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INCREASING LOAD-OUT CAPACITY - COMPARISON OF SKIDDING METHODS

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The purpose of this thesis was to investigate and compare alternative methods to execute skidded load-out of an extremely heavy structure onto a transport vessel.

In typical load-out the structure is skidded along two skidding tracks onto the deck of the transport vessel. However, the bearing capacity of the foundations under the skidding tracks on shore as well as the capacity of the transport vessel is evaluated to require using additional track lines, total of four track lines, to spread the load if the skidded structure is extremely heavy. The additional skidding tracks have not been required in previous projects, however in the future the need of the additional tracks is believed to be inevitable. Therefore evaluation concerning potential skidding methods for the additional tracks was required.

The methods for the study were selected based on the friction reducing principles. The principles were rollers, teflon pads and air cushions. When evaluating the methods emphasis was put on feasibility, friction and load bearing capacity. In the background, survey concerning the costs of the most potential methods was also made. However, the results are excluded from the thesis for confidentially reasons.

The methods found most potential for usage on the additional skidding tracks were the air pad skidding system from Hebetec Engineering Ltd. and the skidding system using teflon pads from Mammoet B.V.

LASTAUSKAPASITEETIN KASVATTAMINEN – LIUKUVAIHTOEHTOJEN VERTAILU

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Asiasanat: lastaus, haalaus, kitka, kantokyky

Opinnäytetyön tarkoituksena oli selvittää ja vertailla tapoja toteuttaa erittäin raskaan rakenteen lastaus ratoja pitkin kuljetusalukselle.

Raskaan rakenteen lastauksen on todettu vaativan useampia ratalinjoja. Normaalisti lastaus on toteutettu työntämällä rakennetta kahta ratalinjaa pitkin kuljetusalukselle. Suurilla kuormilla ratalinjojen perustukset sekä kuljetusaluksen kuormankantokyky vaativat kuitenkin kuorman jakamista useammalle ratalinjalle. Ratalinjoja on arvioitu tarvittavan yhteensä neljä. Lisäratoja ei olla aikaisemmin käytetty, mutta tulevaisuudessa tarpeen on arvioitu olevan väistämätön. Tämän vuoksi selvitystä soveltuvista lastausmenetelmistä lisäradoille oli tarpeen tehdä.

Ennalta soveltuviksi arvioidut menetelmät jaettiin kolmeen ryhmään perustuen kitkan vähennys periaatteeseen. Ryhmät olivat rullat, teflon palat sekä ilmatyynyt. Menetelmiä arvioitaessa painotettiin soveltuvuutta, kuormankantokykyä sekä kitka-arvoa. Parhaiten soveltuviksi arvioitujen menetelmien kohdalla selvitettiin myös kustannukset. Kustannusarviot ovat kuitenkin salassapitosyistä jätetty pois raportista.

Parhaiten soveltuviksi menetelmiksi arvioitiin ilmatyynyihin perustuva järjestelmä Hebetec Engineering Ltd:ltä sekä teflon paloihin perustuva menetelmä Mammoet B.V:ltä.

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ABBREVIATIONS

TOF	=	Technip Offshore Finland Oy
EPC	=	Engineering, Procurement & Construction
SPAR	=	Single Point Anchor Reservoir
Ton	=	Metric Ton
DNV	=	Det Norske Veritas
PTFE	=	PolyTetraFluoroEthylene
SWL	=	Safe Working Load

1 INTRODUCTION

Technip S.A. is a worldwide project management, engineering and construction company for the energy industry, in particular for the oil and gas industry. The company has 36 500 employees in 48 countries, headquarters is located in France, Paris. Technip is active in three business sectors: subsea, offshore and onshore. /1/

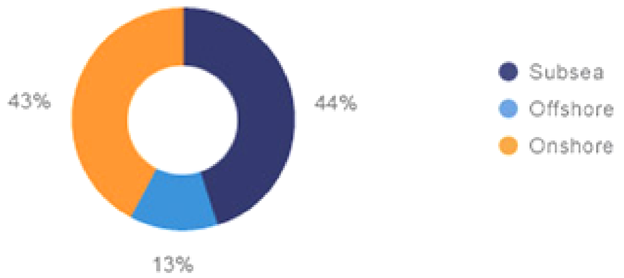

Figure 1.1: Breakdown of 2011 Revenues by Activity. /1/

Subsea segment covers design, manufacturing and installation of rigid and flexible subsea pipelines and umbilicals. Onshore segment covers full range of facilities for the oil and gas chain, petrochemicals and other energy industries, such as nuclear, renewables including biofuels and offshore wind turbines. Offshore segment covers engineering, procurement, construction, installation, commissioning and refurbishment of offshore facilities for the oil & gas industry. In offshore segment Technip S.A. has a subsidiary in Finland, Technip Offshore Finland Oy. /1/

Technip Offshore Finland Oy, TOF, is a project management and construction company focusing on offshore construction projects installed all over the world. TOF also makes products for other sectors, e.g. pressure vessels and other demanding heavy industry structures. The company has a strong position as a competitive EPC contractor of SPAR platform hulls. SPAR hulls are constructed by dividing the hull into subassemblies. The subassemblies are joined in a workshop to form larger sections, blocks. Blocks are then transported onto an outdoor assembly track where the blocks are mated to form a complete hull. After construction, the complete hull is then loaded out along skidding rails onto a heavy transport vessel and transported to desired destination.

Figure 1.2: Load-out of a SPAR hull

Over the years the weight of the products at TOF have increased even to 47 000 tons. Line loads for assembly tracks have increased from 25 tons/m to 200 tons/m. Increased weight has brought challenges for controlling loads during load-out operations. Loads on assembly tracks as well as on heavy transport vessels have increased beyond acceptable limit. To compensate the increased loads additional skidding tracks are required to spread the load.

Furthermore, the increased weight has brought heavy loads to quayside structures. Hull is pushed along rails with several hydraulic jacks. Due to the increased weight jacking force has also had to be increased, which has led to heavy loads for quayside structures and connection between land rails and ship rails. To avoid strengthening of the quayside structures, it is desirable to decrease the jacking force needed, in other words to decrease the frictional resistance of the moving structure. At the moment steel rollers are used to provide skidding. Steel rollers have rather advantageous friction properties, on the other hand, due to the structure, they have low tolerance for straightness deviations in track lines. Deviations are caused by e.g. misalignments and thermal expansion.

The load-out system has initially been designed for line load of 45 tons/m per track line. As the loads have over the years increased, the system has been strengthened to tolerate the increased loads. Nowadays foundations under the assembly tracks allow a vertical line load of 225 tons/m per track line and the quayside structures a horizontal load of 500 tons per track line. However, as the loads have increased even more in recent years, and the trend seems to be towards even heavier structures in the future, the capacity of the load-out system is pushed to the limits. The usage of the additional skidding tracks, total of four track lines, is becoming inevitable as the loads on the skidding tracks as well as on the transport vessel are beyond acceptable limit with only two track lines. Therefore evaluation concerning potential skidding equipments for the additional skidding tracks shall be carried out to in order to found a feasible skidding method for the additional skidding tracks.

The purpose of this thesis is to investigate and compare alternative ways to execute skidding on the additional skidding tracks that have not been used previously. Emphasis shall be put on the main skidding tracks as well, since some of the methods are feasible on the main skidding tracks. The goal is to find a feasible alternative, which tolerates misalignments and has advantageous friction properties.

2 LOAD-OUT

Load-out, as the name implies, means loading a structure from its origin to a vessel for transportation to its destination. The term load-out is often used in heavy industry when structure is moved from the place where it's fabricated onto a marine vessel (a ship or a barge) for transportation to its final destination. The structure can be moved onto the transport vessel in the longitudinal or transverse direction of the vessel. Load-out can be carried out in various different ways, e.g. by means of lifting, roll-on/roll-off, floating or skidding. The skidding method is most suitable for moving extremely heavy loads, and is used at TOF. /2/

2.1 Skidding Method

In a skidded load-out the structure is commonly pushed (by hydraulic jacks) or pulled (by strand jacks) onto heavy transport vehicle. The load is fitted with skid shoes that move along skidding rails. The force required to move the structure along skidding rails depends on the friction between the skid shoes and the skidding rails. The initial force required to move the structure from the static state is usually greater than the force required to keep it moving. To reduce the frictional resistance of the moving structure, e.g. teflon pads or steel rollers may be added between skid shoe and skid rail. Also lubricants are effective in reducing friction. The speed of the load-out operation depends on several factors, such as the stroke of the jacks. /2/

Standard skidding method utilizes typically only two skid shoes to support the structure, additional skid shoes may be used to spread the load. The loads on the skid shoes are in relation to the properties of the structure moved. Loads are not uniform all along the skidding rail. By adding hydraulic cylinders between the skid shoe and the structure loadings may be controlled and distributed evenly all along the skidding rail, see fig. 2.1.1. /2/

Figure 2.1.1: Skidding with hydraulics

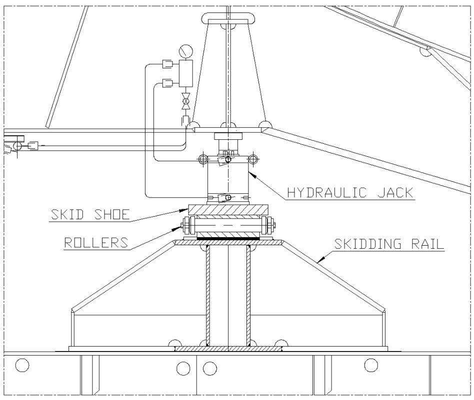

Figure 2.1.2: Typical skidding arrangement

At TOF products are loaded onto a heavy transport vessel by skidding the structure with hydraulic jacks over the stern of the vessel onto a stowage position on the deck of the vessel. The load is fitted with skid shoes. The number of the skid shoes and tracks depends on the allowable load on the stern area of the transport vessel. The additional skid shoes and tracks are used to spread the load if needed. The load is supported with hydraulic jacks, and as usually the center of gravity is in the center of the structure, the load can be equally distributed between the skid shoes. After skidding the structure onto the stowage position the load is then transferred onto a wooden cribbing and is fastened to the deck of the vessel.

Figure 2.1.3: Skidding of a spar hull

2.1.1 Skidding Track

In a skidded load-out the structure is skidded along rails onto a transport vehicle. TOF's assembly site contains two separate assembly lines, southern and northern. Both of the lines consist of two rail lines, see fig. 2.1.4. Allowable load on the northern rails per rail line is 100 tons/m and on the southern 225 tons/m.
The additional skidding tracks have not been used formerly and therefore the strength of the tracks is not defined.

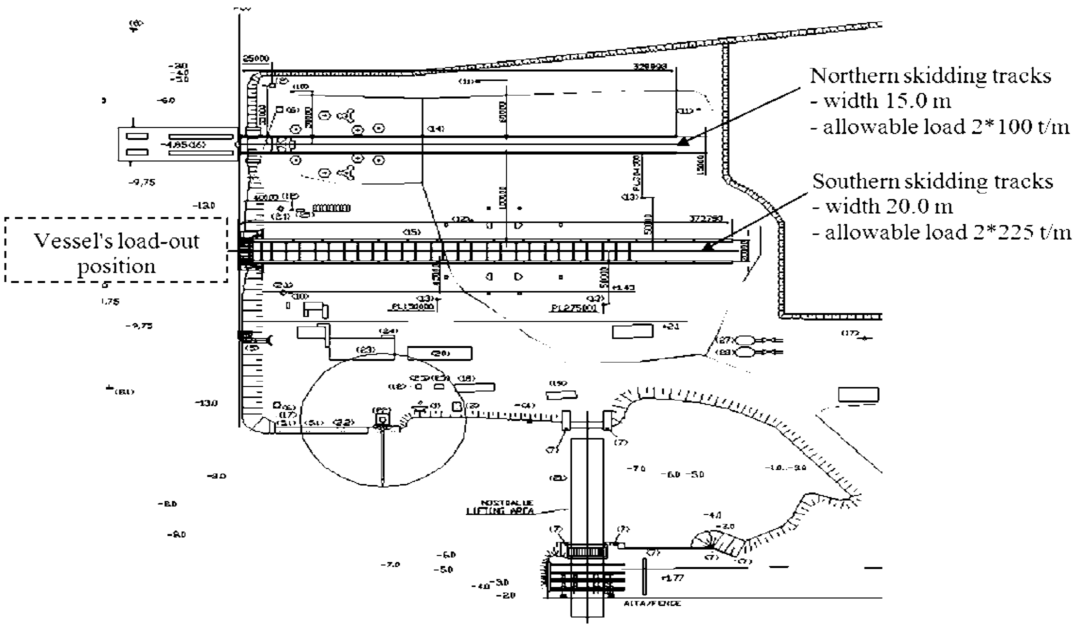

Figure 2.1.4: Assembly site

At TOF the skidding rails are not continuous over the whole skidding length, they are separate on the shore and on the heavy transport vessel. Rails are mounted in a way that the top flanges are coplanar to each other, connection between the rails is conducted with a link beam, as illustrated in figures 2.1.5 and 2.1.1. Typical structure of a skidding rail beam is shown in figure 2.1.6.

