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ONLINE SAFETY MONITOR DESIGN OF THE JACKET PLATFORM BASED ON STRUCTURAL MEMBERS FAILURE STUDY

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ABSTRACT

Currently, the Jacket platform plays pivotal role in offshore oil exploitation. However, since many fixed platforms become ageing, the periodic detection and safety assessment is necessary for the platform structures during the service. In this paper, a sensitivity diagnose method is proposed, based on the fact that some members of jacket platform are very sensitive to the damage of the structure. At first, we numerically calculated the dynamic response of the platform with failure members in extreme sea environment, where the pile-soil interaction was considered. Then the sensitive members and the sensitivity distribution were concluded. The statistics show that the group of sensitive members is entirely different in different destructive cases. In other words, the change of stress on the members, caused by the member failure, is unique. Therefore, the sensitivity diagnose method is feasible and we can find the failure members based on the change of stress.

Keywords: jacket platform, online safety monitor, member failure, stress sensitivity,

INTRODUCTION

As the deep sea oil drilling gradually develops, the near sea oil exploitation still constitutes a large ratio in developing countries, where the jacket platform plays vital role. Currently, there are over a hundred of jacket platforms in the Bohai Sea and South China Sea. The large steel structures are prone to be damaged during their service lives, caused by factors such as corrosion, fatigue, impact, and hostile sea environment, so the occurrence of damage during the life of an offshore structure is unavoidable. Where detection and repair of damaged members is not in time, damage could continue to the point of failure with potentially severe ramifications.

Therefore, it is indispensable to monitor and accurately assess the serving state of jacket platforms online. Such real-time processing would keep track of the safety and integrity of structures, so that we could find the damaged members promptly and repair them instantly to prevent severe accidents and huge economic losses. However, certain detecting methods of today, including ROV, ultrasonic examination method and radioactive method, are post-mortem and fail to implement real-time monitor of structures online. Compared with those, a method using dynamic response data of the jacket platform, including natural frequency[1], natural modes[2] and modal strain energy[3,4], is very mature and cost-effective for the fault diagnos. Most importantly, the monitor is online. Yet such a method has limits[5]: colored noise of irregular waves[6] and test noise[7] would considerably interfere with the modal identification and greatly affect diagnose result.

In this paper, we proposed a method to monitor the safety of the jacket platform in service, and named it sensitivity diagnose method. It could only detect major removal of members. When an important member is damaged and removed, the stress on particular members would change significantly, i.e. these members are sensitive to the damage. In other words, based on the change of stress collected by strain

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sensors, we can obtain real-time evaluation of the safety of the platform and position the damaged area. Considering the high cost of destructive test and practical test, to start with, we conduct numerical calculation of destructive cases and respectively obtain stresses on the platform as different members get damaged and removed. In the calculation, pile-soil interaction[8] was considered as well as wind, current and wave loads in extreme environment[9-12]. Comparing the result with that of integrated platform, we can find the sensitive members, which serves as the basis and initial step for online safety monitor design.

FINITE ELEMENT MODEL AND ENVIRONMENT LOADS

Finite Element Model

The finite element model of the jacket platform is shown as Fig. 1 and Fig.2. The water depth of the platform is 17 meters, and the calculation of hydrodynamic force on the underwater jacket is based on Morison Equation. The piles reach 90 meters below the mud line and the soil composes of sand, soft clay and stiff clay. The reaction force of soil is simplified to the force caused by non-linear springs, whose stiffness is calculated based on soil characteristics.

This paper focuses on the extent to which stress on key members is sensitive to structural failure, rather than the relationship between the stress and sea loads. Thus, here we only select 50-years return level of sea conditions for calculation. Specifically, we calculated the dynamic response of the jacket platform with one removed member and without any damages respectively. The removed member is presumed to be one of No. 6, No. 21, No. 24, No. 25, No. 28 and No. 29 member. Via comparing the result of damaged and integrated platform, we can find the sensitive members.

In the transient analysis of the jacket platform, the discrete finite element model obeys the equation of motion shown as:

$$[M]\{\ddot{x}\}+[C]\{\dot{x}\}+[K]\{x\}=\{F\}$$

where $[M]$ is the mass matrix of the structure and apparatus,$[C]$ is the structure damping matrix,$[K]$ is structure stiffness matrix; $\{x\}$ is displacement vector; $\{F\}$is the environment loads, including wind forces F_W, current loads F_C, wave loads F_{WAVE} and soil reaction forces.

Wind Loads

The calculation of wind forces is based on API RP 2A, as shown:

$$F_W=(\rho/2)V^2C_SA$$

where V is the wind speed; C_S is the shape coefficient based on API RP 2A; and A is the head-on wind area of superstructure.

