FINAL PUBLISHABLE REPORT

CONTRACT N° : ENK6-CT-1999-00018

ACRONYM : OCDV

TITLE : Offshore Construction and Decommissioning Vessel

PROJECT CO-ORDINATOR :

Master Marine AS

PARTNERS :

Rexroth Hydraudyne BV

REPORTING PERIOD : FROM 01/02/2000 TO 31/01/2004

PROJECT START DATE : 01/02/2002 DURATION : 48 Months

Project funded by the European Community under the EESD Programme (1998-2002)

Part 1: Publishable Final Report

1 EXECUTIVE PUBLISHABLE SUMMARY

The objective of the OCDV project has been to develop a concept for a new type of heavy lift vessel devoted to perform safe, environmentally friendly and cost-effective removal and installation of offshore platforms, where the entire platform Topsides and Jackets are removed (or installed) in single lift operations.

Importantly the new concept will make significant reductions in the requirement for offshore personnel, support vessels, offshore accommodation and shuttle transportation, beneficial to overall safety, as well as costs, when working in a potentially hostile environment such as the North Sea. The dismantling onshore at a purpose built facilities under controlled industrial conditions will be more cost effective, safer and environmentally sound than any method of offshore dismantling.

The developed heavy lift vessel, also named Offshore Construction and Decommissioning Vessel (OCDV) takes the form of a U-shaped floater which is vertically moored and tensioned to "active" suction anchors in order to almost eliminate the vessel swell and wave induced vertical motions. The load transfer operation of Topsides and other heavy construction elements to / from the vessel will then be better controlled and thus avoiding damage to the structures in the installation /removal operation and it will improve safety for the personnel involved in this sensitive operation.

A Horizontal Positioning System (HPS) has been developed for keeping the vessel in a target position, within a certain operational envelop relative to the platform substructure allowing the vessel to follow the wave frequency motions but reducing the second order motion of the vessel and by that minimizing the horizontal amplitude by about 50%.

A Load Transfer System (LTS) has been developed supporting the platform Topside from underneath in several lifting points and thus distributing the load evenly. The system allows for vessel wave frequency motions when performing load transfer operation without introducing large dynamic loads into the platform.

The overall target of the Project has been to conclude the vessel's operational methodology and workability, its main dimensions and its key operational equipment.

Computer analysis and simulations of vessel and systems has been verified by wind tunnel tests of vessel and Topside, tank model tests of hull and systems and offshore model tests of suction anchors.

2 PUBLISHABLE SYNTHESIS REPORT

2.1 INTRODUCTION

Master Marine AS and Rexroth Hydraudyne has together developed a heavy lift vessel devoted to perform safe, environmentally friendly and cost-effective removal and installation of offshore platforms and where the entire platform Topsides and Jackets are removed (or installed) in single lift operations.

We would like to thank the European Commission and the Research Directorate General for its encouragement and financial contribution in this Research and Technical Development (RTD) project.

The financial contribution from European Commission through the 5th framework program has made it possible for Master Marine AS and Rexroth Hydraudyne to execute this RTD work. The joint effort in the RTD work will hopefully result in commercialisation of the concept and system developed in the project.

2.2 OBJECTIVE AND STRATEGIC ASPECTS

Large offshore platform Topsides have in the past been built up module by module, on a Main Support Frame (MSF) supported by a substructure at the offshore location. This has required several offshore lifts, a long commissioning phase and expensive offshore infrastructure (crane vessels, barges, tugs, accommodation vessels, helicopters, supply vessels, rescue vessels etc).
Removal of platform Topsides has up to now been a reverse operation to installation, where the Topsides are dismantled offshore, module by module, which require a long offshore preparation phase, several lifts and an expensive offshore infrastructure in a hazard environment.

The objective of the OCDV project has been to develop a concept for a new type of heavy lift vessel devoted to perform safe, environmentally friendly and cost-effective removal and installation of offshore platforms and where the entire platform Topside is removed (or installed) in one single lift operation.

Importantly the new concept will make significant reductions in the requirement for offshore personnel, support vessels, offshore accommodation and shuttle transportation, beneficial to overall safety, as well as costs, when working in a potentially hostile environment such as the North Sea. The dismantling onshore at a purpose built facilities under controlled industrial conditions will be more cost effective, safer and environmentally sound than any method of offshore dismantling.

The developed Offshore Construction and Decommissioning Vessel (OCDV) takes the form of a U-shaped floater which is vertically moored and tensioned to “active” suction anchors in order to almost eliminate the vessel swell and wave induced vertical motions. The load transfer operation of Topsides and other heavy construction elements to / from the vessel, in open sea, will be better controlled by almost eliminating the vertical motions and thus avoiding damage to the structures in the installation /removal operation and to improve safety for the personnel involved in this sensitive operation.

A Horizontal Positioning System (HPS) has been developed for keeping the vessel in position, within a certain operational envelop, relative to the platform substructure.

A Load Transfer System (LTS) has been developed supporting the platform Topside from underneath in several lifting points and thus distributing the load evenly. The system allows for certain vessel motions when performing load transfer operation without introducing large dynamic loads into the platform.

The overall target of the Project has been to conclude the vessel’s operational methodology and workability, its main dimensions and its key operational equipment.

2.3 SCIENTIFIC AND TECHNICAL DESCRIPTION OF THE RESULTS

2.3.1 Introduction

The OCDV concept is based on a floater vertically moored and tied down to active suction anchors, outfitted with a horizontal positioning system and a flexible load transfer system.
The vessel is able to transport and install, or remove, heavy offshore platform structures, such as Topsides and Jacket structures, in single lift operations.

