Monitoring-based safety evaluation of offshore jacket platform structure

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ABSTRACT: One of the goal of structural health monitoring (SHM) is to assess the structural condition with the inputs from SHM system. Based the monitored data from real offshore platform structure, the system safety evaluation method is studied in this paper. Firstly, the ultimate base shear capacity is determined by updating the structural stiffness with identified structural frequencies. Secondly, the monitoring index for structural system safety is determined by the ultimate base shear capacity based on the design code, monitoring goal and structural system mechanical property. Finally, an online safety evaluation procedure is proposed using base shear force as the control parameter. The proposed online safety evaluation method is applied in the structural health monitoring system for CA32A platform structure. Based the monitored data from the offshore platform, the evaluating results indicate the structure is in safe condition.

1 INTRODUCTION

Offshore structures often have a long service period of several decades, during which they are inevitable to suffer form environmental corrosion, long term load or fatigue effects, material aging or their coupling effects with extreme loading, and then the damage accumulates, performance degenerates or capacity resisting from disaster actions reduces and even disaster occurs since their failure under the extreme loading. Therefore, the structural health monitoring systems more and more are important technology to ensure them health. The structural health monitoring technology for offshore platform has been studied since 1970's, such as structural integrity monitoring using vibration signals of structure and structural parameters identified based on these signals was described by Begg [1]. So far a large number of productions have been obtained [2,3,4], these productions mainly focus on the parameter identification and the damage diagnosis, but the structural safety evaluation theory, one of important contents of SHM, is studied rarely. In mainland China, under support of China Ocean Oil Company, Ou *et al* [5] largely studied the technology of online monitoring and safety evaluation and developed an online health monitoring system for one of typical platform structure, JZ20-2MUQ steel jacket platform. At present, the structural health monitoring technology still isn't perfect, such as the structural system mechanical parameter and structural monitoring index of safety evaluation

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don't consider the effect of real-time structural parameter.

In this paper, the theory and method of safety evaluation are systemically studied. Firstly, online health monitoring system for CB32A steel jacket platform, developed is introduced. Secondly, the ultimate base shear capacity is determined by updating the structural stiffness with identified structural frequencies. Thirdly, the monitoring index for structural system safety is determined by the ultimate base shear capacity based on the design code, monitoring goal and structural system mechanical property. Finally, an online safety evaluation procedure is proposed using base shear force as the control parameter and is applied in the structural health monitoring system for CA32A platform structure.

2 INTRODUCTION OF SHM SYSTEM FOR CB32A OFFSHORE PLATFORM

The online health monitoring system for CB32A steel jacket platform (Figure 1) has been developed under support of the National Hi-tech Research and Development Program of China in 2001 and finished in 2004. The CB32A platform locates in Chengbei Oil field in Bohai sea and water depth 18.2m. The platform structure is made up of pile, jacket and top structure. The jacket is a structural type of four legs and its top elevation is 5.0m. The platform suffers from four environmental loads of wind, wave, current and ice. The monitoring system is made up of subsystem of ocean environmental factors monitoring, structural response monitoring, real-time data acquisition, real-time database managing, long-distance monitoring and operating and applying subsystem of parameter identification, diagnosis and orientation of damage, safety evaluation and pre-alarm and so on. Diagram of the monitoring system is shown in Figure 2. The subsystem of structural response monitoring includes 269 optical fiber bragg grating sensors, 178 polivinylidene fluoride sensors, 56 fatigue life meters 16 acceleration sensors. The subsystem of ocean environmental factors monitoring includes an anemoscope made in USA and an AWAC-Acoustic Wave and Current made in Norway.

Figure 1: A photograph of CB32A platform.

