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Evaluation of environmental parameters in Floatover installation in mating stage using Design of Experiment methods

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ABSTRACT

This paper appraises the environmental parameters affecting the Floatover installation method. While this method demands extensive logistics, hardware, and planning from the first stage till the last, Environmental parameters are the main sources of creating external forces. Comprehension of the environmental features and their influence plays a significant role. In this paper, the application of the Design of experiments (DoE) in the offshore installation is examined. This methodology involves the mathematical procedures of designing experiments that allow a precise and effective evaluation of response features using the least number of analyses. By using response surface methodology and Taguchi design, which are methods of DoE, the significance of each parameter is assessed and a function is developed that holds the response with respect to the input environmental parameters. The magnitude of the impact forces acting on the leg mating unit is chosen as the response. Hydrodynamic time domain analysis based on these methods was done. This study was performed for a semi heavy weight topside and a typical T-shaped barge with six degrees of freedom for the Persian Gulf region.

1. Introduction

One of the most important activities of commissioning fixed offshore structures is topside installation. With the increase of weight and development of integrated topsides, the conventional method of lifting has faced defying challenges due to the heavy weight. Traditionally topsides are installed in one piece or modularly on the substructure using an offshore crane vessel. Since the 70s alternative method of Floatover installation has been used throughout the world. This is mainly because of three reasons, namely (a) increase of topsides weight and lack of a capable crane vessel in the area [1] (b) economical aspects [2], and (c) development of integrated topsides in one module [3]. Concerning the qualification of the engineering firms involved in the installation process, this method usually gets done as follows (a) Load-Out (b) Sea Transportation (c) Float-over Stand-off (d) Docking of Installation Vessel (e) Pre-mating Position of the Installation (f) Vessel Mating of Integrated Deck to Jacket (g) Post-Mating Position of Installation Vessel (h) Un-Docking of Installation Vessel. In each of these stages, there are needs and challenges to deal with [4].

Floatover Installation is performed by lowering the topside and transferring its weight on the substructure smoothly using the control systems and shock absorbers [5]. There are three widely used technologies to perform this task, namely (a) HIDECK (b) UNIDECK and (c) SmartLeg [6]. In this method, the goal is to minimize collisions between jacket legs and the vessel and impact forces acting on the legs caused by lowering. To achieve this goal, there exist hardware and elements. One of the main elements is leg mating units. They are placed on top of each legs to absorb impact loads by dampening [7]. If they fail to damp impact loads, these forces make deformations in the jacket legs. Figure 1 shows the other participating elements, namely stabbing and receptor cone, jacket legs, Deck Support Units, Deck Support Frame/Structure, leg mating units, and the barge. Lack of knowledge or miscalculation in the hydrodynamic analysis and acting forces on the leg mating units can cause failure or make them overdesigned, which are the least expectant in offshore industries.

The participation of auxiliary elements such as fenders and guide structures depend on the capabilities of the parties involved but generally, elements shown in figure 1 are present in every Floatover installation project.

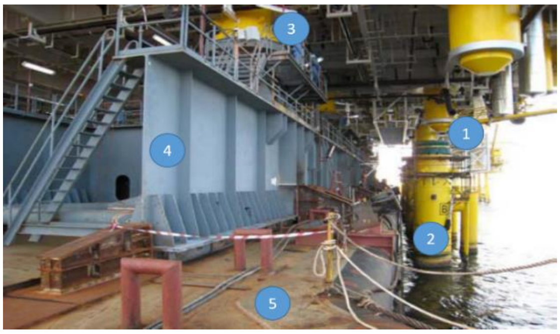


Figure 1 Floatover hardware [7] – (1) Stabbing Cone (2) Leg Mating Units inside jacket legs with receptor cone (3) Deck Support Unit (4) Deck Support Frame (5) Barge

Bokhorst Et al. stated that Floatover installation depends on performing three focus points in a well-balanced custom. These are: Platform Design, Floatover Equipment and, Environmental Conditions [8]. Additionally, standards and codes have recommended anticipating environmental conditions [9]. Hence it is required to analyze environmental conditions carefully and evaluate their impacts.

Kocaman & Kim calculated vertical forces and impact loads of Arthit field Floatover installation in Thailand [10]. According to Tan et al., for every installation project, hardware such as leg mating units and deck support units must get designed sophisticatedly [11]. This study was done for Arthit oilfield too. Appropriate design of hardware such as leg mating units highly depends on the input data, which is hydrodynamic analysis.

In an extensive study, Yuan et al. considered design aspects of the leg mating units. They analyzed a typical leg mating unit and evaluated different failure scenarios. They also compared numerical results with dynamic physical model for elastomeric materials. They comprehensively elicited load variations and impact forces [12].

Many industries and processes have used the design of experiments methodology to assess the impact of factors involved in the process. This method helps engineers and decision-makers to choose the right factors and eliminate unnecessary factors in order to make every factor sufficient and optimize the response [13]. Response surface methodology provides an experimental strategy to optimize the mathematical equation relating to the factors involved. Likewise, this method firstly was used in chemical industries [14].

Taguchi design is a statistical approach developed by Taguchi and Konishi [15] which has been used to optimize the factors participating in industrial process and improve the quality of components that are manufactured [16]. This method has been employed extensively in various science and engineering disciplines such as biotechnology [17], electronics [18] and, solids [19].

