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The Loss of the Sleipner A Platform

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ABSTRACT

Offshore installations are complex and expensive engineering structures that are unique in terms of their design and operational characteristics. Over the past three decades, there have been major advancements in the technology used to extract oil and gas, which has enabled exploration to extend to challenging and hostile environments, including the Troll field in the Norwegian sector of the North Sea. The Sleipner platform was the first of three concrete gravity base structures to be used to extract oil and gas from this field, and great effort was placed on a timely start-up of gas deliveries in order to ensure the credibility of Norway as a reliable European energy partner.

The gravity base structure (GBS) of the Sleipner platform was the twelfth in a series of GBS platforms of Condeep-type designed and built by the company Norwegian Contractors in Gandsfjorden near Stavanger, Norway. On August 23 1991, during a controlled ballasting operation in preparation for deck mating, the Sleipner platform sank. All 14 people onboard the platform was rescued by nearby boats without injuries. The failure involved a total economic loss of about 700 million dollars.

Safety is a major concern for all offshore operations and a proper risk management plan is critical in ensuring a safe and successful project. Risk management involves the identification of hazards associated with a specified activity in order to minimize the probability of their occurrence, and/or mitigate their consequences. Risk management is particularly important in hostile ocean environments such as the North Sea, where even the most routine and simple tasks could result in great consequences should trouble strike.

The following paper will discuss the sinking of the Sleipner A platform and explore the investigation that took place immediately following the disaster. The paper will also discuss the coastal facilities required to construct Condeep platforms, as well as the role of risk management in the process. Finally, the impact to subsequent offshore structures following the Sleipner platform sinking will be assessed.

1 INTRODUCTION

The Troll field, located in the Norwegian sector of the North Sea, is located 100km North-West of Bergen, Norway as shown in Figure 1 below. The Troll field, operated by Statoil, contains about forty percent of the total gas reserves on the Norwegian continental shelf (NCS) and is expected to produce for at least another seventy years [1].

Figure 1 – Location of the Troll Field [1]

The Sleipner platform was one of three platforms to be used to extract oil and gas from this field. It was to cover the first three years of the Troll gas contract and great effort was placed on a timely start-up of gas deliveries in order to ensure the credibility of Norway as a reliable European energy partner.

2 PLATFORM DESIGN

2.1 Construction Sequence

The harsh environmental conditions of the North Sea have led to the development of the concrete deep water structure, or “Condeep” platform design. Construction of Condeep platforms begin in dry dock, where the lower domes and part of the cylindrical walls are cast. The lower domes are essentially hollow concrete shells that form the base of the structure, which sits on the sea floor. The shells can be filled with solid ballast, seawater, or oil. By regulating the amount of ballast in the shells, the buoyancy of the structure can be controlled. Following the construction of these shells, the dry dock is flooded and the partially complete structure is floated out and anchored at the deep-water site. When the concrete structure is completed, additional water ballast is added until the top of the concrete structure is nearly submerged. Next, the top deck platform is floated over the top of the concrete structure, water ballast is pumped from the buoyancy cells and the concrete structure rises to mate with the deck structure [2]. The top deck of the platform typically provides accommodations and supports drilling and process equipment.

2.2 Design Challenges

A critical factor on the design of a Condeep platform is the thickness of the walls. If the walls are too thin, they may fail under very high water pressures. The walls are particularly at risk of failing during deck mating, during which they are exposed to the highest hydrostatic pressures. Unlike typical land-based structures, however, the wall thickness cannot be simply increased to ensure a very conservative design. If the walls are too thick, the structure will not be able to float, or will not be hydrostatically stable during the tow-to-field.

2.3 Sleipner A Platform

The Sleipner platform was designed with 24 cells, 4 of which extended as shafts to support the deck structure. The gravity base covered an area of 11,900m^2 and the shafts were at a height of 110m above the base. The exterior walls of the cells were circular with a radius of 12m, while the interior walls which separated the cells were straight [3]. The intersection of the interior walls formed a triangular void called a tricell; there were 32 tricells in total present on the Sleipner Platform as shown in **Error! Reference source not found.** below. The walls of the tricells had to resist substantial hydrostatic pressure due to openings at the top which filled the tricell with water once the tops of the cells were submerged. The tricells were later discovered in the investigation to be the point of failure in the sinking of the platform.

