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CLASSIFICATION OF OFFSHORE OIL AND GAS PLANTS

KLASIFIKACIJI NAFTNIH I GASNIH POSTROJENJA NA VODI

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- oil and gas industry
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- fixed platforms
- compliant tower
- tension leg platforms
- spar platforms

Abstract

Oil and gas plants can be classified into onshore plants and offshore plants, colloquially called oil and gas platforms or simply oil platforms. Oil rigs represent an enormous feat of engineering developed from over 150 years of industrial expertise. This paper shows the classification of oil and gas platforms according to their constructions and purposes and describes the types of oil platforms, their construction, advantages and disadvantages.

Ključne reči
- gasna i naftna industrija
- postrojenje na vodi
- fiksna platforme
- usidreni tornjevi
- platforme sa zategnutim kracima
- spar platforme

Izvod

Postrojenja za naftu i gas se mogu podeliti na postrojenja na kopnu i postrojenja na vodi, kolokvijalno nazvana naftne i gasne platforme ili jednostavno naftne platforme. Naftne platforme predstavljaju ogroman podvig inženjeringa razvijan preko 150 godina. U ovom radu prikazana je klasifikacija naftnih i gasnih platformi prema njihovoj konstrukciji i nameni i opisani su tipovi naftnih platformi, njihova konstrukcija, prednosti i nedostaci.

1. INTRODUCTION

There are a number of classifications of oil and gas facilities. One of the very common classifications of these facilities is according to the position in relation to the input raw material and according to it these facilities can be classified into upstream oil and gas facilities, intermediate facilities and downstream oil and gas facilities. In addition to this classification, oil and gas plants can also be divided in relation to the base on which they are located. Within this classification, oil and gas plants can be classified into plants located on land (onshore plants) and plants located on (in) water (offshore plants), which are colloquially called oil and gas platforms or simply oil platforms. Plants on land can largely be identified with the classification of plants according to the position of the input raw material into the plant, while the situation with plants in water is somewhat different. The origin and development of oil platforms dates back to the middle of the 19th century.

2. CLASSIFICATION OF OFFSHORE PLATFORMS ACCORDING TO THEIR CONSTRUCTION

In general, there are a large number of types of oil and gas platforms, and they can be classified into the following categories according to their construction and purpose:

- Fixed (conventional) platforms;
- Compliant towers;
- Tension Leg Platforms;
- Mini tension leg-platforms;
- Spar platforms;
- Semi-submersibles platforms;
- Floating production, storage, and offloading facility;
- Sub-sea completion and tie-back to host facility
- Jack up rigs /1, 2/.

2.1 Fixed (conventional) platforms

Fixed oil platforms are structures (usually welded steel structures) on seas or oceans (used for offshore oil and gas drilling purposes) that are permanently fixed in place on the seabed by means of pile foundations, mat foundations or other methods that produce support pressure. Fixed drilling rigs can generally be divided into two types: rigid fixed drilling rigs and flexible drilling rigs. A rigid fixed drilling platform is a permanent fixed drilling platform that does not move under the influence of the marine environment. These platforms can be classified into two types:
- Platforms for piles;
- Gravity oil platforms.

Pile foundation platforms consist of columns (piles) that absorb vertical loads and resist horizontal loads. The most widespread is the platform with a cover, however, quite often on the seas, both monopod and three-legged (three-column) platforms are buried (left construction in Figure 1). Gravity oil rigs rest directly and stably on the seabed based on their own gravity, not on pillars (right structure in Figure 1). The most common platform is a concrete gravity platform, followed by a steel gravity platform, although mixed concrete-steel platforms can also be found /3/.

Figure 1 Piled oil platform and gravity oil platform /4/

The largest platform ever built is called Bullwinkle and is located in the Gulf of Mexico. The measured height of this metal structure is 412 meters. The Bullwinkle rig boasts a very light truss type construction, something not normally seen on rigs built for use in the North Sea. It should be emphasized here that Bullwinkle would not survive the harsh conditions in the North Sea because this structure is not strong enough. Figure 2 shows the transportation of the Bullwinkle platform structure.

Figure 2 Transporting the Bullwinkle platform to the location /6/

A flexible drilling rig is a deep drilling rig that can swing at a certain angle around a fulcrum within an allowable range under the influence of marine environment loads. To meet the needs of deepwater operation, this type of platform usually uses a thin steel casing as a column that is inserted into the seabed through pipes; cement is injected between the column and pipe, creating a single pile and pipe assembly that is attached to the steel liner structure. Some flexible drilling rigs may use ropes or cables to generate back force. This type can be divided into flexible platforms with towers in a row, flexible platforms with camel types of columns and others /3-5/.