Current Loads

Current can only induce drag force. Yet for the case

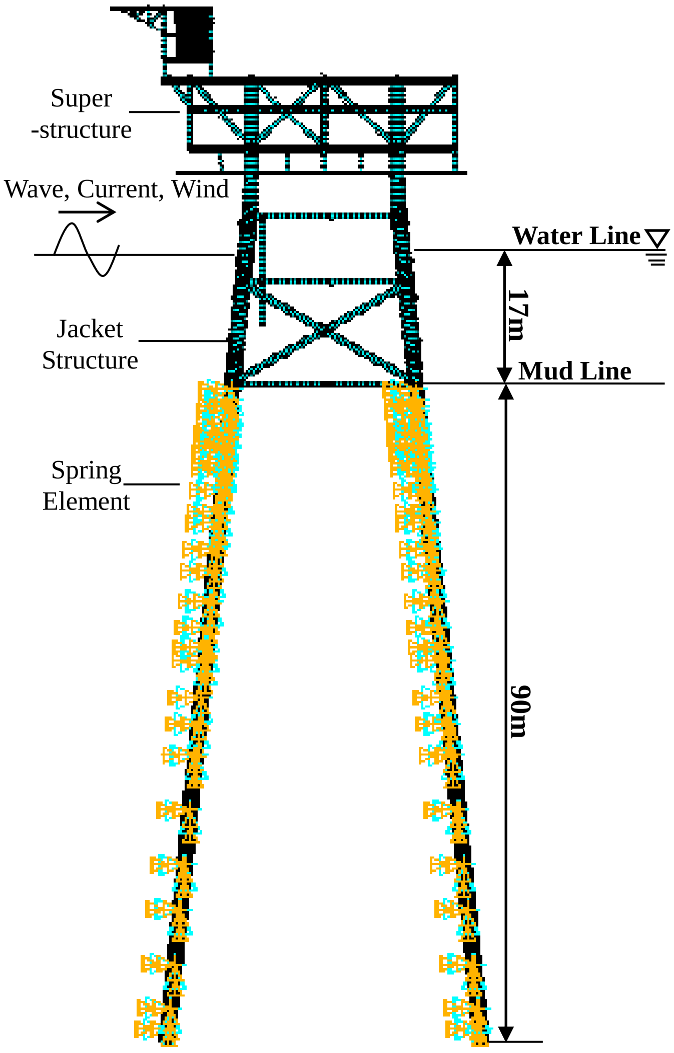

Fig. 1 Finite Element Model of The Jacket

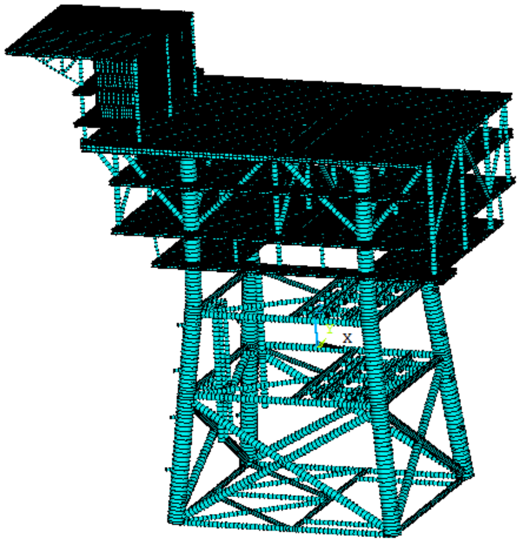

Fig.2 Finite Element Model of Jacket and Superstructure

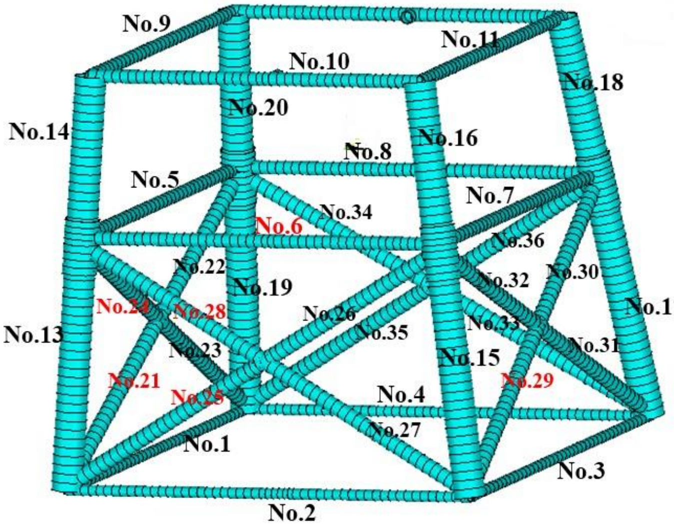

Fig.3 No. of the Jacket Members

current and wave co-exist, the required drag force is induced by the composition of current velocity and the wave velocity in horizontal direction. Current load per unit length is shown as:

$$F_C = \frac{1}{2}\rho C_D D U_C^2$$

where C_D is the drag coefficient normal to the axis of the member; D is effective diameter of circular cylindrical member including marine growth; U_C is the current velocity.

Wave Loads

In this sea state, we use the fifth Stokes theory to calculate the hydrodynamic force on the jacket considering that the ratio of wave amplitude to wave length is very large. For jacket members with small scale, drag force and inertial force take most count of the total hydrodynamic forces. So Morison Equation is suitable for this case and can get accurate result.

Wave loads per unit length based on Morison Equation are shown as:

$$F_{WAVE} = \frac{1}{2}\rho C_D D|U|U + \rho C_M \frac{\pi D^2}{4} a$$

where C_D and C_M is the drag coefficient and inertial coefficient respectively; D is effective diameter of circular cylindrical member including marine growth; U and a are the component of the velocity vector and acceleration vector (due to wave and/or current) of the water normal to the axis of the member.

