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Effect of elevational and member damage on jacket strength: Sensitivity and reliability review of South Pars phase-20 jacket, using push-over analysis

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A B S T R A C T

Continuous operation of fixed offshore structures forms one of the most important aspects in the global oil and gas industry. In this paper, functional considerations for damaged fixed offshore platforms were studied through the application of pushover analysis. A case study was used to model non-linear behaviors of the structure, and a three dimensional model of South Pars development phase-20 offshore jacket in the Persian Gulf was simulated using Bentley SACS 5.7 software.

Analysis of an intact offshore jacket was performed to calculate the ultimate base shear as an indicator of the jacket's ultimate strength to compare with the damaged jacket's base shear, this proportion represented as reserve strength ratio and damaged strength ratio, indicated the sensitivity of the platform.

Eighteen scenarios simulated damage to the platform's braces and legs, regard to the eight load combinations used for each case.

Significant behavioral changes caused by damage to the upper-level members rendered the jacket non-operational. Damage to the legs increased damage sensitivity by as much as 4 times more than intact condition. Brace damage due to position increased the sensitivity about 1.4 times, particularly in the direction of lateral loading, to which a damaged brace made its maximum resistance contribution.

1. Introduction

The Iranian offshore oil and gas industry Flourished in early 1960s through the development of the Bahregansar field; this decade can be described as the Persian Gulf fossil fuels' exploitation era. During these years, exploration operations advanced into deeper waters, and other oil fields, such as the Furozan and Esfandiar came into operation.

South Pars is the world's largest gas field in the Persian Gulf, and it is located in the territorial waters of both Iran and Qatar. The National Iranian Oil Company (NIOC) discovered this field in 1990, and it was put into operation in 2001, In the Iranian section, 24 development phases have been defined and 41 wellhead platforms have generated extraction and transportation operations to deliver gas from the sea to onshore facilities. According to the 25-year jacket life-span design, the current jackets have expended more than 15 years of their expected life; therefore, the time is right to begin reliability studies.

For enhanced oil recovery, there is an increased demand to extend the life of platforms and to use damaged offshore platforms, which leads to lower costs, including repair, or the installation of new structures, and the consequently stoppage of oil production (Nichols et al., 2006). However, safety requirements consider that an existing platform should undergo an assessment process if one or more of the following conditions exist: addition of personnel, increased loading on structures or damage is found during routine inspection (Kheiri and Bahaari, 2006).

The safety and integrity of a offshore structure against loads, which initially was acceptable, may not continue to provide satisfactory performance under such damage conditions. Corrosion, fatigue, crack and other damages to the original design may have occurred and decrease the ability of structures to withstand against self and environmental loading. Damage results in decreased safety margins, creating the worst hazard for many of the offshore structures.

Considering importance of damage issues in Persian Gulf, driven from South Pars gas field 13th phase oil tanker accident, back in March 2015 an accident occurred on the SPD13-A Platform. Although at the first jacket still be in place but after few days jacket overturned, Drowned and lying on the seabed, see Fig. 1. Accident did not cause any fatalities or injuries, but challenged knowledge about impact and damage hazard and revealed the needs to considering the damage assessment (Ziyari, 2015).

The current industry practice is to obtain the reserve strength ratio and reliability index using push-over analysis to determine the level of

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Fig. 1. South Pars SPD13-A jacket one day after accident and before collapse.

safety for the jacketed facilities that assist decision making for the continued usage of damaged jacket platforms.

Initialisms		**Variables**	
RSR	reserve strength ratio	M	mass
DSR	damaged strength ratio	C	damping
SDOF	single degree of freedom	Q	force
MDOF	multiple degrees of freedom	V	base shear
SF	safety factor	T	period
		x	displacement vector
		K_e	elastic stiffness
*	equivalent	K_s	hardening stiffness
-	average	ϕ	shape vector
		H	wave Height
		t	wave Period

2. Methodology

2.1. Offshore jackets' reliability

Structural safety is generally assumed to be obtained through designing structures according to established standards and methods. If a building is intended to be used in a damaged condition, a thorough control of the structural safety must be executed.

As the safety of the structure in most cases depends on the structural system strength to withstand against loads, this is an approach to evaluate system strength directly by linear elastic or non-linear elastoplastic analysis, however, non-linear analysis is the most commonly-used method for this type of analysis, typically performed using a non-linear finite element program taking into account nonlinearities in both geometry and material behavior (Ersdal, 2005). Additionally, the quantification of reliability levels for structural elements can be accomplished considering one or more failure criteria, such as ultimate strength, yield strength, and fatigue strength (Ferreira et al., 2005).

