INTERNATIONAL JOURNAL OF
COASTAL, OFFSHORE & ENVIRONMENTAL ENGINEERING
IJCOE Vol.7/No. 2/Spring 2022 (24-30)

Available online at: www. Ijcoe.org

Risk Assessment of Fixed Offshore Jacket Platforms: A Persian Gulf Case Study

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ARTICLE INFO

Article History:
Received: 29 Dec. 2021
Accepted: 25 May. 2022

Keywords:
Risk Assessment
Structural Integrity Management
Fixed Offshore Jacket Platform
Vulnerability
Consequence of Failure

ABSTRACT

Offshore platforms are among important structures whose performance during their life-time and beyond is of significant importance. One of the approaches for ensuring a platform's fitness-for-purpose condition is the structural integrity management system. In this process, a wide range of risk assessment approaches can be carried out to investigate the platforms' performance. These assessments are divided into qualitative, semi-quantitative and quantitative methods, whose outcome is the risk level of the structure under investigation. By obtaining the risk level, the condition of the platform can be surveyed and certain actions can be defined to ensure that the platform remains fit-for-purpose. In this study, a fixed offshore jacket platform located in the phase 19 of the South Pars gas field in the Persian Gulf is investigated using a semi-quantitative risk assessment method. Based on certain assumptions, the risk level obtained for this platform can be categorized as intermediate. By knowing the risk level, risk mitigation actions can be carried out and inspection intervals can be defined.

1. Introduction

The oil and gas industry is among the important industries that has always faced significant challenges. This industry provides a huge amount of energy needed in the world and a significant part of it is in offshore areas. Therefore, this industry has always been accompanied by continuous developments in technology and related advances in dealing with hazards such as explosions, fire, hurricanes, etc., along with facing other issues such as modern exploitation needs.

Offshore platforms are considered as important structures in the oil and gas industry, which are divided into different types; including fixed and floating [1]. Due to the significant importance of these structures, extensive research has been done on their various aspects. These include examining their behavior [2, 3], analyzing their response and the dynamic behavior of their components [4], and investigating different aspects of reliability analysis applied to them [5, 6].

Fixed jacket platforms have been considered as one of the most common offshore platforms in the oil and gas industry around the world since the mid-19th century. Since the maintenance of existing platforms is economically more cost-effective than establishing a new platform in the region, it is tried to extend the operational life of these platforms even beyond their original design life. Therefore, the use of appropriate methods for continuous evaluation and inspection of these platforms during their lifetime and even beyond that is of particular importance [7].

In recent decades, several researchers have reviewed and evaluated fixed jacket platforms in different regions according to methods based on platform reliability and risk level. In 2002, Stacey et al. [8] reviewed and evaluated fixed offshore platforms in the waters around the UK and surrounding areas. Connor et al. in 2005 and 2006 [7, 9, 10] reviewed the risk-based structural integrity management of offshore oil rigs and performed some case studies on structures in the Gulf of Mexico and elsewhere. In addition, they mentioned factors such as structural ultimate limit state (ULS) analysis and reserve strength ratio (*RSR*), along with explanations of the first version of the API

(American petroleum institute) code for managing the integrity of structures. It should be noted that the structural integrity management system is a complete process to ensure that a structure is fit-for-purpose during its operational life, which consists of four main elements called data collection, evaluation, strategy and planning, and finally, execution of the program [11]. In another study, Aeran et al. [12] examined a jacket platform in the Gulf of Suez in the Red Sea. In Guede's research in 2019 [13], a comprehensive explanation of various qualitative and quantitative methods was provided to assess the level of risk of fixed platforms and apply structural integrity management system on them. In addition, a group of ten platforms with different specifications and functions were selected in this article, and after the relevant studies and analyses, the platform that was in the most critical condition was selected to continue the study and assess the relevant risk.

