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Multi-objective optimization of Tension Leg Platform using evolutionary algorithm based on surrogate model

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ABSTRACT

An Innovative Tension Leg Platform (TLP) Optimization Program, called ITOP, has been developed to solve the multi-objective optimization problem for TLP. We first examine the hydrodynamic behavior of a base TLP for wave headings between 0° and 45°. The numerical results show that the maximum heave and surge motion responses occur in 0° wave heading in long-crest waves. It is found that the dynamic tension of No. 8 tendon is larger than the other tendons and reaches its maximum in 45° wave heading. It can be attributed to the fact that heave and pitch motions are almost out of phase for wave periods between 10 and 15 s. Because the maximum wave elevation occurs near the northeast column and the vertical motion is very small, the minimum airgap occurs there. Moreover, a surrogate model based on radial basis function (RBF) has been built and adopted to estimate the hydrodynamic performance of TLP. A multi-objective evolutionary algorithm, Non-dominated Sorting Genetic Algorithm II (NSGAII), is employed to find the Pareto-optimal solutions. By comprehensive and systematic computations and analyses, it is revealed that the maximum dynamic tension shows positive correlation with pontoon height and width, but negative correlation with hull draft, column spacing, and column diameter. The most efficient modification strategy for design is proposed to reduce the maximum dynamic tendon tension. According to the strategy, the column spacing, draft, and column diameter should be increased in sequence. By applying this strategy, the maximum dynamic tendon tensions can be reduced while the total weight of the platform is minimized as much as possible.

1. Introduction

As the offshore oil/gas exploration moves toward deep water, floating production platforms, such as Floating Production Storage and Offloading (FPSO), Semi-submersible (SEMI), Tension Leg Platform (TLP), and Spar, have been widely adopted in recent years (API RP 2SK, 2005). Different from the other three floater concepts either using taut or semi-taut mooring systems, TLP is a compliant floating platform moored to seabed by several tendons which are pretensioned by excess buoyancy over total structural weight. The stability and vertical motion performance (heave, roll, and pitch) of TLP are much better than FPSO and traditional SEMI. Because of TLP's excellent motion performance, production wellheads and dry tree can be placed on the deck so that the cost for fabrication, production, and maintenance can be reduced accordingly. In conceptual or preliminary design phases, hull sizing is one of the most important task which can have significant effects on global motion performance and total cost for a project. In practice, hull sizing is an iterative process, which can be called as 'design spiral' (API RP 2T, 1997). It usually relies on designers' engineering experience acquired from the previous projects. Therefore, through conventional design approach, it's very difficult and time-consuming to achieve an optimal design for better global motion performance and lower cost.

A few researchers have put forward the optimization methods in order to achieve the optimal hydrodynamic performance for various offshore floating structures. For example, Akagi et al. (1984) applied generalized reduced gradient algorithm (GRGA) on hull-form optimization for a SEMI, in which the displacement, variable load, and heave motion were analytically formulated as objectives. Clauss and Birk (1996) used a commercial code, WAMIT, to evaluate the hydrodynamic performance of an arbitrary hull form, instead of using simplified

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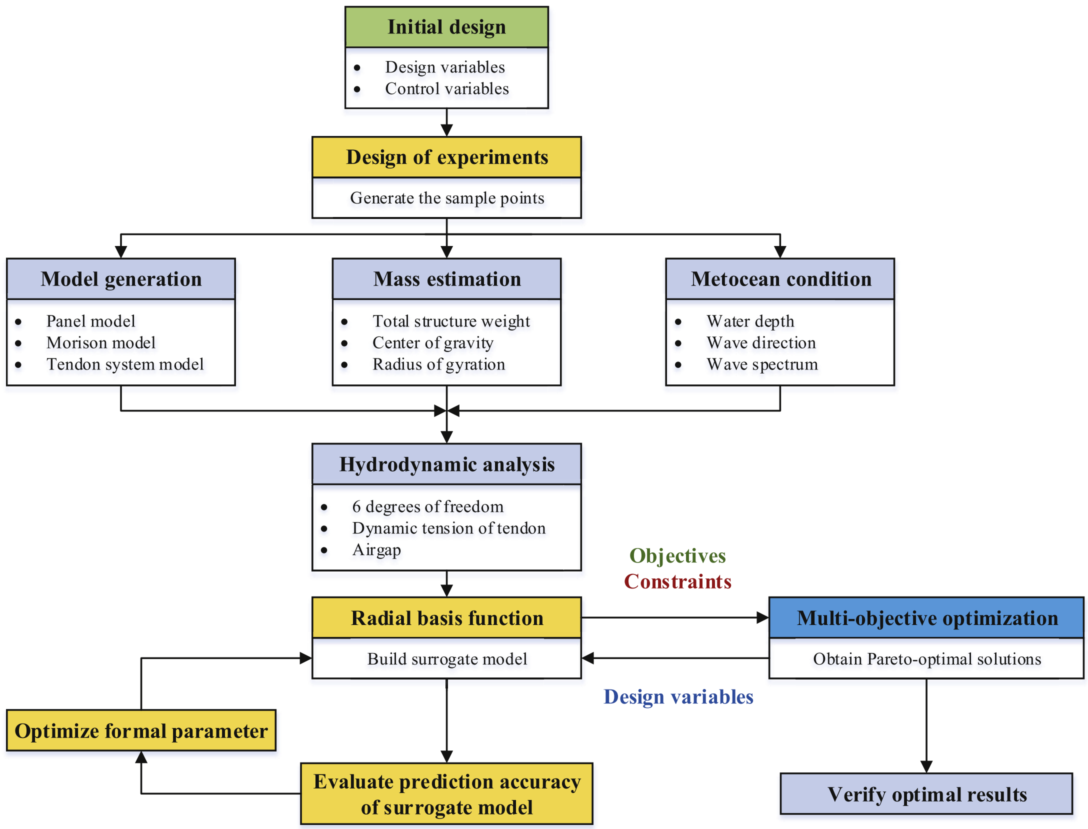

