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TECHNICAL NOTE

Study of Fixed Jacket Offshore Platform in the Optimization Design Process under Environmental Loads

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ABSTRACT

In the structural optimization problem, the aim is to decrease the amount of structural costs and weight, but the safety of platform should not violate the individual limits enforced by offshore codes. The outer diameter and thickness of members are two important variables in the optimization process and their final dimensions should be obtained according to the optimization algorithms such as genetic algorithm. In this process, weight of the jacket is the objective function of optimization problem and constraints are design criteria such as axial and flexural stresses, buckling of members and displacement of offshore structure that should satisfy the limitations imposed by offshore design codes. The drag forces of wave, current and wind on a unit length of structural tubular members of the jacket which are located below and above water surface are directly related to their outer diameter. However, the inertia force of wave is related to the square of the outer diameter. Thus, by changing outer diameter of structural elements during the optimization process, sea environmental forces on these members and their resultant forces on the platform will change. The structural members of the jacket are classified in four main groups including legs, horizontal members, diagonal braces and vertical braces. Each of these groups has different contribution in the optimization process and their degrees of importance are investigated in this research. The results show that horizontal members of jacket have major contribution in the optimization process among other groups. Afterward legs and diagonal braces have the second and third ranks in the contribution percentage respectively. Finally, the lowest contribution in optimization process belongs to the vertical braces.

1. Introduction

Optimization of the design of fixed offshore platforms has been carried out by many researchers in last decades. In their studies, researchers and engineers proposed different objective functions and decision variables. They also have utilized different methods for optimization problems. Deserts and Deleuil supposed the geometry of fixed offshore platform as objective function [1]. Kleiber et al. took the volume of fixed offshore platform as objective function and mean values of cross-sectional areas of elements and vertical position of first and second decks as decision variables. They used stability-oriented reliability-based optimization algorithm based on the Rackwitz-Fiessler method combined with sequential quadratic programming [2]. Weight of jacket platform was considered by Kang et al. as objective function. They have optimized the diameter and wall thickness of members using constrained variable metric method [3]. In other investigation, total cost of jacket platform in its full service period was taken as the objective function and the initial reliability vector of the layer elements partitioned in advance was taken as the decision variables by Song and Wang. This model was a non-linear programming problem which was solved with the Lagrange multiplier method [4]. Also Song and Wang, in another paper, took the total weight of fixed offshore platform as objective function and diameter and wall thickness of piles, jacket legs, chord tubes and inclined struts as the decision variables. The bound search method is used to find the optimum solution of the fuzzy optimization problem by searching the optimum level cut set which is at the intersection set of fuzzy constraint set and fuzzy objective set [5]. Fadaee and Besharat took into account the weight of fixed offshore platform as objective function and outer diameter and thickness of platform members as decision variables. The optimization process was carried out by genetic algorithm [6]. In another investigation, weight of fixed offshore platform and legs batter were considered as objective function and decision variable respectively by Mohammad Nejad et al. [7].

As it is clear from all these papers, most of them did not utilize the new methods such as meta-heuristic methods in the optimization process. Also, they only focused on the methods applied in the optimization of design of offshore platforms and optimization process. They didn't take into account the percent of contribution of each jacket elements in the optimization process. In this research, the optimum values of cross-sectional geometric properties of tubular members of the fixed offshore platform jacket consisting outer diameter and thickness as decision variables in the optimization problem are obtained using genetic algorithm. In the in-place analysis, gravity loads and sea environmental forces from eight different directions including wave, current and wind forces are imposed on the platform. The drag forces of wave, current and wind for all of elements which are located below and above water surface, are directly related to the outer diameter. But, the inertia force of wave is related to the square of the outer diameter. Thus, by changing outer diameter of the members during the optimization process, sea environmental forces on a unit length of these members will change and consequently their resultant forces on the platform are adjusted. The structural members of the jacket are classified in four main groups including legs, horizontal members, diagonal braces and vertical braces. Each of these groups has a specific contribution in the optimization process and their degrees of importance can be identified.

2. Optimization Problem

In this study, we try to optimize the weight of the jacket via genetic algorithm. All components of the optimization problem, including decision variables, objective function, constraints and etc. are briefly explained in the subsequent sections.

2.1. Decision Variables

In the optimization problem, decision variables are important factors. We suppose the outer diameter and thickness of structural tubular members of jacket as decision variables. The tubular elements are classified in sixteen different member groups in order to decrease number of decision variables and size of chromosome. Four groups of these sixteen member groups contain the horizontal members in the frames. As shown in Figure 1, these members are at 64.7, 35 and 13 *m* below LAT and at 5.75 *m* above LAT which we classified them in H01, H02, H03 and H04 respectively. The location and initial values of outer diameter and thickness for these member groups are shown in Figure 1 as well.