2.2 Compliant towers

Anchored (aligned) towers are similar in construction to fixed platforms, as both are anchored to the seabed and hold most of their equipment above the surface. But compliant towers are taller and narrower than fixed platforms, swaying in the wind and almost seeming to float. This is made possible because their cladding is divided into two or more parts, with the lower part serving as the base for the upper mantle and surface objects. These towers are strong enough to withstand hurricane conditions. They are usually placed in waters whose depth ranges from 450 to 900 m. currently; the deepest is Chevron Petronius (Chevron Petronius) in waters with a depth of 623 m. The first tower appeared in the early 1980s with the installation of Exxon's Lena oil platform /6/.

Figure 3 Platform for oil and gas type-Anchored tower /6/

2.3 Tension Leg Platforms

Tension Leg Platform or platforms with extended tension legs (Extended tension leg platform) are vertically anchored floating structures that are usually used for the production (processing) of oil or gas at sea, and are especially suitable for water depths greater than 300 meters (about 1000 feet) and less than 1500 meters (about 4900 feet). The use of platforms with tensioned legs is also suitable for offshore wind turbine installation needs. The basic design of the tension leg platforms includes four columns (cylinders) filled with air, whose centres are placed at the edges of the square. These pillars are supported and connected by pontoons, similar to the design of a semi-submersible production platform. Nevertheless, since their inception in the mid-1980s, the TLP designs of these platforms have changed according to development and production requirements /7/. Figure 4 shows the Olympus oil platform with tension legs, which is owned by the Dutch company Royal Dutch Shell /8/.

Figure 4 Olympus-Platform with tension legs /9/

Nowadays, improvements to these types of platforms have been developed which include the following types:
• Extended tension leg platforms,
• Moses tension leg platform;
• Sea star-TPL-platforms /7/.

One of the most famous platforms of this type is called Magnolia and is placed in the Gulf of Mexico. It is one of the deepest oil platforms (1,432 m) and is used for oil drilling. Figure 5 presents this platform in its operational mode /10, 11/.

Figure 5 Magnolia oil platforms in operation /11/

The MOSES Self Stable Integrated Platform (SSIP) is a group of tension leg platforms that has inherent stability that allows integration of the dock and commissioning topsides into the hull structure, wet towing of the integrated platform to the installation site and eliminates the need for expensive temporary buoyancy or rigging assistance with the help of a suitable crane. The fuselage configuration consists of a central base structure, four Tendon Support Structures (TSS) and four vertical pillars. The base and tendon structures are located deep below the surface of the water and provide a significant part of the platform's buoyancy. Each tendon support structure is a variable-depth rectangular pontoon structure that is oriented radically from the base structure. The columns are located at the ends of the upper part of the platform, as a rule, they are smaller than the columns of conventional platforms with tensioning legs and are rectangular in shape. A total of eight chords are supported at the end of the choral support structures (two at each end) via top ties on the landscaped porch. Here it is also necessary to emphasize that one of the most famous platforms in the world, which is located at a great depth (1311 m) belongs to the Moses type of platform, it is called Marco Polo and is located in the Gulf of Mexico near Houston. This platform has been in operation since 2004 (Figure 6) /12/.

Figure 6 Marco Polo Platform in the Gulf of Mexico /12/

Platforms with a tension leg in the shape of a sea star (Sea star-TPL-platforms) belongs to the group of platforms with a leg and minimal tension (Mini tension leg-platform). These types of platforms are miniature platforms with a tensioned leg. The lower hull is filled with water during drilling, which increases the stability of the platform against wind and water movement. The construction costs of these platforms are moderate and they are usually placed in waters between 200 and 1000 meters deep. They can be used as auxiliaries, as satellites (wellbore arrays) or as initial production platforms for larger fields in deeper water environments /6, 13, 14/

2.4 Spar platforms

Spar platforms are marine structures used to secure a floating oil/gas platform. Spar rigs were developed as an extreme deepwater alternative to conventional rigs. The spar platform consists of large-diameter vertical floating cylinders that support the deck. The spars are permanently anchored to the seabed by a spread lashing system consisting of a chain-wire-chain or chain-polyester-chain configuration. These types of oil rigs are among the largest rigs used in oil and gas facilities. Here it is necessary to mention that sometimes even

90% of the height of the cylinder (spar) is under water. Spar oil platforms are made for depths of about 1000 meters, although with the application of new technologies, the depths for their installation have increased to 2500 meters, classifying them as oil and gas extraction equipment that can work at the greatest depths. The largest Spar platform installed so far - Shell Perdido (Shell Perdido) is located in the Alaminos Canyon in the Gulf of Mexico and was placed at a depth of 2438 m (Figure 7), with the cost of its construction in 2010 amounting to 3 billion dollars /6, 15/.

a)

b)

Figure 7. Shell Perdido spar platform a) 3D model b) in operation /16/

In general, spar oil rigs are constructed in three configurations: conventional with a cylindrical hull made of one part (Classic spar), truss spar (Truss spar) in which the intermediate section is composed of truss elements connecting the upper buoyancy hull (also called solid tank) with a lower soft tank containing permanent ballast and cell spar (Cell spar) where the platform is made of several vertical cylinders (Figure 8). /15, 17/.

