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The Sea Gem: A Story of Material Failure

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ABSTRACT

Offshore structures are continuously subjected to large loads caused by environmental conditions in their local operating area. In the North Sea, this can include wave, wind, ice and current loads. Material failure, such as fatigue, is a seemingly small problem that can quickly cause major damage and sometimes even catastrophic failure.

In the 1960s, the pioneering days of the oil and gas industry, engineering and safety standards for design and operation of drilling rigs were severely limited. Operators were eager to discover first oil and begin development of this promising and lucrative industry. Shortly after British Petroleum (BP) obtained leases for the British North Sea, the company chartered an American barge to be converted into a 10-leg drilling platform. The Sea Gem was the first drilling rig to discover oil in the British North Sea. However, in 1965, as it was jacking down, the platform collapsed. 19 out of a 32-person crew died on December 27, 1965, just three months after discovering what is today's West Sole Field.

It was determined that the disaster was due to material failure caused by corrosion, brittle fracture due to temperature change, and cyclic loading on the legs. This paper investigates the circumstances around the disaster, the aftermath and the engineering lessons learned that sparked critical changes in the oil and gas industry.

1 INTRODUCTION

Since in the 1850s oil exploration has been on-going in the North Sea, mainly in Norwegian and German territory. British Petroleum (BP) began exploring the British Continental Shelf with many small, high cost units throughout World War II. When Britain sold licenses for the area, BP acquired twenty-two in total, including block 48/6- the most desired and promising lease. However, BP were yet to own a drilling rig.

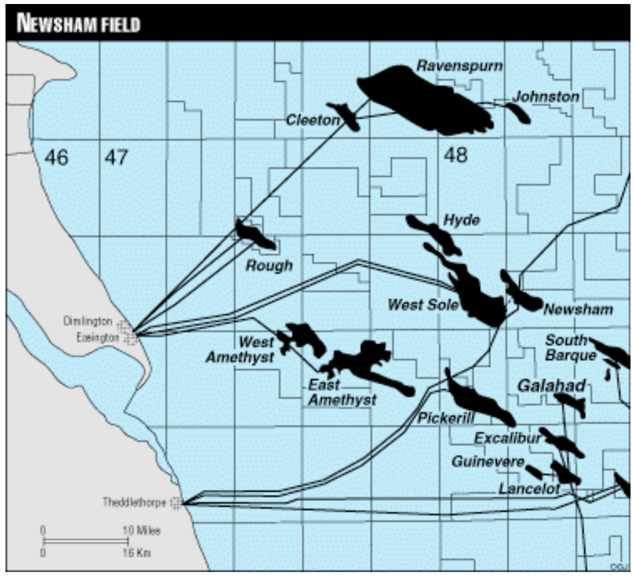

Figure 1: Oil fields in North Sea showing West Sole Field (location of the Sea Gem) [1]

In 1964, BP converted an American barge, originally built in 1952, to a 10-leg drilling platform. Living quarters, a helicopter-landing pad and second hand drilling equipment from their projects in Trinidad were added. The drilling rig measured 27.4 meters wide, 3.96 meters deep and 75.3 meters long. It weighed 5080 tonnes, with a working height of 15.24 meters, placing it adequately over significant wave heights in the area. This drilling rig, called the Sea Gem, was towed to block 48/6 in June of 1965.

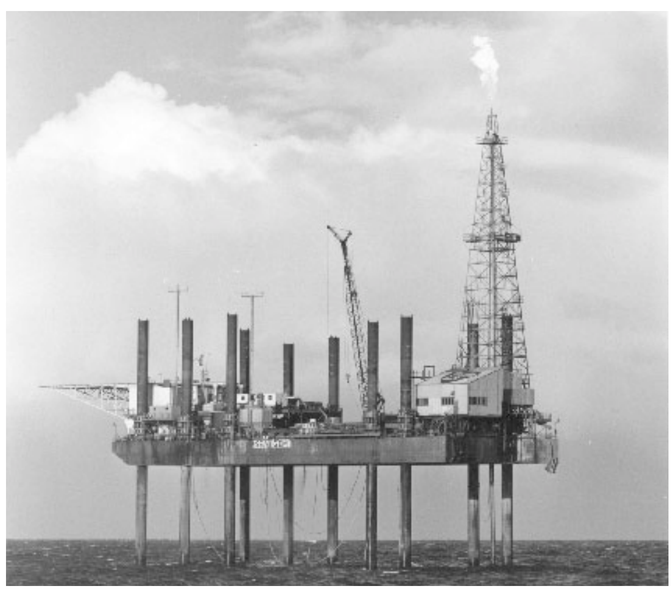

Figure 2: The Sea Gem drilling platform [2]