Pile-Soil Interaction

Three methods are mainly used to calculate the soil reaction for laterally-loaded piles, named limit subgrade reaction method, elastic subgrade reaction method and composite subgrade reaction method. The composite subgrade reaction method, or named p-y curve method, is the most widely used in ocean engineering. p-y curve refers to the variation of the actual lateral resistance with the lateral deflection at a given depth. In this thesis, p-y curve is attained based on API RP 2A[13].

The lateral soil resistance-deflection (p-y) relationships for sand are non-linear and in the absence of more definitive information may be approximated at any specific depth H, by the following expression:

$$p = AP_U \tanh\left(\frac{K\times H}{A\times P_U} y\right)$$

where A=0.9 for cyclic loading; Pu is ultimate bearing capacity at depth H; K is initial modulus of subgrade reaction; H is the depth.

Also, the p-y curve for stiff clay and soft clay can refer to API RP 2A.

In addition of the lateral force, tip-load and axial load contribute to soil reaction force, and they can be calculated based on tip-load-displacement (Q-z) curve and axial load transfer (t-z) curve respectively.

RESULTS AND DISCUSSION

The dynamic response of the jacket platform with different damaged members under sea states of fifty years return period was numerically calculated. By comparing the Von Mises Stress between damaged and integrated platform, as shown in Fig. 4, we can find the sensitive member and further sensitive position on the member, which can provide guidance for the online monitor. In this thesis, we define a parameter, Δs , to express the sensitivity of the member to structural failure.

$$\Delta s = \frac{\max(s_I, s_F)}{\min(s_I, s_F)}$$

where the S_I and S_F refer to the maximum of the stress in the steady state for integrated and damaged platform respectively.

As the Δs approaches to 1, stress change approaches to 0, which means the related member is of no sensitivity; and a bigger Δs indicates that the member is more sensitive.

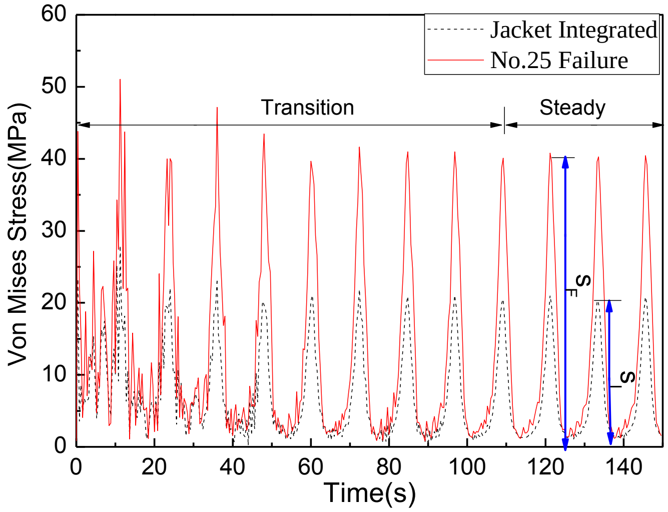

Fig.4 Time Series of the Observation Point on the Jacket With or Without Failure

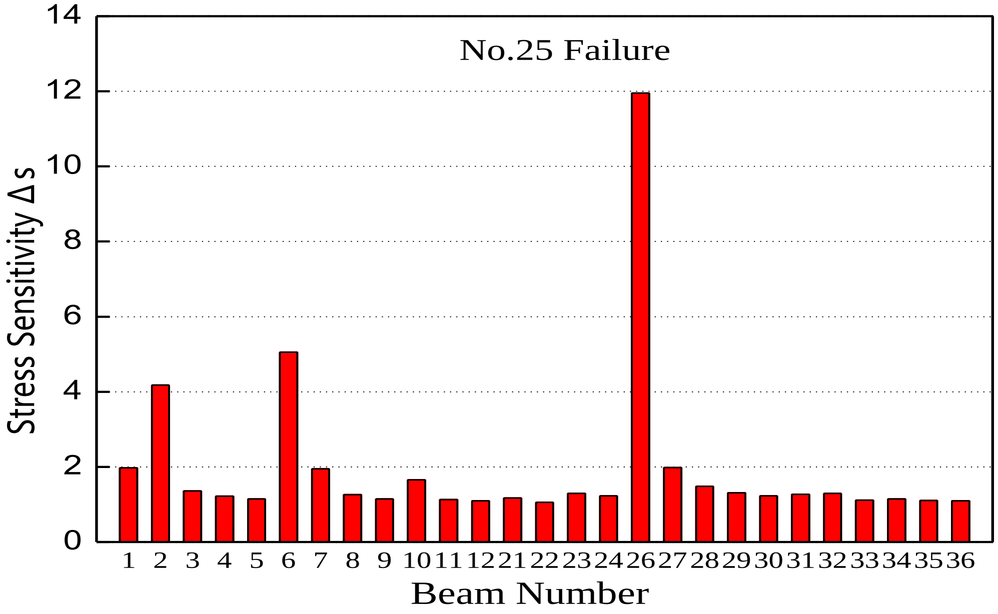

Fig. 5 Maximal Stress Sensitivity on Each Member(No.25 Failure)

