well as the increased operational capacity due to the identified technologies. The focus has been on technologies that can reduce the key contributors of the VDL.

The capacity of the drilling rig Maersk Deliverer, together with the characteristics of the drilling rigs on the market today was used as a basis to identify the largest contributors of the VDL and the potential increase in capacity.

The results show that there is potential to reduce the required VDL by applying new technologies. For existing rigs this means increased operational capacity, e.g. a 4th generation drilling rig has the potential to operate within the same operational range as a 5th generation drilling rig. The reduction in required VDL also leads to more free storage space, which is an advantage when drilling in remote locations. For the development of future generations of drilling rigs the results indicates that the size can be reduced without decreasing the operational capacity.

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ABBREVIATIONS

B	Centre of Buoyancy
BOP	Blowout Preventer
DDS	Dual Drill String
DFV	Dual Float Valve
DGD	Dual Gradient Drilling
G	Centre of Gravity
GM	Metacentric height
GZ	Righting arm
ID	Inner Diameter
K	Keel of the vessel
LSW	Lightship Weight
M	Metacentre
MD	Measured Depth
MN	Mega Newton
MODU	Mobile Offshore Drilling Unit
MPD	Managed Pressure Drilling
MRL	Mud Return Line
NCS	Norwegian Continental Shelf
NMA	Norwegian Maritime Authority
OD	Outer Diameter
RDM	Reelwell Drilling Method
RMR	Riserless Mud Recovery
SMO	Suction Module
SPM	Subsea Pump Module
SSDR	Semi-submersible Drilling Rig
TDA	Top Drive Adapter
USD	US Dollars

VCG	Vertical Centre of Gravity
VCS	Vacuum Conveyor Separator
VDL	Variable Deck Load
WD	Water Depth (surface to seabed)

1. INTRODUCTION

1.1 BACKGROUND

As the oil and gas industry are moving into even deeper waters and deeper wells and exploring areas with harsher environment, the technology requirements are increasing. From Figure 1 the development of the rigs from the past 50 years is shown. [1] The rigs have tripled in size with corresponding increase in cost. The average construction cost of rigs under construction has increased with approximately 40% compared to the present rigs from the 6th generation. [2] It is desirable to manage this development in another direction. To do this, the size and cost of the drilling rigs has to be challenged. Developing new technologies is the key to succeeding, not just for developing a new generation of drilling rigs, but also to increase the capacity of older rigs.

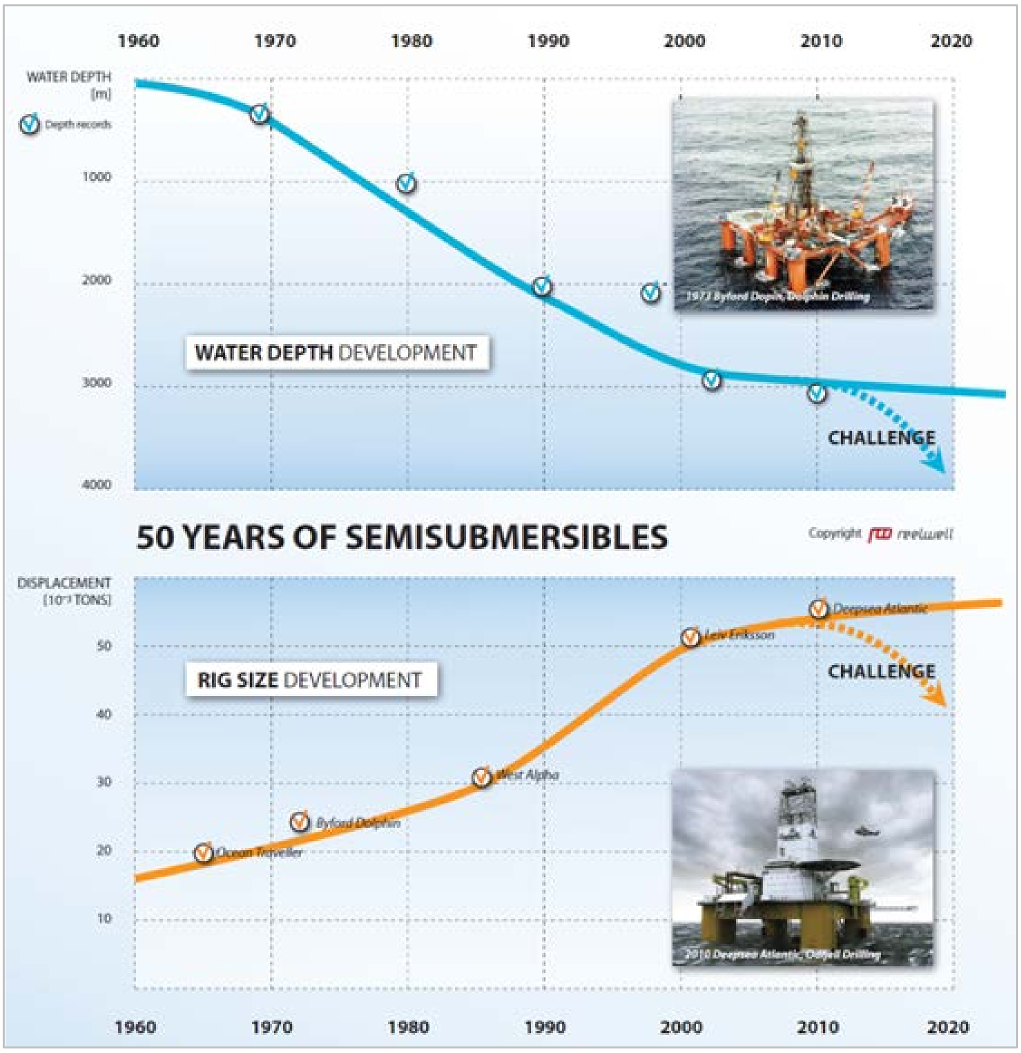


Figure 1 - 50 years of semi-submersibles. [1]

1.2 OBJECTIVES AND STRUCTURE OF THESIS

The general purpose of this thesis is to study the variable deck load (VDL) on a semi-submersible drilling rig, and how new or existing technology can reduce the required VDL. The contributors of the VDL will be studied, and a selection will then be established and analysed. A study of technologies with potential to reduce the selected parts of the VDL will be performed. The goal is to establish how much the required VDL can be reduced by utilizing these technologies and possibly combine them. The consequences of the established reduction will then be studied, and can be divided into two secondary objectives:

1) Increased capacity of existing semi-submersible drilling rigs
2) Development of future generations of semi-submersible drilling rigs

The structure of the thesis and the objectives of every step will be as follows:

- **Chapter 2** will establish an overview of the development of the generations of drilling rigs. This will provide an understanding of why it is important to analyse the reduction possibilities.
- **Chapter 3** will establish an overview of the stability of a vessel. This will give an understanding of the benefits of a reduced VDL, especially concerning the centre of gravity.
- **Chapter 4** will establish the contents of the term VDL, and what impact VDL will have on the design of a drilling rig. It will also present how the various loads on a drilling rig are monitored, and provide an understanding of the limitations of VDL. The largest contributors of the VDL will be established, and a selection of these will be established for further analysis.
- **Chapter 5** will establish an overview of the technologies that can enable reduction of the selected contributors of the VDL, and briefly explain how they can reduce it.
- **Chapter 6** will present and discuss the results of how much the VDL can be reduced by applying the technologies presented in chapter 6.
- **Chapter 7** will present various scenarios where the VDL can be reduced, and operating capacity of the rigs can be increased, according to the results from chapter 6.
- **Chapter 8** will present a conclusion of the established results, and what the results means for the secondary objectives.
- **Chapter 9** will present recommendations for further work.

1.3 LIMITATIONS

The rigs considered in this thesis are mainly from the 2nd to the 6th generation, excluding cold stacked rigs and under construction. The riser tension analysis is done in a simplified manner, looking at the risers as steel pipes, excluding such as flanges and the flexjoint. The composite risers are assumed to have as many buoyancy elements as a conventional steel riser. The mud density is assumed to be 1,5 kg/l throughout the entire thesis. When calculating volume of mud in well and volume of extracted formations, the same measured depth and true vertical depth is assumed in all cases. The actual numbers is not the essential part in all calculations, but the reduction when comparing conventional and new technologies.

1.4 RESEARCH METHODOLOGY

The thesis will study the variable deck load (VDL) and critically analyse the impact of different contributing factors. Some of the data collected could not be found in text books, but was gathered from professionals in the industry and the rig database, RigLogix.

2. STATE OF THE ART SEMI-SUBMERSIBLE DRILLING RIGS

This chapter will present the generations of semi-submersible drilling rigs and their characteristics. There has been a great development in the capacities of a semi-submersible drilling rig from the 1st generation to the 6th generation. Table 1 presents the general characteristics of the generations of drilling rigs. [2]

Table 1- General characteristics of the generations of semi-submersible drilling rigs. [2]

Generation	Year built	WD [ft]	Drilling depth [ft]	Displacement [mT]	VDL [mT]
1st	1962-1969	600-800	20 000	7 000-10 000	1 000 - 1 200
2nd	1970-1980	1 000 - 1 500	20 000 - 25 000	17 000 - 25 000	2 300 - 3 300
3rd	1980-1985	1 500 - 2 500	25 000	25 000 - 30 000	3 000 - 4 000
4th	1985-1990	3 500 - 7 000	25 000 - 30 000	30 000 - 40 000	3 500 - 5 000
Modernization	1990-1997	6 000 - 8 000	25 000 - 30 000	25 000 - 30 000	5 000 - 6 500
5th	1998-2005	7 500 - 10 000	30 000 - 35 000	35 000 - 40 000	5 000 - 8 000
6th	2006-	10 000	35 000 - 40 000	45 000 - 55 000	7 000 - 8 500

By mapping the characteristics of the existing drilling rigs, a simple prognosis of the future development was made, as illustrated in Figure 2 with the exponential trend line. [2]

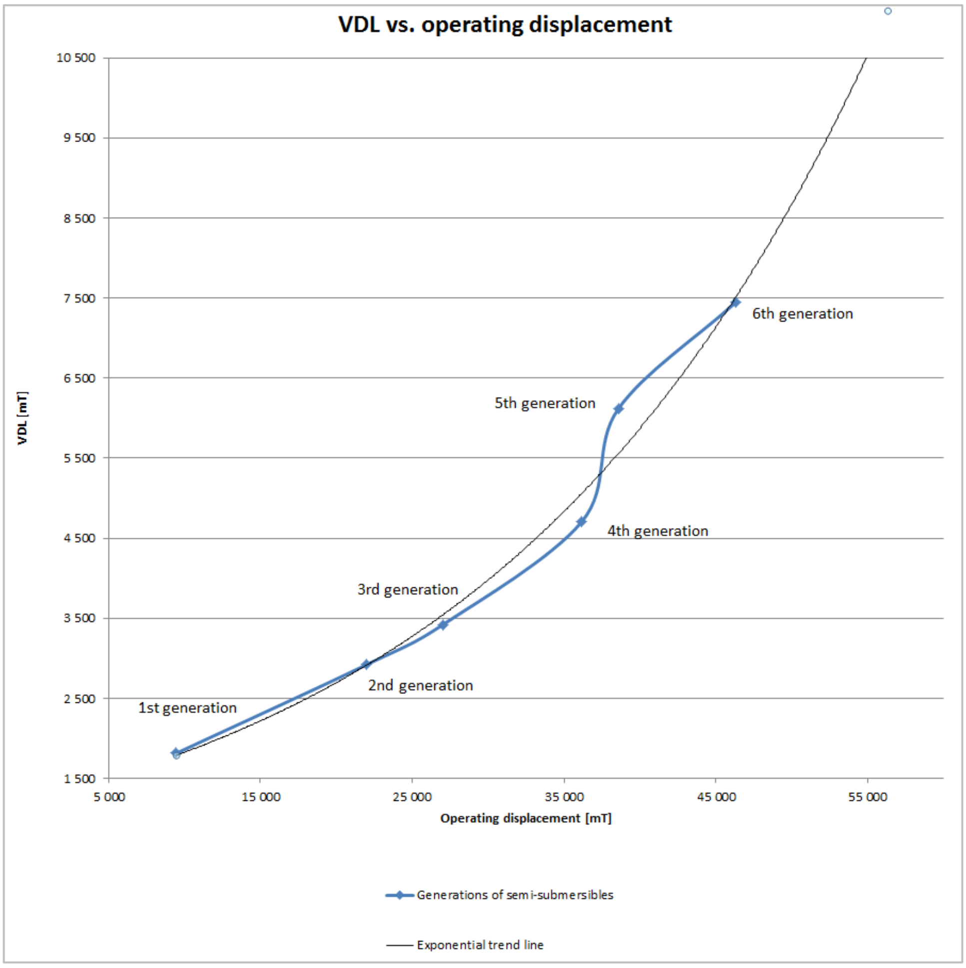


Figure 2 - VDL vs. operating displacement for the generations of semi-submersible drilling rigs. [2]

Figure 3 illustrates the percentage of rigs from each generation on the market today (second quarter in 2014). Cold stacked rigs and rigs under construction are not included. Rigs from the 2nd, 3rd and 4th generation together represent 62% of the total rig market. [2] An increase in the operational capacity would give a wider range of options for both the rig owners and operating companies. The potential for increased operational capacity will be presented and discussed in chapter 7.

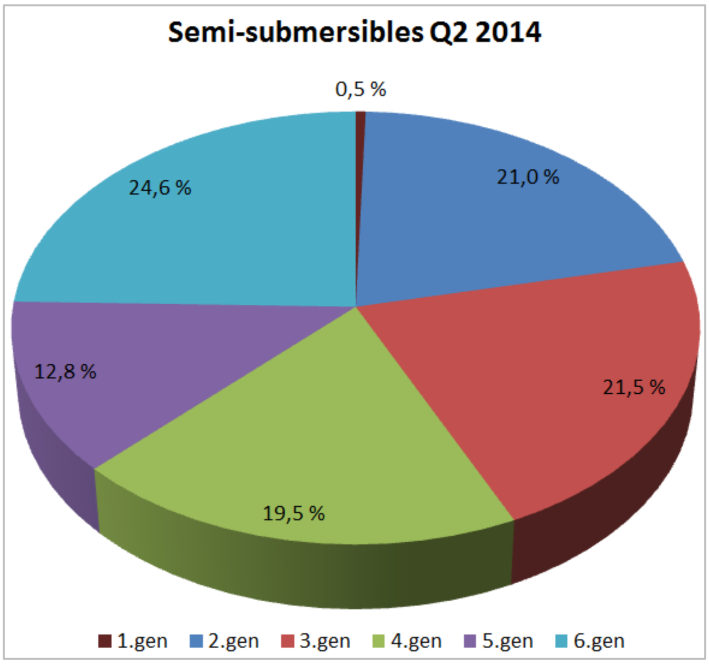


Figure 3 - Generation share of the market. [2]

2.1 FIRST GENERATION (1960'S)

The first semi-submersible drilling rig (SSDR) was Bluewater No.1. It was converted from a submersible hull by Shell Oil in 1961. This was the start of the SSDRs. The 1st generation units could either sit on bottom or drill from a floating position, to avoid being unemployed. The designers of the first generation units strived to optimize the vessel motion characteristics, and that led to vessels with different shapes and characteristics as shown in Figure 4. [3]

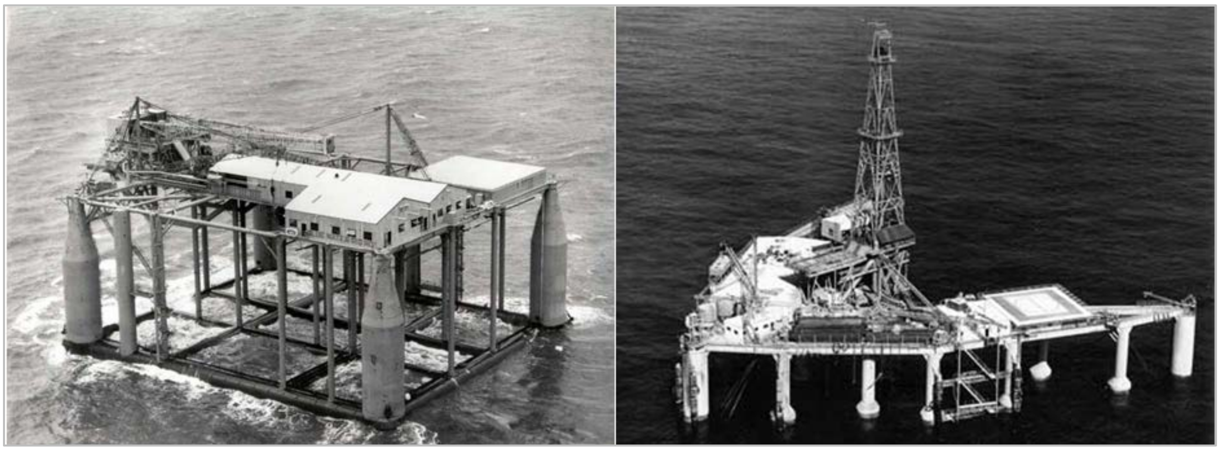


Figure 4 - Bluewater No.1 and Ocean Driller. [4][5]

2.2 SECOND GENERATION (1969-74)

The second generation was built in the early 1970s. They were built with a more advanced subsea and mooring equipment. Most of the rigs built in this period were designed for water depths around 600 feet. The *Ocean Victory class* shown in Figure 5 is a typical rig design from this generation. In this period their focus was on reducing rig motion, as well as increased VDL rating. [3]

Figure 5 - Ocean Voyager, Ocean Victory-class. [3]

2.3 THIRD GENERATION (1980-85)

In the first half of the 1980s the third generation of rigs were built. This era is dominated by the Aker H3 design. These rigs were more robust than the previous generations, and especially suitable for the North Sea. Many of the Aker H3 rigs were upgraded in the modernization period, and extra columns were added to meet the stability requirements. Essar Wildcat in Figure 6 has four extra columns. [3]

Figure 6 - Essar Wildcat, Aker H3. [2]

Many were built, and, in the middle to late 1980s, a number of 3rd generation SSDRs were designed and built to be able to moor and operate in water depths greater than 900m, and in harsher environments. Many of these units were upgraded in the 1990s for even deeper water depth ratings with more capabilities and became 4th generation units. With a few exceptions, the operating displacement of these units went from approximately 20000 mT in the 1970s to more than 30000 mT in the 1980s. [3]

2.4 FOURTH GENERATION (1985-90)

The 4th generation was a small group of rigs. Because of the aggressive development of the 3rd generation, few 4th generation rigs were built during this period. These rigs were designed to meet a more specific market, like deeper waters and harsher environment. [3] Their characteristics were increased VDL and larger displacement. West Alpha, from Figure 7, is a relatively small rig compared to other rigs from this era. Out of the 38 4th generation rigs in the market today, only 14 of them were built during this period. The remaining 24 rigs were converted from previous generations to 4th generation in the following modernization period, and some were built later on. [2]

Figure 7 - West Alpha. [2]

2.5 MODERNIZATION (1990-97)

In the late 1980's the market for new-build semisubmersibles went down. This was a reaction to the huge number of 3rd generation rigs that was built in the early 1980's. Even though the day rates increased, the generated income was not high enough to support a new-build program. Rigs from the second and third generation were not generating enough revenues, so the drilling companies decided to upgrade some of these units. The rigs could now generate enough income again, but were not able to do deep water drilling.

Shortly into the conversion process, the drilling companies realized that not every rig was a candidate for conversion. They had to rank the rigs after various criteria such as; age and general condition, the current profit status of the rig and how much available free deck space for new equipment there was. To drill in deeper waters, the mud system needs more mud volume and more pumping capacity. This requires larger capacity and storage, and could limit the available VDL during operation and transit. [6]

2.6 FIFTH GENERATION (1998-2005)

When the drilling industry wanted to drill even deeper wells in greater water depths, the modernized rigs from the previous generation were not meeting the new requirements. The modernized rigs were limited by the original design, especially regarding displacement and deck load capacity. The 5th generation drilling rigs made several new accomplishments such as deepest water depth and deepest subsea completion so far. This generation, as shown in Figure 8, is characterized by higher displacement and VDL. These rigs showed significant performance gains compared to the previous generations. Specific equipment improved, to increase the performance of e.g. flow rates and pump pressure. Another factor that generally improved the performance of these rigs was that most of the units from this generation have dynamic positioning. This eliminates the time spent on anchor handling operations. [7]

Figure 8 - Eirik Raude. [2]

2.7 SIXTH GENERATION (2005-CURRENT)

The sixth generation is dominated by rigs designed for deepwater and harsh environment. This is due to the increasing interest in exploring new areas like the arctic parts of Canada, Greenland, Russia, Atlantic Margin, the Norwegian Continental Shelf, Brazil, West Africa as well as new areas of Australia and the Gulf of Mexico. [8] The sixth generation is clearly dominated by deepwater and winterized rigs. Transocean Barents as shown in Figure 9 is an Aker H-6e design. [2] It is a typical deepwater – and harsh environment rig from this generation. Its characteristics are very large displacement and VDL (64500mT and 7000mT). [2] This rig is winterized and also able to drill in water depths up to 3048m. Many rigs from both the 5th and 6th generation are equipped with the time-saving Dual RamRig system. [2] The Dual RamRig system has no draw-works, and the topdrives are hydraulically handled. It also allows for the auxiliary rig to make long sections of equipment ready for deployment in the main rig. [9]

However, some moderate sized rigs were built and they are perfectly suited for the North Sea and Norwegian Sea. COSLPioneer, as shown in Figure 9, is a moderate sized rig. It has relatively small displacement and VDL (36400mT and 4000mT) compared to Transocean Barents, and can operate in water depths up to 750m. [2]

Figure 9 - COSLPioneer and Transocean Barents. [2]

3. STABILITY OF A VESSEL

When a vessel is floating at rest, it is in static equilibrium. The forces of buoyancy and gravity are acting equally on the same line, but in opposite directions. This is the vessel's ability to resist overturning forces and return to its position after the disturbing forces are removed. [10] A vessel must withstand external forces and internal loads from e.g. waves, wind, flooding or shifting of cargo. Ballast water is used to maintain stability.

3.1 STABILITY AT SMALL ANGLES OF INCLINATION

Initial stability is the stability for a small deviation from the original position. The metacentric height (GM) is a measure of the vessel's initial transverse stability. It expresses the stability of the vessel at small inclinations. [11] Figure 10 shows the relationship between the components of the formula for initial stability.

$$\overline{GM} = \overline{KB} + \overline{BM} - \overline{KG}$$

- G = Centre of gravity.
- M = Metacentre.
- B = Centre of buoyancy.
- K = Keel of the ship.

According to the requirements from The Norwegian Maritime Authority (NMA) the GM for semi-submersibles shall be at least 1,0 meter for all operating – and survival conditions, and at least 0,3 meters in temporary conditions. [12]

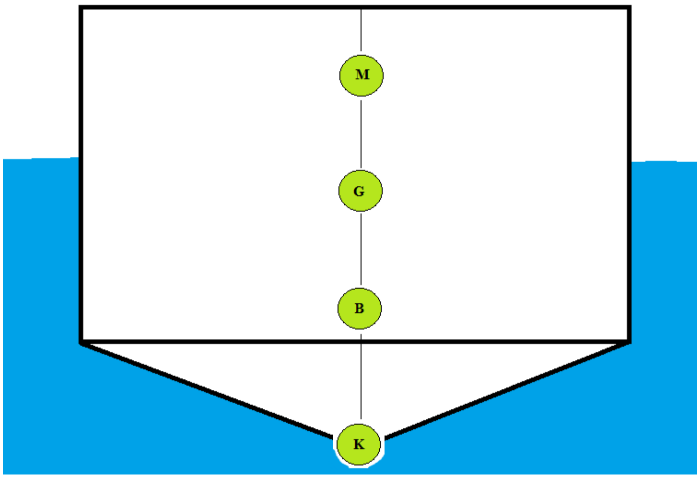


Figure 10 - Simplified sketch of vessel stability.