The rig commenced the North Sea offshore oil and gas industry on September 30, 1965 when it discovered gas 42 miles off the mouth of the River Humber in what is now the West Sole Field. In December 1965, the discovery was determined to be a commercial field. The rig was then scheduled to move to another location for further drilling.

2 SUMMARY OF ACCIDENT

Celebrations of the oil discovery were short lived when on December 27, 1965 the platform collapsed. Outlined below are significant events before and during the collapse. These events have been summarized from the "Report of the Inquiry into the causes of the Accident to the Drilling Rig Sea Gem" by the Ministry of Power. [3]

1.1.1 Pre-Collapse Incidents

The rig was jacked up to working height in early June of 1965. Visual checks and minor adjustments of jacks and tie-bars were conducted, but no alarming or concerning events occurred throughout the drilling process, which ended on October 12. The first event of significance occurred on November 23, when two inboard facing tie-bars on one leg snapped off. It was observed that at the time winds gusted up to 135 km/hr. Parts were replaced with spares kept on-board, and other tie-bars on the leg were inspected but showed no signs of damage or strain. The crew felt no anxiety or concern over the event and operations continued as usual.

On December 19, it was attempted to lift a jackleg from the seabed to inspect the footing and foundation conditions. However, the leg was stuck in the seabed and lifting produced slippage of the other legs. The operation was abandoned and all legs were equalized on December 21 to a height of 38 feet. On December 22, the leg was finally raised above the seabed, but not high enough for adequate inspection. It was then driven back into the ground at full force. It is important to note that while this leg was off the seabed, the neighbouring legs bore all load of the rig. Furthermore, it cannot be confirmed that when driven back into the ground the leg retook its full share of the load.

1.1.2 The Collapse

On December 27, a jacking operation began in order to lower the Sea Gem by 3.05 meters. This was in preparation for movement of the rig to another location. At the time, the wind was north northwest, wave heights were less than 3 meters and the air temperature was 3°C. When the procedure began, forward jacks moved as expected, but intermediate moved less than forward and aftermost ones were unresponsive. Operators could not specify the reason for failure through visual inspection. There was no report of unusual, alarming or emergency situation by the operator. The senior operator decided to recover original position by releasing air from the forward jack cylinders. However, this manoeuvre caused the portside jacks to slip. Shortly after, the forward starboard legs collapsed beneath the water line, leaving the hull at an uneven keel. The torsion of the fall caused a 4-inch wide tear in the hull, which filled with water and the vessel sank.

It is difficult to apply a time-scale to the events of the collapse. Eyewitness information can only conclude that it occurred quickly. Therefore, it is impossible to be certain that other constituents of the legs and connection system did not fail at some point in the collapse.

Figure 3: The Sea Gem collapsed [4]

The British ship Baltrover happened to be nearby and was first to spot the collapse of the Sea Gem. At 14:09 GMT on December 22, 1965 it sent a radio message to shore for further help, and then picked up several survivors and two bodies from the sea. Survivors were rescued in a joint effort by passing ships and two helicopters - one Royal Air Force and the other civilian. In the tragedy, 19 (people?) out of the 32-person crew died.

3 CAUSES OF COLLAPSE

In the investigation after the wreckage, it was determined by a tribunal that "some part of the suspension system linking the hull to the legs must have failed. The evidence…points irresistibly to tie-bars as having been, by their failure, the initiators of the collapse. It was that failure that introduced incalculable dynamic forces, which, once set in motion, led cumulatively to the disintegration of the whole structure."

