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Risk Assessment Approaches for Offshore Structures

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ABSTRACT: Risk assessment and management was established as a scientific field some 30–40 years ago. Principles and methods were developed for how to conceptualize, assess, and manage risk. These principles and methods still represent largely the foundation of this field today, but many advances have been made, linked to both the theoretical platform and practical models and procedures. The purpose of the thesis is to perform a review of these advances, with a special focus on the fundamental ideas and thinking on which these are based. We have looked for trends in perspectives and approaches, and we reflect on where further development of the risk field is needed and should be encouraged. The present study is written for readers with different types of background, not only for experts on risk.
However, there is a conflict between the cost impact and safety aspect. E&P managers as well as government supervisor authorities are constantly faced with decisions to be made regarding of safety. In order to ensure comparability and to set priorities application of QRA is a useful tool to justify choices made with regard to personnel safety, environmental protection, asset damage and business reputation, it is recommended to apply the systematic cause analysis method and develop the risk management models which contains an integral approach toward the health, safety and environmental aspect.

1 INTRODUCTION

An offshore platform is a large structure (floating or fixed) which is used to house workers and machinery needed to drill wells in the ocean bed, extract oil and/or natural gas, process the produced fluids, and ship or pipe them to shore. Based on the geographic location a platform cab is fixed to the ocean floor, can consist of an artificial island, or can be a floating structure. The offshore platforms can be classified based on operating water depths, and the two classifications are shallow water offshore platforms and deep-water offshore platforms. Also, the offshore platforms can be classified based on their objective, and the two classifications are drilling offshore platforms, offshore storage platforms and drilling/storage/offloading platforms. The shallow water offshore platforms can be of two types: fixed offshore platforms and floating offshore platforms. The classification of the offshore platforms is listed in Table 1.1. Until recently, the production economics ensured that most of the offshore platforms were located on the continental shelf at shallow water depths. However, because of drying resources at the shallow water depths and with advances technology and increasing crude oil prices, drilling and production in deeper waters have become both feasible and economically viable. This has given rise to the more interest into the deeper water platforms [1].

In general, an offshore platform can have around 30~50 wellheads that are located on the platform, and directional drilling allows reservoirs to be accessed at both different depths and remote positions up to 10~15km from the platform. The remote subsea wells are connected to the platform by flow lines and by umbilical connections and these subsea solutions consist of single wells or of a manifold centre (i.e. consisting of orbits whose behavior around the equilibrium point is not controlled by either the attraction of the stable manifold or the repulsion of the unstable manifold) for multiple wells [2].

1.2. Offshore structure problems

Engineers in the offshore construction industry must face a multiplicity of risks. Uncertainties are magnified for offshore structures compared to on-land structures owing to the relative severity and unfamiliarity of the ocean environment, the scarcity of data about loads and materials, and the expense of data gathering. In this section a brief review of methods for assessing risks which are primarily technical in nature; that is, risks attributable to either natural or accidental loads, structural materials, or foundation deficiencies. Such risks yield in varying degrees to quantitative treatment and can generally be reduced by engineering effort and appropriate expenditure of funds [3].

The term risk is synonymous with probability of "failure" within a given time period, where "failure" means that the structure, its foundation system, or one of its components reaches a "limit state." The "limit state" may relate to the behavior of the entire structure (e.g., collapse, excessive elastic deformation, excessive permanent deformation); to a structural component (e.g., exceeding yield limit or ultimate strength); or to the foundation (e.g., instability, excessive settlement, excessive differential settlement, or soil liquefaction). Many different approaches to engineering risk assessment for offshore structures are possible, ranging from entirely subjective and implicit risk evaluation to application of formal methods of applied probability. The appropriate level of treatment of uncertainty depends on such factors as the specific purpose of the risk assessment; the type, amount and quality of data available; the degree to which the phenomenon at hand lends itself to probabilistic modeling; and the importance of (and the funds involved in) the decision situation which calls for the risk assessment [4].

