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STRUCTURAL ACCIDENTAL EVENTS ON OFFSHORE STRUCTURES IN NORWAY

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1. INTRODUCTION

The Norwegian Petroleum Directorate (NPD) is responsible for the govermental supervision towards safety and working enviromnet on the Norwegian Continental Shelf, and is in the area prvided with a high degree of authority.

One of the NPD's assignments consist of establishing a legal framework which reflects the risks in petroleum activities, and how this experience has been incorporated in the new regulations conserning risk analysis.

This paper will mainly describe :

- the requirements for the structural design against accidental events.

- major structural accidental events in Norway.

- changes in the regulation and the guidelines caused by the incident by the sinking of the Sleipner GBS.

2. REGULATORY REQUIREMENTS

The design against accidental events are regulated through two regulations : the regulation about load bearing structures stipulated 7 th of February 1992[2] and the regulation concerning implementation and use of risk analysis in the petroleum activities stipulated 12th of July 1990[1].

In addition each of the regulations have guidelines giving guidence to each paragraph in the regulation. The 7 th of february 1992 new guidelines about the determination of loads and load effects were also stipulated[3]. These also give some help in the design against accidental events.

These regulations handle both mobile drilling units and fixed structures in the same way. Both types of structures have to comply to the regulation.

2.1 THE RISK ANALYSIS REGULATION

The risk analysis regulation says that risk analysis should be performed during all the phases of the development of a field. The results from the risk analysis will be a basis for the design against accidental loads.

The regulation (§ 11) says that the operator and not the NPD, shall in principal define acceptance criteria for risk in the activities. This is a new approach compared with the practice established in the NPD guidelines for safety evaluation of platform conseptual design, issued 1.9.1981. Acceptance critirias then varies from one operating company to another. Requirements stipulated by or in pursuance of law or regulations, including requirements with regard to risk reducing measures, and the operator's safety objectives for the activities, shall though form the basis for defining acceptance criterias. The acceptance criterias should relate themselfes to both risk for personell, environment and ecconomic values.

The acceptance criteria shall be defined before the analysis is carried out.

Risk acceptance criteria determine against which accidents and to what extent one has to protect oneself. Risks which exceedes the acceptance criterias have to be regarded as a design accidental event. A proper design has to be undertaken to reduse the risk to an acceptable level.

Also the events which give a risk which is lower than the acceptance criterias have to be evaluated. Attempts shall be made to the extent possible to eliminate or reduce the individual risk identified through a risk analysis. The operators is required to strive to achive the lowest possible risk level, but for such cases cost-benefit considerations considerations are performed.

The regulation and the corresponding guidelines are general in nature and will not give you any guidance to numbers as such. This is left to the detail regulations and guidelines and to the operator to specify.

For further discussions about the regulation reference is made to Ingrid Årstad[4].

2.2 THE REGULATION FOR LOAD BEARING STRUCTURES

The regulation for load bearing structures give you som acceptance criterias for a risk analysis. It gives :

- a level of loading, as a returperiode of theaccidental loads (10¿^{4} pr year)
- level of strenght (2,5% and 5% fractiles)
-safety factors, as load- and material factors and also fatigue safety factors
- requirements to resistance in damaged conditions
- requirements concerning controll and verification

In combination these factors should describe an acceptable safety level for the design of offshore structures. In practices there is not performed any risk analysis against environmental loads. A reference to the design work and a the criterias in the regulation is commonly used.

A risk analysis is though neccessary to performe in cases as ship collisions, dropped objects, handling of ballast systems and fire/explosion loads.

2.3 THE GUIDELINES ABOUT LOADS AND LOAD EFFECTS

These guidelines[3] give some guidence to a level of numbers and methods how to obtain loads from accidental loads on a load bearing structure. In cases where the guidelines give numbers NPD to not expect any documentation from the operator of the number or method as such.

Concerning fires and explosions the guidelines only give lists of what kind of events that should be evaluated.