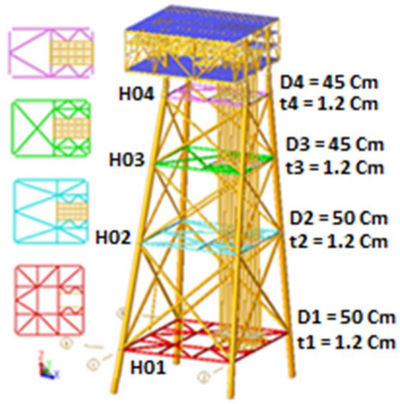

Figure 1. H01, H02, H03 and H04 member groups

Another three groups from sixteen member groups belong to the diagonal braces. Figure 2 shows the elevation of these diagonal braces in platform which are classified in JB1, JB2 and JB3 respectively. The location and initial values of outer diameter and thickness of each element in these member groups are shown in Figure 2 as well.

Eight groups of the sixteen member groups are included in the legs that four groups of them have two single side battered legs and another four member groups have two double side battered legs. The single side battered legs are situated between the fourth horizontal frame at elevation 64.7 *m* below LAT near the seabed and the elevation at 77.7 *m* below LAT named LG1, also between two horizontal frames at 35 *m* and 64.7 *m* below LAT nominated LG2, between elevations at 13 *m* and 35 *m* below LAT

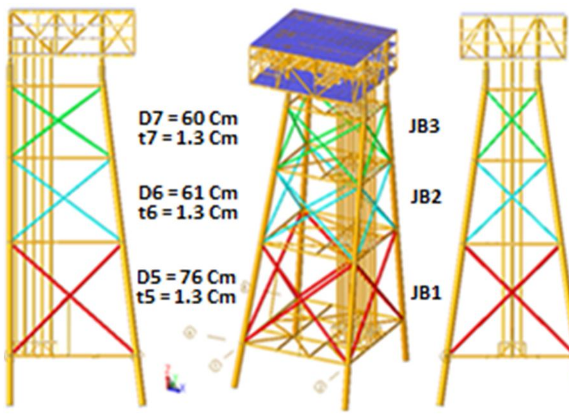

Figure 2. JB1, JB2 and JB3 member groups

between jacket walkway frame at 5.75 *m* above LAT and 13 *m* below LAT are named LG3 and LG4 respectively. The location and initial values of outer diameter and thickness of these member groups are shown in Figure 3.

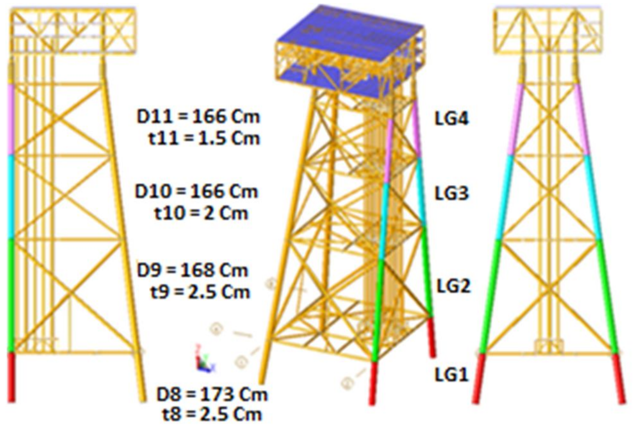

Figure 3. LG1, LG2, LG3 and LG4 member groups

The double side battered legs are situated between two levels of 64.7 *m* and 77.7 *m* below LAT, also between 35 *m* and 64.7 *m* below LAT, between two elevations of 13 *m* and 35 *m* below LAT and finally between jacket walkway frame at 5.75 *m* above LAT and 13 *m* below LAT which are named LGA, LGB, LGC and LGD respectively. These tubular members and the initial values of outer diameter and thickness are clearly shown in Figure 4.

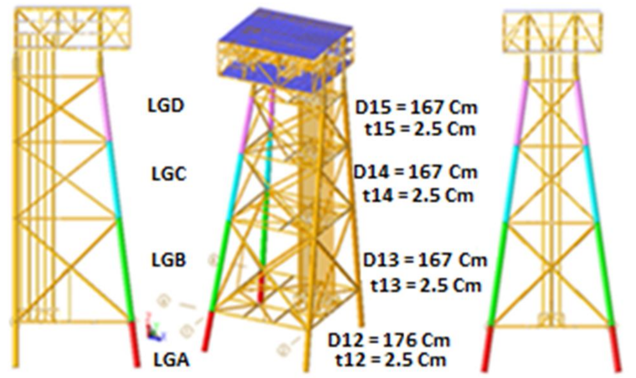

Figure 4. LGA, LGB, LGC and LGD member groups

The last group contains the vertical braces. Each brace is located between the fourth frame at 64.7 *m* below LAT and conjunction node of diagonal braces, which are located between two levels of 35 *m* and 64.7 *m* below LAT in each row. The location and the initial values of outer diameter and thickness of these braces in member group VB1 are shown in Figure 5.
Each of these sixteen member groups of the jacket tubular elements are made of welded pipes with different thickness varying from 2 *mm* up to 15 *cm* continuously. The type of steel material used for construction of this platform is S355.