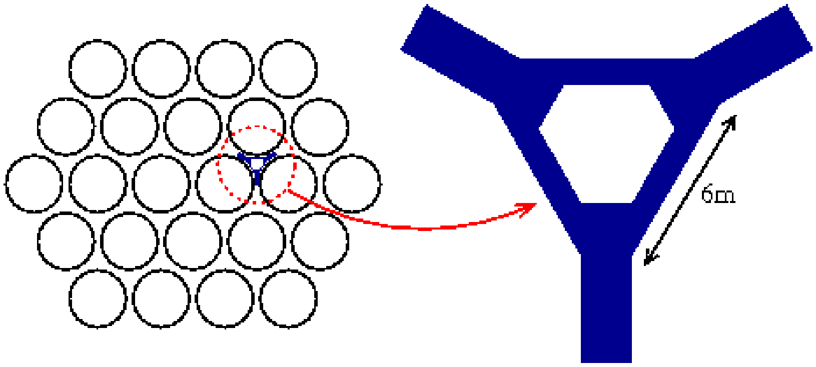

Figure 2 – The Triangular Void called a Tricell [4]

3 THE ACCIDENT

The construction of the Sleipner platform began in July 1989. The GBS was completed up to the upper edge of the cells in dry dock, while the upper domes of the cells and shafts were completed after the platform was towed to the deep-water site. The accident occurred in the morning of August 23, 1991 during a controlled ballasting operation in preparation for deck-mating. The purpose of the controlled ballasting operation was to check the platform for minor leakages, to test the mechanical equipment under real operations and to familiarize the personnel with the operating systems [2]. During deck-mating a Condeep structure is typically about 20 meters deeper in the water than during operations, and as a result experiences critical hydrostatics pressures. When the Sleipner platform was about 5 meters from the planned deck-mating depth, a loud noise was emitted from a shaft of the structure, signalling a failure in a cell wall which allowed water to rush into the drill shaft. The emergency deballasting pumps could not keep up with the water flow and as a result the structure sank [3]. It took approximately 18 minutes for the platform to be completely submerged following the first sign of the accident. When the platform hit the seabed floor, at a depth of 220m, it caused a seismic event registering 3.0 on the Richter scale, and the impact reduced the platform to a pile of debris [1]. All 14 people onboard the platform was rescued by nearby boats without injuries. The failure involved a total economic loss of about 700 million dollars [4].

4 THE INVESTIGATION

The investigation group, formed immediately following the accident, consisted of members from the operating company, license partners, and observers from the authorities. The mission of the group was to go through the conditions connected to the accident itself, its causes, and to evaluate eventual actions related to existing and future concrete platform structures [5]. Underwater inspections indicated that the structure had been completely demolished by the accident, and therefore no physical evidence was available to clarify the cause [2]. The investigation focused primarily on technical hazards such as sinking scenarios, design standards, and critical areas of the structure. Quality assurance programs were also evaluated.

The investigation identified the tricell walls and their supports to be the only area with significant weaknesses. Calculations also showed that the load at the time of the accident was at or near the ultimate capacity of these walls, and sinking scenarios confirmed that a single leak from one tricell joint could result in enough water entry to sink the structure within the observed time [1]. Analysis of stresses in the tricell joints was accomplished using the linear elastic finite element program NASTRAN, which had been developed by NASA [6]. The investigation identified that the reason for the weaknesses and reduced load-bearing capacity was due to the unfavourable geometric shaping of some finite elements in the global analysis, see Figure 3 below. As a result, the shear forces at the walls of the supports were underestimated by approximately 45 percent, leading to failure.

