POLISH MARITIME RESEARCH Special Issue 2017 S2 (94) 2017 Vol. 24; pp. 74-80
10.1515/pomr-2017-0067

ANALYSIS AND EXPERIMENTS ON SEA LOAD AND FASTENED MECHANICS ON PIPE CLAMPS

Zhuo Wang [1]**, Ph. D.,**
Bo Zhang[1]**, Ph. D.,**
Tao Wang [2]**, Ph. D.,**
[1] College of Mechanical and Electrical Engineering, Harbin Engineering University, Harbin, China
[2] School of MechanicalEngineering, Hebei University of Technology, Tianjin, China

ABSTRACT

When an offshore oil field completed and put into production, new subsea pipelines and the new cable need to be established. Cable protection pipe clamp is used to fix cable protection pipe on the jacket. In order to avoid the problem of traditional steel structure clamp splice, counterpoint, fastening difficulty when installed cable protection pipe under water, reduce the risk and workload of under water, This paper develop a new type of portable connecting riser clamp –"backpack clamp" which solve the riser cable protection pipe difficult underwater installation problem. The main structure of backpack clamp used three valves type structure. The load characteristic of a clamping device was determined by the Morison equation which was a classical theory. Clamp device underwater mechanics analysis model was established. The minimum tension pre-tightening force was determined. The results show that the strength of the base meets the requirements after strength analysis with finite element analysis method, stability and strength experiments, which means the clamp based on resin matrix composite is feasible.

Keywords: Pipe clamps, Sea environmental load, Fastening mechanics,Strength analysis

INTRODUCTION

Offshore oiland gas resource development has attracted the attention of the whole world because of the increasing depletion of land oil and gas resources.Exploit advanced marine petroleum equipment is an important symbol of the effective development of offshore oil and gas resources[1]. Offshore oil and gas resource development are based on the offshore platform structure.The structure of jacket platform is large and complex,and the sea breeze,ocean wave,ocean currents,sea ice always has impact on it[2]. The offshore jacket platform will appear in different forms of damage which work in the harsh marine environment for a long term,the main damage types including dent,corrosion foundation erosion and sea ice[3].

With the vigorous exploitation of the world marine resources, ocean engineering is developing rapidly, which makes the ocean engineering cable needs expanding, and its related technology has put forward higher requirements, one important link is the research of submarine cable laying, protection and maintenance[4,5,6]. The science of submarine cable laying and maintenance technology can better use of favorable conditions and avoid unfavorable conditions in the marine environment. The science, economics economy and reliability of the submarine cable project are promoted and its service life is increased. This paper will study the new nonmetal type of vertical pipe clamp which based on composite material resin. Marine environment load and device mechanical properties are analyzed [7, 8. 9].

STRUCTURE DESIGN OF BACKPACK CLAMPS

The backpack clamp device is mainly composed of compound material matrix, three clamps fastening connector (including long screws, pre-clamping bolts, flat steel components and compressive steel plate), which is shown in Fig.1.

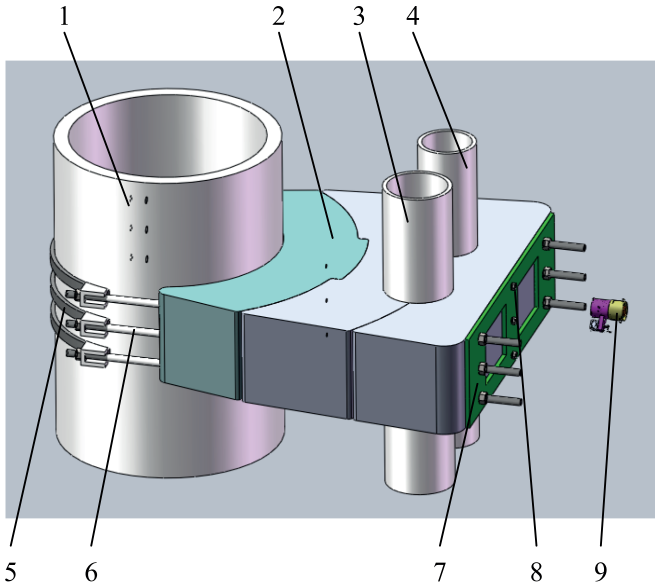

Fig.1. Overall structure of backpack clamp device (1- jacket 2- clamp 3- the big cable protection pipe 4-the small one 5-flat steel component 6-long screw 7- compressive steel plate 8-pre-clamping bolt 9-fastening machine)

