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Comparison of Reserve Strength Ratio and Capacity Curve Parameters of Offshore Platforms with Distinct Bracing Arrangements

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ABSTRACT:
The phenomenon of corrosion, especially in the Persian Gulf region, is the main cause of the deterioration of offshore platforms, due to the high corrosion of its water. This phenomenon occurs mostly in the area of water spraying, threatening the members of the first floor of the jacket, legs, and piles in this area. In the current study, the effect of bracing arrangement on the Capacity Curve and Reserve Strength Ratio of Fixed-Type Offshore Platforms is investigated. In order to continue the operation of the platform, two modes of robust and damaged structures are considered, while checking the adequacy of the platform capacity based on the allowable values of API RP-2SIM regulations. The platform in question is located in the Persian Gulf, which is modeled on the Open SEES software. In this research, the Nonlinear Pushover Analysis has been used. After validation, the Capacity Curve of the studied platforms is obtained and then their Reserve Strength Ratio is calculated. Results are compared with the criteria in the API-2SIM regulations.

Keywords: Fixed-Type Jacket Structure, Structural Integrity Management, Nonlinear Pushover Analysis, Robust and Damaged Structure, Reserve Strength Ration, Capacity Curve.

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I. INTRODUCTION:

In the Persian Gulf, for the development of the South Pars Gas Field, Fixed-Type Jacket Structures have been used. As the service life of these platforms increases, the structures suffer from damage due to corrosion, impact of vessels, deterioration, and the phenomenon of fatigue and cracks in the joints, which in addition to affecting the structural performance and bearing capacity of the platform, will also affect platform operation. But the damage due to corrosion, is the most important parameter in deterioration of jacket in this area. The members that are more vulnerable to this phenomena are legs, piles and braces in the first floor that are under the influence of water spraying.

Currently, many analytical methods have been proposed to study the nonlinear behavior of offshore platforms, however, no coherent classification has been provided. The process of Structural Integrity Management of structures is a continuous process to express the capacity adequacy of an offshore platform from the time of operation to its decommissioning. This process provides an approach to understanding the impact of deterioration, damage, load changes, and accidental overload [1].

The purpose of this study is to investigate the effect of bracing arrangement on the capacity curve and Reserve Strength Ratio of offshore platforms, in two modes of Robust and Damaged structure. This is used to evaluate the adequacy of platform capacity based on API RP -2SIM and further continue the activity of the platform for the intended user. In this research, for the damaged condition, the damage caused by the corrosion phenomenon for the platform located in the Persian Gulf is investigated in two different bracing arrangements. The limitations of the bracing arrangements are in accordance with the API RP2A regulations. Finally, the effect of damage on the reserve resistance ratio for the two bracing arrangements is studied for a more improved bracing arrangement according to the API regulations.

The influential factors that lead us to use the process of Structural Integrity Management, with the examination of the methods of damage detection in fixed offshore platforms in the Persian Gulf region are as follows [2]:

- At present, many analytical methods have been proposed to study the nonlinear behavior of offshore platforms, but no coherent classification has been provided. The process of Structural Integrity Management has the ability to help.
- Various methods for determining the type of damage have not been examined in the country's bylaws and instructions. In the process of Structural Integrity Management, these methods will be applied and implemented accurately and systematically.
- At present, inspection methods and maintenance systems fail without identifying identified patterns. For this reason, implementing preventive repairs and predicting platform failure is virtually impossible.

