“十二五”国家重点图书
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KEY TECHNOLOGY ON DEEP-WATER SEMI-SUBMERSIBLE DRILLING PLATFORM: GLOBAL PERFORMANCE; STRUCTURE ANALYSIS; VORTEX-INDUCED VIBRATION

谢 彬 杨建民 主编

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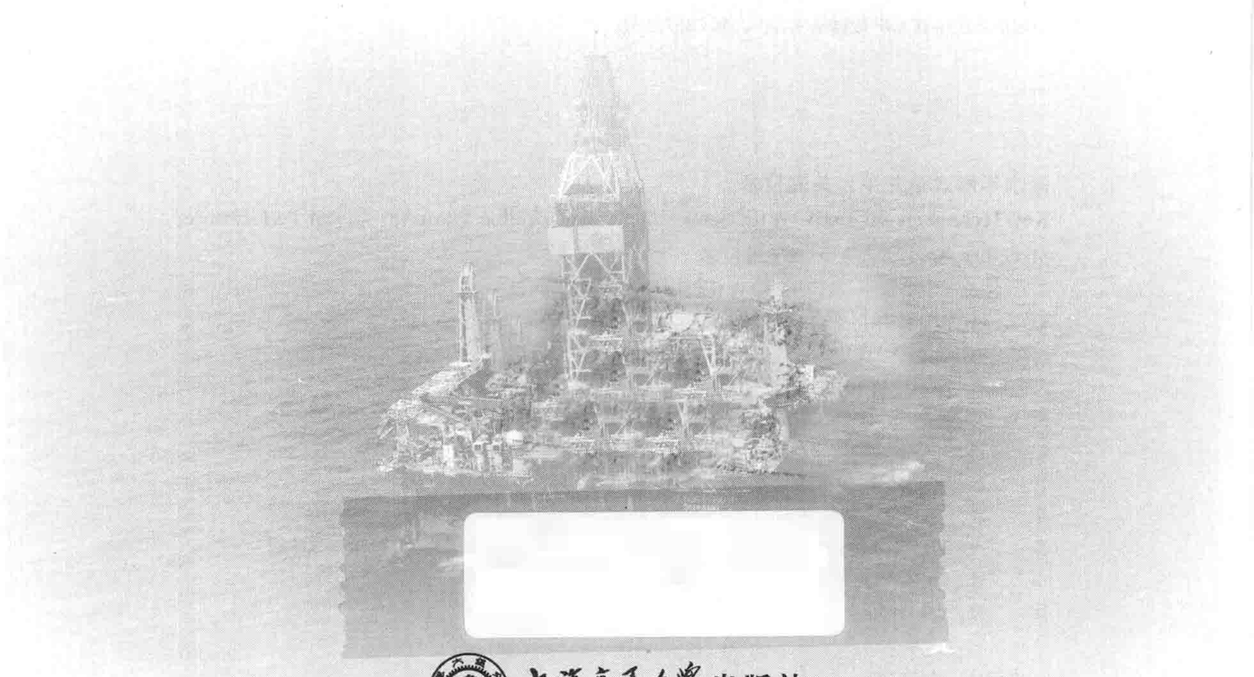

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Abstract

This book is based on the project 'Research on the Key Technology of 3 000 m Deepwater Semi-submersible Drilling Platform' aiming at solving the key issues of design and construction techniques. It contains 5 parts, including environment of South China Sea, hydrodynamic performance of semi-platform, structure analysis of semi-platform, vortex induced vibration, and expand research.

This book reflects abundant research results of design and construction techniques of deepwater semi-submersible drilling platforms.

This book will provide a very good reference for researchers and engineers in the field of offshore technology.