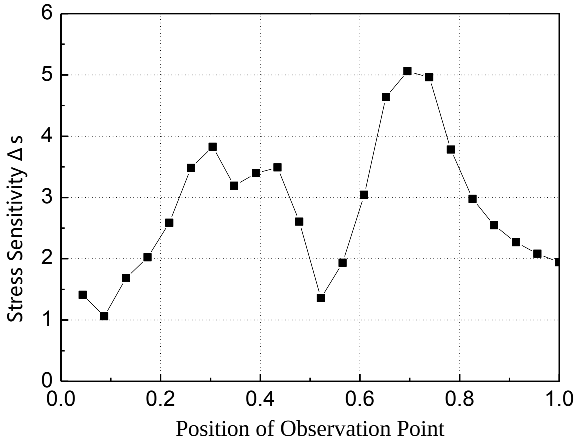

Fig. 6 Stress Sensitivity of Observation Point on Member 6

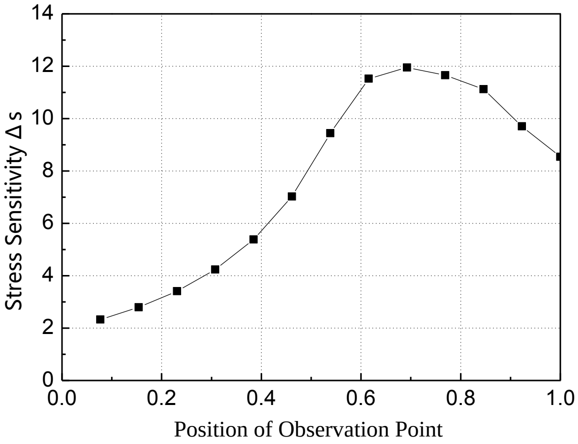

Fig. 7 Stress Sensitivity of Observation Point on Member 26

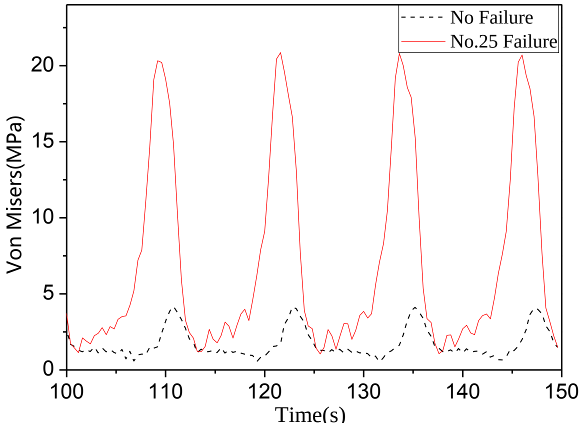

Fig. 8 Von Mises Stress of Most sensitive Point on Member 6

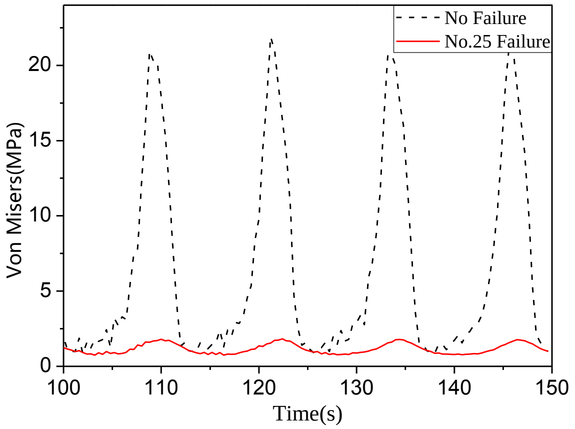

Fig. 9 Von Mises Stress of Most sensitive Point on Member 26

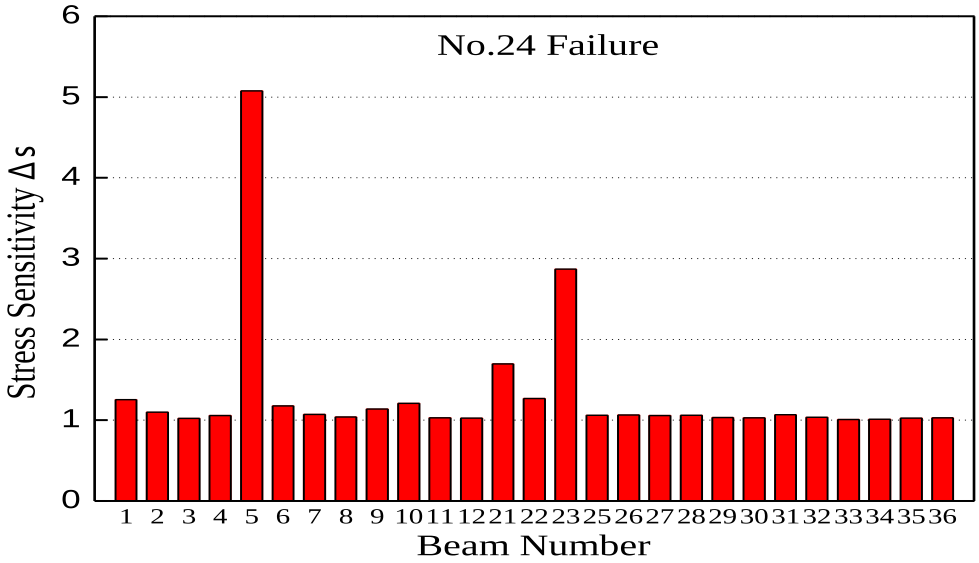

Fig. 10 Maximal Stress Sensitivity on Each Member (No.24 Failure)