Two different types of hull shapes have been developed for the “single lift” concept, a column-stabilized unit, “Master Mind” and a catamaran shaped unit, “Sea Fork One”

Column stabilized unit “Master Mind”

“Master Mind” Main particular	
Hull Length overall	107.8 m
Hull Breadth overall	81.0 m
Hull Height	36.2 m
Length of pontoons	104.8 m
Breadth of pontoons	16.0 m
Height of pontoons	10.2 m
Operational Draught	9-22 m
Displacement	39 000 T
Equipment	
Quarters	140 persons
Helicopter deck	S 61
Propulsion	6*3300 kW
Dynamic Positioning (DP) system	IMO Class 3
Suction Anchor vertical holding capacity	4*2200 T
Revolving Cranes (main hoist)	350/250 T
Lifting Capacity	
By de-ballasting	16 000 T
By strand jacks in moon pool	18 000 T
By ship cranes (tandem lift)	600 T

Catamaran-shaped unit "Sea Fork One"

Item	Dimensions	Comments
Length pontoons	96,57 m	
Breadth pontoon	17,00 m	
Breadth of moon pool	25 – 51 m	Variable size.
Moulded draught pontoons	27,07 m	
Length transverse box	85,00 m	
Breadth transverse box	26,64 m	
Height transverse box	10,27 m	
Light weight	16.580 T	
Displacement	31.200 T	Including 14.000 T pay load
Transit draught	5,90 m	Excluding pay load
Transportation draught	6,40 – 9,40 m	2.000-14.000 T pay load
Operation draught	6,40 – 14,00 m	
Lifting capacity	14.000 T	North Sea Platform∗
Lifting capacity	18.000 T	GOM Platform∗

∗ Depending on platform geometry and elevation.

The column stabilized unit is more suited for operations in the North Sea whilst the more weather sensitive catamaran-shaped unit is better suited economically for operations in Golf of Mexico.
The catamaran-shaped unit have however an acceptable operability in the North Sea during summer season if used as a pure lifting tool

Methods and systems as developed in this RTD work are the same for the column stabilized unit as for the catamaran shaped unit.

Three systems have been developed in order to ensure a safe load transfer operation offshore, in open sea:

- Tie Down System (TDS)
- Horizontal Positioning System (HPS)
- Load Transfer System (LTS)

TDS

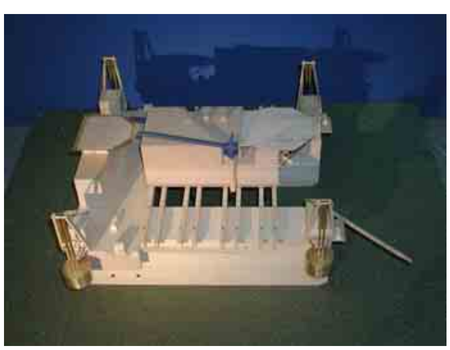
During offshore load transfers (by ballasting/ de-ballasting) the OCDV will be moored vertically by the tie-down system having the effect of almost eliminating the vertical movements (heave, roll and pitch) caused by wave loads. A suction anchor has been developed able to withstand the tie down forces of some 1600-1900 T per anchor, even in a seabed consisting of sand.

HPS
The horizontal positioning system controls the OCDV position relative the offshore structure, keep it at a target position within a certain envelope, allowing the vessel to follow the wave induced motions but reducing the second order motion of the vessel and by that minimizing the horizontal amplitude by about 50%.

LTS
The load transfer system is a supporting structure, protruding in the moon pool of the OCDV, carrying the cargo from underneath. The structure can be relocated on deck of the vessel to fit for different size of cargo. The LTS is flexible in the horizontal plane, allowing the vessel to follow the wave induced motions during load transfer operations, in order to avoid large dynamic loads from the vessel acting on the platform.

Researched and viable design solutions for the hull, main components and systems of the vessel has been developed followed by detailed analysis and computer simulations to prove the feasibility of the concept. Tank model tests of hull and systems and suction anchor tests at offshore location has been performed to verify the results from computer analysis and simulations.

Tank model test of "Sea Fork One"



Wind tunnel test of "Sea Fork One" and Topside

2.3.2 Tie Down System (TDS)

The OCDV will prior to and during the load transfer operation of construction element in open sea (to/from fixed structures) be vertically moored and be tied down to suction anchors and thus have the motion characteristics of a tension leg platform (TLP). Heave, pitch and roll motions will almost be eliminated (only residual vessel motions from elasticity in tendons remains) which are essential during initial touch and connection between load-transfer beams on the OCDV and the Topside. The impact load in the Topside from kinetic energy of the vessel is, due to the above, nearly eliminated.

The TDS also enables a quick separation between the topside and the substructure (Jacket) by activating quick release jacks and thus avoids pounding between the Topside (resting on the OCDV) and the substructure.

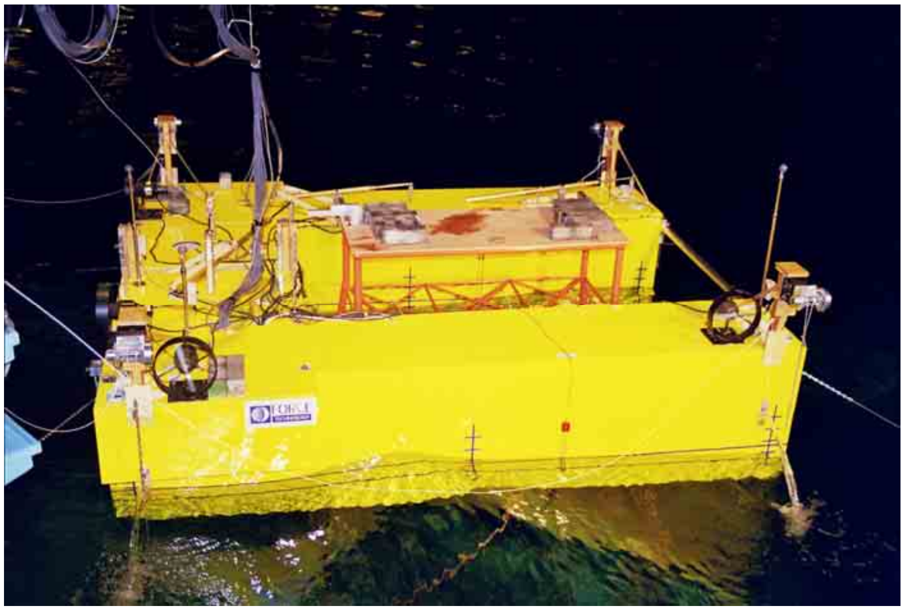
The TDS consists of traction winches, storage reels, steel wire ropes (tendons), blocks and sheaves, hydraulic jacks and suction anchors.