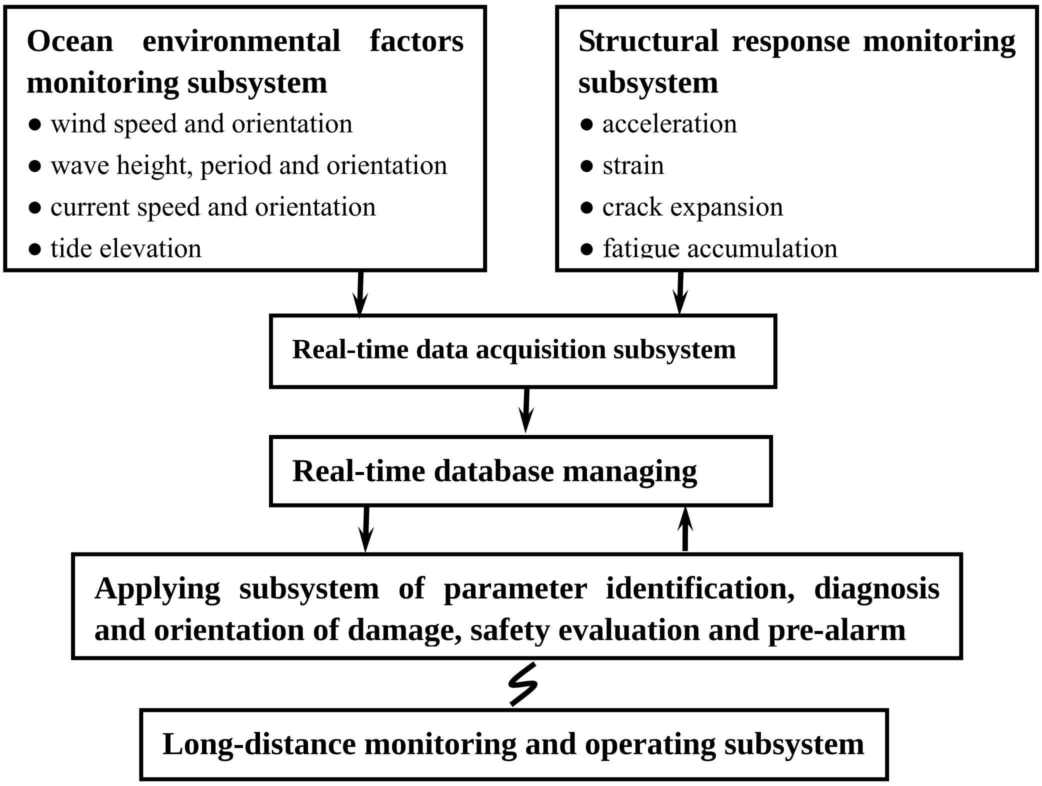


Figure 2: Diagram of real-time safety monitoring system for the CB32A platform.

3 ONLINE MONITORING SAFETY EVALUATION OF JACKET PLATFORM STRUCURE

Jacket platform is a large-scale and over-static structure and have a large number of redundancies, so failure of single component or several components can’t usually result in performance losing of structural system or failure and collapse of structural system. It is obvious that safety of structural system is more important and reasonable than that of structural component. The environmental loads with large variation are controlled loads of platform structure and threaten its safety, compared with fixed load with small variation, so base shear or overturning moment capacity of platform structure may regard as a parameter describing mechanical property of structural system [6]. When water depth of platform structure is more than 30m structural overturning moment capacity should regard as the parameter, otherwise structural base shear capacity should regard as the parameter. According to environmental property of CB32A platform, the safety evaluation theory and method for jacket platform structure is developed based on its base shear capacity in this paper.

Based the determinate structural design theory, safe condition of structure is determined by compared its real-time load effect (base shear) with its resistance (safety monitoring index based on real-time ultimate base shear capacity). So calculation method of real-time base shear, real-time ultimate base shear capacity and safety monitoring index and safety evaluation theory carefully are studied in the following.

3.1 Real-time ultimate base shear capacity

3.1.1 *Determination of real-time ultimate base shear capacity*

Based geometry and material parameters of design, fabrication and installation (DFI) structure, element model of platform structure may be built, but the model can't consider the impact of non-structural component in original structure and all damage in-serve structure on structural stiffness. Considering real condition of in-serve structure, its element model is corrected by updating the original element model with the structural model error and damage.

According to the element model based on the DFI parameters, the relation between structural base shear and top displacement can be obtained by static non-linear analysis (Pushover analysis), so the ultimate base shear capacity can be determined by the displacement corresponding with the limit state ruled. The method of the ultimate base shear capacity determination is in essence that a real structure is equivalent to a single freedom structure. The relation between structural base shear and top displacement describes in essence stiffness property of structural system. In other words, the ultimate base shear capacity can be determined by the displacement corresponding with the limit state ruled and the structural system stiffness. So the real-time ultimate base shear capacity may be determined by updating original structural system stiffness with the structural model error and damage.

The natural frequency of structure only depends on the structural stiffness and mass. The differences between the mass of design and in-service structure isn't noticeable and all damages in structure aren't change its mass, so the differences in the structural stiffness mainly result to that between the natural frequencies of structure based on the DFI parameters and real conditions. It is assumed that the change rule of the structural system stiffness based on the DFI parameters and real structure is consistent with that of their generalized stiffness corresponding with first step mode, so the correction factor of the structural system elastic stiffness may be defined as

$$\varphi = K_{rg1} / K_{dg1} \tag{1}$$

where, K_{rg1} is a generalized stiffness corresponding with first step mode of real structure; K_{dg1} is a generalized stiffness corresponding with first step mode based on the DFI parameters.