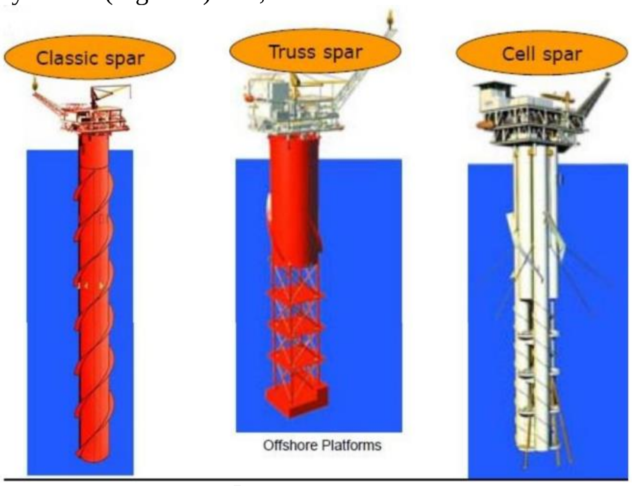

Figure 8 Construction solutions of spar oil platforms /25/

2.5 Semi-submersibles platforms

Semi-submersibles platforms belong to the group of floating platforms that were initially used for oil extraction, while more recently they are also used for the processing of fluids extracted from the seabed. In general, the water stability of these platforms is based on the characteristics of their hulls. Namely, these platforms have hulls (pillars and pontoons) that have enough thrust to float; but on the other hand, their weight is enough to keep them in an upright position. Semi-submerged platforms are usually placed in waters whose depths range from 60 to 3000 meters /22/, /26/, /27/, and /28/. Semi-submerged floating platforms are a preferred construction solution compared to other types of platforms due to several of their advantages, the most important of which are the following: better stability in extreme working conditions, larger deck area, superior construction and installation characteristics, as well as their greater mobility. The natural (own) frequencies of semi-submerged platforms vary inversely with the draft and the length of the platform, that is, the appropriate choice of geometric shape is an essential criterion during their design. With these platforms, there are six degrees of freedom of movement. Within these 6 degrees, 3 degrees correspond to translational movement along the three main axes, i.e. pitch (along the X-axis), swing (along the Y-axis) and heave (along the Z-axis). In addition to this, rotation around the three main axes is enabled, i.e. turning (around the X-axis), tilting (around the Y-axis) and turning (around the Z-axis). Beyond these six degrees of freedom, semi-submersible platforms are designed to remain highly flexible in the horizontal plane. This means that significant impact, swing and deflection are allowed. To ensure comfortable operation and the necessary connection between the funicular and the platform, they are designed to remain rigid in the vertical plane. Therefore, the movements of moving, tilting and turning are very controlled (Figure 9). /18, 19/.

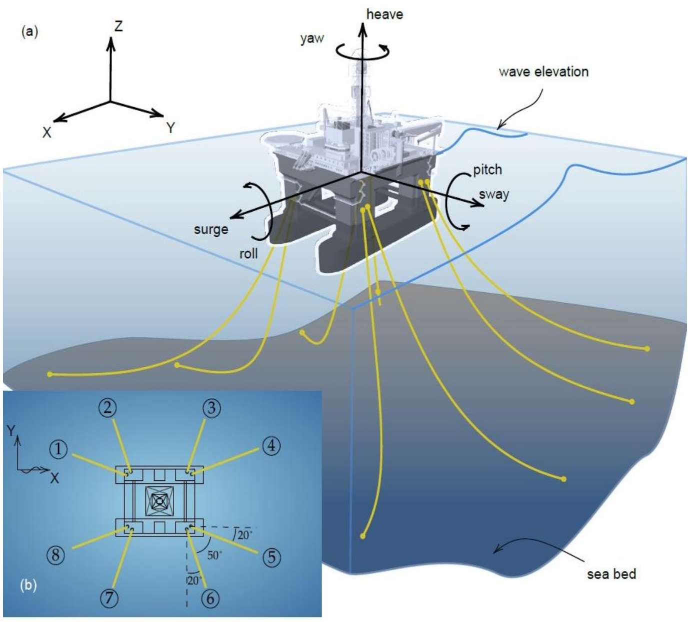

Figure 9. 6 degrees of freedom of semi-submerged platforms /18/

An overview of the previously mentioned main parts of semi-submerged platforms and at the same time most other types of oil and gas platforms, i.e. offshore plants, are as follows:
• Substructure;
• helideck platform;
• Pontoons;
• Vertical columns;
• Deck;
• drilling derrick;
• Mooring system;
• dynamic positioning system (dynamic positioning system);
• Staff section (living quarters);
• Moon pool;
• control room with instrumentation equipment (navigate bridge);
• Mud processing and mud pits.