Petropars Iranian Company was established in 1997 and since then, various phases in the huge South Pars gas field, located 100 km off the coast of Iran in the Persian Gulf, have been established by this company and its reputable partner internationally established companies. This company is now one of the most reputable exploration and production companies in Iran [14]. The development plan for phase 19 of the South Pars gas field was handed over to Petropars Company in 2010. Drilling in this phase began in 2012 and was completed in 2015. The official inauguration of the South Pars Phase 19 development project also took place in 2017. This phase includes a total of 4 offshore platforms and 21 wells.

Due to the significant importance of the Persian Gulf region and its resources, the use of appropriate management systems to control and monitor various operations such as drilling, production, etc., should be dealt with special care. One of the important issues in this field is the evaluation of existing platforms and one of the primary methods to do so is to determine the risk of a platform’s collapse. For this purpose, it is necessary to consider the vulnerability of the structure and the consequence of its failure.

One of the useful sources used in this area is the guideline provided for the evaluation of offshore jacket platforms in the North Sea; the TPM guideline [15]. According to this manual and the framework proposed therein, the vulnerability and the consequence of failure of structures are calculated using semi-quantitative methods and based on them, the risk level of the desired platform is determined. In this paper, the mentioned instructions have been applied on one of the platforms in phase 19 of the South Pars gas field and based on this approach, the risk level of the platform is determined.

2. Materials and methods

The history of the structural integrity management system dates back to the 1940s. At this time, in order to design fixed offshore platforms in shallow water, the member-based design approach was used, which also had a good performance. In fact, operating experience has shown that well-maintained platforms were durable and stable, even beyond what the member-based design approach showed. However, after the lifespan of the platforms ended, it was required to use and exploit them even beyond the specified lifespan. Therefore, the need to use appropriate approaches to this goal became more apparent [16].

For this reason, in the early 1970s, it became necessary for engineers to develop a new approach as an alternative to the member-based design controls to ensure that their intended platform continued to function in accordance with its purpose while it was safe to use. As a result, new maintenance guidelines and evaluation processes have been put in place to make better use of the full capacity of offshore structures [16].

The assessment guidelines developed in this field used a risk-based approach. This approach considers the likelihood of platform failure along with the consequence of failure, which includes three main components; namely, environmental, economic, and life safety consequences. Then, the platforms are categorized according to their risk level (e.g. high, intermediate, and low). Over time, considerable progress has been made in the capabilities of the oil and gas industry in general, and the technologies needed to achieve sufficient confidence in the reliability of various valuation methods have been developed. This led to a better and more appropriate understanding of platforms’ behavior in severe offshore environmental conditions and a better ability to describe performance during structural service [16].

As more advanced technologies and methods have emerged, the need to use the structural integrity management system for offshore structures became more and more obvious, and several instructions and regulations were created for this purpose. Examples of these regulations include the US Petroleum Institute Structural Integrity Management Regulations [11], the International Standard ISO 19902 [17] and the Norwegian Regulations [18]. According to these guidelines, the structural integrity management system is divided into 4 main stages called data collection, structural evaluation, strategy and planning, and finally, program implementation. It should be noted that this process is basically a cycle and after the final stage, which is implementation of the program, new data is entered into the system and this process is repeated to ensure the fitness-for-purpose of a platform.

One of the main elements of the structural integrity management system is the calculation of the level of risk of a structure. Knowing this, it is possible to take the necessary measures to reduce this level, if necessary, or, to determine the required inspection period as well as defining its scope and details. In general, there are several methods for calculating the level of risk, which are divided into qualitative, semi-quantitative, and fully quantitative methods. In this research, the general process of calculating the level of structural risk based on the TPM guideline [15], which is based on semi-quantitative methods, is described.

According to the TPM guideline, a risk matrix, which is a 5×5 matrix, can be used to achieve a relative rather than absolute risk level. A general example of this matrix is shown in Figure 1.