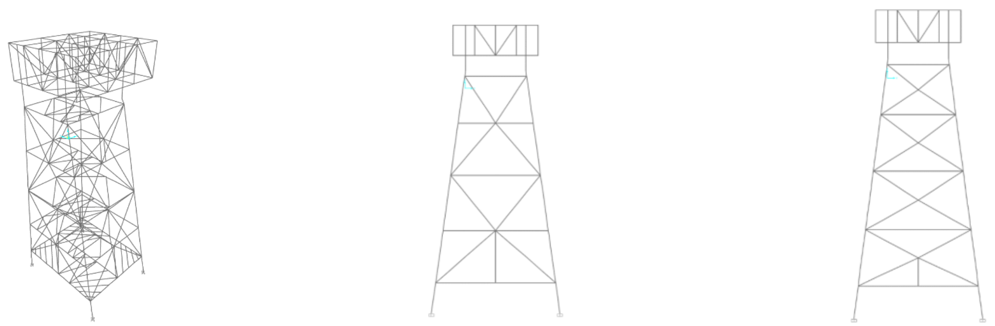
Table 1 shows the minimum acceptable criterion for the resistance ratio according to the API RP-2SIM regulations.

Table 1- Evaluation performance criteria based on the level of importance of the platform and the Reserve Strength Ratio[3]

Exposure Category	Reserve Strength Ratio	
	Before Edition 20^{th} of API RP-2A	After Edition 20^{th} of API RP-2A
L1	1.2	1.6
L2	0.8	1.2
L3	0.6	1.0

Modeling:

The platform under study is a fixed offshore platform of the four-legged jacket type, which is located in the waters of the Persian Gulf in the South Pars region. Due to the use of self-lifting drilling rig, the legs of the platform are on one side with a one-way slope and on the other side with a two-way slope. Figure 1 shows a three-dimensional view of the platform in question and one of its frames.



a. Three-dimensional view of the platform under study

b. View of one of the main frames of the platform and bracing arrangement No. 1

c. View of one of the main frames of the platform and bracing arrangement No. 2

Figure 1- Three-dimensional view of the platform and one of its frames

The structure of the offshore platform jacket is composed of steel members with clamped joints. The platform deck beams are of I sections and the other members in the platform are tubular sections. In jacket platforms, the piles are used as foundations, therefore, the piles will be placed inside the bases to a certain height. In the present study, it is assumed that there are piles along all the pillars and the distance between the piles and the platform pillars is filled with cement slurry. Table 2 gives the general specifications of the platform:

Table 2- General specifications of the platform

Overall height of the platform from the seabed (meters)	93.5 meter
Dimensions of deck plan- levels 12+ and 23+ meters	27.5*32.5
Dimensions of the first level plan of the jacket in 4.5 + meters	20*24
Slope of legs	1:8
Water depth in the study area	70.5
Deck weight (ton)	2300

Jacket weight (ton)	1800

The equivalent beam method has been used for simplicity in the modeling process with high accuracy. In this equivalent method, to model the pile-soil-structure interaction, the piles are modeled in a special depth called the entrapment depth. In the present study, it is assumed that the first layer of soil under the seabed (15 to 20 m) is soft clay that gradually hardens, which is an acceptable assumption for the Persian Gulf region. The Davisson & Robinson relation has been used to calculate the length of the pile grip [4].

According to the API-RP-2A guidelines, local buckling is basically unlikely at D / t less than and equal to 60 [5]. Due to this issue, in the studied offshore platform based on the characteristics of sections that all have a D / t less than 60, it is not necessary to study the local buckling phenomenon.

Lateral Loading Pattern:

In Nonlinear Pushover Analysis, choosing the right loading pattern is very important in obtaining the correct results. The importance is estimated to be more critical than the precise determination of the displacement of the target.[5]

In the case of offshore platforms, since the predominant force in most cases is the force due to the waves (as opposed to the force due to the earthquake), in this study, the lateral loading is due to the wave load. Therefore, to determine the load pattern for folder analysis, we must pay attention to the wave load pattern on the platform.

The governing relation for calculating the force due to waves on thin and cylindrical structures such as offshore platforms is Morrison (1950).

$$F = \rho C_M A a_w + \frac{1}{2}\rho C_D |v| v d \quad (1)$$

According to the recommendation of API RP2A regulations, for drag and inertia coefficients, the values of 0.6 and 1.5, respectively, for smooth cylinders and the values of 1 and 2, for rough cylinders, can be considered [6].