Clamp fastening need a set of special under-water fastening machinery - hydraulic stretching device. The backpack clamp matrix is adopted three valve structures, which convenient for installation and repair. Three groups of flat steel component are connected with long screws by thread. Long screw piece 6 through matrix mounting holes advance buried and compressive steel plate installation holes. The backpack clamp is pensioned by hydraulic stretching device which ensures the tensioning load appropriately. The characteristic is simple, labor-saving and operation convenient under water. Pre-clamping bolts are used to connect three clamp matrixes to cable protection pipes, which conducive to overall hoisting and installation under water. After six fastening nuts are tensions, the installation of cable protection pipes to the jacket is completed.

SEA LAOD ANALYSIS OF BACKPACK CLAMPS

Marine environment and sea conditions should be studied before offshore structures analysis and design, which are the important work in the design of marine engineering. For the backpack clamp device, the impact of wave load and the current load on the cable protection pipes and clamp device will be mainly researched [10].

Morrison equation is the main wave forces calculation method when an object is smaller than wavelength relatively [11]. For the coordinate system as showed in Fig.2, arbitrary height z of protection pipes, pipe length *dz* horizontal wave force is

$$dF_H = f_H dz = \frac{1}{2} C_D \rho D u_x \left| u_x \right| dz + C_M \rho \frac{\pi D^2}{4} \frac{\partial u_x}{\partial t} dz \quad \textbf{(1)}$$

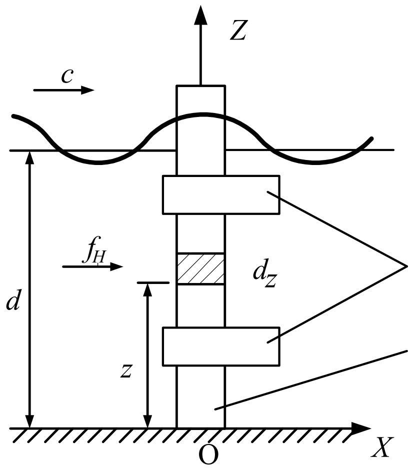

Fig. 2. Cable protection pipe is subjected to wave forces (1-cable protection pipe 2- backpack clamp)

Where F_H: the horizontal wave force of cable protection pipes; u_x: wave particle horizontal velocity in protection pipe axis arbitrary position at *z* height; *D*: the outer diameter of cable protection pipe; *ρ*: the density of seawater; C_D: drag coefficient vertical to the protection pipe axis direction (the reaction of the liquid viscosity effect); C_M: inertia force coefficient (quality coefficient).

According to the actual loading of backpack clamp, Ariy linear wave theory is adopted in the analysis of wave motion characteristics. Velocity of wave particle in the horizontal direction is shown in equation (2) [12].

$$v_x = \frac{\partial \Phi}{\partial x} = \frac{\pi H}{T} \frac{\mathrm{ch}\left[k\left(z+d\right)\right]}{\mathrm{sh}\left(kd\right)} \cos\left(kx - \omega t\right) \quad \textbf{(2)}$$

As showed in Fig.3, the horizontal velocity of wave changes as the cosine law with the phase (time). With the increase of water depth, velocity decreases and the surface wave motion is the most severe. With the increase of water depth, the impact of the phase of horizontal velocity of wave particle decreases gradually, which illustrates the particle motion of wave mainly occurs in the surface of water.