3.2 STABILITY AT LARGER ANGLES OF INCLINATION

Another important part of a vessel's stability is the righting arm. As shown in Figure 11, the righting arm (GZ) is the horizontal distance between the centre of gravity and centre of buoyancy. The B in this case is the centre of buoyancy in inclined mode, and ϕ is the heeling angle. When the heel angle exceeds a certain value it is not applicable to express transverse stability by GM, but by GZ. The heeling angle limitation is approximately 5 to 10 degrees. [11]

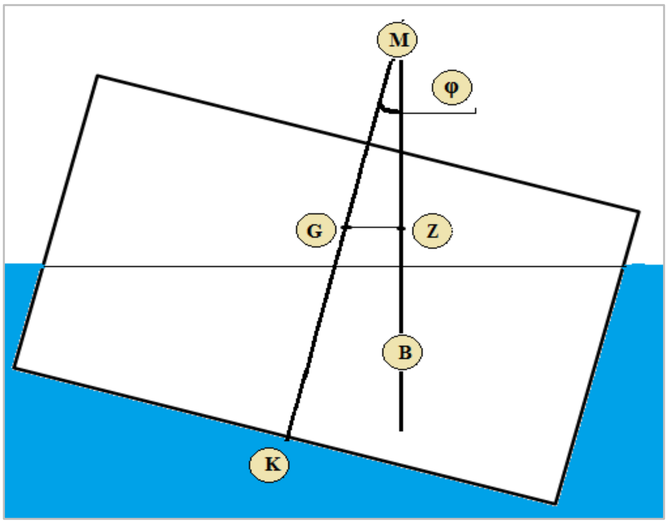


Figure 11 - Simplified sketch of transverse stability at larger angles of heel.

The righting arm is a measure of the vessel's stability. This can best be explained graphically, as shown in Figure 12. During normal conditions the righting arm will increase up to a certain point, where it will start to decline and return to zero. The righting moment acts against the heeling moment. When the righting moment is equal to the heeling moment there is equilibrium. If the arm of the heeling moment is larger than the GZ-arm at angle of maximum stability, the vessel will capsize. [10]

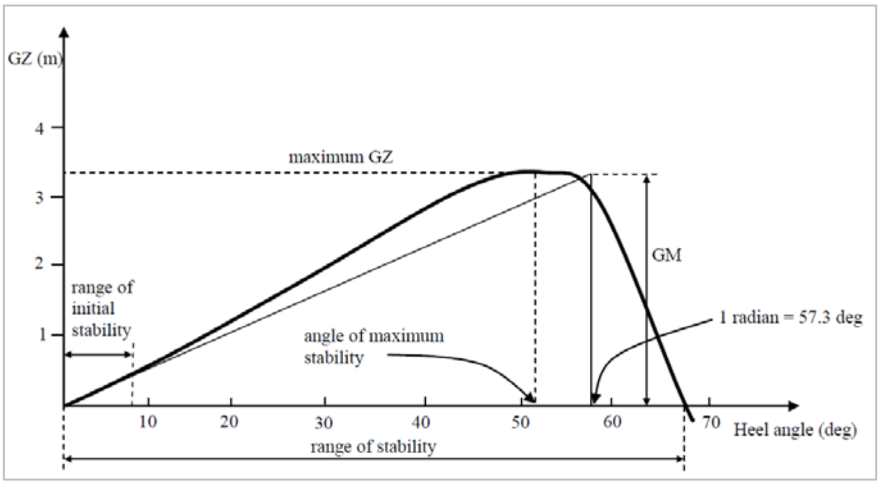


Figure 12 - Typical stability curve. [10]

3.3 INTACT STABILITY

Intact stability is the stability of an undamaged vessel. The NMA has the following general requirements for intact stability, where the symbols are illustrated in Figure 13. [12]

- Static angle of inclination due to wind (θ1) shall not exceed 17° in any condition.
- The «second intercept» between the righting moment curve and the wind inclination moment curve (θ2) shall occur at an angle of 30° or more. The «second intercept» is defined as the point where the righting moment curve, corrected for any progressive flooding, crosses the wind inclination moment curve for the second time.
- The righting moment curve shall be positive over the entire range of angles from upright to the second intercept.

The following requirements are only applicable for semi-submersibles:

- The metacentric height (GM) shall be at least 1.0 metres for all operating conditions and survival conditions. The metacentric height shall never be less than 0.3 metres in temporary conditions.
- The area under the righting moment curve up to the «second intercept», or alternatively to a smaller angle, shall be not less than 30% in excess of the area under the wind inclination moment curve to the same limiting angle.
- Alternative stability requirements may be approved by the Norwegian Maritime Authority, e.g. based on model tests, cf. § 4, provided an equivalent level of safety is maintained.

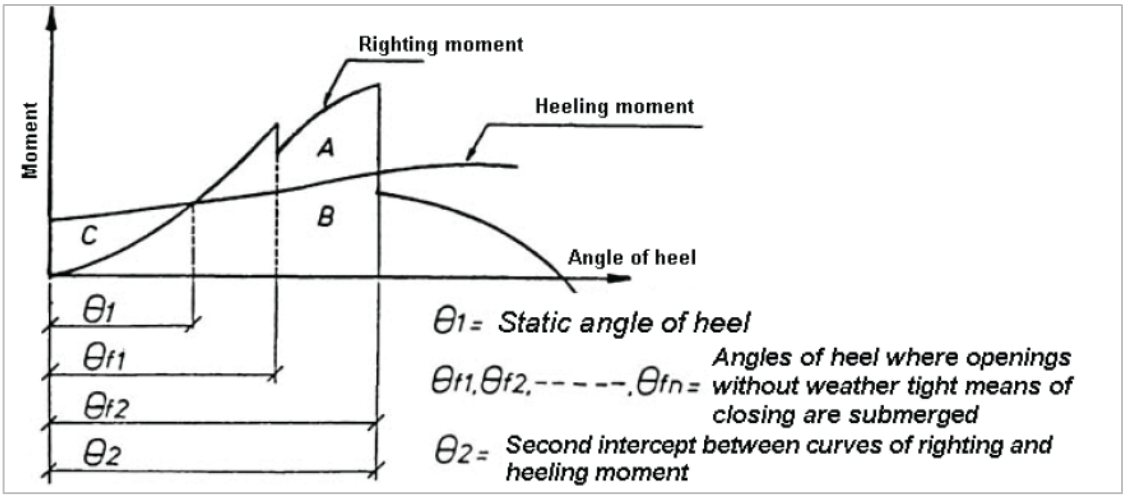


Figure 13 - NMA intact stability curves. [12]

3.4 DAMAGED STABILITY

The damaged stability is the stability of a vessel when there is damage to the hull. This damage can come from events such as collision with another vessel or grounding. When looking at SSDRs, collision with another vessel is the most likely unwanted event. [10]

The hull is designed to withstand a potential flooding, and is divided into several watertight compartments. The NMD has the following regulations the unit shall be able to withstand: [12]

- Flooding of any one single watertight compartment.
- Flooding of watertight compartments breached by low energy collision with attendant vessel. Damage penetration is assumed to occur anywhere within a vulnerable zone extending from 5 metres above to 3 metres below the considered draught. The horizontal penetration is 1,5 metres high and the horizontal extent is 3 metres.

3.5 VCG-CURVES

In addition to intact stability and damaged stability, the vertical centre of gravity (VCG), also called KG (Figure 10) is very important to the vessel's stability. The VCG curves show maximum allowable vertical centre of gravity, and is usually a function of the draught. Monitoring the VCG is a daily procedure for drilling rigs, to make sure that the VCG is lower or equal to the maximum allowable VCG. With regards to the VCG, the rigs shall be operated according to the ballasting curve. The maximum allowable VCG is calculated for different conditions with various draughts such as operation, transit, survival and temporary condition as shown in Figure 14. [13]

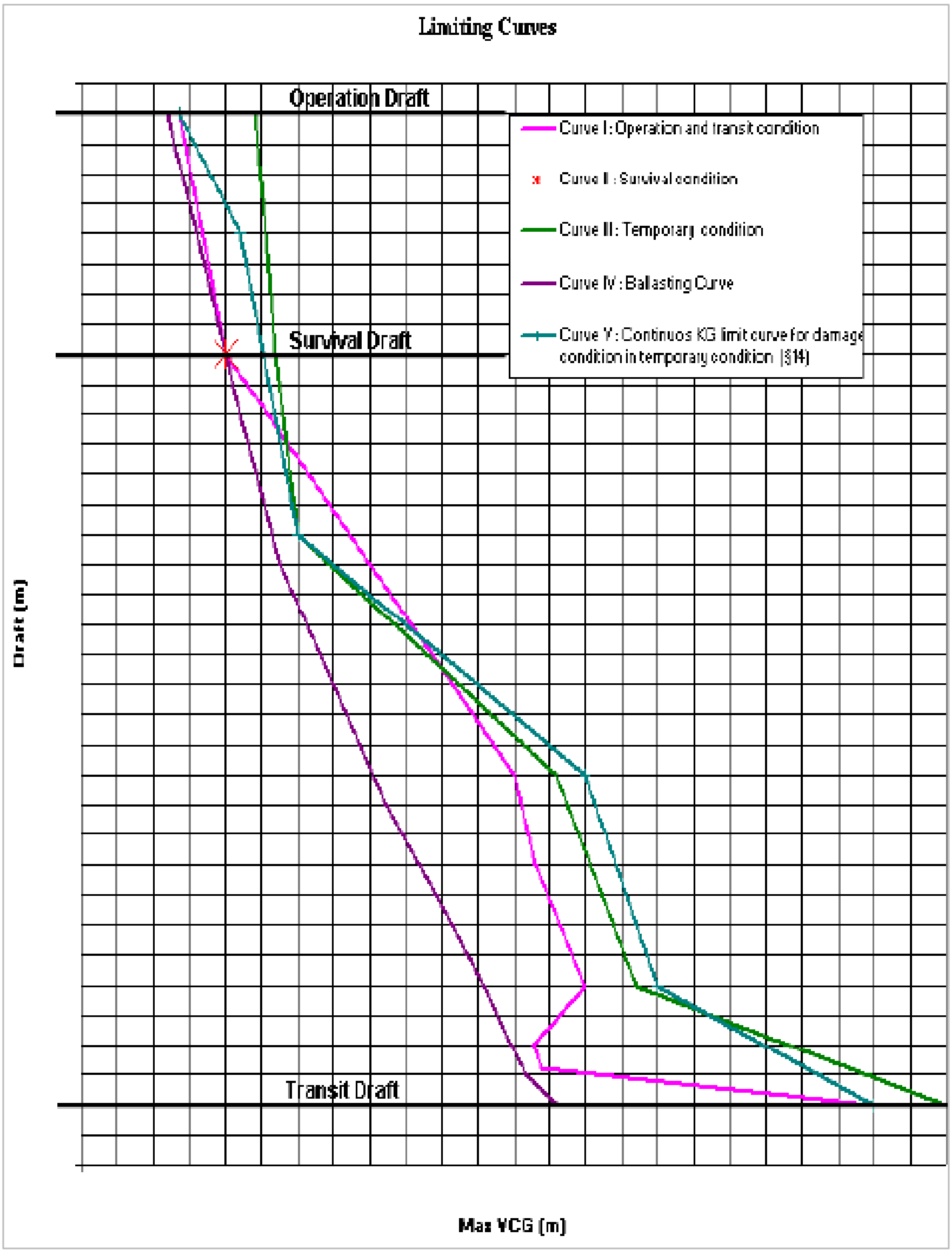


Figure 14 - Limiting curves for max. VCG. [13]

4. VARIABLE DECK LOAD (VDL)

This chapter will present the contents of the term VDL, the largest contributors, as well as how the VDL is monitored.

The definition of the term VDL is not standardized and varies from operator to operator, and from contract to contract. Figure 15 illustrates a general structure of the various loads.

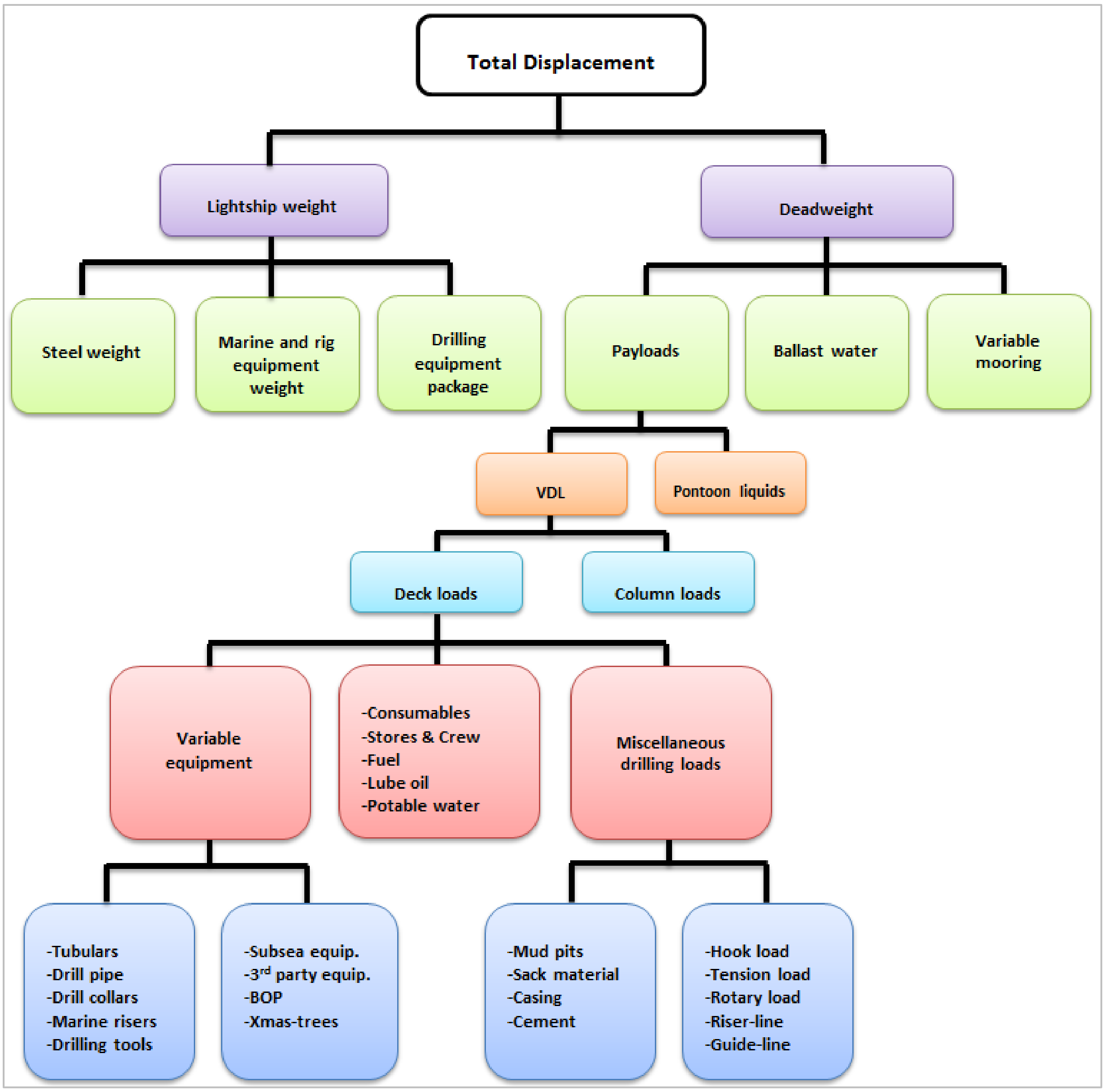


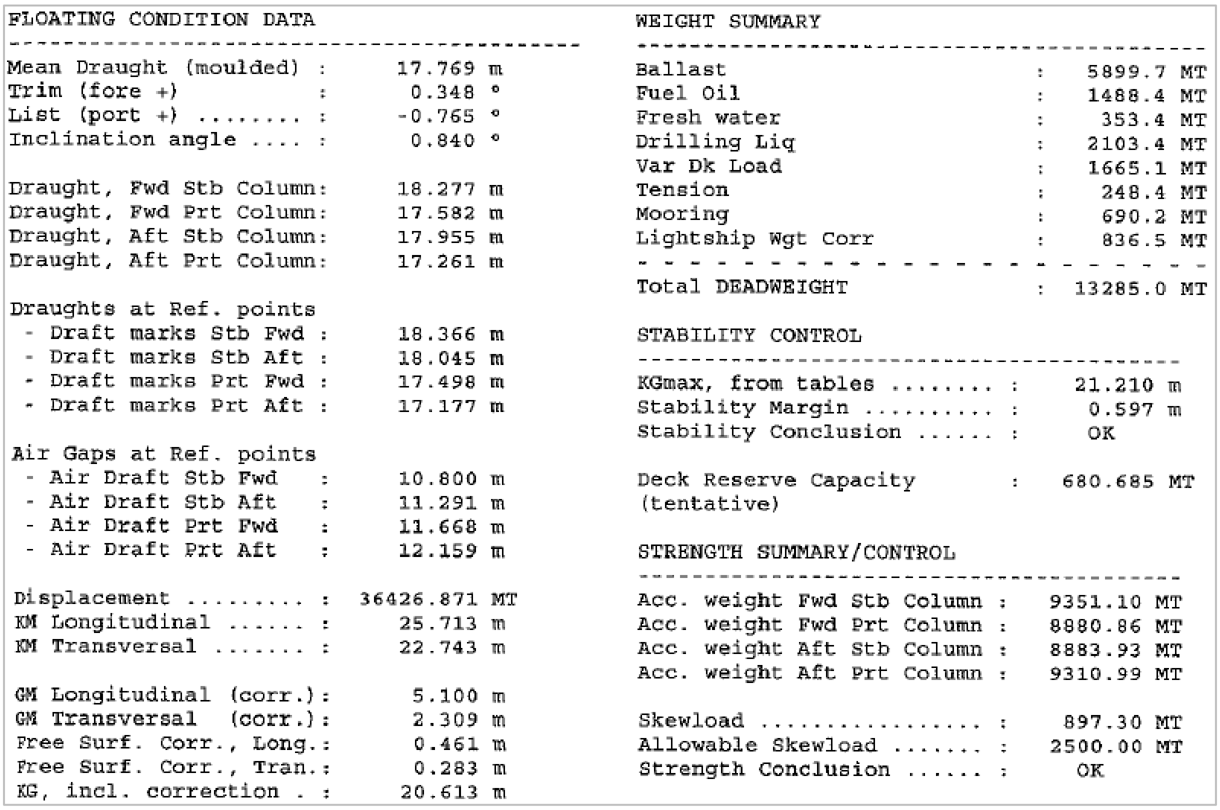
Figure 15 - Weight breakdown of total displacement. [14]

Table 2 - Description of the weight and loading terms. [14]

Item	Description
Total displacement	The total weight of the rig measured in draught marks ready for operation.
Lightship weight (LSW)	The total weight of steel weights and equipment weights, considered to belong to the rig at all times independent of operations.
Dead weight	Total carrying weight capacity of the rig, i.e. all removable items illustrated in Figure 15 as the sum of payloads, ballast water and variable mooring loads.
Steel weight	All structural steel, outfitting, foundation, supports and secondary steel weights. Construction elements of various materials. Wind walls, railings, platforms, floor plates and gratings. All of this is included under this main item of the LSW.
Marine and rig equipment	All equipment necessary to operate the rig independent of operations including electrical cables, junction boxes, piping weights and liquid in systems. However, excluding equipment consumables.
Drilling equipment packages	All equipment included in the drilling package that is installed on the rig independent of operations, including liquids in systems.
Payloads	Total weight of the VDL and column loads and variable pontoon liquids related to the rig operation.
Ballast water	Total ballast water weight, contributing to trim and stability of the rig at different draughts, but not contributing to payloads.
Variable mooring	Total weight of variable mooring equipment and tension loads to be carried by the rig in different operating conditions.
Variable deck load (VDL)	The part of the payloads that are carried in deck box and columns.
Pontoon liquids	The part of the payloads that are stored in the pontoon tanks, i.e. products of the operation or liquids that are consumables, excluding ballast water.
Deck loads	Part of the VDL that are carried in the deck box.
Columns loads	Part of the VDL that are carried in the columns.
Variable equipment	Equipment specifically related to the drilling – or other operation that can be removed or replaced if required.
Miscellaneous drilling loads	Variable loads related to the production.
Consumables, stores and crew	Variable loads related to: - Rig and other equipment consumables. - Equipment spares. - Crew and crew provisioning (food, water etc.). - Miscellaneous consumables and stores.

As illustrated and explained in Figure 15 and Table 2, the VDL consists of various loads. In simple terms, it can be explained as the loads on a rig that is not permanent. Rigs designed for deepwater operations could have an issue with logistics when it comes to resupplying, as they may be farther from shore. Having a large VDL capacity would then be a benefit. As the generations of drilling rigs have been developed, the VDL has increased. Having a large variable load capacity can be attractive for clients but it is very expensive, both when it comes to day rates and the actual cost to build the rig. The environmental conditions are very important in the design phase. There shall be a sufficient air gap between the deck box and the water level, so that there will be no wave impact on the underside of the deck box at survival draught. Rigs designed to operate in environments like the North Sea must have greater column height than rigs designed to operate in areas with moderate weather conditions. Determining the size of the pontoons is an important part of the design phase. Large pontoons allow for high VDL capacity, but the steel weight, cost and station-keeping forces will be increased. Therefore, the design phase is of great importance, to make sure the rig has optimum motion characteristics and VDL capacity without having to add sponsons to maintain the stability and not exceeding the planned cost. [15]

Monitoring the VDL is a daily routine on a drilling rig. The input data are registered in a loading computer system, and the stability, weight and strength are summarized as shown in Figure 16. The data is valid for a typical small semi-submersible drilling rig with operating displacement of approximately 40 000mT. The floating condition data and stability control expresses the stability status of the rig. The lightship weight corrected item consists of ghost weight and the corrected lightship weight. The ghost weight can be excess cargo, gear and miscellaneous equipment left on board. During a modification, new equipment can be installed, and can result in an increased lightship weight. These weights are not included in the VDL, but will reduce the VDL capacity. The issue regarding ghost weight can be handled by having a well-organized logistics system. The deck reserve capacity is the remaining VDL available. From the case in Figure 16, the theoretical maximum VDL consist of the deck reserve capacity and the VDL, to maintain the required stability. [13]