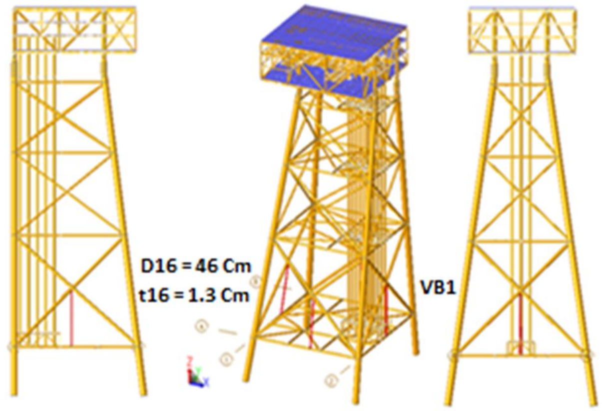

Figure 5. VB1 member group

Also, outer diameter of tubular members is a continuous variable in the optimization process. The lower and upper boundary values for this cross section Property are selected based on physical constraint that the size of outer diameter should be greater than two times the size of thickness in pipes. Also the ratio of outer diameter to thickness must not be greater than 300 based on the restriction given in API-RP-2A-WSD. Thus, the size of outer diameter for each member group varies between two and three hundred times of the size of thickness considered for that member group as continuous variable. In other words, the size of outer diameter can be selected between the lower limit equal to 4 *mm* and the upper limit equal to 45 *m*.

2.2. Objective Function

The weight of each member is calculated based on multiplying the density of steel material in its cross section area and length. The length of elements is assumed constant during the optimization process. The summation of all members' weight gives total weight of the jacket elements. Therefore, the value of jacket weight is a function of outer diameter and thickness and these values can be changed. The weight of jacket is determined by

$$W_{jacket} = \sum_{i=1}^{n} \gamma_i . L_i . A_i \quad (1)$$

In this equations γ_i stands for density of steel material of the i-th tubular member and for all steel members of the platform is constant and equal to 7.849 *Ton/m³*. L_i and A_i are the length and the cross section area of the i-th tubular member respectively. A_i is calculated by Eq.(2).

$$A_i = \frac{\pi({D_O}_i^{\,2} - ({D_O}_i - 2t_i)^2)}{4} \quad (2)$$

Where in this equation, ${D_O}_i$ and t_i are the outer diameter and thickness of the i-th tubular member, respectively. Regarding all these equations, weight of the jacket is a function of decision variables including outer diameter and thickness of its tubular members. Therefore, weight of the jacket is considered as objective function in the optimization problem as well.

2.3. Constraints

In the optimization problem we need to specify our constraints and the designs which satisfy all constraints can be supposed as the feasible designs. There are some different approaches to identify feasible designs. Analysis and design of the platform are usually carried out under different combinations of sea environmental forces and two dead and live loads in extreme storm conditions. All members of the platform are designed and controlled according to two standard specifications of API-RP-2A-WSD, 21st edition, and AISC, 9th edition, codes. Thus, the constraints of the optimization problem are based on the design criteria for three different expressions of stresses ratio, buckling and displacement controls. The SACS software calculates the maximum combined stress ratio based on stress ratios given in the codes and its value should be less than 1. For extreme environmental loads conditions which are considered in the optimization problem as a load combination, the basic allowable stresses have been increased by 0.33 as recommended in the codes.

The first important buckling of structural members is based on overall buckling. The overall buckling is controlled based on the slenderness ratio of elements by SACS finite element software.

Determination of slenderness ratio for cylindrical compression members should be in accordance with the provision given in AISC code. In the analysis for determining the effective length factors, we should consider both joint fixity and joint movement. Moreover, the characteristics of the cross-section and the loads acting on the member should be taken into account as well. Bending moment reduction factor is taken 0.85 as recommended in AISC 9th Edition, section H1.c [8]. Buckling coefficient values are given as input values in the member group properties of SACS input file and L_y, L_z are modified for each member. SACS multiplies both K and L values to estimate effective buckling length. K factors used for calculating allowable axial stresses for each member are shown in Table 1 [11].

Table 1. K factors of jacket tubular members

Member	Buckling Coefficient
Braced Jacket Legs	1.0
Unbraced Jacket Legs	1.2
Jacket Braces in elevation (face to face)	0.8
Jacket X-Braces in elevation (Longer segment length of X-braces)	0.9
Horizontal members in plan	0.8

The second important buckling of tubular elements is local buckling. For local buckling of the tubular members, we should estimate diameter to thickness ratio; *D/t;* where *D* and *t* are diameter and thickness of tubular member respectively. Unstiffened cylindrical members fabricated from steel materials should be investigated for local buckling due to axial compression when the *D/t* ratio is greater than 60. Also, when the *D/t* ratio is greater than 60 and less than 300, with thickness more than *6 mm*, both the elastic and inelastic local buckling stresses should be controlled due to the axial compression [9].

