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Stress verification of a TLP under extreme wave environment

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Abstract: Stress response of a tension leg platform (TLP) in extreme environments was investigated in this paper. A location on one of the gussets was selected as the object point, where directional stresses were numerically simulated and also experimentally verified by a strain gage. Environmental loading and the platform's structural strength were analyzed in accordance with industrial standards, utilizing linear wave theory and the finite element method (FEM). The fast Fourier transform technique was used to calculate the stress response amplitude operators (RAO) from the records of measurements. A comparison was performed between the stress RAO of the numerical simulation and that of the actual measurements. The results indicated that the stress RAO of the numerical simulation fitted well with measured data at specified wave headings with different periods.

Keywords: TLP; stress RAO; extreme environment; numerical simulation; monitoring measurement
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1 Introduction

Offshore structural damage by hurricanes is attracting more and more attention at present. In the Gulf of Mexico, many platforms, rigs, MODUs and pipeline segments were damaged by hurricane Ivan, Katrina and Rita in 2005. Sea-star TLP TYPHOON was one of the examples of serious damages, which capsized by Rita due to one of its broken mooring lines. In view of these incidents, offshore standards for design and construction have to be improved to make these structures adapt to hostile and extreme conditions[1]. Besides the common design operating and survival conditions (1 year, 10 years and 100 years), the extreme condition as high as 1 000 year return period may need to be considered in the design verification.

The study on TLP started relatively late in China, and had been carried out only by fewer researchers. Most of the work focused on the design methods and analysis techniques based on some conceptual design of platforms. The Group for Typical Deep Water Platform Conceptual Design[2-4] analyzed a 1 000 m water depth classical TLP on scantling methodology, hydrodynamics, structural strength, fabrication and installation. Their study details the hydro pressure, global stress, girder/stiffener sizing consideration. DNV Sesam code was used as the main tool to perform the analysis.

ZENG, et al.[5-6] developed a theoretical model for analyzing the nonlinear dynamic behavior of a tension leg platform with finite displacement. The governing differential equations of the tension leg platform considering comprehensive nonlinearities are deduced. The numerical analysis of a typical tension leg platform named 'ISSC TLP' was performed. Yu, et al.[7] introduced a basic structure and motion characteristics of TLP analysis method including frequency-domain solution and time-domain solution.

Because of the complexity of a real sea, model test is usually necessary to verify theoretical design and analysis for large scale platforms. Thomas B. et al.[8] calculated Snorre TLP response in the time domain using the SIMO software developed by MARINTEK. It was concluded that the main discrepancy between the model test and analysis results of tether tension was not in the magnitude but in the simultaneity of wave frequent and high frequent tether response. A. Naess, et al.[9] presented a study of the extreme response statistics of a tension leg platform (TLP) in random seas.

However model test in a small scale can only simulate the original platform approximatively. In some aspects, model test can't give reasonable results because of the restrictions of model sizes, basin tank and operations. The challenging development of new platform concepts and their installation in deeper water in more remote areas and more severe weather conditions requires direct feedbacks from offshore experience, design and engineering. Moreover the platform operation itself can be enhanced by utilizing the actual behavior of the platform and its environmental conditions. The full scale monitoring measurement can show the platform's response accurately. H. Van, et al.[10]

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etc. pointed out the importance of platform's monitoring on site. He also pointed out that the present day's sensor technology, data acquisition and transmission systems enable the continuous monitoring of the structure's dynamic response to the actual environmental conditions. Motions, loads, structural response as well as the detailed wind, wave and current conditions at the platform can be recorded to derive the environmental loading, the platform response characteristics and special phenomena such as VIV. Obviously adequate analysis and presentation of the measured results are crucial to meeting the objectives of a monitoring campaign. Radboud, et al.[11] presented their full scale monitoring work of Marco Polo TLP, which experienced hurricanes Ivan, Katrina and Rita in 2005. Many valuable data were collected on the wave, wind, current, as well as the response of the TLP in the hurricane conditions.

This paper analyzes the stress level of a gusset of a large TLP using numerical method. A comparison between measured and numerical results is performed and it shows that numerical analysis can simulate platform's actual response reasonably and accurately.

2 Loads and responses

The TLP hull structure consists of four columns, a base, a node and a tension support structure (TSS). The Node is located at the lower ends of the columns and connects the TSS to the base structure. The hull size is shown in Fig.1.