The hydraulic jacks of the TDS supporting the upper blocks on the OCDV can work in four different modes:

- Constant tension mode whilst deploying and recovery of the suction anchors.
- None return valve mode during the pre-tensioning phase of the tendons.
- Locked mode during load-transfer and initial lift off of Topside from Jacket.
- Controlled quick release mode during final separation of Topside from Jacket.

The steel wire ropes (tendons) are, after full penetration of the suction anchors, pre-tensioned in order to avoid slack in the system when a wave trough is passing. Pre-tension is performed by de-ballasting the OCDV using four ballast tanks to be emptied by gravity.

The method for pre-tensioning of the TDS by de-ballasting gravity tanks and operation of hydraulic jacks in a “none return valve mode” has been tested out in tank model tests with great success.



The analysis and model tests show that the TDS is a viable system able to decrease vertical motions significantly on a floater exposed for waves in open sea.

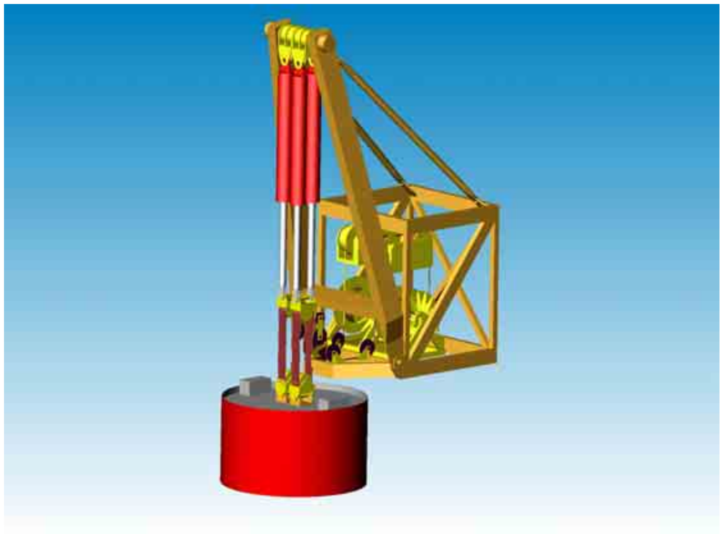
Analysis performed in this RTD work shows reduction in vertical motions of up to 98 % for the catamaran shaped unit “Sea Fork One”. The residual motion of the OCDV is a function of Hs, Tz, wave headings and water depth/stiffness in TDS.

The amplitude, before the TDS is deployed, is a factor of 5 times larger on the catamaran shaped unit. The reduction in vessel motion for the column stabilised unit is therefore not as significant as for the catamaran shaped unit when the TDS are deployed.

The TDS will simplify for design of the load transfer system for both type of hull were vertical motions has been decreased considerable after the TDS has been deployed.

The dynamic forces per anchor position are about 600 T for the catamaran shaped unit based on Hs= 2.3m and about some 900 T for the column stabilised unit based on Hs=2.5 m.

We have made some continues improvement of the TDS design through this RTD work and have ended up with a modular system for each anchor position, where each module contains two traction winches, two storage reels, one A-frame, four hydraulic cylinders, two block and tackle systems, one suction anchor and drive and control systems for the above components.



Tie Down System

Each tie down system shall be remote operated from an operation control centre and the anchors shall be deployed and recovered simultaneously in order to save operational time and decrease the required weather window.

Suction anchors have been developed for the OCDV able to handle some 2000 T (static plus dynamic loading) in vertical holding capacity.

The innovative suction anchor design developed in this RTD project uses mainly the suction force and not the skirt friction to achieve a vertical holding capacity. The anchor is able to achieve vertical holding capacity also in seabed with fine and medium sand if the suction is maintained by running the suction pump continuously.

Most of the “suction anchors” used in the industry today is not really suction anchors but rather suction installed piles. The vertical holding capacity is mainly taken by the skirt friction and the suction is only used to penetrate the piles into the seabed. This type of anchor requires a large skirt height and is not so suited for use in sand type of bottom.

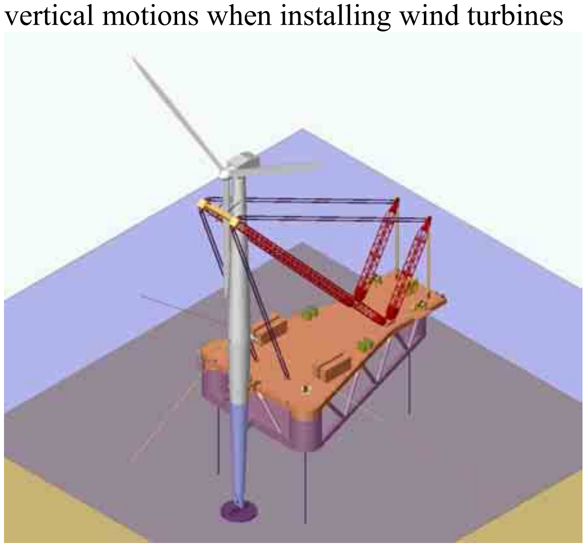
The emphasis of the research work was concentrated on conceptual design of the suction anchor, auxiliary systems and instrumentation. Parameter studies were performed to come to an optimal skirt height / anchor diameter ratio. A filter design was developed to avoid that the soil plug was evacuated when running the pumps continuously.