Taguchi’s methodology for the robust parameter design problem revolves around the use of orthogonal designs where an orthogonal array involving control variables is crossed with an orthogonal array for the noise variables [20].

In this study, two main objectives are to find what environmental parameters have a significant impact on generating forces on leg mating units and creating an equation which transfers environmental condition to applied force in leg mating units. By evaluating the relationship between each parameter and factors, this equation can be used as preliminary data for future projects. For this purpose, two approach were used. In the first approach, the Plackett Burman method was applied for screening insignificant parameters. Then the final model was created with response surface methodology. In the second approach, optimization took place without screening with Taguchi design. This paper is arranged as follows. In Section 2, the methodology and approach of the study is introduced and the problem is described. Section 3 briefly explains the theoretical topics used in the research. First, the equations of motion of the system involved in the Floatover installation are discussed, and then the statistical methods used to construct the function are introduced. In Section 4, the results obtained from the two models of response surface and Taguchi are presented. This section also provides an interpretation of the results obtained. Finally, some concluding remarks are mentioned and the restrictions and suggestions for future studies are also given.

2. Methodology

In nature, using the design of experiments demands a sequence of runs to take place. The difference among these runs is according to the level of parameters. In this paper seven environmental parameters were examined. Table 1 shows these parameters and their levels.

According to table 1, minimum and maximum values are demonstrated, including parameters with different levels. Significant wave height and the period data are upper and lower bounds of the Persian Gulf, which is from Kamranzad Et al. [21] and the rest are mean values of the region. The purpose of this study firstly is to analyze the significant parameters and secondly to measure the impact. To achieve this goal, two methods of response surface methodology and Taguchi design are selected which are sub methods of Design of Experiments (DoE). Five random conditions expressing different sea conditions were selected to verify the predicting ability of each model. Because of constraints in each approach, the levels were selected in a way to represents actual sea conditions. For instance, directions vary from 0 to 90 degrees, considering the factorial design has two levels. RSM provides an accessible estimation of variations on the response surface as changes are imposed on the design parameters [22]. This method provides a nonlinear surface to predict responses. In the second approach using the Taguchi run order, a linear regression takes place to describe the relationship between the environmental parameters. In the end, two models are verified by comparing their results with the hydrodynamic model. The process of the study is illustrated in figure 2. This figure shows the difference when screening is used.

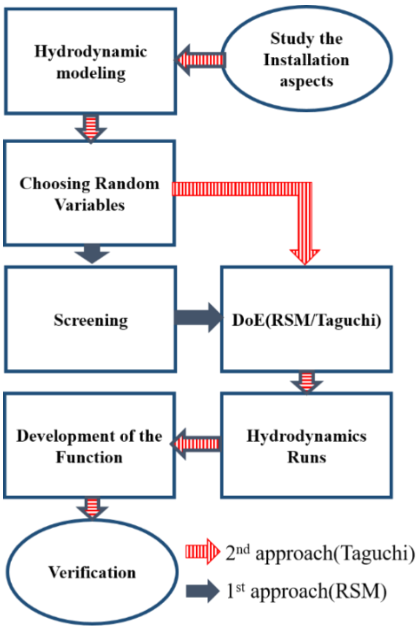


Figure 2 Process of the paper and used methods

Table 1 Parameters and their levels

Parameters	Levels	
Hs: Significant Wave Height (m)	0.04	2.45
T: Period(s)	2.2	6.62
CV: Current Velocity (m/s)	0.1	1
WV: Wind Velocity (m/s)	4	12
WiD: Wind Direction (degree)	0-90	180-270
WD: Wave Direction (degree)	0-90	180-270
CD: Current Direction (degree)	0-90	180-270

3. Theoretical Background

3.1 Hydrodynamic Analysis

The movements and forces applied to the system involved in the Floatover installation are analyzed using the Cummins equation [23]. This equation is solved in the time domain considering nonlinear expressions. As this equation contains convolution integral, it is very time-consuming. In this equation $x(t)$ is the vector of all degrees of freedom to evaluate the motions. In this study, all six degrees of freedom are considered. In case of zero forward speed, it takes the following form.

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

In equation (1) M is the mass matrix of the system and $A(\infty)$ is the infinite frequency added mass matrix. The second term in this equation is the convolution integral, which is replaced numerically to increase the computational speed [24]. K is also the system's hydrostatic stiffness matrix. On the right side of this equation, there is the sum of excitation and the external forces.

Using Fourier transform, Ogilvie considered equation (1) in the frequency domain in which the convolution integral terms were removed [25]. This equation is given as follows (2).

$$\hat{x}(j\omega)\{-\omega^2[M + A(\omega)] + j\omega B(\omega) + K\} = \hat{f}(j\omega) \quad (2)$$

In this equation, $\hat{x}(j\omega)$ and $\hat{f}(j\omega)$ are the Fourier transforms of $x(t)$ and $f(t)$. $A(\omega)$ And $B(\omega)$ are hydrodynamic coefficients and are added mass and radiation damping, respectively. Obtaining the coefficients and solving the equation can be done using MOSES software. Ogilvie also found the relationship between the coefficients in Equation (1) and (2).

In the analysis of the Floatover installation process, the draft of the vessel gradually increases until it reaches the predetermined endpoint. Therefore, the equation above is time-dependent in terms of forces being inherently time-dependent, and in the sense that even with constant external conditions, the increment in draft causes changes in the system [26].

