Reliability analysis of leg mating unit under impact loads due to Floatover installation

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ABSTRACT

Regarding Iran's needs to increase its current oilfields production, especially in the South Pars field and decommissioning new fields, it is a necessity to fully understand and comprehend the Floatover installation method as a cost-effective and reliable method and as an alternative for traditional lifting method. This method is complex in nature and demands the study of all environmental parameters and elements involved. All of these parameters contain uncertainty. This study examines the environmental uncertainties and uncertainty in steel by comparing leg mating units and using Taguchi design and response surface methods. A model including a jacket, topside, and a barge with 6 degrees of freedom was developed to assess hydrodynamic analysis in the Persian Gulf. Then, using the Taguchi design and the Box-Behnken method, and by monitoring the maximum von Mises stress, the explicit limit state function was generated. This stress was calculated using a finite element model that represents impacts and interactions. By creating two limit state functions, reliability analysis was performed. In these functions, the effect of environmental parameters on the failure of the leg mating units was investigated. Finally, the effect of environmental uncertainties and the yielding stress of steel in the Floatover method were evaluated using FORM and SORM methods and Monte Carlo simulation. It was concluded that uncertainties in steel and some of the environmental parameters have a significant impact on failure.

KEYWORDS

Floatover, Leg Mating Unit, Reliability analysis, Response surface Methodology, Taguchi method

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1. Introduction

One of the most important steps in the commissioning of offshore structures is the installation of the topside. Regardless of the technical complexities for performing offshore installation, the installation process, sea environment, and other equipment are accompanied by uncertainties. The reliability analysis method is used to evaluate these uncertainties.

Traditionally, installation at sea is done by using an offshore crane. With the increase in the weight of the topsides, this method faced some limitations. These limitations are deck weight, increased site-to-shore distance, and heavy costs, namely [1, 2]. Therefore, the Floatover method emerged as a reliable and cost-effective method. Special equipment for Floatover installation is required to perform this method safely and efficiently. In the Floatover installation method, to transfer the load safely, leg mating units are used[3], which are usually installed at the end of the jacket legs. In two extensive studies [4, 5], Chen et al. Examined different aspects of movements and forces in the installation of a flute. However, these studies were performed for models with one and three degrees of freedom, and in these studies, it was suggested to investigate the effects of other degrees of freedom.

This study pursues two main goals. The first goal is to evaluate the effect of uncertainties on the leg mating unit and establishing probabilistic view in the decision-making process in the design. The second goal is to investigate the effects, importance, and significance of environmental parameters in the Floatover installation method and generating a limit state function that relates environmental parameters to the stress in the leg mating units. Turning to a probabilistic approach in the design of leg mating units can be a great aid in engineering judgment. A comparison between prototype models using the reliability method can affect the decision-making process and risk levels in the project. Because a limit state function is required for reliability assessment, the limit state function that shows the boundary between failure and safety was developed using the Taguchi and the response surface methods.

2. Methodology

According to the purpose of this study, which is to assess reliability, the limit state function was first generated. In this research, two approaches have been used to form this function. In the first approach, the response surface method (RSM) is used and in the second approach, the Taguchi method is used. In each of these approaches, a different leg mating model is used. First, a hydrodynamic model is developed in the MOSES software. In this research, environmental data of the Persian Gulf have been used. Using the response surface and Taguchi methods run orders, hydrodynamic runs were performed to calculate the forces acting on the leg mating units. The outputs of the hydrodynamic model were entered as input forces on the finite element model of the leg mating units. Then the maximum von Mises stress in the outer body of the leg mating was calculated. ABAQUS was used to model the impact forces acting on the leg mating units. Using these stresses and response surface and Taguchi methods, limit state functions were created for each approach. Figure 1 shows the process of this paper.