The developed anchors have 10 m in diameter and about 4 meter in required shirt penetration.
Each anchor is outfitted with two pumps. One of the pumps will run constantly in order to maintain the suction force during the period when the anchor is employed. The suction force will otherwise decrease due to drainage of water through the seabed sand. A second pump is installed as back up, if failure occurs on the first pump.
Typical required pumping capacity for maintaining the suction force is some 200 m^3/hour per anchor.

A 2 meter diameter model anchor has been fabricated and tested out from a Jack Up rig at an offshore location in order to verify the operability of the anchors as well as to verify the theoretical computer model of the anchor. The offshore test confirms the operability of the suction anchor and the theoretical results from suction anchor analysis.

Suction Anchor Test October 2002

The TDS could be used for different applications.
Below shows an illustration of an installation vessel of offshore wind turbines. The vessel is moored vertically to suction anchors to “eliminate” vertical motions when installing wind turbines



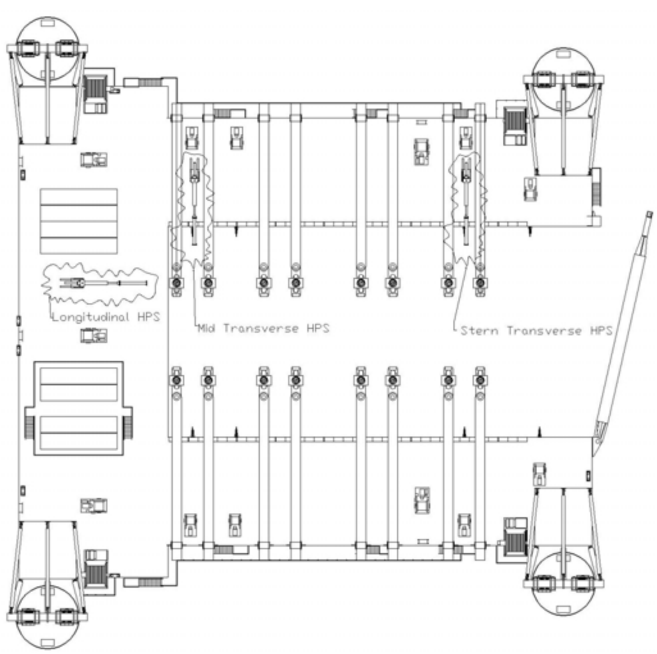
2.3.3 Horizontal Positioning System (HPS)

The purpose of the HPS is to control vessel position and orientation relative the platform and minimise the low frequency motions of the OCDV during the load-transfer operation but still allowing for wave frequency motion in order to simplify the load-transfer system but without introducing huge dynamic forces from the vessel enter into the platform.

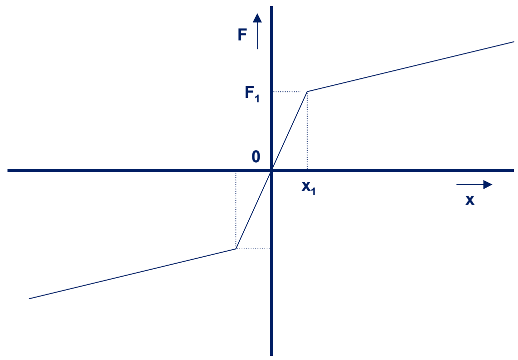
The horizontal positioning system shall reduce the motions in three degrees of freedom (surge, sway and yaw), while the other three degrees of freedom of the vessel (roll, pitch and heave) are already restricted by means of the Tie Down System, activated before deploying the HPS.

Different types of systems have been evaluated keeping the OCDV in a target position, within a certain operational envelope, relative to a platform. The conventional catenaries mooring system and the propulsion/DP systems will both have a large envelope which require corresponding large operational envelope of load carrying point when designing the Load Transfer System (LTS). The OCDV will further require significant power installed in a propulsion/DP system in order to survive a “wave train” passing the OCDV. Typical motive power in a propulsion system able to keep the vessel in position is some 25 - 30.000 Hp for a “Master Mind” type of vessel in a sea state of Hs = 2.5 m based on a DP II system.

The horizontal positioning system developed in this RTD work consists of 3 hydraulic jacks connected between the OCDV and the platform. Two jacks are controlling the transverse position and orientation of the OCDV relative a platform, reducing the sway and yaw motions and a third Jack is controlling the longitudinal position, reducing the surge motions.
Each HPS subsystem mainly comprises a long stroke hydraulic cylinder that connects the OCDV and the Topside.



The unique with the developed system is that the hydraulic jacks are working in a spring mode with a special spring characteristics. The Jacks are very stiff in the beginning until a certain deflection and will thereafter have a “soft” spring characteristics.



The above described spring characteristics will work as a filter, reducing the second order motions significantly but allowing for wave frequency motions.

The forces required to stop the second order motion is only some 10% of the forces required to stop the wave frequency motions. Typical forces required to stop the second order motion is some 200 T for the OCDV in an operational condition
Typical forces required to stop the wave frequency (first order) motions is some 2000 T for the OCDV in an operational condition.
A platform will be able to accommodate forces generated by dynamic load caused by second order motions of the OCDV but will probably have difficulties accommodate forces generated by dynamic load caused by wave frequency motions.

Results from theoretical analysis, confirmed by results from tank model tests, shows reduction in vertical motions of some 50-60 % when HPS is deployed for the catamaran shaped unit “Sea Fork One”.

Tank model test of HPS

A second function of the HPS is to secure the Topside to the vessel at the moment of lift off of the Topside from the Jacket. The HPS will damp and after some seconds eliminate relative motions between vessel and Topside after lift off, thus working as a temporary sea fastening.

Maximum loads expected in the HPS jacks are some 300 T per jack when working as a temporary sea fastening.

The system allows further for adjustment of Topside position on the OCDV after lift off, prior to making permanent sea fastening.

