Design Optimization of Braces for Three-Legged Minimum Jacket Offshore Structure

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Abstract. The innovative design of offshore structures has developed rapidly in line with the increasing demand for energy from oil and gas in the world. One of the innovations is the effort to use a modified or minimum jacket structure. The minimum jacket structure is a concept that is very suitable to use in shallow water marginal fields, because the structural design is more economical in terms of cost, reusable, and easier to move than the conventional jacket. This study presents design optimization of the existing jacket platform in terms of brace pattern (configuration) and dimension selection with the objective function being to minimize the weight of the jacket platform. The optimization process was carried out with 2 steps of optimization scenarios which are selecting the most optimal jacket brace configuration among various variations and determining the most optimal jacket brace dimensions through a static in-place analysis of the jacket structure. The brace configuration variations considered are V-brace, N-brace, and K-brace patterns. The second optimization step is the determination of the brace dimensions including outside diameter (OD) and wall thickness (WT) by considering 12 model variations. The results showed that the optimization result on the existing minimum jacket has complied with the whole criteria and yielded a lighter structure weight of 3,542.11 kips. This optimized minimum jacket structure became 15.9% lighter than the weight of the existing initial jacket structure, which is 4,211.96 kips.

Keywords: Topology optimization · Minimum weight · Brace pattern · Minimum jacket offshore structure

1 Introduction

The development of oil and gas technology is always accompanied by innovations, especially in the jacket structure design. Design of minimum facility platforms (MFPs) is expected to produce a minimum jacket structure in terms of the weight of the structure and more economical cost, so that it is suitable for marginal field exploration.

Previously, there have been many studies discussing the modification of the minimum jacket structure. One of them was using a modular design approach for minimum low-cost facilities. The study has conducted modifications to obtain a minimum jacket structure which used conductors as the main support for the topside in which it is called Conductor Supported Minimum Offshore Structures (CoSMOs) [1]. Another research on minimum

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jacket platforms has also been carried out by designing a minimum jacket for marginal areas in western India in which the research compared the form of a minimum jacket structure with leg variations [2].

Optimization is a very important process at the initial stage of designing the jacket structure because the design optimization process aims to obtain an optimal jacket structure both in terms of shape and strength. Previous research with the structural optimization method has been carried out by optimizing the tie-brace design of the blasting dolphin structure at the oil/condensate terminal of the Idol strait due to the increasing load on the export activity of the tanker [3]. Moreover, a study about the optimum arrangement of braces on jacket platforms based on strength and ductility has been done. By using a simple logical method for investigating the strength and ductility of the jacket structure, it is shown that the global geometry and configuration of the braces are very important and effective in both strength and ductility parameters [4]. In addition, research at Bohai Gulf proposed an acceleration-oriented design optimization of ice-resistant jacket platforms. This approach focused on the dynamic performance of the jacket platforms in terms of the deck acceleration and worked on the structural optimization technique to achieve economical and rational design [5].

Another study is about Optimization Approach in Offshore Wind Energy Supporting Structure Design in which optimization is used in the conceptual design stage of the wind turbine. The optimization process is carried out by two methods, which are artificial intelligence and optimization selection methods [6]. Moreover, there is a study about topology optimization design for offshore platform jacket structure in which the optimization results are compared to the original platform for static performance, dynamic performance, and Ultimate Carrying Capacity (UCC) [7]. In addition, another study on the design optimization process of a fixed jacket offshore platform under environmental loads was done. This study utilized an objective function of the amount of steel material used by the structural members with variations in their diameter and thickness [8].

The present study discusses design optimization of the brace configuration and dimension of an existing three-legged jacket structure in order to obtain the minimal weight of the jacket. The optimization process was carried out in 2 steps of optimization scenarios. The first step is to make a selection from a variety of brace configurations and then followed by sizing the outside diameter (OD) and wall thickness (WT) of the members for the selected brace pattern.

2 Method

The flowchart of the design optimization of braces for the minimum jacket is shown in Fig. 1. In this study, optimization was carried out to design a three-legged minimum jacket structure with a minimum weight in which the weight of the jacket must be lighter than the existing conventional jacket. Based on the flowchart, the first step in this analysis is modeling the jacket structure using SACS 12 software and validating with the weight control data from the company. After modeling the minimum jacket, input the loads on the structure such as all equipment loads, operational loads, live loads, and environmental loads.