Reliability studies originated in the early 1970s with Bea of the Shell Oil Co., who structured reliability analysis into five parts: loading probabilities, resistance probabilities, reliability estimates, value analysis, and design criteria, Shell engineers devised a reliability assessment procedure based on hindcast data and push-over analysis with the help of probabilistic methods in the aftermath of Hurricane Camille in the Gulf of Mexico at 1969 (Bea, 1974). The aim of their study was to obtain comparative reliability indices and failure probabilities through conducting push-over analysis on a jacket platform that experienced the Hurricane Camille loading and an extreme loading from hindcast data. They have concluded that their reliability modeling technique can be confidently applied to the problem of the optimization of design criteria and reassessment (Tromans and van de Graaf, 1994).

Kheiri and Bahaari (2006) with using ABAQUS software performed push-over and nonlinear dynamic analysis for two platforms. Results show that the estimated RSR by nonlinear dynamic analysis was higher than estimated RSR by static push-over analysis method and in both methods local failures occurred before total loss.

Kolios and Brennan (2009) studied the jacket reliability issues, by analyzing those factors which affecting reliability, included corrosion, member capacity deterioration, various wave theories, different surface roughness, material yield strength, different design codes and standards, the stochastic nature of loads and resistance, and the variability in limit states with different analysis methods, such as finite element by SESAM computer software.

Pattaradanai (2010) conducted a sensitivity analysis to calculate RSR for jacket platforms in Thailand's waters. This study examined the effect of varying parameters effects on RSR, followed by regression analysis to obtain the RSR through computation, rather than conducting the lengthy and monotonous push-over analysis.

Azman (2011) assessed effect of the environmental loading changes on the reliability index using two simplified structural reliability analysis method and using Gaussian distribution function as statistical method, the purpose of this study is with comparing the results, validation and efficiency of the methods be evaluated.

Karimi et al. (2015) evaluated the ship impact effects on the South Pars 20th phase jacket. They modeled 8 most likely collation scenarios use push-over analysis conducting SACS software to shown force-displacement diagram due to impact position. Results from one controlled and 2 uncontrolled criterions shown that, although in some scenarios criterion will not passed but in important scenarios such as raiser collision, structure have sufficient strength and stability.

2.2. Non-linear collapse analysis

Static push-over analysis has no rigorous theoretical foundation. It is based on the assumption that the response of a structure can be related to the response of an equivalent single degree of freedom (SDOF) system. This implies that the response is controlled by a single mode and that the shape of this mode remains constant throughout the time history response. Clearly, both assumptions are incorrect, but pilot studies carried out by several investigators (e.g., Saiidi and Sozen, 1981; Fajfar and Fischinger, 1988; Miranda, 1991; and Lawson et al., 1994) have indicated that these assumptions led to rather good predictions of the maximum seismic response of multi degree of freedom (MDOF) structures, provided their response was dominated by a single mode.

The formulation of the equivalent SDOF system is not unique, but the basic assumption common to all approaches is that the deflected shape of the MDOF system can be represented by a shape vector ($\boldsymbol{\phi}$) that characterizes the elastic and inelastic response of the structure. Accepting this assumption and defining the relative displacement vector X of an MDOF system as $\mathbf{X} = \{\boldsymbol{\phi}\}x_t$ (x_t = roof displacement), the governing differential equation of an MDOF system can be written as

$$M\{\varnothing\}\ddot{x}_t + C\{\varnothing\}\dot{x}_t + Q = -M\{1\}\ddot{x}_g \quad (1)$$

where M and C are the mass and damping matrices, $\mathbf{Q}$ denotes the story force vector, and $\ddot{x}_g$ is the ground acceleration. Presuming that the shape vector $\{\boldsymbol{\phi}\}$ is known, the force-deformation characteristics of the equivalent SDOF system can be estimated from the results of a nonlinear incremental static analysis of the MDOF structure, which usually produces a base shear roof displacement (V-δ_t) diagram shown in Fig. 2 by solid lines (Krawinkler, 1996).

Methods typically used for collapse analysis include geometric stiffness and material nonlinearities. Both linear elastic analysis and design and non-linear analysis and design follow the lower bound theorem from the theory of plasticity as the normal design principles for structures. Hence, both the linear and non-linear design and