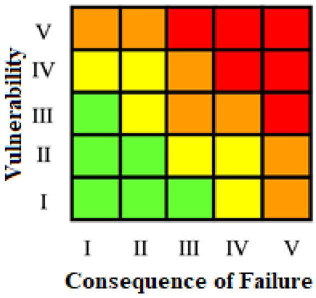


Figure 1. A sample 5×5 risk matrix

As shown in Figure 1, the formation of the risk matrix requires two main components, which are the vulnerability of the structure and the consequence of its failure. The latter one is divided into safety, environmental and economic consequences. In order to determine the level of these components, platform's characteristics such as number of legs, bracing system, and function of the structure are required. In the following, both components of risk matrix are described separately.

In the assessment of the vulnerability of the structure, the specific and generic characteristics of the structure are considered. Specific features of the structure include its position, the number of braces, and its reserve strength ratio (*RSR*). This quantity actually represents the ratio of the base shear of an undamaged structure at the time of collapse ($BS_{ult\_undamaged}$) to the design base shear (BS_{design}). In other words,

$$RSR = \frac{BS_{ult\_undamaged}}{BS_{design}} \tag{1}$$

The generic characteristics of a structure are basically the degree of redundancy provided by different bracing systems and how they affect the reliability of the structure. The degree of redundancy can be expressed using the residual resistance factor (*RRF*) obtained for generic bracing systems based on their type. This factor is actually the ratio of the base shear of the damaged structure at the time of collapse to the base shear of the undamaged structure at the time of collapse. In other words,

$$RRF = \frac{DSR}{RSR} \tag{2}$$

in which, *DSR* indicates the ratio of reserved strength in the damaged state. It is actually the ratio of the base shear of the damaged structure at the time of collapse ($BS_{ult\_damaged}$) to the design base shear. It means,

$$DSR = \frac{BS_{ult\_damaged}}{BS_{design}} \tag{3}$$

As mentioned, the *RRF* value actually indicates the degree of redundancy of a structure, and by using the *RRF* distribution of different generic bracing systems (shown in Figure 2), the degree of redundancy and robustness of the bracing system can be determined. Of course, it should be noted that the *DSR* and *RSR* values are related to the specific characteristics of each structure and the use of the obtained distributions for a generic structure cannot fully and realistically indicate the state of a particular structure. However, this method can be used for initial evaluation and assessment purposes.

As shown in Figure 2, 5 types of generic bracing systems are considered in the TPM guideline; namely, single diagonal, inversed K, K, X, and diamond shapes. It should be noted that a structure can have a combination of the mentioned bracing systems, thus making the use of engineering judgment to determine the governing bracing system behavior of the structure an important matter.

In the vulnerability assessment, after determining the type of structural bracing system, the corresponding *RRF* values can be obtained using log-normal distributions and the corresponding $RRF_{limiting}$ value is calculated. This value actually represents an estimate of the amount of *RRF* that indicates damage to the most critical member, i.e. the member whose damaged condition would have the greatest effect on the strength of the structure. The *RSR* of the structure is calculated by performing nonlinear static (pushover) analysis using the SACS software, which is based on finite element formulation for structural analysis. Now, given the two values of *RSR* and $RRF_{limiting}$, the value of $DSR_{limiting}$ is obtained using Eq. (2). Then, using the long-term load distribution (LTLD), the storm return period associated with the $DSR_{limiting}$ value is obtained. In fact, LTLD represents a linear-logarithmic relationship between the ratio of the storm wave return period to the design wave return period. This distribution basically represents the annual probability of a storm event beyond a given load *E*, which in this case is equal to the $DSR_{limiting}$ value. This probability is indicated by $P_{damaged}$ and is equal to:

$$P_{damaged} = A \exp\left(\frac{-E}{E_0}\right) \tag{4}$$

where the coefficients *A* and E_0 represent constants that are determined depending on the region under study. It should be noted that Eq. (4) is only valid when $E > 0.8$