Based on offshore code specification, horizontal displacement of jacket should be limited to 1/200 height of jacket above seabed level. Since the height of jacket from seabed is 73 *m* in our case, the maximum allowable lateral deflection should be less than 36.5 cm. This constrain criterion is applied in the optimization process as the ratio of maximum lateral deflection to the maximum allowable.

Finally the minimum internal diameter of legs should be more than the outer diameter of piles with 5 *cm* minimum clearance between them in advance, due to the construction restrictions, which piles should be driven into the legs and spacers with 3 *cm* thickness should be between piles and legs.

2.4. Equivalent Free Function

The principle of the genetic algorithm is based on unconstrained functions. Therefore an additional modification function is formed by penalizing the objective function and omitting the constraints of the optimization problem to utilize genetic algorithm in optimization process. In this research, equivalent free function is determined by adding exterior penalty function to the weight objective function of the jacket. Eq.(3) shows the relationship between equivalent free function, objective function and exterior penalty function.

$$\phi = W_{jacket} + R_P . \sum_{i=1}^{nc} \left[max\left(0, \frac{g_i}{g_a} - 1\right)\right]^2 \qquad (3)$$

Where ϕ, W_{jacket} and R_P are equivalent free function, objective function and adjusting coefficient for constraints respectively. Also, g_i/g_a is the maximum stress ratio of i-th member group or the maximum horizontal deflection ratio at the working point elevation of the platform [6]. In addition nc represents the number of constraints in the optimization problem which is equal to 31 in our investigation. The adjusting coefficient is supposed here is the maximum weight of the platform with the upper limits for outer diameter and thickness of all tubular members of the jacket which becomes equal to 3749.104 *MN*, to avoid the occurrence of wrong designs.

2.5. Optimization Method

Nowadays optimization design of offshore platform has got more attention in the offshore industries due to limitation of resources and high volume of construction materials used in the offshore construction and also utilizing the new methods in the optimization process to perform it more accurately.

In the computer science field of artificial intelligence, genetic algorithms (GAs) belong to the larger class of evolutionary algorithms, which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, selection, mutation, and mate. GA method is a search heuristic method that is routinely used to generate useful solution to optimization and search problems [10].

As the decision variables of the optimization problem or genes of the chromosomes are continues and have real values, therefore, a continuous genetic algorithm is used in the optimization problem. Continuous genetic algorithm to minimize cost function, works directly with continuous variables. Also, due to using SACS software as an exterior operator to evaluate the chromosomes, the genetic algorithm which is used in this optimization problem is interactive genetic algorithm. Values considered for genetic algorithm parameters and methods used in its operators to find optimum values of outer diameter and thickness of the jacket tubular members for the platform are given in Table 2 [11].

Table 2. Specifications of the genetic algorithm

Parameter or Operator	Value or Method
Population size	50 [*Chromosome*]
Elite size	1 [*Chromosome*]
Selection	Tournament
Tournament size	10 [*Chromosome*]
Mate	Single point crossover
Crossover fraction	1
Mutation	Uniform
Mutation rate	0.01
Insertion	Complete
Stopping criterion	1000 [*Generation*]
Function value	148 [*Ton*]

3. Platform Description

The three dimensional model of platform is comprised of the jacket and topside. The optimization process of outer diameter and thickness of tubular members of the platform jacket against sea environmental forces is carried out in the conditions of the 100-year storm and still water depth. The lengths of tubular structural members of the platform jacket are considered constant and equal to their initial values. The density of steel materials of the platform members is constant and equals to 7.849 Ton/m^3. The tubular members of the platform jacket are constructed from S355 steel plate.

3.1. Fixed Offshore Platform Model

The deck structure is integrated with the jacket model to provide requisite jacket top stiffness as well as to transfer the topside loads accurately to the jacket structure. The overall size of deck is approximately 32.5 *m* × 27.516 *m* as shown in Figure 6. The topside is composed of upper deck, upper mezzanine deck, lower mezzanine deck and lower deck. All pipes and equipment such as mechanical equipment, instrumentation equipment, tanks, fire and safety equipment and electrical equipment aren't modeled on the topside decks. However, their weights are considered in the simplified platform model. The upper deck is at elevation 25.092 *m* above LAT and the upper mezzanine deck is at elevation 21.6 *m* above LAT. Also, the lower mezzanine deck and lower deck are at elevations 18.05 *m* and 13.75 *m* above LAT respectively.

The fixed offshore platform has a main intermediate four leg structure called jacket. The legs on face row 2 are single battered at 1:7 in this direction and vertical in the other. The legs on face row 1 are double battered at 1:7 in this direction and at 1:8 in the other. Foundation of the platform includes four piles which are considered extension of legs through the seabed soil to the fixity level, so that it is fixed in that elevation. These piles have a cross section with an outside diameter of 1524 *mm* and a wall thickness of 88.9 *mm*. According to type of the soil which is stiff greenish clay, the fixity level of piles is considered 8.5 times of their outside diameter. Thus the depth of fixity from seabed elevation is approximately 13 *m* [12].