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FLOATING CONDITION DATA                          WEIGHT SUMMARY
-------------------------------------------      -----------------------------------------
Mean Draught (moulded) :       17.769 m          Ballast                       :   5899.7 MT
Trim (fore +)          :        0.348 °          Fuel Oil                      :   1488.4 MT
List (port +) ........ :       -0.765 °          Fresh water                   :    353.4 MT
Inclination angle .... :        0.840 °          Drilling Liq                  :   2103.4 MT
                                                 Var Dk Load                   :   1665.1 MT
Draught, Fwd Stb Column:       18.277 m          Tension                       :    248.4 MT
Draught, Fwd Prt Column:       17.582 m          Mooring                       :    690.2 MT
Draught, Aft Stb Column:       17.955 m          Lightship Wgt Corr            :    836.5 MT
Draught, Aft Prt Column:       17.261 m          - - - - - - - - - - - - - - - - - - - - -
                                                 Total DEADWEIGHT              :  13285.0 MT
Draughts at Ref. points
 - Draft marks Stb Fwd :       18.366 m          STABILITY CONTROL
 - Draft marks Stb Aft :       18.045 m          ---------------------------------------
 - Draft marks Prt Fwd :       17.498 m          KGmax, from tables ........ :    21.210 m
 - Draft marks Prt Aft :       17.177 m          Stability Margin .......... :     0.597 m
                                                 Stability Conclusion ...... :     OK
Air Gaps at Ref. points
 - Air Draft Stb Fwd   :       10.800 m          Deck Reserve Capacity       :   680.685 MT
 - Air Draft Stb Aft   :       11.291 m          (tentative)
 - Air Draft Prt Fwd   :       11.668 m
 - Air Draft Prt Aft   :       12.159 m          STRENGTH SUMMARY/CONTROL
                                                 ---------------------------------------
Displacement ......... :    36426.871 MT         Acc. weight Fwd Stb Column :   9351.10 MT
KM Longitudinal ...... :       25.713 m          Acc. weight Fwd Prt Column :   8880.86 MT
KM Transversal ....... :       22.743 m          Acc. weight Aft Stb Column :   8883.93 MT
                                                 Acc. weight Aft Prt Column :   9310.99 MT
GM Longitudinal (corr.):        5.100 m
GM Transversal  (corr.):        2.309 m          Skewload ................. :    897.30 MT
Free Surf. Corr., Long.:        0.461 m          Allowable Skewload ....... :   2500.00 MT
Free Surf. Corr., Tran.:        0.283 m          Strength Conclusion ...... :     OK
KG, incl. correction . :       20.613 m
```

Figure 16 - Output data from loading computer. [13]

It is not easy to find specific data for VDL. Table 3 shows a list of data of the largest contributors to the VDL, in this case the 6th generation drilling rig; Maersk Deliverer is used as an example. [2] Some of the data was directly collected from the rig's technical specifications, and some of the data was gathered from assuming a weight of a specific item and multiplying it with the capacity, e.g.

$$W_{drill\ pipe} = 45kg/m$$

$$Drilling\ capacity = 9144m$$

$$W_{max.drill\ pipe} = 45 * 9144 \ \approx 410mT$$

The Maersk Deliverer states to have a VDL of 13 500mT. [2]

Table 3 - Largest components of VDL, Maersk Deliverer. [2]

Item	Capacity [mT]
Mud (liquid and active) (ρ=1,5 kg/l)	~4500
Diesel (ρ=0,86 kg/l)	~3830
Riser dry weight on deck	~2675
Riser tension	~1360
Hookload	~1135
Drilling liquids (brine) (ρ=1,2 kg/l)	~900
Casing dry weight on deck	~670
Drill cuttings	~620
Pipebays/setback	~410
BOP stack	~400

However, only a selection of the data will be analysed with the objective to reduce them. Table 4 shows the contributors that will be analysed. Some of the data such as diesel and drilling liquids are considered to be both pontoon liquids and VDL. As this is not stated in the technical specifications, this data will not be analysed. If the analysed data can be reduced, items such as the setback can increase its capacity i.e. able to drill longer wells.

Table 4 - Analysed contributors of VDL. [2]

Analysed items	Capacity [mT]	Part of tot. VDL [%]
Mud (liquid and active) (ρ=1,5 kg/l)	~4500	~33
Riser dry weight on deck	~2675	~20
Riser tension*	~1360*	~10*
Drill cuttings	~620	~5
BOP stack	~400	~3

Maersk Deliverer states to have a VDL of 13 500mT. The selected contributors represent a large part of this. By applying the technologies to be discussed in chapter 5, a correlation between the analysed items can be found e.g. when the riser dimension is reduced, the required mud, riser tension, dry weight of the riser, drill cuttings and the BOP can all be reduced. When the VDL can be reduced, the size of the rig can also be reduced.

* The riser tension and dry weight of riser is a load that never occurs simultaneously. As the reduced required capacity of dry weight of riser continues to be larger than the original riser tension, the dry weight will be taken into account when finding the reduced requirements for VDL in chapter 7. The reduced requirements for riser tension will be utilized to find the increased water depth capacity.

5. ENABLING TECHNOLOGIES

This chapter will present technologies that have the potential to reduce the variable deck load (VDL). The concept of slender wells is essential when discussing potential VDL reduction. The slender well enablers are as follows:

- Formation targets requiring less casing strings
- Dual Gradient Drilling (DGD)
- Riserless Mud Recovery (RMR)
- Managed Pressure Drilling (MPD)
- Reelwell Drilling Method (RDM) and RDM-Riserless

In the following these cases will be further discussed.

5.1 SLENDERWELL SYSTEMS

Most wells today are drilled with the conventional 21” riser system. In great water depths, the weight related to the riser with a 21” nominal outer diameter (OD) and 19-1/2” nominal inner diameter (ID) represent a major part of VDL. From the example in chapter 4, the dry weight of the riser represents approximately 20% of the total VDL.

When the formation target and enabling technologies allows it, longer sections can be drilled without setting casing. Longer sections of casing can give slender wells. Table 5 shows a conventional casing program and Table 6 shows a reconsidered casing program when applying the slenderwell system. In this slender well casing program the 30” casing can be eliminated. [16][17]

Table 5 - Conventional casing program. [16]

Hole size [in]	Casing size [in]	Casing type
36	30	Conductor
26	20	Surface
17-1/2	13-3/8	Intermediate
12-1/4	9-5/8	Intermediate
8-1/2	7	Liner

Table 6 - Slender well casing program. [16][17]

Hole size [in]	Casing size [in]	Casing type
26	20	Conductor
17-1/2	13-3/8	Surface
12-1/4	9-5/8	Intermediate
8-1/2	7	Liner

By using a slenderwell and corresponding riser system, the riser nominal diameter can be reduced to 16”, and the benefits of this will be presented in section 6.1. From Table 7 the dimensions of a slenderwell and conventional system are presented. [18]

Table 7 - Riser dimension with buoyancy elements. [18]

Nominal size	Conventional system	Slenderwell system
Riser w/ buoyancy elements OD [in]	≈54	≈41
Riser without buoyancy elements OD [in]	21	16
Riser ID [in]	19-1/2	14-1/2
Wellhead ID [in]	18-3/4	13-5/8
BOP ID [in]	18-3/4	13-5/8

As seen from Table 7, the slender riser system can be installed with a smaller ID in the BOP and wellhead than the conventional 18-3/4”. This means reduction in weight when the BOP is stored on the rig.

However, there are some limitations regarding a slenderwell system. After the BOP is landed, there is a restraint for the maximum OD of the drill bit. This can limit the application of the slenderwell system in wells that need larger sections of casings. [16][18]

However, the slenderwell system offer significant benefits, which will be discussed more thoroughly in section 6.1. The system is however not applicable for all wells. Deep wells with challenging formation target may not be suitable for the use of this technology.

Note that this case assumes the same length of sections in the comparison of the casing programs.

The technologies described in the following are claimed to have inherent ability to drill longer sections and thereby reduce the number of casings required.

5.1.1 DUAL GRADIENT DRILLING AND RISERLESS MUD RECOVERY

Another slenderwell enabler is Dual Gradient Drilling (DGD). The basic concept of DGD is to have the riser filled with seawater instead of mud. DGD differs from conventional drilling by the use of two fluids with different density in the annular space while drilling, as illustrated in Figure 17. [19]

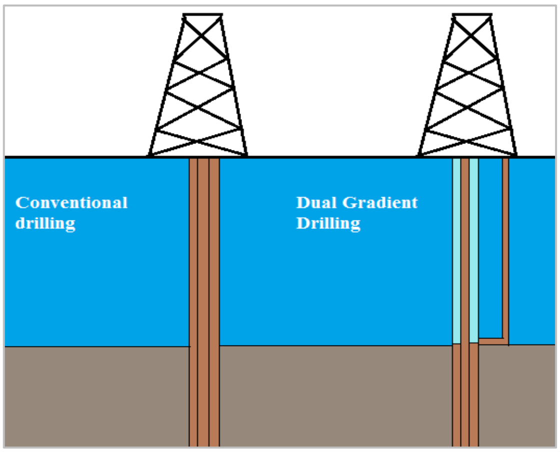

Figure 17- Conventional drilling vs. DGD.

The pressure at the wellhead will be equal to the hydrostatic head at the mudline, because of the seawater-filled riser. This will increase the drilling window as illustrated in Figure 18. Dual gradient drilling will enable drilling of longer sections before being forced to set casing. [19]

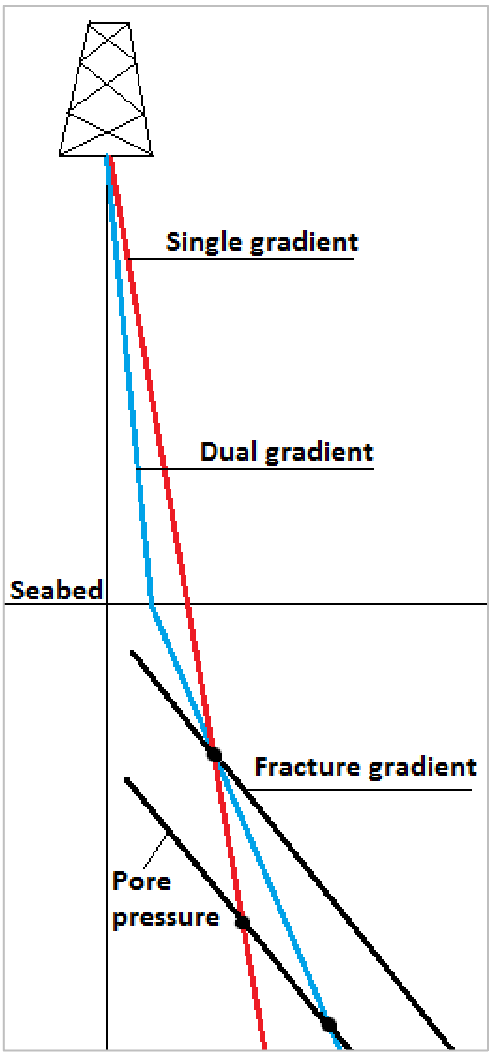

Figure 18 - Drilling window with single gradient and dual gradient.

The idea of DGD has existed since the 60's, but none was commercially developed. [20] In the 1990s many companies tried to develop a DGD technology, without succeeding in commercializing their technology. One of the companies that succeeded is AGR with their Riserless Mud Recovery (RMR). This technology is presently only applicable in the pre-BOP phase. [21]

When drilling the first section of a well (the top-hole section) the integrity of the well is especially compromised. RMR enables more stable top-hole drilling, longer sections, as well as a reduction in discharges to environment at the mudline. [21]

The method is a DGD system, based on returning the mud via a mud return line by using a subsea pump module, as shown in Figure 19. The suction module (SMO) is connected to the subsea pump module (SPM) via a hose. Fluid and cuttings are extracted from the SMO and pumped back to the rig via the mud return line (MRL). In areas like the Gulf of Mexico and parts of West Africa, pore pressures are quite high while the fracture resistance pressures are quite low. Due to the small margin between these, many sections of casing has to be set in the upper-hole sections and in deeper pressure transition zones. As illustrated in Figure 18, the drilling window will increase when utilizing DGD. Because of this, longer sections can be drilled with the same mud weight without having to set casing. [21][22]

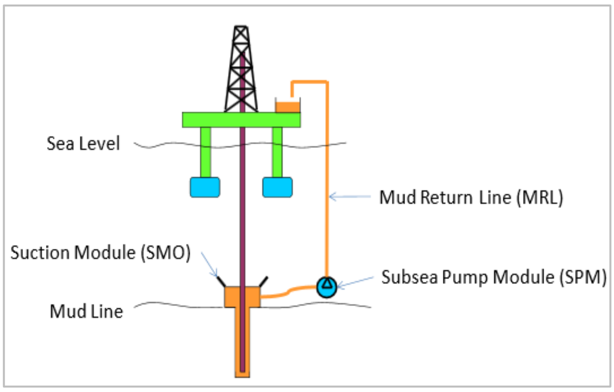

Figure 19 - RMR. [22]

5.1.2 MANAGED PRESSURE DRILLING (MPD)

MPD is one of the technologies that can enable usage of a slenderwell system. The Underbalanced Operation and Managed Pressure Drilling Committee of the International Association of Drilling Contractors define MPD as follows: [23]

"An adaptive drilling process used to precisely control the annular pressure profile throughout the wellbore. The objectives are to ascertain the downhole pressure environment limits and to manage the annular hydraulic pressure profile accordingly. It is the intention of MPD to avoid continuous influx of formation fluids to the surface. Any influx incidental to the operation will be safely contained using an appropriate process."

Accurately controlling the pressure in an enclosed system implies the acceptance of drilling with narrower margins to the pore pressure. Due to this, longer sections can be drilled without setting casing. [24] This can enable usage of the slenderwell system, in the same way as DGD.

5.1.3 REELWELL DRILLING METHOD (RDM) - RISERLESS

The oil and gas industry is always striving for new technology to overcome their challenges. However, it is a long way from a field trial to commercializing the technology. Reelwell drilling method (RDM) is a drilling technology based on some new principles. The RDM is a MPD technology and has been applied in two commercial onshore wells in Canada and Saudi-Arabia. The key element of the system is the Dual Drill String (DDS). The main difference from conventional methods is that the returning fluid and cuttings are transported back to the surface through the inner part of the string instead of the annulus, as shown in Figure 20, illustrating a land rig application. The Dual Float Valve (DFV) works as a crossover in both the downward flow of the drill fluid and the returning flow of the fluid and cuttings from the well. The drill string is terminated in a Top Drive Adapter (TDA), which contains a dual swivel system for supply and return of drill fluids. The drilling fluid is pumped into the TDA by the rig, and the fluid flows downwards via the annulus of the DDS. [25]

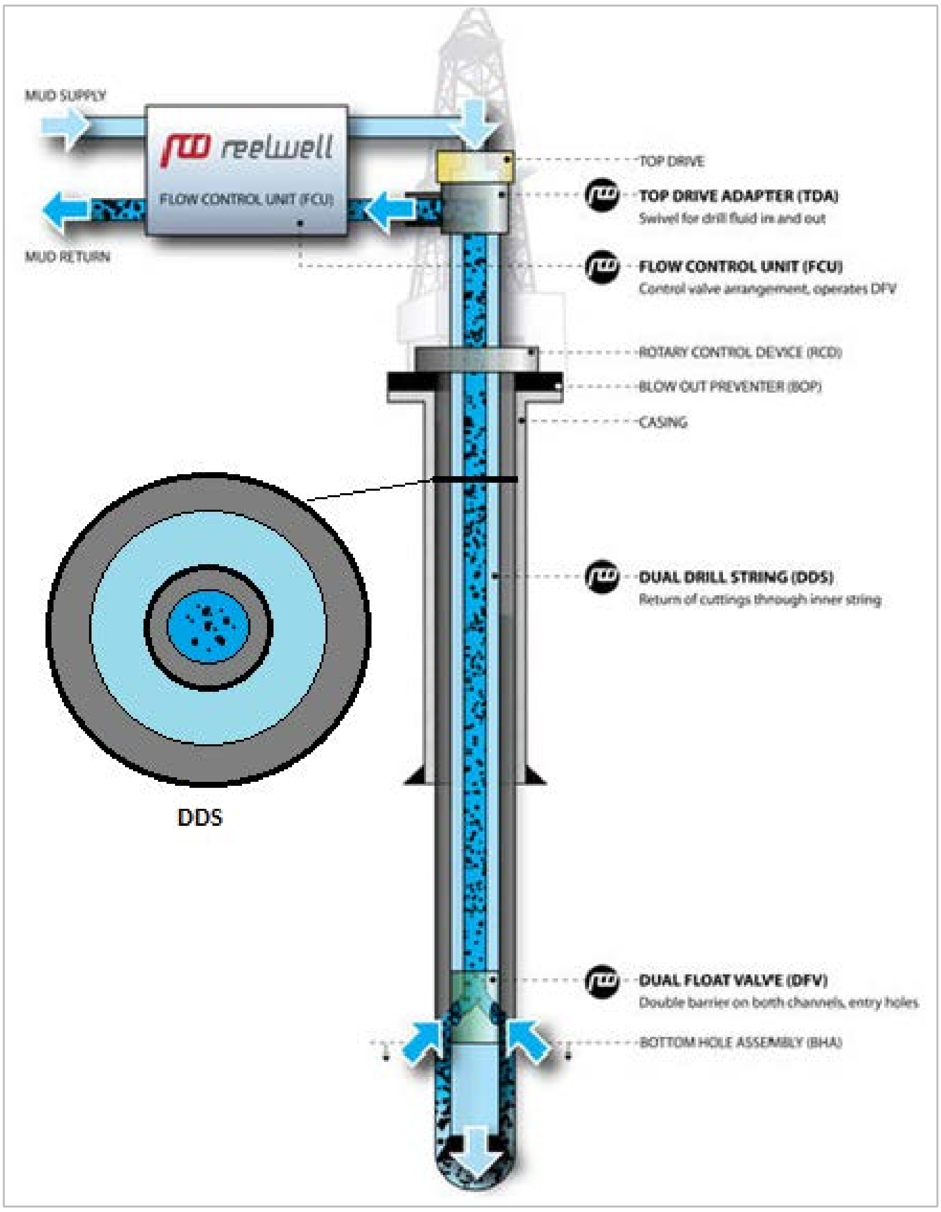

Figure 20 - RDM. [25]

The same principles as RDM on a land rig will be applicable on a mobile offshore drilling unit (MODU). The fact that the return fluid is internal in the DDS implies that the riser and associated systems can be omitted from the system. Figure 21 shows a simplified comparison between conventional drilling and riserless drilling from a MODU. This technology has several applications and benefits. The DDS may be used for all phases of drilling a well, and as the RDM is based on a mechanically fully enclosed system, and representing a new way of handling challenging formations, it could potentially increase lengths of drilled sections as for DGD and MPD. [1] The benefits from this technology will be presented in section 6.2.

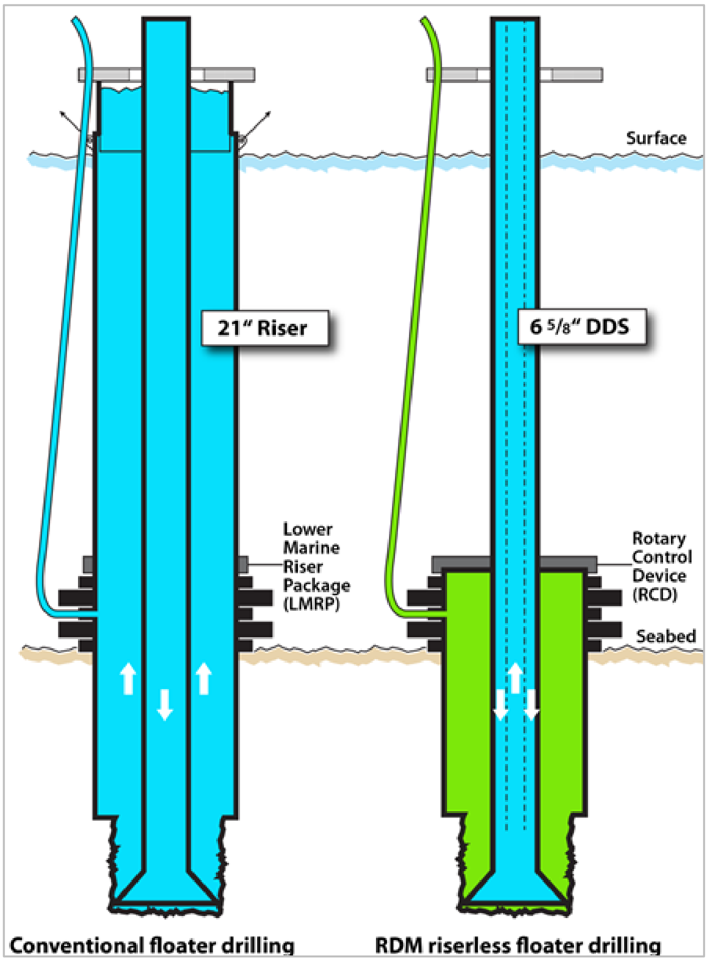

Figure 21 - Conventional floater drilling vs. RDM-Riserless drilling. [1]

5.2 ALTERNATIVE RISER MATERIALS

When the oil and gas industry moved into deeper waters, there was a concern of the weight of the steel risers when stored on deck as well as the tensioning capacity. From the example in chapter 4, the dry weight of the risers represent 20% of the total VDL, and the riser tension capacity represent 10% of the total VDL. If a slender well is not applicable, looking into different riser materials can help reduce that part of VDL. Especially aluminium and composite risers were considered alternatives in the research and development process that emerged in the 90's. [26] In 2000 the first prototype of Noble Drilling's aluminium-alloy riser was tested. [27]

The Noble Leo Segerius was the first drillship to deploy the new aluminium-alloy drilling riser. This was the first industry-approved aluminium-alloy drilling riser. [27]

When the first of these risers were used on the drillship, they were rated for use in water depths in excess of 5 000 ft. In later years, ultra-deepwater risers have been introduced to the market. The drilling rig Noble Dave Beard is rated for 10 000 ft. water depth, and is equipped with ultra-deepwater aluminium risers. [28] The technology enables increasing water depth capacity for drilling vessels. According to Noble Drilling, the aluminium-alloy riser can be 30% lighter than a conventional steel riser. [27]