2 RISK ASSESSMENT METHODS

2.1 *Choice of Approach*

2.1.1 *Introduction*

The terminology for risk studies is:

- Risk analysis - the estimation of risk from the basic activity "as is".
- Risk assessment - a review as to acceptability of risk based on comparison with risk standards or criteria, and the trial of various risk reduction measures.
- Risk management - the process of selecting appropriate risk reduction measures and implementing them in the on-going management of the activity
- These basic approaches are illustrated in Fig.1. The figure shows that hazard identification (HAZID) is an essential component of all three types of study.

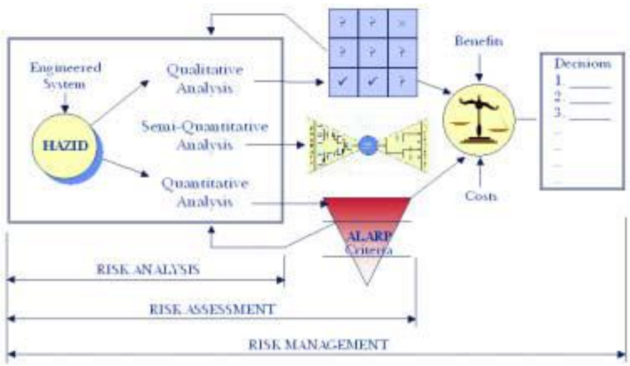

Figure 1. Risk Assessment Approaches

Table 1. Classification of the offshore platforms

Shallow water offshore platforms	Deepwater offshore platform
A. Fixed platforms: Concrete offshore platforms, offshore steel platforms, and concrete-steel Offshore platforms. Operating range: up to 600m. Concrete-steel offshore platforms: Normally unmanned offshore platforms and Offshore conductor platforms (offshore satellite platforms). Operating range: up to 500m. B. Floating platforms: Compliant offshore platforms and jack-up offshore platforms. Operating range: 600~1000m.	A. Semi-submersibles: Operating range: 1000~2250m. B. Drill-ships: Operating range: 2250m onwards. C. Tension leg offshore platforms: Operating range: 1000~2000m. D. Spar offshore platforms: Operating range: 1500~2500m. For economic reasons, both semi-submersible and drillship are designed to have capacities for production and storage (for semi-submersible the design capacity is low, but for drillship it is high). Operating range: For drilling and storage at the moderately deeper water, (water depth < 2250m) semi-submersible is and will remain an attractive option. However, for ultra-deepwater (water depth > 3500m) large size drillships will become the more favourable option in future.
Floating offshore production systems: FPSO (floating production, storage, and offloading system) offshore ship, FSO (floating storage and offloading system) offshore ship, and FSU (floating storage unit) offshore ship.	
Shallow water depths: less or equal than 1000m, deep-water depths: more than 1000m.	

CONSEQUENCE					INCREASING PROBABILITY				
Severity Rating	People	Assets	Environ-ment	Reputation	A Rarely occurred in E&P industry	B Happened several times per year in industry	C Has occurred in operating company	D Happened several times per year in operating company	E Happened several times per year in location
0	Zero injury	Zero damage	Zero effect	Zero impact	Manage for continued improvement				
1	Slight injury	Slight damage	Slight effect	Slight impact					
2	Minor injury	Minor damage	Minor effect	Limited impact					
3	Major injury	Local damage	Local effect	Considerable impact					
4	Single fatality	Major damage	Major effect	Major national impact	Incorporate risk reducing measures				
5	Multiple fatalities	Extensive damage	Massive effect	Major international impact				Intolerable	

Figure 2. ISO 17776 Risk Matrix

2.1.2 *Types of Risk Assessment*

Risk assessment can be applied in approaches described as Qualitative, Semi-Quantitative and Quantitative, and the project manager needs to decide which the right approach for the job is. The basic aim is risk reduction and the key test is one of reasonable practicability. In general, qualitative approaches are easiest to apply (least resource demands and least additional skill sets required) but provide the least degree of insight. Conversely quantitative approaches (QRA) are most demanding on resources and skill sets, but potentially deliver the most detailed understanding and provide the best basis if significant expenditure is involved. Semi-quantitative approaches lie in between these extremes. Thus, a coarse hazard identification can support both qualitative and semi-quantitative risk assessments, whereas a detailed hazard identification can support any level of risk assessment [5].

