OTC 14211

Riser Tower Installation

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Abstract

The paper describes the offshore operations and associated engineering - riser base and umbilical arch installation, surface tow, upending, docking, deballasting, etc - that led to the successful installation of the three riser towers in the deepwater environment of the Girassol field. The paper concludes on the feasibility of installing riser towers in different field environments.

Introduction

The riser towers, designed, fabricated and installed by the Alto Mar Girassol consortium (AMG) for the Girassol field, are a new and unique design. The riser tower concept was originally proposed in October 1997 as part of the design competition for the Girassol project. In July 1998, TotalFinaElf Angola and its partners, finally selected the riser tower solution for the Girassol UFL (umbilical flowline) system.

The engineering team had to design the riser towers primarily to meet stringent thermal insulation requirements but also to ensure that the structure would be installable with conventional installation spreads. This challenge was overcome by developing safe and efficient installation methods verified by proper analysis and testing.

The three riser towers were fabricated at the Angolan yard at Lobito and delivered on schedule to be towed to the Girassol field. At this stage of the project, those who had put so much efforts in the concept had to go through a very stressful period. Meanwhile the offshore construction team carried out the operation successfully three times in less than 25 days, finishing one day prior to the arrival of the floating production, storage and offloading (FPSO) unit on site.

This success and the experience gained from the Girassol project, firmly establishes the riser tower concept as an important solution for deep and ultra-deep field development projects. The flexibility of the concept makes adaptation to greater water depths and hasher meteocean conditions relatively straightforward.

Brief description of the riser tower

Fluid and piping system

The riser tower consists of following:

- Four production risers (8in)
- Four gas lift risers (3in)
- Two gas/water injection risers (8in)
- Two service line risers (2in)

Riser tower main components

The riser tower integrates the following components (fig a-1):

- A buoyancy tank (fig a-2) with a support balcony for the flexible risers and gooseneck spools to ensure flow continuity.
- A bundle (fig a-3) comprised of a 22in steel central core pipe with production, injection, gas lift and service risers placed inside sets of buoyancy/insulation foam elements.
- A taper joint and transition pieces between the buoyancy tank and the bundle.
- Two independent umbilical support arches (fig a-4) to allow installation of up to four umbilicals per tower.
- A riser foot structure (fig a-5) with a male Rotolatch connector, a temporary buoyancy tank and riser configuration designed to interface and ensure flow continuity with the static flowline system through flanged rigid spool pieces.
- A riser tower anchor (RTA) (fig a-6) embedded in the seafloor with a female receptacle for the Rotolatch connector and two sheave mechanisms used to pull down the tower on its anchor.

Riser tower main data and characteristics for installation:

Overall riser tower structure characteristics:

- Overall length of the structure: 1,280m
- Mass of the riser tower during installation (with buoyancy tank ballasted) approximately: 3,400 metric tons (t)
- 600kN positively buoyant when submerged at Girassol field (water density 1,026 kg/m^3)

Buoyancy tank characteristics:

- Length: 40m
- Diameter: 5-8m
- Volume displaced: 1,220m^3
- 200kN positively buoyant during installation operation
- Mass of steel structure empty: 350t
- Mass of buoyancy tank ballasted: 1,214t

Riser bundle characteristics:

- Outside diameter: 1.45m
- Linear mass of the bundle: 1654kg/m
- 600N/m positively buoyant when submerged

Taper joint and transition piece characteristics:

- Length: 65m
- Mass: 100t
- 200kN negatively buoyant when submerged.

Riser foot characteristics:

- Length: 27m
- Mass: 40t
- 10kN positively buoyant when submerged.

Riser tower anchor characteristics:

- Height: 23m
- Diameter: 8m
- Mass: 190t
- 1,550kN negatively buoyant when submerged

Umbilical arch characteristics:

- Diameter: 12m
- Mass: 13t

Riser Tower installation Operations

Risk management: a key factor to a successful operation.

At the start of the project, AMG management identified the riser tower installation as an operation with significant level of risk. The main reasons being that no such installation operation had ever been carried out previously, and the consequences of any incident would have a severe impact on the overall project.

The risk analysis approach adopted by the project required the installation engineering to undertake the following actions in order to reduce the identified risks to an acceptable level:

- Conduct extensive numerical/scale model analyses to verify structure behavior.
- Perform HazId/HazOp (hazard identification and operability) sessions and technical review by expert committees.
- Carry out a series of function and fit up tests to validate the design and installation engineering.
- Develop a comprehensive familiarization program for the offshore installation team.

At a very early stage of the project, contingency scenarios were considered:

- Adverse environmental conditions
- Breakdown or rupture of installation spread, structure or equipment.
- Inability to meet installation specifications.

In response to these contingencies, a number of possible behavior scenarios for the structure under different configuration at sea were studied and appropriate emergency and back up procedures were developed. The design of the riser tower also had to be reviewed in light of safety considerations.

On June 16, 2001 in Lobito Bay at the Sonamet fabrication yard, jointly owned by Sonangol and Stolt Offshore, the first riser tower was rigged and inspected for towing to and installation at the Girassol field. On July 11, the offshore operations team successfully completed the installation of the third and last riser tower. The entire operation took less than 25 days with no major incident. The installation of each riser tower took between eight and nine days as scheduled, proving that the pre-planning by the offshore team allowed the learning curve to be at its optimum during the first installation.

The next paragraphs further detail each main installation activities of the riser towers.

Riser Tower Anchor (RTA) installation.

The riser tower anchor (RTA) design is based on the suction anchor principle used for FPSO mooring system.

Numerical analyses identified the possible risk of heave amplification under certain seastate conditions and the selection of an appropriate handling system was of paramount importance. Seaway Polaris was selected as the most suitable vessel among the Stolt Offshore fleet to carry out this work. The existing heavylift crane was upgraded to be able to handle a load of 450t at 2,000m water depth a dual capstan winches equipped with left and right handed wire to avoid rotation of the load during the descent.

A numerical model demonstrated that ship response to seastate conditions off West Africa did not necessitate the use of a heave compensation system.

The installation tolerances of the structure were optimized through a proper evaluation of the tower component performance to allow maximum installation flexibility:

- Tilt angle: -5^o to +7.5^o
- Heading: +/-7^o
- Position: +5m in FPSO direction, -3m in FPSO opposite direction and +/-5m lateral

Two deadweights were pre-installed within a long baseline array and holdback slings made to adjust and control the structure just before final landing. This device proved itself useful as the remotely operated vehicle (ROV) had some difficulty in controlling such a load due to its mass and excess of heave motion.

The heave motion of the RTA at sea matched the numerical model predictions within 15% accuracy.

The RTA self-penetrated in the seabed and was then driven its complete burial by means of a suction pump mounted on the ROV. Finally the ROV installed two pressure caps to seal the anchor from the external environment. The three RTAs were installed within specifications.

Towing from Lobito to Girassol.