To calculate the base shear due to the wave, it is necessary to extract the diameter and length of all the members, as well as the velocity and acceleration distribution of the wave particles in the water depth. All members of the platform jacket are affected by the wave force at all levels, including the bases, horizontal and vertical braces; However, the deck members are not affected by the wave force due to the wave height and the height of the deck from the free surface of the water.

Table 3- Wave-induced base shear of the two studied platforms in two directions

Jacket Number	**Jacket #1**	**Jacket #2**
Direction	F_T(kN)	**F_T(kN)**
X	6173	**6891**
Y	4649	**5184**

Approach for modeling the corrosion phenomenon:

Initially, a number of members were selected for each structural member (vertical braces, horizontal braces, and jacket bases) that were prone to corrosion damage. For the members selected to model the corrosion phenomenon, at each stage of the damaged analysis, the thickness of the member is determined according to the percentage of damage and this amount is applied in the OpenSEES. On the other hand, due to the nature of the corrosion phenomenon, it can be interpreted that this damage can also affect the characteristics of steel materials. To consider this effect, this phenomenon has been applied to the OpenSEES at each stage of damage analysis by changing the modulus of elasticity of the corroded members.

Considering that the phenomenon of corrosion affects the members of the platform over time, to take into account this time course, damage analysis was performed in three stages. In the first stage, the corrosion rate was 30%, in the second stage, 60%, and in the last stage, it led to complete rupture of the injured limb. It is important to note that in Appendix software, a convergence error occurs if a completely corroded member is lost that has lost its structural function. To solve this problem, in the last stage of damage analysis, a limit state was considered for the characteristics of corrupted members so that without removing them, the rupture of these members could be done correctly in the software. In Figure 2, the members selected to apply the corrosion phenomenon can be seen. For each group of members there is an element to inflict damage.

b a

Figure 2- Selected members for corrosion modeling

II. RESULT AND DISCUSSION:

According to the diagram in Figure 3, the capacity curve in the X direction is higher than the capacity curve in the Y direction. This was quite predictable given the greater stiffness in the X direction. Of course, it should also be noted that the maximum wave height with a 100-year return period in the X direction is a higher number than in the Y direction; That is why the platform is designed in a stronger X direction. The studied platform has continued to work in both X and Y directions in a healthy condition without any of its main members, especially the piles and legs, breaking, and from its maximum capacity to Optimally used syntax.

Capacity Curve and Reserve Strength Ratio of platforms in Robust condition

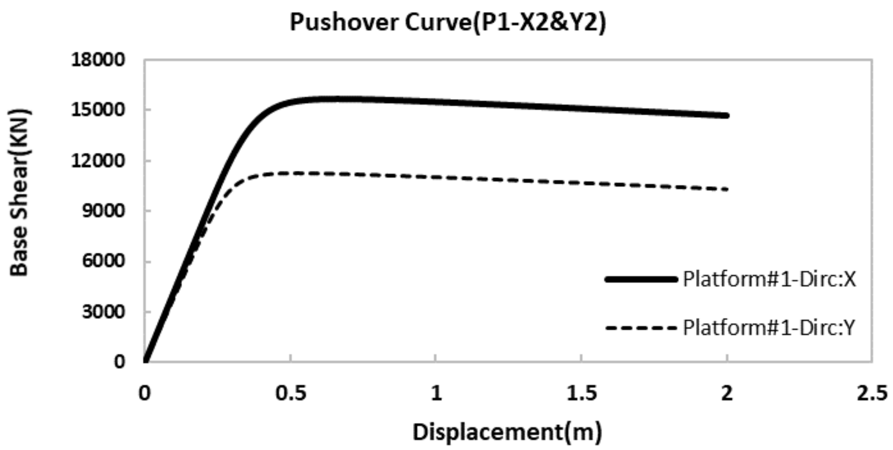


Figure 3-Capacity Curve Platform 1-Robust Structure

Figure 4 shows the capacity curve of platform number 2 in both X and Y directions simultaneously. By comparing the diagrams in Figure 3 and Figure 4, the behavior of platform number 2 is very similar to the behavior of platform number 1. The difference in the obtained values, which is between 10 to 15 percent difference, is due to the difference in the arrangement of the braces. In platform number 2, unlike platform number 1, after entering the nonlinear region, the slope of the graph is almost horizontal for both directions; This means that the decline of the platform in this case is much slower than platform number 1, and this is an advantage.