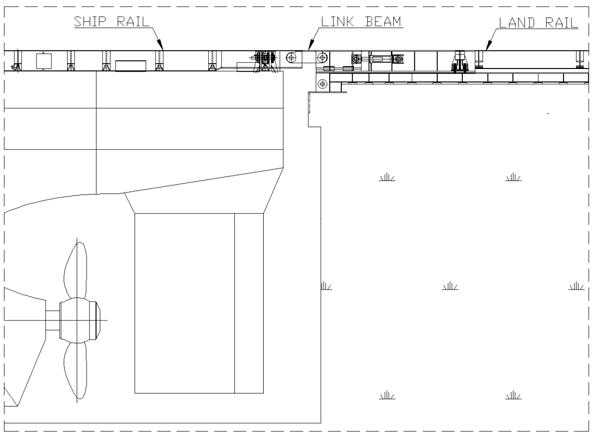

Figure 2.1.5: Connection of the skidding rails

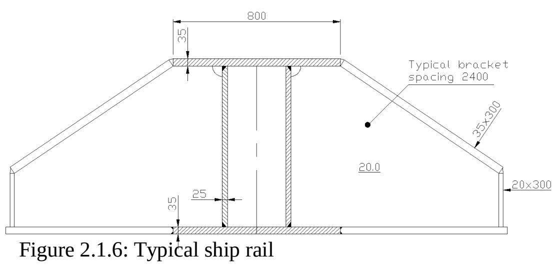

Figure 2.1.6: Typical ship rail

2.1.2 Link Beam and Positioning of the Vessel

The skidding tracks on the shore and on the vessel are connected with a link beam that allows the floating vessel to slightly move horizontally. The vessel is hold on an even keel as far as possible by ballasting the vessel.

Figure 2.1.7: Connecting the link beam

The positioning of the vessel is essential since the skidding tracks have to be aligned properly in order to have a successful load-out operation. The vessel is moored perpendicular to quay with wire ropes. The positioning is carried out with hydraulic cylinders.

Transversal positioning is controlled with two cylinders affecting to a beam welded onto the deck of the vessel. With the system, the vessel is adjusted into a right position so that the link beams can be connected. The vessel is hold in a straight line by adjusting the link beam longitudinally with two cylinders mounted on both sides of the link beam. Since the link beam is connected to rails on the vessel, the vessel can be adjusted by pushing the link beam forwards or pulling the beam backwards.

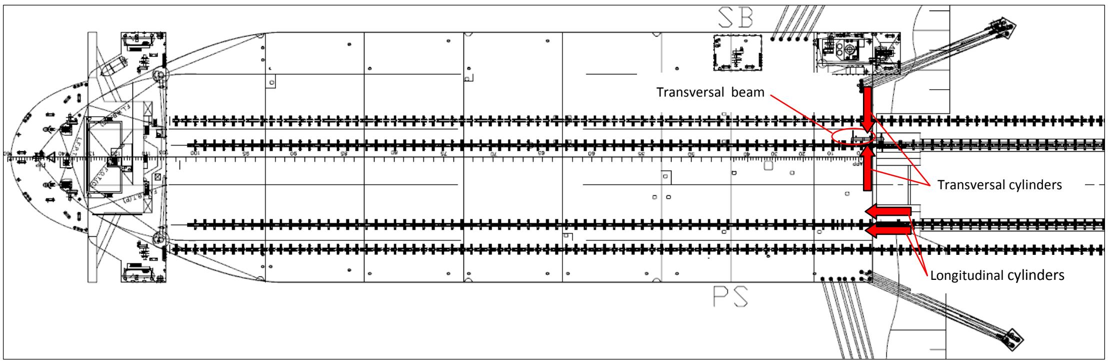

Figure 2.1.8: Positioning of the vessel

2.1.3 Current Rollers

At TOF rollers are used to provide skidding. Rollers are added between the skid shoe and the skidding rail in roller units. The roller units are laid on the skidding rail for the whole skidding length before the actual skidding operations begin.

Roller unit consists of seven rollers that are connected from both ends to a longitudinal flat bar. The longitudinal flat bars are connected together with four transversal beams. The roller units are connected to each other with seam plates.

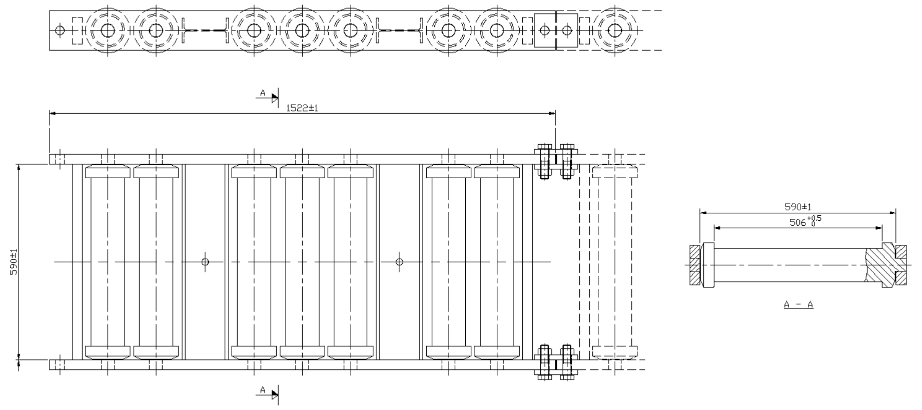

Figure 2.1.9: Roller unit

The skid shoe travels along rollers with a roller plate that is fitted under the skid shoe beam. The rollers then again travel along the roller plate that is fitted on top of the skidding rail's top flange. The roller plate on skid shoe is welded onto the skid shoe. Figure 2.1.10 illustrates the arrangement of the roller plates and the roller units.

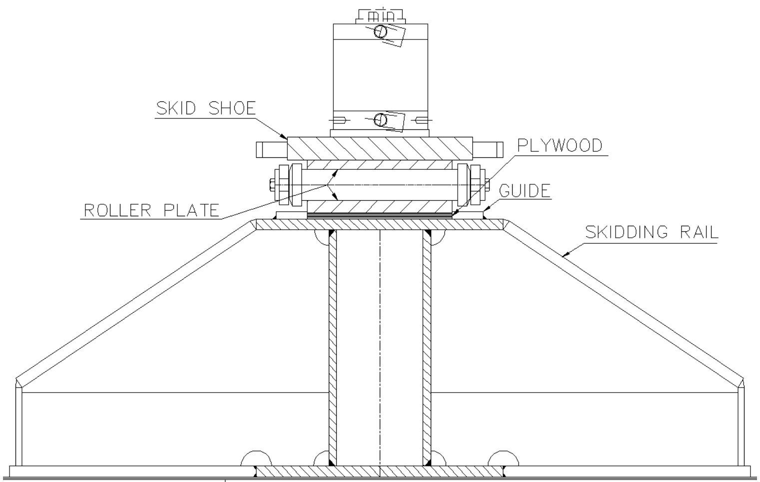

Figure 2.1.10: The arrangement of the skidding equipments

The roller plate on the skidding rail is placed on top of plywood that is fitted on top of the skidding rail. To ensure that the plywood as well as the roller plate holds in straight line guide plates are welded to the skidding rails top flange, see fig. 2.1.11.


Figure 2.1.11: Roller plate on the skidding rail

Disadvantage with rollers has proven to be low tolerance for transversal movements in skidding operations due to the structure of the rollers. At TOF products are loaded out from outdoor assembly area. The products can be up to 200m long and 46m high. Due to exposure to environmental conditions, thermal expansion may cause bending to the structure. Bending together with misalignments in track lines and roller plates has caused problems in the skidding operations. When the skidding track or roller plate and the skidded structure deviates in straightness, the rollers flange may collide with the roller plate. Figures 2.2.1 and 2.2.2 illustrate collisions that have occurred when alignments have not been properly executed.


Figure 2.2.1: Collision


Figure 2.2.2: Collision

When the skidding track is not properly aligned the skidded structure may also push the rollers laid ahead out of line, as in fig. 2.2.3. Rollers are laid onto the skidding track for the whole skidding length before the actual skidding operations begin. Therefore the rollers are without load until the skidded structure comes on and they are able to go out of line with fairly low effort. Only flanges at the ends of the roller are preventing roller unit from going out of line.

Figure 2.2.3: Roller unit out of line

To avoid the risk of collisions, it is essential that roller units as well as the skidding rails and roller plates are aligned properly and hold in a straight line. In recent projects attention is paid in particular to the track alignments and to the straightness of the floating transport vessel. Also bio-degradable oil has been added to reduce friction. As a result of the actions made, skidding operations in recent projects has proceeded without major problems.

The friction coefficient for steel roller/steel is 0.02 both in static and in dynamic conditions according to classification rules, DNV Load Transfer Operations (April 2012). The classification rules requires to record i.e. used push/pull forces, from which realized friction coefficients can be conducted. Figure 2.2.4 illustrates realized friction coefficients in TOF’s projects. Projects are in chronological order, lowest being the most recent one. The measured friction coefficients support the fact that rollers are functioning more effectively when skidding tracks are properly aligned.

Unit	Weight 1000kg	Friction 1000kg	Friction coefficient	Note
*********	9700	160	0,016	North Tracks
*********	10500	180	0,017	North Tracks
*********	11000	190	0,017	North Tracks
*********	11000	250	0,023	North Tracks
*********	14230	435	0,031	South Tracks
*********	17917	452	0,025	South Tracks
*********	23671	660	0,028	South Tracks
*********	24379	451	0,019	South Tracks
*********	20940	376	0,018	South Tracks

Figure 2.2.4: Realized friction coefficients

2.1.4 Push-Pull Unit

In a skidded load-out the structure is pushed or pulled onto the transport vessel. At TOF the structure is pushed from the shore side end with hydraulic gripper jack units. The units are mounted consecutively on both skidding rails. The number of the units depends on the needed jacking force. Also reserve units are required for safety and contingency reasons.

To ensure a feasible load-out, pushing system must also be capable to pull. The push-pull units used at TOF have a pushing capacity of 110 tons and pulling capacity of 80 tons. The unit consists of hydraulic friction-lock gripper and two double acting hydraulic cylinders. The hydraulic power units are added behind the push-pull units on both tracks. The push-pull units are operated by one operator per rail. Operators are in constant visual contact. The synchronizing between the rails is conducted by signs only.

Figure 2.2.5: Push-pull units on the rails

Figure 2.2.6: Push-pull unit assembly

The push-pull unit operates by clamping the flange of the skidding rail with hydraulic gripper and then extending the cylinder. The gripper acts as a moveable reaction point for the jack. After one stroke the gripper is released and the cylinder retracted, advancing the gripper into a new anchor position. The cycle is then repeated as many times as is required to move the load.