Upon completion of the pressure testing of the riser tower in the bay of Lobito, a surface diving team from the Stolt Offshore vessel American Pride began to rig the structure in preparation for the towing operation to the Girassol field. Two motion recording units (MRU) were installed on the first riser tower (one at the foot extremity and the other one 100m from the extremity) to collect motion data from the structure during the towing operation for future comparison with analysis results.

The leading dynamic positioning (DP) tug Seaway Explorer and the trailing tug Seacore Voyager were mobilized to surface tow the riser tower to the Girassol field. American Pride and its surface diving team acted as guard and assistance vessel during the towing operation.

The leading towline consisted of 3in wire attached to the riser tower foot by means of two sacrificial strops. The Dead Man Anchor (DMA), to be used for the upending operation, was pre-rigged and hanging at the stern roller of the vessel in order to reduce the risk of handling such a load at sea. The trailing towline consisted of a bridle attached to the buoyancy tank through two padeyes. The bridle was connected to a 4in ballast chain deployed from the trailing tug's tow winch (fig b-1). The role of the ballast chain was to control the depth of the buoyancy tank and act as a spring to a constant holdback tension to the tower. A safety surface buoy attached to the buoyancy can provided a net buoyancy of 800kN to prevent the riser tower from descending too deep in case of accidental flooding or loss of the ballast chain by the trailing tug.

Towing the structure in a buoyant state had been decided for safety reasons and to ensure the reversibility of the operation at any stage of the installation program. After the riser tower had left Lobito Bay (fig b-2), the buoyancy tank was submerged to a depth of –50m from surface by progressively deploying the ballast chain from the trailing tug (fig b-3). This operation was required to reduce the stress generated by waves at the taper joint level.

The 600km-tow route was carefully engineered using fatigue simulator software developed specifically for that purpose (fig b-4). American Pride, equipped with a Datawell buoy, recorded the seastate conditions every six hours so that the actual fatigue damage ratio of the structure could be estimated directly on site during the towing operation. The seastate conditions measured were:

- 1.5m<significant height (Hs)<3.4m
- 11s<wave period (T)<16s
- 20°<wave direction<50°.

The leading tug towed the structure using 80%-90% of its power at a tow speed which varied from 3.5knots (kt)to 4.2kt and a maximum dynamic tension reaching 1700kN. The trailing tug applied a constant back tension of 300kN. Tension meters installed onboard recorded both trailing and leading tensions. An acoustic transponder with a depth sensor monitored continuously transmitted the depth of the buoyancy tank to the trailing tug. The tow master and ship captains were monitoring the behavior of the riser tower and towing vessels using a tug management system and Differential Global Positioning System installed onboard each ship. The convoy behaved extremely well during the whole towing operation and both captains did not experience any problems controlling their respective routes.

The convoy arrived at the Girassol field (fig b-5) and positioned itself in dedicated target areas to prepare for the upending operation. The leading tug switched the DP mode while the trailing tug continued to maintain back tension.

The surface diving team from American Pride had to re-rig the tower in upending mode by deploying the 80tDMA and installing the two Dyneema pulldown slings from the DMA to the riser tower bracket (fig c-1). A second surface diving team surveyed the riser tower to verify the status of the structure and to install monitoring transponders for the upending operation. Some temporary buoyancy elements, originally pre-installed to reduce fatigue stress, were also removed and the safety surface buoy was re-configured for the upending operation.

At the end of this operation American Pride was released to prepare the next tower in Lobito Bay.

The three towing operations were carried out successfully with no physical damage to the structures reported after inspection. The cumulative fatigue damage coefficient was well below the targeted limit of 0.1.

Upending and connection to the RTA.

Although the upending of each tower from horizontal to vertical configuration was extremely spectacular, it remained a straightforward operation once the engineering analyses and step by step upending tables were finalized.

A dedicated subsea intervention vessel equipped with two ROVs and a video transmission link to the lead tug was required to monitor this operation and carry out the subsea intervention tasks. The vessels used in this role were the Seaway Eagle for the two first towers and Seaway Polaris for the last tower.

The trailing vessel remained in a dedicated target area keeping back tension, while the leading tug was paying out the towline to allow the DMA to descend (fig c-2). The subsea intervention vessel monitored the riser behavior during the descent. The weight of the DMA made the riser foot dive in a controlled manner.

Using the DP system, the leading tug adjusted its position in accordance with the engineering upending table and kept the tower under tension. The deployment of the DMA was halted once approximately 1,400m of towline was paid out. The leading tug then moved towards the trailing tug to reduce the gap between vessels. As a result of this move, the tower continued to progress toward its vertical configuration.

Once the riser foot was above the RTA, the upending operation stopped to allow the subsea intervention vessel prepare the docking operation. The ROV passed each individual Dynema pulldown slings through the sheave mechanism on top of the RTA (fig c-3). The positions of both the trailing and leading tugs were adjusted to transfer the tension from the towline to the pulldown slings. The ROV cut the towline extension connected to the DMA to free it from the riser tower.

At this stage the bottom of the riser tower was controlled through the towline, DMA and pulldown slings (fig c-4). The position of the trailing tug was adjusted to provide a better alignment between the tower foot and the RTA receptacle (fig c-5). The leading tug moved away from the RTA increasing the pull down tension and bringing the tower down. Once the tower was gently heaving 1m above the receptacle, the leading tug continued to move forward to stab the Rotolatch connector inside its receptacle. When the Rotolatch was fully engaged inside the receptacle, the tension was released by moving the leading tug backward to activate the latching mechanism of the Rotolatch (fig c-6).

The tower raised about 0.8m until it was fully latched and the locking dogs came into contact with the receptacle arrestor. At this stage the tower was secured and the tension further released by continuing to move the leading tug backward towards the RTA, while the DMA altitude was continuously monitored by the ROV.

The riser tower behaved in accordance with the operational upending table established during engineering. Little adjustment was required to correct the position of the tower prior to docking. Although the trailing vessel was not equipped with a full DP system, the skipper managed to keep the vessel positioned within acceptable limits for an extended period. The 4in chain provided sufficient flexibility to accommodate vessel excursions.

The dynamic response of the riser tower and pulldown arrangement confirmed the prediction of the engineering analyses. The double amplitude heave motion of the riser foot prior to docking was less than 0.4m.

Buoyancy tank de-ballasting and pipe flooding and pigging

Once the tower was properly secured to its base, the connector tension had to be increased to its nominal value by de-ballasting the top buoyancy tank compartments. This operation was conducted in three stages:

1. De-ballast first series of compartments to create a maximum bottom tension of 4000kN.
2. Flood and gauge the four production risers and increase weight of the riser tower to about 2,000kN.
3. Complete de-ballasting of the rest of the compartment to bring bottom tension to its nominal value (3,500kN).

The subsea intervention vessel performed the de-ballasting operation. Pressurized nitrogen tanks were stored on deck of the vessel. An ROV stabbed the nitrogen line at the top of the riser tower and operated the valves from the panels located along side the tank.

When sufficient tension was applied to the Rotolatch connector, both towing vessels were released from the tower with towing equipment and DMA recovered to deck. Both towing vessels returned to the Lobito Bay to prepare for the installation of the next riser tower.

