20 YEARS DECOMMISSIONING EXPERIENCE - EVOLUTION OF INNOVATIVE SOLUTIONS

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SUMMARY

Decommissioning is an increasing market sector which has been gradually gathering momentum particularly in the North Sea. The forecast expenditure for removing existing platforms increases with time. This comes together with the increasing complexity of the decommissioning operation. Experience and expertise in this field are key for success. Saipem have been contracted to perform a number of 'removals' ranging from subsea templates, subsea pipelines, seabed debris clearance, jacket structures and topside modules. This paper provides an account of our experience gained over the last 20 years performing decommissioning activities. The paper presents the evolution of the techniques developed and focuses in particular on the Lift and Tow method developed after 2004 for a number of subsea applications. Problems always materialise post contract award due to inadequate data. The paper gives a detailed description of the Lift and Tow method along with various innovative techniques developed for this method, ranging from lifting operations supported by motion forecasting through to personnel access onto the structures.

NOMENCLATURE

CDP1	Concrete Drilling Platform 1
DES	Drilling Equipment Set
DP	Dynamic Positioning
DP1	Drilling Platform 1
DRM	Drilling Rig Module
DSM	Drilling Support Module
EPR	Engineering, Procurement and Removal
Hs	Significant Wave Height
ILT	Internal Lifting Tool
MCP01	Manifold Compression Platform 1
MSF	Module Support Frame
PMMF	Pipeline Movement Measurement Frame
QP	Quarters Platform
RAO	Response Amplitude Operator
SBS	Skid Beam Structure
SSCV	Semi-Submersible Crane Vessel
S7000	Saipem 7000
TCP2	Treatment Compression Platform 2
TLP	Tension Leg Platform
TP1	Treatment Platform 1
TOGI	Troll Oseberg Gas Injection

1. INTRODUCTION

Saipem has been undertaking decommissioning work since 1996. If the removal of some modules from the Ninian Platform back in 1991 is included, which was before the name decommissioning became the vogue, the tonnage would be higher.

This paper describes how removal methods and operations have evolved in the last 20 years due to the resources available and the environmental, safety and economic challenges of decommissioning, giving what are considered to be robust solutions for offshore platform removal. Innovative operational practices and bespoke equipment have been developed in this process. These are described where relevant within this paper. Table 1 below shows the various significant structures removed by us since 1996 and indicates a complete overall tonnage in excess of 133,000 tonnes.

Table 1 - List of Various Projects with Removed Tonnage

Project/Description	Removal Year(s)	Tonnage Removed
Esso Odin	1996/1997	16,210
Tommeliten Gamma Template	2001	1,212
Hutton TLP Foundation Templates	2002	8,400
Bouri DP4 Drilling Sets	2004	5,800
Brent Flare Tower* and anchor	2005	5,100
Frigg Field (QP Jacket*)	2005/2010	75,065
TOGI Template*	2011/2012	1,800
Mad Dog Drill Rig	2012	2,750
Heimdal Drill Rig	2013	1,064
Drill Rig 5820	2013	3,083
2/4-S Jacket* and Tripod	2014	11,972

The projects highlighted (*) involved the use of the "lift and tow" method that is described subsequently.

All Offshore removal operations were carried out by the Semi-Submersible Crane Vessel (SSCV), S7000 in Dynamic Positioning (DP) mode. Some preparations work on the projects was performed from the platforms or other smaller construction vessels.

Offshore removal operations have relatively low limiting sea states, therefore efficient removal methods had to be developed to efficiently utilise the weather conditions expected. The highlighted projects will be briefly described in this paper and expanded with more details for cases related to the Lift and Tow operation.

2. DECOMMISSIONING PROJECTS

2.1 ESSO ODIN REMOVAL, 1996-1997

In 1996, we were contracted to remove the Esso Odin platform located in Block 30/10 within the Norwegian sector of the North Sea. The Odin platform was in a depth of 103 meters.

Odin was the first large fixed installation to be decommissioned in the North Sea. The total weight removed was 16,210t including topsides and jacket. Underwater cutting of both members and piles was performed in the process of jacket removal. The jacket was cut into sections subsea and transported on the deck of the S7000.

The decommissioning process presented many technical challenges. As this was the first significant decommissioning project for us, these challenges included weight control, unknown materials, condition of the various structures plus unforeseen soil conditions. These combined to make the project very unprofitable.

2.2 TOMMELITEN GAMMA TEMPLATE, 2001

Tommeliten Gamma was located in 72m of water in the Southern part of the Norwegian sector of the North Sea, South West of the Ekofisk field centre. The template comprised a six slot pre-drilling template along with a main template, which encompassed the pre-drilling template. Both templates were removed together, in a single lift. The 1212t template assembly was lifted from the seabed using a tandem configuration, over the SSCV port side for placement onto pre-installed grillages on the S7000 deck. Divers were used in connecting the pre-installed lower rigging. Pile cutting was successfully achieved by use of shaped explosive charges.

It is worthy of note that the initial engineering studies/designs etc. were hampered by certain information concerning the template being vague. This created difficulties with lifting analyses plus grillage and seafastening design. However, this is quite usual in decommissioning projects as most other projects also have encountered similar issues.

