Vibration Responses of SCR with the Installation of Monitoring Devices

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Abstract. In order to ensure the integrity and safety of deepwater risers during the development of deepwater oil and gas fields, the on-site monitoring technology of risers has become a research hot point in the field of marine engineering. Riser monitoring devices have large quality, which will change the vibration responses in practical engineering. In this paper, the vibration modality of a steel catenary riser (SCR) with monitoring devices is simulated in time domain using professional marine software Orcaflex, including static, dynamic and strength characteristics of SCR and is based on catenary method and centralized mass method. The effects of SCR vibration with and without monitoring devices are compared and analysed on the static characteristics, dynamic characteristics and strength.

1. Introduction
In 1994, Shell installed the first catenary on Auger which is a tension leg platform[1]. Because of its simple installation, low cost and good applicability, the catenary riser has been successfully applied to various platforms. In the deep-sea environment, the riser is prone to fatigue, buckling and other failure modes because the pipeline is subjected to its own gravity, wind, wave and current action and the load generated by the upper floating body movement. Although in the early stage of design, the strength of risers was solved by means of improving design standards or increasing safety factor, there were still risers damaged. Once the riser system fails, it will endanger the whole process of offshore oil and gas exploitation, and even a series of serious accidents will occur. Therefore, on-site monitoring technology for riser emerges as the times require, accurately and directly reflects the characteristics of riser system under actual working conditions, provides a realistic basis for optimization of riser and guarantees the safe operation of riser.

Since 1998, Brazil Petroleum put the first SCR riser with monitoring system into actual production. At present, the SCR riser with monitoring device has been widely used, and the various field monitoring data returned have also been successfully applied. In order to ensure the safety of the riser with monitoring device, based on the catenary method and centralized mass method, the performance of the steel catenary riser before and after the installation of monitoring device is calculated and analysed by OrcaFlex software in time domain, including the static, dynamic and strength aspects of the riser, and the installation of monitoring device is discussed. The influence on the performance change of various risers.
2. SCR real-time monitoring

SCR monitoring is very complex and expensive. In order to establish a systematic method of SCR field integrity management and to study the latest technology suitable for SCR monitoring and testing, 16 companies and associations jointly carried out a joint industrial project of SCR integrity management (IM JIP). In general, SCR field monitoring includes: meteorological and marine environmental parameters (wind load, wave spectrum, current profile), fatigue load caused by upper floating body movement, mooring system tension, vortex-induced vibration (VIV), splash zone and touchdown point [3].

At present, our country does not have a good ability to collect data. Overseas 2H Offshore, Furgo, Insensy, RTI, StainStall BMT and other companies have developed rapidly in the monitoring of deep-water marine structures system [3]. Furgo and other companies are specialized monitoring companies, which have a certain market in monitoring technology, while 2H Offshore is an offshore engineering company with many years of experience in marine structures. At present, 2H Offshore INTEGRIPod [4-5] self-contained motion sensor has been put into use in the above monitoring system. Real-time monitoring technology mostly uses self-contained sensors, which can independently complete data acquisition and storage, and realize online data detection.

In 1998, Brazilian Petroleum Corporation applied the monitoring system of P-18 semi-submersible platform as shown in Figure 1 [6], including meteorological and marine environmental parameters monitoring system: meteorological sensor, ocean meteorological buoy, acoustic Doppler velocity profiler; high precision GPS and inertial positioning system were used for floating position and motion monitoring; and three seats were used for riser VIV monitoring. Scale accelerometer and 2-coordinate angular rate sensor. On-line monitoring system is also used on one of the SCR platforms of the Tahiti Oilfield in the Gulf of Mexico. Two sets of strain and five sets of motion monitoring equipment are arranged in the top suspension area, ten sets of strain and motion monitoring devices are arranged in the contact area within the interaction between pipe and soil, and motion sensors are arranged in the streamline section. In summary [3-7], the existing SCR monitoring devices are generally equipped with acceleration sensors, angular velocity sensors, tilt lines, strain gauges, LVDT, differential global positioning system (DGPS) sensors and fixtures. The quality of existing SCR monitoring devices is generally from 60 kg to 150 kg. SCR real-time monitoring system is generally composed of several monitoring devices. Please follow these instructions as carefully as possible so all articles within a conference have the same style to the title page. This paragraph follows a section title so it should not be indented [2-3].

![Figure 1. P-18 platform monitoring system [6]](image_url)
3. Simulation and analysis

3.1. Basic theory of SCR vibration analysis

In this paper, the monitoring device is equivalent to a regular geometric mass block attached to the SCR surface with a certain volume. The model is shown in Figure 2.