This conclusion was drawn from the following facts:

- 5 legs in the wreckage had missing or broken tie-bars;
- Tie-bars retrieved by divers were examined and had fractures that were brittle and originated from severe notches, weld defects and fatigue cracks;
- Conditions at the time of the accident were conducive to brittle fracture;
- The jacks were still intact and in compression state in the wreckage (therefore not the cause of collapse).

Cyclic loading is the repeated application of a load over time, causing a decrease in the maximum load a structure can withstand. As the same force is applied repeatedly, a small crack(s) will grow until the component fails. Witnesses of the Sea Gem collapse spoke of rust and dust coming from the jacks on the port side, but noticed no such phenomenon on the starboard. Also, no witness spoke of any "bang" on starboard side, indicating the tie-bars did not fail mechanically. Therefore, it is likely that a fracture of the starboard legs below the surface of the sea caused the starboard side to fail. This failure was possibly from cyclic loading. Vibrations throughout the rig are unavoidable from drilling operations. In the vessel's log, excessive vibrating was recorded but was determined not to have caused the collapse.

A more likely cause for the fatigue is cyclic loading due to environmental forces. The North Sea is ravaged with heavy seas and high winds. BP was inexperienced in this type of environment, with previously having worked in the Gulf of Mexico. It is possible that in the rapid design of the Sea Gem these loads were underestimated or neglected. Today, wave loading on drill rig legs are determined using Morison's Equations. The total wave force (F) on a member element of volume (dV) and projected area (dA) can be determined by:

$$dF = C_m \rho dV \dot{u}_n + \frac{1}{2} C_d \rho dA |u_n| u_n \qquad (1)$$

where C_m and C_d are inertial and drag coefficients respectively, ρ is the fluid density, and $\dot{u}_n$ and u_n are instantaneous wave fluid acceleration and velocities normal to the member axis. Wave loading on a bottom-loaded cylinder is demonstrated in Figure 4.

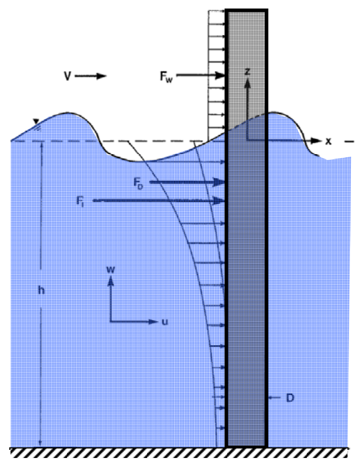

Figure 4: Wave loading on typical jack-up drill platform leg [5]

Today there are comprehensive software programs and analytical formulas that utilize Morison's equation to ensure the material properties and dimensions can withstand the highest possible loads in a region. Morison's Equation was published in 1950 and during the Sea Gem conversion there were few legal or class requirements for the platform leg design to meet. BP most likely did not utilize adequate wave loading formulations for the North Sea. Over time it was possible that constant loading from wave conditions could lead to small fractures in the legs, eventually initiating the leg's collapse.

Wind loading was of concern on the high superstructure of the rig. Wind loading on the Sea Gem (*F*) can be represented as a function of the wind velocity (*U*), air density (*ρ*), frontal area facing the wind (*A*) and drag coefficient (C_d).

$$F = \frac{1}{2} C_d \rho A U^2 \qquad (2)$$

The wind was noted to be very high during the collapse. If a large wind gust acted out of the horizontal, the large helicopter deck would increase frontal area (A) and cause enormous forces on the structure. Since the beam was one-third of its length and the supports failed successively (not simultaneously), it is logical to believe that wind loads on the structure added to the collapse.

Finally, a major initiator of the failure was brittle fracture in the steel. This phenomenon occurs if a normally linear elastic material is cooled and it becomes brittle. In this situation, the material has a lower resistance to an applied load and is more susceptible to sudden and rapid failure. The tie-bars were made from steel plate of a quality satisfactory in terms of the original specification. However, a Charpy V-notch impact test was conducted at the water temperature at time of collapse. It showed that fractures originated from severe notches such as fatigue cracks. Therefore, it is justified to say that the disaster was at least partially initiated from brittle fracture of the tie-bars at below yield stress.

4 AFTERMATH

The tribunal investigating the case made several recommendations, even though it was not expressly required. A notch tough steel with a Charpy value of 47.5 Newton-meters at 0°C should be specified for tie-bars which are to be used in winter conditions in the North Sea. Also, consideration should be given to provide shelter from the weather for jacks in these conditions.