Impact load time histories highly depend on the sea condition. For instance, Chen et al. developed two models in two separate studies with one and three degrees of freedom, respectively [27, 28]. For this paper, a hydrodynamic model is developed with MOSES software to analyze the motions and interactions between the barge, jacket, and topside. The deck support structure consists of six support units. The deck weighs 13,000 tons. A real T-shaped barge is used, which utilizes 8 Morning lines to control the movements. The barge and deck assembly are free to move at six degrees of freedom, and the magnitude of the forces acting on the leg mating unit is calculated. To describe the ocean wave spectra, the ISSC spectrum is exerted and the sea environment is similar to South Pars field. The whole model and mooring schematic configuration are demonstrated in figure 3. All of the time histories are during 100 percent load transfer.

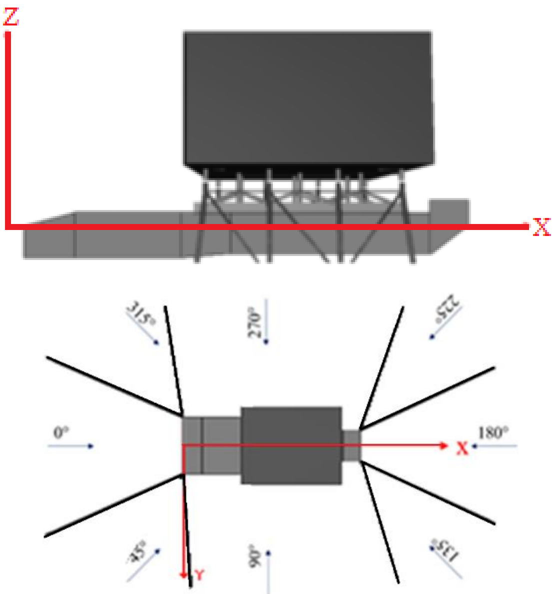


Figure 3 Model schematic description

To verify the hydrodynamic model and check the output of the model, the impact forces applied on leg mating units must be examined. At the end of the loading stage, all the topsides weight should be transferred on the jacket legs. Given the weight of the deck, which is equal to 13,000 tons, the weight applied to the legs should be in the same range. The force applied to the leg mating units in the two sea states and in the form of time histories is shown in Figure 4-6.

To test the quality of the model, Jung et al. suggested that the loads on the leg mating units should be equal to the total weight of the deck [1]. This was also the case in the research of Kocaman and Kim [10]. Tahar et al. have also stated in their research that in the 100% loading stage, all the weight must be transferred [29]. This was also mentioned in previous researches.

Figure 4 shows the load on the legs in a case where the significant wave height is 0.04. Due to the height of the water wave and having the vessel moored, this condition is very similar to the static condition. Therefore, as shown in this figure, the sum of the applied forces is practically equal to the weight of the deck. But Figure 6 shows the impact loads in the case where the significant wave height is 2.45. In this case, the maxima in the time history is obviously higher. This increment is actually the dynamic effect and contribution. But the important point is that the average of the time history is very close to 13,000. Also, this increase is about 30%, which is quite similar to the results of Jung's research.

According to the scale of Figure 4, this time history has practically become a straight line, which explains the static state. Figure 5 shows the sum of the forces with a more accurate scale.