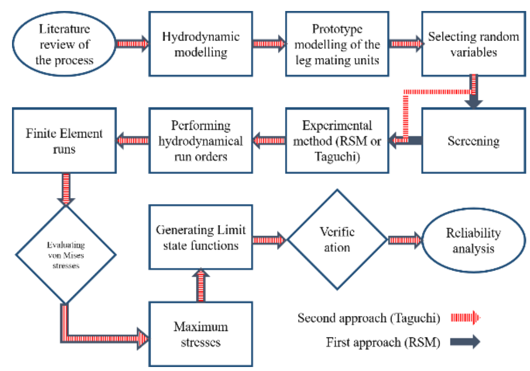

Figure 1 flowchart of the study

Cummins equation has been used to evaluate the movements and forces applied. This equation is solved by considering nonlinear expressions in time history.

$$[M + A(\infty)]\ddot{x}(t) + \int_0^t h(t-\tau)\dot{x}(\tau)d\tau + Kx(t) = f^E(t) \quad (1)$$

Solving this equation is very time-consuming due to having convolution integral. To develop the limit state function, in the first approach, the full quadratic model (eq. (2)) is used and in the second approach, a linear model is used (eq. (3)), in which x are variables.

$$y = \gamma_0 + \sum_{i=1}^{k} \gamma_i x_i + \sum_{i=1}^{k} \gamma_{ii} {x_i}^2 + \sum_{i<j}\sum \gamma_{ij} x_i x_j \quad (2)$$

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n + \varepsilon \quad (3)$$

FORM and SORM methods were also used to calculate reliability index. The Monte Carlo simulation method was also utilized to validate the results. The general form of this method is in the form of Eq. (4).

$$p_f \approx \frac{number\ of\ failures\ (n)}{number\ of\ simulations\ (N)} \quad (4)$$

3. Results and discussion

After performing hydrodynamic and finite element runs, the maximum von Mises stresses were calculated. The results for the Box Behnken model are given in Table 1. The quality of the models created in the two approaches is given in Table 2. Because in the RSM model, interactions and second-order terms are present in the model, and also in this model, three variables were selected after screening, the accuracy of this model is much higher.

Table 1 RSM results and fitted values

Randomized run orders	Hs [1]	Wave Direction [1]	T [1]	Von Mises Stress (pa)	Fitted value (pa)
5	0.04	90	2.2	2.661E+08	2.59E+08
7	0.04	90	6.62	2.669E+08	2.7E+08
1	0.04	0	4.41	2.664E+08	2.68E+08
2	2.45	0	4.41	3.761E+08	3.73E+08
6	2.45	90	2.2	3.427E+08	3.4E+08
9	1.245	0	2.2	2.788E+08	2.85E+08
8	2.45	90	6.62	3.862E+08	3.93E+08
3	0.04	180	4.41	2.664E+08	2.69E+08
12	1.245	180	6.62	3.218E+08	3.16E+08
4	2.45	180	4.41	3.692E+08	3.68E+08
11	1.245	0	6.62	3.220E+08	3.18E+08
14	1.245	90	4.41	3.411E+08	3.41E+08
13	1.245	90	4.41	3.411E+08	3.41E+08
15	1.245	90	4.41	3.411E+08	3.41E+08
10	1.245	180	2.2	2.792E+08	2.83E+08

Table 2 quality of the models

	R-sq	Adjusted R-sq
RSM	99.04%	97.30%
Taguchi method	94.77%	90.20%

To evaluate the uncertainties in the steel, the yielding stress was added to the limit state function. Thus, the limit state function constructed in the first approach (RSM) is in the form of Eq. (5).

$$g = Y - (165878979 + 31738273\,Hs + 420533\,WaveD + 42794569\,T - 2256350\,Hs^2 - 2259\,WaveD^2 - 4575823\,T^2 - 15929\,HsWaveD + 4008562\,HsT - 754\,WaveDT) \quad (5)$$

Finally, a reliability analysis was performed for the constructed limit state functions. The results are presented in the form of the reliability index in Table 3 .

	FORM	SORM	MCS
RSM	2.81391	2.90713	2.91106
Taguchi method	2.88599	2.87021	2.85058

5. Conclusion

Some of this research concluding remarks are as follows

• In Floatover installation, significant wave height, wave period, current velocity, and wave direction have a more significant effect on increasing the forces acting on the leg mating units.

• Wind parameters including wind velocity and direction have little effect on the changes of forces on the leg mating units.

• Steel uncertainties significantly affect the reduction of the reliability index. So that the changes in the probability of failure are reduced by an average of thirty times.

6. References

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