The de-watering piping of the riser tower was sized to minimize the duration of the operation. Similarly a flooding line was stabbed on a dedicated manifold located at the top of the tank and all production risers were flooded and gauged by pumping inhibited water inside the pipes. The de-watering and flooding operations took approximately 10 hours.

Umbilical support arch installation.

The installation of the umbilical support arch (fig d-1) was also a unique operation. The arch is imposing by its size and mass compared to the riser bundle structure. The design of the hangoff device had to be carefully engineered to ensure an easy and safe installation operation.

Seaway Polaris' crane with its heave compensation system was used to deploy the arch in an horizontal configuration. An ROV was then able to guide and approach the riser bundle, dock the guiding system along the bumper frame of the tower. The load was then slowly placed inside the receptacle of the tower. Once the top of the arch was resting on the receptacle, the lifting wire was paid out to tilt the arch down in a vertical position. The arch was then secured by means of two ROV activated clamps. This operation did not raised any particular concern and was completed in less than 8 hours.

Installation Engineering

General

The Girassol experience proved that targeted engineering is absolutely crucial to the success of offshore operations. Installation issues must be tackled at an early stage of a project to accept suggestions from all upstream project disciplines (design engineering, procurement or fabrication). The main installation requirements must be established before design engineering is completed, purchase agreements are in place and construction engineering is finalized.

Once installation spreads are mobilized at sea, the latitude to find a swift response to an unexpected scenario is very limited and generally very costly. As a result installation engineering must ensure that both offshore and onshore personnel are prepared to handle contingency scenarios.

Competent engineers, conversant with the reality of offshore operations, must develop appropriate installation methods to ensure safe and efficient installation operations. Calculation engineers must develop reliable numerical models to confirm the behavior of the structures involved and verify installation methods. Analyses from numerical model must also allow further optimization of the installation methods and sizing of the installation aids.

Validation of sophisticated numerical models, such as dynamic response of vessels and structures at sea, is thus a key issue. This implies comparing results with other software through third party verification or conducting appropriate full or reduced scale model tests.

In addition some aspect of the installation engineering can only be validated and checked through full-scale testing programs, such as shallow and deepwater tests, fit-up test in factory or on the yards, etc.

Design of the riser tower

One of the difficulties when designing a structure, such as the riser tower, is to carefully split the responsibilities between the design and installation engineering. Both discipline managers must understand their conflicting constraints and decide which should take precedence. Many aspects of the tower design had to be reconsidered based on installation restrictions. Some of these aspects are presented below:

- Buoyancy tank and riser bundle connection: Originally the tower bundle and the buoyancy tank were two separated structures (fig d-2) interconnected by a universal joint. The riser pipes terminated underneath the tank at the extremity of the bundle. This concept had many advantages from design and fabrication perspectives as it eliminated the fatigue issue and the need to interconnect the bundle to the buoyancy tank through a taper joint. However this option was rejected as it presented major installation issues, such as connection of the tank at sea, lack of adequate space for connecting the flexible risers and others.
- The weight and buoyancy estimate of the different components of the riser tower had to be carefully validated by the installation engineering team to ensure that the structure was going to be installed with the appropriate buoyancy.
- Umbilical support arch: Independent arch supports, installed on the seabed, were at one stage considered. Having the support arch system attached to the riser tower presented great advantages by simplifying the field layout and freeing more corridors for future field extension. It was also a commercially more attractive solution. The installation engineering validated this solution by outlining the requirements for designing the hangoff and attachment of the arch to the riser bundle.
- The pulldown system on top of the RTA (fig d-3) was designed to ensure that the ROV could effectively place the pulldown sling through the sheave.
- Attachment of the towline to the riser structure: This aspect was particularly delicate and the ROV supervisor carefully reviewed the design to ensure that the disconnection operation was acceptable.
- Installation tolerances: Installation tolerances are generated by design limitation considerations. These limitations had to be thoroughly analyzed so that it would not penalise the operation by imposing unjustified tight tolerances.
- Any component of the riser tower designed to be manipulated by an ROV - flooding panel, valve panel, temporary buoyancy elements, RTA pressure caps, etc - had to be fully reviewed by personnel familiar with ROV operations

Towing and fatigue analysis

The towing and fatigue analysis is a typical example of an area in which close interface and cooperation between design and installation engineering is essential. The design engineering had the responsibility to design the riser tower structure in accordance with the fatigue design code. Installation engineering had the responsibility to define the limitations of the towing operations to the Girassol field and optimize the operation.

The design engineers developed a three-dimensional numerical model using Orcaflex software to evaluate the fatigue damage generated by seastate conditions, i.e. wave height, period and incidence with the structure (fig e-1).

A program at a test tank was carried out on a scale model to verify and validate the numerical analyses. Both approaches confirmed the behavior of the tower in towing conditions:

- Beam sea has little impact on the structure
- Stern or head sea makes the structure undulate at the same frequency of the wave.

At this stage the engineers only used the numerical model to develop the engineering.

Fatigue damage response amplification operators (RAOs) to seastate conditions were established (fig e-3). Weather statistics in Angola were analyzed to establish a typical scenario based on wave occurrence for yearly seastate conditions. This was used to confirm that the tower structure was fit for purpose.

The numerical model showed that the taper joint only experienced high fatigue ratio with head sea conditions. However review of the weather statistics along the towing route demonstrated that the tower would never be towed under this circumstances. Fatigue damage ratio was basically building up at riser foot.

The analysis also showed that wave incidence coming from the leading tug (head sea on fig d-4) were not acceptable for the towing configuration considered. They also showed that for a certain wave incidence (Quartering Sea on fig d-4) the structure might come into resonance with wave period since the projected incidence angle of the swell directly alter the wave period. As a result the convoy heading had to be adjusted to preferably sail either in beam sea or stern sea.

A software simulator was developed to estimate fatigue damage ratio generated by a specific towing and sea state scenario. This simulator was then used to optimize the towing routes and provides a live fatigue damage ratio of the structure throughout the operation. The simulator was also used to confirm that the weather window was acceptable to tow the tower from Lobito to Girassol. The contingency port was Luanda which offer little impact on fatigue should the riser tower had to be towed in sheltered conditions.

The as-built fatigue damage ratio calculated by inputting the seastate and tow route conditions into the simulator confirmed a low fatigue ratio in the structure. These values, shown on figure e-2, are less than the allowable limits of 0.1 at riser foot and 0.016 at taper joint.

Once the towing operation was completed, the data collected from the MRU was analyzed. The measured heave motions at the riser foot were less than those calculated by the numerical model while motion along the riser were similar. Fatigue damage induced in the tower was actually even less than expected. It was also noticed that the tower never came into resonance with the waves even for the critical incidence of quartering sea.