The water depth at platform location is 64.7 *m* below LAT, which is also assumed to be the Chart Datum reference level. In the platform, top of jacket is at elevation 7.25 *m* above LAT, jacket walkway frame is at elevation 5.75 *m* above LAT, the second frame is at elevation 13 *m* below LAT, the third frame is at elevation 35 *m* below LAT, the conductor guide frame is at elevation 61.2 *m* below LAT and the fourth frame aligned with seabed level or mudline level is at elevation 64.7 *m* below LAT. Figure 6 shows some views of the platform model in SACS finite element software.

3.2. Environmental Data and Design Assumptions

Environmental data of the platform model for in-place analysis are based on South Pars field data. The wind loads are calculated based on the API-RP-2A-WSD, using following directional wind speeds for 100 year extreme storm conditions. The one minute mean wind speeds of maximum wind speeds at 10m above mean sea level from eight main geographical directions are given in Table 3 based on specification of project. Also it should be noted that each directional data in Table 3 represents the respective geographical direction from which winds are blowing [11].

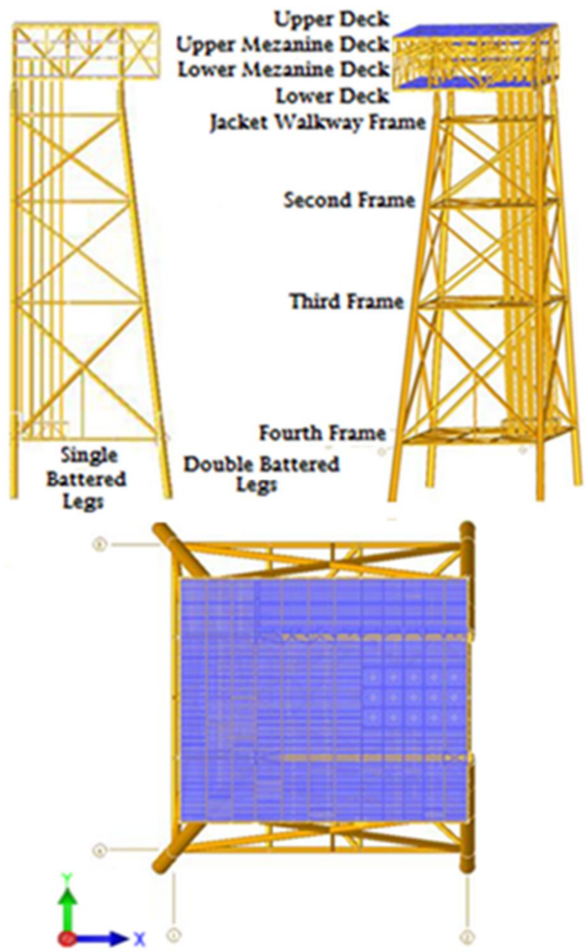

Figure 6. The platform model in SACS software

Table 3. Wind data for 100-year extreme storm conditions

Geographical Direction (from)	Wind Velocity
North	35.6 [*m/s*]
North East	34.9 [*m/s*]
East	36.0 [*m/s*]
South East	35.2 [*m/s*]
South	33.4 [*m/s*]
South West	33.0 [*m/s*]
West	35.6 [*m/s*]
North West	36.7 [*m/s*]

Wind is often treated as a time-invariant process, which has a mean value equal to its turbulent velocity. With this simplification, the effect of wind on an offshore structure is represented with a mean force. In this case the wind load is given by an expression in terms of a wind drag coefficient. The wind force acting on a unit length of a structural tubular member is found to vary with the square of the blow velocity in Eq.(4).

$$f = \frac{1}{2}\rho C_D D_O U_w^2 \quad (4)$$

Where ρ is air density, C_D is a constant known as the drag coefficient, D_O is the outer diameter of the structural tubular member normal to the wind flow and U_w is mean wind velocity. The drag coefficient is a function of the Reynolds number which is based on mean wind velocity and member diameter [9].

Minimum water depth for the in-place analysis is taken as LAT. The 100-year maximum still water depth for the in-place analysis is taken as lowest astronomical tide level from seabed plus values of mean highest high water and 100-year storm surge as shown in Table 4 [11].

Table 4. The 100-year maximum still water depth data

Geographical Direction (from)	Depth
North	66.4 [*m*]
North East	66.4 [*m*]
East	66.5 [*m*]
South East	66.6 [*m*]
South	66.5 [*m*]
South West	66.4 [*m*]
West	66.5 [*m*]
North West	66.6 [*m*]

Directional waves are used for the in-place analysis. Wave heights with associated period for 100-year extreme storm conditions are shown in Table 5. It should be noted that each directional data represents the respective geographical direction from which waves are coming. Wave loads are generated using the environmental criteria together with an applicable wave theory and Morison equation as outlined in API-RP-2A-WSD code [11].