Substructure plays a vital role in the platform's ability to adjust its position, providing stability against the relentless forces of the ocean /20/.

According to the activities (purpose) for which semi-submerged oil platforms are used, they can be classified into the following categories:
• Mobile offshore drilling units (MODU);
• Semi-submersible crane vessels (SSCV);
• semi-submerged auxiliary equipment for servicing facilities on the water (offshore support vessels - OSV);
• offshore production platforms;
• Offshore rocket launch and landing platform).

Mobile offshore drilling units (MODU) are stable platforms used for oil and gas drilling at sea. They can be towed to a suitable position by a tug and anchored, or moved and held in position using their own azimuth thrusters with dynamic positioning (Figure 10).

Figure 10 Platform used for offshore drilling /20/

Semi-submersible crane vessels (SSCV), as the name suggests, are platforms that are partially submerged in water with cranes installed on their shores. This type of construction ensures greater stability and balance of the object that is raised on them. The added balance is crucial as it lowers the likelihood of the object being transported destabilizing and falling into the water. They also have rotary or swivel cranes. The tonnage that can be towed and lifted by semi-submersible crane ships varies from ship to ship, however they have a much higher lifting capacity than conventional crane vessels and can handle up to approximately 14,000 tonnes /22/. The largest semi-submerged platform with a crane built so far is called Sleipnir and was built by Heerema in 2019 /23/. Offshore platforms arose as a result of the discovery of oil fields in coastal locations and semi-submerged drilling platforms were converted for use as combined drilling and production platforms. These platforms offered very stable and cost-effective processing facilities. The first semi-submersible floating production platform was Argill FPF converted from Transworld 58 a semi-submersible drilling platform in 1975 for the Hamilton brothers' Argyll oil field in the North Sea. As the oil industry advanced into deeper waters and harsh environments, dedicated semi-submerged production platforms were designed. The first purpose-built semi-submerged platform for oil processing was the Balmoral platform in the North Sea of the United Kingdom in 1986.

Figure 11. Balmoral platform-well production platform /24/

More recently, a large number of semi-submerged platforms have been converted from drilling platforms to production platforms or built as production platforms. The most famous production platforms in the world so far are:

• Petrobras 36-semi-submerged platform converted from the Spirit of Columbia drilling platform;

• The Atlantis PQ platform, which is jointly owned by British Petroleum and the Australian mining company BHP;

• Thunder Horse PDQ-GVA4000 largest semi-submersible production platform built. Petrobras 36 (P-36) was at one time the largest semi-submerged oil platform in the world before it sank on March 20, 2001.

It was owned by Petrobras, a mixed Brazilian oil company (public-private) based in Rio de Janeiro. The cost of the platform was $350 million (currently $602 million). The 33,000-tonne (36,000 short tons) facility was converted by Davie Industry, Lévis, Canada, into the world's largest oil production platform (Figure 12). The P-36 worked for Petrobras at the Roncador Oil Field, 130 kilometers (80 mi) off the Brazilian coast, producing about 84,000 barrels (13,400 m3) of crude oil per day /24/.

Atlantis-PK is a semi-submerged oil platform of BP and BHP joint venture of British Petroleum and the Australian company BHP on a permanent location above the Green Canyon Atlantis Oil Field in the deep sea of the Gulf of Mexico, 190 miles (310 km) south of New Orleans. "PK" identifies the rig as a production facility with crew quarters. The hull of the platform was designed by GVA and built by Daewoo Shipbuilding & Marine Engineering (DSME) in Okpo, South Korea. Its upper modules are built in Morgan City, Louisiana, with hull integration in Ingleside, Texas. Operating at depths greater than 2,100 meters (6,900 ft), Atlantis was the deepest moored semi-submersible platform in the world at the time it was installed (Figure 13).