2.3 HUTTON TLP FOUNDATION TEMPLATES, 2002

The Hutton Tension Leg Platform (TLP) was located in Block 211 /27-28 of the U.K. Sector of the North Sea. That was the first TLP used in North Sea. Four foundation templates were removed.

Each template was approximately 22m x 19m on plan by 11m high in 148m of water. Every template was secured to the seabed by 8 piles and 1 pin pile. The 4 TLP tethers were removed and the piles were cut 1.0m below the seabed in readiness for lifting.

The weight of the templates ranged between 1510 and 1660te. The piles were cut by internal pile cutting tools and the templates were each lifted from the seabed using a tandem lift configuration, over the SSCV port side. Each template was then set down onto pre-installed grillages on the S7000 deck and transported back to the yard.

Figure 1 - Hutton Foundation Template Lift-Off from Sea Bed

2.4 BOURI DP4 DRILLING SETS, 2004

The Bouri DP4 platform was in Western Libyan waters and was to be upgraded as part of Western Libyan Gas project. The modification work included decommissioning and removal of 5 modules. The removed modules comprised:

- Upper mast of derrick structure
- Lower derrick, drilling substructure and skid Base
- Drilling mud tank
- Mud and cement drilling module
- Power and bulk drilling module

A total of 5,800t of modules were lifted by S7000 and set down in a temporary position on the S7000 deck. Subsequently, modules were transferred onto another vessel to return to shore for disposal.

2.5 BRENT REDUNDANT FACILITIES FLARE TOWER, 2005

The Brent flare was located in 140m of water in Block 211/29 in UK sector of North Sea. The work scope included the removal and disposal of the Flare Tower together with the gravity base and six concrete anchor blocks from the Brent Spar.

The combined Flare Tower and Gravity Base were lifted using 8 basket slings placed around the flotation tanks (2 at each lift location on the base). Each set of basket slings were connected to a doubled sling suspended from the underside of an Internal Lifting Tool (ILT) receptacle. This rigging, and the ILT receptacle, were installed as part of the preparation activities to be carried out from a Diving Support Vessel by divers prior to the S7000 arrival. We were responsible for the supply of all rigging, lifting clamps, shackles, spreader bars, horizontal restraint frame, etc., to be used by the S7000.

The static weight in water of the Flare Tower and Gravity Base was approximately 1540 tonnes (including buoyancy), excluding rigging and 'attachments' (horizontal restraint frame, clamps etc).

The Flare Tower and Gravity Base were lifted as one complete unit, using the 1st Auxiliary hooks of both S7000 cranes working in tandem, as shown in Figure 2.

Figure 2 - Brent Flare Tower Lift-Off from Sea Bed

Once lifted, the Flare Tower and Gravity Base were "towed" by the S7000 to the Aker Kvaerner disposal facility at Stord. There it was upended, so that, with the Gravity Base rested on the seabed and the Flare Tower left free floating. Finally it was lifted inshore by a smaller shear leg crane barge and moved into a dry dock for disposal activities to commence. Specific details will be discussed subsequently.

2.6 FRIGG FIELD DECOMMISSIONING, 2005-2010

The Frigg field is located in both blocks 25/1 of the Norwegian sector and 10/1 of the UK sector of the North Sea, approximately 180km West-North-West of Stavanger and 400km North-East of Aberdeen in a water depth of 100m. The field layout is shown in Figure 3.

Our responsibility was for the removal of the following structures:

- The wrecked Drilling Platform 1 Jacket (DP1)
- Treatment Platform 1 (TP1) Topsides and the Module Supporting Frame (MSF).
- Treatment Compression Platform 2 (TCP2) Topsides and the 9000t Module Support Frame (MSF)
- Quarters Platform (QP) Topsides and QP Jacket by Lift and Tow method
- Drilling Platform 2 Topsides
- Concrete Drilling Platform 1 Topsides

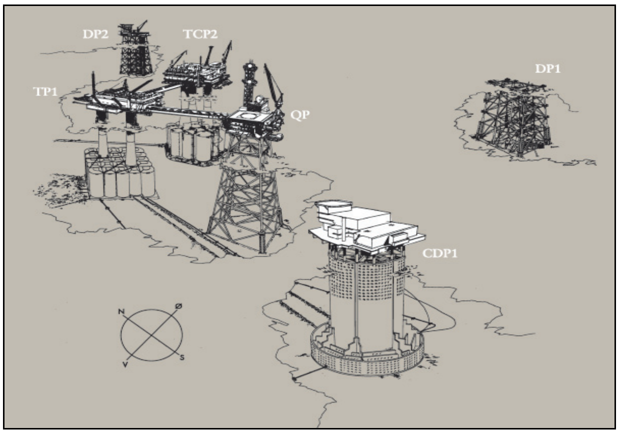

Figure 3 - Frigg Field

Figure 4 - Concrete Drilling Platform 1 - Platform Before and After Removal

Figure 5 - The 9000t MSF Removal

In addition, we also removed the Manifold Compression Platform 1 (MCP01) Topsides. The whole campaign spanned 5 years and finally was completed in January of 2010.

The 9000t TCP2 MSF was placed onto the flat top cargo barge, S600, using a rubber sea-fastening system to avoid offshore welding on the cargo barge. This seafastening system is patented (AkerSolutions FlexSeaFast) and is effectively a friction pad system. It was applicable to the MSF as it was a relatively wide and 'low height' structure with no expected uplift during transportation.