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PREFACE

There are abundant petroleum and gas resources in the South China Sea, which occupy 1/3 of China's total amount of natural oil and gas. And nearly 70% of them are stored in deep water area. However, due to the harsh environmental condition in South China Sea, including frequent typhoons in summer and continuous monsoons in winter, the exploration and development of deepwater oil and gas in South China Sea are confronted with severe challenges. To prepare the required equipments for the development of deepwater oil-gas field in South China Sea, China National Offshore Oil Corporation (CNOOC) launched the research programme on the first deepwater semi-submersible drilling platform in China in January 2006. The deepwater semi-submersible is a kind of mobile drilling platform, which can be used in a repetitive pattern. Because of its excellent performance in the sea, strong seakeeping capacity, large deck area, large carriage capacity and good adaptability to a wide range of water depth, the deepwater semi-submersible is widely used in every sea area around the world. Moreover, it will become the most promising equipment for offshore oil exploration and drilling in the next decade. However, the design and construction techniques of deepwater semi-submersible are monopolized by several developed countries, leaving China still blank in this area. So, for China, it's of great significance to break the technological monopoly and obtain independent intellectual property rights of deepwater semi-submersible drilling platform technology. For one thing, it has practical values for the development of offshore technology in China; for another, it also has strategic meanings to promote China's offshore oil industry in deepwater area. Supported by Ministry of Science and Technology of China, a major project of National High-tech R&D Program of China (863 Program), titled 'Research on the Key Technology of 3 000 m Deepwater Semi-Submersible Drilling Platform', was officially approved in 2006. China Offshore Oil Research Centre took the lead of this research, cooperating with several prestigious universities, shipbuilding enterprises and research institutions, all of which formed a group for this project. Based on the amalgamation of industry, education, and research, the research group accomplished the task successfully with four-year hard working. The project has passed the examination from the 863 Program under the Ministry of Science and Technology of China. Meanwhile, the research group is also awarded Excellent Executive Team in the national scientific and technological plans during the 11th Five-Year Plan Period by the Ministry of Science and Technology of China.

Based on the construction of HYSY981, the project 'Research on the Key Technology of 3 000 m Deepwater Semi-Submersible Drilling Platform' aiming at solving the key issues of design and construction techniques. Through combinating research with application, 36 technological breakthroughs have been made and some of the results reach the world advanced levels. This book reflects abundant research results of design and construction techniques of deepwater semi-submersible drilling platforms and will be a good reference for researchers and engineers in the field of offshore technology.

Up to now, some high-level deepwater structures, including HYSY981 Drilling Platform and HYSY201 Deepwater Pipe Lay Crane Vessel, have been constructed successfully. With more and more large-volume structures for offshore oil exploration and development being put into use, speed up development has been made in deepwater equipment in China. The deepwater oil and gas field development in South China Sea expedites scientific and technological progress in China. May the publication of this book will benefit comprehensive researchers and engineers in the field of offshore technology.

Key Words

Contents

INTRODUCTION

0.1 Introduction

To satisfy the increasing demand of oil resource, the trend of exploitation of offshore oil and gas resource has appeared, especially in deep water. The South China Sea is one of the 4 largest offshore oil and gas reserves in the world. A preliminary estimate of the geological oil resources in the South China Sea is about 23～30 billion ton, but the distribution of the oil and gas reserves is mainly in deep water.

The priority for deepwater exploration is developing deepwater drilling equipment. Two kinds of deepwater drilling equipments (the semisubmersible rig and the drilling ship) have been developed worldwide. The semisubmersible rig has obvious advantages including superior performance and good seakeeping. So it is used more than drilling ship in deepwater drilling.

However, due to China's late involvement in the deepwater oil and gas industry, its research and development (R&D) technologies are still underdeveloped, and the key technologies used in deepwater drilling equipment are behind those advanced countries in offshore R&D by 15～20 years[1].

In such circumstances, China has decided to invest in R&D of the offshore oil and gas industry. The design and manufacture of HYSY981 has been listed in the National '863' Program Plan, and it has made many breakthroughs for domestic deepwater engineering technology. The HYSY981 is China's first independently designed and constructed 6th-generation semi-submersible rig, which CNOOC (China National Offshore Oil Corporation) possesses its independent intellectual property right. The HYSY981 is capable of drilling, completion, testing and workover. The main operating area is the South China Sea, but the rig can also cover Southeast Asia, West Africa, Gulf of Mexico, etc. The maximum operating water depth is 3 000 m and the maximum drilling depth is 10 000 m. At present, the concept design, basic design and detailed design have been completed. The platform is in construction in Shanghai Waigaoqiao Shipyard and expected to operate in 2011.