Figure 12. Petrobrac-36 platform during work and sinking /24/

Thunder Horse is the largest offshore installation of its kind in the world. Daewoo Shipbuilding & Marine Engineering (DSME) in Okpo, South Korea, was then loaded onto the heavy vessel MV Blue Marlin and transported to Kiewit Offshore Services in Ingleside, Texas, where it was integrated with its upper modules that were built in Morgan City. The 15,813 nautical mile (29,286 km; 18,197 mi) voyage around the Cape of Good Hope took nine weeks (63 days), from 23 July to 23 September 2004. Shortly after being placed in its intended location, the platform was evacuated with the approach of Hurricane Dennis in July 2005. After the hurricane passed, the platform tilted 30 degrees and was in danger of falling. The platform was designed for the 100-year period, however inspection teams found no damage to the hull or leaks through the hull. Instead, a misplaced 6-inch pipe allowed water to flow freely between several ballast tanks that set off a chain of events that caused the platform to tend to overturn into the sea. The platform was fully repaired about a week after Dennis, delaying commercial production originally scheduled for late 2005. During the repair, it was discovered that the underwater collector was severely cracked due to poorly welded pipes. Six weeks later the platform was almost directly hit by Hurricane Katrina, but this hurricane did not cause any damage to the platform.

Figure 13. Thunder Horse processing platform after hurricane and after repair /25/

2.6 Jack –up rigs

Jack-up rigs are similar to drilling barges, with one difference - when the crane is towed to the drilling site, three or four legs are lowered while do not rest on the seabed. This allows the work platform to be above the surface of the water, unlike a floating barge. However, cranes are suitable for shallower waters, as extending these legs too deeply would be impractical. This was also determined by the use of appropriate 3D-models during their design (Figure 14) /26/.

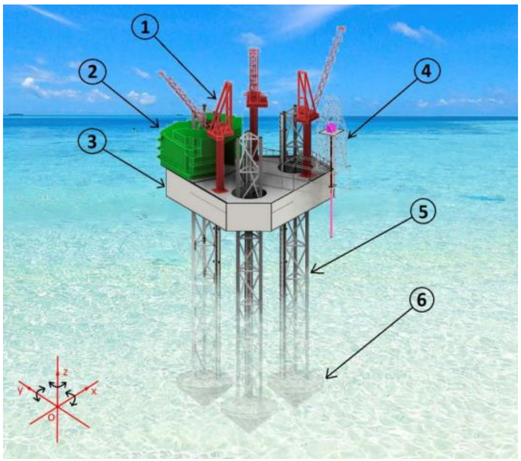

Figure 14 3D-model of a height-adjustable oil rig with basic elements: 1-crane, 2-operating space, 3-base, 4-tower with drilling rig, 5-drill legs, 6-foot plates /26/

The crane design can use three or four legs. So far, two main types of legs are in use (1) open legs resembling electric poles, which are made of tubular steel sections that are crossed, making them strong and light (and Fig. 15), and (2) pole legs, which are made of steel pipes.

Figure 15 Height-adjustable oil rig with four column legs /27/.

These types of rigs are a more logical choice for drilling in softer subseas as the footing plates of these rigs are used by the rigs to distribute the weight of the rig across the seabed. In addition, adjustable-height rigs have two types of lifting devices—when the crane is on site, the legs are lowered to the ocean floor, and the hull and rig are raised well above the water's surface and away from potential waves. The first type of lifting device uses hydraulic cylinders equipped with movable and stationary wedges - the cylinders extend and retract to climb up and down the legs of the crane. Another type of lifting device uses a bar and two gears that turn to move the legs up and down. Whichever type of leg is used in the rig design, the crane legs rise through holes in the rig's hull while the deck is used to support the rig's derrick and other associated equipment. There, the rig is mounted on the hull - the most popular rig design is the cantilever crane in which the rig is mounted on a single shoulder that extends outward from the drill deck. In this way, drilling can be done through existing platforms, as well as outside it. Because of the range of motion that the console provides, most modern height-adjustable platforms are adjustable-vision platforms that include a console. Another type of drilling platforms with adjustable height is the platforms with the hole (known in the oil and gas industry as key way jackup platforms). The drilling hole of these rigs is made with a hole in the drill pipe and the drilling tower is placed above it. During the execution of exploratory drilling, they are often carried out using these types of platforms, where the drill bit can also be pushed using a special mechanism that passes through the hull of these platforms. It has cantilevered lifting platforms. In addition, it should be noted that when the support legs are not deployed (raised to a vertical position), the height-adjustable platform can float, which makes this type of mobile mobile drilling rig quite easy to transport from one drilling site to another. The primary advantage of the jacking rig design is that it offers a stable platform with no movement in drilling position and is relatively quick and easy to mobilize. Although originally designed to operate in very shallow water, newer units, such as ultra-heavy duty Maersk MSC C170-150 MC is the largest height-adjustable platform ever built that can operate in the water to vision 150 meters, while the maximum height of her legs is 207 meters. The most famous drilling of this platform was carried out in the exploration Martin Linge field in the Norwegian North Sea, Fig. 16 /28, 29/ which was carried out by the company Maersk Intrepid.