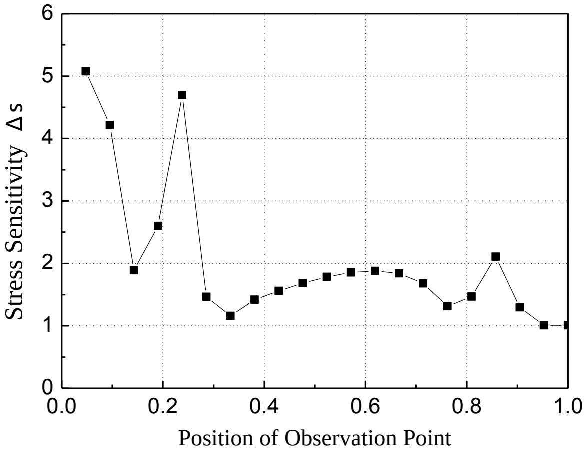

Fig. 11 Stress Sensitivity of Observation Point on Member 5

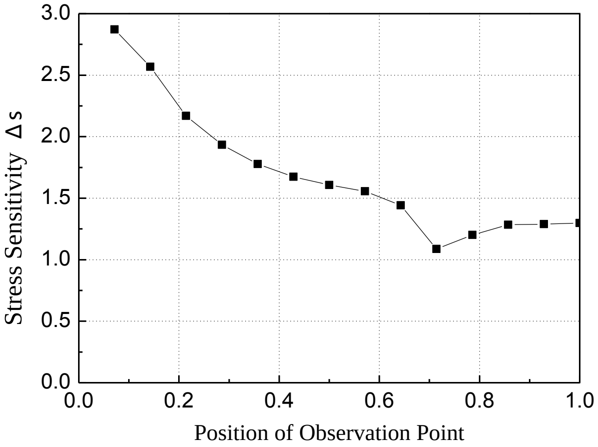

Fig. 12 Stress Sensitivity of Observation Point on Member 23

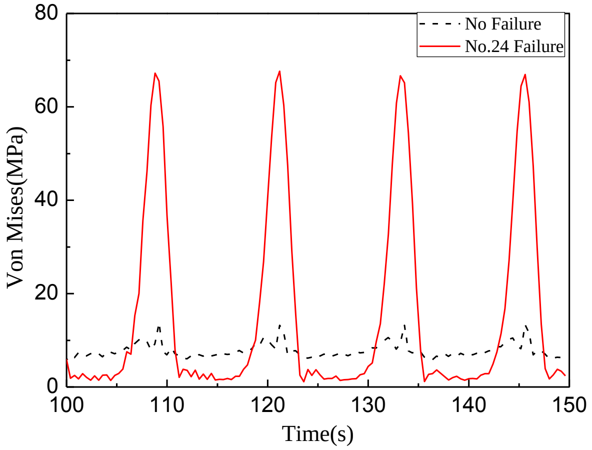

Fig. 13 Von Mises Stress of Most sensitive Point on Member 5

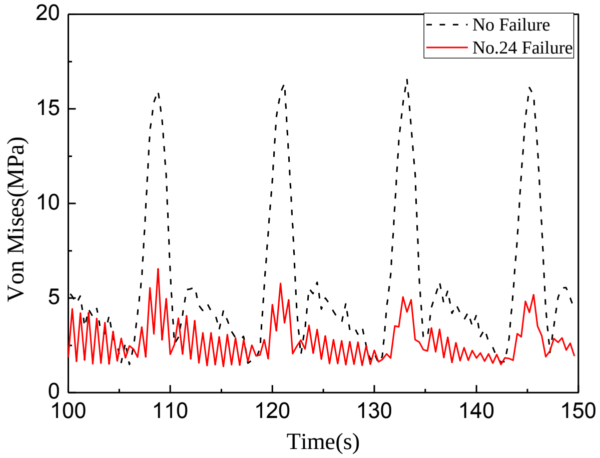

Fig. 14 Von Mises Stress of Most sensitive Point on Member 23

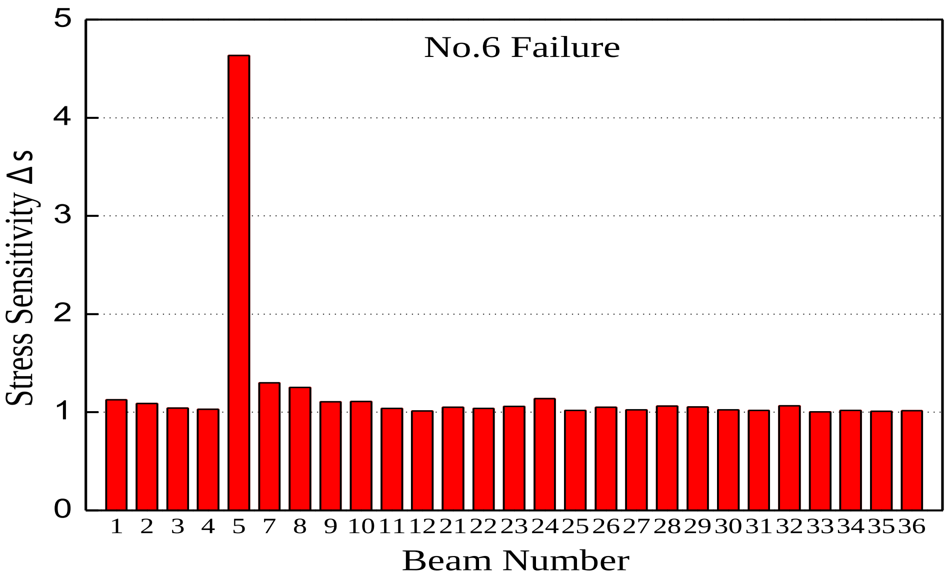

Fig. 15 Maximal Stress Sensitivity on Each Beam(No.6 Failure)