According to theory of structural natural frequency calculation, the K_{rg1} and K_{dg1} may be obtained

$$K_{rg1} = \omega_{r1}^2 M_{rg1} \tag{2}$$

$$K_{dg1} = \omega_{d1}^2 M_{dg1} \tag{3}$$

where, ω_{r1} and ω_{d1} are respectively the structural natural frequency of corresponding with first step mode based on real structure and the DFI parameters; M_{rg1} and M_{dg1} are respectively the generalized mass corresponding with first step mode based on real structure and the DFI parameter.

The differences in the mass of design and in-service structure isn't noticeable and all damages in structure aren't change its mass, so it is assumed as

$$M_{rg1} \cong M_{dg1} \tag{4}$$

According to Eqs. (1), (2) and (3), the correction factor is obtained

$$\varphi \cong \omega_{r1}^2 / \omega_{d1}^2 \tag{5}$$

In order to determine the ultimate base shear capacity of real-time structure based on the DFI parameters and the φ, three assumptions are described in the following.

(1) The all correction factors of the structural system elastic and elastic-plastic stiffness for all direction of wave or ice load case are equal.

(2) The structural system ultimate elastic displacements based on the real condition and the DFI parameters are equal.

(3) The structural system ultimate elastic-plastic displacements based on the real condition and the DFI parameters are equal.

So the ultimate base shear capacity of real-time structure can be determined by the steps which are given as following.

(1) Calculate the mechanical parameters of structure based on the DFI parameters, such as the elastic and elastic-plastic stiffness of structural system for all direction of wave or ice load case, and the ultimate elastic and elastic-plastic displacements of the structural system.

(2) Calculate the natural frequency of structure based on the DFI parameters.

(3) Identify the structural natural frequency of using the acceleration data monitored.

(4) Calculate the elastic stiffness K_{re} and elastic-plastic stiffness K_{rp} of real-time structural system with following Eqs.

$$K_{re} = \varphi K_{de} \tag{6a}$$

$$K_{rp} = \varphi K_{dp} \tag{6b}$$

where, K_{de} and K_{dp} are respectively the elastic and elastic-plastic stiffness the structural system based on the DFI parameters.

(5) Determine the relation between the base shear capacity and top displacement of real-time structure.

(6) Determine the ultimate base shear capacity of real-time structure based on the relation and the displacement of the limit state ruled.

3.1.2 *Mechanical parameter for CB32A platform structure system*

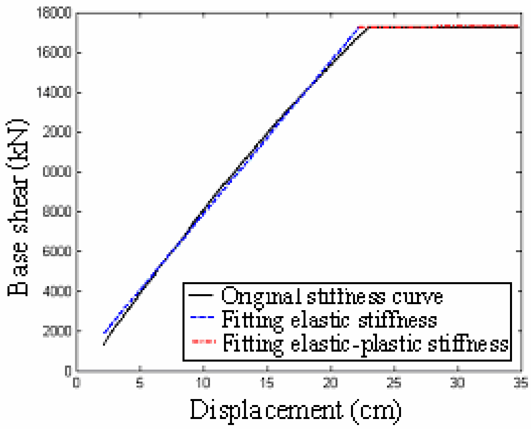
The relation between structural base shear and top displacement, which is a foundation calculating the ultimate base shear capacity of real-time structure, can be determined by static non-linear analysis based on the DFI parameters. According to the DFI parameters of CB32A platform and the Collapse analysis module of the professional design and analysis software of SACS for offshore platform structure, the relations are obtained and listed in Tables 1 and 2 and their partial results are shown in Figures 3 and 4.

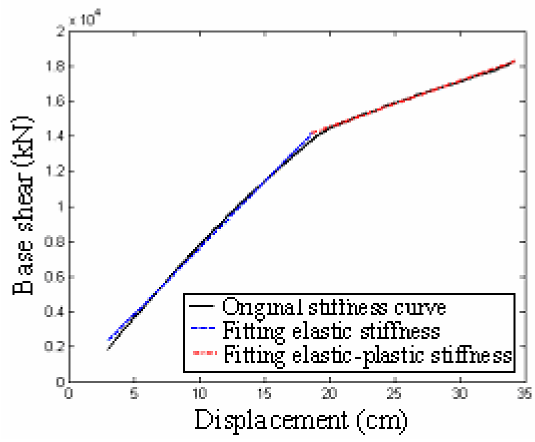
Table 1: Mechanical parameters of original structure (wave case).