Figure 16 MAERSK-MSC C170-150 MC platforms with adjustable height /29/.

CONCLUSIONS

After analysis of different types of oil platforms, their construction, advantages and disadvantages, one can conclude the following:

A fixed (conventional) platform is a permanent fixed drilling platform that does not move under the influence of the marine environment.

Compliant towers are similar in construction to fixed platforms, as both are anchored to the seabed and hold most of their equipment above the surface. Compliant towers are taller and narrower than fixed platforms, swaying in the wind and almost seeming to float.

Improvements of platforms with tensioned legs are noticeable, include the following types: Extended tension leg platforms, Moses tension leg platform, Sea star-TPL-platforms.

In any case, structural integrity of oil platforms strongly depends on strick obay of manufacturing rules, especially those concerning welding, as one can learn from the Alexander Kielland oil platform disaster, briefly described in the Appendix, /30,31/.

Acknowledgement

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APPENDIX - The Alexander Kielland disaster

On the evening of 27th March, 1980, a couple of minutes before 6.30 p.m., the Alexander Kielland, a drilling rig converted into an accommodation platform and located in the North Sea, started to capsize and within 20 minutes had overturned killing 123 of 212 people on board. The Alexander L. Kielland was a mobile platform of the Pentagone type, Fig. A1, and was designed and built in France at the Dunkirk Shipping Yards. The main concern herein is the 'D' column and the bracing D-6 (24 m long pipe of diameter 2.6 m and thickness 26 mm), Fig. A2, together with the flange plate, inserted and welded to the bracing (D-6) and elongated hole (300 x 800 mm) located on the bottom of the bracing next to the sonar flange plate.

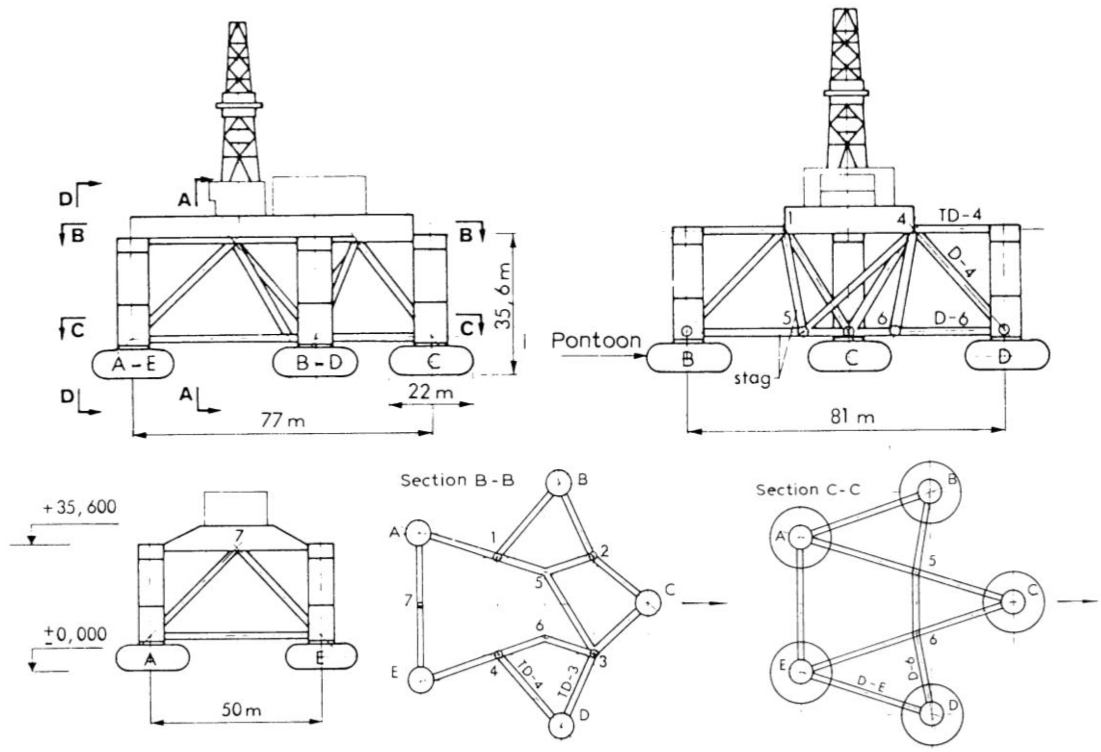

Fig. A1 A mobile platform of Pentagone type

Welding of the flanges to the elongated opening and air hole was performed the main installation team, while the welding of the non load-bearing sonar flange plate was the responsibility of the other team. No stress analysis of the sonar flange plate fitting was made, contrary to the oval hole flange plate. This turned out to be a vital omission. The main braces were of a welded construction and made from a Nb-microalloyed fine-grained steel.