. After calculating the value of $P_{damaged}$ and determining the probability of the critical member failure (P_{sever}), which is obtained based on the previous data from the damaged members on different platforms over previous decades, the vulnerability of the structure (P_f) can be calculated:

$$P_f = P_{damaged} . P_{sever} \tag{5}$$

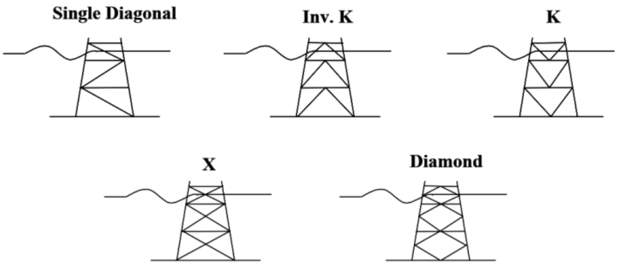


Figure 2. Generic bracing systems

The second component required for the structural risk assessment, according to the TPM guideline, is the consequence of structural failure. In general, this component is examined according to three aspects; namely, the life safety, the environment and the economic consequences. In the developed model, a scoring process is used to evaluate the overall consequence of failure rating. In this approach, which is in fact a semi-quantitative method, using the score assigned to each of the factors affecting the consequence of failure, as well as the weight assigned to each of these factors, according to the intensity of their impact and assigned importance, a value that indicates the rating of the consequence is obtained:

$$CR = 0.6SR + 0.3ER + 0.1BR \tag{6}$$

In Eq. (6), the *CR* parameter represents the overall score of the consequence of failure, and each of the parameters *SR*, *ER*, and *BR*, represent the scores of life safety, environmental, and economic factors, respectively. Since the life safety factor is more important than the other two factors, the weight considered for the effect of this factor is also higher. Each of these factors is essentially equal to the sum of its related indices listed in the relevant tables in the TPM guideline [15]. Depending on the use of the platform, whether it is manned or unmanned, and whether it is a satellite platform or it belongs to a group of structures (i.e. hub), the values of these indices are different for each factor.

The other two influential parameters in these factors are the type of hydrocarbon product extracted (i.e. oil or gas) and the percentage of personnel on board on the manned platforms. Obviously, if the platform is permanently manned, this percentage is 100%, but if the considered platform is actually part of a group of facilities connected by several bridges, then an overall estimate is needed to determine the percentage of personnel on board on each of the platforms and equipment in this complex.

Finally, after determining each of the indices in addition to considering all of the effective parameters, the value of each of the relevant factors is obtained. Then, by using them in Eq. (5) and applying the relevant weights, the rating of the consequence of failure is obtained.

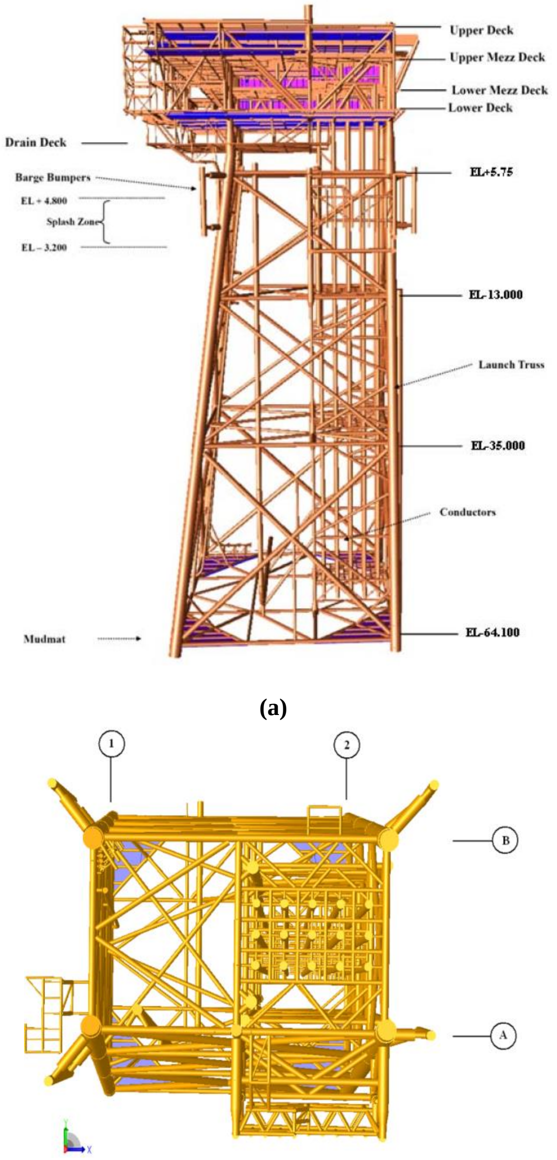
After assessing the two components of the risk matrix; namely, the vulnerability and the consequence of failure, according to the risk matrix shown in Figure 1 and the classifications presented in Table 1 for both components, the risk level of the considered structure can be determined.