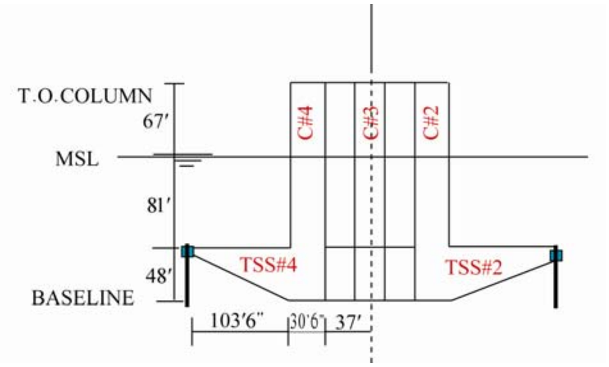


Fig.1 The main sizes of TLP hull

The hydrodynamic analysis was carried out for survival conditions using WAMIT (MIT). The wetted surface of the hull was modeled with 11720 nodes and 11680 elements (Fig.2). The model weight, center of gravity and inertia radius were based on the data for the original platform. The added mass and damping were adjusted according to the model test data and experience about this TLP prototype.

The FE model was created using Ansys, which had 58800 nodes and 107700 elements. One of the vertical gussets was selected as the crucial stress component. Monitoring gages were placed on the gusset and the stress was posted at the same location.

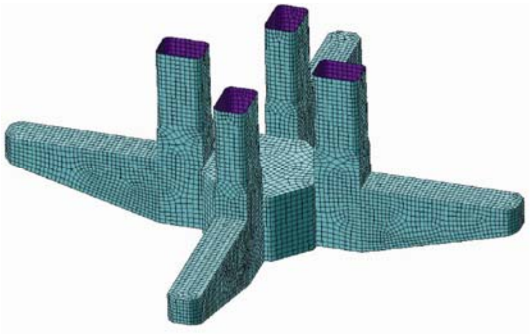
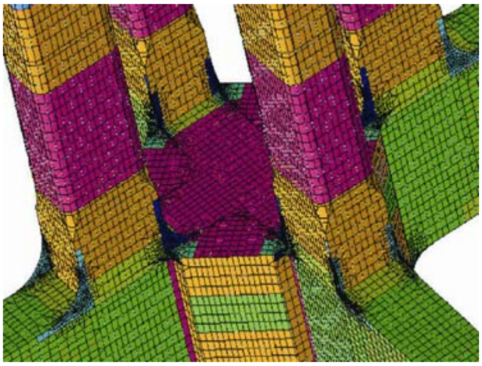


Fig.2 Wet panel model of the TLP

(a)Strain gauge layouts



(b) FE model

Fig.3 Strain gauge layouts and FE model

The spectral method is used to calculate the stress RAOs with different wave directions and circular frequencies (Fig.4). In total 16 wave directions and 20 frequencies were set up in the process. The hydrodynamic load was calculated using the linear 3-D frequency-domain method (WAMIT).

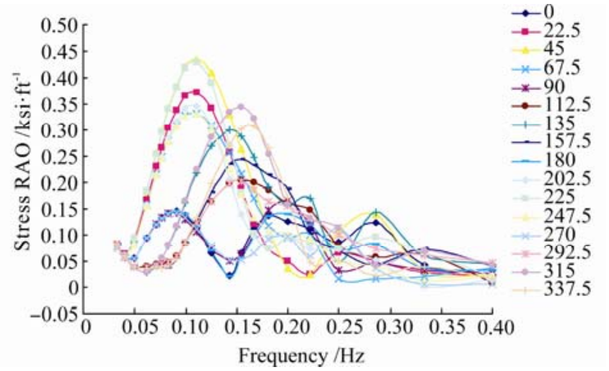


Fig.4 Stress RAO of numerical analysis

3 Monitoring data process

Since the short period waves can be treated as a stationary normal stochastic process, the structure responses induced by these waves can be described by a linear time-invariant system. Utilizing linear transformation method of stochastic process theories, the structural stress response characteristics can be obtained from the statistical properties of the waves. Under the wave pressures, the output responses relating to wave input is as follows:

$$S_{\varsigma}(\omega,\theta)=[H(\omega,\theta)]^{2}S_{w}(\omega,\theta). \tag{1}$$