Diverless operations were used in removing the wrecked Drilling Platform 1 Jacket (DP1). The jacket was cut into three sections and transported on the S7000.

Concrete Drilling Platform 1 (CDP1) was both prepared and removed by the S7000 over a six month period which extended into the winter months. Whilst it was a challenging exercise, we gained valuable experience in the Engineering, Procurement and Removal (EPR) aspects of a decommissioning project.

2.7 TOGI TEMPLATE REMOVAL, 2011-2012

The TOGI template was located in 302m of water about 130nm North East of Stavanger in the Troll Field. A 20'' pipeline and umbilical was connected to the template. Four piles connected the template by swaging to the seabed.

The structure was installed by S7000 back in 1989. The removal included three campaigns, which were for survey and inspection in July 2011, preparation for removal in April 2012, and removal and back loading to shore in August 2012.

Figure 6 - TOGI Template Lift-Off Near Shore

In April 2012 during the survey, approximately 650 t grout/drilling mud was found inside the template well bay and presented a technical challenge towards the original planned removal operation. It was then concluded to use the "Lift and Tow" methodology to remove the template and back load to shore. This will be further described subsequently.

2.8 MAD DOG DRILLING RIG, 2012

The Mad Dog platform is a truss spar with 12 wells in sector Green Canyon 782 located in approximately 1372m (4,500 feet) of water, approximately 190 miles SE of New Orleans, Louisiana. The topside includes production facilities, a drilling rig and living quarters for 126 personnel.

The Mad Dog drilling rig module (DRM) comprises a drilling equipment set (DES), skid beam structure (SBS) and drilling support module (DSM). The DES was lost while the DSM was badly damaged during hurricane Ike in 2008.

The existing 2400t DSM (with the SBS attached) was removed from the Mad Dog spar, placed and seafastened on transportation barge and then transported to shore for offloading. It was lifted offshore by the tandem cranes of S7000. During the lift, the motion and attitude of the structures changed. This phenomenon was caused by the Truss spar and the relatively large spar draft change when the DSM was removed. Detailed analysis was required to ensure the action offshore by the S7000 did not compromise the lift.

Figure 7 - Mad Dog DSM Removal

The new DRM was then installed by S7000 during the same campaign.

2.9 HEIMDAL DRILL RIG, 2013

The Heimdal field is in block 25/4 of the Norwegian sector of the North Sea, in a water depth of 120 m.

The drilling facilities on the Heimdal platform were removed in two parts by S7000 in August 2013. The first part, the derrick, weighed approximately 150 tonnes.

The removed items were seafastened onto the S7000 deck for transportation and subsequently offloaded directly on to the quayside at the disposal facility.

Figure 8 - The Removal of Heimdal Drilling Derrick

The second part, including the substructure and skid base, weighed approximately 1000t. Again, the condition and weight data were somewhat vague.

2.10 DRILL RIG 5820, 2013

The BD1 Platform is situated in the Al Jurf Field, Mediterranean Sea, approximately 60 nautical miles North West of Tripoli, off the coast of Libya.

Eight modules from the BD1 platform were removed as part of the Mabruk Oil Operations' Rig 5820 project in 2013.

These modules are listed as follows,

- Living Quarter module
- Living Quarter Support Frame
- D3 module
- D2 module
- D1 module
- Drilling module
- P-Tank module
- Mud Treatment module

The modules were lifted and loaded onto the deck of S7000 which then transited to Almeria in Spain where the modules were offloaded directly on to the quayside.

2.11 EKOFISK 2/4S REMOVAL, 2014

The field location is approximately 200 miles South West of Stavanger in approximately 80m water depth. The decommissioning work included the removal of the Ekofisk 2/4-S Tripod and Jacket structures.

The scope of work included project management, procurement, surveys, engineering, offshore preparation, fabrication, removal, area clean up and final survey. All removed items were transported to Kvaerner (formerly Aker) Stord disposal site on the West coast of Norway.

The following items were removed and transported to the disposal site:

- A 2500t Tripod with a small 142t deck. The tripod had six skirt piles, each of which was cut approximately 2m below the mud line
- A four legged jacket structure weighing approximately 9330t in air (included the remaining piles, grout, marine growth etc.). The jacket had sixteen skirt piles in total, each of which were cut approximately 2m below the mud line.
- Two subsea pipeline movement measurement frames (PMMFs) and a subsea riser section.

Figure 9 - Tripod and Deck

The tripod and deck were separated and lifted onto the S7000 deck and transported to the disposal facility. The jacket structure was removed by Lift and Tow method which, again, was caused by the deficiencies in supplied data.

Prior to S7000 arrival in field, a pre-removal campaign was performed to excavate the area surrounding the jacket and tripod piles. The piles were cut 2m below the seabed with diamond wire cutting equipment. Only those piles required for stability were left for the S7000 to cut. The subsea PMMFs were removed in the pre-removal campaign. Upon reaching the disposal facility the tripod units were lifted onto the quayside.

Figure 10 - 2/4S Jacket Removal

Figure 11- Access Platform to the 2/4S Jacket and Tripod

Another key aspect of this removal was the remoteness and lack of access to both jacket and tripod. Bespoke access platform, walkways and ladder structures, as shown in Figure 11, were fabricated. These pre-fabricated access ways provided fast and effective egress to the tripod and jacket which would have not been achieved within the same time frame using offshore scaffolding.