2.3.4 Load Transfer System (LTS)

A Topside to be removed (or installed) is lifted from underneath by a number of load carrying points. Design criteria for the Load Transfer System (LTS):

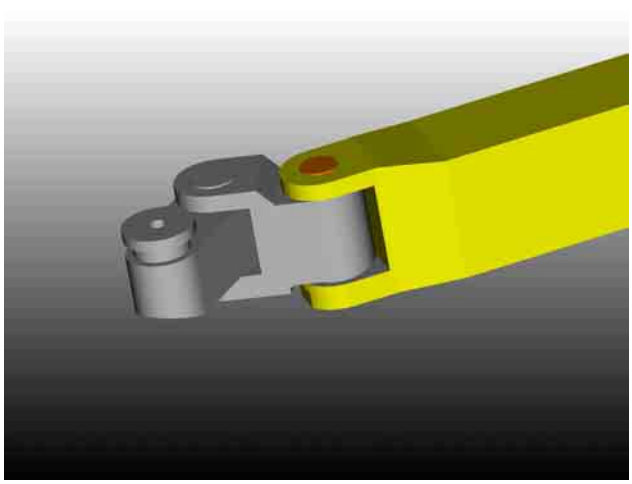
- The system should allow that the OCDV follow the natural wave frequency motion whilst performing a load transfer operation in order to avoid huge dynamic loads from vessel acting on the platform.
- The system shall be adjustable able to carry different size of platforms
- Load carrying point shall be located as close as possible to jacket leg connection to the Topside where strong point in the Topside could be found.
- The system shall be easy to deploy and retract.
- The system shall be constructible and easy to maintain

Typical size of dynamic forces required to fully stop the vessel motions caused by wave frequency loading is some 2-3000 T for a sea state of about Hs = 2.5 meter. This loading could cause serious damage to the platform structural integrity and especially to the Jacket structure. Since the loading is acting on the Topside or the upper part of the Jacket, the lower part is exposed for large bending moment (some 2 - 300.000 Tm) in addition to large shear forces.

Two different load transfer systems have been developed allowing for horizontal movement of the OCDV whilst performing load transfer operations at offshore location, and those avoiding large dynamic wave loading acting on the vessel is transferred to the platform.

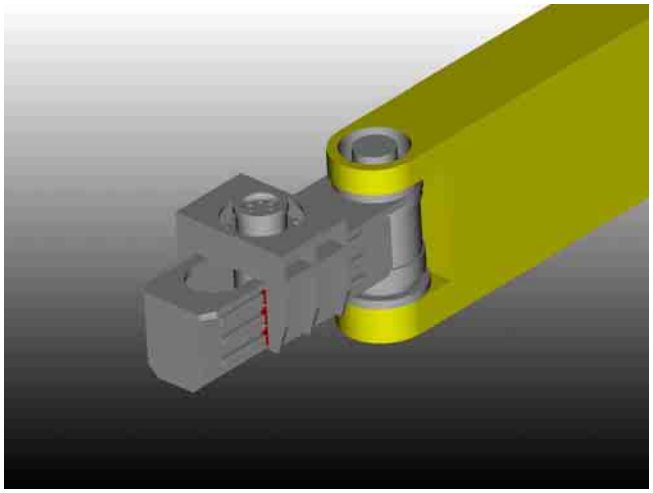
Two hinged beam system

One system consists of a number of retractable main beams. Two hinged beams are mounted on each main beam and the load carrying point is located at the tip of the outer hinged beam. The rotation of the two hinged beams allows the load carrying point to move in a defined area of the horizontal plane.



Two Hinged Beam System

Single hinged beam / trolley system
The two hinged beams have been replaced by one hinged beam and a trolley running on top of this beam on the other system developed. The load carrying point is placed on the trolley. The combination of rotation of the hinged beam and longitudinal displacement of the trolley allows the load carrying point to move in a defined area of the horizontal plane



Single hinged beam/trolley system

The DYNAMO calculations of the catamaran-shaped unit "Sea Fork One" show that the required horizontal "stroke" in the load transfer beams is about +/- 1.7 m for beam sea. If the HPS active compensate for offset caused by mean environmental force the maximum required stroke is then reduced to +/-1.48 m. The horizontal displacement is somewhat less for head sea.

The horizontal stroke of the HPS for the column stabilized unit "Master Mind" is about +/- 0.7 m.

Equalizing jacks
Both systems are equipped with equalizing jacks which are the load carrying member. The equalizing jacks ensure an even load distribution during load transfer operations. The equalizing jacks are working in a spring mode allowing for some residual vertical motions of the OCDV without introducing large dynamic loadings in the Topside. The load transfer operation is performed by de-ballasting the vessel and simultaneously increasing the spring stiffness in the equalizing jacks. The equalizing jacks are also performing the lift off operation (initial separation of Topside from platform substructure).

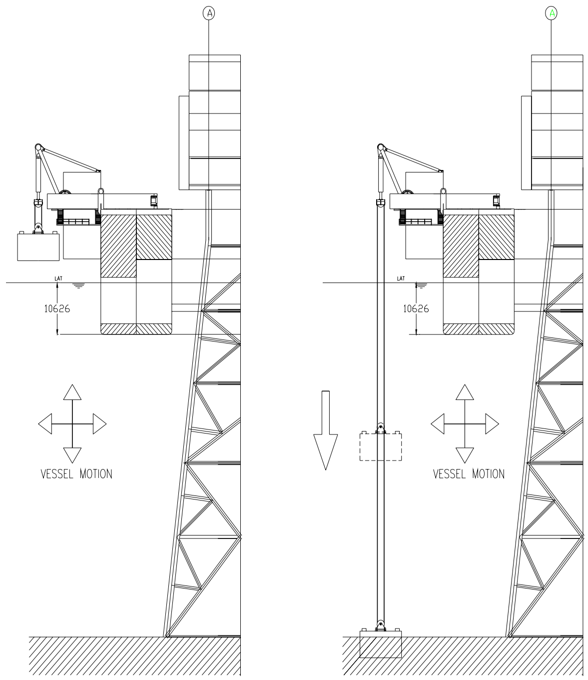
The main beams carrying the single hinged beam/trolley system (or the two hinged beam system) can be retracted in order to allow clearance whilst positioning the vessel.