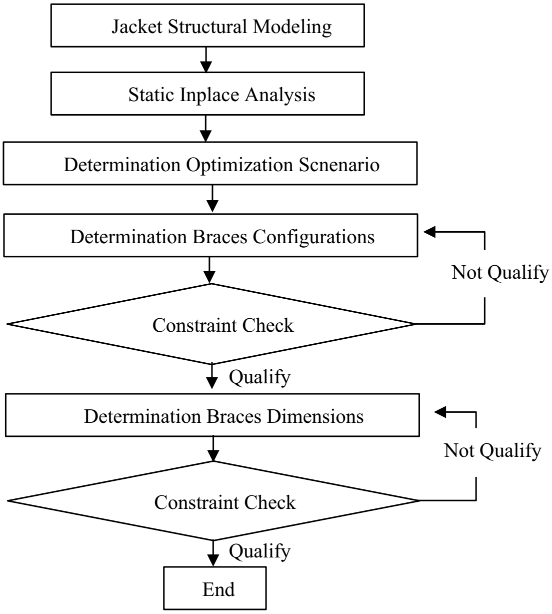


Fig. 1. Flowchart of the design optimization of brace system

In-place analysis is a static analysis used to ascertain whether the structure can withstand the load when it is being operated, either gravity load (dead load, live load, and equipment load) or environment load. In this analysis, a ratio between member stress and allowable stress, called UC (unity check), is used to assess the strength adequacy of all structural members of the jacket structure where the UC value must be less than 1.

In this study, optimization was carried out to design a three-legged minimum jacket structure with minimum weight. Determination of the optimization scenario on a minimum jacket structure refers to API RP2 A WSD code [9]. The following equation was used to calculate the weight of the jacket structure.

$$wjacket = \sum_{i=1}^{n} Yi.Li.Ai \tag{1}$$

where Yi is the density of the material, and Li and Ai are the length and cross-sectional area of the structural members. The optimization scenario of the minimum jacket structure is by selecting the variation of the brace configuration and the variation of the brace dimension, either outside diameter (OD) or wall thickness (WT).

The shape of braces to be considered consists of several types, such as K-braces, V-braces, N-braces, and X-braces. Each brace has its advantages and disadvantages. The selection of the brace type should be based on the environment, redundancy, and structural characteristics of the jacket [10]. Changes to the jacket configuration will be carried out at an elevation of -110 ft to -224 ft with the existing configuration being the X-braces.

Determination of the jacket structure bracing dimension was carried out in 2 stages. The first stage is the determination of the initial brace dimension variation. Based on API RP 2A WSD about structural steel pipe, for the selection of braces dimension variation refers to the API 5L 2004 code [11]. After determining the initial dimension, the tubular joint criteria must be checked based on API RP 2 WSD by using the geometric parameters of β, τ, γ, and D/t. Then in the second stage, the most optimum value of the braces dimension was calculated. Changes in the brace dimensions (horizontal and diagonal braces) were applied to all jacket elevations by making 12 variations of the braces dimension.

3 Results and Discussion

3.1 Jacket Structural Modeling

The jacket structure was modeled by using SACS software in terms of the jacket substructure only. A topside/superstructure part of the platform with a weight of 1,050 kips was modeled as joint loads exerted on top of the jacket. The structural model of the jacket structure can be seen in Fig. 2.

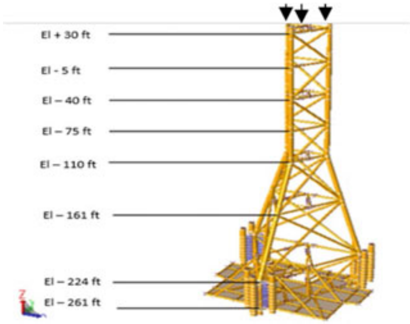


Fig. 2. Model of the minimum jacket platform for the analysis

3.2 Static In-Place Analysis

Based on the in-place analysis carried out on the minimum jacket structure, it is obtained that all members have UC < 1, in which the member with the largest UC is at member 0022–0025 with a UC of 0.261. This largest UC is still relatively small, therefore an optimization can be carried out to obtain the optimum jacket structure in terms of the weight of the structure.

3.3 The Optimization Scenario

The jacket optimization was carried out by 2 optimization scenarios, which are by selecting the variation of the brace's configuration at an elevation of –110 ft to -224 ft and the second scenario is the determination of the brace dimension (horizontal and diagonal braces) at elevations (+) 30 ft to (−) 224 ft of the jacket.

The objective function of the jacket optimization is the weight of the jacket structure. Meanwhile, the constraints for the optimization with the brace configuration selection are stress (UC < 1) and slenderness ratio (kL/r < 90) of the member, while the brace dimension optimization constraints are the joint deflection check (deflection < 0.875), joint punching shear stress check (UC < 1), and member stress unity check (UC < 1).