Composite risers are another technology that was in the loop of research and development. Several companies have been working on composite riser systems such as ABB Vetco Gray and Kvaerner Oilfield Products.

One alternative is to only replace the kill and choke steel lines on the riser with composite. ABB Vetco Gray claims that a drilling rig could then increase the maximum water depth by 1 000 - 1 500 ft. without any modifications. [26] The other alternative is to use composite in the entire riser, this could save up to 1/3 to 1/2 of the weight of a steel riser system. Not all of the joints would have to be composite though, it would be a combined system. By using steel joints in the lower riser section, more stability and an easier running process would be provided to the composite system. However, a major disadvantage is that the composite risers could cost as much as 50% more than conventional steel risers. [26]

Both the aluminium-alloy and composite riser material technologies would be beneficial for the VDL on a drilling rig. It would reduce the required riser tension and the dry and submerged weight of riser.

The potential for reduced VDL when utilizing alternative riser materials will be presented in section 6.3.

5.3 MUDCUBE

In conventional drilling fluid and solids management systems, waste volumes and mud loss represents a major cost. Compared to other drilling related equipment, the development of this technology has been overlooked. Although the traditional method has been improved, there are still room for improvement. [29] Cubility has developed a new solid control system, MudCube vacuum conveyor separator (VCS), where the traditional mechanical process of shaking the fluids and solids to separate them is eliminated. According to Cubility, the benefits of the VCS compared to conventional technology are as following: [30]

- Eliminated oil-mist exposure in the shaker room
- Reduced noise and vibration in the shaker room
- Remote monitoring, resulting in reduces man hours and better overview
- Reduced weight of equipment
- Reduced need for new drilling fluid because of reduced mud loss

The weight from the drill cuttings will be analysed when utilizing MudCube compared to a conventional system. Cubility claims that the cuttings from a standard well on the Norwegian Continental Shelf (NCS) can be reduced from approximately 620mT to 440mT as presented in Table 8. [30]

When combining the MudCube technology with a slender casing program, the weight drill cuttings will be further reduced.

Table 8 - Drill cuttings from a conventional system vs. MudCube. [30]

System	Drill cuttings [mT]
Conventional system	620
MudCube	440

The impact of the reduction to the VDL will be presented in section 6.4.

6. POTENTIAL FOR REDUCING THE VDL

This chapter will present and discuss the results of the potential to reduce the VDL by applying the technologies presented in chapter 5.

6.1 REDUCTION WITH SLENDERWELL

The slenderwell technology has the potential to reduce several components on a drilling rig. The following cases will be presented:

- Dry weight of riser
- Mud in riser
- Mud in well
- Total mud in riser and well
- Riser tension
- BOP weight and size

6.1.1 DRY WEIGHT OF RISER

The weight of the riser when stored on deck is a major part of the VDL. The dry weight of the risers represents 20% of the total VDL, as presented in chapter 4. From Table 9, the general reduction when downscaling from a 21” riser to a 16” riser will be about 40%. It is claimed that as a rule of thumb for the design water depth, 90% of the full length of the riser will have buoyancy elements. [15]

$$Reduction_{dry\ weight\ of\ riser} = 1 - \frac{543}{891} \approx 0{,}4$$

Table 9 - Dry weight of riser for 16" and 21". [31]

Riser system	Dry weight without buoyancy elements [kg/m]	Dry weight with buoyancy elements [kg/m]	1000m [mT]	2000m [mT]	3000m [mT]
Conventional	486	936	891	1 782	2 673
Slender	298	570	543	1 086	1 629

6.1.2 MUD IN RISER

As the inner volume of the riser decreases with a slenderwell system, so will the mud volume required. From the example in chapter 4, the mud represents 33% of the total VDL.

From Table 10 it is found that the mud weight in the riser can be reduced by 46%.

$$Reduction_{mud\ in\ riser} = 1 - \frac{190}{354} \approx 0{,}46$$

Table 10 - Weight of mud in riser. [31]

Mud in riser [mT]			
Mud weight = 1,5 kg/l			
Riser type	1000m	2000m	3000m
Conventional	354	708	1062
Slender	190	379	568

The calculations and data can be found in Appendix A.

6.1.3 MUD IN WELL DUE TO SLENDER CASING PROGRAM

The usage of a slenderwell system will lead to a reconsideration of the casing program, and some of the largest casings can be eliminated. It will definitely reduce the cost, as about 15-20 % of the completed cost of a well comes from the tubing and casing. [32] By having longer casing sections the required mud volume can be reduced. There will also be less cement needed due to smaller annulus. When drilling larger sections, some rigs have problems with handling the cuttings from the well. This will also be handled with a slenderwell as there will be less cuttings returning to the rig. The total volume of mud needed in a well in the formation and casing for the conventional and slender casing program from section 5.1 is presented in Table 11. This gives a reduction of 45% when using the slender casing program. Calculations and illustrations of this are found in Appendix A.

Table 11 - Total volume of mud in formation and casing. [17][31]

Casing program	Total mud in formation and casing [m^3]
Conventional	≈ 625
Slender	≈ 345

$$Reduction_{total\ mud\ in\ formation\ and\ casing} = 1 - \frac{345}{625} \approx 0{,}45$$

6.1.4 TOTAL MUD IN RISER AND WELL

The total mud in riser and well in 1000m water depths with a conventional system and a slenderwell system is presented in the Table 12. The data can be found in Appendix A.

Table 12 - Total volume of mud in riser and well at 1000m water depths. [31]

Riser system	Mud in riser [m^3]	Mud in well [m^3]	Mud total [m^3]
Conventional	236	625	861
Slender	126	345	471

$$Reduction_{Mud\ total\ conv.to\ slender"} = 1 - \frac{471}{861} \approx 0{,}45$$

The total mud required will be reduced by 45% when utilizing a slenderwell system. Reducing the required mud capacity will have a great impact on the VDL, as mud represents 33% of the total VDL, previously presented in chapter 4.

6.1.5 RISER TENSION

The required riser tension can also be reduced with a slenderwell system. The total weight of the riser and mud will decrease, and accordingly will the tension required be reduced.

To illustrate the tension requirements for a 16" riser in a simplified manner, an assumption regarding the proportionality of decrease in the cross-sectional area is made. This means that when the OD decreases from 21" to 16", the wall thickness will also decrease. (Proven by the zero differential hoop stress in Appendix A)

The cross-sectional reduction is given by:

$$\left(\frac{OD_{16"}}{OD_{21"}}\right)^2 = 1 - \left(\frac{16}{21}\right)^2 = 0{,}42$$

This result means that the riser weight has the potential to be downscaled by 42%. A calculation of this is shown in Appendix A. [33]

The riser tension analysis performed is simplified, neglecting the flanges and buoyancy modules. Due the buoyancy modules, the actual tension required would be lower than the ones found in the simplified riser tension analysis. However, the purpose is to find the reduction when downscaling from a 21" to a 16" riser. The mud density is chosen to be 1,5 kg/l. The tension required to hold a pipe can be found from the following formula: [34]

$$Tension = W_{tot} - W_f$$

$$W_{tot} = W_{true} + W_{mud}$$

$$W_f = weight\ of\ displaced\ fluid$$

The calculations are found in Appendix A.

$$T_{21"at\ WD=1000m} \approx 535mT$$

$$T_{16"at\ WD=1000m} \approx 314mT$$

$$Reduction_{tension\ required} = 1 - \frac{314}{535} \approx 0{,}42$$

From both the cross-sectional reduction and the reduction in the simplified riser tension analysis, a reduction of 42% is applied. The required riser tension capacity for a 16" riser on drilling rigs today is found in Appendix A and B.

By reducing the riser from a 21" to a 16", the water depth capacity for the rigs can be increased. This will be presented in section 7.4.

6.1.6 BOP STACK

Most rigs today are equipped with a conventional 18-3/4" BOP stack. By implementing the slender BOP system, i.e. 13-5/8 BOP, there will be weight savings for the VDL. [35] The weight of the BOP varies from model to model, in rated pressure and from manufacturer to manufacturer. The weight of the conventional and slender BOP stacks is not the essential part, but the reduction ratio between them. The weight of a conventional BOP is assumed to be 400mT. Scaling down the size of the BOP from 18-3/4" to 13-5/8" can be expressed as follows:

$$Linear\ ratio_{Slender\ BOP\ vs\ conv.\ BOP} = \frac{13{,}625}{18{,}75} \approx 0{,}7$$

Assuming the same reduction three dimensionally, the following will express the weight reduction:

$$Reduction_{BOP\ in\ 3D} = 1 - 0{,}7^3 \approx 0{,}6$$

The slender BOP will then have a weight of:

$$W_{BOP\ reduced} = 400 * 0{,}4 \approx 160mT$$

6.2 REDUCTION WITH RDM-RISERLESS

The RDM-Riserless method will eliminate a considerable part of the VDL. In principle there is no riser tension required in RDM-Riserless. The auxiliary lines from the conventional riser are gathered in a utility line, controlling the well and the BOP, and the drill string is in all cases suspended by the top drive, as illustrated in Figure 22. The Reelwell DDS might be heavier than a standard string depending on the well case. This needs to be taken into consideration in a more detailed description. [1]

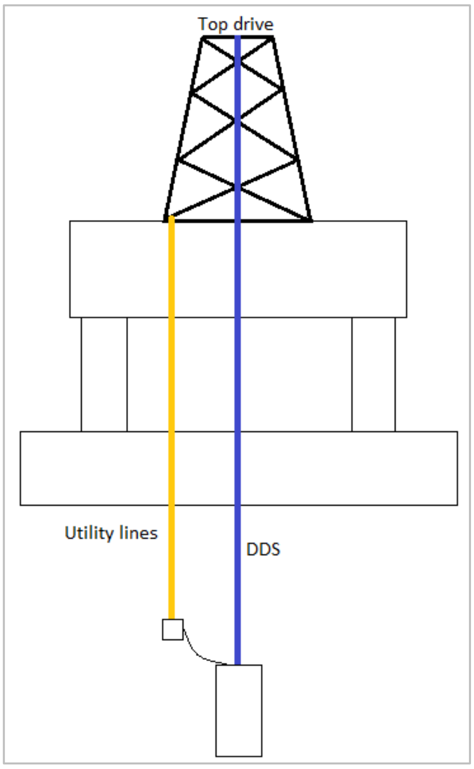

Figure 22 - RDM-Riserless from a floater. [1]

As previously stated, RDM-Riserless technology is based on elimination of the conventional riser. This can lead to a reduction in the analysed elements of the VDL. This chapter will analyse the reduction potential when eliminating the riser i.e. not a combination of the slenderwell system and RDM-Riserless.

The following cases will be presented:

- Dry weight of riser
- Mud in riser
- Total mud in riser and well

6.2.1 DRY WEIGHT OF RISER

In the RDM-Riserless system, a Dual Drill String (DDS) can replace the conventional riser. Table 13 presents the dry weight of the conventional and DDS system. [31][36] The dry weight can be reduced as follows:

$$Reduction_{DDS\ to\ conv.riser} = 1 - \frac{82}{891} \approx 0{,}9$$

The dry weight of the riser can be reduced by 90% when utilizing RDM-Riserless compared to a conventional riser. The data can be found in Appendix A.

Table 13 - Dry weight of riser for conventional system and DDS system. [31][36]

Riser system	Dry weight [kg/m]
Conventional	891
DDS	82,3

6.2.2 MUD IN RISER

The volume of the DDS is noticeably smaller than the volume of a conventional riser. Table 14 presents the volume of mud in the conventional riser and DDS. The volume of mud required will be reduced as follows:

$$Reduction_{Conv.riser\ to\ DDS} = 1 - \frac{17}{236} \approx 0{,}93$$

The mud in the riser can be reduced by 93% when utilizing RDM-Riserless compared to a conventional riser.

Table 14 - Volume of mud in riser for conventional system and DDS system at 1000m water depths. [31][36]

Riser system	Mud volume [m^3]
Conventional	236
DDS	17

6.2.3 TOTAL MUD IN RISER AND WELL

The total mud in riser and well in 1000m water depths with a conventional system and RDM-Riserless is presented in the Table 15.

$$Reduction_{Conv.riser\ to\ DDS} = 1 - \frac{642}{861} \approx 0{,}25$$

Table 15 - Total volume of mud in riser and well for conventional system and DDS system at 1000m water depths. [31][36]

Riser system	Mud in riser [m^3]	Mud in well [m^3]	Mud total [m^3]
Conventional	236	625	861
DDS	17	625	642

The total mud required will be reduced by 25% when utilizing RDM-Riserless compared to conventional systems. Reducing the required mud capacity will have a great impact on the VDL, as mud represents 33% of the total VDL, previously presented in chapter 4. The increased operational capacity due to reduced total mud volume will be presented in chapter 7.

6.3 REDUCTION WITH ALTERNATIVE RISER MATERIAL

Using a lighter material in the risers is an easy way to reduce the weight on the rig without making very big modifications. Both the aluminium and composite will have a substantial impact on the VDL, as shown in Table 16. The data can be found in Appendix A.

Table 16 - Reduction potential for dry weight of riser and riser tension with alternative riser material.

Riser type	Dry weight [kg/m]	Dry weight with buoyancy elements [kg/m]	Weight of riser [mT] in WD 1000m	Riser tension [mT] in WD 1000m	Reduction in weight [%]	Reduction in riser tension [%]
Conventional	486	936	891	535	0	0
Aluminium-alloy	340	655	624	389	30	27
Composite	283	546	520	333	42	38

The results clearly show great advantages regarding the VDL. However, the alternative riser materials are quite expensive, especially the composite risers which can be as much as 50% of the steel riser. The delivery time is longer than with conventional risers. [26]

6.3.1 DRY WEIGHT

As presented in section 5.2, the weight of the aluminium-alloy riser can be reduced by 30% compared to a conventional steel riser. The weight of the aluminium-alloy risers is calculated with the assumption that 90% of the full length of the riser has buoyancy elements.

$$Reduction_{Dry\ weight\ from\ conv.riser\ to\ alum.riser} = 1 - \frac{624}{891} \approx\ 0{,}3$$

The dry weight of the riser can be reduced by 30% when utilizing an aluminium-alloy riser instead of a conventional riser.

As stated in section 5.2, the use of composite risers, can reduce the weight of conventional steel risers by as much as 1/3 to 1/2. It is assumed that the weight of the steel will be reduced by the average value of these, 42%. The weight of the composite risers is calculated with the assumption that 90% of the full length of the riser has buoyancy elements.

$$Reduction_{Dry\ weight\ from\ conv.riser\ to\ comp.riser} = 1 - \frac{520}{891} \approx\ 0{,}42$$

The dry weight of the riser can be reduced by 42% when utilizing a composite riser instead of a conventional riser.

6.3.2 RISER TENSION

The reduced weight of the riser when utilizing alternative riser materials will also have an impact on the riser tension. From the data in Table 16, the reduced required riser tension when utilizing alternative riser materials can be described as follows:

$$Reduction_{Required\ riser\ tension\ from\ conv.riser\ to\ alum.riser} = 1 - \frac{389}{535} \approx 0{,}27$$

$$Reduction_{Required\ riser\ tension\ from\ conv.riser\ to\ comp.riser} = 1 - \frac{333}{535} \approx 0{,}38$$

Noble Drilling are utilizing aluminium-alloy risers on some or their drilling vessels. The semi-submersibles Noble Dave Beard and Noble Therald Martin are equipped with aluminium-alloy risers. [37] In Table 17 the Noble rigs are compared with rigs that utilize conventional risers, and are rated for approximately the same water depths.

Table 17 - Characteristics of drilling rigs utilizing aluminium-alloy risers vs. conventional risers. [2]

Rig Name	Genera-tion	Constr.cost [mill. USD]	Day rate [USD]	Max WD [ft]	Drilling depth [ft]	Operating displacement [mT]	VDL [mT]	Riser tension [MN]
Noble Dave Beard	6	375	220 000	10 000	35 000	40 500	5 443	11,1
Scarabeo 8	6	614	460 000	10 000	35 000	54 000	5 987	16
Noble Therald Martin	2	42	270 000	4 000	25 000	19 057	2 499	2,8
Transocean Leader	4	75	406 000	4 500	25 000	44 459	4 599	5,3

The Noble rigs have lower displacement and VDL than the rigs with approximately the same water depth and drilling depth rating.

When comparing the riser tension capacity of Noble Dave Beard and Scarabeo 8 the reduction is as follows:

$$Reduction_{NDB\ to\ S8} = 1 - \frac{1131}{1631} \approx 0{,}30$$

The tensioning capacity of Noble Dave Beard is 30% less than the capacity of Scarabeo 8. When comparing this to the performed riser tension analysis, there is a small deviation in the reduced riser tension requirement when using aluminium-alloy risers instead of conventional risers. However, as the riser tension analysis is performed in a simple manner, there will be certain deviations.

The comparison of the Noble rigs and the Saipem and Transocean rigs clearly shows that utilizing alternative riser materials is a great advantage. The Noble rigs can operate in the same water depths as the rigs they are compared to, and have a smaller VDL capacity, and reduced rig size.

The increased water depth capacity and the total impact of analysed reduction in VDL due to alternative riser materials will be presented in section 7.3.

6.4 REDUCTION WITH MUDCUBE

The MudCube technology has the potential to reduce the weight of the drill cuttings stored on the rig. The following cases will be presented:

- Reduction in drill cuttings with a conventional casing program.
- Reduction in drill cuttings with a slender casing program.

From the example in chapter 4, the drill cuttings represent 5% of the total VDL. Although it does not represent a major part of the VDL, it is a technology that is correlated to the slenderwell technology.

It is assumed that the entire volume of drill cuttings from the well is stored on board of the rig before offloading.

In addition to reducing the VDL, the reduced weight of drill cuttings will lead to less offloading time and overall costs when transporting the cuttings to shore. Slender wells will also lead to less drill cuttings, as the formation volume is smaller.

6.4.1 DRILL CUTTINGS WITH A CONVENTIONAL CASING PROGRAM

Cubility claims that the MudCube technology can reduce the weight of the drill cuttings from a standard well on the NCS as follows:

$$Reduction_{Drill\ cuttings\ with\ MudCube} = 1 - \frac{440}{620} \approx 0{,}3$$

This means that the drill cuttings can be reduced by 30%.

6.4.2 DRILL CUTTINGS WITH A SLENDER CASING PROGRAM

The reduction in drill cuttings, when comparing the volume of extracted formations in the conventional and slender casing program is as follows:

$$Reduction\ in\ drill\ cuttings_{Conventional\ vs.slender} = 1 - \frac{190}{270} \approx 0{,}3$$

The volume of drill cuttings from extracted formations can be reduced by 30% in a slenderwell system. The data can be found in Appendix A.

When combining the slenderwell technology and MudCube, the weight of the drill cuttings can be reduced as follows:

$$W_{drill\ cuttings\ reduced\ by\ MudCube\ and\ slenderwell} = 440 * 0{,}7 \approx 310mT$$

$$Reduction_{MudCube\ combined\ with\ slender\ casing\ program} = 0{,}7 * 0{,}7 \approx 0{,}5$$

The result states that by utilizing MudCube combined with a slender casing program the weight of the drill cuttings can be reduced by 50%, from 620mT to 310mT. The total impact of this on the VDL will be presented in chapter 7.

7. INCREASED OPERATIONAL CAPACITY

This chapter will initially present four scenarios where the VDL is reduced according to the results from chapter 6, and then present scenarios where the required riser tension is reduced according to the results from chapter 6. The following scenarios will be presented:

- Slenderwell systems
- RMD-Riserless
- Alternative riser materials
- Slenderwell systems combined with RDM-Riserless
- Increased water depth capacity due to reduced requirements for riser tension

Note that the reduction from MudCube is assumed in all scenarios for the VDL as it is an independent technology, and the results are found in section 6.4.

The example of Maersk Deliverer from chapter 4 will be the case in this chapter as well. As previously stated, Maersk Deliverer has a VDL of 13500mT. The weight of the analysed VDL is 8194mT. This gives the following ratio:

$$Ratio_{analysed\ vs.\ total} = \frac{8194}{13500} \approx 0{,}6$$

This means that the analysed VDL represent 60% of the total VDL.

The data can be found in Appendix A and B.

7.1 SLENDERWELL SYSTEMS

The scenario of reduced VDL utilizing a slenderwell system combined with MudCube is presented in Table 18. The reduction potential is found from section 6.1 and 6.4.2. The capacity is found from the example in chapter 4.

Table 18 - Reduction potential for VDL with a slenderwell system.

Item	Capacity [mT]	Reduction potential [%]	New required capacity [mT]
Mud	4500	45	2475
Dry weight of riser	2674	40	1604
Drill cuttings	620	50	310
BOP stack	400	60	160
Total	**8194**	**44**	**4549**

The reduction in required VDL capacity can be expressed as follows:

$$Reduction\ in\ required\ capacity = 8194 - 4549 = 3645mT$$

The reduction in required capacity for the analysed VDL can be found as follows:

$$Reduction_{VDL-slenderwell} = \frac{3645}{13500} \approx 0{,}27$$

When analysing the selected part of the VDL, it is found that the capacity can be reduced by 27%. Figure 23 provides a schematic comparison of the real VDL and the new required VDL as a function of the operating displacement for drilling rigs today. As illustrated in Figure 23, a drilling rig with an operating displacement of 45000mT will reduce the required VDL from 5920mT to 4320mT when utilizing a slenderwell system. The same applies for a rig with an operating displacement of 65000mT, which will decrease the required VDL from 10780mT to 7870mT. The requirement for operating displacement will also be reduced. As illustrated in Figure 23, when the slenderwell system is applied; the requirement for operating displacement will be reduced to 34500mT and 54500mT respectively.

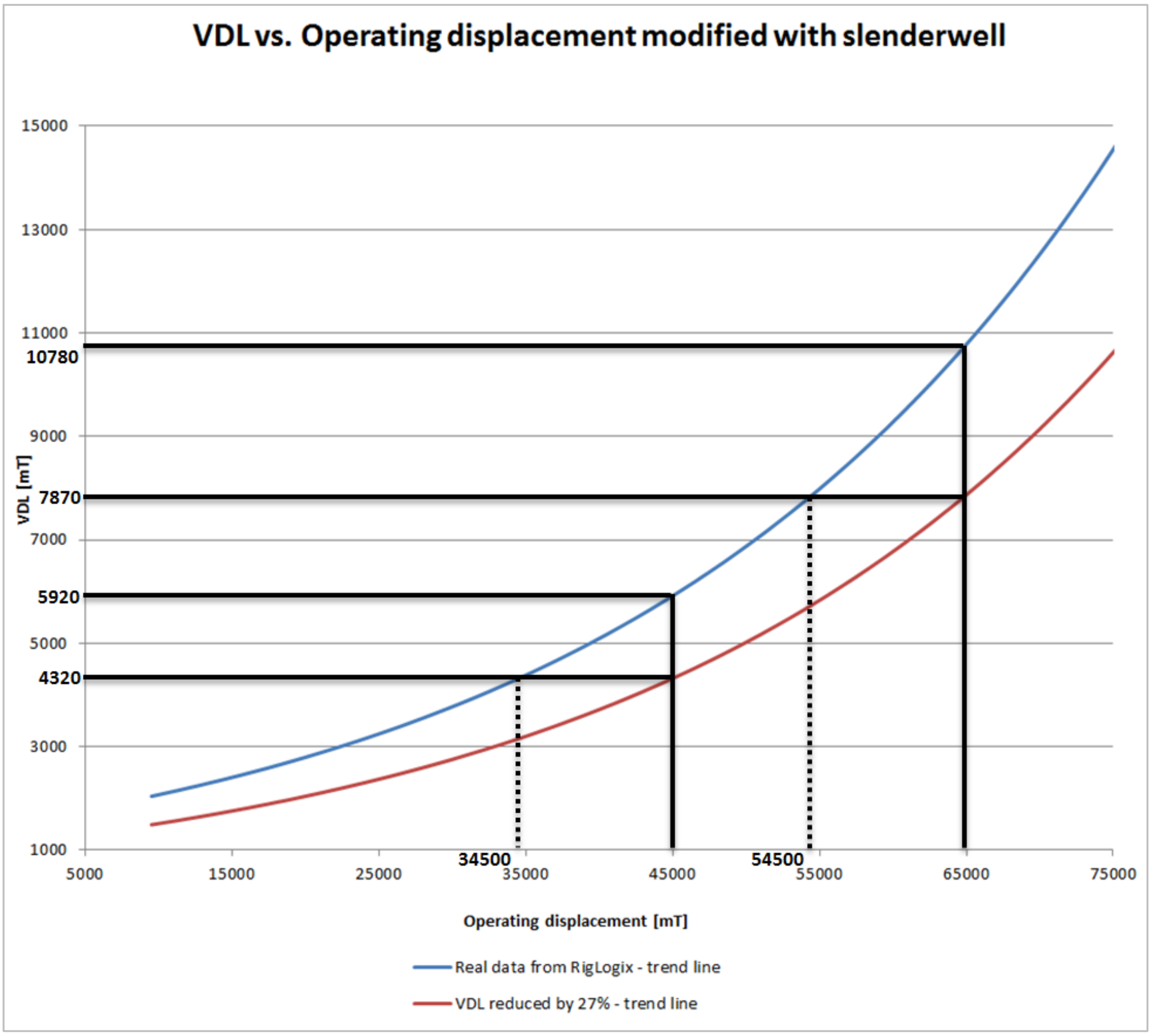

Figure 23- VDL vs. operating displacement modified with the slenderwell system.

7.2 RDM-RISERLESS

The scenario of reduced VDL utilizing RDM-Riserless combined with MudCube is presented in Table 19. The reduction potential is found from section 6.2 and 6.4.1. The capacity is found from the example in chapter 4.

Table 19 - Reduction potential for VDL with RDM-Riserless.

Item	Capacity [mT]	Reduction potential [%]	New capacity [mT]
Mud	4500	25	3375
Dry weight of riser	2674	93	187
Drill cuttings	620	30	440
BOP stack	400	0	400
Total	**8194**	**46**	**4402**

The reduction in required VDL capacity can be expressed as follows:

$$Reduction\ in\ required\ capacity = 8194 - 4402 = 3792mT$$

The reduction in required capacity for the analysed VDL can be found as follows:

$$Reduction_{VDL-RDM-Riserless} = \frac{3792}{13500} \approx 0{,}28$$

When analysing the selected part of the VDL, it is found that the capacity can be reduced by 28%. Figure 24 provides a schematic comparison of the real VDL and the new required VDL as a function of the operating displacement for drilling rigs today. As illustrated in Figure 24, a drilling rig with an operating displacement of 45000mT will reduce the required VDL from 5920mT to 4260mT when utilizing RDM-Riserless. The same applies for a rig with an operating displacement of 65000mT, which will decrease the required VDL from 10780mT to 7760mT. The requirement for operating displacement will also be reduced. As illustrated in Figure 24, when RDM-Riserless is applied; the requirement for operating displacement will be reduced to 34000mT and 54000mT respectively.

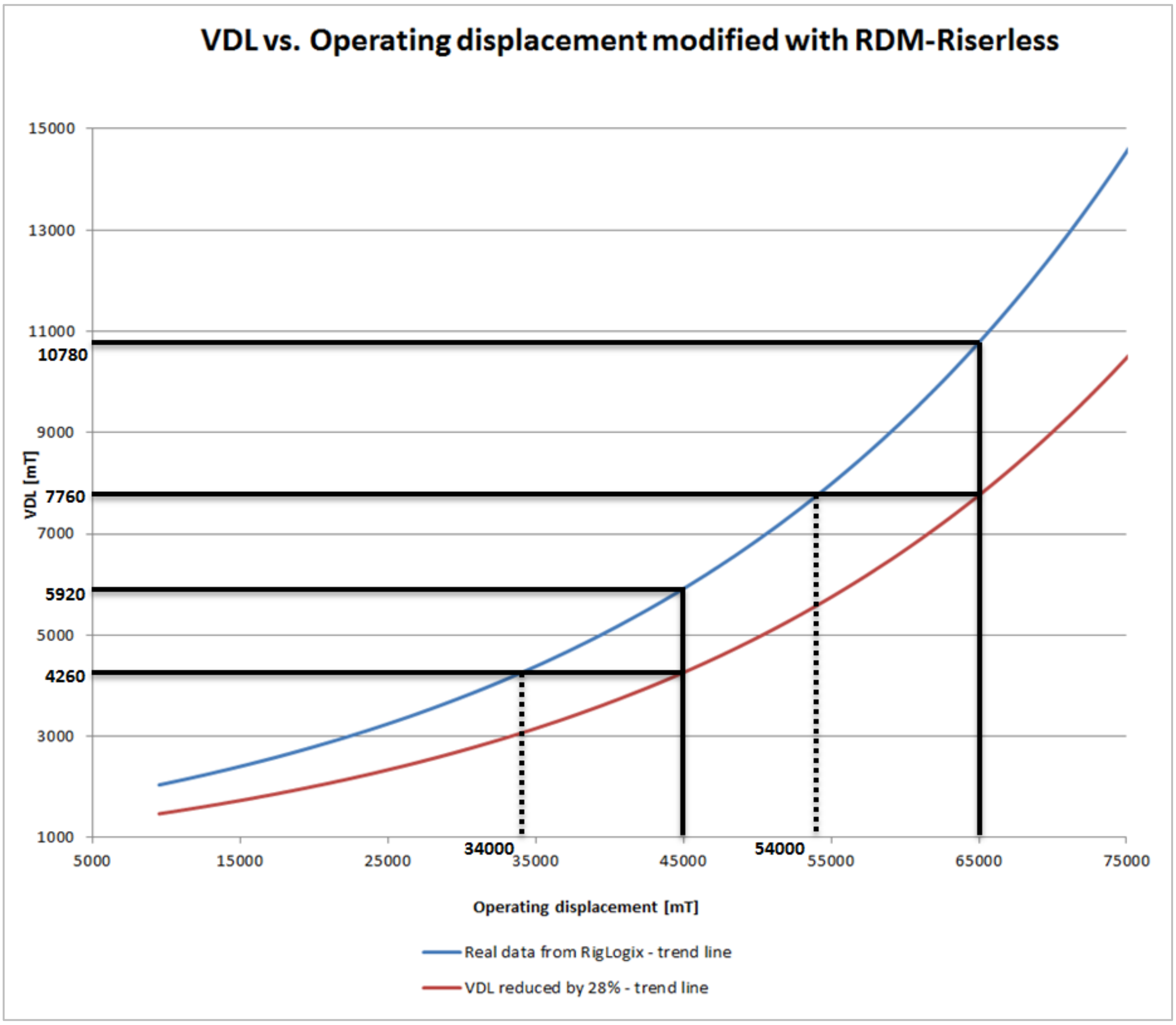

Figure 24 - VDL vs. operating displacement modified with RDM-Riserless.

7.3 ALTERNATIVE RISER MATERIALS

The scenario of reduced VDL utilizing alternative riser materials combined with MudCube is presented in Table 20 and 21. The reduction potential data is found from section 6.3 and 6.4.1. The capacity is found from the example in chapter 4.

Table 20 - Reduction potential for VDL with aluminium-alloy risers.

Aluminium-alloy riser			
Item	Capacity [mT]	Reduction potential [%]	New capacity [mT]
Mud	4500	0	4500
Dry weight of riser	2674	30	1872
Drill cuttings	620	30	440
BOP stack	400	0	400
Total	**8194**	**12**	**7212**

The reduction in required VDL capacity can be expressed as follows:

$$Reduction\ in\ required\ capacity = 8194 - 7212 = 982mT$$

The reduction in required capacity for the analysed VDL can be found as follows:

$$Reduction_{VDL-aluminium-alloy\ riser} = \frac{982}{13500} \approx 0{,}07$$

Table 21 - Reduction potential for VDL with composite risers.

Composite riser			
Item	**Capacity [mT]**	**Reduction potential [%]**	**New capacity [mT]**
Mud	4500	0	4500
Dry weight of riser	2674	42	1551
Drill cuttings	620	30	440
BOP stack	400	0	400
Total	**8194**	**16**	**6891**

The reduction in required VDL capacity can be expressed as follows:

$$Reduction\ in\ required\ capacity = 8194 - 6891 = 1303mT$$

The reduction in required capacity for the analysed VDL can be found as follows:

$$Reduction_{VDL-composite\ riser} = \frac{1303}{13500} \approx 0{,}1$$

When analysing the selected part of the VDL, it is found that the capacity can be reduced by 7% with an aluminium-alloy riser or 10% with a composite riser. Figure 25 provides a schematic comparison of the real VDL and the new required VDL as a function of the operating displacement for drilling rigs today. As illustrated in Figure 25, a drilling rig with an operating displacement of 45000mT will reduce the required VDL from 5920mT to 5500mT or 5320mT when utilizing alternative riser materials. The same applies for a rig with an operating displacement of 65000mT, which will decrease the required VDL from 10780mT to 10020mT or 9700mT. The requirement for operating displacement will also be reduced. As illustrated in Figure 25, when alternative riser materials are applied; the requirement for operating displacement will be reduced to 42500mT or 41500mT and 62500mT or 61500mT respectively.

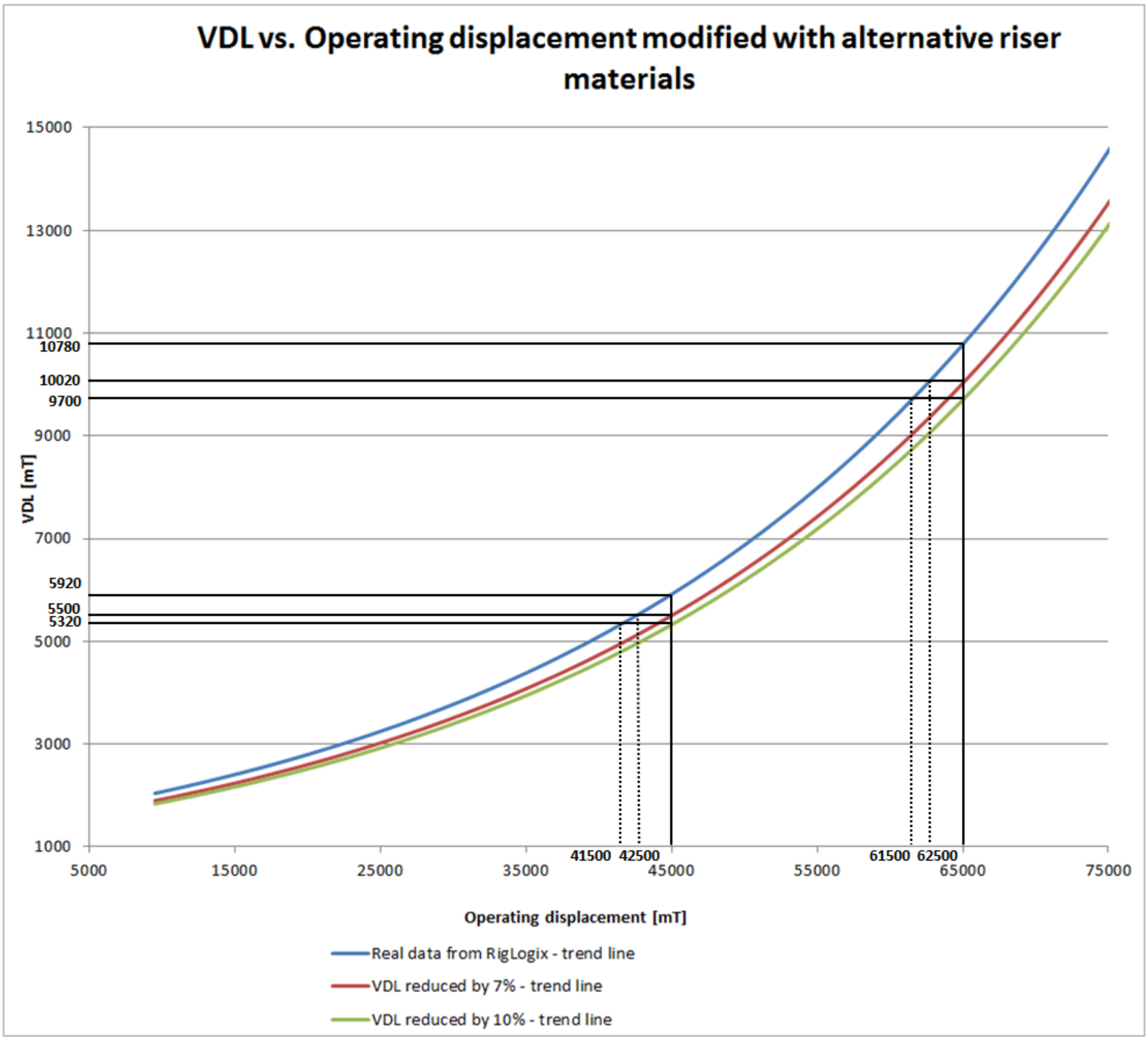

Figure 25 - VDL vs. operating displacement modified with alternative riser materials.

7.4 SLENDERWELL SYSTEMS COMBINED WITH RDM-RISERLESS

The scenario of reduced VDL utilizing a slenderwell system combined with RDM-Riserless and MudCube is presented in Table 23. The reduction potential is found from section 6.1, 6.2 and 6.4.2. The capacity data is found from the example in chapter 4.

The total volume of mud in riser and well when combining the slender casing program and RDM-Riserless compared to conventional system is presented in Table 22.

Table 22 - Total volume of mud in riser and well for conventional system and RDM-Riserless combined with a slender casing program.

System	Mud in riser [m^3]	Mud in well [m^3]	Mud total [m^3]
Conventional	236	625	861
DDS and slender casing program	17	345	362

The reduction in total mud can then be found as follows:

$$Reduction_{Total\ mud-combined\ slenderwell\ and\ RDM-Riserless} = 1 - \frac{362}{861} \approx 0{,}58$$

The total volume of mud in riser and well when combining RDM-Riserless and the slender casing program will be reduced by 58%.

The BOP stack is also assumed to be slender.

Table 23 - Reduction potential for VDL with RDM-Riserless combined with the slender casing program.

Item	Capacity [mT]	Reduction potential [%]	New capacity [mT]
Mud	4500	58	1890
Dry weight of riser	2674	93	187
Drill cuttings	620	50	310
BOP stack	400	60	160
Total	**8194**	**69**	**2547**

The reduction in required VDL capacity can be expressed as follows:

$$Reduction\ in\ required\ capacity = 8194 - 2547 = 5647mT$$

The reduction in required capacity for the analysed VDL can be found as follows:

$$Reduction_{VDL-combined\ slenderwell\ and\ RDM-Riserless} = \frac{5647}{13500} \approx 0{,}42$$

When analysing the selected part of the VDL, it is found that the capacity can be reduced by 42%. Figure 26 provides a schematic comparison of the real VDL and the new required VDL as a function of the operating displacement for drilling rigs today. As illustrated in Figure 26, a drilling rig with an operating displacement of 45000mT will reduce the required VDL from 5920mT to 3430mT when utilizing a combination of the slenderwell system and RDM-Riserless. The same applies for a rig with an operating displacement of 65000mT, which will decrease the required VDL from 10780mT to 6250mT. The requirement for operating displacement will also be reduced. As illustrated in Figure 26, when the combined technologies are applied; the requirement for operating displacement will be reduced to 27000mT and 47000mT respectively.

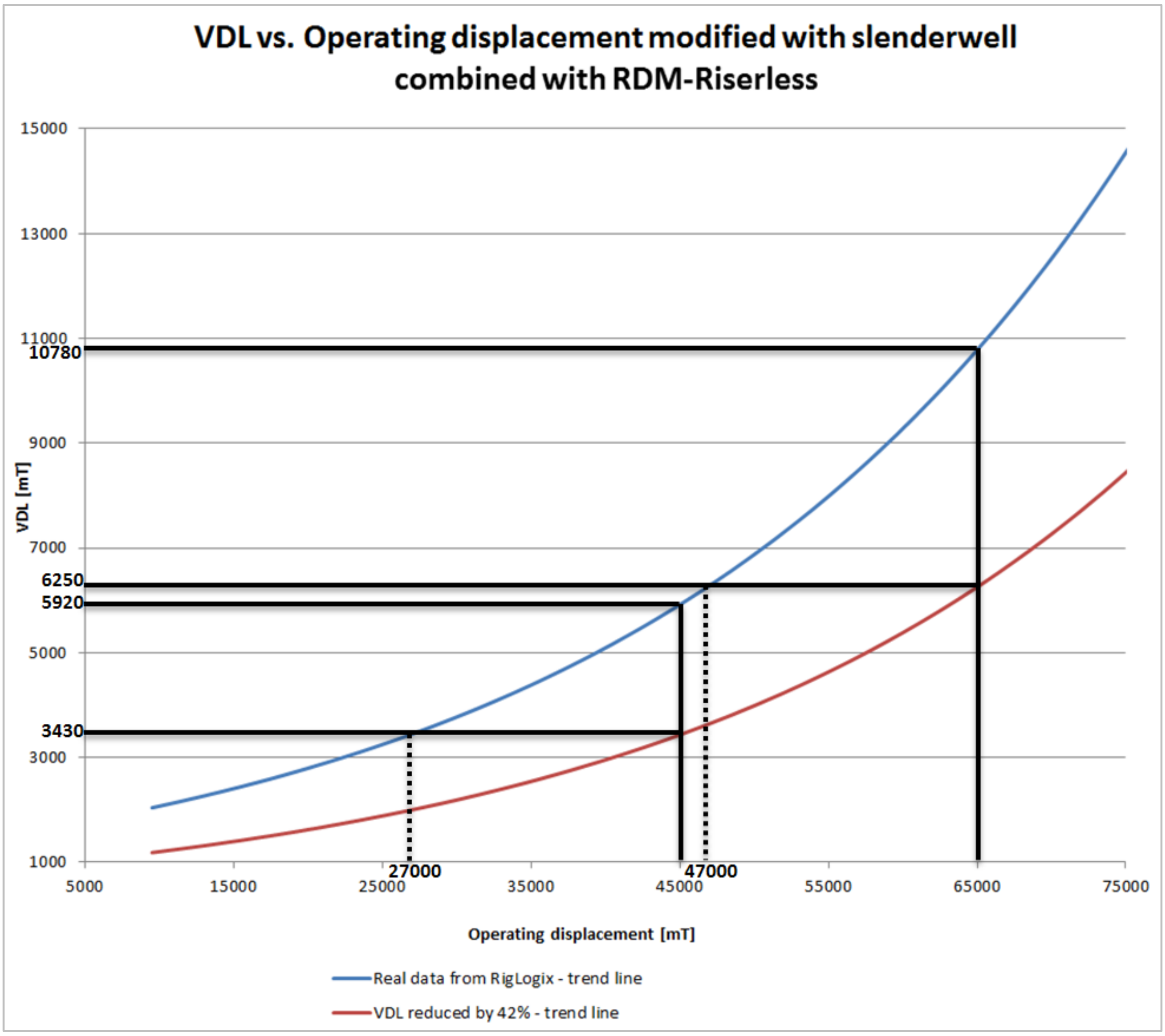

Figure 26 - VDL vs. operating displacement modified with RDM-Riserless combined with the slender casing program.

7.5 INCREASED WATER DEPTH CAPACITY

Utilizing a slender riser or alternative riser materials will increase the water depth capacity for a drilling rig due to the reduced riser tension requirements. Figure 27 illustrates a comparison of the alternative riser technologies, with the riser tension as a function of the water depth.

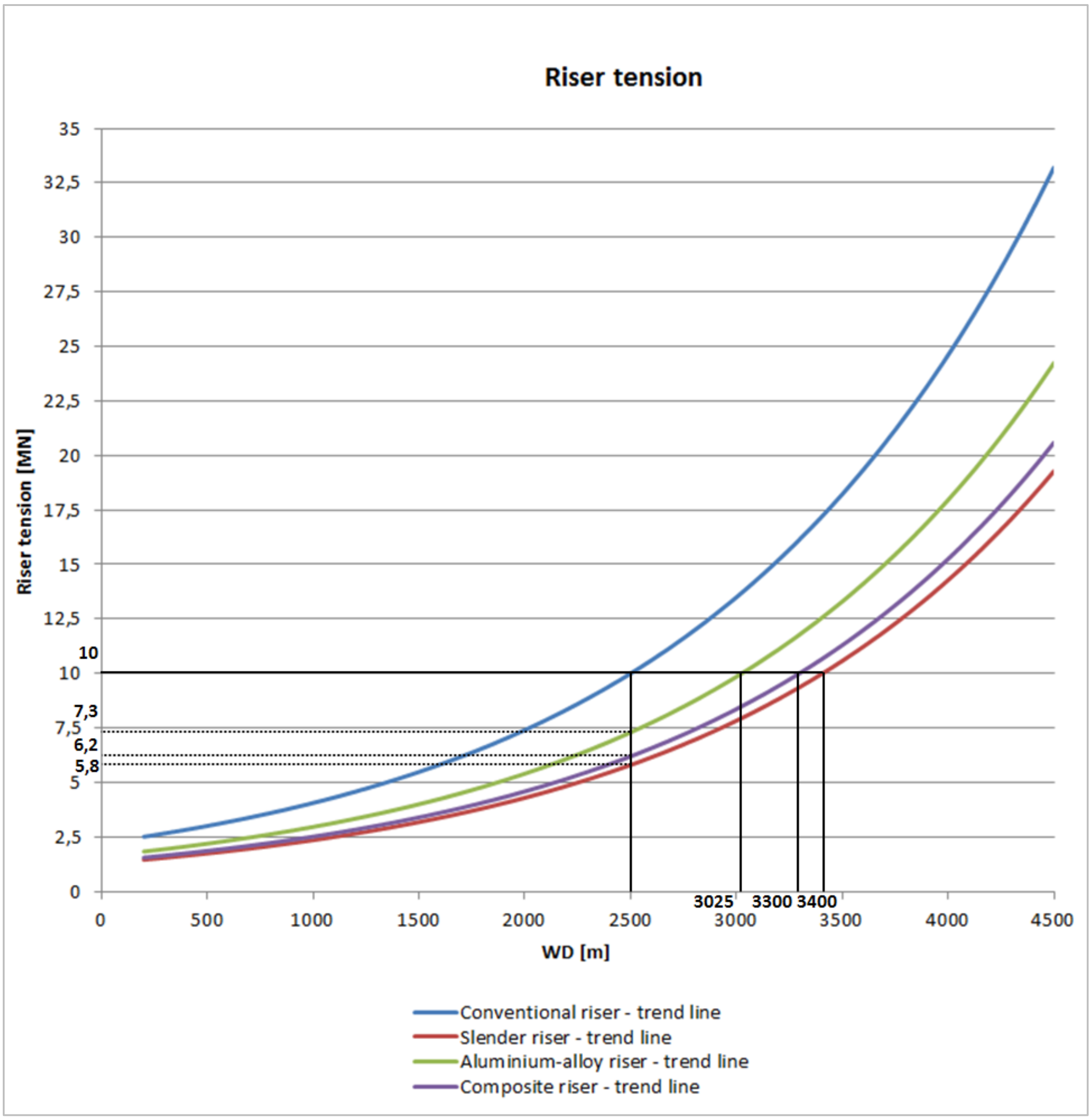

Figure 27 - Increased water depth capacity due to reduction in required riser tension.

From the example in Figure 27, it is shown that a rig can increase its water depth capacity with as much as 900m when applying a different riser technology. The calculations and data points are found in Appendix A and B.

The reduced riser tension requirements due to alternative riser technologies will as shown in Figure 27 result in increased water depth capacity. In Table 24, the average riser tension capacity in every generation is presented, with the corresponding increased water depth capacity as illustrated in Figure 27.

