Damage Diagnosis of Top Tensioned Riser Based on Strain Response

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Abstract. Strain has a high sensitivity to structural damage and can be used for damage diagnosis of marine risers in engineering. Considering the structure and boundary conditions of the top tensioned riser, it can be simplified to the Euler-Bernoulli beam element, and the strain equation on the riser wall is derived. The element Root-Mean-Squared Strain (RMSS) difference is proposed as the damage index parameter of the riser. The finite element software ANSYS is used to simulate the element strain response of the 1000m length top tensioned riser in the South China Sea with different damage locations, damage degree and sea state parameters, and the RMSS difference curve is drawn. The results show that the RMSS difference has high sensitivity to the riser structure damage, and the damage position of the riser can be effectively identified in many different situations.

1. Introduction
The exploration and development of marine oil and gas resources is a project with large investment, difficulty, high risk and complicated technology. In the process of marine oil and gas development, the riser system bears important tasks such as transporting oil and gas and water injection. It is an important part of oil and gas development system, and its performance has an important impact on the cost and efficiency of oil and gas development. In the long-term service process, marine risers are damaged by external disturbances, corrosion, pipe and construction quality, causing major economic losses, casualties and environmental pollution [1]. All major international oil companies attach great importance to the establishment of the ocean safety during the service. Real-time control of mechanical parameters and monitoring of the health of risers can effectively reduce the occurrence of accidents and play a very positive role in the production and development of offshore oil and gas engineering. [2].

Structural damage diagnosis is a core component of structural health monitoring technology. The theory of damage identification based on structural dynamics is mature and widely used. The main index are structural natural frequency, displacement modal and strain modal.

Most of the above strain-based damage diagnosis methods need to obtain the Multistage strain modes of the structure and the strain modal data before the structure is damaged. Due to the particularity of its service environment, it is difficult to obtain the strain modal of the risers by vibration. In this paper, a method of element RMSS Strain difference is proposed, which can diagnose the damage of deep-sea top tensioned risers only by using the strain response of structures under marine environmental loads.
2. Element RMSS Difference Method for Riser Damage Diagnosis

During oil and gas drilling, the bottom of the top tensioned riser is connected with the wellhead device through universal joint, and the top is connected with the platform through the heave motion compensation device [3]. The heave compensation device provides a large static pre-tension for the riser, and its expansion function can offset the larger heave motion of the platform, so as to avoid the great change of the axial force of the riser. The load on top tension riser is mainly composed of two parts: transverse load and axial load. The transverse load mainly includes environmental loads such as wind, wave and current, and the axial load mainly includes the top tension and the self-weight of riser. In the structural design, the top tension is usually 1.2-1.6 times the wet weight of riser. The load and deformation during riser operation are shown in Fig. 1.

![Figure 1. Schematic chart of load and deformation of riser](image)

The tensioned riser on the deep sea top conforms to the basic assumption of the Euler-Bernoulli beam, so it can be simplified as the Euler-Bernoulli longitudinal and transverse bending beam model. Its displacement equation is as follows:

$$\frac{d^2}{dx^2} \left( EI \frac{d^2 y}{dx^2} \right) = q$$

(1)

Among them, q is the external load distributed along the length direction of the beam. According to the assumption of flat section, the relative elongation (i.e. strain) of the fibers at the neutral layer V above the beam is as follows [4]:

$$\varepsilon = \frac{(\rho + \nu)d\theta - \rho d\theta}{\rho} = \frac{\nu}{\rho}$$

(2)

$$\frac{1}{\rho} = \frac{|\frac{d^2 y}{dx^2}|}{\left[ 1 + \left( \frac{dy}{dx} \right)^2 \right]^{3/2}}$$

(3)

In the formula, P is the radius of curvature of the neutral layer of the beam. Under practical engineering conditions, the bending deformation of the beam is small, $dy/dx$ is small and $(dy/dx)^2$ can be neglected, so the curvature of the bending axis of the beam can be approximated as follows:

$$\frac{1}{\rho} = \left| \frac{d^2 y}{dx^2} \right|$$

(4)

In the substitution of formula (4) into formula (2), it can be obtained that:

$$\varepsilon = \nu \frac{d^2 y}{dx^2}$$

(5)
By substituting formula (5) into formula (1), the strain equation at the distance from the neutral surface V of the beam structure can be obtained.

\[
\frac{d^2 \varepsilon}{dx^2} = \frac{q_v}{EI}
\]  

(6)

From the formula, it can be seen that the strain at a certain point of the riser diameter is related to the elastic modulus of the riser and the distributed load on the riser surface. When the distributed load is fixed, the strain at a certain element increases with the decrease of the elastic modulus at that point. The RMSS difference of riser element is now defined as:

\[
\Delta \varepsilon = |\varepsilon_{i-1} + \varepsilon_{i+1} - 2 \varepsilon_i| \quad (i = 1,2,3\ldots)
\]  

(7)

Among them, \(\varepsilon_i\) is the RNSS value at element I. The RMSS difference between a certain element and its adjacent elements can be used to diagnose the damage of the riser under the action of marine environmental loads.

