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Stress Analysis of the Subsea Dynamic Riser BaseProcess Piping

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Abstract: Thesubsea dynamic riser base（SDRB）is an important piece of equipment for the floating production platform mooring system.One end is connected to the rigid pipeline, carrying a rigid pipeline thermal expansion load and the other end is connected to a flexible riser, carrying the dynamic load of the flexible riser, so its function is a transition connection between the flexible riser and the rigid pipeline which fixes the flexible riser on the seabed. On the other hand，as a typical subsea product, the design will satisfythe requirements of the standards for subsea products. By studying the stress analysisphilosophy of the topside piping and subsea pipeline, a physical model and procedure for piping stress analysis of the SDRB have been established.The conditions of the adverse design load have been considered, and a combination of the static load from the rigid pipeline and the dynamic load flexibility has also been optimized. And a comparative analysis between the AMSE, DNV and API standards for piping stress with the checking rules has been done.Because theSDRB belongs to the subsea pipeline terminal product, the use of DNV standards to check its process piping stress is recommended. Finally, the process piping stress of the SDRB has been calculated, and the results show that the jacket pipe and the carrier pipe stress of the SDRB process piping satisfy the DNV standards as a whole.The bulkhead cannot be accurately simulated by the AutoPIPE software which uses the FEA software ANSYS inthe detailed analysis, but the checking results will still meet the requirements of the DNV standards.

Keywords:subsea product design; subsea dynamic riser base(SDRB); process piping stress analysis; flexible riser; rigid pipeline

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1 Introduction

The subsea dynamic riser base (SDRB) as a typical subsea productis an important piece of equipment for the floating production system. It is not only an important oil and gas transportation channel, but also is a key anchor point for the dynamic riser and cable transition to static (Fang, 2003; Li *et al.*, 2010; Chen *et al.*, 2011). For process piping on the SDRB, one end is connected to the rigid pipeline, carrying a rigid pipeline thermal expansion load.The other end is connected to the flexible riser(Bai *et al.*, 2005), carrying the dynamic load of the flexible riser, which determines the complexity of the process piping stress analysis(API RP 2RD, 2009).

Currently a mature recommended practice has not been formed and different products cannotbe simplycheckedwith a uniform standard.Studies should be done on the subsea products piping stress analysis regarding the characteristics of each product (Bai *et al.*, 2010; Robinson *et al.*, 2003; Bernt*et al.*, 2007; Antani*et al.*, 2008; Triolo*et al.*, 2010).Typhoonsneed to be especially considered in regard to the South China Sea because of their huge influence on the dynamic response of riser systemsregarding the motion of floating platforms, so much more attention should be paid during the SDRB piping stress analysis and the piping system on the SDRB should be optimized to stand the reactions from the riser system.

This paper will take the SDRB for the dynamic riser of the“Lazy S” configuration as the study object that describes the process piping stress analysis method and checking criteria. Fig.1 shows the dynamic riser system of thefloating production storage and offloading (FPSO).

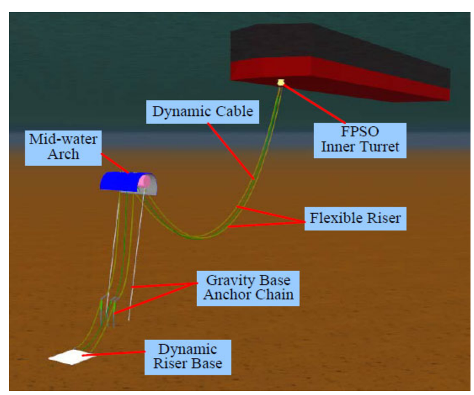

Fig. 1Dynamic riser system of the FPSO(“Lazy S”configuration)

2SDRB process piping stress analysis method and model

Piping stress analysis is an important means to check whether or not there is a reasonable layout of thepiping system (Robleto and Williams, 2010).For the process piping

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in the subsea product, the focus of the whole piping system should first be put on the flexibility, using the elastic deformation of the maximum absorption interface load, and it should satisfy the following design principles at the same time:(1)Use the mature technology of the piping design.(2)Obtain the shortest load transfer path.(3)Avoid interference and keep the piping layout as compact aspossible. (4)Design a type of pipingsupport structure that is reasonable.The load can be effectively transited to the infrastructure.(5) Satisfy the functional requirements of the piping, such as pigging, spare, erosion, corrosion, *etc*.

2.1 Analysis procedure

The procedure for the design of the piping engineering includes, stress analysis of the piping system's first response to a physical model for analysis, consideration and determination of the design parameters, solutions obtained by the software, and finally post-processing of the checking results as per the standard analysis procedure shown in Fig. 2(Ellenberger, 2014; Schwarz,2004; Antaki, 2003).