0.2 Historical Developments of Semi-Submersible Rig

Since the first semi-submersible rig was brought into operation in 1960s, the semi-submersible rigs have experienced six generations development as follows[2]: ① The 1st generation: Before 1971; ② The 2nd generation: 1970s; ③ The 3rd generation: early 1980s; ④ The 4th generation: late 1980s & late 1990s; ⑤ The 5th generation: late 1990s & early 2000s; ⑥ The 6th generation: After 2000. Through the six generations development, improvements in various aspects have been made, including[3]:

(1) Increased operation water depth: The operation water depth of the 1st generation is only 150 m, while the newly built semis can work in the water depth of 3 000 m. It is also estimated that semi-submersible of operation water depth of 4 000~5 000 m would be developed in the following 20 years.

(2) Larger variable deck load (VDL) capacity: VDL is one of the key characteristics for a semi-submersible. VDL has been increased from less than 2 000 t (the 1st generation) to 9 000 t (the 6th generation).

(3) Changed positioning method: The early semi-submersibles were positioned by traditional mooring system. Since the 4th generation, dynamic positioning system (DPS) has been used and has gradually become an important positioning approach especially for water depth above 1 500 m.

(4) Suitable for more severe sea condition: The semi-submersibles have much better hydrodynamic performance so that the platforms can work in more severe sea condition.

(5) Simplified configuration: Simplified configuration with less columns and braces has been more adopted currently.

(6) Larger amount of high strength steel is used: In the manufacture of newly built semi-submersibles, the amount of higher strength steel with yielding stress of 420~460 MPa is about 25%~50% of the whole amount of steel. In the critical connection zone, steel with yielding stress of 700~827 MPa is used.

(7) Installed with more advanced drill rig: With the development of the marine related equipment, more advanced drilling rig has also been installed in the 6th generation semi-submersibles.

0.3 Key Technologies and Innovations of HYSY981

To provide technical support and solve critical issues for the design and construction of HYSY981, we have done numerous R&D, through which we have focused on the key technologies for designing and constructing the 6th generation of semi-submersible drilling rig and made several innovations. These key technologies and innovations can be divided into four aspects as follows.

0.3.1 Design of HYSY981

The whole design process of HYSY981 comprises three phases. Firstly, we made a study on four typical semi-submersible platforms, GVA7500, F&G ExD, Aker H-4.3 and MSC DSS50. After making a comparison of these four platforms and clarifying the determinant design parameters, we brought about the concept design scenario, as shown in Fig. 0.1. The comparison shows that the stability of the concept design is much better than other scenarios, and the air gap of the concept design is superior to other scenarios, while the hydrodynamic performance is in the middle among the scenarios. Finally, we started the basic design based on F&G ExD. To suit the extreme sea condition of South China Sea, we adjusted the mother scenario in following aspects:

(1) The length of pontoon is enlarged to meet the need for larger variable load.

(2) The water plane area of columns is enlarged to provide more stability reserve.

(3) The height of columns is heightened to satisfy the air gap requirement in severe sea condition.

(4) The bow and stern compartments of pontoons and deck are elongated to meet the demand for dynamic positioning system of Class 3 (DPS-3).

The basic design scenario of HYSY981 is shown in Fig. 0.2.