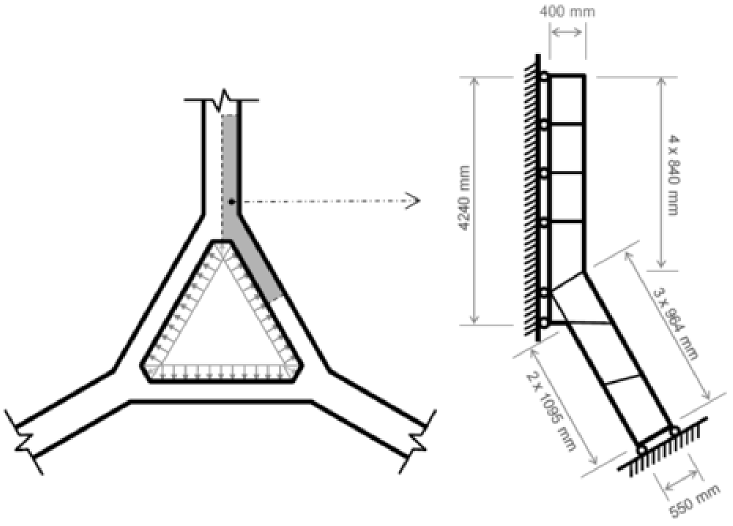

Figure 3 – Tricell Element Model [6]

The investigation team also used an alternative analysis approach, in addition to examining the finite element modelling. Specifically, the method of strut-and-tie modelling was examined. Strut-and-tie modelling approximates a reinforced concrete system with a truss mechanism. This method has the advantage of being highly flexible as an analysis technique and better represents the cracked, plastic behaviour of reinforced concrete at its ultimate limit state. Experimental tests of the tricell joints using the strut-and-tie method verified that failure occurred through the tricell, as shown in Figure 4 below.

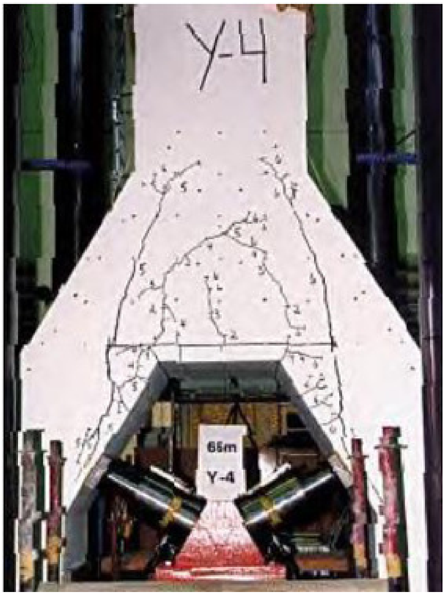

Figure 4 - Experiment test of a tricell joint [4]

In addition to the initial investigation, two model tests were performed in the winter of 1992 that aimed to verify that the failure mode identified from the previous investigation was accurate. One series of the model testing examined several possible water leakage scenarios which might have caused the sinking, while the other set of testing was a structural test in a 1:1 scale of a section of the tricell walls. All tests were in agreement with both the failure mode and the failure load identified from the previous investigation [6].

5 LESSONS LEARNED

The design procedures used to estimate the shear strength of the tricell wall were those contained in the 1977 Norwegian concrete code. These provisions, which remained unchanged as of 2000, predicted failure of the tricell wall when the water pressure reached a head of 120m, almost twice the observed failure pressure [2]. As will be discussed in the following sections, it is extremely important in the design process to apply sound engineering knowledge in addition to using sophisticated computer software and predetermined formulas and codes.

Investigation revealed that the modelling performed with NASTRAN was flawed, and suffered from a number of oversights in the theoretical fundamentals. Of particular interest, the Sleipner tricell finite element model had skewed faces that did not allow a rectangular shape. A known limitation of finite element theory is that a simple solid element with linear shape functions result in erroneous results when the elements are distorted.

In addition to this limitation, the finite element analysis that was performed for the tricell returned a single stress result for each element. In order to expand the results to the edges of the model, the analysts used a second order polynomial curve and fit it to their given data [6]. Extrapolation was then used to reach the point of interest. This extrapolation was later identified as being a key contributor to the underestimation of the capacity of the tricell. This error stemmed from the basic mechanics of materials, which requires a linear modelling of the shear stresses rather than a parabolic one.

The errors committed by the design team were fundamental in nature, and had the sophisticated computer software been diligently used by competent engineers, the failure could have been avoided.

Risk management should be applied to all stages in the design and construction of an offshore structure. In the case of the Sleipner platform, effective risk management would have promoted communication and consultation between the team members. In particular, thorough risk assessments should have been performed for the controlled ballasting operations since during this time the platform was submerged deeper in the water than during normal operating conditions and, as a result, experienced greater hydrostatic forces.