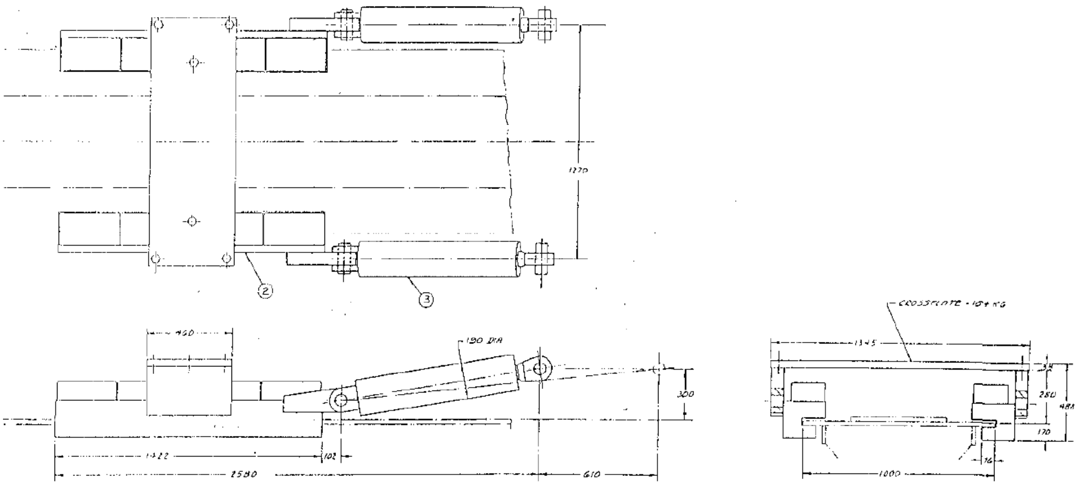

Figure 2.2.7: Push-pull unit

2.2 Quayside and Inland Foundations

Assembly site at TOF consists of two assembly lines, southern and northern. The capacity of the tracks differs, the northern tracks allowable line load is 100 tons/m whereas the allowable load on the southern tracks is 225 tons/m.

The strengthening principle of the both assembly tracks is similar. Foundations are strengthened with reinforced concrete piles at inland areas. All foundations are set on moraine rock and therefore the physical properties of the soil layers above moraine rock are not crucial for the stability of the foundations. The quaysides of the both assembly lines consist of caisson structures.

The capacity on the southern assembly tacks is higher because of more robust strengthening. The foundations under the southern assembly tracks are reinforced with several pile matrices. The pile matrix consists of 300 mm x 300 mm reinforced concrete piles driven to the moraine rock layer, in rows of three piles at 900 mm centers.
The area between the rail lines is reinforced at ~10m with a cross beam and piles under the cross beam. Figure 2.2.8 describes the structure of the foundations under southern assembly tracks. The foundations under northern assembly tracks are reinforced with pile matrix as well. However, the cross beams and piles under the cross beams between the rail lines are excluded. Therefore the capacity on northern assembly tracks is less.

The additional skidding tracks have not been used formerly. However, analyses concerning the strengthening of the foundations are made and the principle of the foundations will be similar with the main skidding tracks.

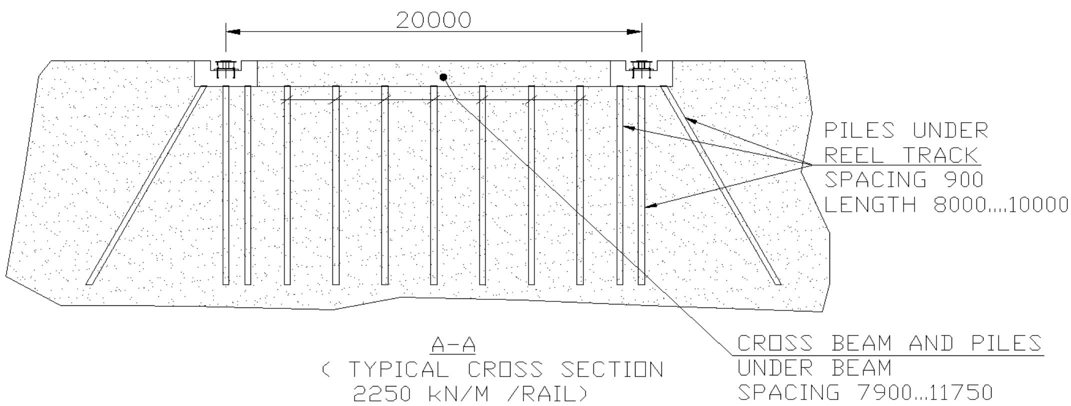

Figure 2.2.8: Cross section of typical foundations

The quayside of the both assembly tracks consists of caisson structures. The caissons are anchored to moraine rock. Caisson is strengthened to withstand the loads affecting the link beam. Despite the strengthening the allowable loads for the quay are restricting pushing forces used at load-out operations. To increase capacity, anchoring to moraine rock needs to be reinforced.

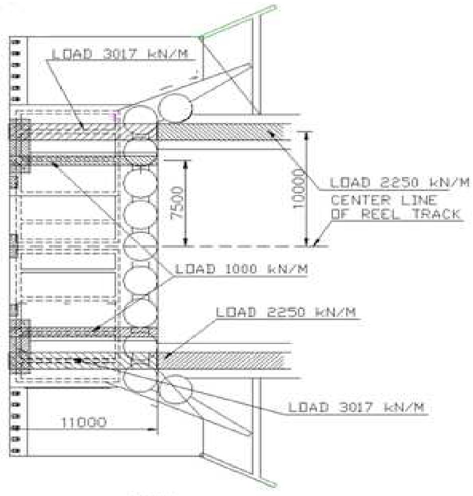

Figure 2.2.9: Structure of the quay

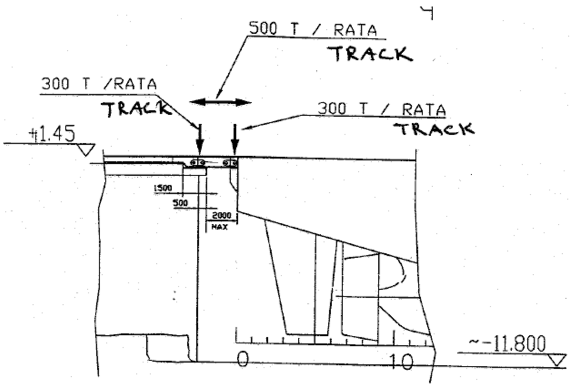

Figure 2.3.0: Allowable loads for the quay and the link beam

3 REQUIREMENTS

The equipment and methods used in offshore marine operations, in which load-out is included, must fulfil the requirements given in the classification rules. Rules are provided by rating institutions, which also ensures that the design and execution plans are feasible, safe and made according to the rules.

Rating institutions that provides classification services for offshore structures are e.g. Bureau Veritas, Det Norske Veritas, Germanischer Lloyd and Lloyd's Register. The rules are somewhat similar with each other. The decision which institution to use is usually made by the client. This study is made in accordance with series of marine operations rules by Det Norske Veritas.

- DVN-OS-H101 Marine Operations General, October 2011
- DNV-OS-H102 Marine Operations Design and Fabrication, January 2012
- DNV-OS-H201 Load Transfer Operations, April 2012
- DNV-RP-H101 Risk Management in Marine and Subsea Operations, January 2003

Classification rules give the guidelines and regulations on which basis the selection of the used equipments shall be made. According to the classification rules, systems and equipment shall as far as possible to be fail safe and so arranged that a single failure in one system or unit cannot spread to another unit. Emphasis shall be put on reliability and the expected behaviour in possible contingency situations. All essential systems, part of systems or equipment shall have spares or back-up alternatives. All systems shall also be tested prior to usage.
If relevant the push-pull system should be able to provide adequate braking capacity at any time. The relevance of the braking capacity shall be evaluated assessing conservatively the possible effects of, track slope (including maximum possible inclinations of the load-out vessel) or extreme low friction (by using rollers or surfaces with very low friction). Skid track levelness tolerances, surface condition and side guides should be adequate for the applied skidding equipment. /3/

At TOF reliability as well as safety are important aspects. Any delays in load-out operations are unwanted since the operations are strictly scheduled and the transport vessel is reserved only for a certain time window. Demurrage days cause costs. Environmental aspects are also important to take into account when planning operations. Safety is a top priority for the clients. Every accident is reported and company’s injury rate is highly emphasized. Above all, the skidding system shall be feasible for the intended purpose.

3.1 Functional and Operational

Functional and operational requirements for the skidding equipments are a high tolerance for transversal differences in straightness of the track lines and differences in levelness. Since the structure is loaded onto a floating vessel via link beam, there is a possibility for vertical differences in track lines. Also a low friction coefficient is a significant factor, allowable horizontal loads for the quay are restricting the usable pushing forces.

Emphasis shall be put on feasibility. The system on additional skidding tracks shall be able to be taken in use in parallel with the system on the main tracks. Thus, the skidding length on the additional tracks may differ from the length on the main tracks. Since the load-outs are conducted in an outdoor environment, the skidding system shall be feasible in all weather conditions. Requirement for braking capacity shall be considered fulfilled with push-pull units operating with clamping principles.

Furthermore, the feasibility in the construction phase of the structure shall be assessed. The structure is erected on the main skidding tracks, where it’s supported with the same equipments which are used in load-out’s. The equipments used on the additional skidding tracks are applied when load-out operations take place and therefore the system does not have to be feasible in the construction phase.

3.2 Design Loads

The loads are always project related, therefore the skidding equipment used on the main skidding tracks shall be designed to tolerate the maximum allowable line load for the skidding tracks, load of 225 tons/m.
The additional skidding tracks are used to spread the load on the transport vessel, therefore the loads for the tracks are vessel related. However, the maximum load considered to be taken with the additional skidding tracks is 100 tons/m.

The required push-pull capacity depends on the friction coefficient and on the weight of the structure. The push-pull systems shall be able to mount consecutively onto the skidding tracks to ensure sufficient capacity.

3.3 Health, Safety and Environment

Health, safety & environment aspects are important to take into account when planning operations. These aspects are highly emphasized by the client and they also reflect to the company’s reputation.

To be considered safe, skidding equipments shall be reliable and arranged so that failure in one system or unit cannot reflect to another unit. Attention shall be paid in particular to supporting the load. Load is supported with hydraulic jacks. In case of a leakage in the hydraulic hoses or failure in the power pack, the load shall have back-up supports. However, when additional skidding tracks are used, only the other system, main or additional, shall have the back-up supports. /3/ /5/

To minimize any risk of incidents, attention shall be paid to working methods and to the working environment during load-out operations. The systems shall be able to be used without or with few as possible personnel in close proximity to the equipments used in operations. Especially in close to the hydraulic hoses since the pressure in the hoses may be up to 380 bars. Usage of possible lubrication has to be conducted in a way that the surroundings of the skidding tracks will not get slippery. Particularly on the deck of the transport vessel. The systems and lubricants used shall be as far as possible environmentally friendly.

3.4 Risk Management

A risk management plan is recommended in marine operations to describe, communicate and document the objectives, responsibilities and activities specified for assessing and reducing the risk to an acceptable level. Risk evaluations are required depending on the complexity and duration of the operation, and the structure itself. Equipments considering skidding shall be considered as applicable. DNV recommends that risks within marine operations are assigned against criteria for personnel safety, environment, assets/lost production and reputation. /3/ /6/

In this study attention is paid to potential risks. However, the actual risk evaluations are excluded.

4 SKIDDING METHODS

Skidding is one of the world's oldest ways of moving heavy loads. Over the years a variety of skidding techniques has been developed and used to move heavy structures. Most of the methods utilize skidding tracks, friction reducing materials and propulsion force to move the structure. In general there are two methods used to propel the structure. One implies a strand jack to pull the structure while the other uses a hydraulic push-pull system. /2/

The skidding methods are selected for this study with two principles in mind. One, the methods should utilize different types of friction reducing principles. Second, if the solution includes propulsion force, the force should be produced with hydraulic push-pull system. Although strand jacks are widely used in heavy move operations they are excluded from this study. The purpose is to concentrate more on the friction and weight carrying properties as well as to feasibility in load-out operations. However, since some of the selected alternatives include integrated push-pull units, concentration will be paid to the pushing capacity as well.