Table 24 - Reduced requirement for riser tension due to the slender riser.

Generation	Riser tension conventional system [MN]	Riser tension requirement slenderwell system [MN]	WD conventional [m]	WD slenderwell [m]
2	3,3	1,9	~650	~1 550
3	3,6	2,1	~800	~1 700
4	6,1	3,6	~1 700	~2 600
5	12,7	7,4	~2 900	~3 800
6	12,9	7,5	~2 925	~3 825

From Figure 27 and Table 24, it is found that the slender riser gives the greatest increase in water depth capacity. Figure 28 and Figure 29 illustrate the increased water depth capacity for two generations of drilling rigs when utilizing a slender riser instead of a conventional riser.

From Figure 28 the average riser tension capacity of a 3rd generation drilling rig is illustrated. An average rig form the 3rd generation has a riser tension capacity of 3,6 MN and water depth capacity of 800m. By utilizing a slender riser instead of a conventional riser, the water depth capacity can be extended to 1700m.

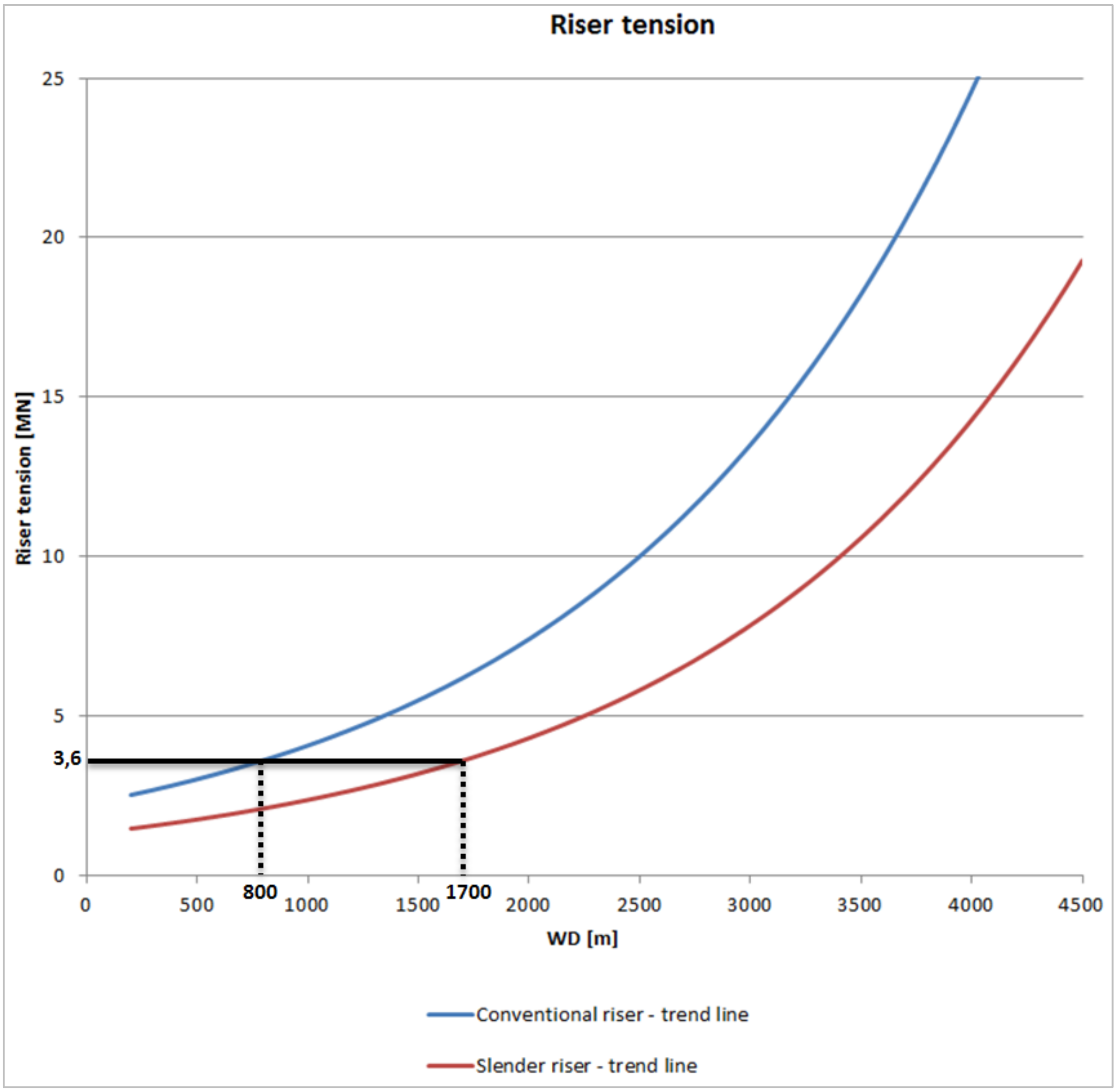

Figure 28 - Increased water depth capacity for 3rd generations utilizing a slender riser.

The average riser tension capacity of a 4th generation drilling rig is 6,1 MN, and the water depth capacity is 1700m. By utilizing a slender riser, an average rig can extend its range of water depth capacity to 2500 as illustrated in Figure 29.

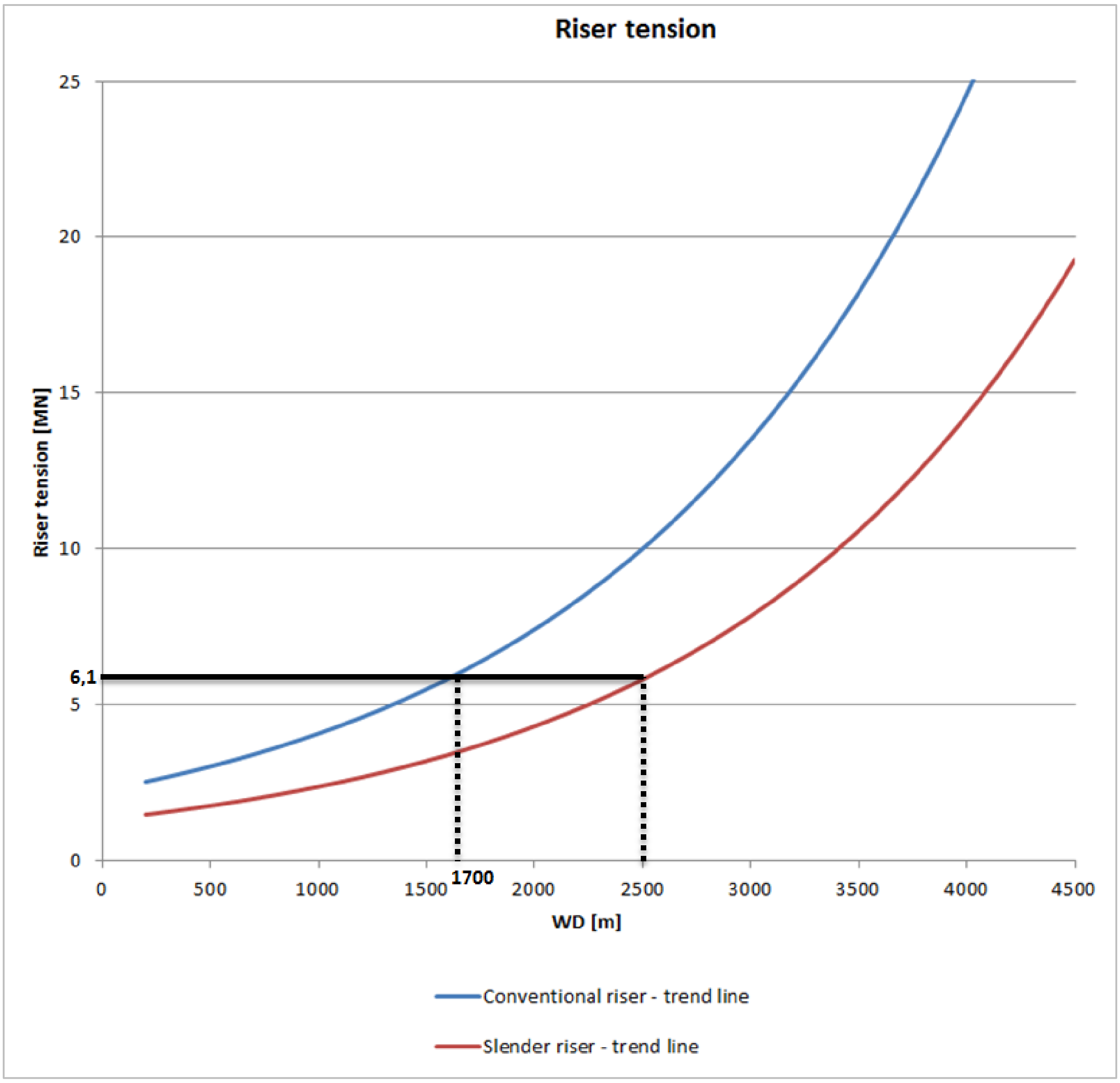

Figure 29 - Increased water depth capacity for 4th generations utilizing a slender riser.

By looking at the graph from a different angle, one can see that for a rig with a conventional system, a riser tension of 10 MN is required to perform operations in water depths of 2500m. Table 24 shows that rigs from the 5th and 6th generation meet these requirements. A slender riser can reduce the required riser tension to 6,1 MN, as shown in Figure 30. This means that a 4th generation can meet the requirements and operate in this water depth due to the reduced required riser tension.

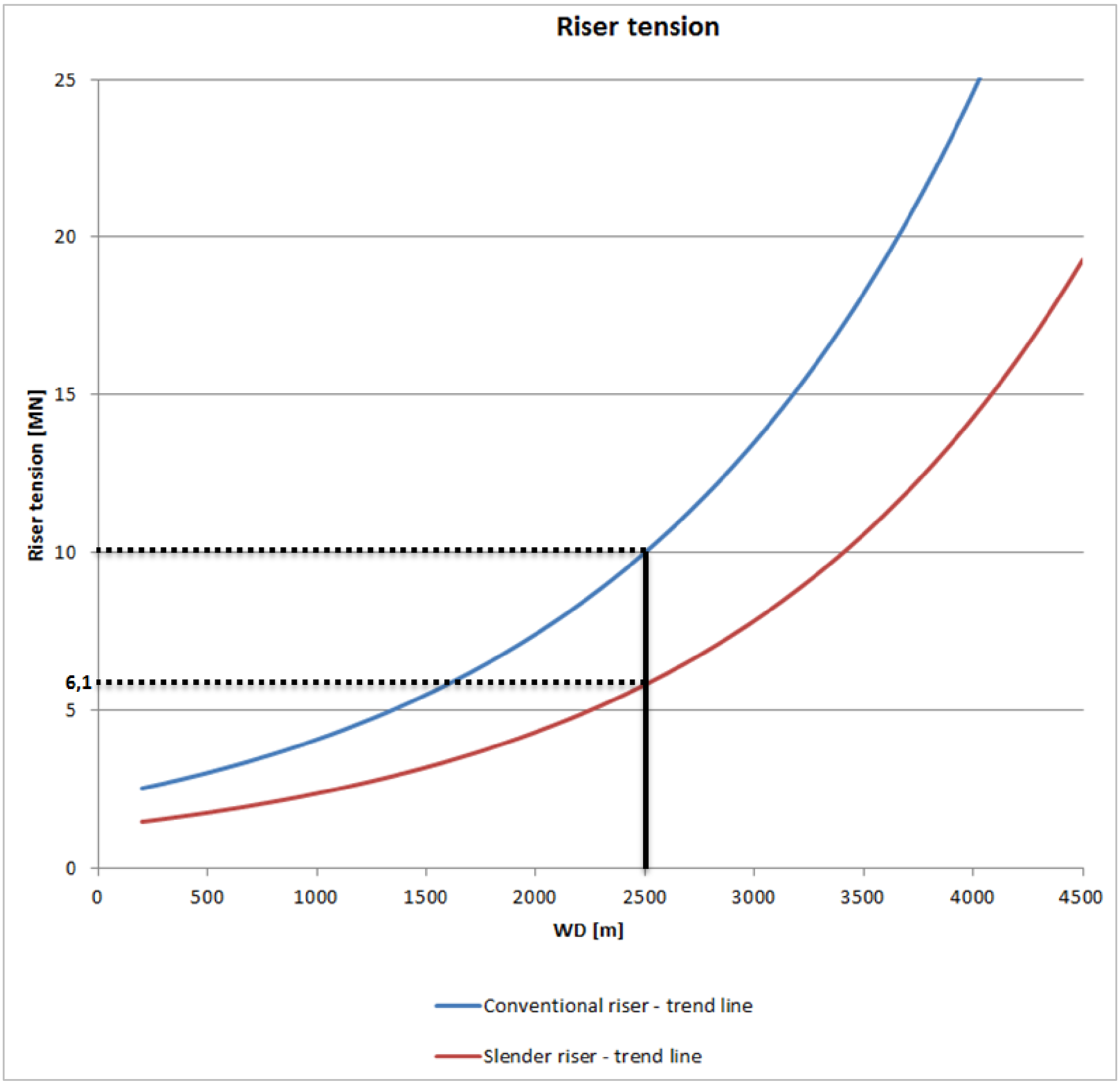

Figure 30 - Riser tension vs. water depth at 2500m.

8. CONCLUSION

The main objectives have been to identify technologies that can reduce the required VDL, and attempt to quantify reduction potentials for key contributors of the required VDL.

The analysis of the reduction potentials was not performed in a detailed manner. As the goal was to illustrate the potential, many assumptions were made.

Mud, dry weight of riser, riser tension, drill cuttings and the BOP stack was selected and analysed to establish a reduction potential and a potential for increased water depth capacity. The key contributors were concluded to be mud and dry weight of riser.

A study of the following technologies was performed to establish the reduction potential:

- Slenderwell systems
- Dual Gradient Drilling
- Riserless Mud Recovery
- Managed Pressure Drilling
- Reelwell Drilling Method – Riserless
- Alternative riser materials in form of aluminium-alloy and composite
- MudCube

The scenarios in Table 25 were selected based on the reduction potential that was established from the results.

Table 25 - Reduction potential for VDL with the identified scenarios.

Scenario	Slenderwell combined with RDM-Riserless	RDM-Riserless	Slenderwell	Composite riser	Aluminium-alloy riser
Reduction potential [%]	**42**	**28**	**27**	**10**	**7**

The scenario where the slenderwell system was combined with RDM-Riserless resulted in a reduction of the required VDL by 42%, and the required operating displacement could be reduced from 65000mT to 47000mT i.e. a reduction of 18000mT.

The scenario where the RDM-Riserless technology was utilized resulted in a reduction of the required VDL of 28%, and the required operating displacement could be reduced from 65000mT to 54000mT i.e. a reduction of 11000mT.

The scenario where the slenderwell system was utilized resulted in a reduction of the required VDL of 27%, and the required operating displacement could be reduced from 65000mT to 54500mT i.e. a reduction of 10500mT.

The scenario where composite risers were utilized resulted in a reduction of the required VDL of 10%, and the required operating displacement could be reduced from 65000mT to 61500mT i.e. a reduction of 3500mT.

The scenario where aluminium-alloy risers were utilized resulted in a reduction of the required VDL of 7%, and the required operating displacement could be reduced from 65000mT to 62500mT i.e. a reduction of 2500mT.

The first part of the secondary objectives has been to establish the potential of increased water depth capacity by attempting to quantify the reduced requirement for riser tension when applying the identified technologies.

Utilizing a slender riser or a composite riser resulted in a reduction of 40% and 38% respectively, of the required riser tension. Operating with a slender riser concluded in that a 3rd generation drilling rig could increase its operating water depth range from 800m to 1700m. It was also concluded that a 4th generation drilling rig could increase its operating water depth capacity range from 1700m to 2500m. Requirements previously met by 5th and 6th generation drilling rigs, could now be met by a 4th generation drilling rig.

By utilizing new or different technologies on existing drilling rigs, the required capacity will be reduced. Many 3rd generation drilling rigs can then perform the same operations as rigs from the 4th generation. The same will apply for many 4th generation drilling rigs. They can increase their operational range and be able to perform operations with requirements previously only met by the 5th or 6th generations of drilling rigs. By increasing the deck reserve capacity, a rig will have increased capacity for other equipment. An increase in setback and casing capacity will enable drilling of longer wells. The increased capacity will also lead to more free storage space, which will be an advantage when drilling in remote locations.

The other part of the secondary objectives has been to look at the future of the development of new semi-submersible drilling rigs. The semi-submersibles from the 5th and 6th generation have a large VDL capacity and large displacement. By implementing the identified technologies, the size can definitely be reduced without decreasing the operational capacity.

Most of the identified technologies are not frequently used in the industry, and some of them may require a modification of the rig to be able to utilize them. The use of alternative riser materials and the MudCube technology are the technologies that will require the least modification work. However, there is more to gain by utilizing the slenderwell system and RDM-Riserless. Especially when combining them, as the study of the existing drilling rigs clearly concluded. The development of future generations of drilling rigs should aim at customising the rigs based on reduced required capacity.

9. RECOMMENDATION FOR FUTURE WORK

The main focus of this thesis has been to study the largest contributors of the VDL. A selection of technologies with a reduction potential were identified. For future work, it would be interesting to critically analyse all contributors of the VDL, and identify more technologies to reduce them.

The riser analysis has been performed in a very simple manner. For the future a detailed riser analysis would be interesting to perform, to achieve precise results. Many assumptions were made in this thesis. Another target for future work would be to have results based on accurate calculations.

This thesis does not take into account the construction and design aspect of future generations of rigs. An interesting approach for future work would be to design a rig based on reduction in required capacity.

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APPENDIX A

Area of cylinder

$$A = \left(\frac{\pi}{4}\right) * D_i^2 = m^2$$

Volume of cylinder

$$V = \left(\frac{\pi}{4}\right) * D_i^2 * L = m^3$$

Volume of steel in riser and lines

$$V_s = \left(\frac{\pi}{4}\right) * (OD^2 - ID^2) * L = m^3$$

21” riser [31]

$$A_{OD} = 0{,}2234\, m^2$$

$$A_{floatation} = 0{,}5518\, m^2$$

$$A_{riser+floatation} = 1{,}477\, m^2$$

$$A_{ID} = 0{,}1926\, m^2$$

$$A_{lines\ ID} = 0{,}00542\, m^2$$

$$A_{steel\ in\ riser} = 0{,}0308\, m^2$$

16” riser [31]

$$A_{riser} = 0{,}1297\, m^2$$

$$A_{floatation} = 0{,}3167\, m^2$$

$$A_{riser+floatation} = 1{,}477\, m^2$$

$$A_{steel\ in\ riser} = 0{,}0232\, m^2$$

$$A_{lines\ ID} = 0{,}00162 m^2$$

$$A_{steel\ in\ riser} = 0{,}1065\, m^2$$

Total area of steel in lines [31]

$$A_{steel\ in\ lines,21"} = 0{,}031146 m^2$$

$$A_{steel\ in\ lines,16"} = 0{,}01453 m^2$$

Total area of steel in riser and lines [31]

$$A_{steel\ in\ riser\ and\ lines\ 21"} = 0{,}061884\, m^2$$

$$A_{steel\ in\ riser\ and\ lines\ 16"} = 0{,}03768\, m^2$$

Weight of riser and lines

$$W_{riser\ and\ lines} = \frac{(V_s * \rho_{steel})}{1000} = mT$$

Density of steel

$$\rho_{steel} = 7850\ \frac{kg}{m^3}$$

DDS [36]

$$Drillstring_{outer}(OD) = 0{,}168275m$$

$$Drillstring_{outer}(ID) = 0{,}149225m$$

$$Drillstring_{inner}(OD) = 0{,}0889m$$

$$Drillstring_{inner}(ID) = 0{,}0762m$$

$$A_{DDS\ (steel)} = 0{,}006387\ m^2$$

Total area of lines [31]

$$A_{OD\ of\ lines,21"} = 0{,}0739m^2$$

$$A_{OD\ of\ lines,16"} = 0{,}0343m^2$$

Total area of riser and lines [31]

$$A_{OD\ riser\ and\ lines,21"} = 0{,}2973m^2$$

$$A_{\ OD\ riser\ and\ lines,16"} = 0{,}164m^2$$

Total volume of riser and lines (OD)

$$V_{tot(OD)} = A_{\ riser\ and\ lines} * L = m^3$$

Buoyancy in riser and lines

$$B = V_{tot\ (OD)} * \frac{\rho_{seawater}}{1000} = \ mT$$

Density of sea water

$$\rho_{seawater} = 1025\ \frac{kg}{m^3}$$

Volume of mud in riser and lines [31]

$$V_{mud\ riser\ and\ lines\ 21"} = 0{,}2358m^2 * L = m^3$$

$$V_{mud\ riser\ and\ lines\ 16"} = 0{,}1134m^2 * L = m^3$$

Mud weight in riser

$$MW_{riser\ and\ lines} = \rho_{mud}\ \left[\frac{kg}{l}\right] * \ V_{mud\ riser\ and\ lines}\ [m^3] = mT$$

Density of mud

$$\rho_{mud} = 1500\ \frac{kg}{m^3} = 1{,}5\frac{kg}{l}$$

Riser tension, neglecting buoyancy modules

$$T_{mT} = W_{riser\ and\ lines} + MW_{riser\ and\ lines} - B = mT$$

Riser tension in Newton

$$T_{Newton} = \frac{(T_{mT} * 9{,}81\frac{m}{s^2})}{1000} = MN$$

DDS [36]

$$Drillstring_{outer}(OD) = 0{,}168275m$$

$$Drillstring_{outer}(ID) = 0{,}149225m$$

$$Drillstring_{inner}(OD) = 0{,}0889m$$

$$Drillstring_{inner}(ID) = 0{,}0762m$$

$$A_{DDS\ (steel)} = 0{,}006387\ m^2$$

Proof of zero differential hoop stress

Hoop stress equation

$$\sigma_h = \frac{p_i D_i - p_o D_o}{2t}$$

Reduction of Cross Section

$$\left(\frac{OD_{16"}}{ID_{21"}}\right)^2 = \left(\frac{16}{21}\right) = 0{,}58$$

Area of riser

$$\left(\frac{\pi}{4}\right)(OD^2 - ID^2) = \ m^2$$

Inner and outer pressure

$$p_i = 1000m * 9{,}81\frac{m}{s^2} * 1500\frac{kg}{m^3} = 24{,}7\ MPa$$

$$p_o = 1000m * 9{,}81\frac{m}{s^2} * 1025\frac{kg}{m^3} = 15{,}1\ MPa$$

$$t_w = wall\ thickness$$

Area of 21” riser	**Area of 16” riser**
OD = 0,5334m ID = 0,4953m Wall thickness, t_w = 0,01905m $A_{21"} = \left(\frac{\pi}{4}\right)(0{,}5334^2 - 0{,}4953^2) = 0{,}0308m^2$ *Known wall thickness.*	OD = 0,4064m Reduction in Cross Section = 0,58 $A_{16"} = \left(\frac{\pi}{4}\right)(0{,}4064^2) * 0{,}58 = 0{,}0179m^2$ *Unknown wall thickness and ID found as follows:* $A(OD) = \left(\frac{\pi}{4}\right)(0{,}4064^2) = 0{,}1297m^2$ $A(ID) = A(OD) - A_{16} = 0{,}1118m^2$ $ID = \sqrt{\left(\frac{4}{\pi}\right)A(ID)} = 0{,}3773m$ $t_w = \frac{OD - ID}{2} = \frac{0{,}4064 - 0{,}3772}{2}$ $t_w = 0{,}0146m$
$\sigma_{h21"} = \frac{27{,}7MPa*0{,}4953m-15{,}1MPa*0{,}5334m}{2*0{,}01905m} = 148{,}7MPa$	$\sigma_{h16"} = \frac{27{,}7MPa*0{,}3773m-15{,}1MPa*0{,}4064m}{2*0{,}0145m} = 148{,}7MPa$

This gives that hoop stress for 21” riser is approximately equal to 16” riser, proofing the proportional reduction of cross section and hoop stress.

Table 26 - Calculations for 21" riser.

21" riser							
Area of steel [m^2]		0,061884		Area of riser (OD) [m^2]		0,2973	
Water depth [m]	Volume of steel [m^3]	Weight of steel [mT]	Volume of riser (OD) [m^3]	Buoyancy of riser [mT]	Mud weight in riser (ρ=1,5kg/l) [mT]	Riser tension [mT]	Riser tension [MN]
1 000	61,9	485,8	297,3	304,7	353,9	534,9	5,2
2 000	123,8	971,6	594,6	609,5	707,7	1 069,8	10,5
3 000	185,7	1 457,4	891,9	914,2	1 061,6	1 604,8	15,7

Table 27 - Calculations for 16" riser.

16" riser							
Area of steel [m^2]		0,03768		Area of riser (OD) [m^2]		0,164	
Water depth [m]	Volume of steel [m]	Weight of steel [mT]	Volume of riser (OD) [m^3]	Buoyancy of riser [mT]	Mud weight in riser (ρ=1,5 kg/l) [mT]	Riser tension [mT]	Riser tension [MN]
1000	37,7	295,8	164	168,1	186,2	313,9	3,1
2000	75,4	591,6	328	336,2	372,4	627,8	6,2
3000	113,0	887,4	492	504,3	558,6	941,7	9,2

Table 28 - Calculations for DDS.

DDS						
Water depth [m]	Area of steel [m^2]		0,010491	Area of riser (OD) [m^2]		0,02224
	Volume of steel [m^3]	Weight of steel [mT]	Volume of riser (OD) [m^3]	Buoyancy of pipe [mT]	Mud weight in riser (ρ=1,5 kg/l) [mT]	Hook load (excl. drillpipe) [mT]
1 000	10,5	82,3	22,4	23	26,3	85,6
2 000	21,0	164,7	44,8	45,9	52,5	171,3
3 000	31,5	247,0	67,2	68,9	78,8	256,9

Table 29 - Calculations for aluminium-alloy riser.

Aluminium-alloy riser							
Area of alum.-alloy [m^2]		0,061884		Area of riser (OD) [m^2]		0,2973	
Water depth [m]	Volume of aluminium-alloy [m^3]	Weight of aluminium-alloy [mT]	Volume of riser (OD) [m^3]	Buoyancy of riser [mT]	Mud weight in riser (ρ=1,5kg/l) [mT]	Riser tension [mT]	Riser tension [MN]
1 000	61,9	340,1	297,3	304,7	353,9	389,2	3,8
2 000	123,8	680,1	594,6	609,5	707,7	778,4	7,6
3 000	185,7	1 020,2	891,9	914,2	1 061,6	1 167,6	11,5

Table 30 - Calculations for composite riser.

Composite riser							
Area of composite [m^2]		0,061884		Area of riser (OD) [m^2]		0,2973	
Water depth [m]	Volume of composite [m^3]	Weight of composite [mT]	Volume of riser (OD) [m^3]	Buoyancy of riser [mT]	Mud weight in riser (ρ=1,5kg/l) [mT]	Riser tension [mT]	Riser tension [MN]
1 000	61,9	283,4	297,3	304,7	353,9	332,5	3,3
2 000	123,8	566,7	594,6	609,5	707,7	665,0	6,5
3 000	185,7	850,1	891,9	914,2	1 061,6	997,5	9,8

Table 31 - Calculations of area and volume for riser.

Riser type	Riser ID [m]	Riser area [m^3]	Auxiliary lines area [m^2]	Riser volume in 1000m WD [m^3]	Mud volume in 2000m WD [m^3]	Mud volume in 3000m WD [m^3]
21" riser	0,4953	0,2359	0,0432	236	472	708
16" riser	0,3683	0,1262	0,0196	126	252	379
DDS (ID=5,875")	0,149225	0,0175	-	17	35	52

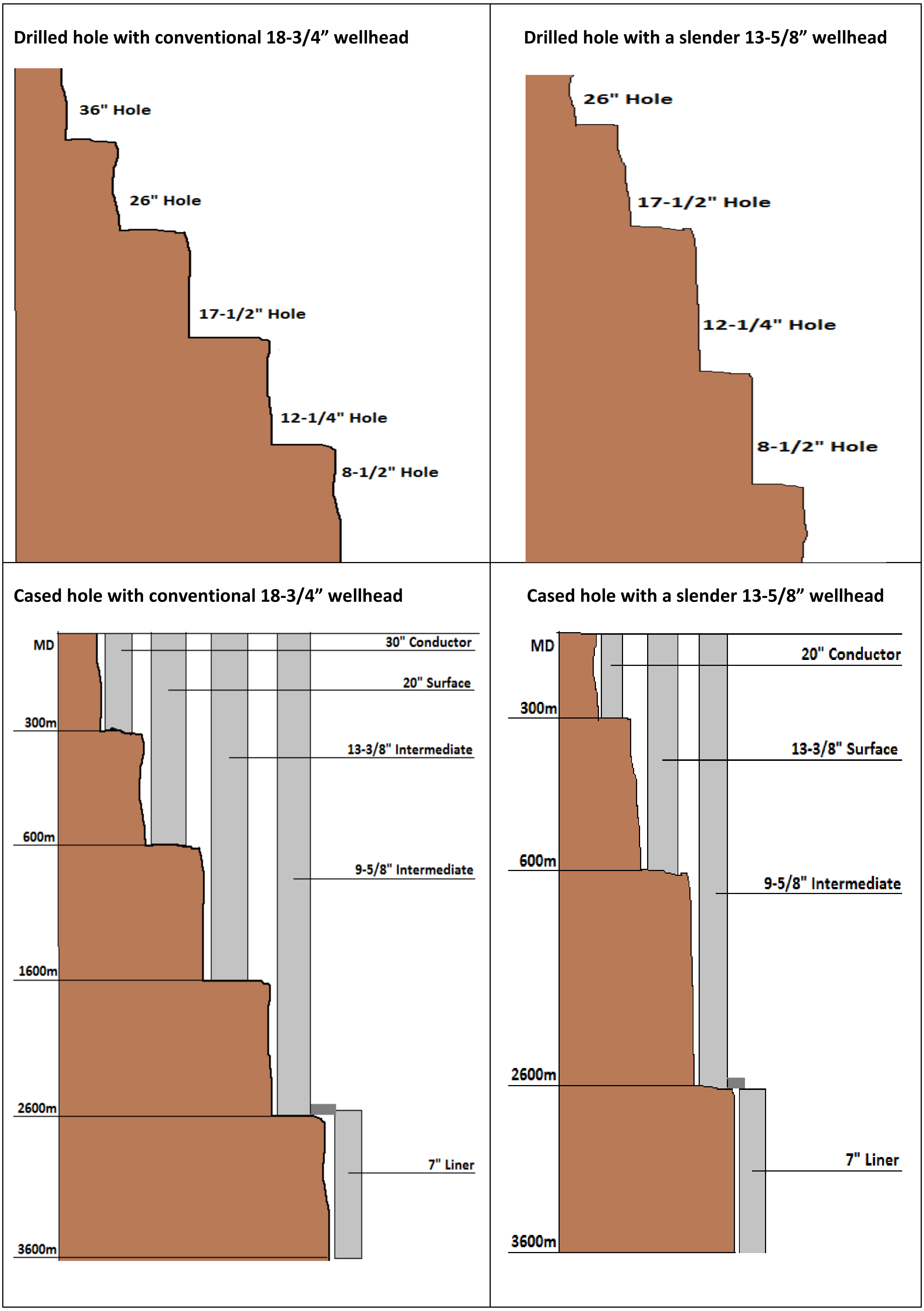

Figure 31- Mud volume in conventional and slender well.

Table 32 - Volume of mud in drilled and cased hole for 18-3/4 wellhead.

Drilled Hole [in]	Cased Hole [in]	Casing ID [in]	Type of casing	Diameter of drilled hole [m]	ID of cased hole [m]	Area of drilled hole [m^2]	Area of cased hole [m^2]	Length of cased sections [m]	Length of drilled sections [m]	MD [m]	Vol. of drilled sections [m^3]	Vol. of cased sections [m^3]