3. Case study of numerical simulation

In this case, the PIPE59 element in ANSYS is used to carry out numerical simulation. PIPE59 element is a uniaxial element which can withstand tension, compression and bending and simulate ocean waves and currents. Each node of PIPE59 element has six degrees of freedom. The element force includes hydrodynamic and buoyancy effects [5]. The element mass includes the quality of attached water and internal water. The axial tension, compression, torsion and bending deformation can be considered.

The parameters of the simulated riser are shown in the following table:

| Table 1. Riser parameters |
|---------------------------|
| Undersea Length m | Internal Fluid Density kg/m³ | External Diameter mm | Wall Thickness mm |
| 1000 | 850 | 360 | 30 |
| Modulus of Elasticity Pa | Poisson Ratio V | Density kg/m³ | Top Tension N |
| 2.1e11 | 0.3 | 7850 | 1.4e7 |

The sea state parameters are taken from the sea state of the South China Sea provided by CNOOC [6], as shown in Table 2:

| Table 2. Sea state parameters |
|-----------------------------|
| Sea State Parameter | Sea State 1 General Operations | Sea State 2 Once in 100 years | Sea State 3 Once in 500 years |
| Wave Height/m | 2.8 | 13.3 | 14.2 |
| Period/s | 8 | 15.5 | 16.6 |
| Velocity/(m/s) | 1.15 | 1.97 | 2.13 |

In this simulation, the riser is divided into fifty elements with equal spacing, one element near sea level and fifty elements near sea bottom mud line. Under the elastic condition, the stiffness of riser is proportional to the elastic modulus, so the reduction of elastic modulus is used to simulate the reduction of stiffness, that is, the stiffness reduction factor of element is used to simulate the damage of riser.

Based on the actual operation of marine risers, the following four simulations are carried out to verify the sensitivity of the element strain difference method to identifying different damage locations, different damage degrees, different environmental loads and multi-location combined damage of marine risers.

3.1 Different Damage Locations

The setting of the relevant damage elements and the RMSS difference curve of the elements are as follows:

| Table 3. Element damage settings at different damage locations |
From the RMSS difference curves of different damage elements of marine risers, it can be seen that at the riser damage element, the decrease of the elastic modulus of the element will increase the element strain at that location, which will lead to a sudden change in the difference curve, while at the undamaged element, the curve is relatively stable. Whether the damage element is located at sea level, in the middle of riser or near the mud line, this method can effectively identify the location of the damage element.

3.2 Different Damage Degrees
The setting of the relevant damage elements and the RMSS difference curve of the elements are as follows:

| Sea state | Damage element | Stiffness reduction factor |
|-----------|----------------|----------------------------|
| 1         | 5              | 30%                        |
| 1         | 21             | 30%                        |
| 1         | 46             | 30%                        |

Figure 2. Element RMSS difference curve of riser at different damage locations.

![Figure 2](image-url)
Figure 3. Element RMSS difference curve of riser at different damage degrees

From the element RMSS difference curves of marine risers with different degrees of damage, it can be seen that \( \Delta \varepsilon \) increases with the increase of the reduction coefficient of the elastic modulus of the element, which is consistent with the relationship of formula (6). At the same time, under different damage conditions, the curve is still very sensitive to the damaged element, and the non-damaged element is very stable.

3.3 Different Sea State

The setting of the relevant damage elements and the RMSS difference curve of the elements are as follows:

| Table 5. Element damage settings at different sea state parameters |
|---------------------------------------------------------------|
| Sea state | Damage element | Stiffness reduction factor |
|-----------|----------------|---------------------------|
| 1         | 21             | 30%                       |
| 2         | 21             | 30%                       |
| 3         | 21             | 30%                       |

Figure 4. Element RMSS difference curve of riser at different sea state parameters

From the element RMSS difference curves of marine risers under different sea conditions, it can be seen that \( \Delta \varepsilon \) increases with the increase of external loads. The curve shows a significant mutation at the damage element and is very stable at the undamaged element.

4. Conclusion

Based on the service characteristics of marine risers, a method of element RMSS difference is proposed in this paper. The PIPE59 element in ANSYS software is used to simulate the damage of top tensioned risers at different locations and sea conditions. The results are as follows:

1) The method of element RMSS difference curve has good sensitivity to the damage of riser at different locations, and it can be accurately identified.

2) If the damage degree of the element increases, the sudden change of the curve increases.

3) The sea condition will also affect the sudden change of the curve. When judging the damage degree of the element, it is necessary to take into account the sea condition and the location of the element at that time.

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