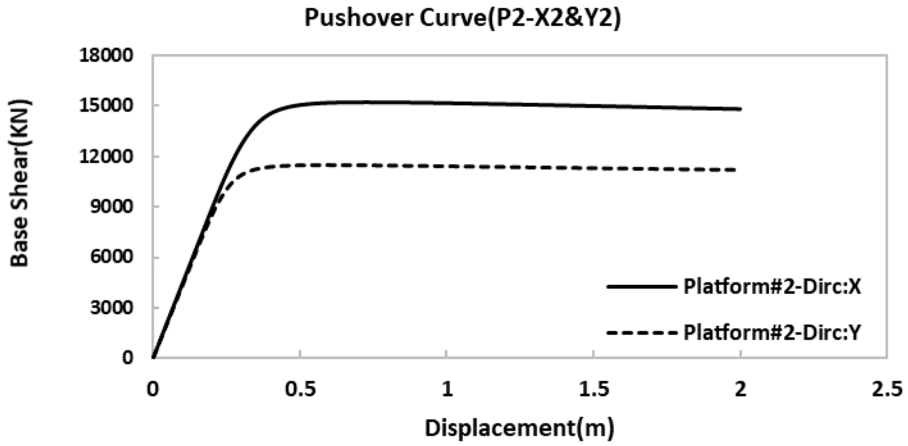


Figure 4- Capacity Curve Platform 2-Robust Structure

The Reserve Strength Ratio of the studied platforms, Robust state is given in Table 4. According to Table 4, both platforms have a suitable Reserve Strength Ratio. The base shear force due to the wave for platform number 2 is about 10 to 15 percent more than platform number 1.

To compare the two studied platforms in a robust condition, it can be said that platform number 1, despite its lower weight, has a higher Reserve Strength Ratio. This indicates that the bracing arrangement used for this platform has been optimally considered, which in addition to lower weight, has also created a higher storage strength ratio.

Table 4- Reserve Strength Ratio of Platforms-Robust Structure

	Wave Force(KN)		Maximum Base Shear(KN)		RSR	
	X	Y	X	Y	X	Y
Platform #1	6173	4649	15651	11287	2.54	2.43
Platform #2	6891	5184	15198	11504	2.21	2.22

Capacity Curve and Reserve Strength Ratio of platforms in Damaged condition

For the studied corrosion percentages, the Reserve Strength Ratio of the studied platforms is given in Table 5. Both platforms have a good Reserve Strength Ratio despite the damage in question. According to the minimum values set by the API-2SIM regulations, the two platforms under study are allowed to continue their operation in all considered failure situations. Unlike a robust platform, the ultimate resistance of Platform 2 is greater than that of Platform 1 in both the X and Y directions for this mode. In the general case-to-component case, the Reserve Strength Ratio of platform number 1 is higher than platform number 2. Platform 1, despite its lighter weight, has a higher storage strength ratio with the application of the assumed failures.