Direction(°)		0	45	90	135	180	225	270	315
System stiffness (10^2kN/m)	elasticity	762.8	756.7	745.6	730.7	763.1	746.2	727.5	712.7
	Elastic plasticity	5.0	264.4	645.5	259.8	5.0	283.1	639.1	269.0
Ultimate elastic displacement (cm)		22.52	18.78	12.57	19.23	22.54	16.50	12.45	17.83
Ultimate displacement (cm)		34.84	34.20	24.76	35.30	34.96	32.23	23.32	32.47

Table 2: Mechanical parameters of original structure (ice case).

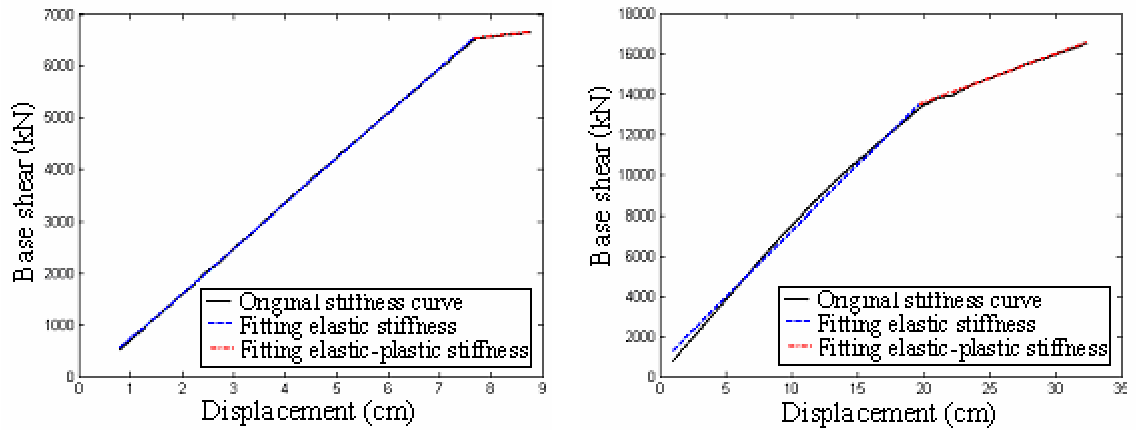
Direction(°)		0	45	90	135	180	225	270	315
System stiffness (10^2kN/m)	elasticity	854.9	667.0	711.5	760.5	840.8	883.2	720.1	846.3
	Elastic plasticity	108.7	242.4	581.6	44.0	172.3	49.5	176.7	65.8
Ultimate elastic displacement (cm)		22.52	7.50	20.58	13.70	18.81	7.51	10.19	12.96
Ultimate displacement (cm)		34.84	8.79	32.34	23.98	24.12	8.89	13.31	14.23





a) 0° direction b) 45° direction

Figure 3: Relation between structural top displacement and base shear (wave case).



a) 0° direction b) 45° direction

Figure 4: Relation between structural top displacement and base shear (ice case).

3.1.3 *Real-time mechanical parameter for CB32A platform structure system*

The method of the ultimate base shear capacity determined by updating the structural stiffness is applied to CB32A platform and its values of the ultimate base shear capacity may be obtained. The real structural natural frequency is identified as 1.53Hz using acceleration data monitored in CB32A platform. The structural natural frequency based on the DFI parameters is 1.26Hz. So the correction factor is obtained by Eq. (2) and its value is 1.21. The value is reasonable as the structure only work for two years and is in good condition, and the structural model based on the DFI parameter doesn't consider the impact of non-structural component on the structural stiffness. According to the correction factor of the structural system stiffness and the mechanical parameters of original structure based on the DFI parameters of CB32A platform, the elastic and elastic-plastic stiffness of updating structural system are obtained and listed in Tables 3 and 4. The ultimate base shear capacities of updating structural system are obtained and listed in Tables 5 and 6.

Table 3: Mechanical parameters of updating structure (wave case).

Direction(°)		0	45	90	135	180	225	270	315
System stiffness (10^2kN/m)	elasticity	923.0	915.6	902.2	884.1	923.4	902.9	880.3	862.4
	Elastic plasticity	6.1	319.9	781.1	314.4	6.1	342.6	773.3	325.5

Ultimate elastic displacement (cm)	22.52	22.52	18.78	12.57	19.23	22.54	16.50	12.45
Ultimate displacement (cm)	34.84	34.84	34.20	22.76	35.30	34.96	32.23	23.32

Table 4: Mechanical parameters of updating structure (ice case).

Direction(°)		0	45	90	135	180	225	270	315
System stiffness (10^2kN/m)	elasticity	1034.4	807.1	860.9	920.2	1017.4	1068.7	871.3	1024.0
	Elastic plasticity	131.5	293.3	703.7	53.2	208.5	59.9	213.8	79.6
Ultimate elastic displacement (cm)		7.50	20.58	13.70	18.81	7.51	10.19	12.96	10.62
Ultimate displacement (cm)		8.79	32.34	23.98	24.12	8.89	13.31	14.23	13.15

Table 5: Ultimate bearing capacity of updating structure (wave case).