Two significant regulations were introduced after the Sea Gem tragedy. It was decided, simply that “someone must be in charge.” This was the beginning of discussion of the Offshore Installation Manager (OIM) position on drilling rigs. Secondly, it became required for a platform to have a supporting vessel onsite at all times. [6]

This disaster sparked many discussions of standard engineering codes for design and structural integrity regulations. The result was a “technological revolution” for offshore platforms to be stronger and safer in order to cope with the hostile North Sea environment. [7] It opened the eyes of professionals, political figures and the public to how minimal health and safety requirements were in the oil and gas industry. Lesson’s learned from the Sea Gem collapse eventually led to the implementation of the Mineral Working (Offshore Installations) Act in 1971. This act provided framework for offshore health and safety regulations and was implemented over the next nine years in the North Sea. [8]

5 CONCLUSION

The Sea Gem pioneered the oil and gas industry in the British North Sea when it discovered oil in September 1965. However, celebrations were short-lived when just three months later, on December 27, 1965, the platform collapsed. 19 out of a 32-person crew died in the tragedy. After an inquiry, it was decided that the cause of the collapse was material failure in the tie-bars connecting the legs to the platform. During the conversion from barge to 10-leg drilling platform, BP neglected to adequately prepare the steel for the harsh environment of the North Sea. Brittle fractures from cold temperatures as well as fatigue from environmental conditions were contributing factors to the collapse.

The disaster sparked a revolution in the industry for greater health and safety requirements by operators. It called for requirements for structural integrity specific to environmental conditions of the North Sea and increased emergency procedures, such as a full-time support vessel on site of platforms.

In the 1960’s, operators were eager and greedy to be the first to discover oil in the British North Sea. BP likely took shortcuts in the design of the Sea Gem platform, sacrificing redundancy and safety for saved time and money. It is believed by the author that these design flaws inevitably caused the failure of the drilling rig and could have been avoided if the proper structural and safety procedures had been followed.

REFERENCES

[1] "Satellite subsea development starts up in North Sea", Oil and Gas Journal, 1996 (Source: http://www.ogj.com/articles/print/volume-94/issue-39/in-this-issue/production/ satellite-subsea-development-starts-up-in-north-sea.html)

[2] Dukes Wood Oil Museum, "The Sea Gem" (Source: http://www.dukeswoodoilmuseum.co.uk/pictures/sea-gem.jpg)

[3] Ministry of Power, "Report of the Inquiry into the causes of the Accident to the Drilling Rig Sea Gem", Her Majesty's Stationery Office, 1967

[4] "Dinghy saved Sea Gem man", This is Nottingham, 2010 (Source: http://www.thisisnottingham.co.uk/Dinghy-saved-Sea-Gem-man/story-12250291-detail/story.html#axzz2LC2bpnyL)

[5] N. Haritos, "Introduction to the Analysis and Design of Offshore Structure- An Overview", eJSE International, 2007 (Source: http://www.ejse.org/Archives/Fulltext/2007/Special/200705)

[6] D. Park, "Never Say Never Again", Oil and Gas IQ (Source: http://royaldutchshellplc.com/wp-content/uploads/2012/02/NeverSayNeverAgain.pdf)

[7] R. Gribben, "BP chief Tony Hayward fights to limit the damage after Gulf of Mexico rig disaster", The Telegraph, 2010 (Source: http://www.telegraph.co.uk/finance/newsbysector/energy/oilandgas/7673234/BP-chief-Tony-Hayward-fights-to-limit-the-damage-after-Gulf-of-Mexico-rig-disaster.html)

[8] P. Lindoe, M. Baram, J. Paterson, "Robust Offshore Risk Regulation – an assessment of US, UK and Norwegian approaches", ESREL2012, Helsinki (Source: http://seros.uis.no/getfile.php/risk.uis.no/Robust%20Regulation/Lindoe,%202012,%20 Robust%20Offshore%20Risk%20Regulation%20%E2%80%93%20an%20assessment%20of%20US,%20UK%20and%20Norwegian%20approaches,%20ESREL%20conference.pdf)