According to the calculation of wave particle horizontal velocity and acceleration in motion characteristics and combining with the Morison equation, the horizontal wave force of whole root protection pipe can be gotten by the integral the equation (1) in cable protection pipe length.

$$F_H = C_D \frac{\rho g D H^2}{2} K_1 \cos\theta |\cos\theta| + C_M \frac{\rho g \pi D^2 H}{8} K_2 \sin\theta \quad (3)$$

Where: H: The wave height; T: The wave cycle; k: The wave number; θ: The wave phase angle;

$$K_1 = \frac{2kd + \mathrm{sh}(2kd)}{8\,\mathrm{sh}\,2(kd)}, \quad K_2 = \tanh(kd).$$

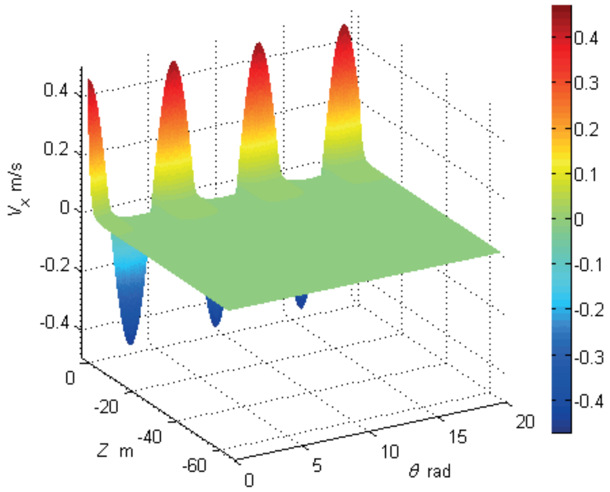

Fig. 3. The horizontal velocity of waves in different phase and depth

v_x – Horizontal velocity of water particle z – depth of the water
θ – Phase angle ($\theta = kx - \omega t$)

This paper is combined with the actual situation and consulted related to specific references in Nanhai Sea, China. Wave height is determined as 1.5m; Wave cycle T is 10s; the minimum wavelength L is 6m. Cable protection pipe diameter D is 0.328m. According to the specification of Chinese fixed offshore platform into level and construction, C_D=1.2, C_M=2.0[13]. The final maximum wave force calculation of single cable protection pipe is 1242N.

The horizontal wave force FH of whole root protection pipe changes with phase θ and relate to cycle T, wave height H, water depth z etc. Firstly, discuss for the condition of given cycle (wavelength), water depth, different wave height, protection pipe wave force changes, as showed in Fig.4.

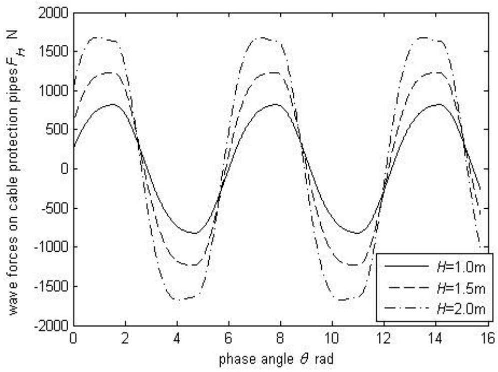

Fig.4. Cable protection pipe wave force varies with the phase angle under the different wave height

As showed in Fig.4, for the condition of water depth d=64m, wave cycle T=10 s, wave height H is 1.0m, 1.5m, 2.0m respectively, and wave force of cable protection pipe changes with the phase angle.

Wave height H has a bigger impact on wave force. The wave forces increase with wave height. Referring to Fig.4, wave height H has a more obvious impact on wave force than cycle T.

Secondly, discuss for the condition of given water depth, different wave height, protection pipe wave force changes with cycle T. As Fig.5 shown, for the condition of water depth d=64m, wave cycle T in the range of 2~20s, wave height H is 1.0m, 2.0m, 4.0m respectively, wave force of cable protection pipe changes with the wave cycle.