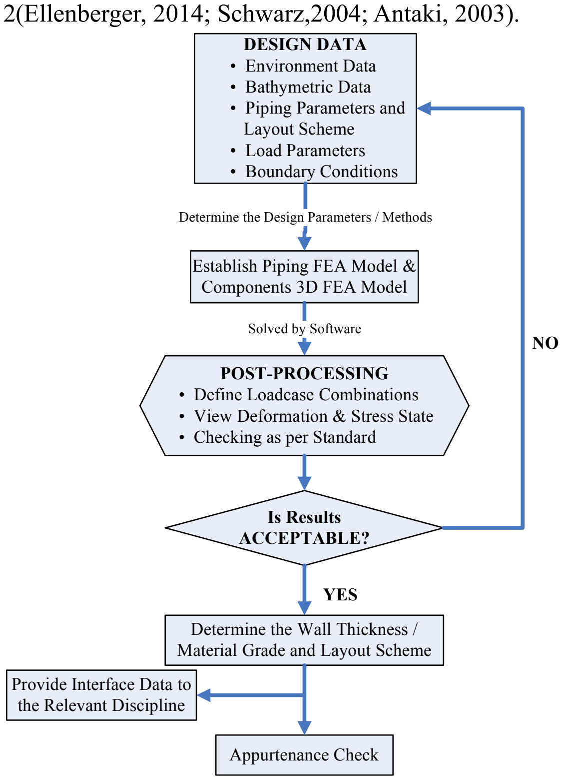


Fig. 2Procedure for the piping stress analysis

2.2 Analysis model

This paper takes the SDRB (dimensions of 9.2 m×7.2 m) withthe gravity-based mudmat as the example. The 3D model is shown in Fig. 3. The design water depth is 105 m, and thereare two process pipings on the SDRB, connected to the dynamic flexible risers from the FPSO respectively.

The transport medium in the process piping is water cut oil, with a105 °C design temperature and 5 MPa design pressure.The piping system as shown in Fig.4, is mainly composed of pipe-in-pipe(PIP)piping, PIP bend, type II bulkhead, subsea misalignment flange, subsea SPO flange and asingle pipe.For the pipe parameters refer toTable 1. The two process piping isfixed on the base via the support sleeve structures welded on the beam. In the design, considering that both ends of the piping carry different loads, different piping supports are adopted. Flexible riser ends carry the dynamic load, the fixed piping supports will be used, of which the piping and the support sleeve structure are welded together, as shown in Fig. 5. The rigid pipeline end carries the expansion load, the guide support will be used, of which the neoprene is employed between the piping and support sleeve structure, so there is no axial constraint for the guide piping support, as shown in Fig. 6. Fixed piping support and guide piping support are shown in Fig. 7.

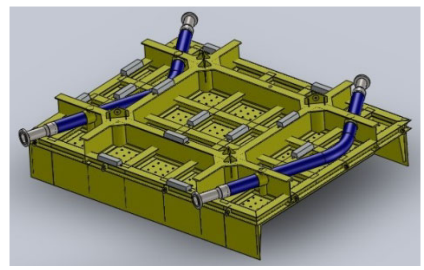
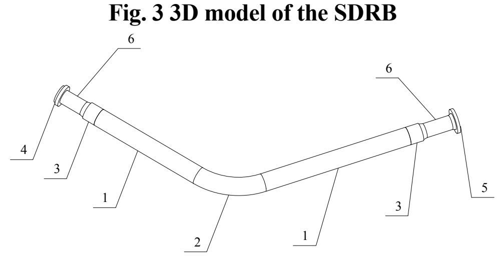


Fig. 3 3D model of the SDRB



1. PIP section; 2. PIP bend; 3. Type II Bulkhead; 4. Subsea misalignment flange; 5. Subsea SPO flange; 6. Single pipe section

Fig. 4Piping system

Table 1Parameters of PIP

Item	Description	Parameter
Carrier pipe	Outside diameter	323.9mm
	Wall thickness	12.7mm
	Internal corrosion allowance	3 mm
	Specified min. yield strength	448MPa
Insulation coating	Material	Polyurethane
	Thickness	25mm
	Density	40~60/(kg·m^{-3})
Jacket pipe	Outside diameter	406.4mm
	Wall thickness	12.7mm
	Specified min. yield strength	448MPa
Jacket pipe anti-corrosion coating	Material	Glassflake epoxy
	Thickness	350μm
	Density	2520/(kg·m^{-3})