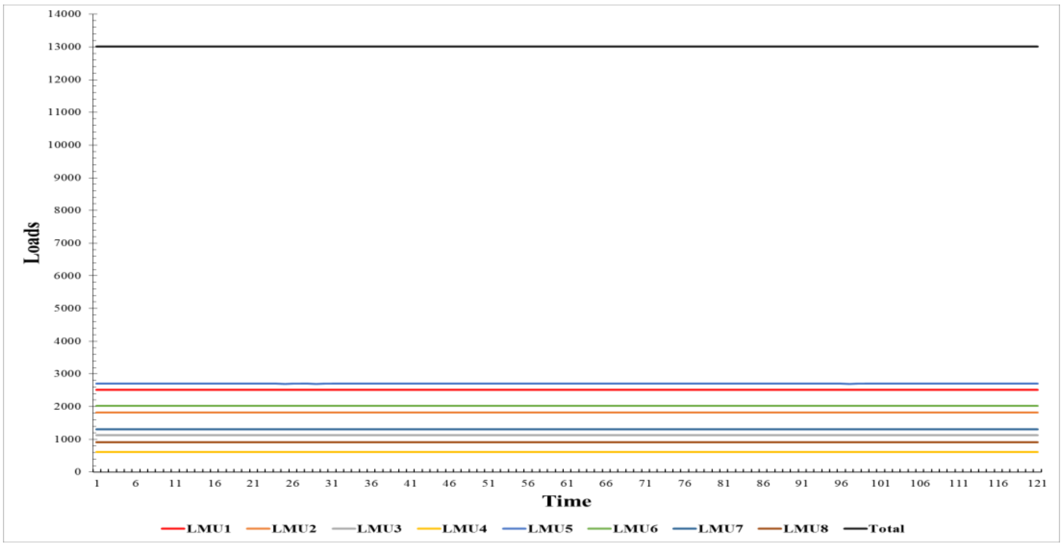


Figure 4 Impact loads in significant wave heights equal to 0.04

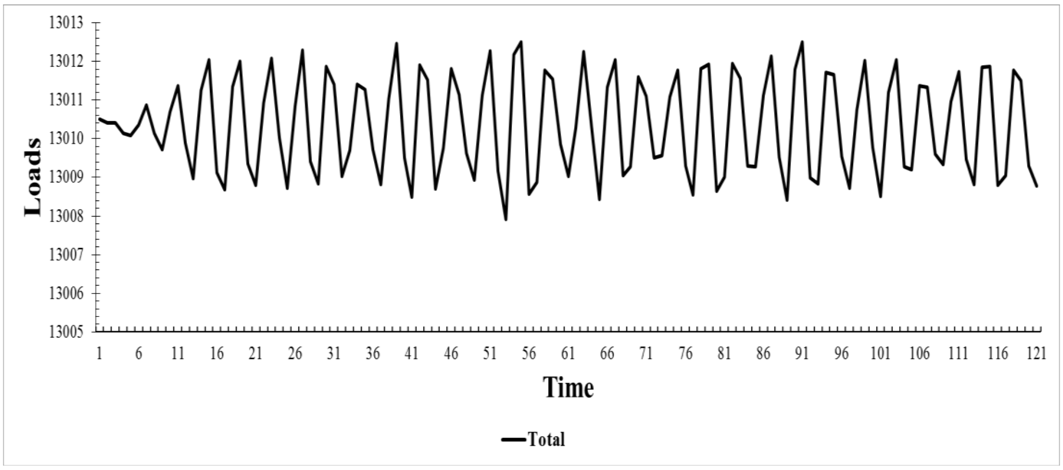


Figure 5 Sum of the impact forces on all eight legs

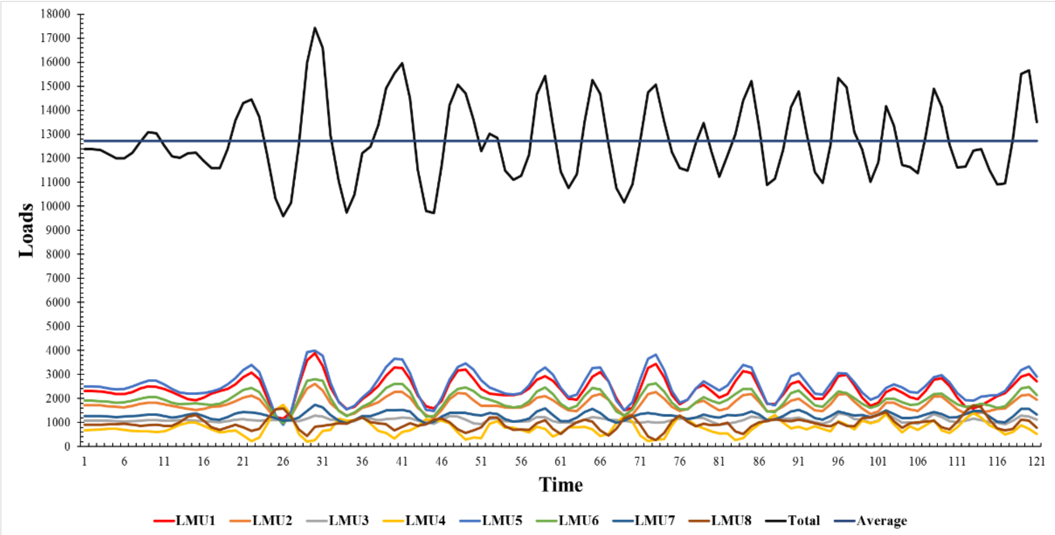


Figure 6 Impact loads in significant wave height equal to 2.45

3.2 Design of experiments

Traditionally experiments were done by changing one factor at a time (OFAT). The statistical design of experiments provides the development and improvement of products and processes scientifically. This method can determine cause and effect relationships and can provide a planned approach to any process with inputs and outputs [30]. The main procedures of this method are factorial design, response surface methodology, and Taguchi design.

3.2.1 Plackett-Burman design

This method which is a two-level factorial design was developed by Plackett and Burman in 1946. Plackett and Burman method devised orthogonal arrays and has been used for screening, which yield unbiased estimates of all main effects to minimize number of runs [31]. These designs are two-level factorial designs to study up to k=N-1 variables in N runs, where N is a multiple of 4 [20]. Due to the two-level design, a first-order model is used to show the effects of different factors. Based on the analysis of variance (ANOVA) of the constructed model, it can be identified what factors are significant [32]. The randomized run order is demonstrated in table 2. + and – represent upper and lower levels. Based on this order 12 hydrodynamic models were executed.

Table 2 Randomized order for 7 parameters

Run	block	A	B	C	D	E	F	G
1	1	+	+	-	+	+	-	+
2	1	-	+	+	+	-	+	+
3	1	+	-	+	-	-	-	+
4	1	+	+	-	+	-	-	-
5	1	+	+	+	-	+	+	-
6	1	-	-	-	+	+	+	-
7	1	-	-	+	+	+	-	+
8	1	-	+	+	-	+	-	-
9	1	-	+	-	-	-	+	+
10	1	+	-	+	+	-	+	-
11	1	+	-	-	-	+	+	+
12	1	-	-	-	-	-	-	-

3.2.2 Box-Behnken design

The Box-Behnken method is one of the response surface methods that has been widely used to optimize the experimental relationships between the factors involved in a process [33]. In this method, the parameters are used at three levels. After performing each run, the relationship between the response and the parameters is calculated using a full quadratic model similar to Equation (3). Analysis of variance will be used to evaluate the significance of the parameters.

$$y = \gamma_0 + \sum_{i=1}^{k} \gamma_i x_i + \sum_{i=1}^{k} \gamma_{ii} {x_i}^2 + \sum\sum_{i<j} \gamma_{ij} x_i x_j \quad (3)$$

As mentioned earlier, constraints on the implementation of the hydrodynamic model should be considered. It is not cost-effective to perform multiple runs. Screening is done to eliminate the least significant parameters. After screening, the three most significant variables are selected to use in the Box-Behnken model. If screening is not performed, instead of 15 runs, 62 runs should be performed. The Box-Behnken design for 3 parameters is shown in figure 7. The three variables are along the principal axes and each node represents an executive run.