Table 1. Categorization of vulnerability and consequence of failure based on TPM guideline [15]

Vulnerability		**Consequence of failure**	
Value	**Group**	**Value**	**Group**
$\leq 1\times10^{-10}$	I	≤ 10	I
$\leq 1\times10^{-8}$	II	≤ 20	II
$\leq 1\times10^{-6}$	III	≤ 30	III
$\leq 1\times10^{-4}$	IV	≤ 40	IV
$> 1\times10^{-4}$	V	> 40	V

In the risk matrix, the lowest left corner represents the lowest risk level and by moving higher to the right side of the matrix, higher risk levels are determined, which represent more critical conditions.

The fixed jacket platform considered in this research belongs to phase 19 of the South Pars gas field, which has four legs and grouted piles. This platform is located at a water depth of approximately 65.7 meters. The total height of the platform is equal to 91.95 meters. The upper part of this platform, with approximate dimensions equal to 32.5 by 27.516 square meters, consists of an upper deck, an upper mezzanine deck, a lower mezzanine deck, a lower deck and a drain deck. This wellhead platform is not manned and its appurtenances include bumpers on all four legs and a boat landing on one of its rows. This platform is basically one of the three platforms in phase 19, which is equipped with minimal production equipment and is connected to other equipment by bridges and therefore, it is not a satellite platform. The general shape of this platform is shown in Figure 3.



(a)

(b)

Figure 3. The fixed jacket platform under study (a) side view (b) top view

3. Results and discussions

The pushover analysis is performed using the SACS software and the *RSR* values of the platform in eight directions, as shown in Figure 4, are calculated under the extreme environmental load condition. The platform's *RSR* is actually equal to the minimum value calculated in the eight directions (most critical state), which is equal to 1.6 according to Table 2.

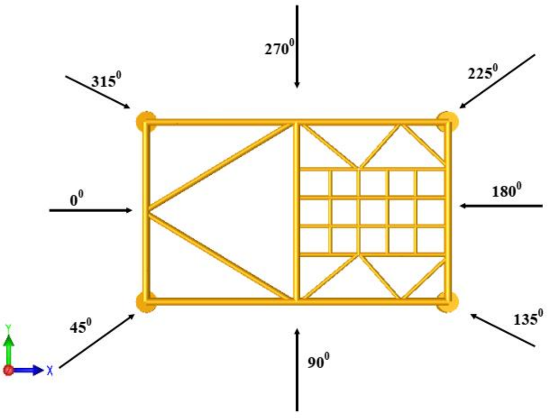


Figure 4. The eight directions for the calculation of *RSR*

Table. 2. The *RSR* values obtained in eight directions

Direction	*RSR*
0°	1.7
45°	1.7
90°	2.2
135°	2.3
180°	1.7
225°	1.6
270°	1.8
315°	2.4