The jacket, upon arrival inshore, was set down onto a surveyed area of the seabed close to the disposal facility. Then the jacket was cut above the waterline and the upper section lifted onto the quay. The lower section was placed on the seabed next to the quay for onward disposal.

3. EVOLUTION OF THE LIFT AND TOW METHOD

Saipem has removed a number of subsea structures and jacket structures throughout the years and various challenges drove us to focus on a unique solution using a "Lift and Tow" method. Available weather windows, large lift vessel availability and enhanced workability inshore have influenced the decision to bring large items from their offshore location to an inshore location or deconstruction site for subsequent separation and disposal. Offshore preparation equipment such as dredging and external and internal pile cutting devices for platform piles have also improved in size and reliability over the years, thus supporting more efficient use of offshore lift vessels for platform removal.

With the Lift and Tow removal method, the structure is suspended by the hooks of the S7000 and partly or entirely submerged. The structure and the crane vessel sail together from the offshore field to the inshore disposal facilities.

It is worth noting the use of this method in the early years was not as originally planned, however, it has now proven itself to be our preferred method to remove this type of structure.

The advantages of the "Lift and Tow" method are listed as follows

- remove the height restriction due to hook elevation limit during lift
- buoyancy of the submerged structure reduces the required hook capacity
- allows removal of the structure in one piece and therefore significantly reducing the offshore operational time and cost
- reduces offshore handling of materials on the deck of the removal crane vessel
- eliminates complex subsea cutting which often results in the structure becoming an unstable mechanism during removal requiring temporary restraints to be installed.

The use of such a method had been conducted in the Gulf of Mexico by others [1] and the transportation of items suspended by cranes is an everyday occurrence. However, the specific issues associated with tow duration, tow distance, tow route residual fatigue lift of structure and suitable weather conditions were seen as the main basic questions to be addressed. They are discussed in detail in the following sections.

3.1 BRENT REDUNDANT FACILITIES FLARE TOWER

The Flare Tower was an equilateral triangle in plan, with sides of 8.5m long. Its overall height, from the centre of the universal joint, was 188.4m. The approximate overall dimensions of the Gravity Base were 30.8m long, 32.8m wide and 6.2m high. The structure between the flotation tanks was divided into five compartments, three of which were filled with reinforced concrete.

Due to the double skin requirements of the originally proposed removal buoyancy tanks and their connection to the flare tower structure became unrealistic. This was coupled with significant concerns over cutting the high strength steel ball joint of the flare tower. The original designed removal method was concluded to be impractical and completely re-evaluated.

During an internal brainstorming meeting between onshore operational engineers and the S7000 offshore team, the concept of using a lift and tow method was founded.

Figure 12 outlines the lift rigging system used for the Brent Flare Tower removal which in itself presented challenges in terms of design and installation. However the system itself is both simple and inherently stable.

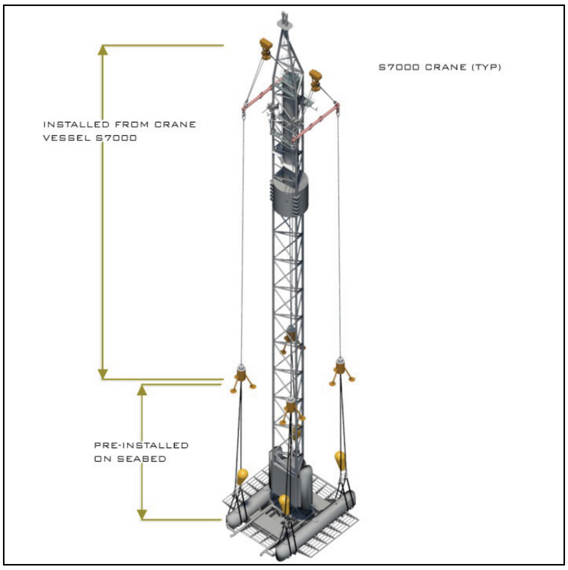

Figure 12 - Brent Flare Tower Rigging System

Various analyses, which are listed below, were required to ensure the method of removal was not flawed. This also included a model test which was carried out at the MARIN's facilities in The Netherland. Analyses carried out included:

- Time domain dynamic analysis using MOSES to check, both hydro-dynamically and structurally, the complete system was adequate.
- Vortex induced vibration analyses for the lift rigging during tow.
- Check any natural periods of vibration of element that could be incurred during the transportation
- Soil-Structure Suction interaction analysis for lifting from seabed.
- Detailed "What if" analyses for the tow journey
- Correlation of expected "analysis" results, including the attitude and physical behaviour.

The journey from the field to the sheltered water was 3 days. A motion forecasting and monitoring system was used to cover the whole tow journey. An instantaneous correlation between the predicted and offshore measured results was performed to ensure the situation was monitored and, hence, the received forecast was further correlated.