2.2 *Risk Matrix Methods*

Risk matrices provide a traceable framework for explicit consideration of the frequency and consequences of hazards. This may be used to rank them in order of significance, screen out insignificant ones, or evaluate the need for risk reduction of each hazard. A risk matrix uses a matrix dividing the dimensions of frequency (also known as likelihood or probability) and consequence (or severity) into typically 3 to 6 categories. To illustrate this, three different risk matrix approaches are presented below [11].

In each case, a list of hazards is generated by a structured HAZID technique, and each hazard is allocated to a frequency and consequence category according to qualitative criteria. In the terms of this guide, this does not constitute quantification (semi or full) and the technique is still classed as qualitative [13].

2.2.1 *Defense Standard Matrix*

A risk matrix that has been applied to marine activities derives from Defence Standard 00-56 "Safety Management Requirements For Defense Systems Part 1: Requirements" (1996). This sets out a 6 x 4 risk matrix based on frequency and consequence definitions as follows. A more detailed version is also provided in Part 2 of the standard, which applies more to reliability of technical systems .

The severity categories are defined as:

Table 2.

Category	Definition
Catastrophic	Multiple deaths
Critical	A single death; and/or multiple severe injuries or severe occupational illnesses
Marginal	A single severe injury or occupational illness; and/or multiple minor injuries or minor occupational illness
Negligible	At most a single minor injury or minor occupational illness

The frequency categories are defined as:

Table 3.

Accident Frequency	Occurrence (During operational life considering all instances of the system)
Frequent	Likely to be continually experienced
Probable	Likely to occur often
Occasional	Likely to occur several times
Remote	Likely to occur some time
Improbable	Unlikely, but may exceptionally occur
Incredible	Extremely unlikely that the event will occur at all, given the assumptions recorded about the domain and the system

There are four decision classes:

Table 4.

Risk Class	Interpretation
A	Intolerable
B	Undesirable and shall only be accepted when risk reduction is impracticable
C	Tolerable with the endorsement of the Project Safety Review Committee
D	Tolerable with the endorsement of the normal project reviews

The actual risk matrix (with the decision classes shown) is as follows:

Table 5.

	Catastrophic	Critical	Marginal	Negligible
Frequent	A	A	A	B
Probable	A	A	B	C
Occasional	A	B	C	C
Remote	B	C	C	D
Improbable	C	C	D	D
Incredible	C	D	D	D

2.3 *ISO Risk Matrix*

An alternative, more up-to-date approach is given in the draft international standard 17776 (ISO 1999). This provides a 5 x 5-risk matrix with consequence and likelihood categories that are easier for many people to interpret (Figure 2). The ISO 17776 matrix uses four types of consequence category: people, assets, environment, and reputation reflecting current good practice in integrating safety and environmental risk decision-making [14].

The ISO risk matrix uses more factual likelihood terminology ("has occurred in operating

2.4 *Risk Ranking Matrix*

A risk matrix has been proposed for a revision of the IMO Guidelines on FSA (IMO 1997) to assist with hazard ranking. It uses a 7 x 4 matrix, reflecting the greater potential variation for frequencies than for consequences.

The severity index (SI) is defined as:

Table 6.

SI	Severity	Effects on Safety	Effects on Ship	S (Fatalities)
1	Minor	Single or minor injuries	Local equipment damage	0.01
2	Significant	Multiple or severe injuries	Non-severe ship damage	0.1
3	Severe	Single fatality or multiple severe injuries	Severe casualty	1
4	Catastrophic	Multiple Fatalities	Total loss	10

The frequency index (FI) is defined as:

Table 7.

FI	Frequency	Definition	F (per ship year)
7	Frequent	Likely to occur once per month on one ship	10
5	Reasonably probable	Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur several times during a ship's life	0.1
3	Remote	Likely to occur once per year in a fleet of 1000 of ships, i.e. 10% chance of occurring in the life of 4 similar ships	10^{-3}
1	Extremely remote	Likely to occur once in 100 years in a fleet of 1000 ships, i.e. 1% chance of occurring in the life of 40 similar ships	10^{-5}

Intermediate indices may be chosen if appropriate. Non-integer values may be used if data that is more specific is available. If risk is represented by the product frequency x consequence, then an index of log (risk) can be obtained by adding the frequency and severity indices. This gives a risk index (RI) defined as:

RI = FI + SI

E.g., an event rated "remote" (FI=3) with severity "moderate" (SI=2) would have RI=5. The risk matrix is as follows (risk indices in bold):

Table 8.