36	30	28,83	Conductor	0,914	0,732	0,657	0,421	300	300	300	197,008	126,377
26	20	19,5	Surface	0,660	0,495	0,343	0,193	600	300	600	102,760	115,605
17,5	13,375	12,861	Intermediate	0,445	0,327	0,155	0,084	1 600	1 000	1 600	155,179	134,099
12,25	9,625	9,03	Intermediate	0,311	0,229	0,076	0,041	2 600	1 000	2 600	76,038	107,425
8,5	7	6,46	Liner	0,216	0,164	0,037	0,021	1 000	1 000	3 600	36,610	-

$$Volume\ of\ drilled\ section = V_{DS}$$

$$Volume\ of\ drilled\ section = V_{CS}$$

$$Total\ mud\ volume_{max} = V_{CS20"} + V_{DS17,5"} + V_{CS13,375"} + V_{DS12,25"} + V_{CS9,625"} + V_{DS8,5"}$$

$$Total\ mud\ volume_{max} \approx 625\ m^3$$

$$Total\ volume\ of\ extracted\ formations_{max} = V_{DS17,5"} + V_{DS12,25"} + V_{DS8,5"}$$

$$Total\ volume\ of\ extracted\ formations_{max} \approx 270\ m^3$$

Table 33 - Volume of mud in drilled and cased hole for 13-5/8 wellhead.

Drilled Hole [in]	Cased Hole [in]	Casing ID [in]	Type of casing	Diameter of drilled hole [m]	ID of cased hole [m]	Area of drilled hole [m^2]	Area of cased hole [m^2]	Length of cased sections [m]	Length of drilled sections [m]	MD [m]	Vol. of drilled sections [m^3]	Vol. of cased sections [m^3]
26	20	19,5	Conductor	0,660	0,495	0,343	0,193	300	300	300	102,760	57,803
17,5	13,375	12,861	Surface	0,445	0,327	0,155	0,084	600	300	600	46,554	50,287
12,25	9,625	9,03	Intermediate	0,311	0,229	0,076	0,041	2 600	2 000	2 600	152,076	107,425
8,5	7	6,46	Liner	0,216	-	0,037	-	1 000	1 000	3 600	36,610	-

$$Volume\ of\ drilled\ section = V_{DS}$$

$$Volume\ of\ drilled\ section = V_{CS}$$

$$Total\ mud\ volume_{max} = V_{CS13,375"} + V_{DS12,25"} + V_{CS9,625"} + V_{DS8,5"}$$

$$Total\ mud\ volume_{max} \approx 345\ m^3$$

$$Total\ volume\ of\ extracted\ formations_{max} = V_{DS17,5"} + V_{DS12,25"} + V_{DS8,5"}$$

$$Total\ volume\ of\ extracted\ formations_{max} \approx 190\ m^3$$

APPENDIX B

Table 34 - Data from RigLogix. [2]

Rig Manager	Rig	Gener-ation	Constr.cost [mill. USD]	Day rate [USD]	Delivery year	Max WD [ft]	Drilling depth [ft]	Operating displacement [mT]	VDL [mT]	Liquid mud [m3]
Northern Offshore Ltd.	Energy Driller	1	26	207 841	1977	1 000	20 000	9 448	1 814	270
Queiroz Galvao Oleo e Gas S.A.	Alaskan star	2	53	304 063	1976	1 673	25 000	20 480	2 087	407
Queiroz Galvao Oleo e Gas S.A.	Atlantic star	2	41	292 368	1976	2 000	21 320	17 578	2 134	419
Dolphin Drilling	Bideford Dolphin	2	35	474 000	1975	1 500	20 000	27 297	3 128	1 049
Dolphin Drilling	Borgny Dolphin	2	40	-	1977	1 750	25 000	24 184	3 201	281
Dolphin Drilling	Bredford Dolphin	2	-	440 000	1980	1 500	25 000	26 575	3 400	528
Dolphin Drilling	Byford Dolphin	2	35	345 500	1974	1 500	20 000	24 280	3 069	633
Caspian Drilling	Dada Gorgud	2	40	-	1980	1 557	20 000	-	2 395	382
ENSCO	ENSCO 5000	2	20	-	1973	2 300	20 000	17 001	2 099	410
ENSCO	ENSCO 5002	2	30	-	1975	3 000	25 000	-	3 000	394
ENSCO	ENSCO 6000	2	65	-	1986	4 000	12 000	18 569	1 230	115
Essar Oilfields Services Ltd.	Essar Wildcat	2	35	285 000	1977	1 300	25 000	24 099	2 253	238
Transocean Ltd.	Falcon 100	2	30	-	1974	2 500	25 000	21 962	3 047	614
Transocean Ltd.	GSF Grand Banks	2	104	408 000	1984	1 500	25 000	24 055	5 693	392
Japan Drilling	Hakuryu-5	2	45	-	1977	1 640	30 000	29 568	1 588	723
Caspian Drilling	Istiglal	2	65	-	1993	2 297	19 685	19 971	3 402	409
Shanghai Offshore	Kan Tan III	2	50	-	1984	660	20 000	21 990	2 693	334
Japan Drilling	Naga 1	2	40	145 000	1974	1 000	30 000	21 118	2 331	394
China Oilfield Services Ltd.	Nanhai II	2	28	-	1974	1 000	25 000	20 932	3 028	293
China Oilfield Services Ltd.	Nanhai VII	2	48	-	1977	3 000	20 000	19 610	3 000	270
Noble Drilling	Noble Driller	2	36	415 000	1976	5 000	30 000	23 220	2 722	254
Noble Drilling	Noble Therald Martin	2	42	270 000	1977	4 000	25 000	19 057	2 499	419

Rig Manager	Rig	Gener-ation	Constr.cost [mill. USD]	Day rate [USD]	Delivery year	Max WD [ft]	Drilling depth [ft]	Operating displacement [mT]	VDL [mT]	Liquid mud [m3]
Diamond Offshore	Ocean Ambassador	2	26	211 000	1975	1 100	25 000	23 020	2 540	420
Diamond Offshore	Ocean Concord	2	38	247 788	1975	2 000	25 000	16 872	2 722	326
Diamond Offshore	Ocean General	2	33	255 000	1976	3 000	25 000	17 109	2 431	493
Diamond Offshore	Ocean Lexington	2	38	300 000	1976	2 500	25 000	16 901	2 468	348
Diamond Offshore	Ocean Nomad	2	30	330 000	1975	1 200	25 000	24 507	2 998	310
Diamond Offshore	Ocean Onyx	2	23	490 000	1973	6 000	30 000	35 561	5 080	1 097
Diamond Offshore	Ocean Princess	2	32	300 000	1975	1 500	25 000	26 100	3 257	370
Diamond Offshore	Ocean Saratoga	2	37	250 000	1976	2 200	25 000	17 109	2 087	270
Queiroz Galvao Oleo e Gas S.A.	Olinda Star	2	-	292 297	1983	3 600	24 600	20 548	3 992	541
Petrobras (NOC)	Petrobras XVI	2	83	-	1984	1 500	25 000	23 005	2 313	400
Petrobras (NOC)	Petrobras XVII	2	83	-	1984	2 300	25 000	23 005	2 313	400
Saipem	Scarabeo 3	2	24	235 000	1975	1 640	26 000	21 779	2 540	348
Saipem	Scarabeo 4	2	24	244 000	1975	1 788	30 000	21 779	2 540	348
Transocean Ltd.	Sedco 704	2	36	374 000	1974	1 000	25 000	23 886	2 901	382
Transocean Ltd.	Sedco 706	2	46	284 000	1976	6 562	25 000	22 686	2 449	327
Songa Offshore AS	Songa Mercur	2	80	-	1989	1 800	25 000	18 125	9 285	596
Songa Offshore AS	Songa Trym	2	42	365 000	1976	1 312	25 000	24 165	3 048	360
Songa Offshore AS	Songa Venus	2	30	-	1975	1 500	25 000	19 684	1 727	314
Stena Drilling	Stena Clyde	2	33	-	1976	1 650	25 000	-	3 220	443
Crosco Integrated	Zagreb 1	2	40	-	1977	1 476	20 000	17 660	1 633	18
Transocean Ltd.	Actinia	3	104	190 000	1982	1 500	25 000	28 110	2 721	450
Atwood Oceanics	Atwood Eagle	3	70	385 000	1982	5 000	25 000	32 394	4 536	576

Rig Manager	**Rig**	**Gener-ation**	**Constr.cost [mill. USD]**	**Day rate [USD]**	**Delivery year**	**Max WD [ft]**	**Drilling depth [ft]**	**Operating displacement [mT]**	**VDL [mT]**	**Liquid mud [m3]**
Atwood Oceanics	Atwood Falcon	3	92	385 000	1983	5 000	25 000	29 369	3 992	358
Atwood Oceanics	Atwood Hunter	3	63	515 500	1981	5 000	28 000	24 067	3 616	516
Odfjell	Deepsea Bergen	3	75	353 878	1983	1 500	25 000	27 957	2 835	639
KNOC (NOC)	Doo Sung	3	82	300 000	1984	1 500	25 000	23 393	3 999	328
ENSCO	ENSCO 5004	3	80	315 000	1982	1 500	25 000	22 641	2 132	352
ENSCO	ENSCO 5005	3	104	-	1982	1 700	25 000	28 109	4 000	471
Transocean Ltd.	GSF Arctic III	3	93	410 000	1984	1 800	25 000	25 641	2 771	352
Transocean Ltd.	GSF Rig 135	3	73	365 000	1983	2 800	25 000	26 796	3 447	591
Transocean Ltd.	GSF Rig 140	3	73	260 000	1983	1 500	25 000	24 309	3 447	737
Shanghai Offshore	Kan Tan IV	3	100	-	1983	2 000	25 000	25 995	4 081	345
Transocean Ltd.	M G Hulme Jr	3	65	190 000	1983	5 000	25 000	28 103	4 063	329
China Oilfield Services Ltd.	Nanhai V	3	110	-	1983	1 500	25 000	25 356	3 938	399
Maersk Drilling	Nanhai VI	3	93	-	1982	1 500	25 000	25 480	2 703	290
China Oilfield Services Ltd.	Nanhai VIII	3	75	-	1982	4 600	25 000	28 109	4 509	657
Noble Drilling	Noble Ton van Langeveld	3	40	278 000	1979	1 500	25 000	37 857	2 994	350
Diamond Offshore	Ocean Guardian	3	120	265 000	1985	1 500	25 000	25 741	3 556	300
Diamond Offshore	Ocean Patriot	3	85	-	1983	1 500	20 000	25 674	2 177	313
Diamond Offshore	Ocean Vanguard	3	90	454 000	1982	1 500	25 000	27 663	2 898	513
Diamond Offshore	Ocean Winner	3	43	270 000	1976	4 000	25 000	19 637	3 556	333
Diamond Offshore	Ocean Worker	3	73	270 000	1982	4 000	25 000	19 637	4 017	429
Diamond Offshore	Ocean Yatzy	3	65	245 000	1989	3 300	20 000	25 972	3 434	524
Diamond Offshore	Ocean Yorktown	3	38	184 000	1976	2 850	25 000	15 064	2 242	318

Rig Manager	Rig	Generation	Constr.cost [mill. USD]	Day rate [USD]	Delivery year	Max WD [ft]	Drilling depth [ft]	Operating displacement [mT]	VDL [mT]	Liquid mud [m3]
Petrobras (NOC)	Petrobras X	3	75	-	1982	3 900	29 520	25 585	3 336	477
Saipem	Scarabeo 6	3	93	340 000	1984	3 600	25 000	31 505	3 353	341
Transocean Ltd.	Sedco 702	3	36	461 000	1973	6 500	25 000	23 342	2 903	395
Transocean Ltd.	Sedco 711	3	112	355 000	1982	1 800	25 000	24 791	3 536	312
Transocean Ltd.	Sedco 712	3	112	386 000	1983	1 600	25 000	25 320	3 989	382
Transocean Ltd.	Sedco 714	3	100	443 000	1983	1 600	25 000	25 932	3 446	334
Songa Offshore AS	Songa Dee	3	120	423 000	1984	1 500	30 000	28 172	3 674	524
Songa Offshore AS	Songa Delta	3	60	-	1981	2 300	25 000	43 520	3 700	999
Stena Drilling	Stena Spey	3	96	355 000	1983	1 500	25 000	29 795	4 149	358
Transocean Ltd.	Transocean Amirante	3	37	-	1981	3 500	25 000	29 105	3 499	335
Transocean Ltd.	Transocean Driller	3	96	263 000	1991	3 000	25 000	30 095	4 063	348
Transocean Ltd.	Transocean John Shaw	3	90	364 000	1982	1 800	25 000	29 688	3 199	414
Transocean Ltd.	Transocean Legend	3	75	424 000	1983	3 500	25 000	28 299	2 599	390
Transocean Ltd.	Transocean Prospect	3	75	405 000	1983	1 500	25 000	29 080	3 399	424
Transocean Ltd.	Transocean Searcher	3	110	392 000	1983	1 500	25 000	28 300	3 049	333
Transocean Ltd.	Transocean Winner	3	114	453 000	1983	1 500	25 000	25 791	3 899	341
Awilco Drilling PLC	WilHunter	3	100	385 000	1983	1 500	25 000	27 596	3 644	355
Awilco Drilling PLC	WilPhoenix	3	100	443 000	1982	1 200	25 000	25 419	2 507	277
Dolphin Drilling	Borgland Dolphin	4	276	530 000	1999	1 500	30 000	28 766	3 503	1 123
ENSCO	ENSCO 5001	4	28	280 000	1975	6 500	25 000	25 577	3 375	844
ENSCO	ENSCO 5006	4	275	495 000	1999	7 500	25 000	39 317	8 855	1 622
ENSCO	ENSCO 6001	4	225	375 000	2001	4 921	25 000	-	3 500	561

Rig Manager	Rig	Generation	Constr.cost [mill. USD]	Day rate [USD]	Delivery year	Max WD [ft]	Drilling depth [ft]	Operating displacement [mT]	VDL [mT]	Liquid mud [m3]
ENSCO	ENSCO 6002	4	225	375 000	2001	5 000	21 000	-	3 493	561
ENSCO	ENSCO 6003	4	250	320 000	2004	5 577	25 000	-	3 500	561
ENSCO	ENSCO 6004	4	250	320 000	2004	5 577	25 000	-	3 500	561
Transocean Ltd.	GSF Celtic Sea	4	278	328 000	1998	5 750	25 000	46 173	5 080	1 316
Transocean Ltd.	Henry Goodrich	4	90	476 000	1985	2 000	30 000	49 705	4 999	525
Maersk Drilling	Heydar Aliyev (Maersk Explorer)	4	275	-	2003	3 000	30 000	30 194	4 400	650
North Drilling Company	Iran Amir Kabir	4	250	-	2009	3 000	20 000	-	-	-
Transocean Ltd.	Jack Bates	4	108	-	1986	6 000	30 000	52 842	6 109	636
Petroserv SA	Louisiana	4	100	425 000	1998	6 200	30 000	-	4 064	513
China Oilfield Services Ltd.	Nanhai IX	4	70	-	1988	5 000	25 000	36 931	3 499	763
Noble Drilling	Noble Amos Runner	4	152	453 000	1999	8 000	30 000	27 230	3 629	1 669
Noble Drilling	Noble Homer Ferrington	4	70	-	1985	7 200	30 000	26 585	3 629	978
Noble Drilling	Noble Jim Thompson	4	142	376 000	1999	6 000	33 000	28 775	3 629	1 739
Noble Drilling	Noble Max Smith	4	148	417 000	1999	7 000	25 000	27 230	3 629	2 188
Noble Drilling	Noble Paul Romano	4	118	400 000	1998	6 000	30 000	27 231	3 629	1 685
Noble Drilling	Noble Paul Wolff	4	175	-	1999	9 200	30 000	31 700	4 990	1 460
Diamond Offshore	Ocean Alliance	4	180	341 000	1988	8 000	35 000	46 366	3 910	474
Diamond Offshore	Ocean America	4	65	475 000	1988	5 000	30 000	42 544	7 500	1 237
Diamond Offshore	Ocean Apex	4	49	-	1976	6 000	30 000	45 164	6 546	588
Diamond Offshore	Ocean Quest	4	22	198 900	1973	3 500	25 000	33 270	5 080	473
Diamond Offshore	Ocean Star	4	24	301 000	1974	5 500	30 000	33 314	5 171	533
Diamond Offshore	Ocean Valiant	4	65	-	1988	6 000	30 000	44 693	6 400	448

Rig Manager	Rig	Gener-ation	Constr.cost [mill. USD]	Day rate [USD]	Delivery year	Max WD [ft]	Drilling depth [ft]	Operating displacement [mT]	VDL [mT]	Liquid mud [m3]
Diamond Offshore	Ocean Victory	4	20	-	1972	6 000	25 000	33 693	5 180	509
Schahin	Pantanal	4	-	365 000	2010	8 000	24 600	-	5 500	843
Transocean Ltd.	Paul B Loyd Jr	4	80	441 000	1987	2 000	25 000	39 501	4 196	506
Petrobras (NOC)	Petrobras XXIII	4	85	-	1985	6 200	25 000	29 665	3 773	1 141
Saipem	Scarabeo 5	4	110	399 000	1990	6 561	29 500	41 998	4 500	1 090
Transocean Ltd.	Sedco 707	4	49	394 000	1976	6 500	25 000	22 713	4 253	641
Stena Drilling	Stena Don	4	330	494 000	2001	1 640	27 800	32 998	3 946	1 030
Transocean Ltd.	Transocean Arctic	4	75	419 000	1986	1 640	25 000	36 199	4 469	175
Transocean Ltd.	Transocean Leader	4	75	406 000	1987	4 500	25 000	44 459	4 599	2 183
Transocean Ltd.	Transocean Marianas	4	224	370 000	1998	7 000	25 000	39 600	3 726	1 590
Transocean Ltd.	Transocean Polar Pioneer	4	95	620 000	1985	1 640	25 000	46 439	4 460	983
North Atlantic Drilling Ltd.	West Alpha	4	75	532 000	1986	2 000	22 000	30 699	5 289	760
Queiroz Galvao Oleo e Gas S.A.	Alpha star	5	385	431 513	2011	9 000	30 000	35 677	8 729	1
Dolphin Drilling	Blackford Dolphin	5	29	419 000	1974	7 000	30 000	33 870	4 500	795
Transocean Ltd.	Cajun Express	5	280	600 000	2000	8 500	35 000	33 791	5 987	1 828
Transocean Ltd.	Deepwater Nautilus	5	330	533 000	2000	8 000	30 000	46 932	-	1 749
Ocean Rig Asa	Eirik Raude	5	555	594 000	2001	10 000	30 000	52 596	6 250	1 668
ENSCO	ENSCO 7500	5	225	-	2000	8 000	35 000	24 314	7 711	1 936
Queiroz Galvao Oleo e Gas S.A.	Gold Star	5	270	354 788	2009	9 000	30 600	35 677	8 729	1 071
Ocean Rig Asa	Leiv Eiriksson	5	440	545 000	2001	8 200	30 000	52 596	6 250	1 668
Noble Drilling	Noble Clyde Boudreaux	5	65	417 000	1987	10 000	35 000	-	5 625	1 603
Odebrecht Oil & Gas	Norbe VI	5	550	299 000	2011	8 000	25 000	30 000	6 150	1 177

Rig Manager	Rig	Gener-ation	Constr.cost [mill. USD]	Day rate [USD]	Delivery year	Max WD [ft]	Drilling depth [ft]	Operating displacement [mT]	VDL [mT]	Liquid mud [m3]
Diamond Offshore	Ocean Baroness	5	24	270 000	1973	8 000	35 000	26 298	5 588	1 170
Diamond Offshore	Ocean Confidence	5	510	550 000	2001	10 000	35 000	47 046	5 996	1 239
Diamond Offshore	Ocean Confidence	5	510	-	2001	10 000	35 000	47 047	5 997	1 239
Diamond Offshore	Ocean Endeavour	5	35	-	1975	10 000	35 000	42 464	6 096	1 608
Diamond Offshore	Ocean Monarch	5	-	420 000	1974	10 000	35 000	43 272	6 096	1 581
Diamond Offshore	Ocean Rover	5	20	464 000	1972	8 000	35 000	30 557	6 160	1 103
Odebrecht Oil & Gas	ODN Tay IV	5	350	355 000	1999	7 900	30 000	41 406	4 990	682
Gazflot, LLC	Polar Star	5	575	-	2011	10 000	24 000	53 759	-	-
Saipem	Scarabeo 7	5	224	430 000	2000	4 900	27 000	38 174	3 493	500
Transocean Ltd.	Sedco Energy	5	335	-	2000	7 500	35 000	34 470	5 998	1 717
Transocean Ltd.	Sedco Express	5	335	-	2000	7 500	25 000	34 470	5 998	1 720
Gazflot, LLC	Northern Lights	5	575	-	2011	10 000	24 000	53 759	-	-
Seadrill Ltd.	West Orion	5	532	624 460	2010	10 000	37 392	-	7 000	2 990
Seadrill Ltd.	West Sirius	5	443	490 173	2008	10 000	37 500	-	7 000	2 989
Seadrill Ltd.	West Venture	5	340	441 000	2000	6 000	30 000	49 310	5 500	2 454
Schahin	Amazonia	6	-	365 000	2011	8 000	24 600	-	5 500	843
Atwood Oceanics	Atwood Condor	6	750	555 000	2012	10 000	40 000	46 499	8 000	3 300
Atwood Oceanics	Atwood Osprey	6	625	470 000	2011	8 200	35 000	49 750	8 992	2 536
Industrial Perforadora de Campeche	Bicentenario	6	633	530 000	2010	10 000	40 000	83 361	-	-
Industrial Perforadora de Campeche	Centenario	6	524	495 000	2010	10 000	40 000	39 372	7 112	3 018
China Oilfield Services Ltd.	COSLInnovator	6	300	335 000	2011	2 500	25 000	33 021	4 000	860