3.2 FRIGG QP JACKET

During the development of the Frigg Deconstruction Project a number of economic challenges were faced across the entire work scope. In order to reduce the economic burden that we faced, the ability to lift and tow the entire jacket structure, which was some 6000 tonnes including pile remnants, was investigated. This approach effectively allowed the offshore campaign to be reduced to a single trip and avoided the expensive and time consuming need to cut the jacket in sections offshore and subsea. For removal, the rigging system was connected to the jacket and in conjunction, the jacket was released from the seabed by dredging and using external pile cutters. This operation was carefully coordinated as the piles were cut in a planned sequence. The complete jacket was then carried to an inshore location. The final separation operation was undertaken inshore in shallow water with benign conditions in a quarter of the time it would take offshore.

The offshore tow was just in excess of two days. Figure 13 shows the simple lifting system adopted.

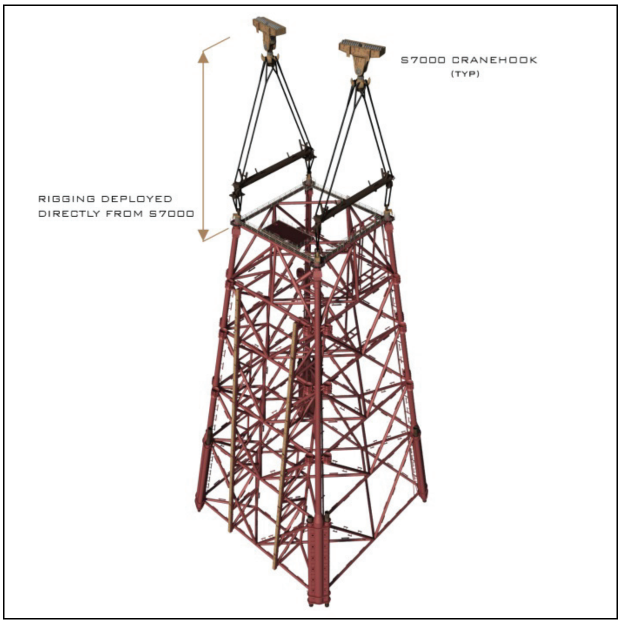

Figure 13 - QP Jacket Rigging System

Again the same basic questions that existed for the flare tower had to be addressed.

3.3 TOGI TEMPLATE

Here the challenge faced was different in so far as an excessive amount of drilling cement was found inside the structure during surveys after the contract was awarded. That precluded the structure to be raised from the sea floor and transferred directly onto the deck of the SSCV S7000 for transport to shore and subsequent offload onto a quayside. With a water depth of 300m, the ability to provide an effective solution was problematic. The revised method employed the use of lift rigging that allowed a high capacity crane hook to be used to lift from the sea floor. Detailed finite element analysis of the lift points and complete structure was performed to demonstrate the veracity of the removal method.

The transportation was performed in a series of steps using temporary emplacements in a suitable shallower water depth, whilst the rigging system was adjusted. This in fact allowed for a series of "way points" to be established reducing the "safe to safe" transportation weather forecast period. Figs.14 and 15 show the lift rigging system used for the various phases of the template recovery. Whilst the tow remained submerged for most of its journey, similar challenges and questions to the previous methods needed to be addressed. The combination of an engineered and operationally driven solution was a key to the successful conclusion of the project. Reference [2] provides a complete presentation of the project.

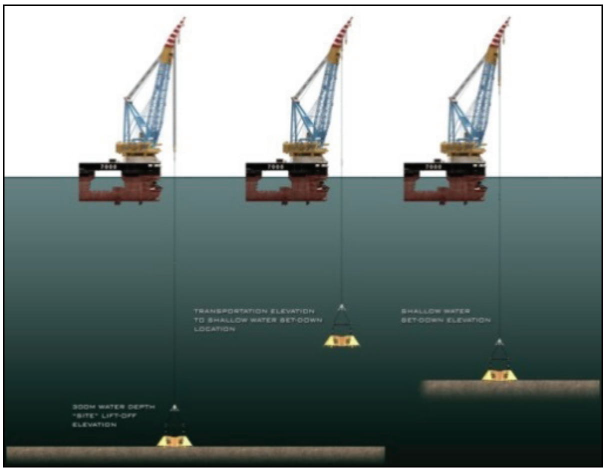

Figure 14 - TOGI Set-Down / Transportation Diagram

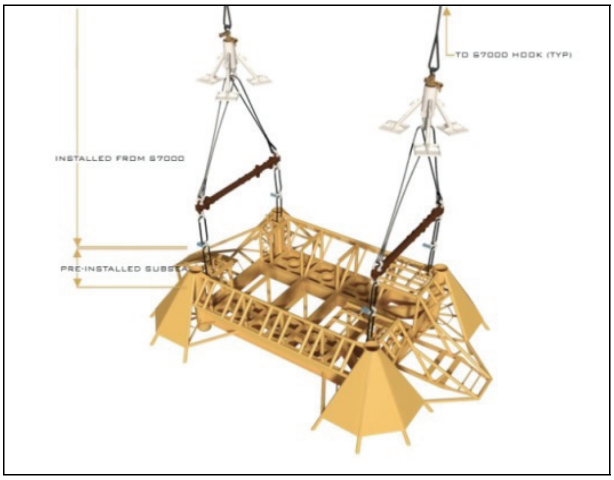

Figure 15 - TOGI Rigging System

3.4 EKOFISK 2/4S JACKET REMOVAL

Having found that the Brent Flare and QP Jacket removal methods were successful both technically and economically, Saipem offered this as their preferred method for the removal of the Ekofisk 2/4-S jacket structure. Statoil accepted the offer including the same lifting configuration as used for the QP jacket. Unfortunately, during the detailed planning phase of this project, it was discovered that the weld between the jacket extension frame and the existing jacket was not suitable to transfer the load. Simple reinforcement or replacement was not suitable as this joint was now at the waterline due to subsidence at Ekofisk. Indeed the extensions section had been originally added in the 1990s as part of a mitigation exercise for the field subsidence.