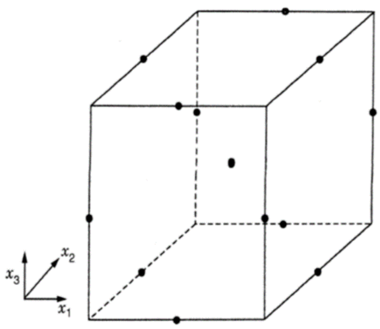


Figure 7 Box-Behnken design for 3 parameters

3.2.3 Taguchi design

The L16 Taguchi design is used in this study to develop an experimental function. The logic of this method is to investigate the ratio of signal (S) to noise (N). Three situations can be considered for this ratio. Since the goal is to find the maximum impact loads due to the environmental conditions, the larger the better signal-to-noise ratio is selected, as shown in equation 4. Two very important differences between this method and the response level methods are the lower number of runs and considering parameters on different levels. In this approach, developed experimental function is produced as a first-order model due to the number of factors using regression, the general form is similar to equation 5.

$$S/N = -10\log(\Sigma(1/Y^2)/n) \quad (4)$$

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n + \varepsilon \quad (5)$$

4. Results and Discussion

Executions were performed according to the designs selected for each method. These methods were selected according to the physical limitations of the hydrodynamic model. It is clear that the purpose of this method is to increase efficiency and the high number of runs will not be affordable. In this section, the results and output of each model are presented. Each model can be analyzed individually by examining the residuals and the quality of regression, but verification is done by comparing the two models. Finally, the predictive accuracy of both models is presented in comparison with the output of the hydrodynamic model.

4.1 Screening

Considering seven parameters, the 12 implementation plan was selected. Based on ANOVA results demonstrated in table 3, the contribution of each parameter is assessed. Significant wave height, period, and wave direction have the most contribution in this process; consequently, they have the least p-values, respectively. Comparing the results, significant wave height, period, and wave direction are selected for the response surface method. In the literature, p-values more than 0.05 are considered insignificant [20].

Table 3 ANOVA table for screening model

Source	DF	Adj SS	F-Value	P-Value
Hs	1	1559869	11.27	0.028
T	1	1445741	10.44	0.032
WD	1	173170	1.26	0.325
CV	1	168294	1.22	0.332
CD	1	137264	0.99	0.376
WiD	1	172853	1.25	0.326
WV	1	135477	0.98	0.379

4.2 Box-Behnken Design

Using the parameters selected in the screening stage, Box Behnken design was performed. Table 4 shows the standard and randomized run orders, hydrodynamic response, fitted values, and residuals.

Table 4 run order and the responses

Standard Order	Run Order	Hs	T	WD	Response	Fitted Value	Residual
5	1	0.04	4.4	0	2528.92	2529.14	-0.2187
7	2	0.04	4.4	180	2528.9	2536.12	-7.2162
1	3	0.04	2.2	90	2517	2491.02	25.9763
2	4	2.45	2.2	90	2568.64	2550.1	18.5413
6	5	2.45	4.4	0	3248.85	3241.63	7.21625
9	6	1.245	2.2	0	2535.39	2561.15	-25.757
8	7	2.45	4.4	180	3230.62	3230.4	0.21875
3	8	0.04	6.6	90	2539.86	2558.4	-18.541

12	**9**	**1.245**	**6.6**	**180**	**3296.47**	**3270.71**	**25.7575**
4	**10**	**2.45**	**6.6**	**90**	**3880.13**	**3906.11**	**-25.976**
11	**11**	**1.245**	**2.2**	**180**	**2540.83**	**2559.59**	**-18.76**
14	**12**	**1.245**	**4.4**	**90**	**2876.95**	**2876.95**	**4.5E-13**
13	**13**	**1.245**	**4.4**	**90**	**2876.95**	**2876.95**	**4.5E-13**
15	**14**	**1.245**	**4.4**	**90**	**2876.95**	**2876.95**	**4.5E-13**
10	**15**	**1.245**	**6.6**	**0**	**3292.17**	**3273.41**	**18.76**

To examine the results and quality of the model, two issues are examined. Residuals and Determination of the model. Figure 8 shows the residuals. In Section a, the residual histogram shows that it has a normal distribution. Also, the residuals are shown versus fits and versus order in sections b and c, which does not show any trend or pattern. Table 5 shows the goodness of fit. Since the values of R-sq and R-sq (adj) are almost the same, it indicates the quality and determination of the model. Therefore, it shows that the model is reliable. It should be noted that the r-squared is not a good criterion for assessing the quality of regression, because by adding redundant parameters, the r-squared increases. For this purpose, the adjusted r-squared is an indicator that is accepted to check the quality of regression by considering the degrees of freedom as a measure of providing information.