Table 5. Wave data for 100-year extreme storm conditions

Geographical Direction (from)	Height	Period
North	9.7 [*m*]	10.0 [*s*]
North East	8.8 [*m*]	9.6 [*s*]
East	10.8 [*m*]	10.4 [*s*]
South East	11.6 [*m*]	10.8 [*s*]
South	10.2 [*m*]	10.2 [*s*]
South West	8.8 [*m*]	9.5 [*s*]
West	10.8 [*m*]	10.4 [*s*]
North West	12.2 [*m*]	11.0 [*s*]

Since the wave flow is not steady and, in particular, since the linear wave flow follows a simple harmonic motion, the flow around the cylinder will be more complex than the steady flow. In a simplified description we can say that the oscillatory flow over one cycle will change the low-pressure region immediately behind the cylinder every half cycle. As the flow direction changes, the low-pressure region will move from the downstream to the upstream side. Thus the force on the cylinder will change direction every half of a wave cycle. Combining the effects of water particle velocity and acceleration, the loading on the structure due to a regular wave is computed from the empirical formula commonly known as the Morison equation. When a current is present, the total water particle velocity is modified by adding the wave particle velocity to the current velocity. If the current is inline, the magnitudes are added to give the total velocity. For a non-collinear current, the component of current in-line with the wave is used. Additionally, the presence of the current alters the apparent wave period. The wave force acting on a unit length of a structural tubular member based on the modified Morison equation is given in Eq.(5).

$$f = \rho C_M \frac{\pi D_O^2}{4}\dot{u} + \frac{1}{2}\rho C_{DS} D_O |u + U|(u + U) \qquad (5)$$

Where in Eq.(5) ρ stands for fluid density, C_M is a constant known as the inertia coefficient, C_{DS} is a constant known as the drag coefficient which corresponds to the combined wave-current flows, D_O is outer diameter of the structural tubular member normal to the wave-current flows, u and $\dot{u}$ are horizontal wave particle velocity and acceleration respectively and finally U is uniform flow velocity [9].

In the design of offshore structures, current is generally considered time-invariant represented by its mean value. The current velocity may have a variation with water depth. The current introduces a varying pressure distribution around a member generating a steady drag force on the offshore structure in the direction of flow. If a two-dimensional structure is placed in a uniform flow, then the force experienced by the structure will depend on the fluid density, the flow velocity and the frontal area of the structure encountering the flow. The current force acting on a unit length of a structural tubular member is found to vary with the square of the flow velocity in Eq.(6).

$$f = \frac{1}{2}\rho C_D D_O U^2 \qquad (6)$$

Where ρ is fluid density, C_D is a constant known as the drag coefficient, D_O is outer diameter of the structural tubular member normal to the flow and U is uniform flow velocity [9]. It should be noted that current is always added in the wave direction. A non-linear stretching of current profile is considered with current blockage factor as per API-RP-2A-WSD.

The current data in Table 6 are given for design of the platform in 100 year extreme storm conditions based on specification of project [11].

Table 6. Current data for 100-year extreme storm conditions

Depth	Current Velocity
Surface	1.28 [*m/s*]
Mid-Depth	1.28 [*m/s*]
1.0 m above seabed	0.78 [*m/s*]
0.5 m above seabed	0.71 [*m/s*]

The thickness of marine growth is 75 *mm* from elevation 2 *m* above LAT to 6 *m* below LAT. This value of marine growth varies linearly from 75 *mm* to 50 *mm* from elevation 6 *m* below LAT to elevation 64.7 *m* below LAT. Dry density of marine growth is 1400 kg/m^3 [11].

Conductor shielding factor as per API-RP-2A-WSD is considered for selected conductors that are located behind the first line, which could be defined according to wave direction, and wave kinematics factor are respectively equal to 0.865 and 0.95. Also current blockage factors for the four leg fixed offshore platform, drag and inertia coefficients and shape coefficients to be used for perpendicular wind approach angles with respect to each projected area for all kinds of members of the platform are given in tables 7, 8 and 9 respectively based on specification of project [11].

Table 7. Current blockage factors in specified headings relative to the platform

Heading	Current Blockage Factor
End-on	0.80
Diagonal	0.85
Broad side	0.80

Table 8. Drag and inertia coefficients for platform members

Member	Drag Coefficient	Inertia Coefficient
Flat members (clean and fouled)	1.60	1.60
Tubular members (with smooth surface)	0.65	1.60
Tubular members (with rough surface)	1.05	1.20

Table 9. Shape coefficients for platform members

Member	Shape Coefficient
Smooth Cylinder	0.5
I-Beams	1.5
Projected Area of Flat Surfaces (on the Decks)	1.0

3.3. Loading

Loads on the platform are classified in three main groups which are dead loads, live loads and environmental loads. Dead loads are permanent loads on each floor such as architectural facilities, electrical equipment, fire and safety equipment, instrumentation equipment, mechanical empty equipment, dry pipes and liquids in mechanical equipment and pipes. Live loads are included in the open area, laydown area, muster area and building area. Directions for the environmental data are considered clockwise, with respect to the true North. Wave, current and wind approaching to the platform are based on these geographical directions.

The incident directions in the SACS model are given in the anti-clockwise direction with respect to the original X-axis of platform, with the platform orientation at 45° West with respect to True North. The corresponding directions between SACS and environmental data are shown in Table 10.