Direction (°)	0	45	90	135	180	225	270	315
Ultimate bearing capacity (kN)	20861	22128	19300	22054	20889	20287	19366	20142

Table 6: Ultimate bearing capacity of updating structure (ice case).

Direction (°)	0	45	90	135	180	225	270	315
Ultimate bearing capacity (kN)	7928	20059	19028	17591	7928	11077	11564	11076

3.2 Monitoring index of offshore platform

The monitoring index of offshore platform is one of significant technologies of real-time safety evaluation. The theory and method of two level monitoring index calculation is developed based on the design code, monitoring goal and structural system mechanical property in the following.

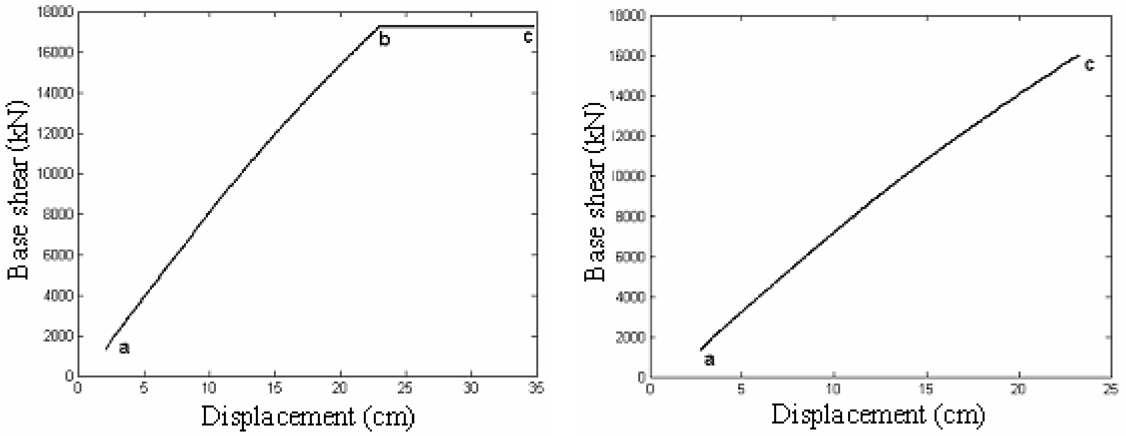
3.2.1 *Division of structural safe state*

According to the Unified standard for reliability design of building structures in mainland china, the structural limit state is divided into serviceability limit state and ultimate limit states [7]. So structural safe condition may be divided into serviceable, near-unsafe and failure condition and they are respectively the structural condition before serviceability limit state, between serviceable and ultimate limit state, and behind ultimate limit state. When the structure is in serviceable condition the productions in it normally carry. When the structure is in near-unsafe condition the large displacement or the local failure influenced on the structural serviceable performance is able to occur, so the productions in offshore platform, such as shutting down the well mouth, stopping oil extraction and so on, must be stopped, and the maintaining and reinforcing measures against the large displacement or the local failure are applied according to the safety requirement or all people in the platform is ready to remove if the large displacement or the local failure influences largely on the structural safety. When the structure is in the ultimate limit state it possibly collapses or fails at any moment, but all productions had been stopped and all people had been removed. So the division for structural safe condition succeeds the safety rule of design code and satisfies with structural health monitoring goal. According to the division of the structural safe condition, two identifying indexes may be obtained. Considering monitoring goal, the two indexes may be defined as first and second level monitoring index, which respectively correspond with the identifying index between serviceable and near-unsafe condition and that between near-unsafe and failure condition.