Upending analysis

The upending analysis was mainly an installation consideration rather than of design. The descent and upending of the tower was not critical as long as tension was applied along the structure. On the other hand, the docking operation was more critical since the dynamic response of the tower under the excitation loads of the DMA and leading tug were difficult to predict. A new numerical model was developed to evaluate heave motions of the tower (fig e-4). These values were incorporated into the specification of the Rotolatch foot connector. A testing program was requested to verify the capability of the connector to latch under installation loads.

The results of the upending analyses were used to establish accurate step-by-step tables for the offshore installation team. The numerical model was also available on board to confirm possible improvements of the offshore procedure.

Testing program

In addition to the installation engineering described in the previous paragraphs, an extensive testing program has been performed throughout the project to validate some aspect of the installation engineering:

- Towing tests at tow tank facilities (fig f-2).
- Upending tests at military facilities in south of France.
- Full-scale tow test in Scotland to confirm that the external skin of the tower did not peel off during towing operation.
- Fit-up and installation test of the umbilical support arch in Lobito yard (fig f-1).
- Handling tests in West Africa at 1,500m water depth with Seaway Polaris to confirm dynamic response of loads hanging from the crane.
- Test of nylon strop to establish axial stiffness in wet and high-tension conditions.
- Trial surface tow test with Seaway Explorer and Seacor Voyager to validate vessel control procedure and train offshore personnel.
- Stabbing and docking test of Rotolatch connector under installation loads. (fig f-3)
- Fit-up test of most of the riser tower components at factory or on fabrication yard.
- Shallow water tests to verify installation interface of the spools with the bottom of the riser tower including MATIS (Modular Automatic Tie-In System) diverless tie-in.

Conclusions

The success of the riser tower installation is the direct result of the efforts put into the engineering preparation work and the rigorous attitude followed to assess risk associated with such operations.

The experience and knowledge gained during the Girassol project has provided the project team with a clear vision of how such a large structure behaves in open seas. It also foresees how to extend the Girassol experience to other fields where environmental conditions are different.

For instance, the fatigue issues could be eliminated if the structure is towed submerged at approximately 20m below the surface. This means that the buoyancy of the tower bundle has to be adjusted to a lower value so it can be brought below the surface by ballasting both extremities of the tower. In such a case, the tower could be towed in any seastate conditions and for longer periods as long as the towing tugs are able to follow the towing route.

The tower installation operation is not limited by the length of the tower thus nor by the depth, as long as the winch drum of the leading tug has the capacity to store the appropriate length of wire. This is a significant issue as it means that the concept of the riser tower could be adapted to even greater water depths.

ACKNOWLEDGEMENT

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Appendix A: Riser Tower Description.

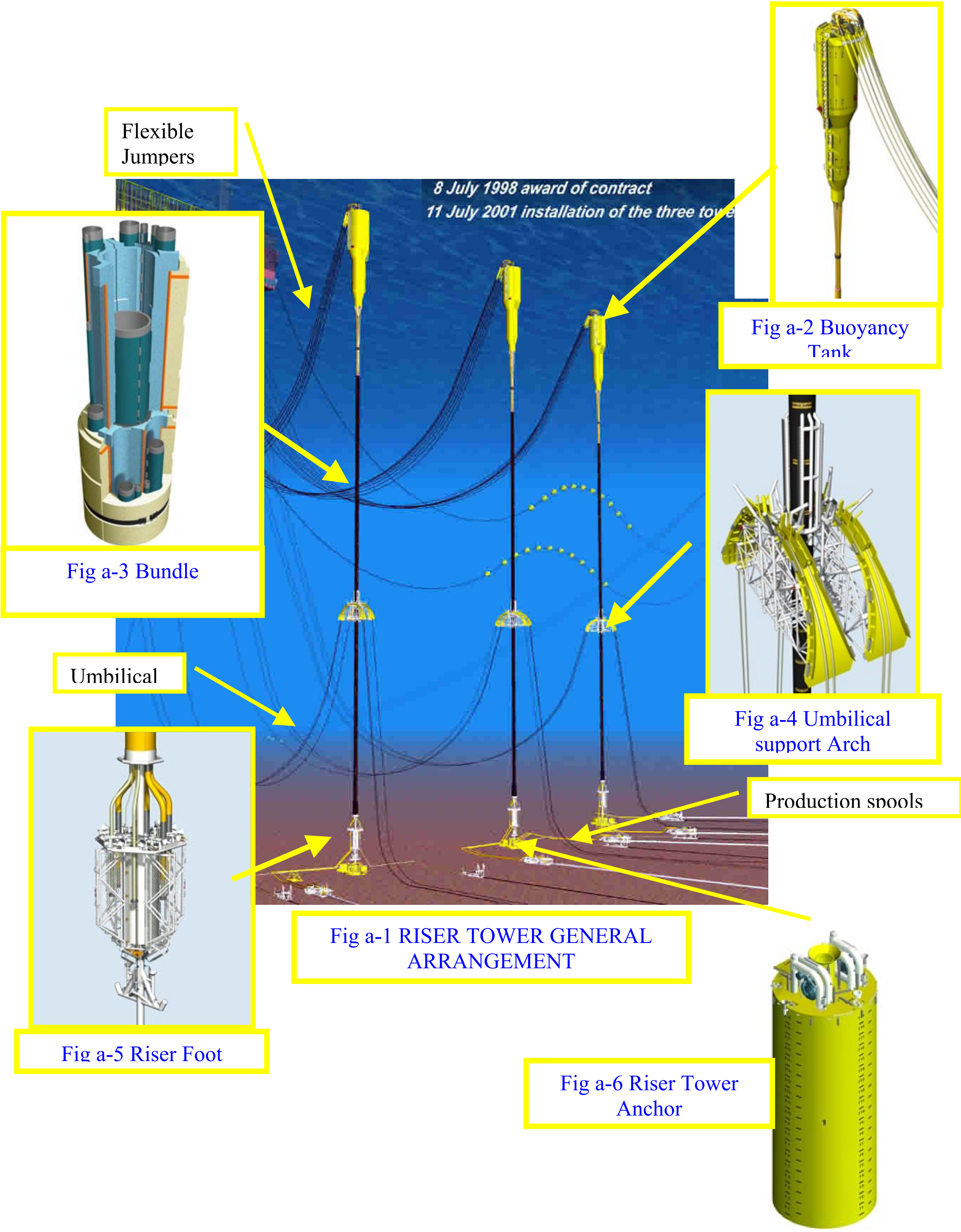


Fig a-1 RISER TOWER GENERAL ARRANGEMENT

Fig a-2 Buoyancy Tank

Fig a-3 Bundle

Fig a-4 Umbilical support Arch

Fig a-5 Riser Foot

Fig a-6 Riser Tower Anchor

Appendix B: Towing to Girassol field.