3.4 Determination of the Braces Configuration or Pattern

Braces configuration optimization (first optimization scenario) was carried out for the elevation of (+) 110 ft to (−) 224 ft. Figure3 shows results of the modeling and in-place analysis on the SACS software with K-brace, N-brace, and V-brace configurations.

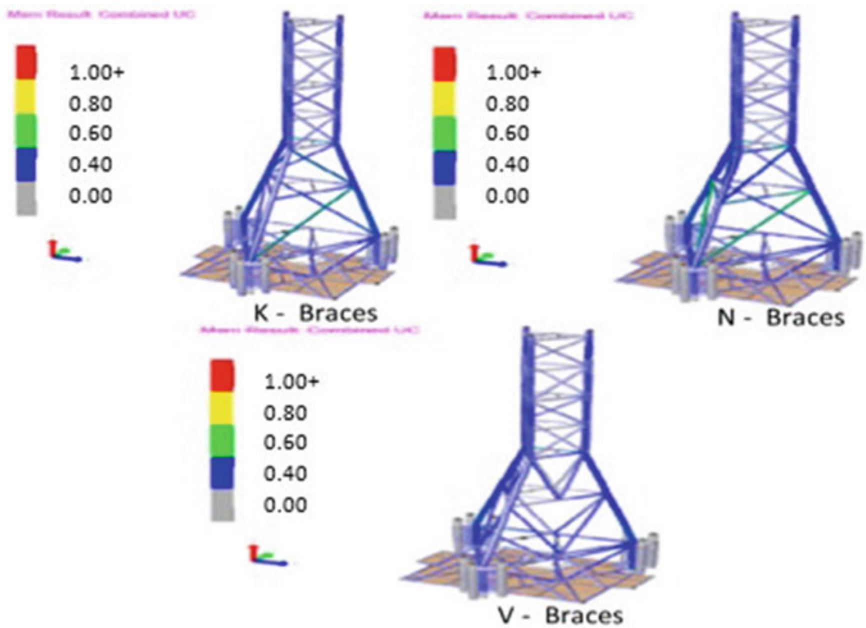


Fig. 3. In-place analysis result with K-brace, N-braces, and V-braces

Determination of the most optimum brace configuration should refer to the constraint, but it is also necessary to consider the weight of the jacket structure because the objective function of this optimization is to minimize weight. Table 1 shows a comparison of the performance of each brace configuration considered based on the maximum constraint criteria.

Based on Table 1, the maximum UC for each configuration of K-braces, N-braces, and V-braces qualifies the constraint because of all of them resulting in UC < 1, while in the slenderness ratio constraint, only the V-brace configuration qualifies the constraint

Table 1. Comparison of each brace configuration performance

Brace configuration	Max UC	Max slenderness ratio	Weight (kips)
K-brace	0.316	110.459	3,961.70
N-brace	0.386	110.459	3,968.87
V-brace	0.326	75.909	4,084.81

because of the slenderness ratio (kL/r) < 90. Then the V-brace configuration is considered as the most optimum configuration at the elevation of (−) 161 ft to (−) 224 ft because it qualifies all constraint criteria and also the resulting weight is lighter than the initial weight of the jacket structure.

3.5 Determination of Brace Dimensions

Determination of brace dimensions was carried out in 2 stages; the first is selecting the initial dimensions (wall thickness and outside diameter) with 3 outside diameter and 4 wall thickness variations for both horizontal and diagonal braces. Then, all the initial dimensions must be checked with tubular joint criteria based on API RP 2 A WSD. The result shows that all variations in the brace dimensions qualify for the tubular joint criteria check. The brace dimension optimization (second optimization scenario) was carried out for the elevation of (+) 30 ft to (−) 224 ft.

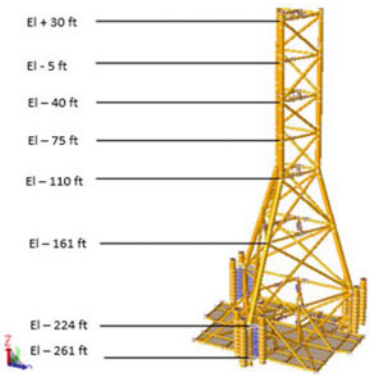
The second stage is to determine the most optimum model of the jacket structure. Based on the selected brace dimensions, all the 12 variation models of the three-legged jacket structure were evaluated based on all loads imposed on it through the in-place analysis and constraint checks. The results in terms of performance comparison of all the 12 models are presented in Table 2.