FI	Frequency	Severity (SI) 1 Minor	2 Moderate	3 Serious	4 Catastrophic
7	Frequent	8	9	10	11
6		7	8	9	10
5	Reasonably probable	6	7	8	9
4		5	6	7	8
3	Remote	4	5	6	7
2		3	4	5	6
1	Extremely remote	2	3	4	5

The risk index may be used to rank the hazards in order of priority for risk reduction effort. In general, risk reduction options affecting hazards with higher RI are considered most desirable [15].

3 CONDUCTING A RISK ASSESSMENT

3.1 *Selection of Risk Assessment Approach*

It is prudent that the selection of risk assessment approach reflects the technical and operational challenges that the facilities are faced with ISO standard 17776 (ISO 1999) suggests four levels of approach to risk assessment:

– Experience/judgement
– Checklists
– Codes/standards
– Structured review techniques.

These approaches are listed in order of complexity, implying that experience and judgement may be sufficient for very simple facilities, whereas structured review techniques (including risk analysis studies) are supposed to be used for the complex facilities and operations. This book only addresses the structured review techniques, whereas the ISO17776 standard addresses the top three approaches mainly. In selecting the appropriate risk assessment tools and techniques, the nature and scale of the installation [6].

3.2 *Quantitative or Qualitative Risk Assessment?*

The purpose of risk assessment is primarily to decide on risk reducing measures in the context of a structured, systematic, and documented process. The documentation requirements for the safety case under UK legislation are in this respect the most explicit, when they require documentation of the outcome of the decision making process for risk reduction measures based on a risk assessment.

This overall purpose is often forgotten, in the sense that companies may think that the purpose of risk assessment is to document that the risk level is tolerable. Even worse, a risk assessment may sometimes be conducted in order to demonstrate that it is acceptable to deviate from regulatory requirements or common industry practice. This is what is referred to as 'misuse of risk analysis'. The next question is to what extent the risk assessment needs to be quantitative. This question is very often repeated, it is sometimes argued that qualitative risk assessment is better, because the numbers are often rather uncertain [7].

The majority's opinion is further that quantification improves the precision when a study is carried out. A qualitative study will discuss various factors, but will often not perform a detailed trade-off between the factors. When quantification is needed, such a trade-off is needed as part of the quantification, and a more precise answer is produced. The approach in ISO17776 is thus fundamentally wrong in many cases, as quantification should be used in the majority of projects, not as the least alternative as the ISO17776 suggests. The proper attention to evaluation of uncertainty and evaluation of model sensitivity is extremely crucial in quantitative studies [8].

Some risk assessments are used in order to establish design accidental loads, such as the structural resistance to impact and/or hat loads. It is not possible to understand how qualitative risk assessments can be used in such cases. However, it should also be realised that there are some examples of use of quantitative risk assessments that are as far from trustworthy as more or less possible. One final overall aspect of quantification may be added; the best use of such studies is often to use ''quantitative studies in a qualitative manner''. Put differently, the quantification is not the goal itself, but just a means to achieve better decision-making [9].

3.3 *Risk Assessment Approach*

There has been considerable focus in the past few years on models for risk assessment in various industries, not the least the offshore oil and gas industry. The most commonly used approach is the ISO31000 standard: Risk management, principles and guidelines on implementation (ISO 2009). The same approach has also been adopted in the NORSOK Z-013 standard: Risk and emergency preparedness analysis (Standard Norway 2010). The same approach is also adopted by the petroleum regulations in Norway, issued by PSA. The main elements of the model for risk assessment according to ISO31000 are presented in Fig. 3 [10].

The core of the process, in the yellow box, is consistent with common practice for many years, in the offshore petroleum industry. The elements outside this core are new elements; establishing the context, monitoring and review as well as communication and consultation. The ISO17776 standard (ISO 1999) is not at all consistent with ISO31000, and for several years, it has been completely overlooked. The most extensive and explicit standard for offshore risk assessment is NORSOK Z-013. There is an ongoing effort to revise ISO17776. The outcome of this work is unknown, and this book is based on the current contents of the relevant standards, not what may be the result of a log process with uncertain outcome. Each of the main elements of this process is outlined in Sects. 6.4–6.10 [12].

