Research on Anti-Noise Ability of Offshore Platform Health Monitoring System Based on Strain Mode Structural Damage Identification

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Abstract. Strain modal structural damage identification is widely used in offshore platform health monitoring. However, due to the limitation of structural testing technology, the complex marine environment around the offshore platform structure is superimposed, such as wind, wave, tidal current and other dynamic environments. In the actual test, many factors interfere with modal identification and damage detection, which brings a certain amount of errors to the identification of modal parameters of offshore platform structure, Thus, the accuracy of loss identification of offshore platform structure is affected. In this paper, the health monitoring system of offshore platform based on strain mode structural damage identification is studied by analyzing the damage identification effect of strain mode structure under different degrees of environmental noise superimposed by single member damage and multi member damage. The research results show that strain mode damage identification can not only accurately locate members, which has better anti-noise ability, but the anti-noise ability under multi member loss is also lower than that under single damage condition. For single member damage, it has better damage identification effect within 10% noise level, and for multi member damage, it just has better damage identification effect within 8% noise level. The research results of this paper find out the base number of damage identification ability of jacket platform structure based on modal parameters, which is a great significance for using strain modal damage identification method in offshore platform structure health monitoring.

1. Introduction  
The key of offshore platform health monitoring lies in the damage identification technology, which has been widely applied and studied by scholars and engineers [1]. Coppolino and Rubin (1980) explored the corresponding changes of the first 25 natural frequency and vibration mode of the platform structure when different members are damaged based on the relevant scale model of a deep-water jacket platform. The sensitivity of two damage fingerprints of frequency and vibration mode to structural member damage is studied [2]. Brinckd (1995) applied auto regressive moving average (ARMA) model to analyse the vibration data of offshore platform structure, and mainly explored the change of natural vibration frequency of platform in case of structural damage [3]. Etube, Brennan and Dover (1999) mainly studied the change of transfer function due to structural fatigue damage based on an offshore jack up platform [4]. Viero and Paula (1999) analyzed and studied the damage identification of offshore platforms [5]; Based on numerical calculation and relevant experimental analysis, Mangal (2001) and...
others studied the change of natural frequency and impulse and relaxation response of the structure of an offshore fixed platform under two working conditions (one is structural damage and the other is the change of deck mass) [6]. In Chinese, Yang Hezhen (2003) proposed the modal strain energy decomposition method, and took the three-dimensional frame structure as an example to illustrate that the modal strain energy decomposition method is suitable for damage monitoring of offshore platforms [7]. Liu Juan (2003) used genetic algorithm in damage identification and diagnosis of offshore platform [8]. Diao Yansong (2006) combined wavelet analysis method with neural network and successfully used this method to identify the damage of offshore platform [9]; Wang Junrong (2009) considered the influence of temperature on structural mode. Based on the damage fingerprint of modal strain energy, the benchmark damage detection test model and jacket model were applied to successfully identify different damage conditions by using the cross model cross mode (CMCM) method [10]. Xu Changhang (2010) analyzed and processed the collected response information of offshore platform experimental model, mainly using empirical modal analysis and Wigner Willie distribution method to preliminarily identify whether the structure is damaged or not [11]. Leng Jiancheng (2014) and others proposed local damage monitoring technology based on alternating current field measurement (ACFM) technology. For a jack up platform, the probability of component crack is estimated based on Bayesian theory [12]. Li Ye (2016) and Yan Dongxu (2017) studied the feasibility of applying wavelet analysis to offshore platform health monitoring and achieved certain results [13, 14]. Zhang Hua (2016) applied acoustic emission technology to the real-time damage monitoring of jacket offshore platform topside structure, studied the monitoring scheme suitable for the project site with a jacket platform as the research object, and proposed the structural health assessment method based on the detection data [15]. Xiong Chunbao (2019) applied global navigation satellite system (GNSS) real time kinematic (RTK) combined with modified decision based (MDB) filter technology to the dynamic deformation monitoring of offshore platform pile legs. MDB filter can effectively remove the random noise and multipath error of offshore platform vibration information.

The theoretical method matches well at the model level, but it has some limitations in practical application, and even produces large errors, which does not have the value of engineering practical application. Mainly due to the limitation of structural experimental testing technology and the complex marine environment around the jacket platform structure, many factors interfere with modal identification and damage detection in the actual test, which brings a certain amount of errors to the identification of modal parameters of jacket structure, thus affecting the accuracy of loss identification of jacket structure.

In this paper, the anti-noise interference ability of offshore platform health monitoring system based on strain modal structural damage identification is studied, and the bottom number of jacket platform structural damage identification ability based on modal parameters is of great significance for jacket platform structural health monitoring.

2. Damage Identification Method Based On Strain Mode

The mode of the structure is related to the mass matrix and stiffness matrix of the structure. When the structure is damaged, the mass matrix and stiffness matrix will change, resulting in the change of structural modal information, and the modes before and after damage will be different. However, the changes of modal parameters caused by different degrees and positions of damage are different. Therefore, the damage can be identified, located and quantified by the modal difference before and after damage [16]. Modal strain energy method is a damage detection method proposed by Kim and Stubbs in 1995 and improved in 2002 [17]. The damage is identified by calculating the change rate of strain energy of each element before and after structural damage.