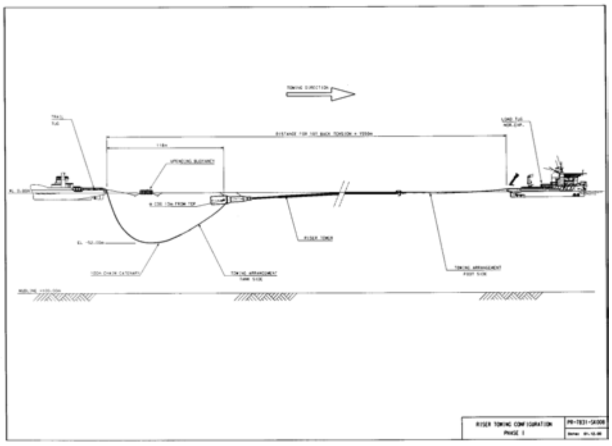


Fig b-1 Towing configuration in Lobito bay

Fig b-2 Towing route outside Lobito bay

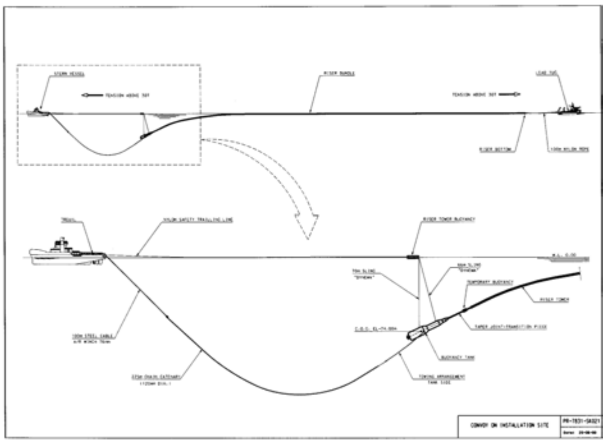


Fig b-3 Towing configuration in deep water

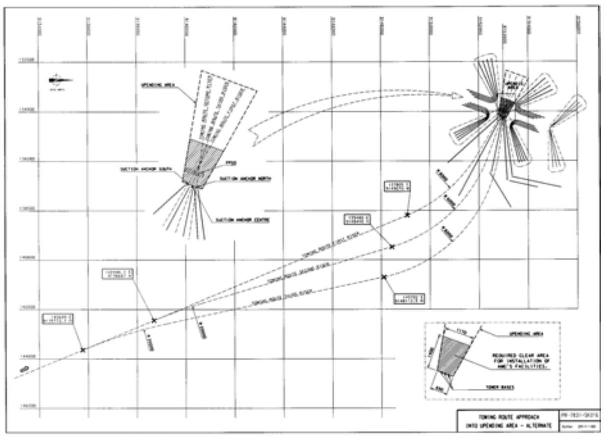


Fig b-4 Towing route at Girassol field

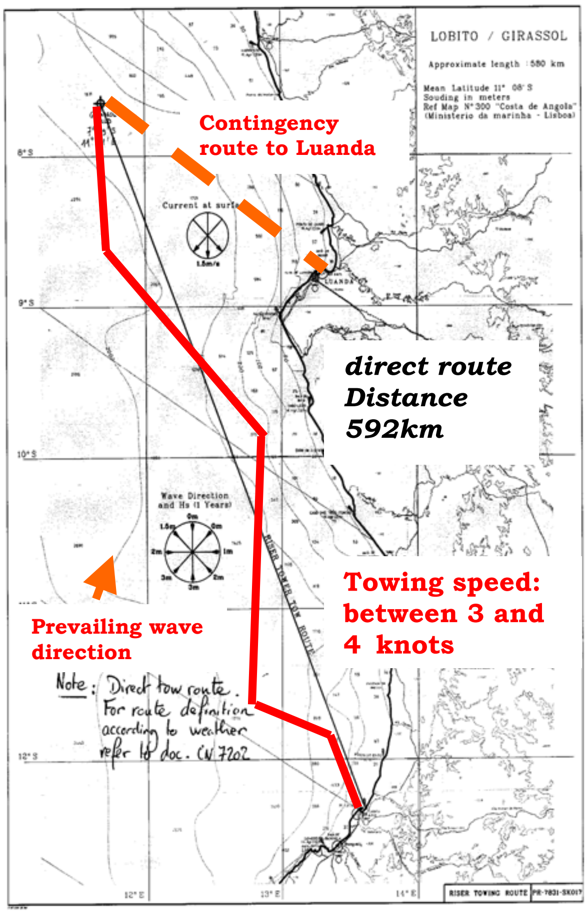


Fig b-5 Towing route to Girassol field

Appendix C: Upending and Connection Operations

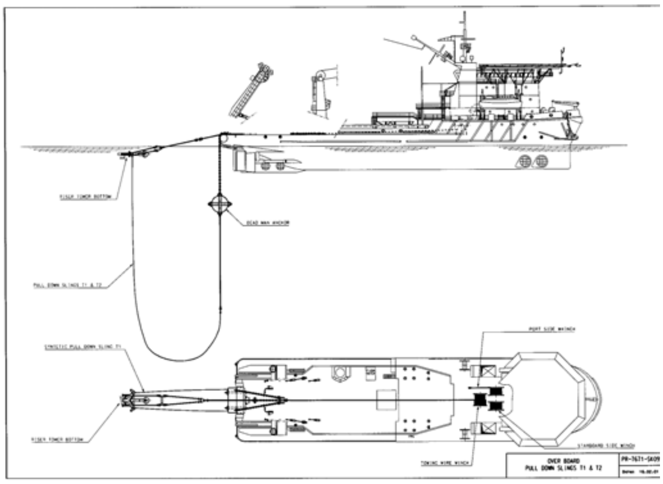


Fig c-1 Deployment of upending rigging equipment