Table 10. SACS and environmental directions data

Geographical Direction	Direction in SACS
South East	0°
East	45°
North East	90°
North	135°
North West	180°
West	225°
South West	270°
South	315°

Eight main incident directions are considered for wind, wave and current. Four directions, which are orthogonal to the jacket, are 0^0, 90^0, 180^0 and 270^0 and four in diagonal directions are 45^0, 135^0, 225^0 and 315^0. Wind and current are added along with the waves. The wind, wave and current are considered to be coincident in time and direction. The eight main wave headings are shown in Figure 7.

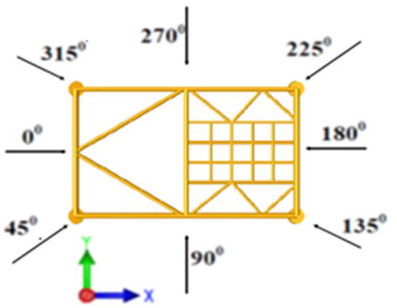

Figure 7. Eight wave, current and wind directional headings

Wave particle kinematics is computed using an appropriate wave theory and apparent wave period as per API-RP-2A-WSD. The wave kinematics factor is used to account for directional wave spreading or irregularity in wave profile shape. The current speed in the vicinity of the platform is reduced by the current blockage factor as per API-RP-2A-WSD.

4. Results and Discussion

Genetic algorithm with function value equal to 148 *Ton* during 1000 generations decreases weight of the jacket from 632 *Ton* in initial design to 484 *Ton* in optimized design.

Optimized values for outer diameter and thickness of structural tubular members of the platform jacket are given in Table 11.

Table 11. Optimized values of outer diameter and thickness

Member Group	Outer Diameter	Thickness
H01	44 [*cm*]	0.9 [*cm*]
H02	36 [*cm*]	0.5 [*cm*]
H03	45 [*cm*]	0.5 [*cm*]
H04	44 [*cm*]	0.7 [*cm*]
JB1	90 [*cm*]	1.1 [*cm*]
JB2	68 [*cm*]	0.7 [*cm*]
JB3	93 [*cm*]	0.8 [*cm*]
LG1	255 [*cm*]	2.4 [*cm*]
LG2	168 [*cm*]	1.9 [*cm*]
LG3	166 [*cm*]	1.5 [*cm*]
LG4	165 [*cm*]	1 [*cm*]
LGA	282 [*cm*]	2 [*cm*]
LGB	167 [*cm*]	2.1 [*cm*]
LGC	166 [*cm*]	1.6 [*cm*]
LGD	166 [*cm*]	1.2 [*cm*]
VB1	95 [*cm*]	0.4 [*cm*]

In the optimization process, merely the cross-sectional properties of the jacket members are changed as decision variables of optimization problem, while their other geometric and physical properties and amount of the gravity loads and sea environmental forces including wave, current and wind imposed on the platform and as well as their direction are maintained constant during this process. Therefore, variation of the drag forces of wave, current and wind on a unit length of tubular members depends on the amount of changing outer diameter. However, variation of the inertia force of wave on a unit length of these members depends on the square of their changing outer diameter.

The initial and optimized values obtained in the optimization process for outer diameter of structural tubular members of sixteen member groups of the platform jacket and their differences are shown in Figure 8.

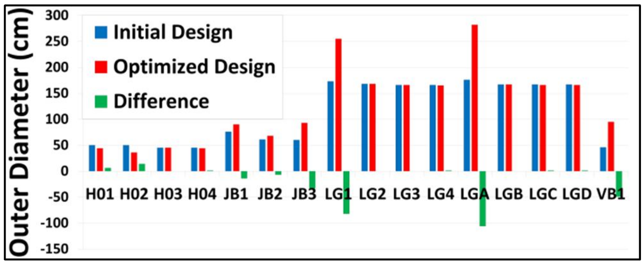

Figure 8. The initial and optimized values of outer diameter of structural tubular members and their differences

Figure 8 shows initial and optimized outer diameter of all member groups of the jacket. As it is clear the outer diameters of horizontal members and legs are almost constant during optimization process except diagonal and vertical braces and the legs which are located below the mudline including LG1 and LGA.

By changing outer diameter of the structural tubular members during the optimization process, sea environmental forces on a unit length of these members and their resultant forces on the platform are being altered. According to constancy size of outer diameter of horizontal members and legs of the jacket which are subjected to the sea environmental forces and increment the size of outer diameter of diagonal and vertical braces, the total maximum environmental force on the platform is increased from 7265.590 *KN* to 7645.602 *KN*. So that the maximum values of sea environmental forces of wave, current and wind on the platform in initial design, which are equal to 4677.732 *KN*, 825.186 *KN* and 1762.672 *KN*, are changed to 5093.33 *KN*, 859.221 *KN* and 1693.051 *KN* respectively in the optimized design. Thus, despite the reduction in the weight of the platform, the amount of total sea environmental force acting on the platform is increased, so that wave has the largest quota than the other two in this increase, because of the inertia term.