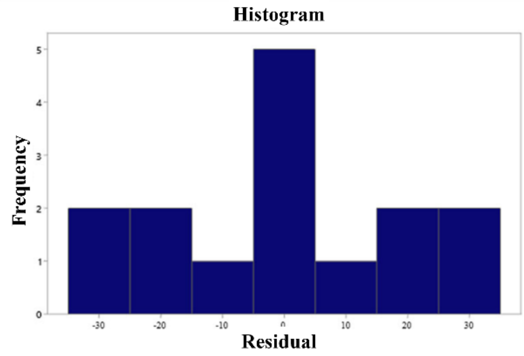
Table 5 Box-Behnken model summary

R-sq	R-sq(adj)
99.83%	99.52%

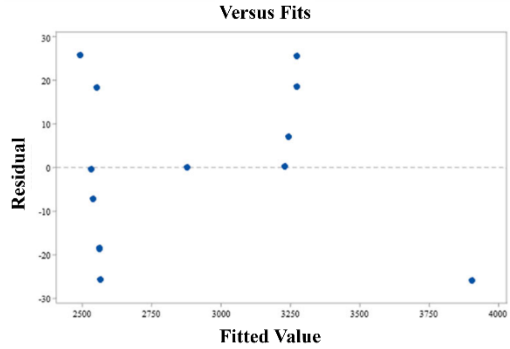
Based on the model developed using Box-Behnken design, demonstrated in table 6 (ANOVA table), significant wave height, period, and their interaction in the model have a significant impact on forces acting on the leg mating units, and changes in the levels of other factors almost do not play significant role in the response.

Table 6 ANOVA Table for Box-Behnken Design

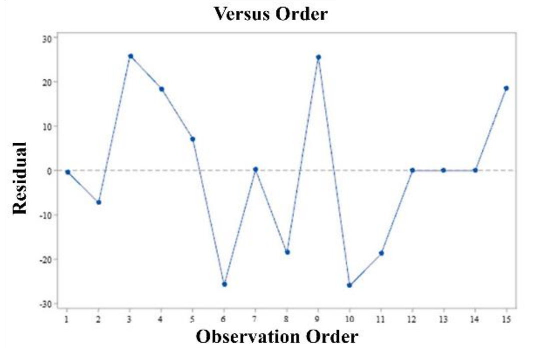
Source	DF	Adj SS	F-Value	P-Value
Hs	1	989515	1185.87	0
T	1	1013012	1214.03	0
WD	1	9	0.01	0.921
Hs×Hs	1	971	1.16	0.33
T×T	1	907	1.09	0.345
WD×WD	1	2055	2.46	0.177
Hs×T	1	415142	497.52	0
Hs×WD	1	83	0.1	0.765
T×WD	1	0	0	0.985



(a)



(b)



(c)

Figure 8 Box-Behnken design residuals (a) Residual Histogram (b) Residual versus fits (c) Residuals versus order

4.3 Taguchi design

After executing 16 runs based on the l16 design which is demonstrated in table 7, the highest experienced impact forces on the leg mating unit are presented in table 8. Figure 9 demonstrates the S/N ratio and mean of means. Because the larger the better signal-to-noise ratio is selected, the greater value of parameters is desired. The steeper slope shows higher impacts on the response. Table 8 also shows the S/N ratios and fitted values for each run. Figure 9 shows the means on each level. Accordingly, the difference in the highest and lowest response determines the significance of each parameter, accordingly one can rank all the parameters in order. Based on the results demonstrated in figure 9, significant wave height, period, and wave direction are the most significant parameters.

Table 7 Taguchi l16 design order with 7 parameters

Runs	WD	WiD	CD	Hs	T	CV	WV
1	0	0	0	0.04	2.2	0.1	4
2	0	90	90	0.8	2.2	1	12
3	0	180	180	1.6	6.6	0.1	12
4	0	270	270	2.45	6.6	1	4
5	90	0	90	1.6	6.6	1	4
6	90	90	0	2.45	6.6	0.1	12
7	90	180	270	0.04	2.2	1	12
8	90	270	180	0.8	2.2	0.1	4
9	180	0	180	2.45	2.2	1	12
10	180	90	270	1.6	2.2	0.1	4
11	180	180	0	0.8	6.6	1	4
12	180	270	90	0.04	6.6	0.1	12
13	270	0	270	0.8	6.6	0.1	12
14	270	90	180	0.04	6.6	1	4
15	270	180	90	2.45	2.2	0.1	4
16	270	270	0	1.6	2.2	1	12

Table 8 Taguchi l16 design results

Runs	Response	S/N Ratio	Fitted Value	Residual
1	2517.0	68.0	2430.5	86.6
2	2527.0	68.1	2672.0	-145.0
3	3498.9	70.9	3628.3	-129.3
4	3966.6	72.0	3884.6	82.0
5	3433.0	70.7	3431.8	1.2
6	3882.5	71.8	3684.2	198.3
7	2519.7	68.0	2300.7	219.0
8	2529.3	68.1	2514.2	15.1
9	2589.4	68.3	2834.9	-245.6
10	2550.7	68.1	2593.9	-43.2
11	3016.1	69.6	3009.9	6.2
12	2540.6	68.1	2807.8	-267.2
13	3086.3	69.8	2888.1	198.2
14	2548.1	68.1	2637.5	-89.4
15	2592.6	68.3	2651.0	-58.4
16	2557.2	68.2	2385.6	171.6