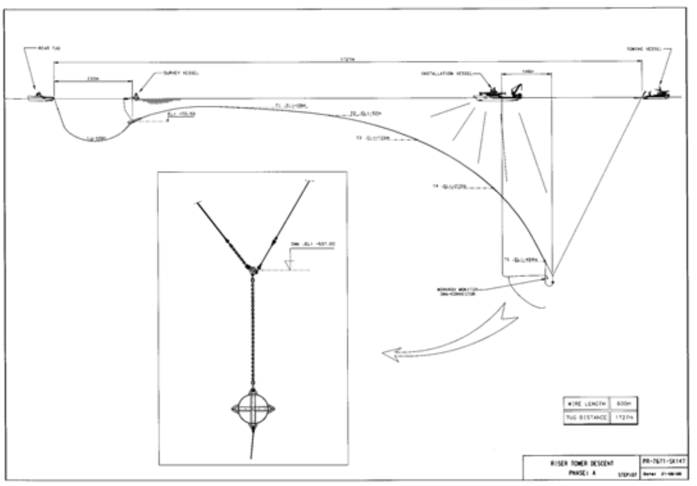


Fig c-2 Upending operation intermediate step

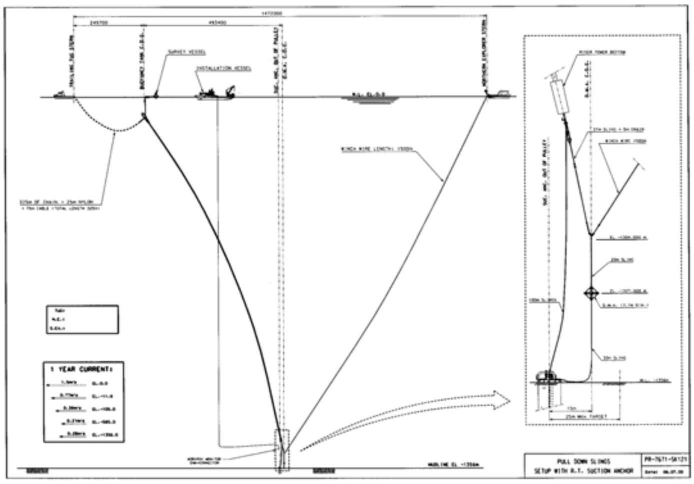


Fig c-3 Installation of pulling slings

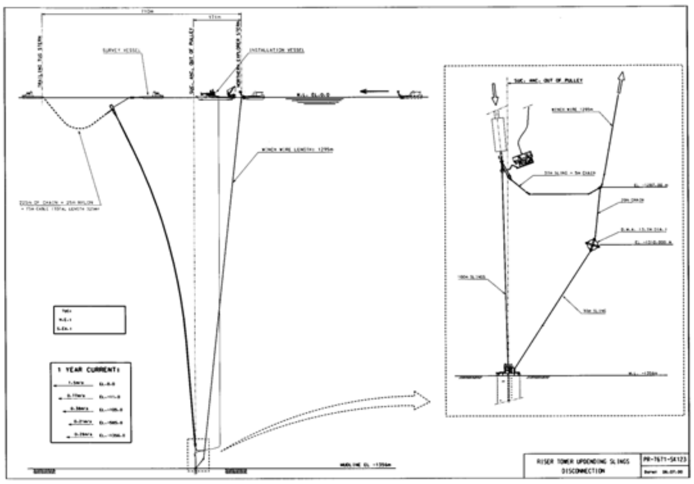


Fig c-4 Disconnection of towing line

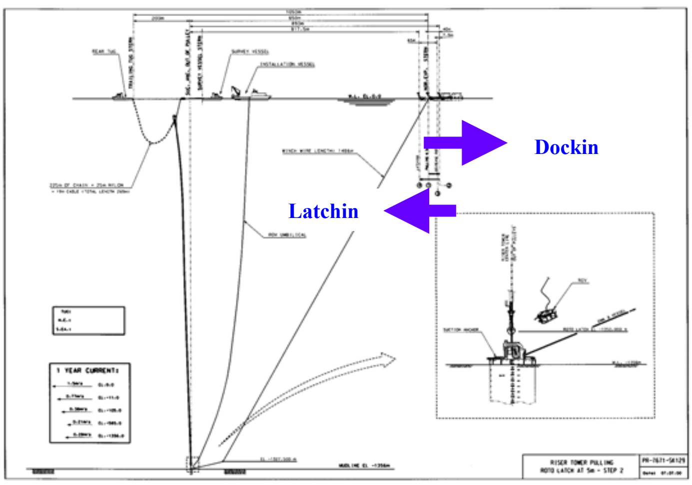


Fig c-5 Riser tower docking onto its anchor

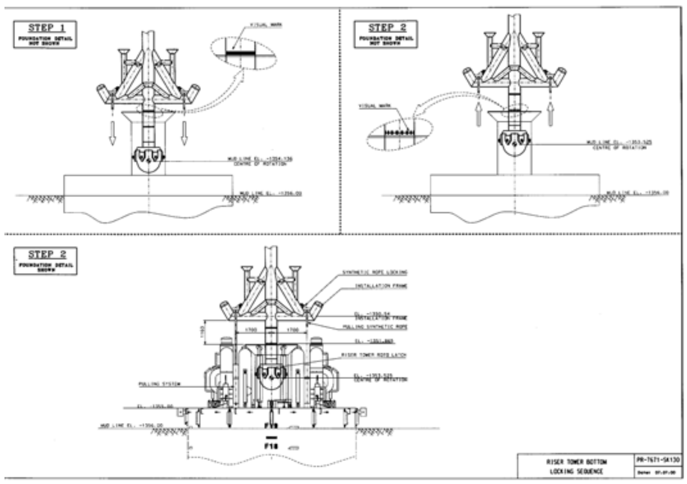


Fig c-6 Roto latch mechanism

Appendix D: Installation Engineering

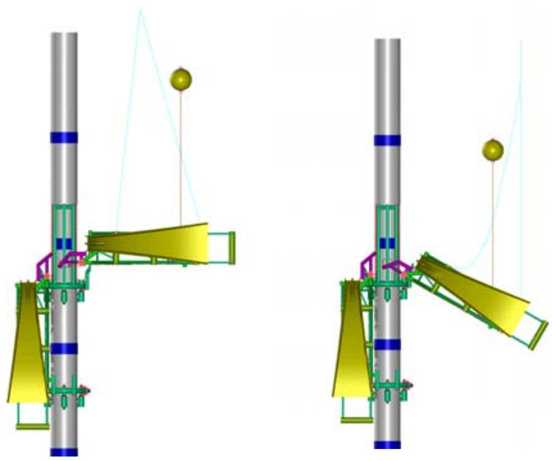


Fig d-1 Umbilical support arch installation