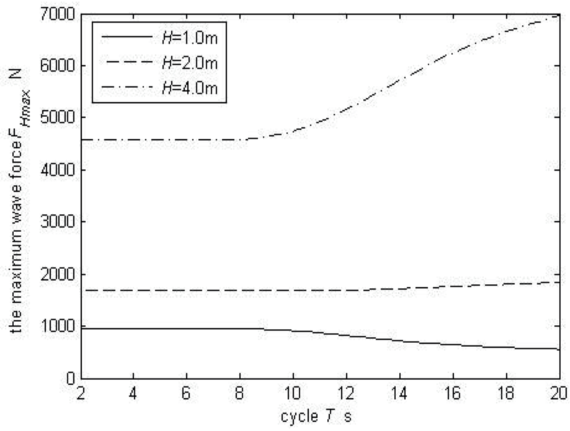

Fig. 5. Maximum wave force of cable protection pipe varies with wave cycle under the different wave height

As showed in Fig.5, with the wave cycle T increasing, the impact on the maximum wave force not process consistency. For the reason that when H=1.0m, the maximum wave force F_{Hmax} is determined by the maximum inertia force and with the increasing of cycle T, the maximum wave force F_{Hmax} decrease; when H=2.0m or H=4.0m, the maximum wave force F_{Hmax} is determined by the maximum inertia force and maximum drag force together and with the increasing of cycle T, the maximum wave force F_{Hmax} increase. The cycle has a bigger impact on wave force under H=4.0m than H=2.0m.

According to the formula (1), for the condition of water depth d=64m, the maximum wave force of cable protection pipe unit length changes with the water depth. As Fig.6 showed, for the condition of the cycle T=10s, wave height H is 1.0m, 2.0m, 4.0m respectively, the maximum wave force of cable protection pipe unit length changes with the wave depth.

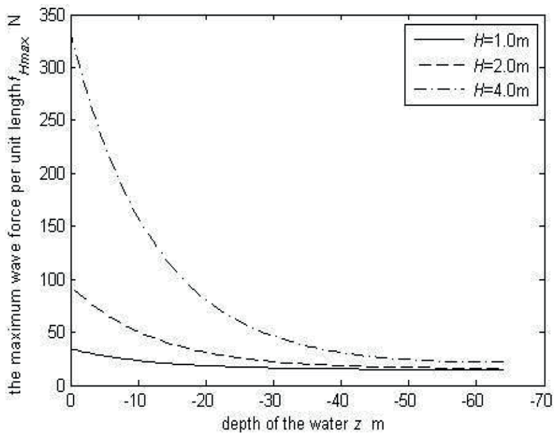

Fig. 6. Maximum wave force of protection pipe unit length varies with depth under the different wave height

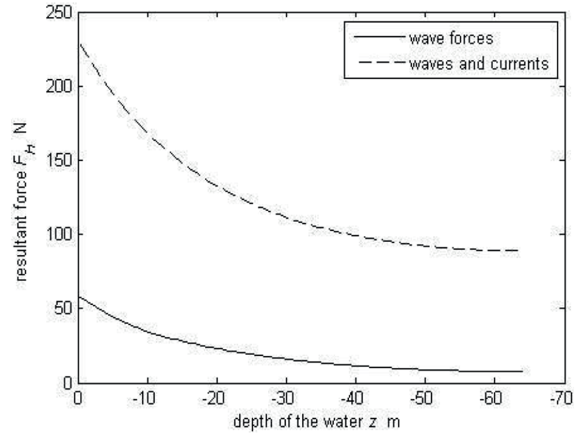

Fig.7. Contrast of protection pipe resultant force between combined wave current and lonely wave action

The origin of the coordinate is in the surface of water. The curve responses water depth and wave height impact on wave force was showed in Fig. 6. Under the condition of certain water depth, the maximum wave force of cable protection pipe unit length decreases with depth increasing. The minimum wave force is at the bottom of the sea; the maximum wave force is in the surface of water. This phenomenon is more obvious with increasing wave height. The greater ratio of wave height and depth, effect of water depth on wave force is more obvious.

In the actual ocean environment, not only existence the waves, there are still current. The cable protection pipe is affected by wave and current in the same direction. Motion characteristics of water particle should consider the joint action of wave and current. The joint action of current and wave greatly increases the drag force of seawater for ocean engineering structures [14].