Determination of the most optimum model must qualify all constraint criteria, in which based on Table 2 almost all models qualify the constraint criteria, except for Model 4 and Model 8. Since the objective function of optimization is to minimize the weight of the jacket, the weight of each jacket structure model will also be reviewed. Based on Table 2, the most optimum option finally is Model 12 because the model qualifies for all constraint criteria and also produces the most minimum weight compared to other models.

Figure4 presents the final form of the minimum jacket structure before and after the optimization, while Table 3 outlines a comparison between the minimum jacket structure before and after the optimization process for all parameters considered.

Table 2. Comparison of all the 12 models based on all constraints considered

Model name	Vertical brace (OD × WT) inch	Horizontal brace (OD × WT) inch	Weight (kips)	Member stress UC	Criteria	Joint punching UC	Criteria	Deflection (ft)	Criteria
Model 1	28 × 1	22 × 0.75	3,872.7	0.345	Ok	0.482	Ok	0.447	Ok
Model 2	28 × 0.875	22 × 0.625	3,791.0	0.392	Ok	0.525	Ok	0.479	Ok
Model 3	28 × 0.688	22 × 0.5	3,681.4	0.461	Ok	0.757	Ok	0.525	Ok
Model 4	26 × 0.5	22 × 0.375	3,569.9	0.557	Ok	1.247	Not ok	0.618	Ok
Model 5	26 × 1	20 × 0.75	3,837.6	0.377	Ok	0.433	Ok	0.468	Ok
Model 6	26 × 0.875	20 × 0.625	3,748.0	0.429	Ok	0.516	Ok	0.492	Ok
Model 7	26 × 0.688	20 × 0.5	3,647.8	0.504	Ok	0.746	Ok	0.548	Ok
Model 8	26 × 0.5	20 × 0.375	3,545.8	0.63	Ok	1.22	Not ok	0.648	Ok
Model 9	24 × 1	18 × 0.75	3,795.7	0.419	Ok	0.429	Ok	0.49	Ok
Model 10	24 × 0.875	18 × 0.625	3,728.9	0.477	Ok	0.503	Ok	0.513	Ok
Model 11	24 × 0.688	18 × 0.5	3,635.7	0.56	Ok	0.799	Ok	0.574	Ok
Model 12	24 × 0.5	18 × 0.375	3,542.1	0.698	Ok	0.92	Ok	0.683	Ok



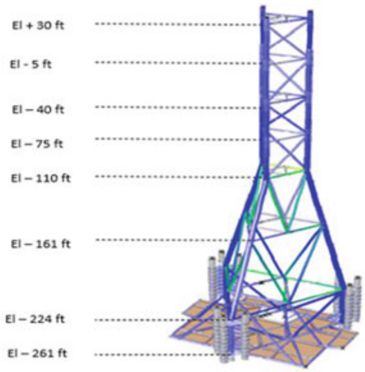


Fig. 4. Comparison of the three-legged minimum jacket structure model: before the optimization (left figure), and after the optimization (right figure)

Table 3. Comparison of a three-legged minimum jacket structure before and after the optimization in terms of weight, strength, dimensions, and brace configuration

Description	Minimum jacket before optimization	Minimum jacket after optimization
Self-weight (Kips)	4,211.96	3,542.13
Maximum Joint Deflection (ft)	0.354 ft	0.683
Maximum Member Stress (UC)	0.287	0.698
Maximum Joint Punching Shear (UC)	0.227	0.92
Outside Diameter Diagonal Braces (inch)	28–30	24
Wall thickness Diagonal Braces (inch)	1.25–1.375	0.5
Outside Diameter Horizontal Braces (inch)	22–26	18
Wall Thickness Horizontal Braces (inch)	0.75–1.00	0.375
Brace configuration at elevation (+) 110 ft to (−) 224 ft	X-braces	V-braces

4 Conclusion

In this study, the optimization aims to produce a lighter minimum jacket structure weight based on the optimum brace configuration system and dimensions. The optimal dimensions of the braces for the optimum three-legged minimum jacket structure are for diagonal braces with an outside diameter of 24 inches and a wall thickness of 0.5 inches, while the horizontal braces have an outside diameter of 18 inches and a wall thickness of 0.375 inches. Then the optimum jacket structure used a K-brace configuration at the elevation of (+) 30 ft to (−) 110 ft and a V-brace configuration at the elevation of (−) 110 ft to (−) 224 ft. The optimum weight of the three-legged minimum jacket structure after the optimization process is 3,542.13 kips, in which the minimum jacket weight after optimization is 15.9% lighter than the existing one before the optimization of 4,211.96 kips.

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