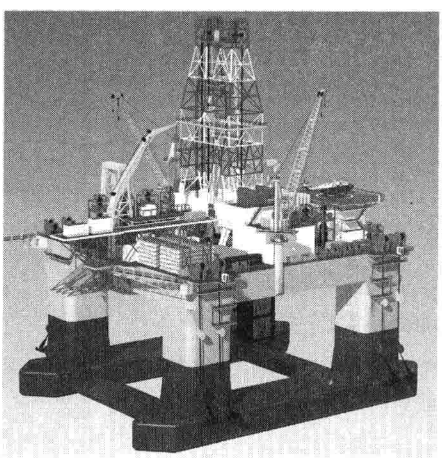

Fig. 0.1 Concept design blue print

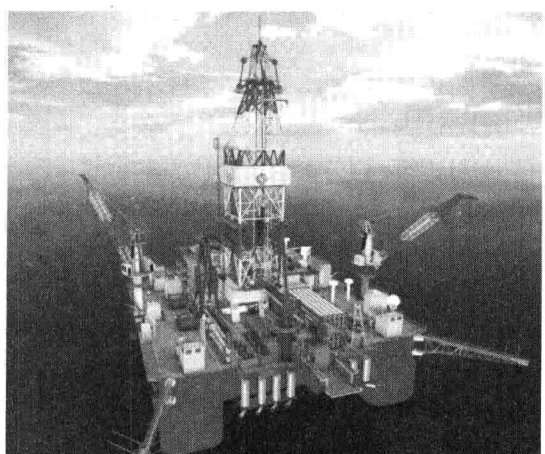

Fig. 0.2 Basic design of HYSY981

Through the design process of HYSY981, we have obtained six innovations as follows.

0.3.1.1 Innovation I: Suitable for the extreme environmental condition in South China Sea

The South China Sea is an area where typhoon happens frequently, with an average of 27～35 times per year. Typhoons are generally stronger than hurricanes, and have resulted in great damages to offshore installations and are principal hazards to offshore operations and platforms in the South China Sea. Serious damage often leads to stoppage of oilfield production. Another special phenomenon occurring frequently in South China Sea is internal waves, which are gravity waves that oscillate within a fluid medium rather than on its surface. Internal waves flow with a maximum speed of 2 m/s, and have much longer periods and larger amplitudes than surface waves. The internal waves may cause great effect to offshore platforms and operations. Consequently, the existence of internal waves should not be neglected.

In our design, 200-year return sea condition of South China Sea is chosen as design environmental condition in stability analysis and global strength analysis. Internal wave is considered in the advanced research for the first time. Through both ways, better reliability of the platform can be achieved.

0.3.1.2 Innovation II: Advanced positioning system

For the sake of both cost and positioning capability, we adopted diversiform positioning strategies in the design of HYSY981. Mooring system is used when operation water depth is below 1 500 m, while dynamic positioning system (Class 3) is used when operation water depth is above 1 500 m. Combined positioning could be used for various sea states. DPS－3 is of higher positioning redundancy thus ensuring platform positioning even if one compartment fails. Fig. 0.3 is a model of DPS－3.

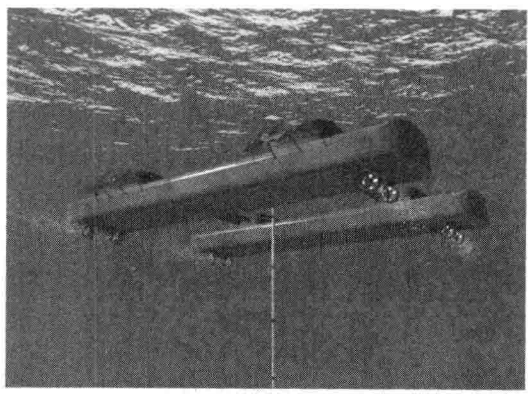

Fig. 0.3 Dynamic positioning system (Class 3)

0.3.1.3 Innovation III: Larger variable deck load (VDL)

VDL is one of the most critical design targets for a drilling semi-submersible, and is a determinant factor for life time cost. The original VDL of F&G ExD is 7 000 t. Through a structural optimization design, a lighter platform weight is achieved and the VDL of HYSY981 is increased to 9 000 t. The VDL of HYSY981 tops among the 6th generation semi-submersible with 4 columns type around the world. As a result, the endurance capability of the platform has been greatly enhanced.

0.3.1.4 Innovation IV: 3D simulation design

The platform model, typical compartment roaming, 3D design of components, construction assembly process and drilling operations process can be displayed in 3D virtual reality environment. The 3D simulation of operations on deck is shown Fig. 0.4. Prior to the manufacture, 3D simulation design can be used to propose or verify an optimal manufacture solution, and optimize on-site operations. The application of 3D simulation design would save much cost and time, and make the operations more rational.