Table 5- Ultimate Resistance and Reserve Strength Ratio of Platforms-Damaged Structure

	Wave Force(KN)		Maximum Base Shear(KN)		RSR	
	X	Y	X	Y	X	Y
			Platform #1			
Corrosion-30%	6173	4649	12872	9029	2.09	**1.94**
Corrosion-60%	6173	4649	12583	8792	2.04	**1.89**
Corrosion-100%	6173	4649	11357	8148	1.84	**1.75**
			Platform #2			
Corrosion-30%	6891	5184	13678	10354	1.98	**2.00**
Corrosion-60%	6891	5184	12642	9567	1.83	**1.85**

Corrosion-100%	6891	5184	11653	8726	1.69	**1.68**

Investigation and Analysis of the results obtained in two modes of Robust and Damaged platform:

Figure 5 and Figure 6 show how the capacity curve of platform number 1 changes in both X and Y directions. As can be seen, as the damage to the platform increases at each stage, the ultimate resistance decreases. Also, with the increase of the amount of damage to the platform, in the final stages of the damage, before reaching the desired target displacement, it suffers the final collapse.

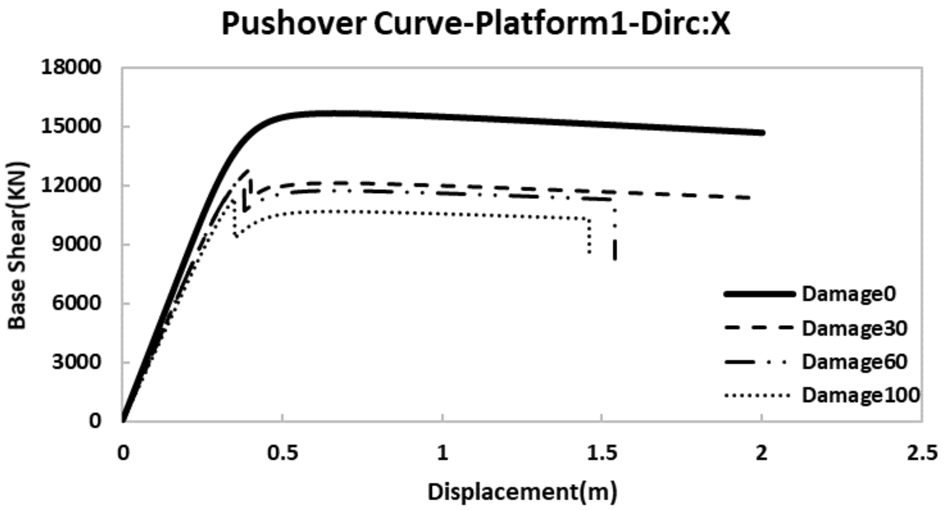


Figure 5- Platform Capacity Curve No. 1- Different modes-X direction

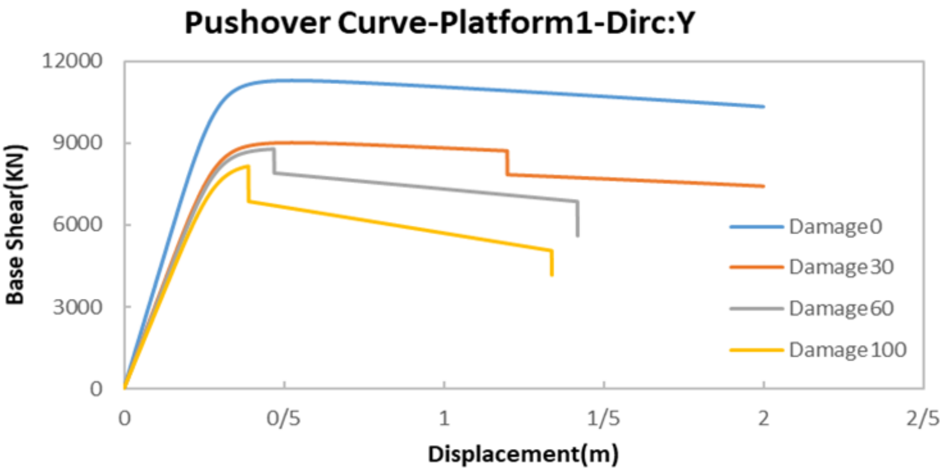


Figure 6- Platform Capacity Curve No. 1- Different modes-Y direction

Figure 7 and Figure 8 show how the capacity curve of platform number 2 changes in both X and Y directions. As can be seen, the slope of the changes in the behavior of the platform in the linear area is much lower than that of platform number 1. Also, in this case, the rate of reduction of the final resistance of the platform is less than platform number 1. However, due to the greater force applied in this case, it has a lower storage resistance ratio compared to platform number 1.