The selected methods are divided into three groups based on the friction reducing principles. The groups are rollers, teflon pads and air cushions. The selected equipments for the roller group are the roller dollies from Hilman Incorporated and the current roller units. The methods utilizing teflon pads are the skidding systems from Mammoet Europe B.V. and Enerpac Integrated Solutions B.V. The method utilizing air layer to reduce friction is the air pad system from Hebetec Engineering Ltd.

The solutions provided by Hebetec, Mammoet and Enerpac include integrated push-pull units as well as load carrying cylinders. The skidding method with Hilman rollers is similar with the current method, only the currently used roller units would be replaced with Hilman units.

4.1 Rollers

Rollers are simple and effective way to reduce friction. Friction coefficient for rollers is 0.02 both in dynamic and static state according to the classification rules, DNV Load Transfer Operations (April 2012). However, as there are a variety of roller types available for heavy move purposes, the friction varies depending on the application. Therefore the friction coefficient stated by the manufacturer is preferred to use in calculations.

In general there are two methods to utilize rollers in skidding. One, the rollers are connected to the moving structure. Second, the rollers are laid onto the skidding rail for the whole skidding length. The second method requires more roller units to be used. In this study both of the methods are represented. Hilman rollers are connected to the moving structure whereas the currently used are laid onto the skidding track.

4.1.1 Current Rollers

The currently used skidding system consists of roller units, skidding tracks, push-pull units and hydraulic jacks to support the load. The method and the associated equipments are described in chapter 2.1.

The principle of the current skidding method is to support the load with hydraulic jacks and use rollers to reduce friction. The propelling of the structure is carried out with hydraulic gripper push-pull units. The load supporting jacks have a capacity of 180 tons. The roller units consists of several rolls connected to each other from both ends with a longitudinal beam. The units are connected to each other with seam plates and are then put on the skidding rail. The push-pull units are arranged consecutively and the combination is pushing the structure from the shore side end. The push-pull unit has a push capacity of 110 tons and pull capacity of 80 tons.

Figure 4.1.0: Currently used skidding method

4.1.1.1 Capacity

The load supporting hydraulic jacks have a safe working capacity of 180 tons. At construction phase the load is supported with blocks placed between the jacks on the skidding shoe. Therefore, the jacks can be arranged with a minimum spacing of approximately 0,7m.

The maximum line load to be supported with the system is then 180 tons/0,7m ≈ 257 tons/m. However, the safe working load of the roller units is only 183 tons/m. Thus, the maximum line load for the system is 183 tons/m.

The push-pull units have a push capacity of 110 tons and pull capacity of 80 tons. The units can be arranged consecutively to ensure sufficient capacity. However, the maximum number of units to be arranged consecutively is five.

4.1.1.2 Friction

The friction coefficient for the rollers is 0.02 both in static (breakaway) and dynamic state according to the classification rules. The realized friction coefficients support the value given in the classification rules. The friction has been approximately 2%.

4.1.1.3 Space Requirement

The skidded structure is supported with sea transportation cradles. The skidding system will support the load from the cradles, therefore the system has to fit under the cradle. The cradles are always project related and thus no strict height limit can be stated. The cradles will be designed so that the used skidding system fits underneath and the cradle has the required strength.

The current system has been used in several projects and therefore the height requirement is well known. The height of the combination of skidding track, rollers and hydraulic jack in half stroke is ~1,6m. The stroke of the 180 tons jack is 150mm.

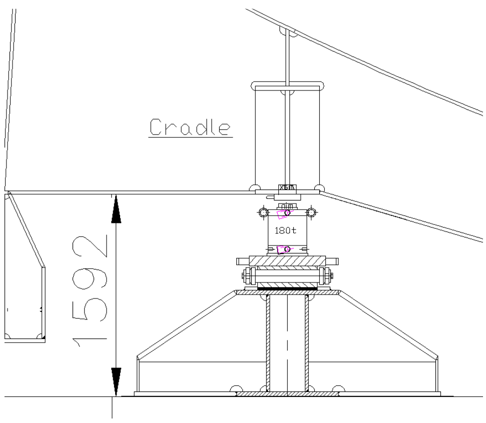

Figure 4.1.1: Height of the current system

4.1.1.4 Feasibility

The current system has proven to be feasible method when skidding tracks are properly aligned and the vessel hold in a straight line. However, now as the loads are becoming higher the system is pushed to the limits. The system is capable only for line loads up to 183 tons/m. Although the capacity of the load supporting jacks is 257 tons/m the capacity of the roller units is only 183 tons/m. The benefits of the system are fairly low friction and great feasibility at construction phase, since the load can be supported with support blocks. The system has also proven to be feasible in all weather conditions.

However, the system has low tolerance for deviations in straightness of the skidding tracks. The deviations increases friction and at the worst case the whole skidding operation has to be aborted because the system is completely jammed. For additional skidding tracks the system is complicated to take in use while skidding operations are in progress. The load is supported with several jacks that are on the skid shoe without fastening. The skid shoe beam with the jacks would have to have an additional suspension system so that the beam would be able to lower down and take in use when needed. The highest risk of the system is the alignments. If the alignments are not properly made the accomplishment of the whole skidding operation is jeopardized.

4.1.2 Hilman Rollers

Hilman Incorporated provides a wide range of high capacity rollers for demanding moving purposes. All Hilman Rollers utilize the endless chain principle, which features a chain of steel rolls capable of rotating about a central load-bearing, steel plate. The result is a high capacity conveyor with low friction. Hilman rollers can be referred to dollies or skates. /7/

Although Hilman provides also motorized rollers and rollers whit hydraulic integration, the roller for this study is selected from the individual super heavy duty rollers product family. Individual rollers are available as standard ranging from 1 to 1000 tons. The requirement is to withstand a 225 tons/m, thus the capacity has to be somewhat 200 tons and the body length has to be selected so that the rollers can be laid consecutively to ensure sufficient capacity.

The rollers with capacity of 200 tons and the shortest body length are the 200-XOTW and 200-X0TWC. The difference between the rollers is the way how the rollers are arranged. The separate rolls are of the same size in diameter and width. Thus, the total footprint of the rollers is the same and the pressure for the skidding track as well. The rollers also have the same friction coefficient. Therefore the rollers can be considered as similar with each other and be evaluated as one. /7/

Figure 4.1.2: Hilman rollers 200-XOTW and 200-XOTWC. /7/

4.1.2.1 Capacity

All Hilman rollers are designed with a safety factor of at least 1.5. Rollers type 200-XOTW and 200-XOTWC have both a safe working load of 200 tons. Both of the roller units are of the same size in body length, 533 mm.

Theoretically the rollers are possible to mount with every 533mm centers. Therefore, the maximum line load for the rollers is the capacity divided with the spacing, 200 tons/0,533m ≈ 370 tons/m. The rollers fulfill the requirements, the capacity can be considered as sufficient for usage on both, main and additional, skidding tracks. /7/

However, the load has to be supported with hydraulic jacks in order to distribute the load evenly and therefore the actual capacity of the skidding system depends on the capacity of the load carrying jacks. Furthermore, it can be assumed that the skidding track will be under high pressures with the Hilman rollers and the usage of high strength roller plates on the skidding tracks is required.

4.1.2.2 Friction

The friction coefficient for the rollers is 0.02 both in static and dynamic state according to the classification rules. However, as the Hilman rollers utilize the endless chain principle the friction is more. The breakaway friction according to Hilman should not exceed 5% on a hard and level surface. It’s also said that the friction has been less under ideal laboratory conditions. For calculations Hilman recommends to use the friction coefficient of 0.05. /7/

4.1.2.3 Space Requirement

The skidding system with the Hilman rollers is similar with the current system, only the currently used roller units would be changed to Hilman roller units. The Hilman rollers are higher than the current rollers, however the height difference is minimal. The height with the Hilman rollers is ~1,7m, when the jack is in half stroke.

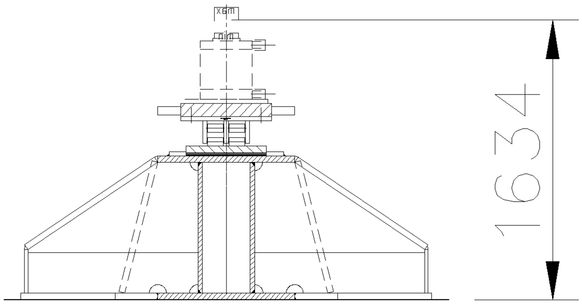

Figure 4.1.3: Height of the skidding system with Hilman rollers

4.1.2.4 Feasibility

The skidding method with Hilman rollers would be a feasible method on the main skidding tracks. The system would be capable for line loads up to 257 tons/m when the load is supported with the old load carrying system. However, the strength of the currently used skidding track would have to be analysed, since the load for the skidding track would be extremely high.

Nevertheless, the capacity of the whole system would be sufficient for the loads that the foundations tolerate. As the supporting principle of the load would be similar with the current, the system would be feasible in construction phase. The system would also be feasible in all weather conditions.

However, the friction with the Hilman rollers would be higher. The friction is 5%, when the skidded loads can be even 47 000 tons, the friction is a significant factor. The Hilman rollers do not require as precise alignments as the current system. Since the roller unit has no flanges and is connected to the transportation cradle, the rollers can roll without restrictions. Nevertheless, the roller units would still have to be installed into a straight line with a high precision. If the units protrude, the friction will increase and there is a possibility that the rollers go off from the skidding track. To keeping the moving structure in a straight line, Hilman provides guide rollers to be attached to the roller units. /7/

Figure 4.1.4: Hilman rollers equipped with guide rollers. /7/

For additional skidding track usage the system has the same drawback as the current system. The system would require additional suspension system and the lowering would increase the risk of misalignments. For main skidding tracks the system has the required capacity, however the friction is high.

4.2 Air Cushion

The air cushions operate by creating a cushion of high pressurized air between the supported load and the surface below. The cushion is created by feeding high pressurized air into a sealed chamber. The load floating over an air cushion has no other contact to the surface below than the sealing ring and therefore the friction is low.

Classification rules do not recognize air cushions and thus no common friction coefficient is given. The friction coefficient is case related and depends on the application, therefore the friction coefficient to be used in the calculations is based on the manufacturers' previous experiences. /8/

Although air cushions are an old innovation and commonly used in heavy move operations, the only system found for load-out purposes was the APS-system from Hebetec Engineering Ltd.

4.2.1 Hebetec APS-system

Hebetec Engineering Ltd. provides comprehensive services in the lifting engineering area. The field of activities ranges from the preparation of solution concepts and the execution of lifting, lowering and skidding heavy loads up to renting out hydraulic devices. The concept selected for this study is the air pad skidding system, APS-system. The APS-system is a skidding system that operates with an air cushion to move heavy loads with a low friction. The system consists of load modules, slide ways, push-pull units and the associated hydraulic and compressed air supply systems. In general, the system includes all that is required in skidding operations. /9/