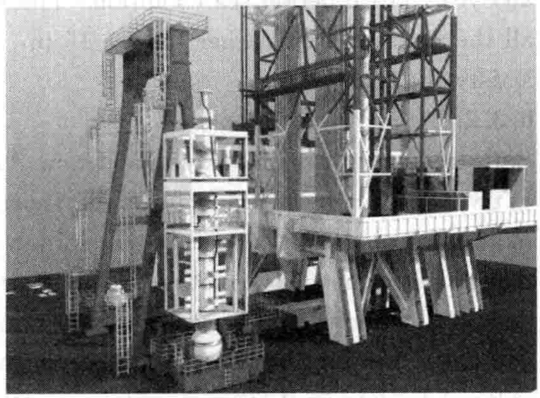

Fig. 0.4 3D simulation of operations on deck

0.3.1.5 Innovation V: Drilling depth, drilling derrick system, drilling riser storage method

The operating water depth of HYSY981 reaches 3 000 m. And the drilling depth of HYSY981 reaches 10 000 m making HYSY981 be capable of covering the majority area of sea. One and a half derrick is used so that the efficiency of drilling and completion operation can be improved.

Both vertical storage and horizontal storage for drilling risers are used. The drilling risers can be much easily transferred to derrick for vertical storage method contrasting to the horizontal storage method. However, the vertical storage method will heighten the center of gravity and impair the stability performance. Moreover, the vertical storage method is not favorable for arrangement. So the adoption of both methods will balance the advantages and disadvantages and achieve the maximum efficiency as a whole.

0.3.2 Numerical Analysis of HYSY981

A comprehensive numerical analysis for HYSY981 has been conducted including stability analysis, global performance, dynamic positioning, global strength and local strength, structural fatigue life, structure collision response, and vortex induced vibration (VIV) for drilling risers and corresponding fatigue analysis.

0.3.2.1 Stability analysis

Satisfying the stability design requirement is the first and most important aspect of semi-submersible design. The platform has been designed, as a minimum, to satisfy the criteria required by ABS(American Bureau of Shipping) rules[4], CCS(China

Classification Society) rules and IMO(International Maritime Organization) Code. Both the intact and damage stability analysis are conducted and further checked. To consider the extreme weather of South China Sea, the intact stability should satisfy 200-year return period sea condition. The results show the metacentric heights for all the conditions are larger than 0. 15 m, and that the intact and damage stability satisfy the rules.

0. 3. 2. 2 Global performance

Both frequency domain analysis and time domain analysis for global performance of HYSY981 have been conducted. The short term predictions of platform maximum motion for operation and survival condition are realized and the results show that its motion performance is excellent. The short term predictions of air gap for various positions of the bottom deck have been calculated and checked, with a minimum air gap of 4. 15 m for survival condition, which shows the structure of the bottom deck will not be subjected to impact even in survival condition.

The time domain coupled analysis is also conducted. The mooring systems for water depths of 500 m and 1 500 m have been designed. The results show that the maximum offset of platform motions is within 3% and 10% of the water depth for 1-year return and 10-year return sea state respectively. The maximum mooring line load for 10-year return sea state does not exceed 60% of breaking strength for intact condition. The time domain coupled analysis results show the mooring system satisfies the positioning requirements.

0. 3. 2. 3 Dynamic positioning system (DPS)

The capacity of DPS has been analyzed. In intact condition, the maximum utilization rate of individual thruster is less than 80% of requirement of American Petroleum Institute (API) for both drilling and standby conditions. In damage condition, the maximum utilization rate of individual thruster is less than 80% of requirements for drilling condition, while it exceeds 80% of API's requirement for standby condition. However, the average utilization rate is 94%, which will not result in loss of position and satisfy the requirements of International Marine Contractors Association (IMCA). The maximum utilization rate of individual thruster for drilling condition is shown in Fig. 0. 5. The DPS design is fitted for the South China Sea environmental condition for the first time and reaches DPS - 3 level. Through the failure mode and effects analysis (FMEA), the results prove that the design meets the requirement of DPS - 3 level.

0. 3. 2. 4 Global strength and local strength analysis

The methods and checking criteria of global strength and local strength analysis are according to ABS rules. The design wave approach is used for global strength analysis. The global strength for survival, operation and towing condition are