Main beams in LTS retracted during positioning

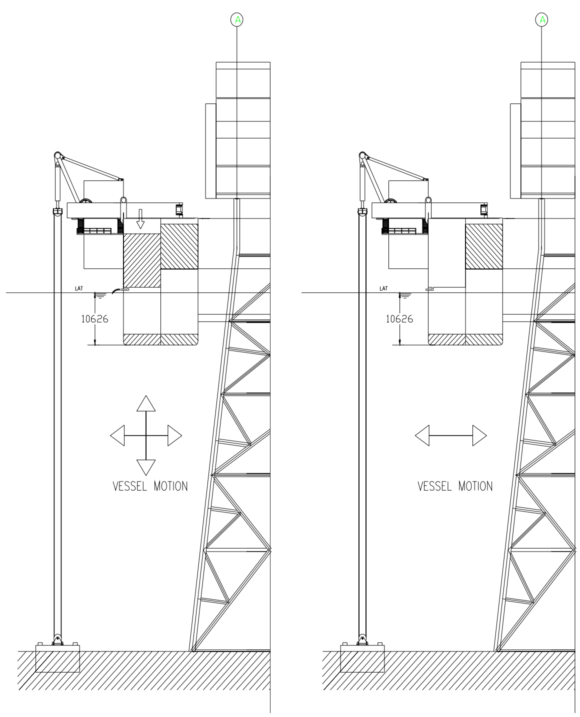
LTS deployed under Topside

2.3.5 Load transfer Operation

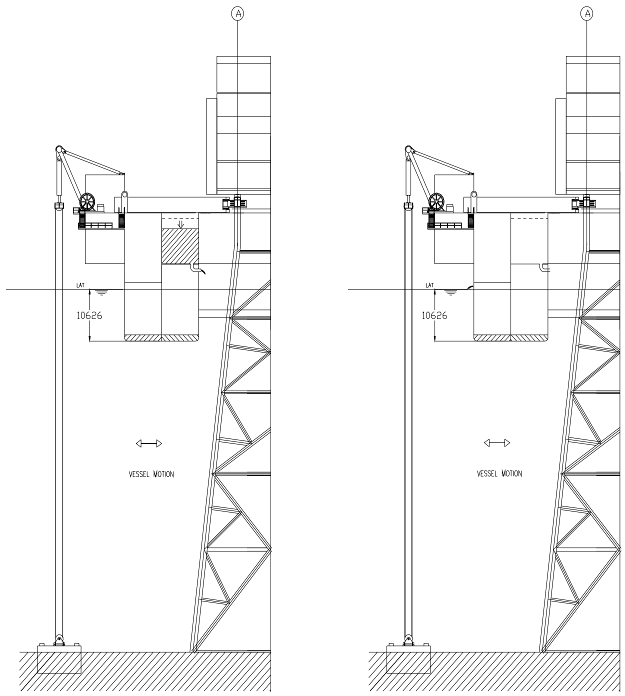
The Load Transfer Operation is illustrated in below sketches.
The operation is estimated to take less than 24 hours including deployment of suction anchors, Horizontal Positioning System (HPS) and Load Transfer System (LTS), load transfer and Lift off, sea fastening, recovery of suction anchors and departure from Jacket.



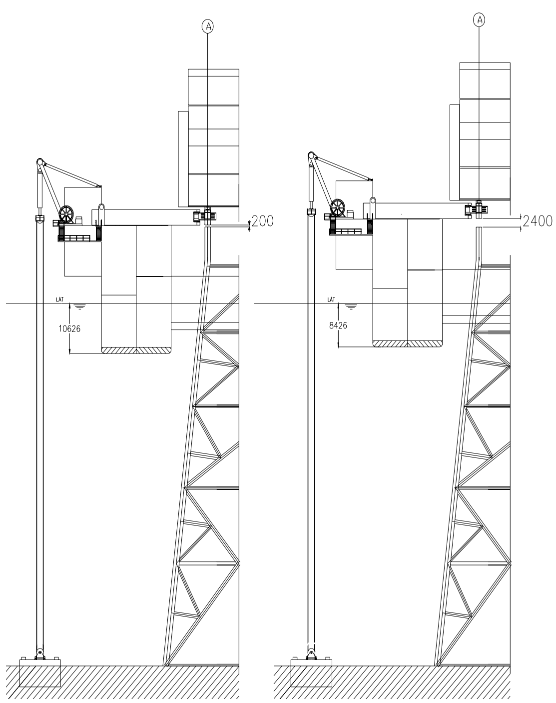
Deployment of suction anchors



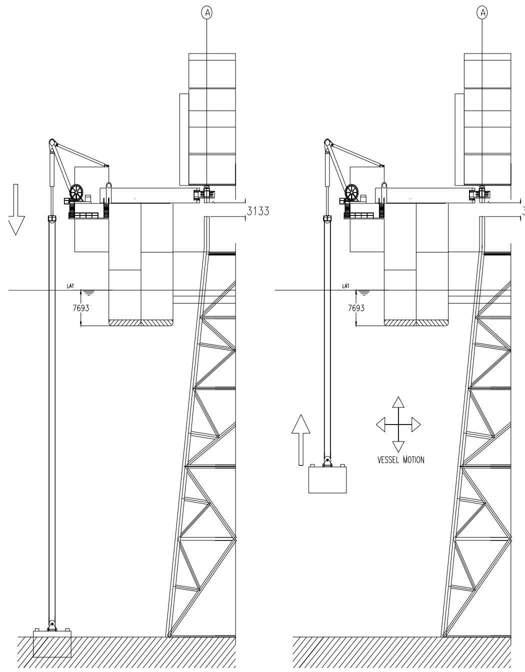
Pre-tensioning of tethers in the Tie Down System (TDS) by de-ballasting four (4) gravity tanks to almost eliminate vessel vertical motions (roll heave and pitch). Deploy the load transfer system.