3.2.2 *Theory and method of monitoring index calculation*

The relation between base shear and top displacement of offshore platform structure indicates that the structural system mechanical property behaves three performances of linear elasticity, elastic-plasticity and failure or two performances of linear elasticity and failure, and show in Figures 5a and 5b respectively, which resembles mechanical property of ductile or brittle material. The structural system of offshore platform may be assumed as a single component and its mechanical property can be described by the relation between base shear and top displacement of platform structure, so the significant mechanical parameters of the structural system can be defined analogously by the theory of material mechanical parameter definition. The structure with the three performances of mechanical property resembles ductile material, which yielded and ultimate base shear capacity are defined as the base shears corresponding with the b and c in Figure 5a respectively. The structure with the two performances of mechanical property resembles brittle material, which ultimate base shear capacity is defined as the base shear corresponding with the c in Figure 5b and which conditional yielded base shear capacity is defined as 0.7~0.85 the ultimate base shear capacity. When the base shear of structure with the three performances is more than its yield base shear capacity, its deformation trend increase and its displacement is larger, which displacement is able to influence on some production in the platform, which indicates the point, which is the b in Figure 5b, is the varying point of the structural system mechanical property and the structure will be in an unsafe condition, so it is assumed that the range before and behind the point b correspond respectively with structural serviceable and near-unsafe condition, and the yielded base shear capacity is regarded as first level monitoring index for offshore platform structure. When the base shear of structure with the three performances is equal to or more than its ultimate base shear capacity, it is in a ultimate state in which structure was able to fail or can’t continue to bear load, so the ultimate base shear capacity is regarded as second level monitoring index for offshore platform structure. The structure with the two performances is different from the structure with the three performances, as its mechanical behavior hasn’t obvious elastic-plastic range and distinct large deformation. Considering structural health monitoring goal, before the structure gets into the failure condition it must live through a near-unsafe condition, which provides an enough safe reserve for stopping production in the structure and all people removing before the structure fails or can’t continue to bear load, so considering the definition of the conditional yielded base shear capacity it may be regarded as first level monitoring index. The second level monitoring index for the structure with the two performances may be determined as that for the structure with the three performances.

According above-mentioned the theory of the monitoring index determination, two methods for the monitoring index determination are inconvenient in course of application. In addition, if the elastic-plastic range of the structural mechanical curve with the three performances is so small that it hasn’t enough safe reserve, which is that the collapses or fails of structural system before the production in the structure doesn’t stop and some people in the structure don’t remove, so the first level monitoring index hasn’t practical use. The method for the first level monitoring index determination of the structure with the two performances hasn’t such shortage. So the first and second level monitoring index for offshore platform are uniformly determined as the conditional yielded and ultimate base shear capacity respectively.



a) Two-linear relation b) One-linear relation

Figure 5: Relation between structural top displacement and base shear.

3.2.3 *Monitoring index for CB32A platform*

According to the correction ultimate base shear capacity in Tables 5 and 6 and the method of monitoring index calculation, their results are obtained and listed in Tables 7 and 8.

Table 7: Monitoring index of real-time structure system safety forCB32A platform (wave case).

Direction (°)	0	45	90	135	180	225	270	315
First level monitoring index (kN)	15646	16596	14475	16541	15667	15215	14525	15107
Second level monitoring index (kN)	20861	22128	19300	22054	20889	20287	19366	20142

Table 8: Monitoring index of real-time structure system safety for CB32A platform (ice case).

Direction (^{o})	0	45	90	135	180	225	270	315
First level monitoring index (kN)	5946	15044	14271	13193	5946	8308	8673	8307
Second level monitoring index (kN)	7928	20059	19028	17591	7928	11077	11564	11076

3.3 Real-time environmental load effect

Ocean environmental loads mainly include wind, wave, current and ice load. They are determined by environmental factors, such as wind speed and direction for wind load, wave height, direction and period for wave load, current speed and direction for current load and so on. According to the environmental factors, their load models and structural model, environmental load effect such as structural base shear can be obtained. The online health monitoring system for CB32A platform can acquires real-timely some environmental factors for environmental load calculation. In order to obtain real-timely the structural base shear using these acquired real-time environmental factors, the function between the environmental factor and its base shear of CB32A platform is calculated by the load model, simulating environmental factor data and the structural model of CB32A platform. The functions between the wind speed and its base shear are listed in Table 9, where, v_z is a wind speed at elevation z and its unit is m/s, α is a factor of ground roughness and its value for sea level is 0.12, and the unit of the base shear F_{wi} is kN. The functions between the current speed and its base shear are listed in Table 10, where, v_c is a surface current speed and its unit is m/s, and the unit of the base shear F_c is kN. The functions between the wave height and its base shear are listed in Table 11, where, h_i is wave height and its unit is *m*, and the unit of the base shear F_{wa} is kN. The functions between the ice thickness and its base shear are listed in Table 12, where, h_i is a ice thickness and its unit is *m*, and the unit of the base shear F_i is kN. The base shears of environmental factor of all directions can be obtained by the linear interpolation.

Table 9: Function of wind speed and its base shear.

Direction (^{o})	Function	Direction (^{o})	Function
0，180	$F_{wi} = 0.3278[v_z/(z/10)^{\alpha}]^2$	90，270	$F_{wi} = 0.3469[v_z/(z/10)^{\alpha}]^2$
45，135， 225，315	$F_{wi} = 0.4762[v_z/(z/10)^{\alpha}]^2$	—	—

Table 10: Function of current speed and its base shear.