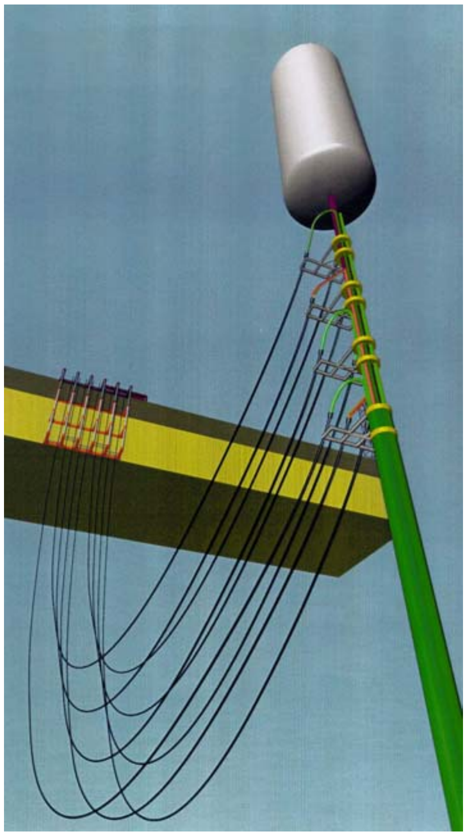


Fig d-2 Buoyancy tank & riser bundle connection original concept

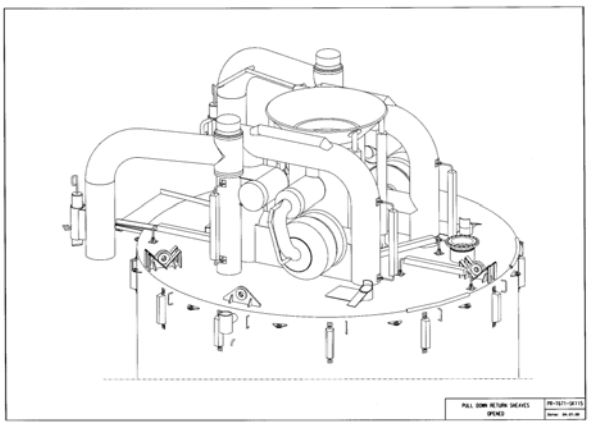


Fig d-3 Pull down sheave on top of the RTA

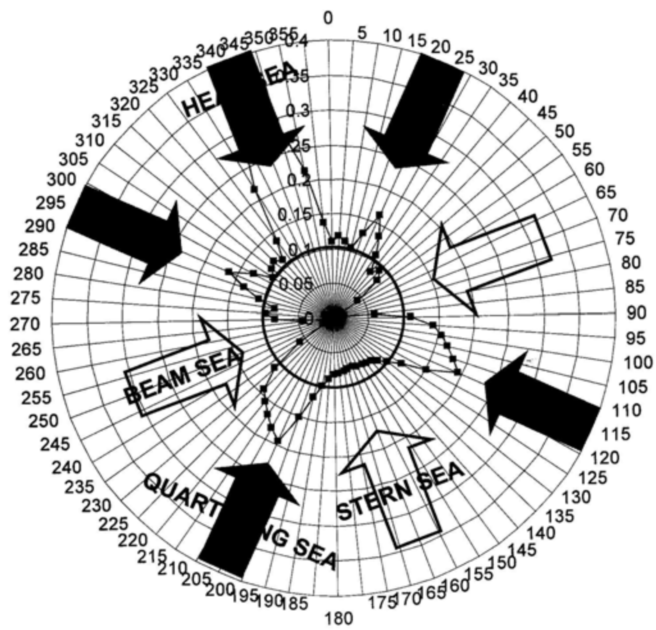


Fig d-4 Fatigue diagram of Riser Tower during towing Operation

Appendix E: Towing and upending analysis results

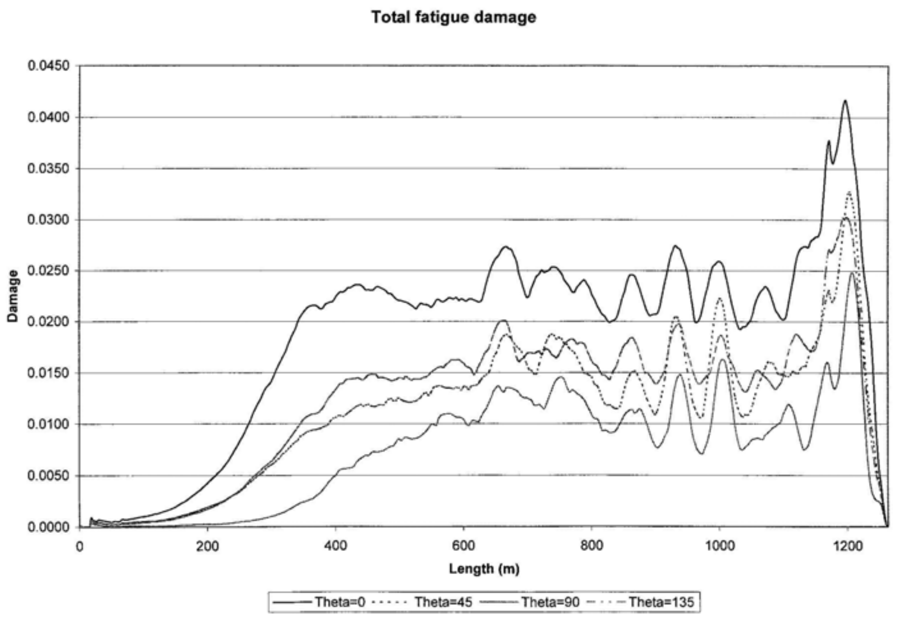


Fig e-1 3D-Fatigue damage ratio along tower

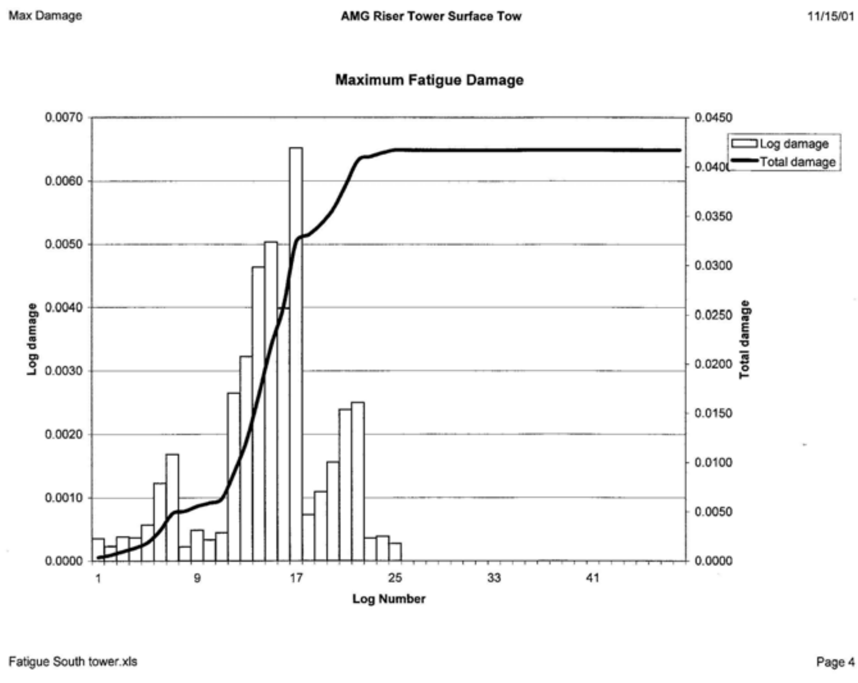
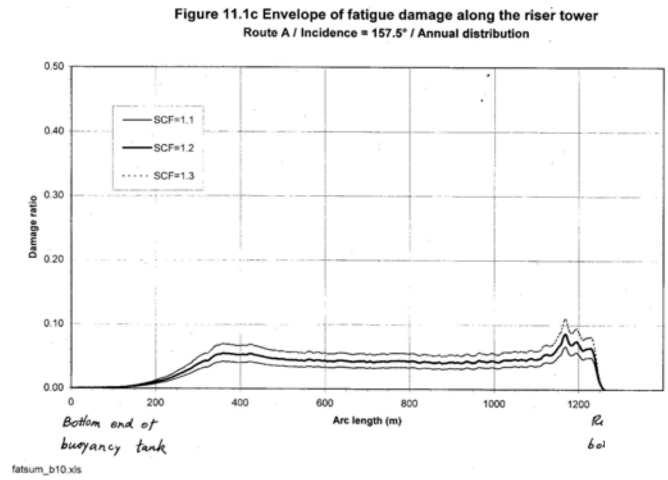