2.1. Istrain Modal Analysis

Suppose the deformation of the elastic structure in three directions is u, V and W, according to the modal definition:
Where, $\psi_i(x)$ is the structural strain mode. Discretization results in:

$$\varepsilon_i = \frac{\partial u}{\partial x} = \frac{\partial}{\partial x} \sum_{i=1}^{\infty} q_i \Phi_i(x) = \sum_{i=1}^{\infty} q_i \frac{\partial \Phi_i(x)}{\partial x} = \sum_{i=1}^{\infty} q_i \Psi_i(x)$$  \hspace{1cm} (2)

The response expression of structural strain tensor can be expressed as:

$$\{\varepsilon_i\} = \sum_{i=1}^{\infty} q_i \{\Psi_i\} = \sum_{i=1}^{\infty} \{\Psi_i\} \{\varphi_i\} \{F\} e^{i\omega t}$$  \hspace{1cm} (3)

The strain gauge generally measures the positive strain of the structure, and equation (4) can be simplified as:

$$\begin{bmatrix} \{\varepsilon_i\} \\
\{\alpha_{xy}\} \\
\{\alpha_{xz}\} \end{bmatrix} = \begin{bmatrix} \frac{\partial}{\partial x}\{\varphi_i^x\} \\
\frac{\partial}{\partial y}\{\varphi_i^y\} \\
\frac{\partial}{\partial z}\{\varphi_i^z\} \end{bmatrix} = \begin{bmatrix} \frac{\partial}{\partial x}\{\varphi_i^x\} \\
\frac{\partial}{\partial y}\{\varphi_i^y\} \\
\frac{\partial}{\partial z}\{\varphi_i^z\} \end{bmatrix}$$  \hspace{1cm} (4)

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\frac{\partial}{\partial z}\{\varphi_i^z\} \end{bmatrix} = \sum_{i=1}^{\infty} q_i \begin{bmatrix} \{\varphi_i^x\} \\
\{\varphi_i^y\} \\
\{\varphi_i^z\} \end{bmatrix}$$  \hspace{1cm} (5)

Formula (5) can be solved to obtain the strain modes in three directions of the structure.

2.2. Damage index based on strain mode difference

The strain mode of the structure will change before and after damage. The strain mode before and after damage is defined as:

$$\Delta \varepsilon(i, j) = |\psi_{ui}(j) - \psi_{di}(j)|$$  \hspace{1cm} (6)

Where $\Delta \varepsilon(i, j)$ is the strain mode difference of j node of the i order mode before and after damage, and $\psi_{ui}(j)$ and $\psi_{di}(j)$ are the strain modes of j node of the i-order mode before and after damage respectively.

By determining the position corresponding to the sudden change of strain mode difference before and after damage, the damaged rod can be located, and the magnitude of amplitude can reflect the degree of damage.

3. Research Object

The total height of this offshore platform is 114m in this paper, including three parts: jacket 13.5m, wind tower 100m and observation platform 0.5m. The assembly dimensions of each part of the structure are shown in figure 1.
3.1. Overall Architecture

Offshore platform structure monitoring is to comprehensively and real-time monitor the static or dynamic performance of offshore platform structure, collect real-time data, process and analyze the data. The monitoring system is mainly composed of sensor system, data acquisition and transmission system, data management system, evaluation subsystem, etc., as shown in figure 2 below.

In this system, the function of sensor system is to perceive the information of offshore platform and convert it into electrical signal; The function of data acquisition and transmission system is to collect sensor signals and transmit them to data management system; The data management system can collect, organize and store the monitored data; The evaluation subsystem evaluates and analyzes the collected data, and feeds back the structural safety information in time.

3.2. Sensor Subsystem

The construction of sensor subsystem is actually to determine the selection and layout of sensors. According to the structural characteristics of jacket offshore platform, the types of sensors can be divided into: (a) offshore environmental information monitoring; (b) Marine environmental information monitoring; (c) Offshore platform structure information monitoring; (d) Component information monitoring of offshore platform; (e) vibration information monitoring of offshore platform.

Based on the above monitoring objectives, inclination sensor, strain sensor, LPR probe, er probe and many other sensors are used. Limited to space, only the sensors that will be used in the follow-up work are shown in figure 3. The layout principle of GPS stations is to set them respectively at the center point of the platform and the open field of vision on the axis; the inclination sensor shall be set at the pole according to its characteristics At the top or bottom of the main pipe, the system is equipped with four inclination sensors at the top and bottom of the main pipe respectively; the setting of strain sensors is
divided into two types, one is set at the midpoint of each layer of guide leg rod, the other is set at the top of guide leg, of which four groups of strain sensors are respectively set at the top of four guide legs, each group contains two strain sensors, and their wires pass through the guide leg section center.