The wave force calculation formula of cable protection pipe on unit length under the joint action of waves and currents for the type (4). Total wave forces on cable protection pipe can be solved by integral calculation.

$$F_H = \frac{1}{2} C_D \rho D (\mathbf{V} + \mathbf{V_c}) \left| \mathbf{V} + \mathbf{V_c} \right| + C_M \rho \frac{\pi D^2}{4} \dot{\mathbf{V}} \quad (4)$$

According to the sea state data, current velocity *Vc* is 0.6m/s; cable protection pipe environmental water depth *d* is 64 m; Wave period *T* is 10s; Wave height *H* is 1.5m. The contrast stress curve of cable protection pipe per unit length by the drag force alone and the resultant force is shown in Fig. 7.

As showed in the curve, the sea loads of cable protection pipe are decreased with depth increased. For the reason that water particle horizontal velocity caused by current is constant in depth. Because the current is considered to be a uniform flow, the inertial force caused by current is very small and the resultant force is mainly produced by the drag force in the deep sea.

Compute the integral of F_H to the depth z range from -64m~0m. The inertial force of cable protection pipe is 78784N under the combined action of waves and currents.

THE STUDY ON MECHANICAL FASTENING PROPERTIES OF BACKPACK CLAMPS

After backpack clamp installation is completed under water, in order to ensure the clamp stable and reliable work, the mechanical analysis of the clamp key components must be done.

The backpack clamp is under the action of wave force and current force underwater. According to the analysis of sea loads in the previous section, environmental loads for each condition act on the cable protection pipe in 8 directions. The Table.1 and Fig. 8 are directions of loading for the conditions of the corresponding reaction loading.

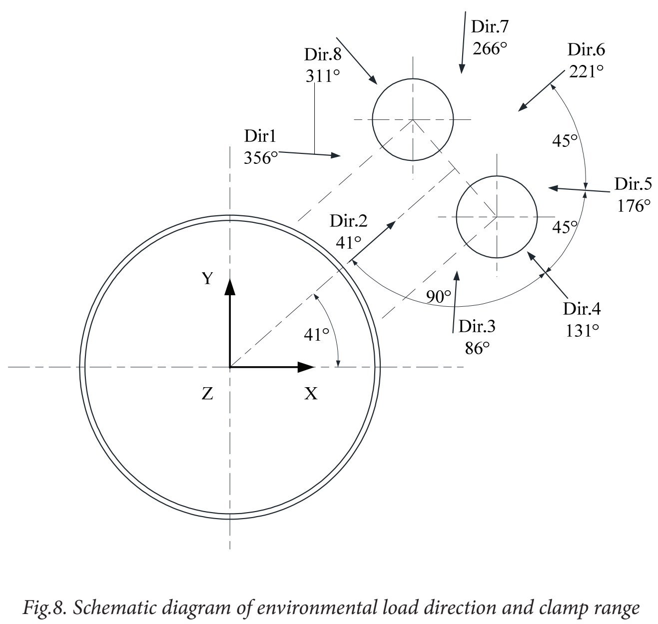

Fig.8. Schematic diagram of environmental load direction and clamp range

Tab. 1. Support reaction force extremum of backpack clamp

load direction	Force (X)	**Force (Y)**	**Force (Z)**	**Torque (X)**	**Torque (Y)**	**Torque (Z)**
Direction 1	37.2	33.6	0	4.97	-3.41	-3.46
Direction 2	52.8	5.27	0	3.66	-2.68	3.08
Direction 3	38.8	-33.1	0	-4.72	1.60	2.00
Direction 4	-3.89	-49.4	0	-4.36	1.78	-2.34
Direction 5	-34.5	-30.1	0	2.39	2.25	2.24
Direction 6	-53.3	3.77	0	-1.33	2.27	1.89
Direction 7	-36.8	38.3	0	2.20	-2.00	-2.27
Direction 8	-2.70	52.8	0	4.67	-2.86	-3.67

Remarks: unit of force: kN, Unit of torque: kN·M.

The backpack clamp pre-tightening force refers to the pre-tightening force of the clamp fasteners, which provided by the long bolt and fastening nut powered by hydraulic stretching device. In order to determine the tension minimum pre-tightening force, the extreme load of the most easily lead to tension failure is taken from clamp counterforce. As showed in Table.2, the environment loads are set on the centroid position of the clamp by using the local coordinate. The distance of matrix centroid to jacket is h, and to the friction surface is d.