Direction (°)	Function	Direction (°)	Function
0，180	$F_c = 47.8145v_c^2$	90，270	$F_c = 50.6746v_c^2$
45，225，	$F_c = 48.8958v_c^2$	135，315	$F_c = 48.9606v_c^2$

Table 11: Function of wave height and its base shear.

Direction (°)	Function	Direction (°)	Function
0	$F_{wa} = 22.07h^2$	180	$F_{wa} = 22.13h^2$
45	$F_{wa} = 22.05h^2$	225	$F_{wa} = 22.56h^2$
90	$F_{wa} = 23.80h^2$	270	$F_{wa} = 23.70h^2$
135	$F_{wa} = 22.39h^2$	315	$F_{wa} = 22.27h^2$

Table 12: Function of ice speed and its base shear.

Direction (°)	Function	Direction (°)	Function
0	$F_i = 6516.9h_i$	180	$F_i = 6516.9h_i$
45	$F_i = 5958.7h_i$	225	$F_i = 8356.4h_i$
90	$F_i = 5111.1h_i$	270	$F_i = 9995.6h_i$
135	$F_i = 5958.7h_i$	315	$F_i = 8356.4h_i$

3.4 Monitoring safety evaluation of platform structure system

The base shear values and direction of the real-time wind, current, wave and ice load can be obtained by the method in the 3.3 section. Considering occurring property of the environmental loads, its action case is divided into wave load and ice load case. The wave load case includes the wind, current and wave load. The ice load case includes the wind, current and ice load. So the total base shear value and direction for the wave load case can be obtained

$$\begin{cases} S = S_1 + S_2 + S_3 \\ \alpha_S = \{\alpha_i \mid S_i = \max(S_1, S_2, S_3)\} \end{cases} \tag{7}$$

where, S_1, S_2 and S_3 are respectively the base shears of the wind, current and wave load, α_i are respectively the directions of the wind, current and wave load and . S is the total base shear, α_S is the direction of the total base shear. The total base shear value and direction for the ice load case can be obtained

$$\begin{cases} S = S_1 + S_2 + S_4 \\ \alpha_S = \{\alpha_i \mid F_i = \max(S_1, S_2, S_4)\} \end{cases} \tag{8}$$

where, S_1, S_2 and S_4 are respectively the base shears of the wind, current and ice load, α_i are respectively the directions of the wind, current and ice load and . S is the total base shear, α_S is the direction of the total base shear.

According to the determinate structural design theory, it is known that if the structural load effect is less than the structural resistance the structure is in safe condition, otherwise the structure is in unsafe condition. So the real-time safety evaluation method of the structural system, which is that the real-time safe condition of structural system is judged by the compare of the real-time total base shear and structural monitoring indexes, be developed. The safety evaluation method be described as following.

If $S < IN_1$, the structural system is in safe state.

If $IN_1 \le S \le IN_2$, the structural system is in near-unsafe state.

If $S > IN_2$, the structural system is in failure state.

Where IN_1 and IN_2 are respectively the first and second level monitoring indexes.

The real-time safety evaluation method is applied to the structural health monitoring system for CA32A platform structure and the monitoring system normally works up to now.

4 REAL-TIME SAFETY EVALUATION BASED MONITORING DATA

4.1 Real-time environmental factor and its load effect

The structural health monitoring system for CA32A platform normally works up to now and a large number of environmental monitoring data is obtained, and their partial data is listed in Table 13. According the function between the environmental factor and its base shear, the load effects of these factors are obtained and listed in Table 14.

Table 13: Observing data of environmental factors.

Time	Wind speed(m/s)	Wind direciton(°)	Current speed(m/s)	Current direciton(°)	Wave height(m/s)	Wave direciton(°)
2006-1-27:03:24	5.13	293.72	0.199	134	0.23	0.2
2006-1-27:03:54	5.3	301.73	0.185	134.1	0.23	0.2
2006-1-27:04:24	3.85	318.02	0.221	125.4	0.23	0.2
2006-1-27:04:56	3.9	309.47	0.247	146.2	0.23	0.2
2006-1-27:05:32	3.86	296.65	0.239	139.2	0.18	0.1

2006-1-27:06:02	3.27	316.96	0.216	134.4	0.2	0.2
2006-1-27:06:38	3.98	332.44	0.135	161.4	0.19	0.2
2006-1-27:07:11	5.08	41.62	0.076	160.3	0.2	0.2
2006-1-27:07:46	4.41	34.05	0.103	155.2	0.2	0.2
2006-1-27:08:18	4.62	32.49	0.061	231.2	0.2	0.2

Table 14: Base shear based on Observing data of environmental factors (unit:kN).