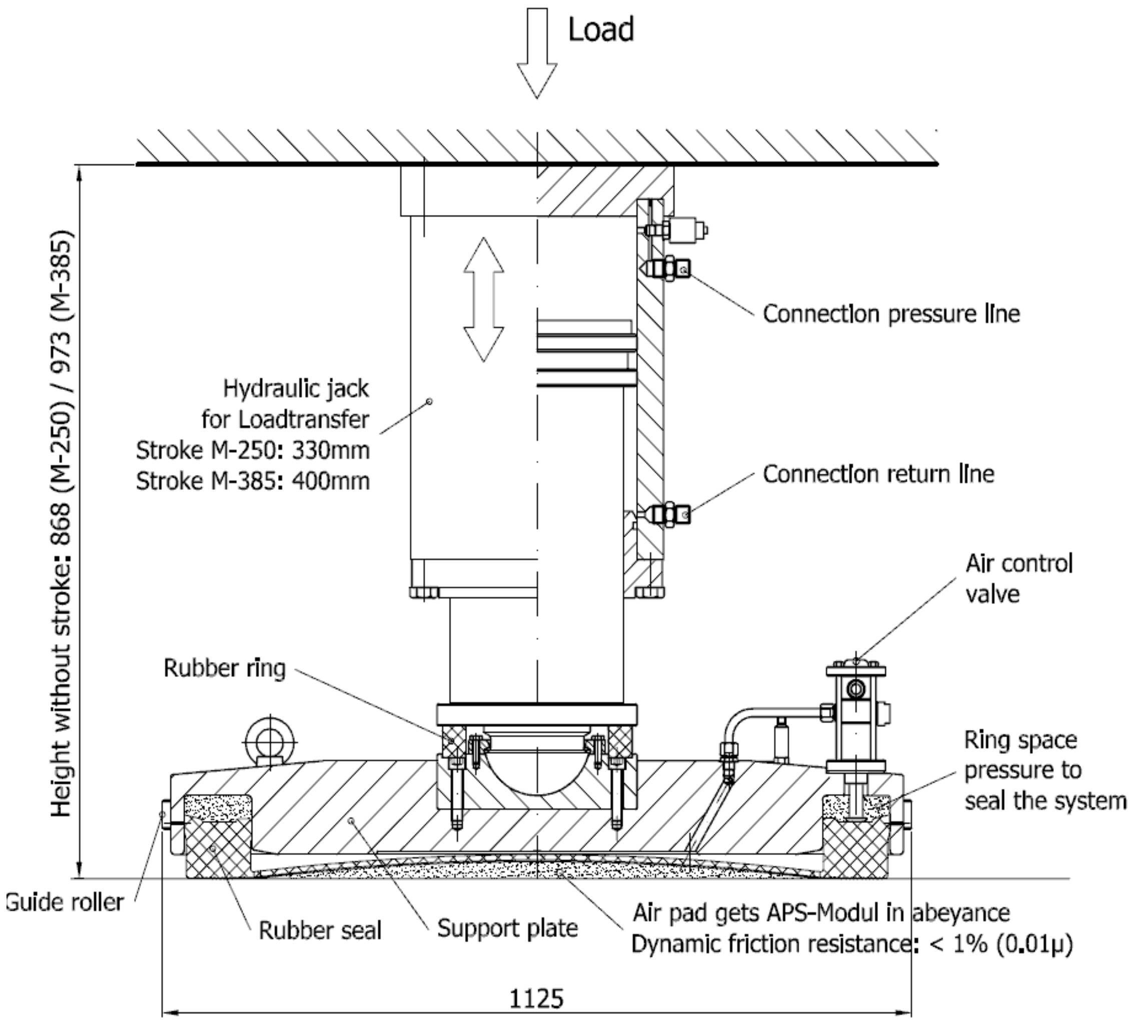

Figure 4.2.0: The operating principle of the load module. /10/

With the APS-system the load is supported with load modules. The load module consists of hydraulic jack that is connected to a support plate. The support plate has an integrated sealing ring at the bottom creating a chamber in which the compressed air is feed. The compressed air creates an air cushion between the module and the surface below allowing the module to slide with an extremely low friction. The modules are available with load carrying capacity of 250 tons and 385 tons. /10/

The APS-modules can be used on any airtight surface with sufficient strength. However, Hebetec recommends to use skidways specially designed for the modules. The skidways have guide boards to guide the modules during sliding operation. Usually more than one skidway is used, but only one skidway is guiding the modules. The guiding skidway has a width of 1200 mm, the other skidways are wider allowing the modules to slide without restrictions. The skidways are lubricated with silicone oil. /10/

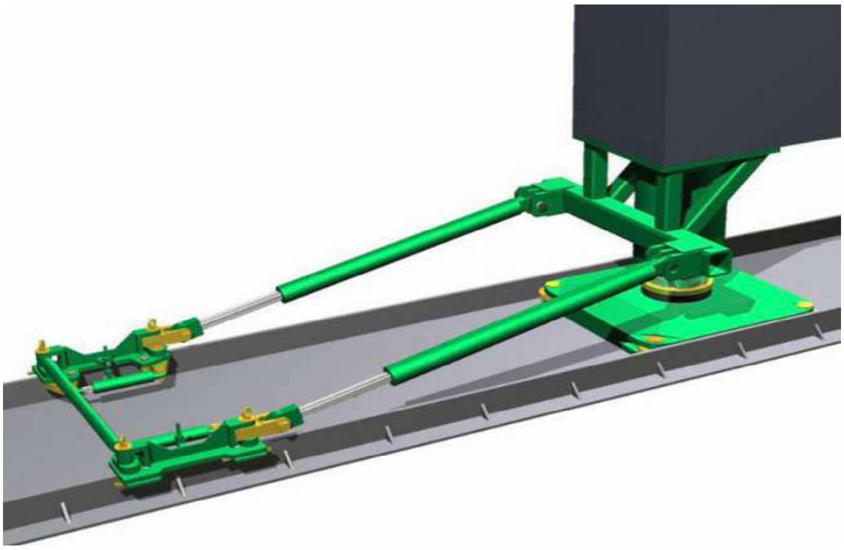

Figure 4.2.1: The skidway, push-pull unit and the load module of the APS-system. /10/

Hebetec provides hydraulic gripper push-pull units specially designed for the APS-system. The units are available with push capacity of 32, 100 and 160 tons. The units operate with the same principles as the push-pull units currently used at TOF.
The units are designed to be used with the skidways that Hebetec provides. The unit clamps on the skidways guide board and then pushes the load forwards by extending the cylinder. /10/

Hebetec also provides the adequate hydraulic and compressed air supply systems. One hydraulic power pack is sufficient for 32 load modules and two or four push-pull units with grippers, depending on the capacity of the push-pull units. The power pack is equipped with wheels and is placed on the skidway where it follows the moving load modules. The compressed air or nitrogen is supplied in bottles or with tanker. The consumption is approximately 5 – 10 m³/h. The APS-system is operated with computer based system, each load module can be controlled individually or in groups. /10/

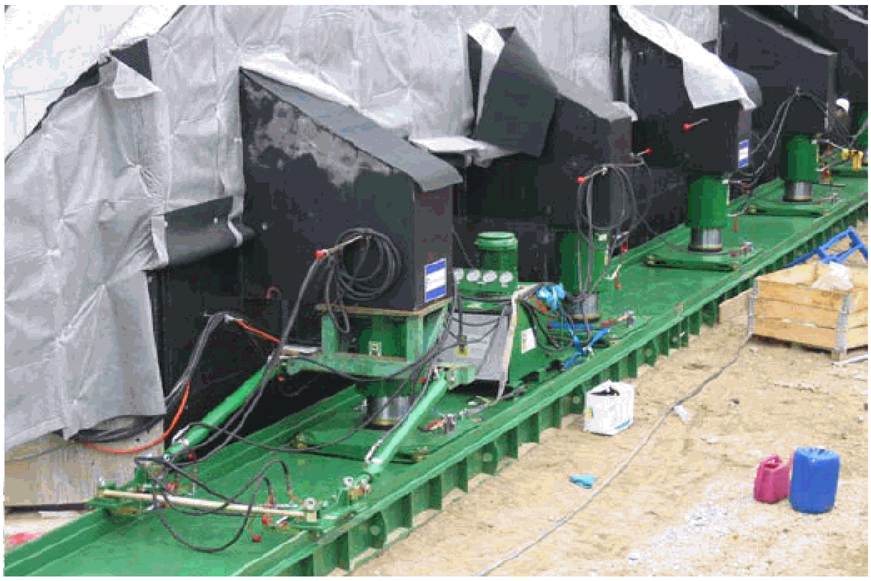

Figure 4.2.2: APS-system in use. /10/

4.2.1.1 Capacity

The load modules are available with capacities of 250 and 385 tons. The safe working load for the modules is 80% of the maximum capacity. Thus, the safe working capacities are 200 and 308 tons. /11/

The load modules can be arranged with minimum spacing of 1250 mm. Theoretically the maximum line load to be supported with the modules is the safe working load divided with the spacing. With 250 tons module the maximum line load is thus, 200 tons/1,25 m ≈ 160 tons/m. And with 385 tons module, 308 tons/1,25 m ≈ 246 tons/m. The APS-system has the sufficient capacity for usage on both, main and additional, skidding tracks.

Push-pull units are available with push capacities of 32, 100 and 160 tons. The most suitable system for TOF's purposes is the one with the highest capacity, push capacity of 160 tons and pull capacity of 80 tons. Since the friction is low, it can be assumed that the required push-pull force can be fulfilled with only few units. Thus the units can be arranged behind the load modules and therefore the load modules can be arranged with a minimal spacing. /11/

4.2.1.2 Friction

The friction of the air cushions depends on the sealing material of the air chambers as well as the contact surface and the air pressure in the chambers. Thus, no common friction coefficient is given in the classification rules.

Hebetec states that the friction for the APS-system has usually been 0.5%. At the lowest the friction has been 0.2% and at highest 1%. For calculations Hebetec recommends to use the friction value of 1%. If the compressed air for some reason leaks out from the chambers, and the whole load of the module will be on the sealing ring, the friction will then increase to 15-20%. However, the skidding operation will be aborted if the air leaks from the chambers. /11/

The skidding tracks used with air cushions have to be air tight. Hebetec recommends to use their own painted steel skidways, however in special cases when the modules have been used on unfinished steel surface the friction has not increased significantly. /11/

4.2.1.3 Space Requirement

The space requirement with the APS-system depends on the load modules. The load module with capacity of 385 tons is 973mm height and has a stroke of 400mm. The module with capacity of 250 tons is 868mm height and has a stroke of 330mm.
The skidways are available in heavy and light versions. The heavy version is higher, skidding surface is 228mm from ground.

The actual height requirement of the APS-system depends on the module and skidway. The skidway also probably requires load spreading beam underneath. The size of the beam depends on the loads. However the combination of the higher load module and skidway requires vertical space of ~1,4m when the cylinder is in half stroke.

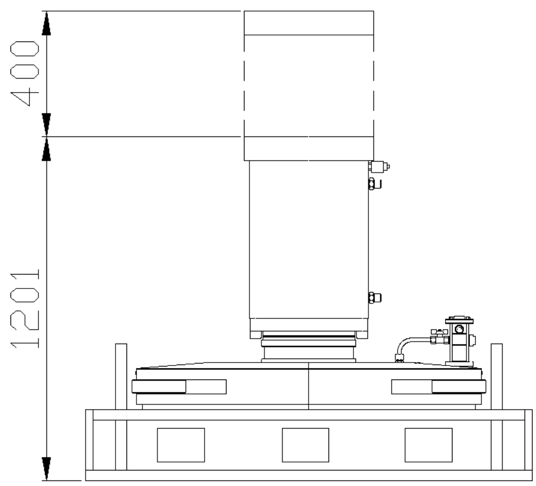

Figure 4.2.3: Height of the APS-system

4.2.1.4 Feasibility

The APS-system meets the load requirements and has the needed capacity for usage on both, main and additional, skidding tracks. The system is suitable for line loads up to 246 tons/m. However the Hebetec's skidways don't spread the load rather well and the system would require to use load spreading beams underneath the skidways. Nevertheless, the capacity would still be sufficient.

Advantages of the APS-system are extremely low friction and fair tolerance for deviations in straightness and levelness. Since the skidways are over dimensioned in wideness, the load module can slide without restrictions. However, one of the skidways has to be narrower and considered as the guiding skidway. The load modules have guiding rollers on sides to guide the moving structure and avoid abrasion with the side flanges of the skidway. The load modules can be controlled individually and therefore deviations in levelness can be compensated by adjusting the lifting cylinder. Since the friction is extremely low, less than 1%, and the push-pull units have a high capacity, only few units are required to propel the structure. The silicone oil used for lubricant is environmentally safe and the structure of the skidway prevents the oil from leaking out to the surroundings.

However, the system has drawbacks. Hebetec provides the system as subcontractor basis by leasing the equipment and operating the system. Therefore, as the construction time is more than a year, the system is not feasible for the usage on the main skidding tracks. However, for usage on the additional skidding tracks the system is ideal. The skidding equipments on the additional tracks are only needed for the actual load-out, not in construction phase. Hebetec course also sells the system, but the system is not also otherwise feasible for the main skidding tracks. The load on the main tracks requires to have back-up supports and the APS-system has no back-up supporting. The APS-system can be taken in use as a secondary system on the additional skidding tracks by lowering the load modules individually. However, generating the compressed air layer takes approximately 2 – 3 minutes.