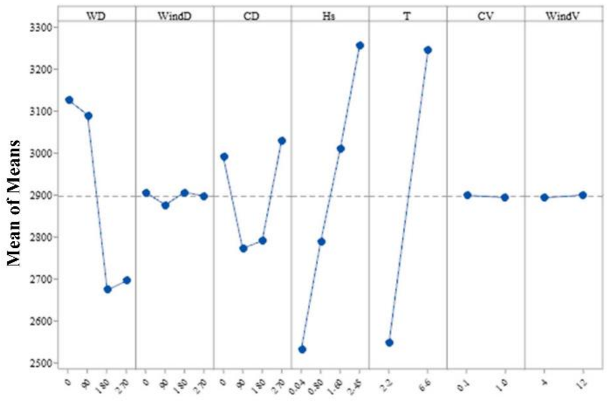


Figure 9 Main effect plots for means

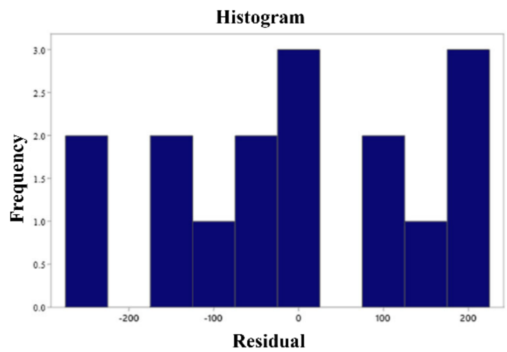
In order to obtain the relationship between environmental parameters and the force applied to the leg mating units, linear regression was performed using Taguchi performances. The purpose of this is to create an experimental function. Table 9 shows the regression quality for this model. Compared to the Box-Behnken method, this generated model is less accurate. Among the reasons are the higher number of parameters and the lack of interactions and higher-order terms. The results of this model are shown in the ANOVA table (Table 10). Similar to the results of the Box-Behnken model, the parameters with p-values less than 0.05 are considered significant parameters. In this way, only the wave parameters affect the response significantly and the current and wind parameters have limited effects.

Table 9 Taguchi model summary

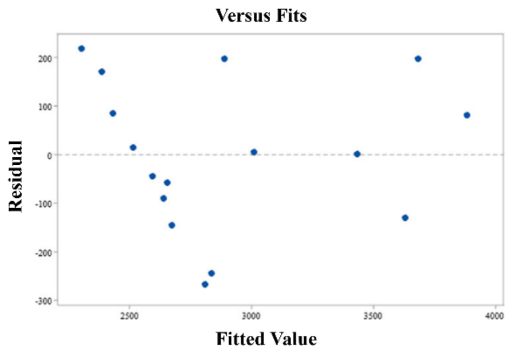
R-sq	R-sq(adj)
91.27%	83.63%

Table 10 ANOVA table for Taguchi method

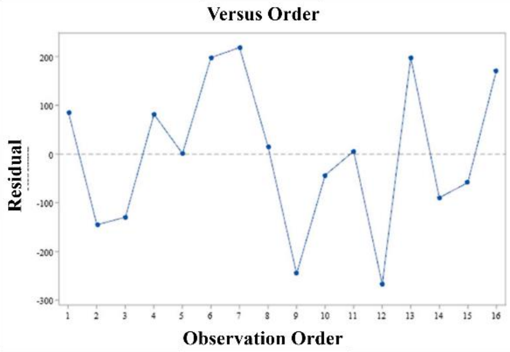
Source	DF	Adj SS	F-Value	P-Value
WD	1	585475	13.26	0.007
WiD	1	7	0	0.99
CD	1	3427	0.08	0.788
Hs	1	1150345	26.05	0.001
T	1	1952468	44.22	0
CV	1	105	0	0.962
WV	1	146	0	0.956



(a)



(b)



(c)

Figure 10 Taguchi design residuals (a) Residual Histogram (b) Residual versus fits (c) Residuals versus order

Although the histogram of the residuals in figure 10 does not follow a normal distribution necessarily, the residual fits and orders do not follow any trend.

4.4 Verification

In order To evaluate the accuracy and predictive quality of each model, the input variables with random levels are set in the model. Comparing the predicted numbers and the output of the hydrodynamic model shows the reliability of the model. To achieve this goal, five runs with parameters outside the levels of Taguchi models and the response surface method have been selected. These runs and parameter levels are shown in the table 11. It should be noted that the response surface model only contains the significant wave height, period and wave direction in a full quadratic model. Equation (6) and (7) are as follows and are developed response surface and Taguchi functions, respectively.

$$R = 2532.4 - 211.2\,Hs - 17.9\,T\;0.477\,WD - 11.2\,Hs^2 + 3.24\,T^2 + 0.00291\,WD^2 + 121.52\,Hs \times T - 0.042\,Hs \times WD - 0.0014\,T \times WD \quad (6)$$

$$R = 2067 - 1.901\,WD + 0.006\,WiD + 0.145\,CD + 298.6\,Hs + 158.8\,T - 6\,CV + 0.8\,WV \quad (7)$$

In all 5 runs, the Taguchi model is less accurate. The values predicted in this method are in some cases conservative and in others less than the hydrodynamic model. The response level model makes the prediction with an error of about 1%. By comparing the results, it is clear that the first method and the response level method perform better in predicting and evaluating the importance of each parameter in the response.