Time	Wind effect	Wind effect direciton	Wind effect	Wind effect direciton	Wind effect	Wind effect direciton	Total effect	Total effect direciton
27:03:24	8.99	293.72	1.94	134	1.17	0.2	12.10	293.72
27:03:54	9.59	301.73	1.68	134.1	1.17	0.2	12.44	301.73
27:04:24	5.06	318.02	2.39	125.4	1.17	0.2	8.62	318.02
27:04:56	5.19	309.47	2.99	146.2	1.17	0.2	9.35	309.47
27:05:32	5.08	296.65	2.80	139.2	0.72	0.1	8.60	296.65
27:06:02	3.65	316.96	2.28	134.4	0.88	0.2	6.81	316.96
27:06:38	5.41	332.44	0.88	161.4	0.79	0.2	7.08	332.44
27:07:11	8.81	41.62	0.28	160.3	0.88	0.2	9.97	41.62
27:07:46	6.64	34.05	0.51	155.2	0.88	0.2	8.03	34.05
27:08:18	7.29	32.49	0.18	231.2	0.88	0.2	8.35	32.49

4.2 Real-time monitoring index

The analyzing results based on response data of structural system and part indicates that the structure is in good condition, so according the ultimate base shear capacity in Table 7 can be calculated the real-time monitoring indexes and their results are listed in Table 15.

Table 15: Monitoring index of real-time structure system safety for

CB32A platform (wave case, unit:kN).

Time	Index type	Direction(°)							
		0	45	90	135	180	225	270	315
27:03:24	First level	15646	16596	14475	16541	15667	15215	14525	15107
	Second level	20861	22128	19300	22054	20889	20287	19366	20142
27:03:54	First level	15646	16596	14475	16541	15667	15215	14525	15107
	Second level	20861	22128	19300	22054	20889	20287	19366	20142
27:04:24	First level	15646	16596	14475	16541	15667	15215	14525	15107
	Second level	20861	22128	19300	22054	20889	20287	19366	20142
27:04:56	First level	15646	16596	14475	16541	15667	15215	14525	15107
	Second level	20861	22128	19300	22054	20889	20287	19366	20142
27:05:32	First level	15646	16596	14475	16541	15667	15215	14525	15107

	Second level	20861	22128	19300	22054	20889	20287	19366	20142
27:06:02	First level	15646	16596	14475	16541	15667	15215	14525	15107
	Second level	20861	22128	19300	22054	20889	20287	19366	20142
27:06:38	First level	15646	16596	14475	16541	15667	15215	14525	15107
	Second level	20861	22128	19300	22054	20889	20287	19366	20142
27:07:11	First level	15646	16596	14475	16541	15667	15215	14525	15107
	Second level	20861	22128	19300	22054	20889	20287	19366	20142
27:07:46	First level	15646	16596	14475	16541	15667	15215	14525	15107
	Second level	20861	22128	19300	22054	20889	20287	19366	20142
27:08:18	First level	15646	16596	14475	16541	15667	15215	14525	15107
	Second level	20861	22128	19300	22054	20889	20287	19366	20142

4.3 Real-time safety evaluation

According to the direction of total load effect, the linear interpolation is employed to calculate the monitoring indexes and their results are listed in Table 16. The structural system safety evaluation method is applied to judge the safe condition of the structural system of CB32A platform and the results in Table 16 indicate the structural system is in safe condition.

Table 16: Real-time safe condition of structural system.

Time	Real-time total load effect (kN)	First level monitoring index(kN)	Second level monitoring index (kN)	Structural safe conditon
2006-1-27:03:24	12.10	14161	18882	safety
2006-1-27:03:54	12.44	14038	18718	safety
2006-1-27:04:24	8.62	15143	20191	safety
2006-1-27:04:56	9.35	13920	18560	safety
2006-1-27:05:32	8.60	14116	18822	safety
2006-1-27:06:02	6.81	15130	20174	safety
2006-1-27:06:38	7.08	15316	20421	safety
2006-1-27:07:11	9.97	16525	22033	safety
2006-1-27:07:46	8.03	16365	21820	safety
2006-1-27:08:18	8.35	16332	21776	safety

5 CONCLUSIONS

In order to satisfy with the application of structural health monitoring method in actual engineering, the system safety evaluation method is studied thoroughly and several conclusions are obtained.

(1) The ultimate base shear capacity can be determined by updating the structural

stiffness with identified structural frequencies.

(2) The monitoring index for structural system safety can be determined by the ultimate base shear capacity based on the design code, monitoring goal and structural system mechanical property.

(3) The real-time safety evaluation method is proposed using the base shear force and the monitoring index based on the ultimate base shear capacity.

(4) The proposed real-time safety evaluation method is applied in the structural health monitoring system for CA32A platform structure and the monitoring normally work. Based on the monitored data from the offshore platform, the evaluating results indicate the structure is in safe condition.

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