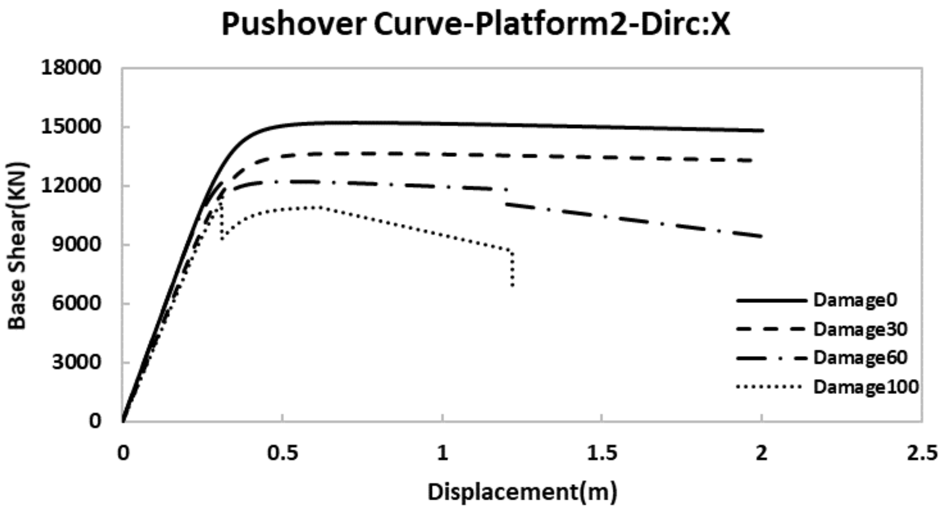


Figure 7- Platform Capacity Curve No. 2- Different modes-X direction

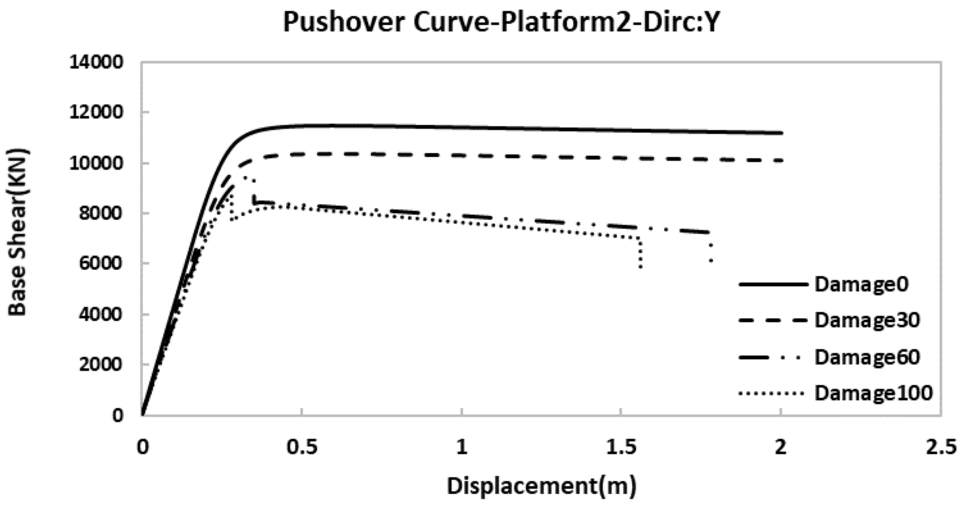


Figure 8- Platform Capacity Curve No. 2- Different modes-Y direction

The amount of variation of the Reserve Strength Ratio of the studied platforms in the different cases studied in Table 6 can be seen. According to Table 6, the reduction rate of the Reserve Strength Ratio in platform number 1 is initially twice that of platform number 2. However, as time goes on and the amount of damage increases in each stage, this amount decreases and in the last stage of the damage, the amount of reduction of the Reserve Strength Ratio for platform number 2 is very close to platform number 1.