![Figure 3. Sensor placement of jacket offshore platform.](image)

3.3. Evaluate the Overall Performance of Subsystems and Platforms
The evaluation subsystem mainly evaluates the overall performance of the offshore platform through real-time data, which includes:
(a) Safety monitoring and early warning evaluation of offshore platform based on static measurement: mainly check whether each index is within the safety threshold by measuring platform displacement, platform inclination and pile foundation bearing;
(b) Overall performance evaluation based on frequency change: it is an important index to evaluate the integrity and safety of the structure. The health state of the structure can be investigated through the change of frequency.

3.4. Simulated Working Condition
In this paper, the reduction of elastic modulus is used to simulate damage. The damage conditions are mainly divided into single member damage and multi member damage. The influence of different damage locations is considered for single member damage. The established damage conditions are shown in table 1.

| working condition | Stiffness damage degree | Damaged components |
|-------------------|------------------------|--------------------|
| A(single member damage) | 5%、10%、20%、30%、40% | One supervisor on the 4th floor |
| B(multi member damage) | 5%、10%、20%、30%、40% | One main pipe and one diagonal brace on the 4th floor |

4. Analysis Of Anti-Interference Ability of Strain Modal Parameter Damage Identification
In order to study the anti-interference ability of the damage identification method of strain mode, and analyse the identification effectiveness and stability under a certain noise level, different degrees of Gaussian white noise are added to the strain mode for identification, and the noise signal is input into the finite element model as excitation. The damage conditions are single member damage (condition 1) and multi member damage (condition 2), and the damage degree is 5%, 10%, 20%, 30% and 40%. The anti noise level under different damage degree under two working conditions is discussed respectively.
4.1. Anti Noise Level of Strain Modal Parameter Damage Identification Under Single Member Damage

Under the noise level of 3%, the strain vibration mode can identify the damage of 5% and 10%. It is concluded that the damage of 5% cannot identify the damaged rod under this noise level, while the damage of 10% and above can still be located by the strain vibration mode at this noise level. When the noise level is 5%, the strain mode identifies the damage of 20% and 30%, and the analysis shows that the damaged rod can be located by the strain mode under the noise level of 30% and more than 5%, but the damaged rod cannot be identified by the strain mode when the damage level is 20%. Under the 11% noise level, the strain vibration mode identifies 40% of the damage. The analysis shows that under the 11% noise level, the damage layer cannot be located at all, and the strain vibration mode has lost the identification effect as shown in figure 4.

![Figure 4](image.png)

**Figure 4.** Anti noise level of strain mode under different damage degrees of single member.

4.2. Anti Noise Level of Strain Modal Parameter Damage Identification Under Multi Member Damage

Under the noise level of 2%, the strain vibration mode can identify the damage of 5% and 10%. It is concluded that the damage of 5% cannot identify the damaged rod under this noise level, while the damage of 10% and above can still be located by the strain vibration mode at this noise level. Under the noise level of 3%, the strain vibration mode can identify the damage of 10% and 20%. It is concluded that the damage degree of 20% and above can be located by the strain vibration mode under this noise level, but when the damage degree is 10%, the strain vibration mode can not be used to identify the damaged rod. Under the noise level of 4%, the strain vibration mode identifies the damage of 20% and 30%. It is concluded that the damage degree of 30% and above can be located by the strain vibration mode under this noise level, but when the damage degree is 20%, the strain vibration mode can not be used to identify the damaged rod. Under the noise level of 5%, the strain vibration mode can identify the damage of 30% and 40%. It is concluded that under this noise level, the damage of 30% and 40% can not be identified by strain vibration mode. It can be considered that the anti-noise level within 40% of the damage degree is within 7%. However, under this noise level, although the damaged member can not be accurately located, the damaged layer number can be identified. Under the 8% noise level, the strain vibration mode identifies 40% of the damage. The analysis shows that under this noise level, the damage layer can not be located at all, and the strain vibration mode has lost the identification effect as shown in figure 5.
5. Conclusion

Based on the structural health monitoring system of offshore platform, two working conditions of single member and multi member loss are constructed by using different degrees of stiffness damage. Based on the strain mode damage identification method, the damage identification effect of single member damage and multi member damage superimposed with different degrees of environmental noise is discussed, and the anti-interference ability in the case of environmental noise interference is discussed. The main conclusions are as follows:

(a) Under the working condition of single member damage and ring noise interference, the strain vibration mode can accurately locate the rod within 40% of the damage degree within 6% of the noise level, and has a good effect of locating the floor number within 10% of the noise level.

(b) Under the condition of multi member damage and ring noise interference, the strain vibration mode is within 5% of the noise level, the rod with 40% of the damage degree can be accurately located, and the damage layer can be located within 8% of the noise level.

(c) Using strain mode shape for damage identification can not only accurately locate the rod, but also have better anti-noise ability. However, the anti-noise ability of multi member loss is also lower than that of single damage condition.

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