A decision was made to continue with the lift and tow method. However a lifting frame and long rigging with clamps connecting into the piles of the jacket were used, as shown in Figure 16.

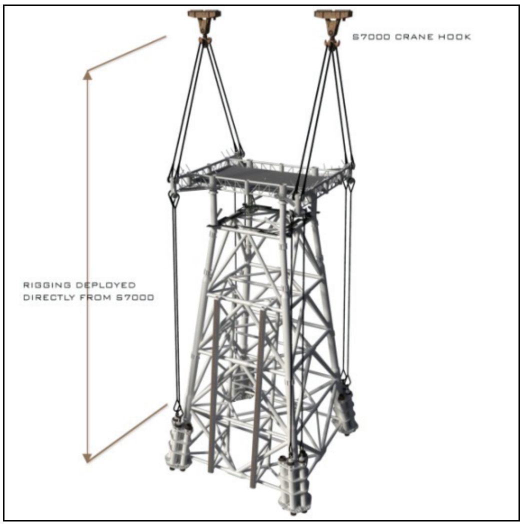

Figure 16 - 2/4S Jacket Rigging System

This arrangement capitalised on the principles established during the Brent flare tower design development with the additional challenge of proving the grouted connection between the pile and pile sleeve would be capable of transferring the jacket loading. The idea in principle was not of concern as the entire weight of the jacket, topsides and associated pay load had to originally be carried by the grouted connections.

Offshore survey, testing and detailed finite element analyses were carried out. These analyses ensured the clamp, pile and grout interaction would not lead to failure. Uniform quality in the grout and connections were found.

4. OVERCOMING THE BASIC QUESTIONS

A number of restrictions and criteria in applying "Lift and Tow" methodology need to be addressed for each operation. Considering each of them presented here, methods were developed in conjunction with others along with review and acceptance by our clients, these methods are described below.

4.1 TOW SPEED AND DURATION

With the present propulsion capability, the S7000 at heavy lift draft is capable of making about 2.5 knots forward speed with the cranes elevated and the weather acting concurrently against the direction of travel. The corresponding weather is listed as follows:

- 20 knots wind
- 0.5m/sec current
- 2.5m significant wave height (Hs)

Model testing was carried out for the tow of the Brent Flare which demonstrated that at this 2.5 knot speed the immersed and suspended structures did not suffer significant dynamic amplification or movement toward the S7000 when being towed. We believe that the optimum solution is leaving the structure suspended freely and not constrained horizontally to the S7000.

Most tow durations in the North Sea area would not exceed 3 days (72 hours) which is at the limitation of a restricted operation weather forecast as defined by DNV Rules [3]. This 3 days duration also ties in with the higher level of confidence in weather forecast.

This knowledge allowed us to consider the feasibility of the Lift and Tow method to be realistic and demonstrable subject to the other constraints being assured.

4.2 TOW DISTANCE

Towing distance can be seen to have the same constraints as the tow duration and tow route. However, Mariners always request to know how far they must travel. In this case a distance of 180nm (333km) is planned between areas where the jacket or subsea structure can be temporarily placed on the seabed prior to continuation of the journey.

4.3 TOW ROUTE

Tow routes must be investigated for a number of attributes namely:

- Adequacy of water depth along the route.
- Seabed infrastructure (pipelines/cables etc) along the route which need to be crossed during the tow-in operation.
- Above water structures, such as power cables and bridges, which may preclude a certain route especially near shore.
- Places in which the structure can be temporarily set-down on the seabed if possible, including seabed surface bathymetry and strength.
- Passage along or across shipping lanes.
- Proximity to airports or other facilities.
- Currents or eddy's present along the route.
- Visibility for ROV activity especially in 'brackish' waters.
- Any change in water salinity, again especially inshore where freshwater rivers may discharge close to the route.
- All authorities that need to be contacted and informed of the passage plan ranging from the military, Civil Aviation Authority, Lighthouse Association and Coastguards.
- Alternative routes require investigation to ensure that safe havens can be reached in the event of an unforeseen situation.
- Minimisation of the tow route distance where possible.

It can be seen from the above this represents a significant effort both in desk top studies and offshore survey data gathering. Specialist companies can assist in provision of information and now we have developed a set of "road maps" or "arterial routes" they use for most tow-in operations, with the need only to process the deviation from the offshore field until it intersects with the "arterial routes".

4.4 RESIDUAL STRUCTURE FATIGUE LIFE

Unfortunately many of the structures to be removed have exceeded their original design life and as such a review of the critical nodes and members must be carried out. The general design review of the structure will pinpoint the areas of special attention. During the offshore inspection survey, flooded member detection along with close visual inspection of nodes after cleaning is performed to check for signs of cracks, damage and corrosion and determination of locations for the drilling of "drain" holes. Again the original designs are not always available and often in terms of fatigue simple assessments were made at that time, some of which have proved erroneous during the life of the structure.