China Oilfield Services Ltd.	COSLPioneer	6	285	315 000	2010	2 500	25 000	36 400	4 000	670

Rig Manager	Rig	Gener-ation	Constr.cost [mill. USD]	Day rate [USD]	Delivery year	Max WD [ft]	Drilling depth [ft]	Operating displacement [mT]	VDL [mT]	Liquid mud [m3]
China Oilfield Services Ltd.	COSLPromoter	6	310	335 000	2012	2 500	25 000	33 021	4 000	450
Odfjell	Deepsea Atlantic	6	583	560 839	2009	10 000	37 500	49 986	7 500	380
Odfjell	Deepsea Stavanger	6	645	420 000	2010	10 000	37 500	55 066	7 500	780
Transocean Ltd.	Development Driller III	6	590	428 000	2009	7 500	37 500	53 717	13 500	1 876
ENSCO	ENSCO 8500	6	312	319 000	2008	10 000	35 000	-	7 257	2 584
ENSCO	ENSCO 8501	6	338	535 000	2009	10 000	35 000	-	7 257	2 576
ENSCO	ENSCO 8502	6	385	530 000	2010	10 000	35 000	-	7 257	3 053
ENSCO	ENSCO 8503	6	427	495 000	2010	10 000	35 000	-	7 257	2 528
ENSCO	ENSCO 8504	6	515	560 000	2011	10 000	35 000	-	7 257	1 860
ENSCO	ENSCO 8505	6	537	495 000	2012	8 500	35 000	-	7 257	1 860
ENSCO	ENSCO 8506	6	560	549 000	2012	10 000	35 000	-	7 257	1 860
Transocean Ltd.	GSF Development Driller I	6	285	-	2005	7 500	37 500	42 190	7 000	3 029
Transocean Ltd.	GSF Development Driller II	6	285	360 000	2005	7 500	37 500	42 190	7 000	3 029
China Oilfield Services Ltd.	Hai Yang Shi You 981	6	880	-	2011	10 000	32 800	-	6 350	-
Odfjell	Island Innovator	6	560	500 000	2012	2 500	26 247	34 509	4 082	650
Industrial Perforadora de Campeche	La Muralla IV	6	633	480 000	2011	10 000	35 000	83 361	-	-
Queiroz Galvao Oleo e Gas S.A.	Lone Star	6	500	349 211	2010	8 000	24 600	29 030	5 869	762
Maersk Drilling	Maersk Deliverer	6	236	450 000	2010	10 000	30 000	52 999	13 500	3 005
Maersk Drilling	Maersk Developer	6	234	520 000	2009	10 000	30 000	52 999	13 500	3 005
Maersk Drilling	Maersk Discoverer	6	234	495 000	2009	10 000	30 000	52 999	13 500	3 005
Noble Drilling	Noble Danny Adkins	6	500	498 000	2009	12 000	37 000	52 596	6 713	2 035
Noble Drilling	Noble Dave Beard	6	375	220 000	2009	10 000	35 000	-	5 443	1 717

Rig Manager	Rig	Gener-ation	Constr.cost [mill. USD]	Day rate [USD]	Delivery year	Max WD [ft]	Drilling depth [ft]	Operating displacement [mT]	VDL [mT]	Liquid mud [m3]
Noble Drilling	Noble Jim Day	6	550	543 000	2010	12 000	37 000	55 429	7 257	2 035
Diamond Offshore	Ocean Courage	6	452	398 000	2009	10 000	40 000	42 411	7 348	2 753
Diamond Offshore	Ocean Valor	6	480	440 000	2009	10 000	40 000	42 411	7 348	2 753
Odebrecht Oil & Gas	ODN Delba III	6	450	337 000	2011	9 000	30 000	36 651	3 879	2 512
Saipem	Scarabeo 8	6	614	460 000	2011	10 000	35 000	54 000	5 987	-
Saipem	Scarabeo 9	6	533	471 000	2010	12 000	50 000	48 019	7 348	1 739
Petroserv SA	SSV Catarina	6	385	600 000	2012	10 000	35 000	-	8 500	2 806
Petroserv SA	SSV Victoria	6	385	473 000	2009	10 000	35 000	-	8 500	2 806
Transocean Ltd.	Transocean Barents	6	560	503 000	2009	10 000	35 000	64 599	7 000	1 700
Transocean Ltd.	Transocean Spitsbergen	6	560	542 000	2009	10 000	35 000	64 599	7 000	1 700
Seadrill Ltd.	West Aquarius	6	530	540 000	2009	10 000	32 800	-	-	2 957
Seadrill Ltd.	West Capricorn	6	640	495 650	2011	10 000	37 500	-	7 000	2 990
Seadrill Ltd.	West Eclipse	6	640	450 000	2011	10 000	40 000	39 372	6 350	2 981
Seadrill Ltd.	West Eminence	6	542	624 460	2009	10 000	30 000	-	6 000	1 100
North Atlantic Drilling Ltd.	West Hercules	6	512	497 000	2008	10 000	32 800	-	13 000	2 957
Seadrill Ltd.	West Leo	6	237	605 000	2012	10 000	35 000	-	6 200	2 000
Seadrill Ltd.	West Pegasus	6	510	555 000	2011	10 000	35 000	49 532	6 200	2 000
North Atlantic Drilling Ltd.	West Phoenix	6	502	454 000	2008	10 000	30 000	-	5 443	1 000
Seadrill Ltd.	West Taurus	6	457	656 662	2008	10 000	37 500	43 399	7 000	2 989

Table 35 - Data from RigLogix. [2]

Rig Manager	Rig Name	Generation	Day rate [USD]	Max WD [ft]	21" Riser tension [MN]	16" Riser tension (42% reduction) [MN]
Shanghai Offshore	Kan Tan III	2	-	660	1,4	0,8
Transocean Ltd.	Transocean Arctic	4	419 000	1 640	1,4	0,8
China Oilfield Services Ltd.	Nanhai II	2	-	1 000	2,1	1,2
China Oilfield Services Ltd.	Nanhai VII	2	-	3 000	2,1	1,2
Queiroz Galvao Oleo e Gas S.A.	Alaskan star	2	304 063	1 673	2,1	1,2
Songa Offshore AS	Songa Venus	2	-	1 500	2,1	1,2
Diamond Offshore	Ocean Princess	2	300 000	1 500	2,1	1,2
Japan Drilling	Naga 1	2	145 000	1 000	2,1	1,2
Diamond Offshore	Ocean Nomad	2	330 000	1 200	2,1	1,2
ENSCO	ENSCO 5002	2	-	3 000	2,1	1,2
Maersk Drilling	Nanhai VI	3	-	1 500	2,1	1,2
Queiroz Galvao Oleo e Gas S.A.	Atlantic star	2	292 368	2 000	2,5	1,4
Noble Drilling	Noble Ton van Langeveld	3	278 000	1 500	2,8	1,6
Essar Oilfields Services Ltd.	Essar Wildcat	2	285 000	1 300	2,8	1,7
Diamond Offshore	Ocean Saratoga	2	250 000	2 200	2,8	1,7
Diamond Offshore	Ocean Concord	2	247 788	2 000	2,8	1,7
Saipem	Scarabeo 3	2	235 000	1 640	2,8	1,7
Saipem	Scarabeo 4	2	244 000	1 788	2,8	1,7
Diamond Offshore	Ocean Ambassador	2	211 000	1 100	2,8	1,7
Dolphin Drilling	Bredford Dolphin	2	440 000	1 500	2,8	1,7
Noble Drilling	Noble Therald Martin	2	270 000	4 000	2,8	1,7
Songa Offshore AS	Songa Mercur	2	-	1 800	2,8	1,7
Dolphin Drilling	Byford Dolphin	2	345 500	1 500	2,8	1,7
Dolphin Drilling	Borgny Dolphin	2	-	1 750	2,8	1,7
Songa Offshore AS	Songa Trym	2	365 000	1 312	2,8	1,7
Transocean Ltd.	Sedco 704	2	374 000	1 000	2,8	1,7
Transocean Ltd.	GSF Grand Banks	2	408 000	1 500	2,8	1,7
Petrobras (NOC)	Petrobras XVI	2	-	1 500	2,8	1,7
Shanghai Offshore	Kan Tan IV	3	-	2 000	2,8	1,7
Odfjell	Deepsea Bergen	3	353 878	1 500	2,8	1,7
China Oilfield Services Ltd.	Nanhai V	3	-	1 500	2,8	1,7

Rig Manager	Rig Name	Genera-tion	Day rate [USD]	Max WD [ft]	21" Riser tension [MN]	16" Riser tension (42% reduction) [MN]
Awilco Drilling PLC	WilPhoenix	3	443 000	1 200	2,8	1,7
Transocean Ltd.	Transocean Winner	3	453 000	1 500	2,8	1,7
ENSCO	ENSCO 5004	3	315 000	1 500	2,8	1,7
Diamond Offshore	Ocean Vanguard	3	454 000	1 500	2,8	1,7
Songa Offshore AS	Songa Delta	3	-	2 300	2,8	1,7
Transocean Ltd.	Transocean Searcher	3	392 000	1 500	2,8	1,7
Transocean Ltd.	Sedco 702	3	461 000	6 500	2,8	1,7
Transocean Ltd.	Transocean Prospect	3	405 000	1 500	2,8	1,7
Transocean Ltd.	Actinia	3	190 000	1 500	2,8	1,7
KNOC (NOC)	Doo Sung	3	300 000	1 500	2,8	1,7
ENSCO	ENSCO 5005	3	-	1 700	2,8	1,7
Saipem	Scarabeo 6	3	340 000	3 600	2,8	1,7
Transocean Ltd.	GSF Arctic III	3	410 000	1 800	2,8	1,7
Crosco Integrated	Zagreb 1	2	-	1 476	3,0	1,8
Transocean Ltd.	Paul B Loyd Jr	4	441 000	2 000	3,0	1,8
Caspian Drilling	Dada Gorgud	2	-	1 557	3,3	1,9
ENSCO	ENSCO 6000	2	-	4 000	3,6	2,1
Diamond Offshore	Ocean Lexington	2	300 000	2 500	3,6	2,1
Petrobras (NOC)	Petrobras XVII	2	-	2 300	3,6	2,1
Diamond Offshore	Ocean General	2	255 000	3 000	3,6	2,1
Stena Drilling	Stena Clyde	2	-	1 650	3,6	2,1
Dolphin Drilling	Bideford Dolphin	2	474 000	1 500	3,6	2,1
Diamond Offshore	Ocean Yorktown	3	184 000	2 850	3,6	2,1
Transocean Ltd.	Sedco 711	3	355 000	1 800	3,6	2,1
Transocean Ltd.	Sedco 714	3	443 000	1 600	3,6	2,1
Transocean Ltd.	Sedco 712	3	386 000	1 600	3,6	2,1
Diamond Offshore	Ocean Guardian	3	265 000	1 500	3,6	2,1
Stena Drilling	Stena Spey	3	355 000	1 500	3,6	2,1
Transocean Ltd.	Transocean John Shaw	3	364 000	1 800	3,6	2,1
Diamond Offshore	Ocean Quest	4	198 900	3 500	3,6	2,1
Dolphin Drilling	Borgland Dolphin	4	530 000	1 500	3,6	2,1

Rig Manager	Rig Name	Genera-tion	Day rate [USD]	Max WD [ft]	21" Riser tension [MN]	16" Riser tension (42% reduction) [MN]
Awilco Drilling PLC	WilHunter	3	385 000	1 500	3,9	2,3
Japan Drilling	Hakuryu-5	2	-	1 640	4,3	2,5
Queiroz Galvao Oleo e Gas S.A.	Olinda Star	2	292 297	3 600	4,3	2,5
Diamond Offshore	Ocean Patriot	3	-	1 500	4,3	2,5
Diamond Offshore	Ocean Winner	3	270 000	4 000	4,3	2,5
Atwood Oceanics	Atwood Falcon	3	385 000	5 000	4,3	2,5
Diamond Offshore	Ocean Worker	3	270 000	4 000	4,3	2,5
Petrobras (NOC)	Petrobras X	3	-	3 900	4,3	2,5
Transocean Ltd.	Transocean Legend	3	424 000	3 500	4,3	2,5
Atwood Oceanics	Atwood Eagle	3	385 000	5 000	4,3	2,5
Songa Offshore AS	Songa Dee	3	423 000	1 500	4,3	2,5
Diamond Offshore	Ocean Yatzy	3	245 000	3 300	4,3	2,5
Transocean Ltd.	GSF Rig 135	3	365 000	2 800	4,3	2,5
Transocean Ltd.	GSF Rig 140	3	260 000	1 500	4,3	2,5
North Atlantic Drilling Ltd.	West Alpha	4	532 000	2 000	4,3	2,5
North Drilling Company	Iran Amir Kabir	4	-	3 000	4,3	2,5
Odfjell	Island Innovator	6	500 000	2 500	4,3	2,5
China Oilfield Services Ltd.	COSLPioneer	6	315 000	2 500	4,3	2,5
China Oilfield Services Ltd.	COSLPromoter	6	335 000	2 500	4,3	2,5
China Oilfield Services Ltd.	COSLInnovator	6	335 000	2 500	4,3	2,5
Caspian Drilling	Istiglal	2	-	2 297	4,6	2,6
Transocean Ltd.	Transocean Amirante	3	-	3 500	4,8	2,8
Atwood Oceanics	Atwood Hunter	3	515 500	5 000	5,0	2,9
China Oilfield Services Ltd.	Nanhai VIII	3	-	4 600	5,0	2,9
Transocean Ltd.	Jack Bates	4	-	6 000	5,1	3,0
Noble Drilling	Noble Driller	2	415 000	5 000	5,3	3,1
Transocean Ltd.	Transocean Driller	3	263 000	3 000	5,3	3,1
ENSCO	ENSCO 6004	4	320 000	5 577	5,3	3,1
ENSCO	ENSCO 6003	4	320 000	5 577	5,3	3,1
China Oilfield Services Ltd.	Nanhai IX	4	-	5 000	5,3	3,1
ENSCO	ENSCO 5000	2	-	2 300	5,7	3,3

Rig Manager	Rig Name	Genera-tion	Day rate [USD]	Max WD [ft]	21" Riser tension [MN]	16" Riser tension (42% reduction) [MN]
Diamond Offshore	Ocean Star	4	301 000	5 500	5,7	3,3
Diamond Offshore	Ocean Alliance	4	341 000	8 000	5,7	3,3
Diamond Offshore	Ocean America	4	475 000	5 000	5,7	3,3
Stena Drilling	Stena Don	4	494 000	1 640	5,7	3,3
Diamond Offshore	Ocean Valiant	4	-	6 000	5,7	3,3
Diamond Offshore	Ocean Victory	4	-	6 000	5,7	3,3
Noble Drilling	Noble Paul Romano	4	400 000	6 000	5,7	3,3
Noble Drilling	Noble Jim Thompson	4	376 000	6 000	5,7	3,3
Transocean Ltd.	M G Hulme Jr	3	190 000	5 000	6,4	3,7
Transocean Ltd.	Transocean Leader	4	406 000	4 500	6,4	3,7
Diamond Offshore	Ocean Onyx	2	490 000	6 000	7,1	4,1
Transocean Ltd.	Transocean Marianas	4	370 000	7 000	7,1	4,1
Noble Drilling	Noble Max Smith	4	417 000	7 000	7,1	4,1
Noble Drilling	Noble Homer Ferrington	4	-	7 200	7,1	4,1
Noble Drilling	Noble Amos Runner	4	453 000	8 000	7,1	4,1
Diamond Offshore	Ocean Apex	4	-	6 000	7,1	4,1
Petrobras (NOC)	Petrobras XXIII	4	-	6 200	8,1	4,7
ENSCO	ENSCO 5001	4	280 000	6 500	8,5	4,9
Transocean Ltd.	Sedco 706	2	284 000	6 562	8,5	5,0
Transocean Ltd.	Sedco 707	4	394 000	6 500	8,5	5,0
Noble Drilling	Noble Paul Wolff	4	-	9 200	8,5	5,0
Transocean Ltd.	GSF Celtic Sea	4	328 000	5 750	8,5	5,0
Saipem	Scarabeo 7	5	430 000	4 900	8,5	5,0
Noble Drilling	Noble Clyde Boudreaux	5	417 000	10 000	8,5	5,0
ENSCO	ENSCO 5006	4	495 000	7 500	8,6	5,0
ENSCO	ENSCO 6002	4	375 000	5 000	8,9	5,2
ENSCO	ENSCO 6001	4	375 000	4 921	8,9	5,2
Odebrecht Oil & Gas	Norbe VI	5	299 000	8 000	8,9	5,2
Transocean Ltd.	Sedco Express	5	-	7 500	8,9	5,2
Dolphin Drilling	Blackford Dolphin	5	419 000	7 000	10,7	6,2
Ocean Rig Asa	Leiv Eiriksson	5	545 000	8 200	10,7	6,2

Rig Manager	Rig Name	Genera-tion	Day rate [USD]	Max WD [ft]	21" Riser tension [MN]	16" Riser tension (42% reduction) [MN]
Transocean Ltd.	Sedco Energy	5	-	7 500	10,7	6,2
Queiroz Galvao Oleo e Gas S.A.	Gold Star	5	354 788	9 000	11,1	6,5
Queiroz Galvao Oleo e Gas S.A.	Lone Star	6	349 211	8 000	11,1	6,5
Noble Drilling	Noble Dave Beard	6	220 000	10 000	11,1	6,5
ENSCO	ENSCO 8505	6	495 000	8 500	11,1	6,5
Odebrecht Oil & Gas	ODN Delba III	6	337 000	9 000	11,1	6,5
ENSCO	ENSCO 8501	6	535 000	10 000	11,1	6,5
ENSCO	ENSCO 8500	6	319 000	10 000	11,1	6,5
ENSCO	ENSCO 8502	6	530 000	10 000	11,1	6,5
Noble Drilling	Noble Jim Day	6	543 000	12 000	11,1	6,5
Noble Drilling	Noble Danny Adkins	6	498 000	12 000	11,1	6,5
Queiroz Galvao Oleo e Gas S.A.	Alpha star	5	431 513	9 000	13,3	7,7
ENSCO	ENSCO 8506	6	549 000	10 000	13,3	7,7
ENSCO	ENSCO 8504	6	560 000	10 000	13,3	7,7
Transocean Ltd.	Development Driller III	6	428 000	7 500	13,3	7,7
ENSCO	ENSCO 8503	6	495 000	10 000	13,3	7,7
Transocean Ltd.	GSF Development Driller II	6	360 000	7 500	13,3	7,7
Transocean Ltd.	GSF Development Driller I	6	-	7 500	13,3	7,7
Maersk Drilling	Maersk Deliverer	6	450 000	10 000	13,3	7,7
Maersk Drilling	Maersk Discoverer	6	495 000	10 000	13,3	7,7
Maersk Drilling	Maersk Developer	6	520 000	10 000	13,3	7,7
Seadrill Ltd.	West Eminence	6	624 460	10 000	14,0	8,1
Odfjell	Deepsea Stavanger	6	420 000	10 000	14,2	8,2
Odfjell	Deepsea Atlantic	6	560 839	10 000	14,2	8,3
Transocean Ltd.	Deepwater Nautilus	5	533 000	8 000	14,2	8,3
Transocean Ltd.	Cajun Express	5	600 000	8 500	14,2	8,3
Ocean Rig Asa	Eirik Raude	5	594 000	10 000	14,2	8,3
Transocean Ltd.	Transocean Barents	6	503 000	10 000	14,3	8,3
Transocean Ltd.	Transocean Spitsbergen	6	542 000	10 000	14,3	8,3
North Atlantic Drilling Ltd.	West Hercules	6	497 000	10 000	15,9	9,2
Seadrill Ltd.	West Aquarius	6	540 000	10 000	15,9	9,2

Rig Manager	Rig Name	Genera-tion	Day rate [USD]	Max WD [ft]	21" Riser tension [MN]	16" Riser tension (42% reduction) [MN]
Diamond Offshore	Ocean Rover	5	464 000	8 000	16,0	9,3
Diamond Offshore	Ocean Baroness	5	270 000	8 000	16,0	9,3
Diamond Offshore	Ocean Confidence	5	550 000	10 000	16,0	9,3
Diamond Offshore	Ocean Monarch	5	420 000	10 000	16,0	9,3
Diamond Offshore	Ocean Endeavour	5	-	10 000	16,0	9,3
Seadrill Ltd.	West Sirius	5	490 173	10 000	16,0	9,3
Seadrill Ltd.	West Pegasus	6	555 000	10 000	16,0	9,3
Seadrill Ltd.	West Leo	6	605 000	10 000	16,0	9,3
Atwood Oceanics	Atwood Osprey	6	470 000	8 200	16,0	9,3
Atwood Oceanics	Atwood Condor	6	555 000	10 000	16,0	9,3
Saipem	Scarabeo 8	6	460 000	10 000	16,0	9,3
Diamond Offshore	Ocean Courage	6	398 000	10 000	16,0	9,3
Diamond Offshore	Ocean Valor	6	440 000	10 000	16,0	9,3
Seadrill Ltd.	West Orion	5	624 460	10 000	19,6	11,4
Seadrill Ltd.	West Taurus	6	656 662	10 000	19,6	11,4
Seadrill Ltd.	West Capricorn	6	495 650	10 000	19,6	11,4
Seadrill Ltd.	West Eclipse	6	450 000	10 000	25,4	14,7
Northern Offshore Ltd.	Energy Driller	1	207 841	1 000	-	-
Transocean Ltd.	Falcon 100	2	-	2 500	-	-
Saipem	Scarabeo 5	4	399 000	6 561	-	-
Transocean Ltd.	Transocean Polar Pioneer	4	620 000	1 640	-	-
Petroserv SA	Louisiana	4	425 000	6 200	-	-
Transocean Ltd.	Henry Goodrich	4	476 000	2 000	-	-
Maersk Drilling	Heydar Aliyev	4	-	3 000	-	-
Schahin	Pantanal	4	365 000	8 000	-	-
Seadrill Ltd.	West Venture	5	441 000	6 000	-	-
Odebrecht Oil & Gas	ODN Tay IV	5	355 000	7 900	-	-
ENSCO	ENSCO 7500	5	-	8 000	-	-
Gazflot, LLC	Polyarnaya Zvezda	5	-	10 000	-	-
Gazflot, LLC	Severnoye Siyanie	5	-	10 000	-	-
Schahin	Amazonia	6	365 000	8 000	-	-

Rig Manager	Rig Name	Genera-tion	Day rate [USD]	Max WD [ft]	21" Riser tension [MN]	16" Riser tension (42% reduction) [MN]
Saipem	Scarabeo 9	6	471 000	12 000	-	-
Petroserv SA	SSV Victoria	6	473 000	10 000	-	-
Petroserv SA	SSV Catarina	6	600 000	10 000	-	-
Industrial Perforadora de Campeche	Bicentenario	6	530 000	10 000	-	-
Industrial Perforadora de Campeche	Centenario	6	495 000	10 000	-	-
North Atlantic Drilling Ltd.	West Phoenix	6	454 000	10 000	-	-
China Oilfield Services Ltd.	Hai Yang Shi You 981	6	-	10 000	-	-
Industrial Perforadora de Campeche	La Muralla IV	6	480 000	10 000	-	-

Graph created from tension data from Excel

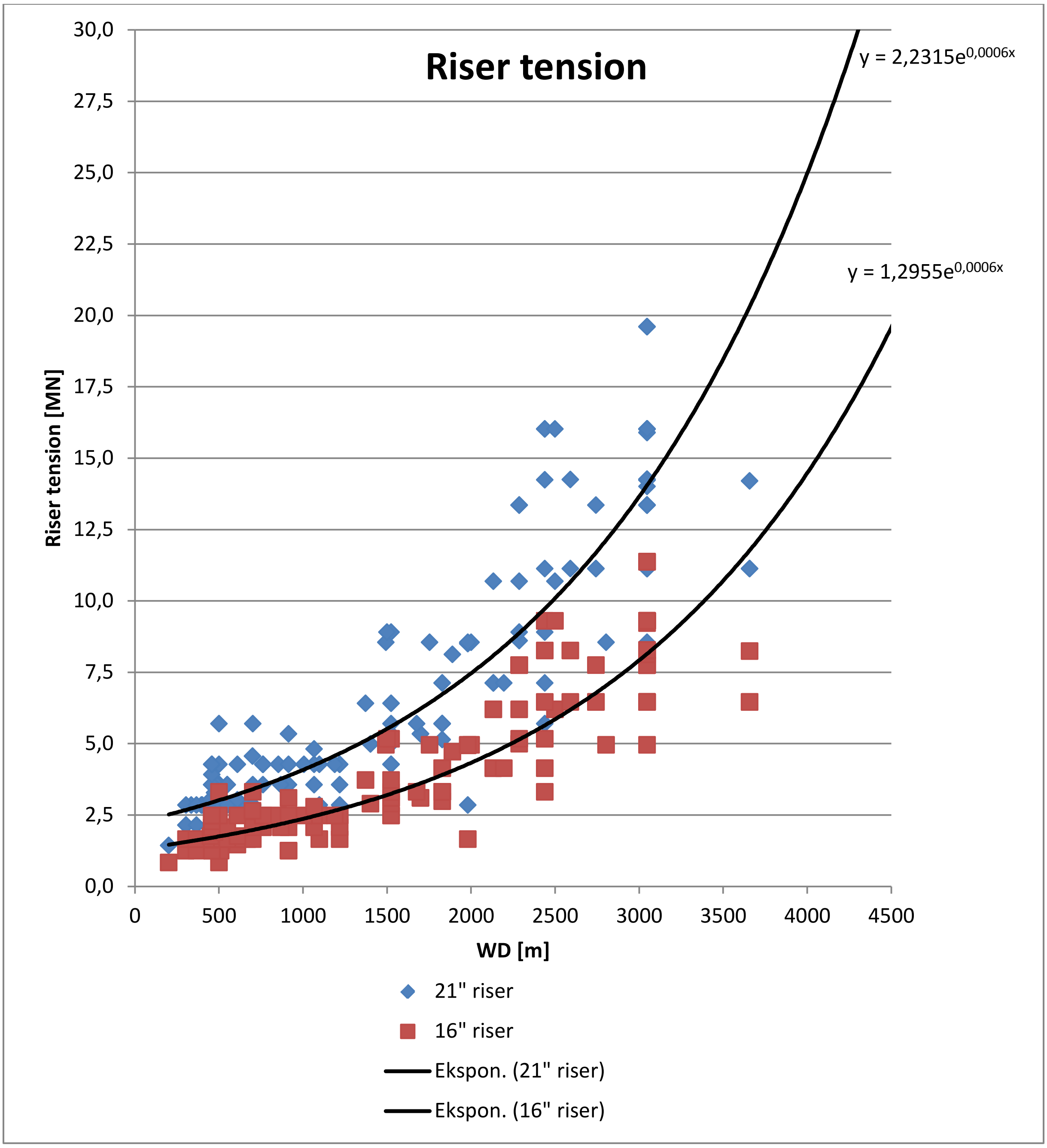

Figure 32 - Riser tension. [2]