4.5 Discussion

Comparing the output of the developed models showed that only the wave related parameters, including the significant wave height, period and wave direction, affect the Floatover method. This was explicit in both models. Due to the accuracy of the two models, including regression quality and predictions, the response surface model showed much higher accuracy. The reasons for this are the presence of screening and the early elimination of ineffective parameters in the process. Also, due to the presence of a full quadratic model, the quality of the regression increases and it is conceivable to check the interactions in the model. Figure 11 and 12 demonstrate the interactions for a set of hold values. This must be considered that variations in period makes higher maxima in the time history causing significant force response. The response investigated in this study is the magnitude of the force applied to the leg mating units. Although this value indicates the resultant force, in reality it is a combination of two horizontal forces and one vertical force. During the 100% load transfer stage, vertical forces are much higher than the two horizontal forces [7]. Horizontal forces are controlled by mooring lines. However, maximum horizontal forces must be considered in the design of the leg mating units. This is one of the limitations in this study. Developed functions does not provide any information about the horizontal forces acting on the leg mating units. It is recommended to study the impact of horizontal forces on the leg mating units.

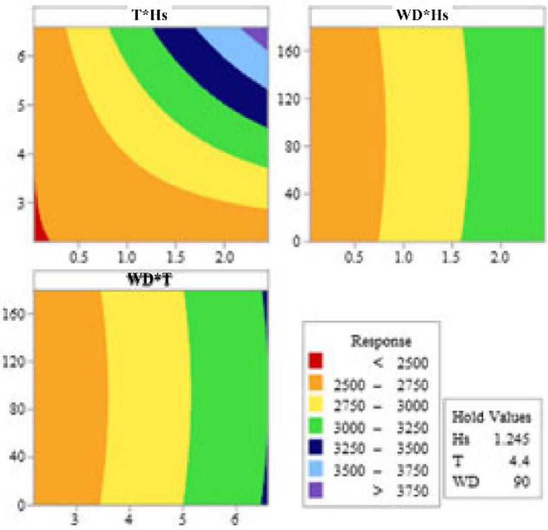
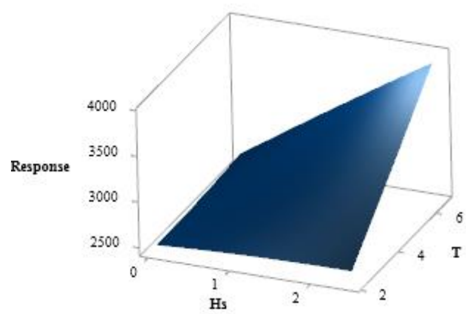
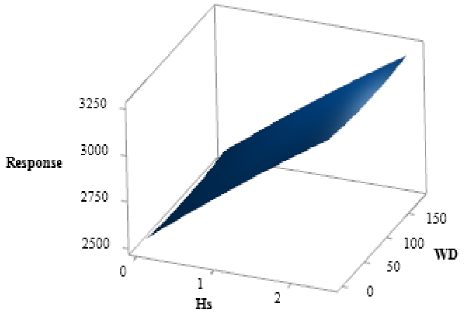


Figure 11 contour plots of response





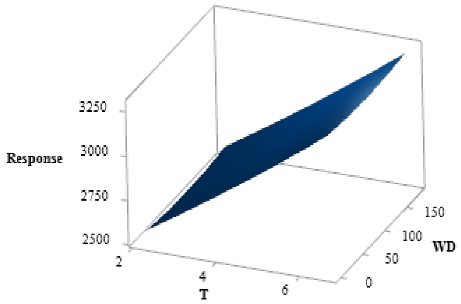


Figure 12 Surface plots of response

5. Conclusions

In this study, two models were developed using the design of experiments method. The purpose was to evaluate the effect of environmental parameters and to create an equation to obtain the maximum environmental forces on leg mating units in the Floatover installation method. The first method was based on the response level methodology, including screening and optimization, and in the second method, this equation was created using the Taguchi design method. The model used in the first method was a full quadratic model and the second method was linear. In order to evaluate the response, the response surface model showed a much higher quality in terms of regression quality due to the elimination of ineffective parameters and considering non-linear response surface. Also, the predictive quality of the response surface model error was about one percent, while for the Taguchi model it was up to ten percent. Both models indicated that the most significant parameters affecting the Floatover installation method were the significant wave height and wave period, respectively. Putting these two variables at a high level increases the response considerably. Both models also showed that wind parameters have the least effect on the forces acting on the leg mating unit.

The marine environment is inherently uncertain. Due to these uncertainties, this study does not suggest to ignore wind parameters completely but recommends studying the significant parameters more carefully. Finally, this method can be used to evaluate the maximum or average of the incoming forces on the leg mating units in future projects.

Table 11 Runs to compare DoE models to hydrodynamic model

Run	Hs (m)	T (s)	WD (degree)	CD (degree)	CV (m/s)	WiD (degree)	WV (m/s)	Hydrodynamic model	Taguchi design	RSM
1	3	7	90	90	0.5	0	10	4209.4	3921.4	4351.8
2	2	4	45	90	0.5	0	10	3030.1	3231.9	2998.0
3	2	4	225	0	1	45	5	3060.2	2869.9	3037.4
4	1	3	0	0	1	90	5	2621.3	2840.5	2650.0
5	0.5	3	90	0	1	90	5	2555.0	2520.2	2560.1

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