For all weather conditions the system can be considered feasible with few observations, the skidways have to be clean and the air pressure decreases at low temperatures. However both of the issues can be overcome. The highest risk of the system is that the compressed air leaks. If the air leaks from the chambers the friction increases dramatically and the skidding operation has to be aborted. Because the system has no back-up supports the maintenance and replacing modules is challenging, if the hydraulic pressure for some reason disappears.

4.3 Teflon Pads

Teflon is the brand name for polytetrafluoroethylene (PTFE) by DuPont Co. Teflon is a thermoplastic polymer. It has many favorable properties, high chemical resistance, high melting point, low friction and excellent dielectric properties. Major drawback of teflon is the limited wear resistance. However, the load-out operation can be considered as a short time duty and thus the wear properties are not important. /12/

The common friction coefficient for teflon against steel is 0.25 in static and 0.10 in dynamic state according to the classification rules, DNV Load Transfer Operations (April2012). However, the friction varies depending on temperature and the loads as well as the contact surface’s quality. The friction is thus case related and depends on the application. The friction value to be used on the calculations should be based on previous experiences or tests. The friction coefficient for the both skidding systems using teflon pads in this study are stated to be lower than the common value given in the classification rules.

The skidding systems selected for this group are the skidding systems from Mammoet Europe B.V. and Enerpac Integrated Solutions B.V. The systems are rather similar with each other. The principles of load bearing, reducing friction and propelling are almost identical. However, the systems have differences in capacity and friction.

4.3.1 Mammoet Skidding System

Mammoet's activities in the offshore industry include the accurate and safe implementation of transport solutions by land and water, load-ins and load-outs, and the assembly of extremely large and heavy items. Mammoet operates and rents skidding systems and strand jack systems to lift, lower or slide heavy loads. The system selected for this study is the skidding system with integrated load carrying cylinder and push-pull unit. /13/

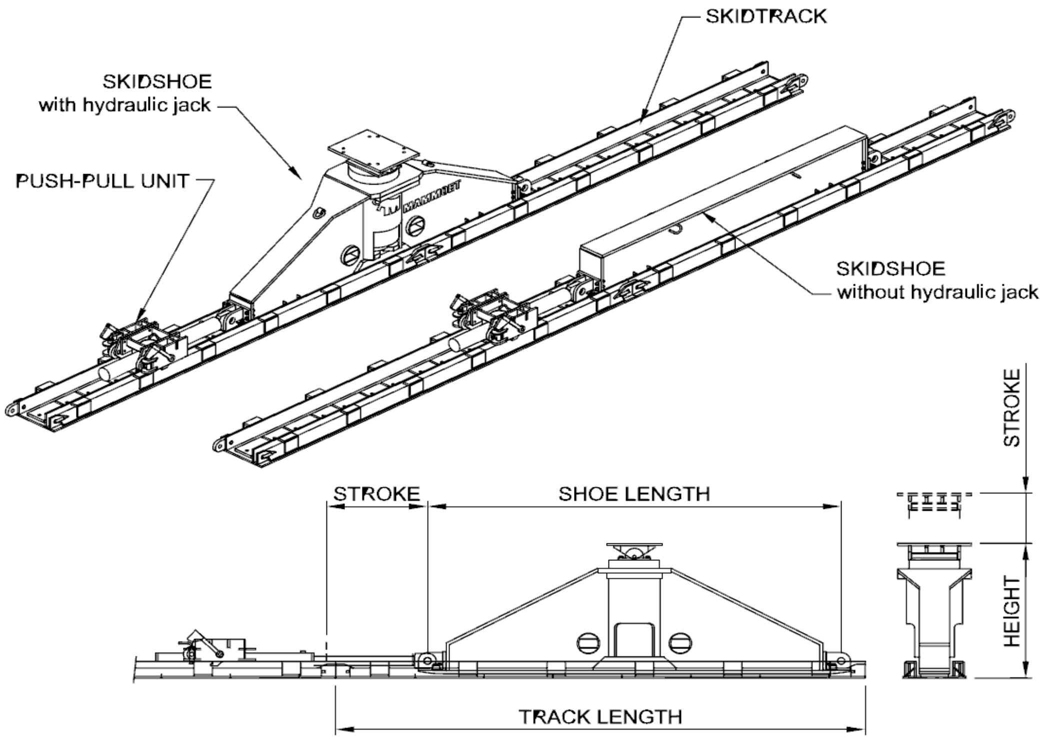

Figure 4.3.0: The skidding system. /13/

The skidding system consists of skid shoes to carry the load, skidding tracks, push-pull units and hydraulic power packs. The skid shoes are available in light, medium and heavy versions. However, the system with integrated hydraulic jack is only available in heavy version with a capacity of 600 tons. /13/


Figure 4.3.1: The skidding system in use. /13/

The push-pull unit in combination with the skidding tracks takes care of the horizontal movement. The push capacity of the unit is 64 tons. The clamping of the unit is executed with lever locks. The skidding track has push-off cams for the lever locks every 690mm. The friction is reduced with teflon pads placed on the skidding track. The skid shoe slides over the pads with a stainless steel plate welded underneath the body. /14/


Figure 4.3.2: The push-pull unit. /13/

4.3.1.1 Capacity

Mammoet's skid shoe with integrated hydraulic jack is only available as a standard with a capacity of 600 tons. The additional push-pull unit for the skid shoe has a push capacity of 64 tons. Both of the loads are safe working loads. /14/

The skid shoes' body length is 4,5m from lifting lugs center to center. Therefore the skid shoes can be arranged with a minimum spacing of approximately 4,7m. The maximum line load for the skid shoe is thus 600 tons/4,7m ≈ 127 tons/m. However, if the skid shoes are equipped with push-pull units the skid shoes can be arranged with minimum spacing of approximately 7,1 m. Since the stroke of the push-pull units cylinder is 1,4 m and the body length of the unit is 1m. The maximum line load for the system with propelling force is thus 600 tons/7,1m ≈ 84 tons/m.

The system has the required capacity for usage on the additional skidding tracks, if the system is not equipped with the push-pull units. The low capacity of the push-pull units together with the rather high friction value requires most probably to use several units to propel the system. The system with the push-pull units does not have the required capacity. However, the system can be used with other push or pull units and therefore the system can be considered as applicable for TOF's purposes.

4.3.1.2 Friction

The common friction coefficient for teflon against steel is 0.25 in static and 0.10 in dynamic state according to the classification rules, DNV Load Transfer Operations (April2012). However, in calculations it is recommended to use the friction value based on previous experiences and test.

Mammoet has empirical information that the friction coefficient for the skidding system has been 0.03 at lowest and 0.05 at highest. For calculations Mammoet recommends to use the friction value of 5%. /14/

4.3.1.3 Space Requirement

The height of the skid shoe including the skidding track and the teflon pads is ~1,5m. The stroke of the integrated jack in the skid shoe is 600mm. Thus, the height requirement for the system is ~1,8m. However, the system most probably requires to use load spreading beam underneath the skidding track and therefore the actual height of the system is higher. The size of the load spreading beam depends on the loads and is therefore project related.

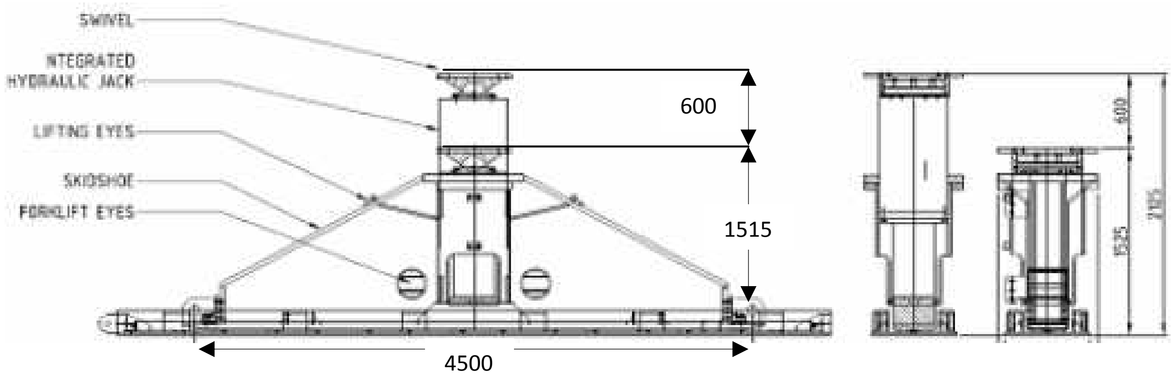

Figure 4.3.4: The height of the skid shoe. /13/

4.3.1.4 Feasibility

The Mammoet's skidding system has the required capacity for usage on the additional skidding tracks if no propelling force is used. The system is applicable for line loads up to 127 tons/m. However, if the system is equipped with push-pull units the capacity is only 84 tons/m. Like the other systems, the system will require to use load spreading beams underneath the skidding track.

The skidding tracks in the system are slightly over dimensioned in width compared to the skid shoes, thus the system tolerates deviations in straightness. However, the skid shoe has no guiding rollers or other materials to reduce friction if the skid shoe collides with the side flanges of the skidding track. Therefore, the tolerance for deviations in straightness is not high. However, the load carrying jacks can be individually controlled and therefore the system tolerates moderate deviations in levelness. The system is feasible in all weather conditions. However, the skidding track has to be clean. The friction of the system is rather high compared to other skidding systems, friction is 5%.

The Mammoet's skidding system would be feasible in the construction phase. The skid shoe operates as a support block when the jack is retracted. However, the system's load carrying capacity is not sufficient for the maximum loads on the main skidding tracks and therefore feasibility in the construction phase is not relevant. Although the skid shoe is capable to support the load when the jack is retracted, the load is still resting on the skid shoe and therefore the replacement or maintenance of the skid shoe is complicated. Mammoet operates as subcontractor basis by leasing and operating the equipment. The concept is suitable for additional skidding track usage, since the equipments are required only for the actual skidding operations.

The system is feasible for usage on the additional skidding tracks. However, drawback is that the system has to have other equipments to pull or push the structure. Also the alignments have to be made with high precision. The alignments are the highest risk of the system. If the alignments are not properly hold the accomplishment of the whole skidding operation is jeopardized. Also loss of pressure in the hydraulic system is crucial, since the system has no back-up supports for the load.

4.3.2 Enerpac Skidding System

Enerpac provides high force system solutions for safe, precise control of movement and positioning. For skidding purposes Enerpac provides a solution including skid shoes, skidding tracks and hydraulic push-pull units. The skid shoes are available with and without integrated load carrying hydraulic jacks. The system selected for this study is the skidding system with integrated load carrying cylinders. /15/

Figure 4.3.5: The Enerpac's skidding system. /15/

The Enerpac's skidding system is considerably similar with the skidding system that Mammoet provides. The load is supported with skid shoes that have integrated hydraulic jacks to support the load. The jacks are available with a capacity of 125 and 250 tons. To skid a load of 500 tons or more it is required to use the skid shoe with a capacity of 250 tons. Thus, the 250 tons skid shoe is the only one to be considered for TOF's purposes. The push-pull unit for the skidding system is only available with a push capacity of 22 tons. However, the skidding system can also be used with other push or pull systems, such as strand jacks, to compensate the low capacity. /15/

The skidding system differs from the Mammoet's skidding system in skidding tracks and the clamping principle of the push-pull unit. The skidding track in Enerpac's system has no flanges on sides, only a plate and a beam welded to the middle. The push-pull unit grips onto the middle beam with wedges, whereas Mammoet's system has lever locks and push-off cams. Friction is reduced on both systems with the same principles, by adding teflon pads onto the skidding track. /15/

4.3.2.1 Capacity

The skid shoe with integrated hydraulic jack is available as a standard with capacity of 250 tons. The additional push-pull unit for the system has a push capacity of 22 tons and pull capacity of 16 tons. Both of the loads are safe working loads. /15/

The skid shoe's body length is 2,3m. Theoretically the skid shoes without push-pull units can be arranged with a minimum spacing of approximately 2,4m. The maximum line load to be supported with the system is thus 250 tons/2,4m ≈ 104 tons/m.