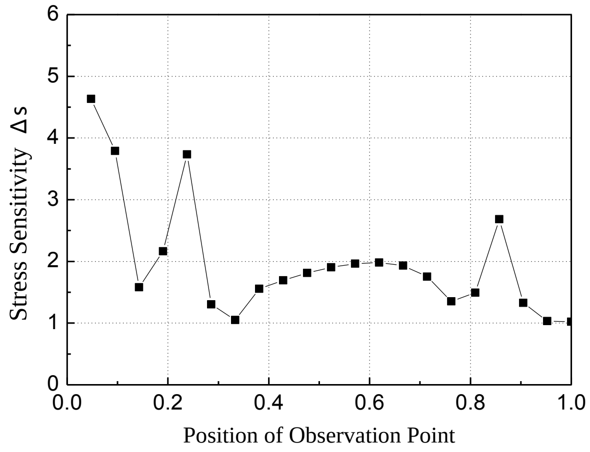

Fig. 16 Stress Sensitivity of Observation Point on Member 5

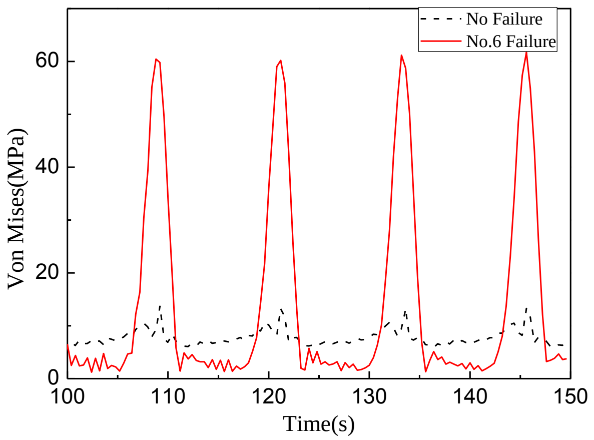

Fig. 17 Von Mises Stress of Most sensitive Point on Member 5

Considering the symmetry of jacket platform, we assume member 6, 21, 24, 25 and 28 are damaged respectively and find the sensitive member under each situation. And then the distribution of stress sensitivity Δs, on each sensitive member are calculated, where measuring point is at 1 m interval. The following analysis is referred to three typical conditions: 25, 24 and 6.

Member 25 Failure

Figure 5 shows the maximal sensitivity on other members when the member 25 is damaged. It indicates that member 26, 6 and 2 are sensitive to the failure of member 25.

Fig.6 and Fig.7 show the distribution of stress sensitivity on member 6 and 26. For member 6, the most sensitive position is near 7/10*L* (*L* refers to the length of the member) from one end; while for member 26, position of 9/13*L* is the most sensitive. Therefore, it is reasonable to set those two sensitive positions as monitor points. When the stresses on the two points have a considerable changes simultaneously, it is of great possibility that member 25 is damaged and requires repairmen.

Time series of the stress on the two sensitive points are shown in Fig.8 and Fig.9. Obviously, stress changes significantly as the member 25 are damaged. With the failure of member 25, stress on member 6 increases, but stress on member 26 almost decreases to zero. These details can also be used to identify the failure of member 25.

Member 24 Failure

According to Figure 10, member 5 and 23 are sensitive to the failure of member 24. And as shown in Fig.11 and Fig.12, the most sensitive points are both located at the end of the member.

Particularly, the stress on the member 5 increased from 18MPa to almost 68MPa, which considerably threaten the

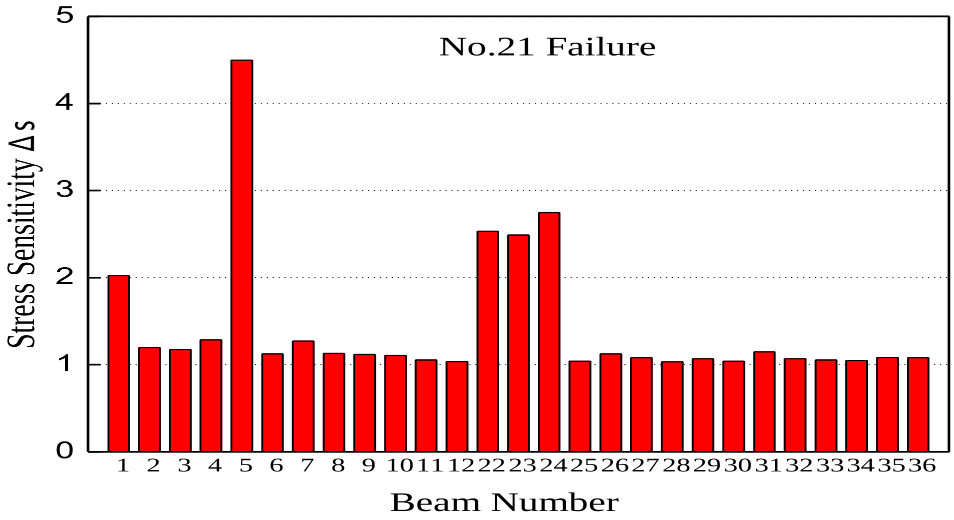

Fig. 18 Maximal Stress Sensitivity on Each Member (No.5 Failure)