Load transfer by de-ballasting “Sea Fork One” and simultaneously increasing the spring stiffness of the LTS equalizing jacks until 110 % load transfer (uplift forces taken by explosive studs between Topside and Jacket).



Lift off of Topside from Jacket by detonation of explosive studs. The LTS equalizing jacks, working in a spring mode, will perform the initial separation (200 mm). Increase of clearance by de-ballasting “Sea Fork One”. Draught will decrease by 2.2 meter.



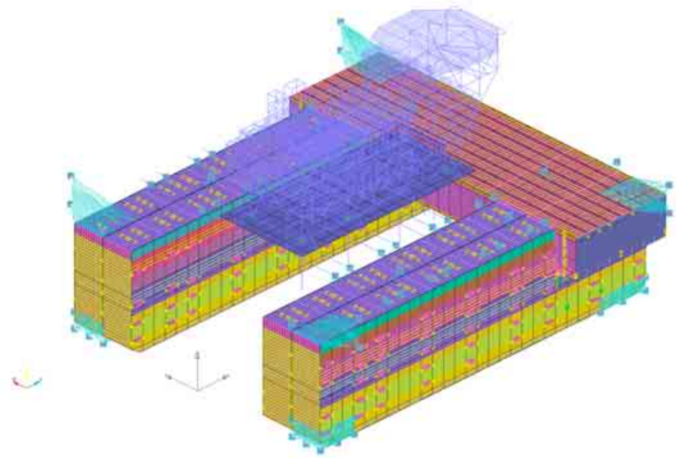
Final Separation of Topside from Jacket by release of forces in the TDS jacks. Draught of "Sea Fork One" will decrease by 0.733 meter. Recover of suction anchors.

2.3.6 Topside transport to shore

The acceleration in the COG for Topside in transport and survival conditions has been calculated. The horizontal accelerations (including gravity component) are given below:

	TOPSIDE TRANSPORT	
	Longitudinal	Transversal
Transport condition (m/s^2)	2.32	3.60
Survival condition (m/s^2)	2.83	4.33

A PERMAS structural analysis model of a typical Topside structure (Ekofisk 37/4A Booster Platform) was coupled to the model of the OCDV "Sea Fork One" to create a global analysis model.



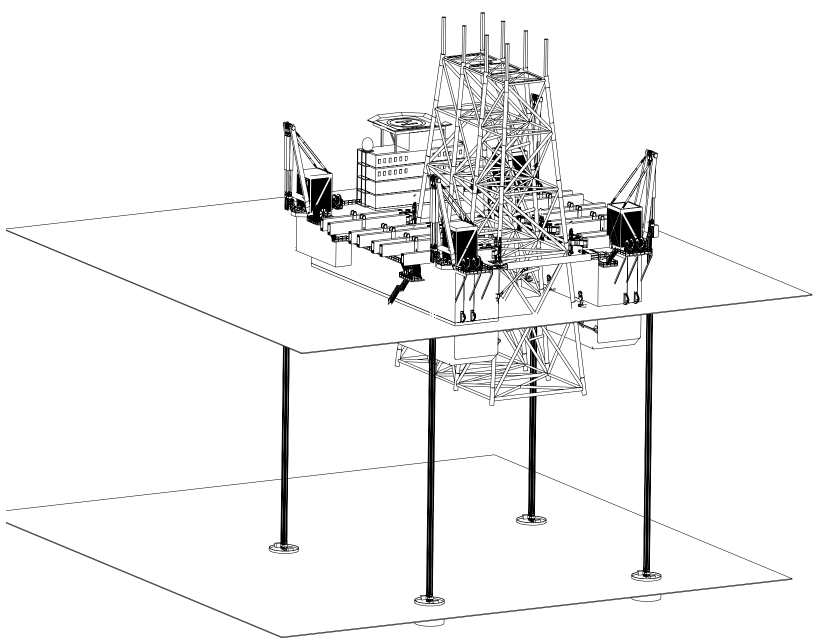
Global model of Sea Fork One and Topside

The most critical condition was the transport condition to shore. In order to capture the effect of the wave action on the catamaran hull and the interaction with the Topsides, the design wave approach was used.
The structural analysis confirms that the OCDV is able to survive a 10 years return summer storm in the North Sea, with a Topside secured to the deck. Some reinforcement of the Topside is however required for the transportation/survival condition.

2.3.7 Jacket Removal

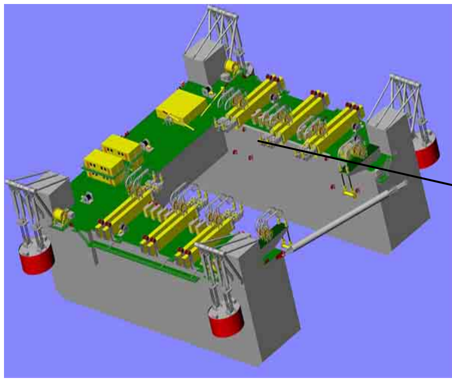
Overview jacket Removal

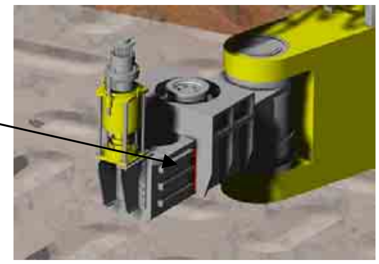
- Prepare Sea Fork One for Jacket Removal
- Tow to waiting site, close the Booster Platform
- Connect mooring lines and wait (if necessary)for favourable weather window
- Winch into position
- Lower suction anchors
- Connect lifting gear
- Load transfer by strand jacks and de-ballasting operation
- Lifting by strand jacks
- Sea fastening
- Recover suction anchors
- Disconnect mooring lines
- Connect tugs for tow to shore
- Offload Jacket at inshore dismantling site
- Cut and lift jacket in sections by floating crane “Rambiz” (3.300 T lifting capacity) or similar crane vessel.
- Demolition of Jacket



Preparation of Sea Fork One for Jacket Removal

The preparatory work for the Sea Fork will take place at a preparation yard. At this yard a strand jack lifting system will be installed on the load transfer beams. A similar system was used for lifting of the Brent Spar platform and for salvage of the "Kursk" nuclear submarine.