Table 6- The amount of changes in the Reserve Strength Ratio of the studied platforms in different conditions

	Platform #1				**Platform #2**			
	X		Y		X		**Y**	
	RSR	ΔRSR(%)	RSR	ΔRSR(%)	RSR	ΔRSR(%)	RSR	**ΔRSR(%)**
Damage0	2.54	**0**	2.43	**0**	2.21	**0**	2.22	**0**
Damage30	2.09	**-18**	1.94	**-20**	1.98	**-10**	2	**-10**
Damage60	2.04	**-20**	1.89	**-22**	1.83	**-17**	1.85	**-18**
Damage100	1.84	**-28**	1.75	**-29**	1.69	**-24**	1.68	**-26**

The amount of changes in the Reserve Strength Ratio of the studied platforms relative to each other is given in Table 7. The Reserve Strength Ratio for platform number 1 is better than platform number 2, in 90% of cases. In this table, the difference between this parameter can be seen in the two platforms. It is worth noting that the rate of change in the Reserve Strength Ratio of the two platforms under study does not follow a specific pattern. The reason for this can be related to the behavior of offshore platforms in the nonlinear region.

Table 7- The amount of changes in the Reserve Strength Ratio of the studied platforms to each other

	X-Direction			**Y-Direction**		
	P1	P2	ΔRSR(%)	P1	P2	**ΔRSR(%)**
Damage0	2.54	2.21	**13**	2.43	2.22	**9**
Damage30	2.09	1.98	**5**	1.94	2	**-3**
Damage60	2.04	1.83	**10**	1.89	1.85	**2**
Damage100	1.84	1.69	**8**	1.75	1.68	**4**

III. CONCLUSION:

In the present study, the behavior of an offshore jacket platform in the South Pars Oil Field located in the Persian Gulf in both robust and damaged conditions was investigated. The aim of this study was to investigate the effect of bracing arrangement on the capacity curve and the Reserve Strength Ratio of offshore platforms in both robust and post-damaged conditions.

- The base shear due to the 100-year wave for platform number 2 was about 10% higher than platform number 1.
- Platform No. 1 with X bracing arrangement produced a higher Reserve Strength Ratio than Platform No. 2 with XH bracing arrangement.
- From a resistance point of view, the bracing arrangement of platform number 2 has shown better results. However, from the point of view of Reserve Strength Ratio, which is the accepted view of API-2SIM regulations, platform number 1 has shown better results.

REFERENCES:

[1]. R. API, "2SIM (2014a)–Structural Integrity Management of Fixed Offshore Structures," *Standard by American Petroleum Institute*, 2014.
[2]. M. Tabeshpour, R. Nobakht, *Non linear Static Analysis, Chapter 3*, Integrated Management of Marine Structures, Ch. 3, 1397
[3]. M. A. El-Reedy, *Offshore structures: design, construction and maintenance*. Gulf Professional Publishing, 2019.
[4]. S. Mazzoni, F. McKenna, M. H. Scott, and G. L. Fenves, "OpenSees command language manual," *Pacific Earthquake Engineering Research (PEER) Center*, vol. 264, pp. 137-158, 2006.
[5]. L. Pasticier, C. Amadio, and M. Fragiacomo, "Non-linear seismic analysis and vulnerability evaluation of a masonry building by means of the SAP2000 V. 10 code," *Earthquake engineering & structural dynamics*, vol. 37, no. 3, pp. 467-485, 2008.
[6]. A. RP, "Planning, designing, and constructing fixed offshore platforms—Working stress design," 2014.