According to the TPM guideline and the value of the *RRF* calculated in this guideline for sample platforms, and by matching the platform studied in this research to the most similar sample platform in terms of its specifications, its *RRF* value is estimated to be 0.9084. After obtaining the values of *RSR* and *RRF*, using Eq. (2), the *DSR* value of the structure, which is equal to the parameter *E* in Eq. (4), is calculated to be 1.4534. It should be mentioned that due to the lack of available data and proper investigation, the constant coefficients *A* and E_0 have been assumed to be equal to what is considered for the northern part of the North Sea, i.e. the values of 13.09 and 0.139, respectively. It's clear that finding the appropriate values of these parameters for the Persian Gulf region would lead to more accurate results. Finally, the value of $P_{damaged}$ according to Eq. (4) for the desired platform is equal to 3.766×10^{-4}.

To determine the value of P_{sever} in accordance with what is stated in the TPM guideline, the inspection programs are assumed to be performed every 3 years, and since the platform under study was designed after 1991, the annual probability of member failure per platform year, which is the price coefficient, is estimated to be 0.004. Therefore, P_{sever} is equal to 0.012.

Now, having $P_{damaged}$ and P_{sever}, the value of P_f, according to Eq. (5), is equal to 4.519×10^{-6}. Thus, based on Table 1, the vulnerability level of this platform belongs to group IV.

To calculate the other component of the risk matrix, which is the rating of the consequence of failure, the relevant scores for each of the life safety, environmental and economic factors are extracted according to the tables in the TPM guideline and finally, using Eq. (6), the final score of the consequence of failure is calculated. Table 3 provides the information required for this process and in Table 4, the calculation of this score and its final value is given.

Table 3. The required information about the platform under study for obtaining the score of consequence of failure

Description	
Wellhead	✓
Drilling	✓
Utilities	✓
Quarters	✗
Compression / Production	✓
Export	✓
Function	✗
Manned	✗
Personnel on Board	-
Satellite	✓
Hub	✗

Table 4. The calculation of the score of the consequence of failure of the platform under investigation

Factor	Value
Life safety (*SR*)	12
Environment (*ER*)	14
Economy (*BR*)	31
Consequence of failure (*CR*)	14

As seen in Table 4, the score of the consequence of failure of the platform under study is 14. Therefore, based on Table 1, this platform belongs to group II in terms of the consequence of failure.

By knowing the group of both components of the risk matrix, the risk level of the structure is determined. Figure 5 shows the risk level of the platform under study in this paper.

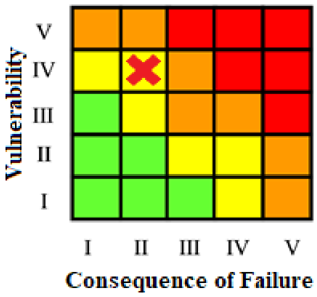


Fig. 5. The risk level of the platform under investigation

By knowing the level of risk of the structure, it is possible to define the required inspection scope and risk mitigation actions to ensure that the platform remains fit-for-purpose.

4. Conclusions

In this study, a semi-quantitative risk-based assessment method, which is one of the main elements of the structural integrity management system to assess the fitness-for-purpose condition of a structure during its life of operation, was applied on one of the fixed offshore jacket platforms in the Persian Gulf. The platform under study belongs to phase 19 of the South Pars gas field, which has four legs and grouted piles.

The method of calculating the risk level was based on the TPM guideline, according to which, using a 5×5 risk matrix that has two main components of vulnerability and consequence of failure, the structural risk level could be determined. Based on the assumptions and calculations, the risk level of the platform was obtained as moderate level, which can be used to take the necessary measures to reduce the risk level or, to determine the required inspection scope and intervals.

As mentioned throughout the text, the results of this study have been obtained using a series of assumptions due to the lack of a series of necessary information, and the purpose of this study was simply to apply the method in the TPM guideline to the platform under study. Obviously, more accurate results can be deduced by using more detailed studies and reducing these assumptions.

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