A dynamic tow-in analysis allows the assessment of the fatigue damage likely to be encountered during the tow-in. This is combined with an assessment of the modern day calculated fatigue life already used. It is worth noting that many joints have a significant fatigue life in comparison to that of the design life criteria set. In most cases only a small number of joints need further investigation usually by finite element analysis to understand if the stress concentration factors are overestimated, which is normally the case.

To date Saipem have found this approach to prove very successful and has allowed the tow-in method to proceed. Should a node appear problematic the intention would be firstly to understand the consequence of its failure during the tow-in and should this prove catastrophic then reinforcement in terms of clamped additional members would be added.

4.5 SUITABLE WEATHER CONDITIONS

Design weather conditions are clearly established in the engineering phase of development based on the theoretical wave spectrum (i.e. wave energy distribution).

However, the actual installation sea state is quite different to the theoretical spectrum due to the calm sea state. The whole sea state will not be dominated by the local wind effect. It most likely comprises of multiple wave components from different directions with different peak periods and spreadings. It will not be enough just to have the forecast significant wave height and wave period, swell height, swell period and swell direction.

The forecast of these conditions to enable the maximum sea conditions to be used is vital for the Lift and Tow operations.

4.5 (a) Motion Forecasting

In order to capture the effects of all wave components, the motion response of the crane vessel with the jacket/subsea structure on the hook is forecast at way points along the tow route, as shown in [4].

The basic element of motion forecast is the wave energy forecast. The forecast information is the distribution of wave energy from different directions and periods. The forecast will be in form of a plain text data file attached to an email and sent to predefined email addresses twice or four times daily. The file will have the forecast wave energy distribution every three hours for a 5 day forecast period.

A proprietary program, VRFGM, from Global Maritime, London, is used to rearrange the wave energy information and present it on the screen. Figure 17 presents a screen shot for reference.

The upper graph shows the variation of Hs for the 5 day forecast period. The lower left-hand-side shows the wave energy distribution in a contour plot at the specified time. The active wave components are clearly identified. Similarly, the wave energy distributions in direction and period are shown in the right-hand-side of the graph. This information gives the engineers and mariners a better picture of the sea state that they would see.

The maximum motion response for a multi-body dynamic system can be forecasted by combining the forecast wave energy distribution and the motion characteristic data, Response Amplitude Operators, (RAO) at a point of the body (e.g. crane tip, jacket leg bottom or centre of gravity etc.), as shown in Figure 18. This gives our offshore teams a clear picture of the dynamic behaviour throughout the whole tow route.

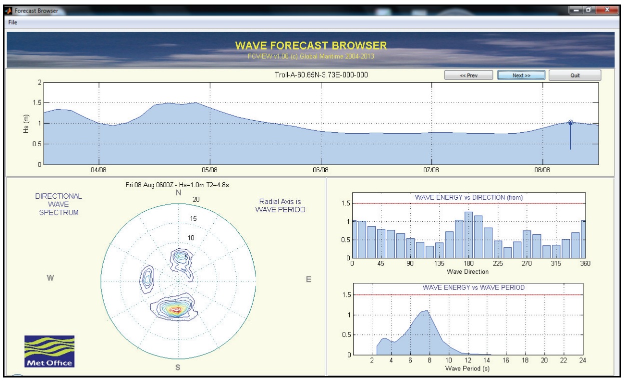

Figure 17 - Sea State Based on Wave Energy Forecast

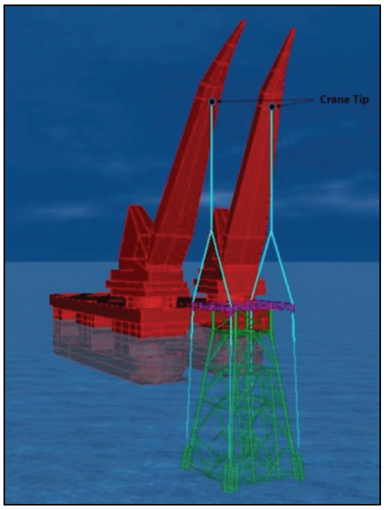

Figure 18 - 2/4S Jacket Lift and Tow

Since the tow route is fixed, the vessel heading relating to North is fixed. Figure 19 shows the forecast 6 degree of freedom motion at the port crane tip as an example.

Similarly, the motion at the bottom of the jacket leg after lift-off can be forecast. Mariners and engineers can have an insight for the motion of the leg once the jacket is lifted from the bed.