6 INDUSTRY IMPACT

The financial loss of the Sleipner platform must take into account both the physical loss of the platform itself, as well as the loss in revenue due to the delay in production. Norwegian Contractors was found to be liable for the failure and dissolved as a company [6].

The construction of a second Sleipner platform was underway prior to the conclusion of the investigation of the first platform's sinking [6]. The second design of the tricell joint included a high amount of shear reinforcement, and test results showed 70 percent greater capacity than the original Sleipner tricells. The new platform was mated to its deck on April 29, 1993, 20 months behind the original schedule. As a result, the production scheme for the Troll Field had to be significantly adjusted and a new riser platform and undersea equipment had to be built to accommodate for this change [2].

It soon became evident in the investigation that there were major flaws in the computer analysis and design routines, and identifying and correcting these errors was to be a major and lengthy process. As a result, the second Sleipner platform was designed using pre-computer, slide-rule era techniques that had been used for the first Condeep platforms designed 20 years previously [3]. The majority of the structure had been designed and built before the new computer results were available.

Today, the exploration and extraction of oil and gas is a highly regulated industry. Safety and reliability is a part of the core business objectives for all the major operators, including Statoil. Statoil's biggest activities are currently located in Norway, where a total of 552 fixed installations on the Norwegian Continental Shelf produce just over 2.1 million barrels of oil per day [1]. Regulatory boards are established in most areas of the world to ensure proper guidelines and procedures are followed. Operators are able to comply with these safety regulations by applying an integrated risk-based approach to their operations. This approach begins with a feasibility study, which is an analysis and evaluation of a proposed project in order to determine if it is technically and financially possible. Next, a risk management procedure is set in place, which is to be followed throughout the life of the installation.

A risk-based approach to offshore installations ensures risk assessments are not only applied to individual systems, but also to the installation as a whole. In other words, the complex interactions between the subsystems in an offshore operation are evaluated to ensure the upmost safety standards will be followed under all operating conditions.

7 CONCLUSIONS

The Sleipner platform was the twelfth Condeep GBS structure built by the Stavanger-based firm Norwegian Contractors and the design did not alter from the previous structures. The platform was to operate in 82m of water, which was substantially shallower than preceding platforms, operating in water depths exceeding 250m. Nevertheless, the sinking of the Sleipner A platform reinforces the importance of effective risk management procedures. In any complex, high risk design it is important to have the involvement of an independent third party. Verification by an independent source may catch errors that were overlooked by the designers. It also helps to ensure that escalation of commitment is avoided. Escalation of commitment occurs when an individual refuses to see errors in his or her own work, and instead tends to invest additional resources in an apparently losing proposition. Assigning different people to the different stages in the design process help prevent this issue.

In addition to the material loss of the structure itself and loss revenue due to the delay in production, it is important to consider the adverse impact to the environment as well. While the sinking of the platform occurred over a relatively short time frame, the impact with the sea floor surface, and resulting scattered debris would have had a negative impact of the surrounding marine life. Unfortunately the full impact to the environment is often unknown, but lingering effects can continue years after the initial disturbance.

As discussed in this paper, it is evident that there were inadequate risk management procedures in place during the design of the Sleipner platform, resulting in the eventual loss of the platform. That being said, when the accident occurred, the quick response of the surrounding boats ensured that no lives were lost. The investigation to follow appeared to be comprehensive and focused on ensuring that similar mistakes were not repeated. The operator quickly formed an internal investigation team, demonstrating an active leadership position. The lessons learned from the sinking of the first Sleipner platform were apparent in the changes that were implemented in the design and construction of the second platform. Furthermore, the oil and gas industry today continuously demonstrates a commitment to the safety and reliability of offshore operations, which is demonstrated in part through the regulatory bodies.

Finally, it is not enough to merely accept published procedures and sophisticated computer software. Instead, one must fully understand the fundamentals to ensure the accuracy of the design. This idea is reinforced by the fact that the second Sleipner platform was successfully designed using hand calculations and core engineering fundamentals. It is evident from this accident that computer analysis is only as good as the user who inputs the model and interprets the results. Rational methods of checking results should always be used and rough estimates of the most important design parameters should be obtained by simple hand calculations. This will allow the computer results to be verified, as well as improve the engineer's understanding.

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