In the optimization problem, the aim of optimizing the design of a fixed offshore platform is to decrease the amount of steel materials used for construction. The amounts of steel materials used in the sixteen member groups of the jacket in initial and optimized designs and their differences are shown in Figure 9.

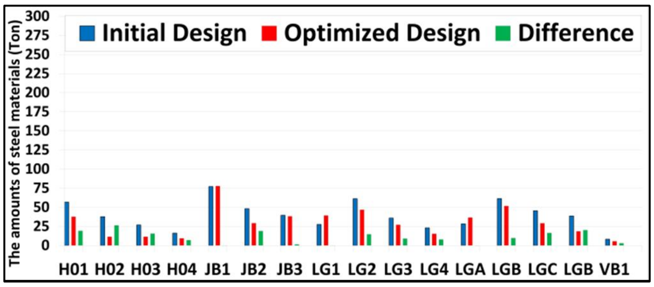

Figure 9. Amounts of steel materials used in the sixteen member groups of the jacket in initial and optimized designs and their differences

Figure 9 indicates the amounts of steel materials needed for thirteen member groups of the jacket are decreased 168 *Ton* in total, but the amounts of steel materials needed for JB1, LG1 and LGA are increased 20 *Ton* in total. Finally the reduction of 148 *Ton* is equal to 23 percent of jacket weight form the initial design. Figure 10 shows the contribution percentages of these sixteen member groups of the jacket in optimization process.

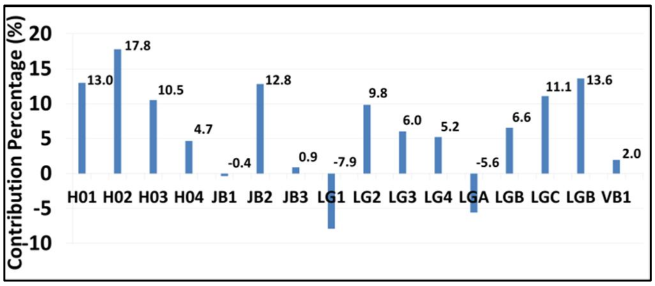

Figure 10. Contribution percentage of the sixteen member groups of the jacket in optimization process

As it is clear from this figure, the maximum contribution comes from three elements of H02, LGB and H01 with 17.8, 13.6 and 13 respectively and 44.4 percent in total. The contribution percentages for three elements of JB1, LG1 and LGA are negative and outer diameters of them are increased in the optimization problem. But it should be noted that JB1 is just subjected to the environmental forces between these three elements. So this member group shouldn't be considered in the optimization problem as decision variable. The total percentage of contribution for four main groups are calculated and shown in Figure 11.

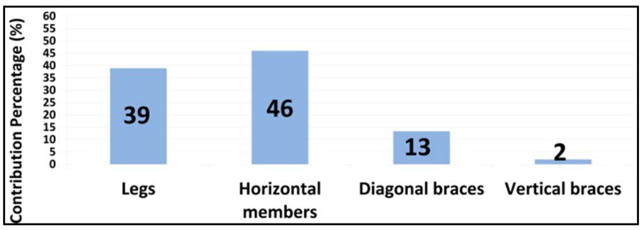

Figure 11. Contribution percentage of the jacket four main groups in optimization process

As is clear from this figure, Horizontal Members of the jacket with 46 percent have the highest contribution in optimization process. Afterward legs and diagonal braces with 39 percent and 13 percent respectively, show the importance in the contribution percentage as second and third ranks. Finally, vertical braces with contribution percentage of 2 percent have the least importance in optimization process. As regards this member group increases environmental forces, therefore they can be excluded from the optimization process.

5. Conclusions

Optimizing the design of a fixed offshore platform decreases the amount of steel materials used for construction and weight of platform, while sea environmental forces on the platform depend on diameters of elements. The drag terms in the wave, current and wind force calculations on a unit length of tubular members of jacket are related to the outer diameter of elements and the inertia force depends on the square of the outer diameter. In this paper it is shown that the total sea environmental force is increased due to changing outer diameter of tubular elements during optimization process.
The structural members of jacket are classified in four main groups including legs, horizontal members, diagonal braces and vertical braces. Each of these groups has different percentage of contribution in the optimization process and has been investigated in this research. The results show that horizontal members have significant contribution with 46 percent. Then legs and diagonal braces with 39 and 13 percent respectively, are ranked second and third in the importance. Finally, vertical braces with 2 percent have the minimum importance in optimization process and it is possible to exclude these elements from the optimization process. Also, it is observed however diagonal braces have 13 percent of contribution percentage in the optimization process, but their outer diameter are increased and so they increase the amount of sea environmental forces on the platform unlike horizontal members and legs of the jacket which are subjected to the sea environmental forces.

6. List of Symbols

LAT Lowest Astronomical Tide
L_y Effective buckling length around the y axis [m]
L_z Effective buckling length around the z axis [m]
K Buckling Coefficient
L Effective buckling length

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