Tab. 2. Environmental load of backpack clamp centroid

Load	X	Y	Z
Force（kN）	55.51	56.08	0.81
Torque（kN·m）	18.07	24.53	0.2

Marine environment load of clamp can be balanced by the friction between the clamp and jacket completely. The contact body of the jacket and the clamp is an arc surface. The positive pressure of balancing marine environmental impact force and torque *F* consists of two parts [15]: including the balance of impact force F_1 and the balance of impact torque F_2. The friction coefficient is experience value 0.2. The corresponding respectively

$$F_1 = \frac{\sqrt{F_y^2 + F_z^2}}{\mu} + F_x \tag{5}$$

$$F_2 = \frac{\left(\frac{M_y}{D} + \frac{M_z}{D} + \frac{M_x}{R/2}\right)}{\mu} \tag{6}$$

The positive pressure *F* is $F=F_1+F_2$, The calculated *F*=684.95kN. Positive pressure *F* is provided by pre-tight fasteners of flat and long screw. The safety factor of pre-tight force *K*=1.5. There are six groups of screw on a total of compressive steel plate. So the minimum pre-tightening force T for each long screw tensioning is

$$T = \frac{K \cdot F}{6} \tag{7}$$

The calculated *T*=17.12t. The pre-tightening force meets the minimum requirements of the tensioned preload. If the actual preload is greater or equal than this value, the whole device can be guaranteed the normal work.

According to the mechanics of model and load parameters, the model is imported and analysis. The pre-tightening force of a single long screw is 171.2kN, so the positive pressure of the clamp matrix is 1027.2kN. According to Table 2, the extreme support reaction force is applied after considering safety coefficient. The safety coefficient is 1.5. The data in Table 2 are multiplied by 1.5 after the force and moment data values loaded in a protective pipe. According to the analysis of the model load setting, Fig.9 is the final result of calculation stress nephogram.

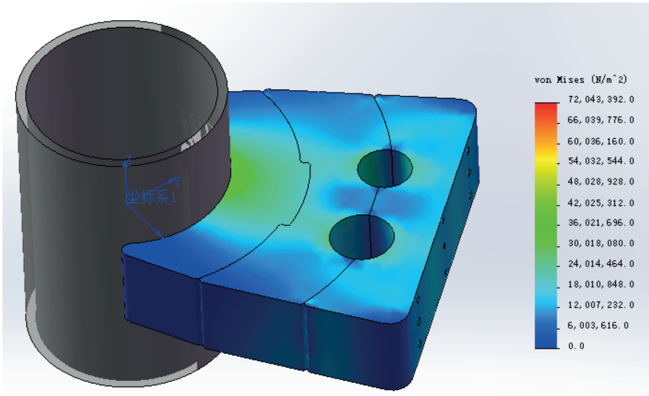

Fig. 9. maximum stress and strain nephogram

As showed in the Fig. 9, the maximum equivalent stress appears at the contact between clamp matrix and cable protection pipe. Maximum equivalent stress is 72.6MPa. The maximum stress is less than the clamp matrix material allowable stress 155MPa. Clamp matrix strength meets the requirements.

The load experiment of backpack clamp products uses experiment platform with the method of hydraulic loading [16]. By the calculation of positive pressure on the clamp pre-tightening in anterior segment, the maximum thrust of wave and current is 78784N, which is rounded by 80kN. The safety factor is 3. As showed in the Fig.10, the maximum thrust of simulation marine conditions is 240kN, which is separated five directions respectively.

The movement is expressed in "m" and stability in "s". The clamp matrix and other parts are not cracked or broken strength failure in the process of experiment, which explains that the structural strength meets the design requirements. As showed in Table.3, it can be obtained that the force of clamp pre-tightening is at least 1100kN under the maximum thrust force of 240KN. Clamp will be stable as function of the current largest force and have the safety allowance of 3 times. The clamp structure stability meets the requirements.