Concerning collisions the guidelines give recommendations concerning size of the colliding vessel, add mass and velocities. A practice has also been established in Norway to review collisions in light of the research work performed by Technica in the Risk Assessment of Buoyancy loss (RABL) Project and the SicteC in the Collide II project.

Concerning dropped objects give som guidence conserning what type of dropped objects which has to be evaluated.

Concerning changes in internal preassure differences or buoyancy the guidelines only give a list of what the designer and the risk analyser should think about. The loss of Ocean Ranger has been in our minds when writing it.

3. EXPERIENCED STRUCTURAL ACCIDENTAL EVENTS

The problems which have caused the most severe accidents in Norway is gross errors in the design and fabrication. Reference is made to the loss of the jacket of Frigg DP1 during installation in 12.10.1974, the capsizing of the quarter platform Alexander Kielland 27.3.1980, and the loss of the Sleipner A condeep structure 23.8.1991. Such accidents have to be prevented through good quality assurance systems during all phases and a conservative design. We have choosen to give a comprhensive descibtion of the Sleipner accident.

Smaller structural accidents have also occured as ship and helicopter collisions, dropped objects and wrong use of ballast systems. This paper

3.1 SHIP COLLISIONS

The following ship collisions have been reported on fixed structures the last 10 years :

A) EKOFISK 2/4 D - jacket - 12.1.1982. Crack in weld between riser protector and doubler plate. Doubler plate was torn loose.

B) EKOFISK 2/4 H - jacket - 13.4.1982. Collision with survey vessel Seaway Falcon. Several nodes and braces got cracks, deflections and dents.

C) VALHALL QP - jacket - 1.7.1982. Collision with supply boat Tender Turbot in boatlanding area. Insignificant damage.

D) STATFJORD-C-SPM - Single Point Mooring Platform - 23.1.1985. Collision with the tanker Poly Viking caused a torsional moment exceeding the design limit. Draintube at colum and host deformed.

E) COD 7/11 A - jacket - 25.5.1986. Structural damage on horizontal brace (140 mm tear). Secondary damage to support beams, stairway and stairway landing platform.

F) ODIN - jacket - 24.12.1986. Dent 700 mm long and 120 mm wide. No influence of overall integrity of the structure.

G) STATFJORD-B-SPM Single Point Mooring Platform - 1986. Access platform extensively damaged by tanker collision during loading operation.

H) EKOFIKS 2/4 A - jacket - 1.12.1987. Boat landing pushed against member during collision with the supplyboat "Nor Truck".

I) STATPIPE 16/11-S - jacket - 1988. Collision with stand- by vessel Geo Boy. 12 scratchmarks with average size 100 * 10 mm and max depth 2 mm.

J) OSEBERG B - jacket - 6.3.1988. Submarine collision with brace. The deflection was 194 cm long, 90 cm wide and 26 cm deep. For more details reference is made to Sveen (1989).

K) GULLFAKS - SPM 1 - loading buoy - 10.10.1991. Collision with the tanker Sarita. Extensive damage was done on the SPM.

L) GYDA - JACKET - 3.11.1991. The supply boat Northern Clipper collided. Only damage on the wodden fenders.

M) STATFJORD-C-SPM - loading buoy - 17.1.1992. Collision with the tanker Evita. Extensive damage was done on the SPM.

Collision causing damage is a frequent situation. As an average approximatly 2 collisions occur per 100 platform years.

Studies of damages on platforms indicate that there are also a high number of small non-reported ship collisions. A ship collision probability of 2% every platform year is considered to be a lower limit estimate of the total number of events. More details can be found in Hamre et al[5].

Four of the collisions have been between a tanker and a loading buoy. Based on this a conclusion must be that there is no real difference in collision frequences between small and large vessels which visit a platform frequently.

Only one of the accidents has been with unauthoriced vessel. That was the submarine collision at Oseberg B in 1988. This give a low collision frequency for non authorized vessels. Several near accidents has though occurred also with non authorized vessels.