However, if the system is equipped with the push-pull units the load carrying capacity will be lower.

The capacity of the push-pull unit requires to use several units and therefore the skid shoes with the units can be arranged only with a minimum spacing of 3,4m. The body length of the skid shoe is 2,3m and the push-pull unit's length is 0,36m and the stroke of the cylinder is 0,6m, therefore the total space requirement for the combination is 3,4m. The maximum line load is thus 250 tons/3,4m ≈ 73 tons/m.

The system has a sufficient capacity for usage on the additional skidding tracks, if the system is used without the push-pull units. The system can be used with other equipments to push or pull the structure.

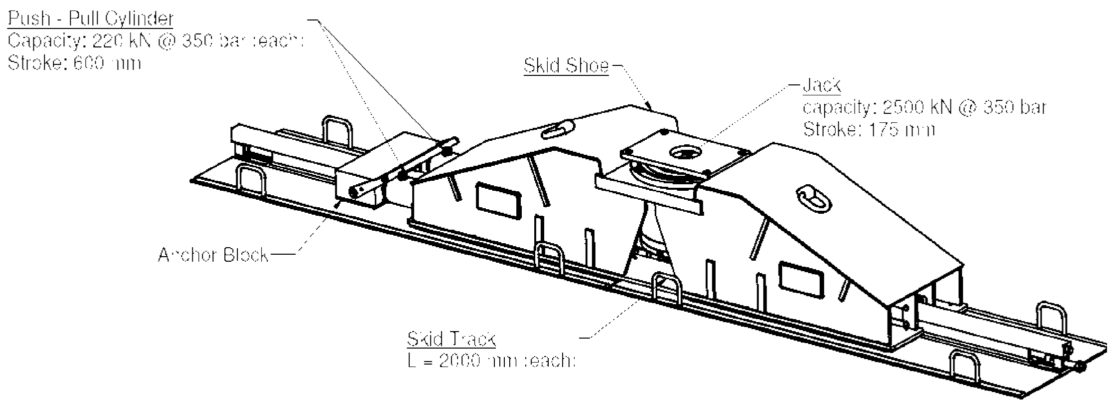

Figure 4.3.6: The capacity of the skid shoe. /15/

4.3.2.2 Friction

Although the Enerpac's skidding system is almost identical with the Mammoet's system and both of the systems use the similar teflon pads on the skidding tracks to reduce friction, the friction is higher with the Enerpac's system.

Enerpac states that the friction value for the system is 8%. /15/

4.3.2.3 Space Requirement

The height of the skid shoe including the skidding track and the teflon pads is ~0,5m. The stroke of the integrated jack in the skid shoe is 175mm. Thus the free height requirement for the system is ~0,6m.

However, the system most probably requires to use load spreading beam underneath the skidding track and therefore the actual height of the system is higher. The size of the load spreading beam depends on the loads and is therefore project related.

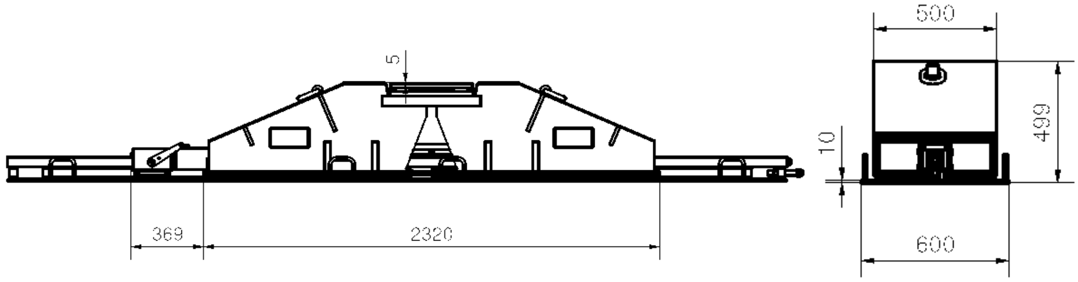

Figure 4.3.7: The height of the skid shoe. /15/

4.3.2.4 Feasibility

The Enerpac's skidding system barely has the required capacity for usage on the additional skidding tracks. The system is applicable for line loads up to 104 tons/m. However, if the system is used with the push-pull units, the capacity is only 73 tons/m. Like the other systems, the Enerpac's system will require to use load spreading beam underneath the skidding track.

The system has a low tolerance for deviations in straightness. The skidding track has a beam in the middle which serves as a guide for the moving skid shoe and on which the push-pull unit clamps on. As the skidding tracks consist of prefabricated sections that are joined together, there is a potential risk for misalignments when the sections are mated. If the tracks are not properly aligned, the skid shoe may collide with the middle beam. And since there is no friction reducing materials, the friction will increase and at worst case the whole skidding operation has to be aborted. The load carrying jacks in the skid shoes can be controlled individually and thus the system tolerates moderate deviations in levelness.

The Enerpac's skidding system is considerably similar with the equivalent system from Mammoet. Both of the systems have the same drawbacks, the system does not have the required capacity if the push-pull units are used. Both of the systems have low tolerance for deviations in straightness. The maintenance of the systems is complicated, since the system has no back-up supports. The load is always supported with the skid shoes. The major difference between the Mammoet's and Enerpac's system is the friction value. The friction value of the Enerpac's system is 8%. The highest risk of both of the systems is the alignments, the systems have rather low tolerance for straightness deviations. In particular the skidding tracks in the Enerpac's system has to be aligned with high precise.

5 CONCLUSION

The purpose of this thesis was to investigate and find alternative methods to execute skidding on the additional skidding tracks that have not been used previously. The methods found potential for the additional skidding tracks are the APS-system and the Mammoet's skidding system. Both of the systems can be leased for the skidding operations. The lease concept is potential since the equipments on the additional skidding tracks are only needed for the actual load-out operation and the need of the additional track lines in general is project related.

Method	Max. Line Load (tons/m)	Friction (%)	Height Space Req. (m)
Current rollers	183	2	1,6
Hilman rollers	257	5	1,7
APS-system	246	1	1,4*
Mammoet skidding system with push-pull units	127 84	5	1,8*
Enerpac skidding system with push-pull units	104 73	8	0,6*

*= Requires also space for load spreading beam

Figure 5.0.0: Summary of the methods

The method currently used on the main skidding tracks is feasible on the additional skidding tracks as well. The current system has advantageous friction value, however the system has low tolerance for straightness deviations. The system is also found complicated for usage on the additional skidding tracks. As the skidding length on the additional skidding tracks is shorter than the length on the main skidding tracks, the skidding system has to be simple to take in use while skidding operations are in progress. Therefore the system is found as not feasible for usage on the additional skidding tracks.

The skidding method with Hilman rollers is similar with the currently used method and is therefore also excluded from usage on the additional skidding tracks. However, the Hilman rollers can be considered for usage on the main skidding tracks. The current system is capable only for loads up to 183 tons/m. By changing the current roller units to Hilman's roller units, the current system would be feasible for the loads that the foundations under the main skidding tracks tolerate. Drawbacks of the Hilman rollers are higher friction value than with the current roller units and also tolerance for misalignments.

The skidding systems from Mammoet and Enerpac are both found feasible for the usage on the additional skidding tracks. However, the friction value is considerably higher with the Enerpac's solution and therefore the system is excluded.

The Mammoet's skidding system can be taken in use on the additional skidding tracks rather simply. The skid shoe would be installed to the transportation cradle and lowered down when needed. The drawback of the system is however alignments, the system has low tolerance for deviations in straightness. Also the friction is higher than with the other potential system, APS-system. If the Mammoet's system is equipped with the push-pull units the capacity is not sufficient for usage on the additional skidding tracks. The capacity is only 84 tons/m. However, the system can be used with other equipments to propel the skid shoes and thus the system can be considered for additional skidding tracks. The capacity without push-pull units is 127 tons/m. Mammoet's leasing concept is found potential for the skidding system used on the additional skidding tracks, since the equipments are only needed for the actual skidding operation.

The APS-system is found the most potential system for the additional skidding tracks. The system has extremely low friction value, usually less than 1%. The system has the required capacity for usage on both, main and additional, skidding tracks. However, as the system has no back-up supports for the load, the system is not found feasible for usage on the main skidding tracks.

The APS-system has slightly higher tolerance for deviations in straightness than the other methods in this study. The skidding tracks are over dimensioned in width compared to the load modules and modules have guide rollers on sides to reduce friction and abrasion between the module and the tracks flange. The APS-system is also simple to take in use on the additional skidding tracks, the load modules would be bolted onto the transportation cradle and lowered down when needed. However, after lowering down the load module the skidding operation has to be interrupted, since generating the compressed air layer takes 2-3 minutes. Since the structure is propelled in sequences, the interruptions are not seen as major drawback. Hebetec, the supplier, operates also as subcontractor basis by leasing and operating the equipments.

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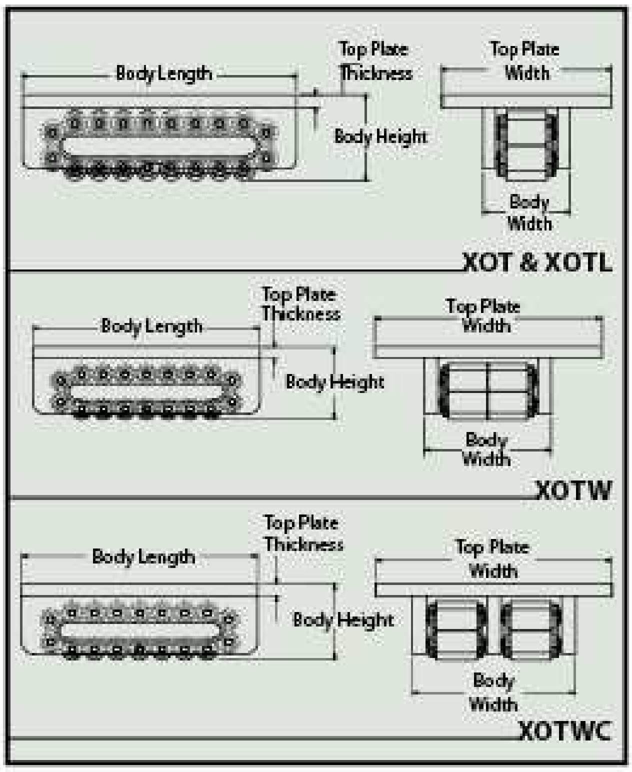
APPENDICES