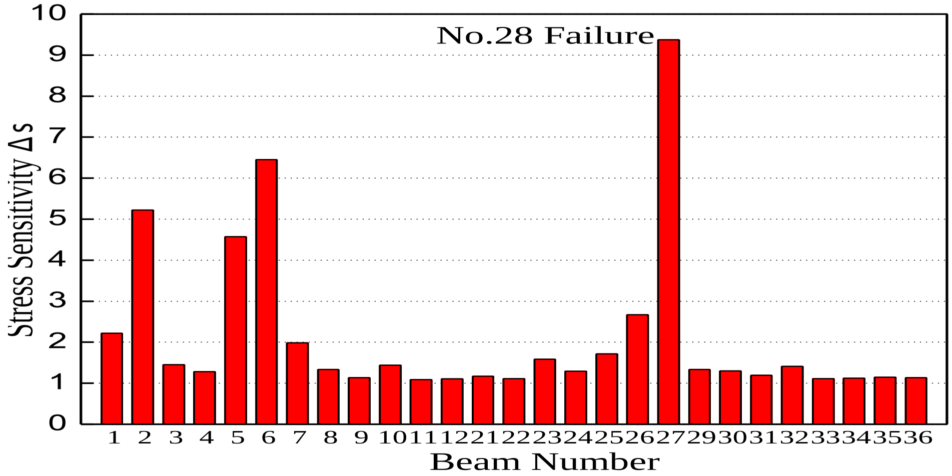

Fig 19. Maximal Stress Sensitivity on Each Member (No.28 Failure)

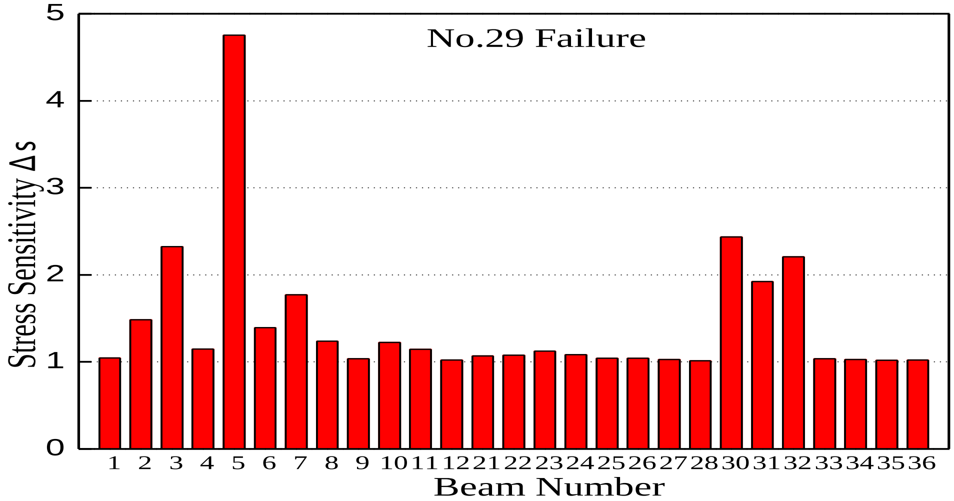

Fig 20. Maximal Stress Sensitivity on Each Member (No.29 Failure)

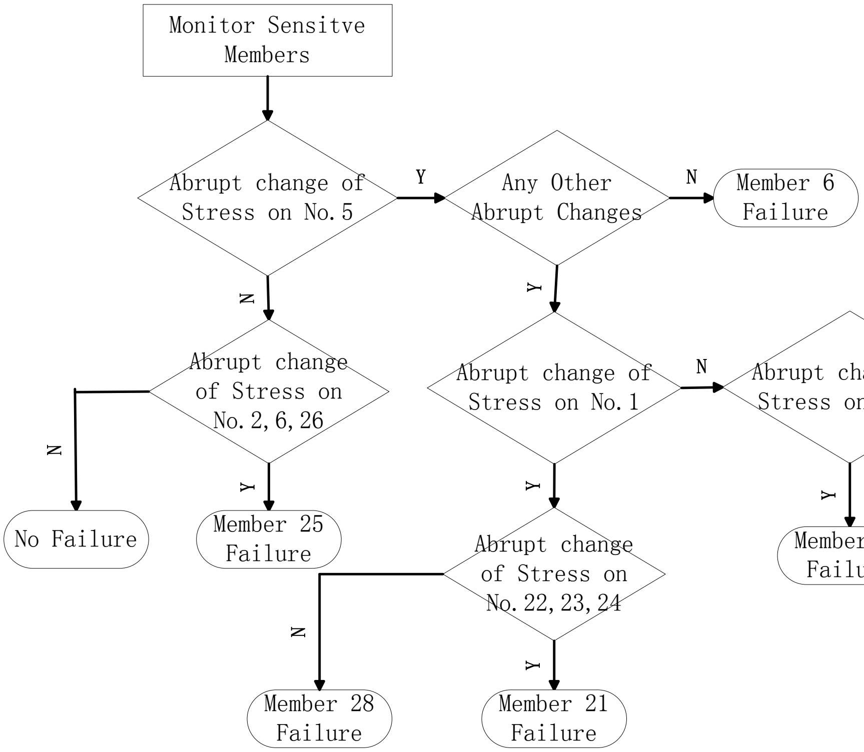

Fig. 21 Fault Diagnosis Process

safety of the jacket platform.