Fig.10. Load experiment of backpack clamp

Tab. 3. The influence of positive force on cable protection

The pre-tightening force	The pre-tightening force of clamp (kN)	500	700	900	1100	1300	1500	1700
	Oil pressure (MPa)	20	27.4	35.2	43.1	50.9	58.7	66.5
Total thrust of manual pump	5MPa (50kN)	s	s	s	s	s	s	s
	10MPa (100kN)	s	s	s	s	s	s	s
	15MPa (150kN)	m	s	s	s	s	s	s
	20MPa (200kN)		m	s	s	s	s	s
	24MPa (240kN)			m	s	s	s	s

CONCLUSION

This paper researched the backpack clamp of ocean jacket cable protection pipe and analyzed three aspects of clamp structure, the sea loads and pre-tightening force strength separately. The backpack clamp matrix is adopted three valve structures. The sea loading form, size and the effects of ocean environmental factors is studied. The minimum pre-tightening force is determined by establishing the mechanical model of the clamp. The maximum stress of is less than the material tensile and compression strength of the finite element analysis of matrix strength. Impact resistance of clamp resin matrix is meeting requirements underwater. Structural stability and strength experiments of backpack clamp device explain that the requirements of strength and stability are qualified and the feasibility of design is verified.

ACKNOWLEDGEMENTS

This material is based upon work supported by the National Science Foundation of China (Grant no. 51479043). The views expressed are authors alone.

BIBLIOGRAPHY

1. Wang Dingya, Zhu Anda. Current situation of offshore petroleum equipment and development orientation of localization. Petroleum Machinery, 2014, 03:89-93.

2. "Detection and maintenance, safety assessment and real time monitoring system for offshore platform structures" *placed second in the National Science and Technology Progress Award.* Journal of Petroleum University: (Edition of Natural Science), 2004, 03.

3. Xu Shuang, Yang Xun, Liu Xiaoqiang. *Research of offshore platform damage type and repair and strengthening method with clamp.* Petroleum Engineering Construction, 2011, S1:65-68+1.

4. Liu Jianlei. *Study on structural safety assessment of existing offshore platforms.* Ocean University of China, 2013.

5. Wang Deyu. *The dynamic response of clamped dented tubular beam under lateral impact.* China Offshore Platform, 1997, 04:15-17+5.

6. Samarakoon S M K, Ratnayake R M C. *Strengthening, modification and repair techniques' prioritization for structural integrity control of ageing offshore structures.* Reliability Engineering & System Safety, 2015, 135: 15-26.

7. Bayazitoglu YO. *Assessment and Repair of Offshore Platform Applications to Bay of Campeche Facilities.* ASME. J. Offshore Mech. Arct. Eng. 1999; 122 (2):81-92.

8. Gong Shunfeng, Jin Weiliang, *The repair of damaged members on offshore fixed platform.* China Offshore Platform, 2001, 02:38-43.

9. ZHANG, D.W. & LUAN, T. & ZHOU B. *Method of tube clip mounting concentricity adjusting water*, Energy and Energy Conservation, 2011, 11: 66-67.

10. Tetsuyoshi, H. & Nur, R. N. & Takao, Y.G. *Revisit of aneurysm clip closing forces*: comparison of titanium versus cobalt alloy clip, Neurological review, 2013, 11:517-522.

11. Qi, B. *Global strength analysis of ultra-deep-water drilling riser*, Harbin engineering university, 2012, 03: 45-56.

12. Fan, B.M. & Ji, C.Y. & Zhang, Q. *The combined action of waves and currents under deep-sea vertical research on the calculation method of fatigue life,* Ship & Ocean Engineering,2008, 2: 91-94.

13. Peng, S. & Deng, Y. X. & Yin, Y.K. *The calculation of parameter analysis platform jacket waves*, China Offshore Platform, 2010, 4:32-35.

14. Jin, H.Y. *Linear wave theory of floating platform based on the analysis of force and motion*, 2012, 07:108-115.

15. Liu, H.X. & Duan, W.Y. & Chen, X.B. *Wave loading on concentric porous cylinders with varying porosity,* Journal of Marine Science and Application, 2013, 12, No 4:400-405.

CONTACT WITH THE AUTHOR

Bo Zhang, Ph.D.

e-mail:jlwzh@163.com: wang_heu@hrbeu.edu.cn

College of Mechanical and Electrical Engineering
Harbin Engineering University

CHINA