As shown in Figure A2b, the flange plate is a short, hollow cylinder, ca. 228 mm long and 325 mm diameter, with wall thickness 20 mm. Similar flange plates were fitted to three of the main braces, i.e. B-5, D-6 and A-5. The flange plate material was of a fine-grained pearlitic-ferritic steel, shaped by bending and butt welding. The profile of the butt weld was of an 'X' form, i.e. it was welded both from inside and outside employing 2 runs on the inside and up to four on the outside, Fig. A3. The welding method was MMA, using flux-covered electrodes. The flange plate was then welded in position using MMA welding of 2-3 runs per weld, employing fillet welds both inside and outside the main brace plate, Fig. A2b. Flux-covered electrodes of 'basic' type, 5 mm diameter, were specified for this purpose. The 'a'-dimension of the weld was given as 6 mm, but the number of runs per weld was not specified. Preheat was neither specified nor employed.

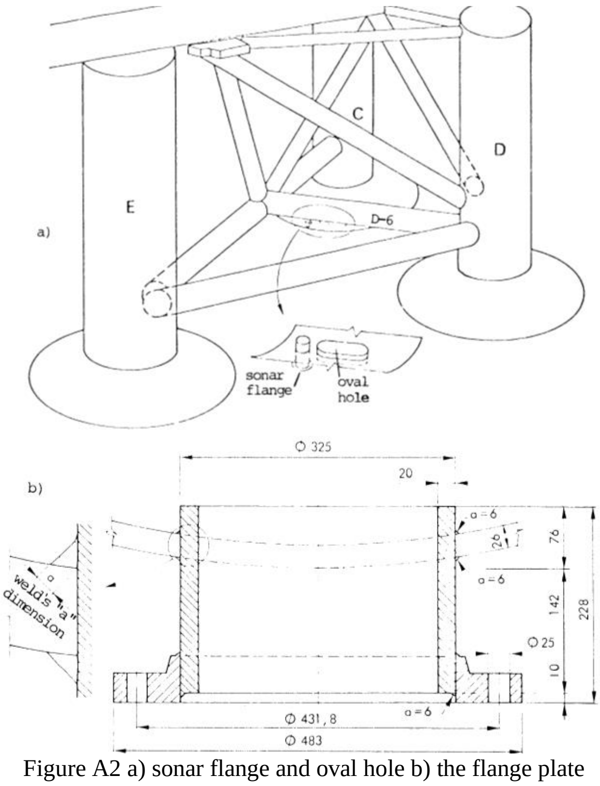

Figure A2 a) sonar flange and oval hole b) the flange plate

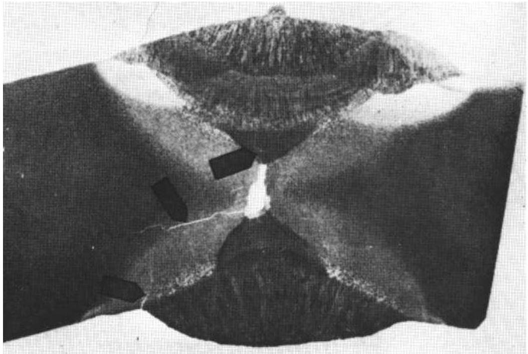

Figure A3 But weld of an “X” form

On the day of the disaster, the weather in the North Sea was stormy with mist and rain and visibility down to about a kilometre. It was also cold, with an air temperature of 4-6 ^{0}C and a sea temperature of 6°C. As the day progressed the weather deteriorated, with the wind blowing at 20 m/s, churning up waves of 6-8 m in height. About half an hour later, at 6.28 p.m., the radio officer on board the Kielland heard a loud thump from below. Not too much notice was paid to begin with, since such noises are not unusual in heavy seas. Soon after the first thump, however, came another and this was followed by a definite listing of the platform. Minutes after the second thump was heard, the platform had already listed over to an angle of 30-35^0 from the horizontal. At 6.53 p.m., 24 minutes after the 'Mayday' was sent out, it was recorded that the Alexander Kielland had completely overturned.

It was later established by the Norwegian Commission that investigated this incident, that the first thump heard by the radio officer was certainly caused by the fracture of the main brace, D-6. Then followed, in rapid succession, failures of the other bracings which connected column D to the platform, these resulting presumably from overloading. The positions of the various fractures of the bracings are shown in Fig. A4. The spacing of the latter fractures led the Commission to conclude that failure of bracings other than D-6 was due to bending.