Fig e-2 As built fatigue ratio calculated from simulator



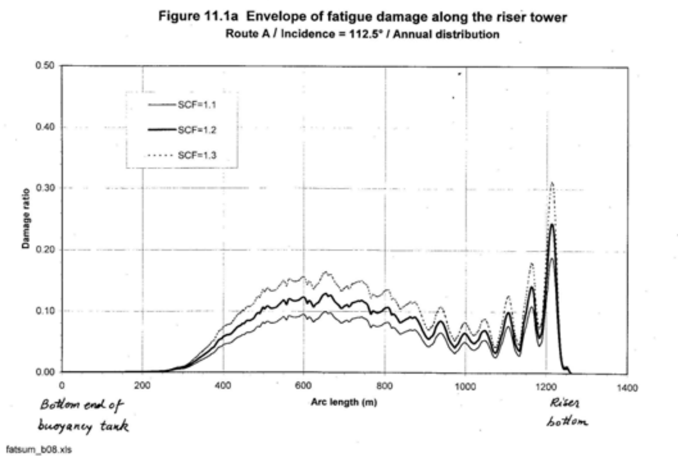


Fig e-3 Fatigue ratio curve along riser tower for 2 wave incidences and for different SCF coefficient

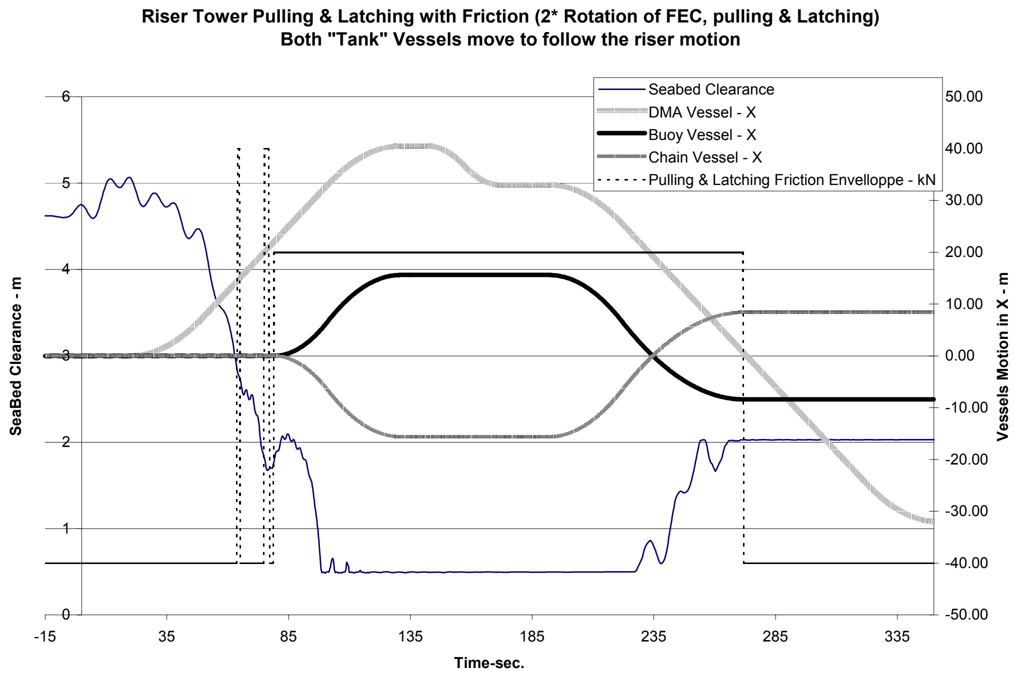


Fig e-4 Docking operation dynamic analysis results

Appendix F: Testing program

Fig f-1 Fit up test of umbilical arch at fabrication yard

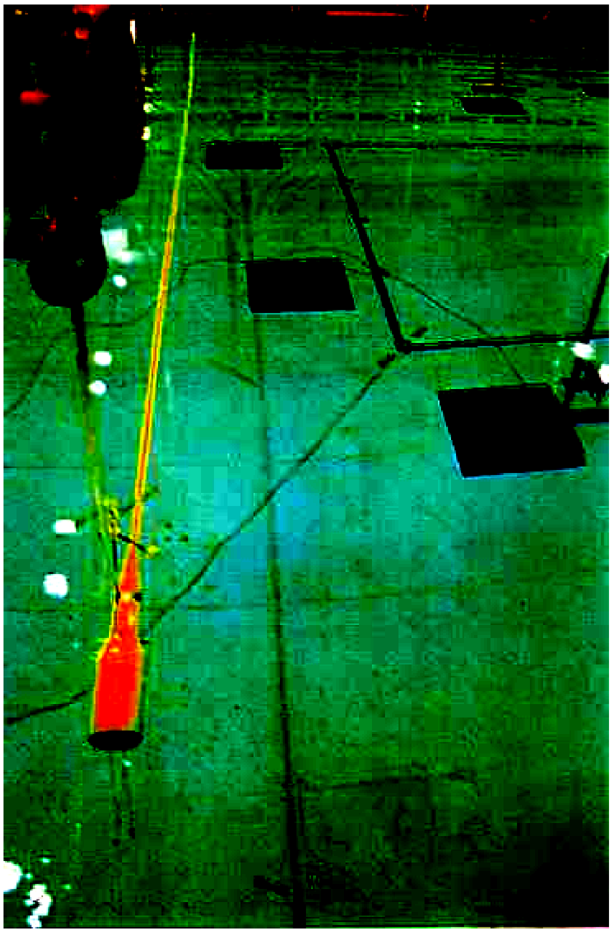


Fig f-2 Tower model at tow tank facilities

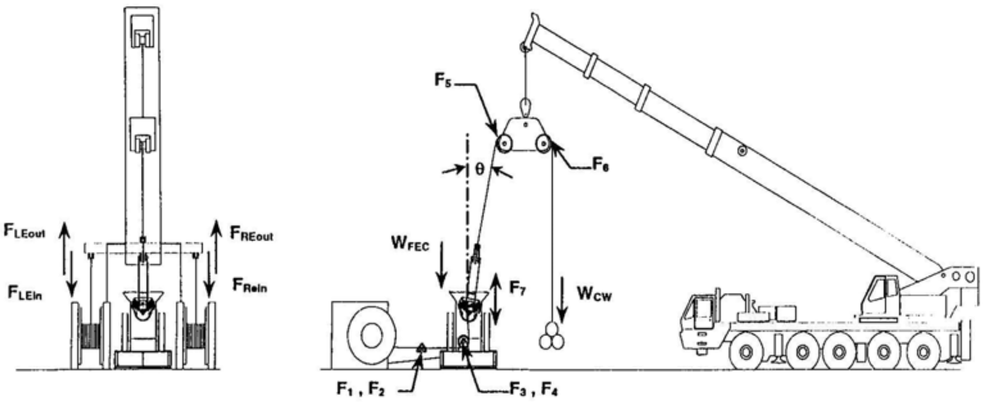


Fig f-3 Test bench for Rotolatch connector