Firstly, the static analysis of SCR is carried out [8]. In practical engineering, fluid passes through SCR, so SCR can not only be regarded as catenary, but also the influence of internal fluid on SCR should be considered. The pressure of the internal fluid produces an additional axial force \( -2\nu \frac{1}{4} \pi d^2 p_m \) and \( \nu \) is Poisson’s ratio.

According to the force balance, the axial force can be obtained as follows:

\[
s = z \frac{\cos \theta}{1 - \sin \theta} \]

\[
T(z) = T_b + (m_{\text{riser}} + m_f)g - \frac{\pi}{4} D^2 \rho_s g z - (1 - 2\nu) \frac{\pi}{4} d^2 p_m - m_f \nu^2 \]

According to (1) and (2),

\[
T(z) = T_b + (m_{\text{riser}} + m_f)g \frac{\cos \theta}{1 - \sin \theta} z - \frac{\pi}{4} D^2 \rho_s g z - (1 - 2\nu) \frac{\pi}{4} d^2 p_m - m_f \nu^2 \]

The transverse vibration equation of the riser is as follows:

\[
 EI \frac{\partial^4 x}{\partial z^4} + [m_f + m_s] \frac{\partial^2 x}{\partial t^2} + \frac{1}{4} \pi d^2 (1 - 2\nu) p_m + [m_{\text{riser}} + m_f] gz \]

\[-\frac{1}{4} \pi D^2 \rho_s g z \frac{\partial^2 x}{\partial t^2} + [m_{\text{riser}} + m_f] \frac{\partial^2 x}{\partial t^2} + 2m_f \nu \frac{\partial^4 x}{\partial z^2 \partial t^2} + C \frac{\partial x}{\partial t} = F\]

By solving the above governing equations, some parameters can be obtained.

Secondly, SCR dynamic analysis is carried out. The time domain dynamic equation of pipeline is expressed as follows:

\[ M \ddot{y}(t) + B \dot{y}(t) + K y(t) = F(t) \]

Fluid forces such as waves and currents received by risers in marine environment are calculated by Morrison equation.

\[ F_j + F_i = \frac{1}{2} \rho C_D \frac{D}{|u + U|} |u + U| + \frac{1}{2} \pi D^2 \rho C_m \dot{u} \]

3.2. SCR model and environmental loads

In this paper, according to the theoretical basis of Chapter 1, the SCR before and after installation of the monitoring device is simulated by using the professional marine software Orcaflex. The specific parameters are shown in Table 1-3. In the analysis process, FPSO is used as a floating body.
3.3. Comparison of simulation results

3.3.1 Static comparison results
Table 4. X-axis displacement and hanging angle comparison

| Parameter                        | SCR   | SCR with monitoring devices |
|----------------------------------|-------|----------------------------|
| X-axis displacement at End A (m) | 9.12  | 8.26                       |
| Touchdown point (m)              | 890   | 818.56                     |
| Suspension angle (°)             | 12.2  | 11.7                       |

By comparison and analysis, it can be concluded that the static performance of suspension area and bottom touching area will be affected by the installation of monitoring device. The displacement of the suspension point decreases along the X-axis and the suspension angle increases, while the displacement of the contact area decreases along the X-axis.

3.3.2 Dynamic comparison results

![Figure 3. SCR displacement along X-axis at End A](image)

Table 5. SCR displacement along X-axis at End A and Touchdown Point

| Parameter                        | SCR   | SCR with monitoring devices |
|----------------------------------|-------|----------------------------|
| X-axis displacement at End A (m) | 11.4  | 8.26                       |
| Touchdown point displacement at End A (m) | 814.89 | 751.71                        |

3.3.3 Strength comparison results

![Figure 4. SCR effective tension at End A and touchdown point](image)
4. Conclusion
In this paper, according to the actual engineering needs, the SCR before and after installation of monitoring device is simulated by Orcaflex, and the effects of installation of monitoring device on the static characteristics, dynamic characteristics and strength of SCR are compared and analysed.

The conclusions are as follows: 1) Installation of monitoring devices has an effect on the static and dynamic shape of SCR, and the main influence is that the displacement of SCR decreases along the flow direction; 2) Installation of monitoring device has an effect on the strength of SCR, and the effective stress of each point of SCR increases; 3) Sensitive position of installation of monitoring device touches the SCR. In the process of installing and monitoring SCR, more attention should be paid to the point area. The research ideas and conclusions of this paper can be used for reference in the installation and design of real-time monitoring system for steel catenary risers.

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Table 6. Effective tension of SCR at End A and touchdown point

| Parameter                  | SCR    | SCR with monitoring device |
|----------------------------|--------|---------------------------|
| Effective tension at End A (KN) | 3186   | 5990                      |
| Effective tension Touchdown Point (KN) | 779    | 815                       |