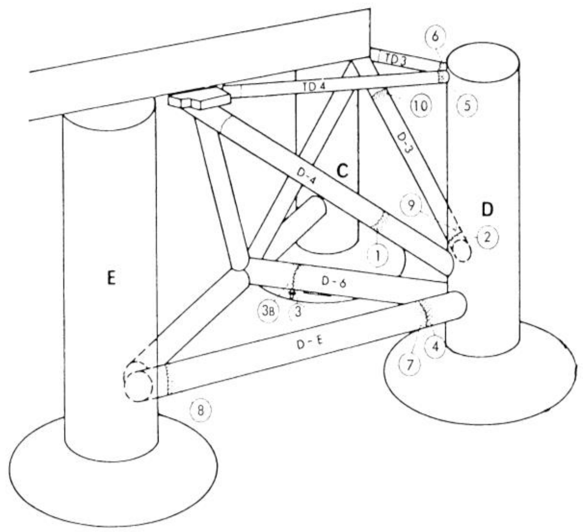

Figure A4 The positions of the various fractures of the bracings

The failure in bracing D-6 was clearly due to fatigue. It was later established that prior to the final fracture, the crack had grown to a length of over 5 m, or ca. 2/3 the circum¬ference of the bracing. Figure A5 shows the recovered D-6 bracing and its schematic view. Studies of the characteristic river patterns of the main fracture confirm this, Figure A6, in which the fracture pattern has been mapped out. As shown in Figure A6; fatigue initiated at two parts of the fillet weld, first at point I and then at point II.

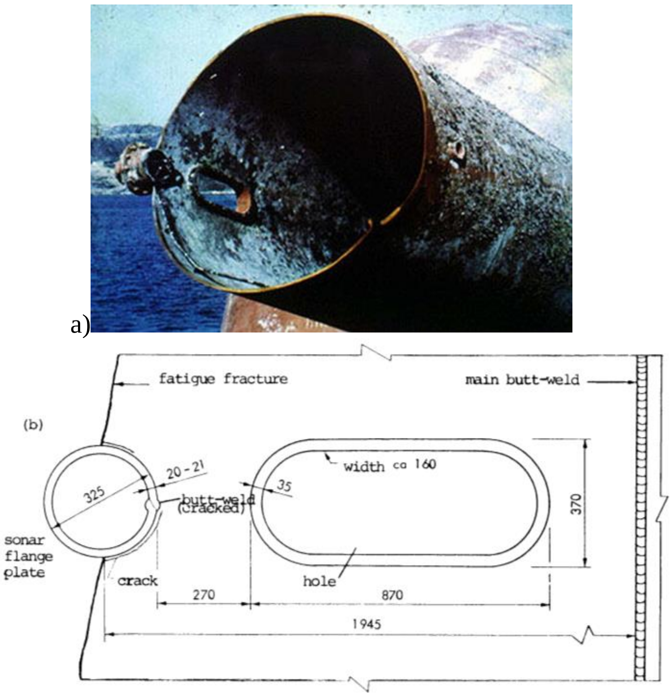

Figure A5. a) The recovered D-6 bracing b)a schematic view

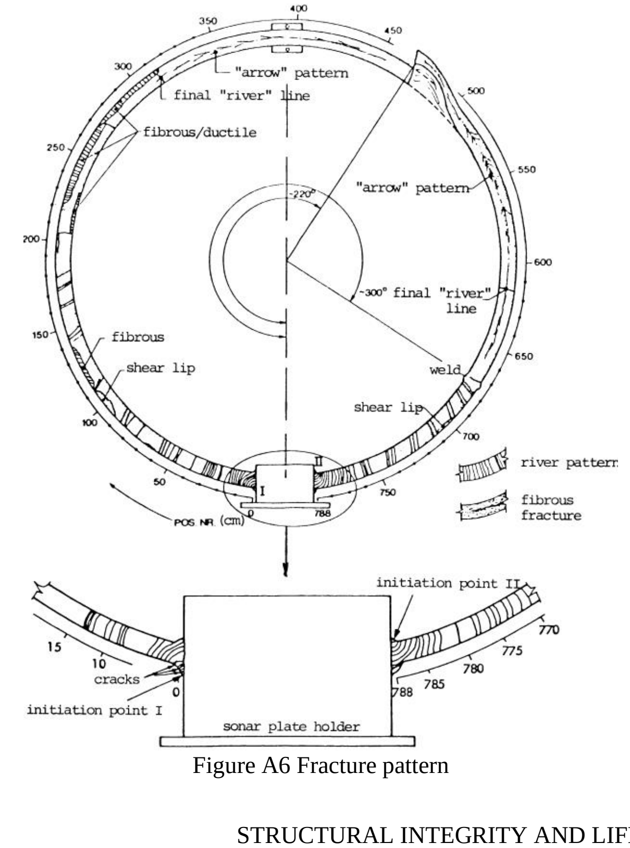

Figure A6 Fracture pattern