3.2 DROPPED OBJECTS

A few cases of dropped objects on the structures have been reprted the last 10 years. The cases are connected to cranes, buoancy tank, pile hammer, fender and sea water pump. Non of the cases have saused any serious damage, but cases like these should be evaluated during the design.

3.3 ERRORS IN BALLASTING AND SEAWORTINESS

Such errors are normally caused by human errors during operation of the platforms. Examles are major ballasting errors on the rigs Henrik Ibsen and ex Håkon Magnus in 1980. An other example is bad seaworthiness of the jackup West Gamma 21.8.1989 causing capsizing of the rig during towing.

Errors connected to human errors is difficult to handle in a risk analysis. As a preventive accition a requirement in the 1992 regulalation for load bearing structures § 15 states that the structure and operations shall be performed in a way preventing a single error to cause a dangerous or an accidental situation.

4.THE LOSS OF SLEIPNER A GRAVITY BASE STRUCTURE (GBS)

4.1 INTRODUCTION

On the 23 th of August 1991 the Sleipner A GBS sank at its moorings during a submergion test in Gandsfjorden outside Stavanger. Despite the very short time it took for the accident to happen, nobody was injured. In the following the actual failure and consequent changes to the Noregian Petroleums Directorate (NPD) regulations are discribed.

4.2 THE ACCIDENT AND THE DIRECT CAUSE

The Sleipner A GBS was a traditional condeep design developed by Norwegian Contractors and Dr. Tech. Olav Olsen.

The GBS consisted of four shafts and twentyfour celles. Total hight of the GBS was 110m and it was to be installed at a waterdepth of 82.50m. A sketch of the installasion is shown in figure 1.

The accident happened during a testrun before deckmating. At this testrun the GBS should have been submerged to a freeboard of 6m. In this condition the structure would be exposed to very high waterpressure. The accident happened at a freeboard of 11m.

The structural failure started with a crack in the wall between drillshaft D-3 and most likely tricelle T-23 at level 32m. This crack has caused a similar crack in one or more of the adjacent tri-celle walls. A sketch of the cracked tricelle is shown in figure 2.

Modeltests which have been carried out show that cracks in two tri-celle walls give effects which agree with observations and evaluations carried out.

The loss of the concrete structure was caused by under- design of the tri-celle walls and the the joint between the tri-celle walls and the celle walls. Calculations indicate that cracks in more than one tri-celle can be explained by the low strength of the tri-celles and by the redistribution of forces that occured after the initial failure.

The following three independent design errors contributed to the failure:

- Design forces were underestimated due to errors in the global analysis.

- Reinforcement was improperly detailed.

- The tri-celle joint was not explicitly designed, it only contained the same reinforcement as the celle wall.

Analyses performed after the accident using different models of the tricell wall and the joint indicate that cracking could be expected at loads corresponding to 60 -70m water column. This is consistent with the load on the walls at the time of failure.

In order to verify that the cause of the loss was shear failure in the tricell wall, a series of full scale tests has been performed. The tests confirmed that shear failure was due to insufficient reinforcement as already found by theoretical calculations.

The Global Analysis

The computer program used for the Sleipner A GBS finite element analysis was NASTRAN, a well known and proven program developed by NASA about 20 years ago. There is no reason to believe that errors in the program was present. However the modelling of the element mesh was unfortunate carried out.

The results from the NASTRAN analysis came out wrong on parts of the structure. In the tri-celle area the share forces represented only 53% of the correct value. The bending moment represented about 77% of the correct value in the same area. The main reason to these bad results were the relatively course element mesh and the apperance of skewed elements in this part of the model. A sketch of the element mesh in the tri-celle area is illustrated in figure 3.

The errors associated with the tricell walls gave rise to underestimated dimensions, and hence insufficient reinforcement.