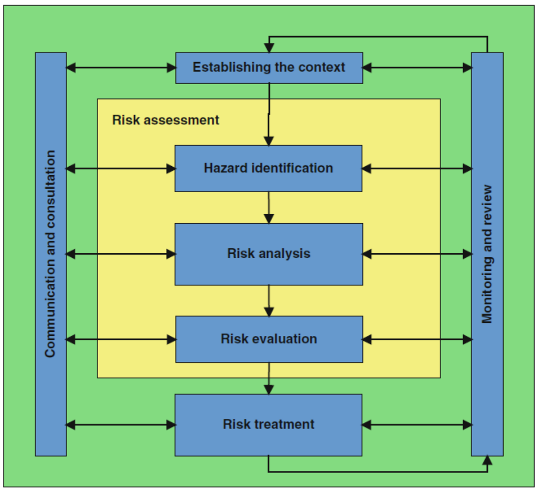

Figure 3. Risk assessment process according to ISO31000

4 CASE STUDY

All data used in the matrix is from the Accidents from 1970 to 2007 Worldwide

Table 9. Data for risk matrix from 1980 to 2012

ID	Event	Repetition	Fatalities count
BL	Blowout	2	13
CL	Collision	15	0
CN	Contact	23	0
CR	Crane accident	476	45
EX	Explosion	7	0
FA	Falling Load	266	23
FI	Fire	163	1
HE	Helicopter accident	1	0
LE	Leakage	1	0
LG	Spill/release	1171	26
TO	Towing accident	47	1
ST	Structural damage	3	0
WP	Well problem	170	1

	Catastrophic	Critical	Marginal	Negligible
Frequent	CR LG FA			WP FI
Probable			BL	
Occasional				CN TO CL
Remote				EX
Improbable				HE LE ST

Defense Risk Class	Interpretation
A	Intolerable
B	Undesirable and shall only be accepted when risk reduction is impracticable
C	Tolerable with the endorsement of the Project Safety Review Committee
D	Tolerable with the endorsement of the normal project reviews

4.1 *Recommendations*

All major company must engage in collaborative effort to guaranty all possible risks, their causes and impacts on offshore platforms are effectively identified and properly recorded.

There must be proper guarantees for researchers to have access to the above-mentioned records in order to facilitate safety and decision-making.

Operators are to further establish more acceptable ways of improving management of safety information in conjunction with regulatory bodies and researchers.

The major company within the industry and regulatory agencies need to have better collaboration and corporation and come up with programme design to attract researchers to participate in efforts to achieve a more efficient safety management.

This programme may also involve enforcement agencies to ensure that researchers have some level of unrestricted and timely access to industry safety data for research purposes.

The operators need to create an enabling environment to guarantee improved data management as well as access to such information for research purposes.

Risk information still require further efforts by both the operators and regulators in order to achieve harmonies system of recording safety and other related information for the industry. This will be achieved if all the major company including regulatory agencies must to be involved in kind of joint-partnership for the purpose of establishing necessary programme specifically for this.

Researchers require solid support from the industry regulators to guarantee them the right to preserve the independence of their findings.

Inherent risks remain major impediments to the safety of offshore oil and gas industry. Therefore, the need to increase efforts towards mitigation of these safety challenges must be accorded high priority and all the major industry company must remain committed and support these efforts in order to achieve improved safety within the industry.

5 CONCLUSIONS AND RECOMMENDATIONS

The risks generated from normal operation of offshore facility shall be adequately identified and controlled by a standard Formal Safety Assessment. For this purpose, risk assessment methods are carried out to assess the different parameter of risk exposed to facility personnel. Individual and societal risks are identified, quantified and compared to acceptance criteria to ensure all risk exposed are identified and control within As Low As Reasonably Practicable (ALARP) level. It is shown that the main increase in risk is from immediate effects. This is mitigated by leak and fire detection, isolation, blowdown or control of ignition sources. Besides, the PFP should be provided to avoid the potential domino effects from ignited events.

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