Fig. 1. Flowchart of overall optimization process. Gray modules: numerical simulations for hydrodynamic estimation; Yellow modules: construction of surrogate models; Blue modules: iterative optimization process; Green module: an initial design obtained from conceptual design stage. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

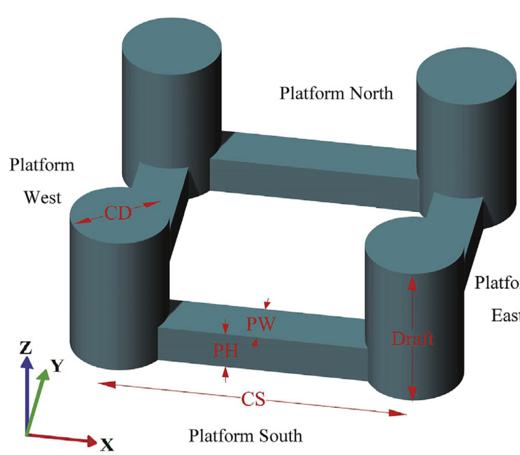

Fig. 2. Definition of the main particulars of the base TLP. CD: column diameter; CS: column spacing; PW: pontoon width; PH: pontoon height.

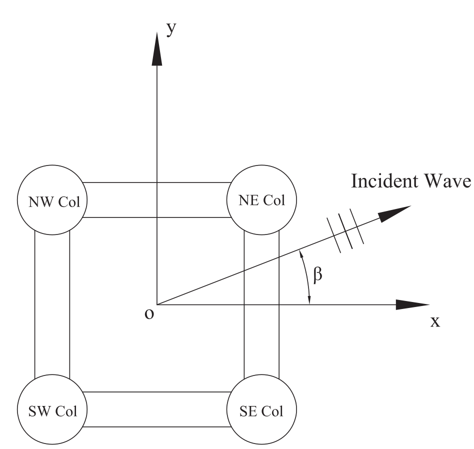

Fig. 3. Definition of incident wave heading β (Plan View) and index of four columns. NW Col: northwest column; NE Col: northeast column; SW Col: southwest column; SE Col: southeast column.

formulae. In the study, nonlinear programming approach (NLP) was introduced to seek the minimum downtime of three different types of offshore structures, including gravity base structure (GBS), TLP, and SEMI. In order to reduce the design variables, Vannucci (1996) simplified the configuration of a TLP by a cylinder with two additional square plates. Based on this simplified model, the minimum weight was obtained by taking stability and hydrodynamic performance as constraints. Birk et al. (2004) compared the differences on improving the seakeeping performance between the deterministic method, such as Sequential Quadratic Programming (SQP), and the global methods, such as Genetic Algorithm (GA) and Adaptive Simulated Annealing (ASA). In their study, the hydrodynamic behavior of each design was estimated using WAMIT. Lee et al. (2007) utilized SQP and GA for the optimization of TLP by considering tendon fatigue life as an objective. Different from this previous hydrodynamic computations, where tendon tensions were simplified by equivalent linear spring, fully coupled analyses, comprised of frequency-domain and time-domain coupled analyses, were conducted by Lee and Lim (2008). More efficient hull shape optimization was obtained based on more accurate prediction of TLP's dynamic behaviors. Birk (2009) adopted a variant of multi-objective evolutionary algorithm (ε-MOEA) for minimizing heave motion while maximizing deck load of a SEMI-type floater. They integrated parametric design tools,