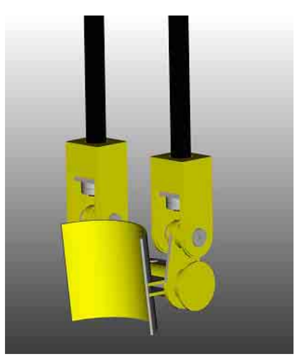


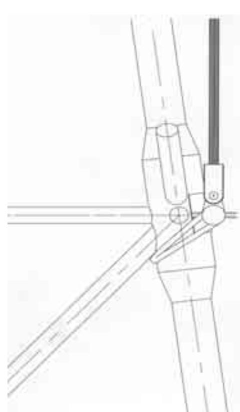


The load transfer beams will be relocated to exactly suit the jacket leg lifting points. Further, pad eyes, for sea fastening of the Jacket, will be welded on the inner side shell of the pontoons of the Sea Fork One.

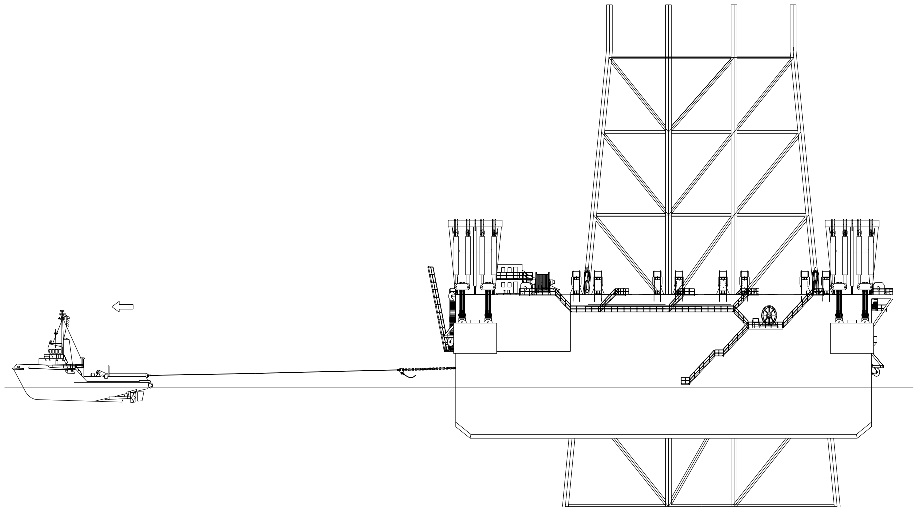
A ROV spread will be mobilised onboard the vessel or on assisting tugs for rigging of lifting attachments to the Jacket. Diving is also being considered as an alternative to ROV operations.

Installation of lifting attachments and lifting
A combined lifting and sea fastening attachment has been developed for lifting and securing of the Jacket. The attachment is connected to the strand jack lifting system by conventional strand anchor pad eyes. The connection is assumed performed by an ROV, but use of divers is being considered. Jacket to be lifted by 16 pieces 900 T strand jacks and will thereafter be secured to the vessel by 16 telescopic arms connected between pad eyes on the lifting attachment and the inner side shell of the hull (horizontal sea fastening). The vertical sea fastening to be achieved by strand anchors pulled against stoppers on strand jack supporting structures. Shimming might here be necessary in order to ensure firm contact.





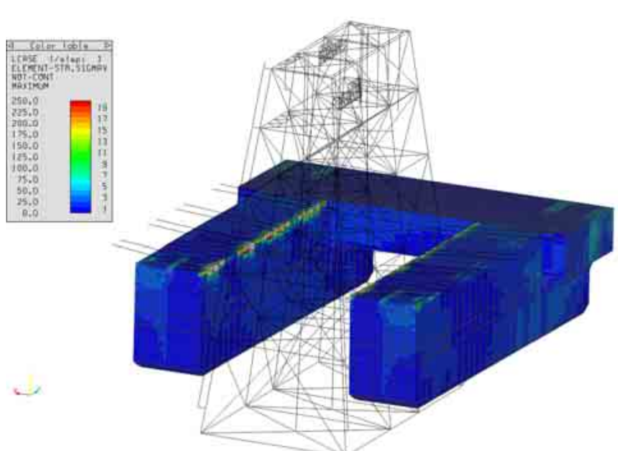
Transport of Jacket to Inshore Dismantling Site
The Jacket will be transported in a partly submersed position to the inshore dismantling site.



Structural analysis
The acceleration in the COG for Jacket in transport and survival conditions has been calculated. The horizontal accelerations (including gravity component) are given below:

	JACKET TRANSPORT	
	Longitudinal	Transversal
Transport condition (m/s^2)	2.30	3.66
Survival condition (m/s^2)	2.85	4.36

The typical Jacket structure (Ekofisk 37/4A Booster Platform) was checked for lifting and sea transportation.



The analysis of the lifting condition with self-weight only showed the global structural usage to be low, with the maximum stress usage in the main load carrying members to be 0.3 with a maximum of 0.49 in a minor member at the upper plan truss.
Results of the transport condition show that the members exposed to wave loads are the most highly stressed. These are exposed high bending moments resulting from the local drag forces induced by the global motions. All members were found to acceptable usages in this condition. The head sea wave gave the highest usages.

The jacket has adequate global capacity to withstand the forces imposed during a 10-year return summer storm in the transport condition.