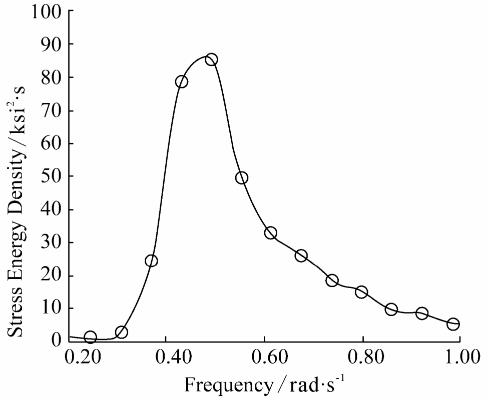
In the equation, $H(\omega,\theta)$ is linear dynamic system transfer function; $S_{\varsigma}(\omega,\theta)$ is responses (wave load, motions, stress etc.) spectral density; $S_{w}(\omega,\theta)$ is wave spectral density; ω is wave circular frequency; θ is wave heading relative to the reference axis.

Six sets of monitoring stress and wave data were selected for processing. The significant wave heights and peak periods are listed in Table.1.

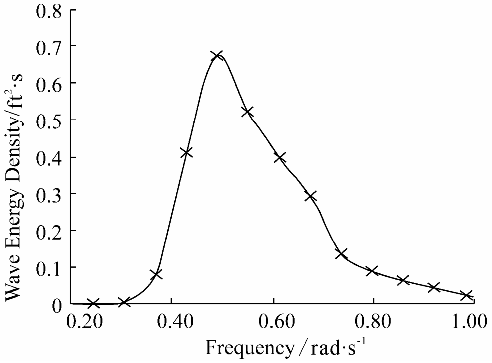
The fast Fourier transform (FFT) method was used to obtain the stress RAO from monitoring wave and stress data. Fig.5 shows an example of wave and stress spectral density in Table.1 (No.1). It demonstrates that the wave energy follows narrow band distribution, and its maximum value occurs in the vicinity of the peak period.

Table 1 Measurement wave statistic data

Time spans	H_s / ft	T_p / s
No.1	26.7	9.9
No.2	36.3	11.4
No.3	26.2	13.5
No.4	32.6	16.4
No.5	30.8	20.6
No.6	32.9	35.9



(a) Measured stress energy density in No.1 time span

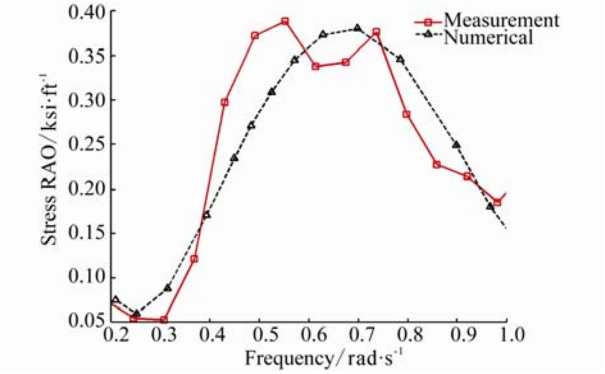


(b) Measured wave energy density in No.1 time span

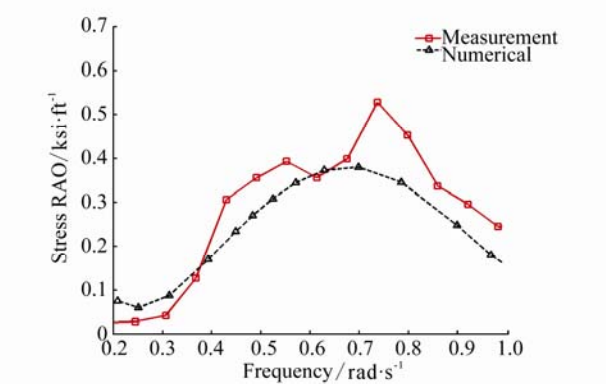
Fig.5 Data statistic for No.1 in Table 1

4 Comparisons

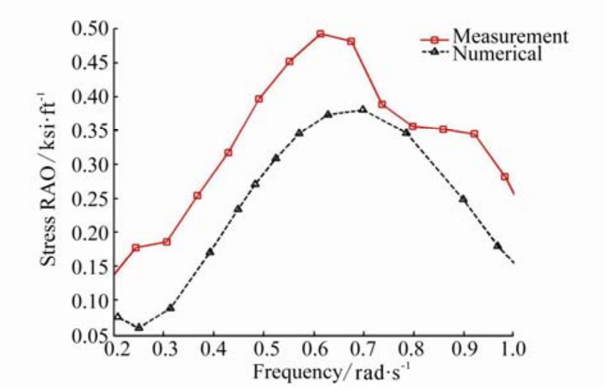
The calculated stress RAOs were compared with the measured data for the similar wave directions as shown in Fig.6. It can be concluded that the numerical results agree reasonably well with the measured data.