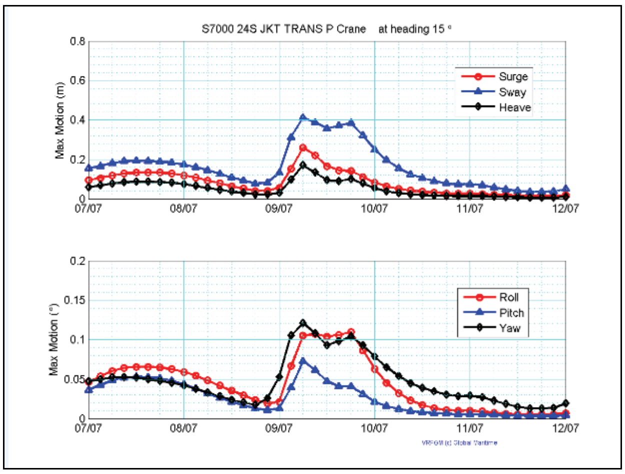

Figure 19 - Motion Forecast at the Port Crane Tip with the Vessel Heading 15° to North

4.5 (b) Motion Monitoring

A crane tip monitoring system was developed for the Brent Flare Lift and Tow removal and deployed onto the S7000. The system architecture is presented in the following Figure

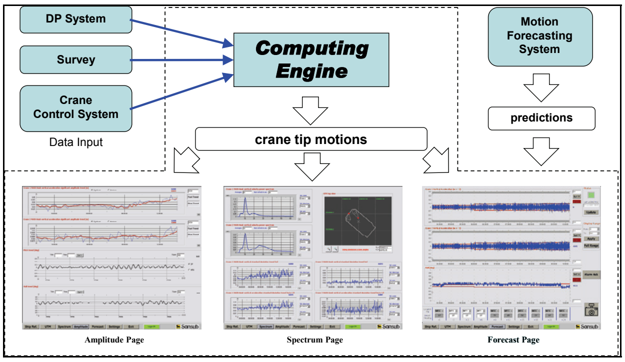

Figure 20 - Motion Monitoring System on S7000

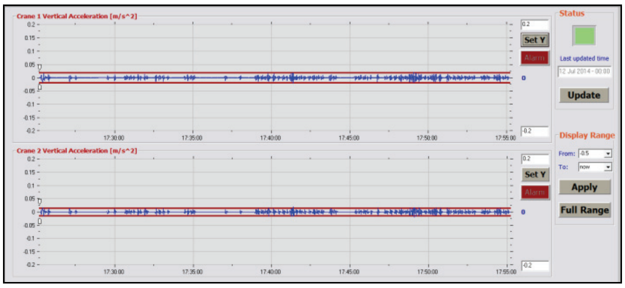

Figure 21 - Motion Forecast and Monitoring System on S7000

The motion of the S7000 is measured by the Motion Reference Units (MRU) of the Dynamic Positioning system on board S7000 and then translated to the crane tip locations. The system also collects the forecast maxima motion from the forecasting machine and presents them together with measured values.

The measured crane tip vertical accelerations are presented in the FORECAST screen of the system as blue lines while the forecast values are in red. This provides an instantaneous correlation on the screen. Figure 21 presents a screen during the tow-in journey.

During the tow-in journey, it is inconvenient to deploy wave rider buoys to monitor the weather. The motion monitoring system provides a mean to monitor the operation and confirm the reliability of the weather forecast. This also fulfils the requirement named by DNV in [3] and hence a higher design criteria ratio (α) can be used in the operation. This ratio (α) is multiplied by the design limiting sea state to get the allowable sea state for the operation. Higher (α) factor means higher allowable sea state and higher operability.

5. THE FUTURE DEVELOPMENT OF LIFT AND TOW METHODS

Saipem having successfully performed a number of removals using the lift and tow method and now feel confident this method is robust both technically and economically. Although, until recently, the use of the method has been as a result of significant challenges as described earlier in this paper, it is believed the following can give rise to improved performance.

- **i.** Development of a deep water quay which is capable of allowing the SSCV S7000 access to place components directly onshore. This avoids either placement onto a cargo barge or onto the seabed for subsequent dissection.
- **ii.** Use of the method for removal of large single topside units. The behaviour of such units is currently under investigation and once known will be reported.
- **iii.** Development of hydraulic internal lifting tools (ILT) capable of delivering 4000t capacity compared to the current capacity of 2500t. These tools allow rapid rigging connection and disconnection in the time critical phase of the offshore works.

6. CONCLUSIONS

Decommissioning is challenging technically, operationally and economically. Most platforms lack detailed information on weights, condition, hazardous materials and recorded change data is sparse. Often the platform has changed ownership with the resulting loss of records. The drive to reduce costs has meant contractual terms are often unfair with respect to the risk balance where the owner tries to pass on the responsibility of finding variance to the removal contractor upon completion of a single offshore survey. This is after the platform has been in the hands of the owner for many years. However, cost effective solutions to unexpected conditions need to be found and Saipem have developed the Lift and Tow method in response to this. We believe the method provides a valuable addition to the necessary array of solutions that are required in offshore decommissioning.

7. ACKNOWLEDGMENTS

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8. REFERENCES

1. VELAZQUEZ E. R., and BYRD R. C., “Gulf of Mexico Deepwater Platform Decommissioning” *OTC proceeding, paper OTC 15113*, 2003.
2. FRENCH S.,” Saipem – TOGI Removal Experience”, *Norwegian Petroleum Society, the*

13th NPF North Sea Decommissioning Conference, 2013.

3. DNV, "Marine Operations During Removal of Offshore Installations", *DNV Recommend Practice, DNV-RP-H102*, 2004.
4. LAI, P., HANNAM, M., MCCARTHY V., and SOVILLA S., "Motion Forecasting and Monitoring for Offshore Installation and Decommissioning Operation" *IMCA Annual Seminar, International Marine Contractors Association*, 2006.