APPENDICE 1



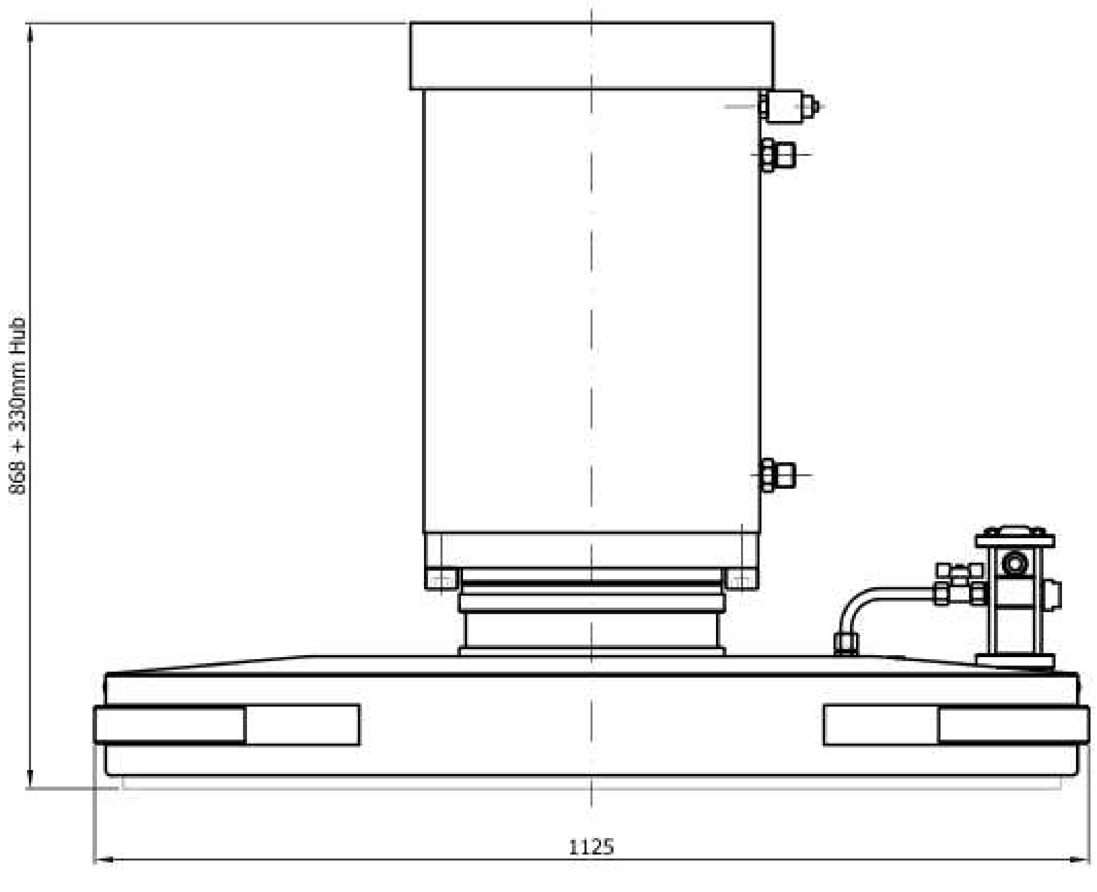
	Capacity	<<<<<Body Dimensions>>>>>			<<<Top Plate Dimensions>>>			<<<<<Footprint>>>>>			
	Capacity Metric Tons	Length	Height *	Width	Thickness	Width	Length	Contact Rolls	Roll Dia.	Roll Width	Weight lbs.(kgs)
		<<<<<<Inches (mm)>>>>>>			<<<<<Inches (mm)>>>>>				<<Inches (mm)>>		
100-XOT	100-tons	21.0 (533)	6.75 (171)	7.875 (200)	1.00 (25)	14.0 (356)	21.0 (533)	7	1-15/16 (49)	3-5/8 (92)	250 (113)
150-XOTL	150-tons	32.0 (813)	6.75 (171)	7.875 (200)	1.00 (25)	14.0 (356)	32.0 (813)	11	1-15/16 (49)	3-5/8 (92)	381 (172)
150-XOTW	150-tons	21.0 (533)	6.75 (171)	9.875 (251)	1.00 (25)	16.0 (406)	21.0 (533)	14	1-15/16 (49)	2-3/4 (70)	299 (136)
200-XOTL	200-tons	36.0 (914)	6.75 (171)	7.875 (200)	1.00 (25)	14.0 (356)	36.0 (914)	14	1-15/16 (49)	3-5/8 (92)	443 (201)
200-XOTW	200-tons	21.0 (533)	6.75 (171)	11.5625 (294)	1.00 (25)	21.0 (533)	21.0 (533)	14	1-15/16 (49)	3-5/8 (92)	364 (165)
200-XOTWC	200-tons	21.0 (533)	6.75 (171)	14.5 (368)	1.00 (25)	21.0 (533)	21.0 (533)	14	1-15/16 (49)	3-5/8 (92)	423 (192)
300-XOT	300-tons	34.0 (864)	10.0 (254)	10.75 (273)	1.50 (38)	21.0 (533)	34.0 (864)	8	2-15/16 (74)	5 (127)	849 (385)
500-XOT	500-tons	34.0 (864)	10.0 (254)	20.0 (508)	1.50 (38)	30.0 (762)	34.0 (864)	16	2-15/16 (74)	5 (127)	1430 (649)
750-XOT	750-tons	34.0 (864)	10.0 (254)	27.5 (699)	1.50 (38)	37.5 (953)	34.0 (864)	24	2-15/16 (74)	5 (127)	2044 (927)
1000-XOT	1000-tons	Consult factory for product specifications and weight									

** Height includes Top Plate Thickness*

Air - Pad - Sliding - System **APS M-250**

Technical Data

Capacity:	2500 kN
Stroke:	330 mm
Area "Pressure Line":	707 cm²
Area "Return Line":	176 cm²
Weight:	1600 kg
Dimension b x h:	1125 x 868 mm
Base plate:	340 x 340 mm
Attachement:	4 piece M24



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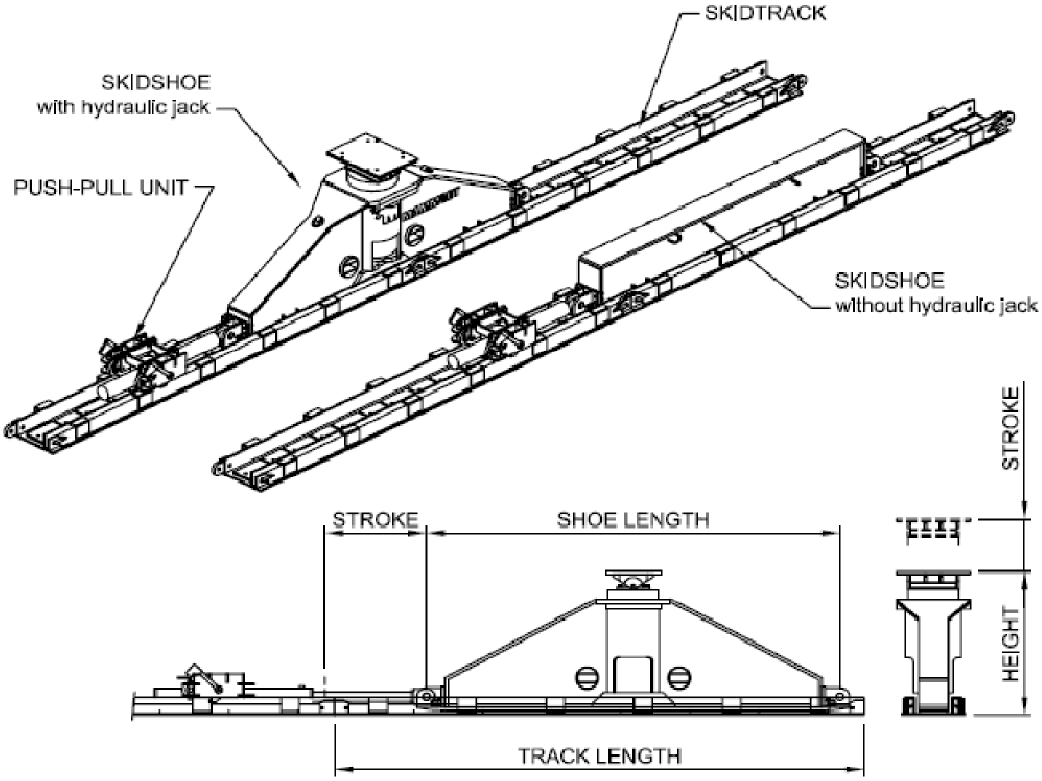
MAMMOET

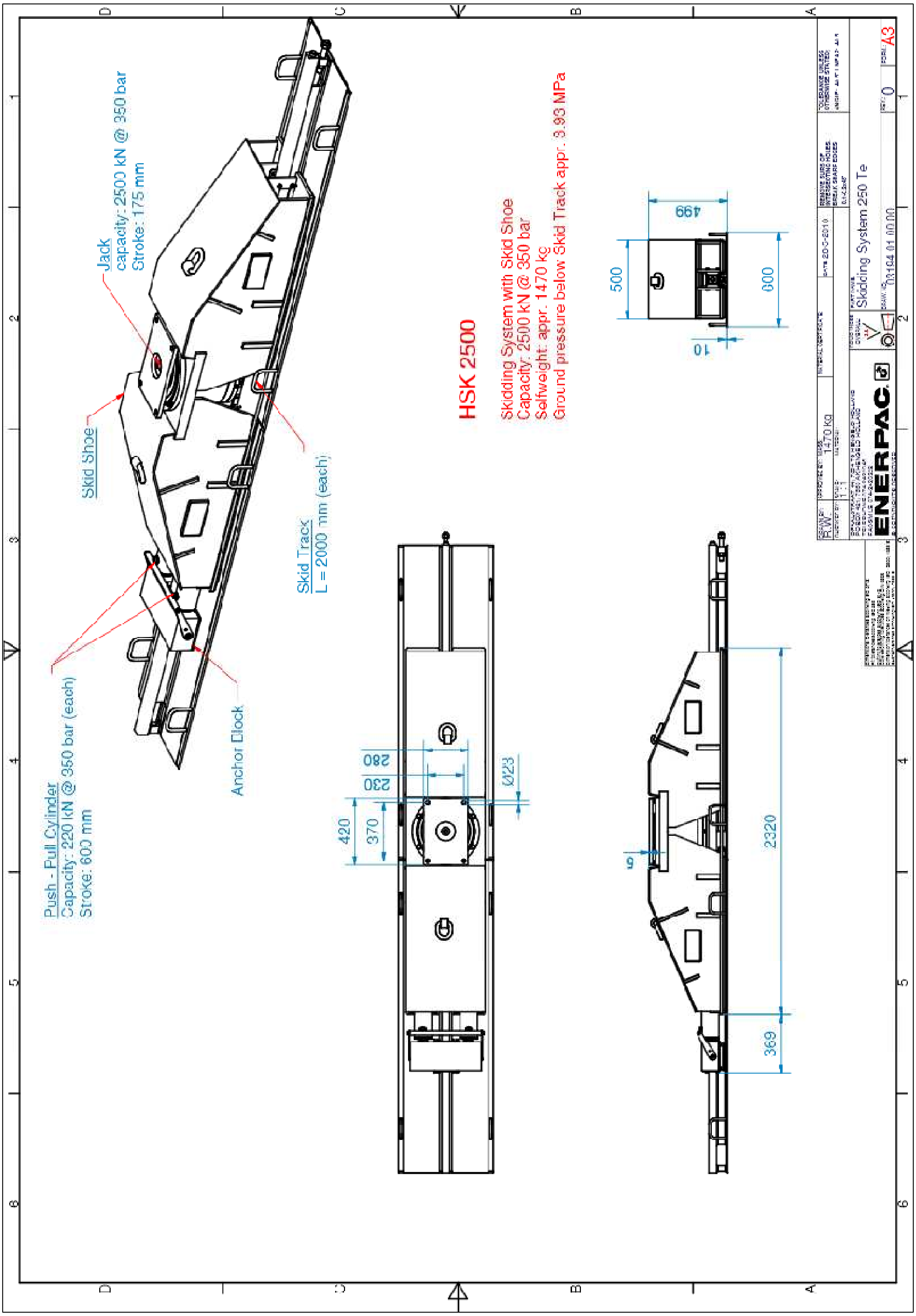
SKIDDING



Skidding				
Specifications	**Heavy System with hydraulic jack**	**Heavy System without hydraulic jack**	**Medium System without hydraulic jack**	**Light System without hydraulic jack**
Skidshoe				
Capacity:	600	600	200	125 / 50
Stroke:	600	n.a.	n.a.	n.a.
Weight:	4600	1750	704	270 / 640
Length (Center to Center):	4500	4500	3000	2250 / 5250
Width:	800	330	300	292
Height (incl. Track & Teflon):	1515	655	383	320
Skidtrack				
Weight:	1217	1217	114	450 / 950
Length:	5760	5760	2000	2500 / 5500
Width:	680	680	420	550
Height:	200	200	115	280
Push-Pull Unit				
Capacity:	64	64	20	38
Stroke:	1400	1400	600	600
Weight:	740	740	79	150

Weights and capacities in metric tonnes, dimensions in meters.

APPENDICE 4


Jack
capacity: 2500 kN @ 350 bar
Stroke: 175 mm
Skid Shoe
Skid Track
L = 2000 mm (each)
Push - Pull Cylinder
Capacity: 220 kN @ 350 bar (each)
Stroke: 600 mm
Anchor Block
HSK 2500
Skidding System with Skid Shoe
Capacity: 2500 kN @ 350 bar
Selfweight: appr. 1470 kg
Ground pressure below Skid Track appr. 3.93 MPa
Skidding System 250 Te
ENERPAC
A3