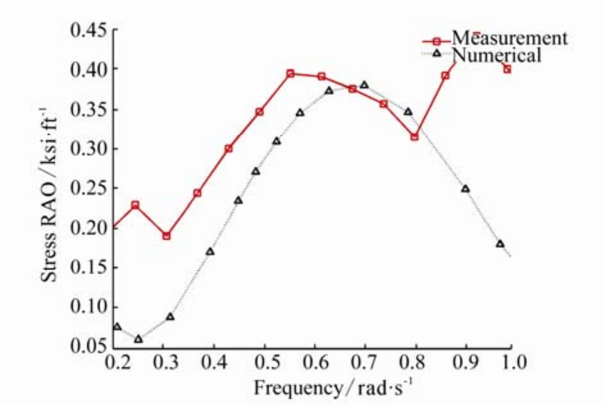
(a) No.1



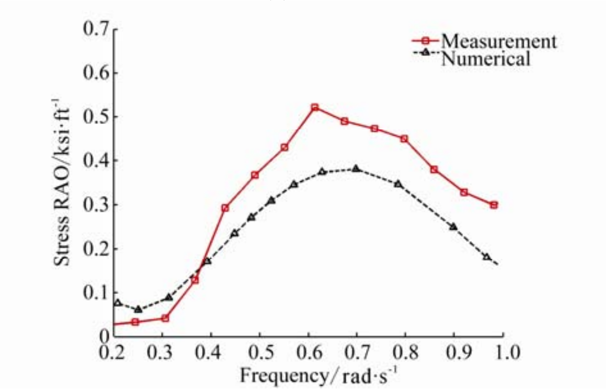
(b) No.2



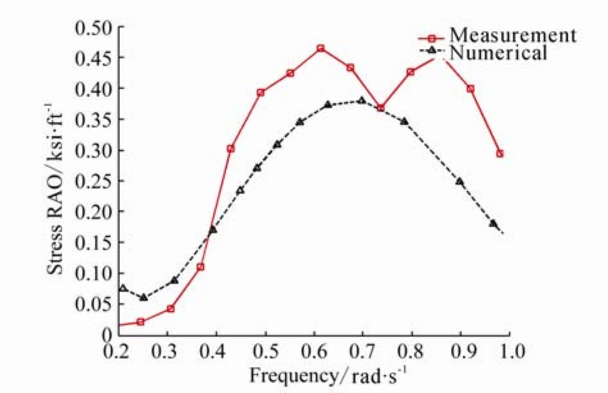
(c) No.3



(d) No.4



(e) No.5



(f) No.6

Fig.6 Measurement and numerical stress RAOs

5 Conclusions

The stress response of a TLP under extreme environment was investigated in this paper. A location on one gusset of the TLP was selected as object point, where the same directional stress was posted according to the arrangement of the strain gages. A stress RAO comparison was performed between numerical simulation and actual measurement. The results indicate that stress RAO of numerical simulation fitted well with the measured data. The measured wave elevation and stresses were found to match the narrow banded distribution as described by Jonswap spectrum.

The frequencies considered in this paper don't include the 1st order resonance, and the structure responses at high frequencies were discarded during the analysis as they were far away from the wave peak period with negligible wave energy.

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极端环境条件下 TLP 平台的应力校核

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摘　要：计算校核了某 TLP 平台垂向肘板在极端环境条件下的应力响应. 该垂向肘板为 TLP 立柱与张力支撑系统（TSS）间的连接件，是 TLP 平台强度评估的关键部位. 根据通用的业界标准，平台的环境载荷计算采用三维线性理论，结构分析使用有限元方法. 应力数值计算与处理与实测应变片的位置和方向完全一致. 平台在位监测的数据使用 FFT 技术进行了处理，得到了不同时段统计下各浪向的应力谱密度（RAO）. 数值计算与平台在位实测对比表明，数值模拟的应力谱密度与实测数据吻合较好，业界的分析方法可以在极端条件下对 TLP 的关键部位进行有效的强度分析.

关键词：TLP 平台；应力谱密度；极端环境条件；数值模拟；在位监测