Detailing of reinforcement

Critical reinforcement in the tricell joints was not properly detailed. The T-headed bars used were improperly anchored. These T-headed bars function were to minimise tension cracks in this area. T-headed bars are ordinary bars with bearing plates welded to both ends. A sketch of the layout of the reinforcement in the tri-cell area is illustrated in figure 4.

Design of tri-celle joints

Transverse reinforcement in the tricell joints was based exclusively on the reinforcement provided in the adjacent cell-walls. This approach did not capture the way the joints actually function, and resulted in insufficient reinforcement in the joints to resist the forces from the two connecting tricell walls. A sketch of the joint is shown in figure 5.

4.3 CONSEQUENT CHANGES TO NPD REGULATIONS

The incorrect design of the tricell walls in Sleipner A GBS is caracterised as "gross error". Loadfactors and/or materialfactors are not meant to be an assurance against design errors of such a magnitude as represented in this case.

On the other hand one would expect the quality assurance system iplemented to "gross errors".

Important factors in a quality assurance system to be mentioned are independent verification work and imployment of qualified personell. These factors failed in the design phase of Sleipner A GBS.

Independent verification

The investigation carried out concludes that verification work of the finite element analysis and the design work were not satisfactory carried out. The verifcation work was unsatisfactory with respect to both quality and extent.

Based on the above conclusions supplements to NPDs Regulation for Structural Design of Loadbearing Structures are made. The same requirement concerning operators independent verification is still present. But now the intention of this requirement is outlined quite comprehensible in the guidelines.

In the guidelines it is stated that the verification work shall be comprehensive. The requirement implies a direct responsibility to perform an active control of all phases and not just oversee the contractors quality assurance system. It is also recommended that verification work should bee a combination of design review and independent calculations.

Personell qualifications

Another conclusion made is that the competance of personell involved in numerical analysis work and structures should have been better.

With respect to competance of personell the new Regulations requires establishment of qualification requirements for key personell involved in design and independent verification work.

In the guidelines this requirement is further described. It is stated that a technical responsibel for design shall be appointed in the organisation. This person shall have wide experience in structures. It is also said that this person shall have time available to follow up the technical part of the work. It is espected that this person shall be able to undertake alternative calculations and independent evaluations of design work.

4.4 SLEIPNER SUMMARY

As a result of the Sleipner A GBS accident there has been some changes in NPDs audit activity concerning loadbearing structures. In our audits we put more effort on checking personells qualifications and also the quality of independent verification work carried out.

It is a general opinion that the "lesson learnt" from the Sleipner A GBS accident is relevant not only for design of concrete structures. The recommendations and conclusions from Statoils Investigation report[6] are of greate interest also for personell involved in design of steel structures. It is therefore important that information about the Sleipner GBS accident is made available.

5. SUMMARY

Based on the two NPD regulations a good basis for developing design accidental criterias for offshore structures is established.

Several minor accidents have occured caused by what is regarded as accidental events. The largest accidents in Norway have though been caused by gross errors in the design or fabrication. Giving in mind that the design have to be followed by a comprehensive quality system.

6. REFERENCE

1. NPD : Regulation conserning implementation and use of risk analyses in the petroleum activities with guidelines, issued 12.7.1990.

2. NPD : Regulation for structural design of loadbearing structures intended for explitation of petroleum resources with guideline, issued 7.2.1992.

3. NPD : Guidelines for the determination of loads and load effects, issued 7.2.1992

4. Ingrid Årstad : The use of risk analyses in the petroleum activities on the norwegian continental shelf: the point of view of the authorities, paper at Risk analysis for the offshore industry III, Aberdeen, 1-3 April 1992.

5. Reidar Hamre, Arne Kvitrud and Kåre Tesdal : In service experience of fixed offshore structures in Norway, paperet at OMAE-1991 conference, Stavanger, 1991.

6. Statoil : Sleipner A gravity base structure loss Final report dated 24.4.1992.