Member 6 Failure

As shown in Fig.15, only member 5 is sensitive to the failure of member 6 and the stress on 5 raises up to 60MPa. It may because most load on member 6 is supported by member 5. Technically, the diagnose result can be more accurate with more sensitive members. However, if the group of sensitive members was unique, the method would be still effective. Based on all the result of the numerical calculation, the sensitive member is unique for the failure of member 6. During the monitor, we can draw the conclusion that member 6 has been damaged if the only stress on member 5 suffered from great change.

Other Members Failure

As the member 21, 28 and 29 are damaged respectively, the maximal sensitivity on other members are shown as Fig.18, Fig.19 and Fig.20. It clearly indicates that there are many sensitive members under the three situations. In terms of member 21, the Von Mises stress on member 1, 5, 22, 23 and 24 changed a lot; member 2, 5, 6, 26 and 27 are sensitive to the failure of member 28 and the maximal sensitivity Δs reaches 9; and for member 29, its group of sensitive members include member 3, 5, 30 and 32.

We propose that sensitivity Δs bigger than 2 could serve as the criterion for diagnose. And then the group of sensitive members for each destructive case is shown in Table 2.

Table 2 Sensitive Members

No. of Damaged Member	Group of Sensitive Members
6	5
21	1,5,22,23,24
24	5,23
25	2,6,26
28	1,2,5,6,26,27
29	3,5,30,32

DIAGNOSTIC METHOD

According to Table 2, the group of sensitive members for each destructive case is different from each other. Despite the same sensitive member, the distribution of sensitivity Δs is different. Therefore, the sensitivity diagnose method is feasible. Based on the results of numerical calculation, we develop a diagnostic scheme as Fig.21.

CONCLUSION

In this paper, a sensitivity diagnose method is proposed for online safety monitor of jacket platform. At first, we numerically calculated the dynamic response of the platform with failure members under 50-year return level of sea conditions, where the pile-soil interaction was considered. And then we define a parameter Δs to express member sensitivity to structure failure. Based on the sensitive member group for each destructive case, we can draw conclusions as follows.

1. Local stress increases so rapidly when some members are

damaged that it would be a great threat to the safety of the jacket platform, such as member 6 and member 24. So it is necessary for online safety monitor.

2. The group of sensitive members is entirely different in different destructive cases. In other words, the change of stress on the members, caused by the member failure, is unique. Even though there maybe some similar sensitive members in different cases, such as member 5 being sensitive to member6, 24, 28 and 29, the sensitivity distribution on each member is different. Therefore, the sensitivity diagnose method is feasible for online safety monitor.

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REFERENCES

1 Jeong-Tae Kim, Yeon-Sun Ryu, Hyun-Man Cho, Norris Smbbs. Damage identification In beam-type structures: frequency based method vs mode-shape-based method, Engineering Structures,2003,25：57~67．

2 Ho Y.K, Ewins DJ. On structural damage identification with mode shapes, Proceedings of European COST F3 Conference on System Identification&Structural Heath Monitoring, Madrid, Spain,2000,677-686．

3 Law,S.S., et a1．Modal strain energy changes in neural network damage assessment, Proceedings of the International Conference on Advances in Structural Dynamic, edited by J．M．Ko and Y．LXu, The Hong Kong Polytechnic University, Hong Kong, Dec，2000,1037-1044．

4 Yang Hezhen, Li Huajun. Damage Localization of offshore Platform under Ambient Excitation, China ocean Engineering, 2003，17(4)：495--504．

5 Doebling SW, Farrar C R, Prime M B, et al. A review of damage identification methods that examine changes in dynamic properties. Shock and Vibration Digest, 1998; 30 (2) : 91—105

6 Shi X, Mizuno K Matsui T, Ohmori H. Modal identification from ambient response of a jacket-type offshore platform in multi-directional irregular waves. J. of Structural and Construction Engineering, 2004, (585)：239-247．

7 Doebling S W，Farrar C R Prime M B．A summary review of vibration-based damage identification methods. Shock Vibration Digest, 1998，205(5)：631-645．

8 B. Asgarian, A.A. Aghakouchak, Incremental Dynamic Analysis of Jacket Type Offshore Platforms Considering Soil-Pile Interaction, 2008, The 14th World Conference on Earthquake Engineering

9 A Method to Evaluate The Consequences Of Member Failure In Jacket-Type Offshore Platform Structure. James K. Nelson, 1983, PHD, the Faculty of the Department of Civil Engineering

10 Moan T. Collapse Behaviour of Trusswork Steel Platform, BOSS'85, 1985

11 Van J.W., Statistical Verification of Predicted Loading and Ultimate Strength against Observed Storm Damage for an Offshore Structure, OTC, 1991, P.109-P.118

1 2 Dynamic response of offshore jacket structures under random loads, Ahmed A. Elshafey, Mahmoud R. Haddara, H. Marzouk, Marine Structures, 2009

13 API RP 2A "Recommended Practice for Planning, Design, and Construct Fixed offshore Platform –WSD" (1993)