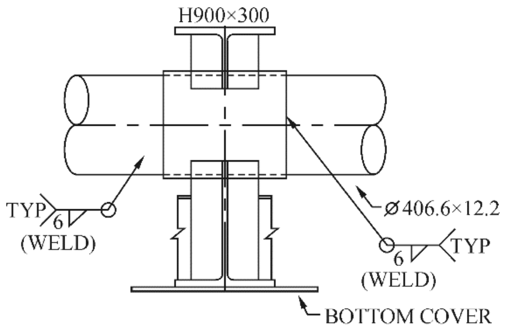


Fig. 5 Fixed piping support

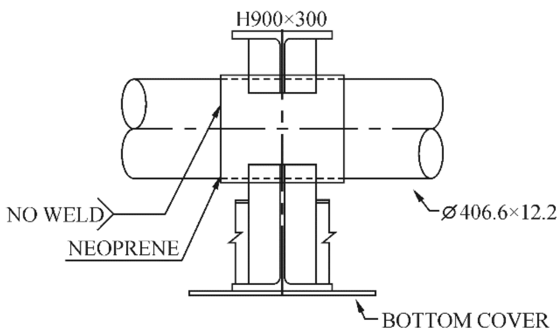
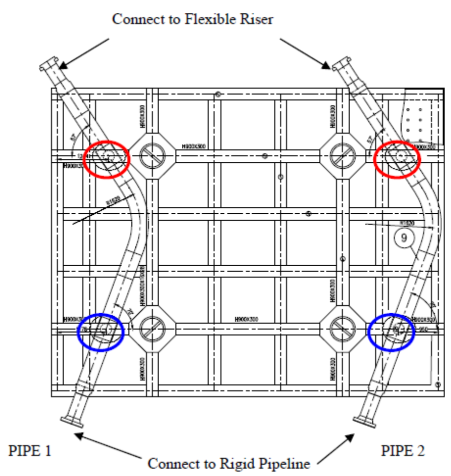


Fig. 6 Guide piping support



Red – Fixed Piping Support; Blue – Guide Piping Support

Fig. 7 Fixed piping support and guide piping support

Dynamic analysis of the proposed riser system layout leads to the following maximum response as shown in Table 2 which is evaluated to be acceptable for the riser and well within the design capacity of the end fitting.

The expansion length and axial force of the pipeline due to thermal movement will lead to a reaction at the interface with the SDRB piping through theassociated spool piece which is not an order of magnitudecomparable with that of the riser system and will not be listed because of paper space limitations.

Table 2Reaction forces from riser system

Item	Static	Dynamic
Max. tension	20.9kN	48.7kN
Max. shear forces	23.4kN	45.0kN
Max. bend moments	49.7kN·m	125.0kN·m
Max.torsion moment	0.3kN·m	50.0kN·m

Notes:

1) STATIC loads are obtained without the environment load applied. DYNAMIC loads are obtained with consideration that the environment load is applied.

Through the analysis of the physical model, for this example, the AutoPIPE software will be used for stress analysis of the whole piping system. The vertical *Y*-axis nominates the elevation while the positive *X*-axis points to the rigid subsea pipeline.The detail finite element model is shown in Fig. 8.

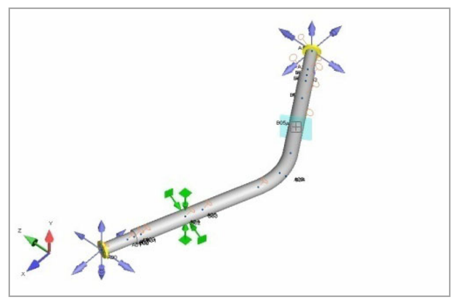


Fig. 8 AutoPIPE model of the piping stress analysis

Because the bulkhead representedin the AutoPIPE software cannot be accurately simulated, the FEA software ANSYS will be used for the detailed analysis. For the bulkhead, the nodes at the end of the jacket pipe extension are fully fixed as shown in Fig.9. The internal pressure and external hydrostatic pressure effects are considered during all the design conditions. The node loads applied to the carrier pipe ends ofthe piping system are extracted from the AutoPIPE output. The loads' directionwill be converted from the AutoPIPE local coordinate to the ANSYS user specified coordinate.

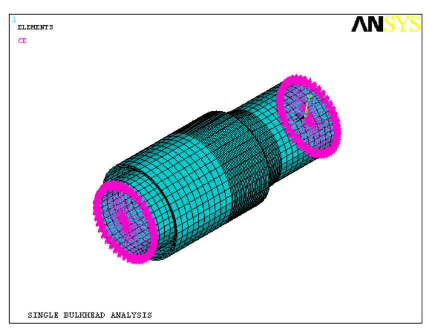


Fig. 9 ANSYS model ofthebulkhead

2.3 Loadcasecombination

Process piping stress checkingstandard forSubsea product should follow ISO 13628-15 (International Organization for Standardization, 2010), which recommends that piping stress can be checked as per the following standards, ASME B31.4(American Society of Mechanical Engineers, 2009), ASME B31.8(American Society of Mechanical Engineers, 2010), ASME B31.3 (American Society of Mechanical Engineers, 2008), DNV-OS-F101 (Det Norske Veritas, 2005) and API RP 1111(American Petroleum Institute, 2009) and so on.

The design loads for the piping system mainly include: (1) Functional load, refers to the required load that the system exists, uses and disposes of under the various load conditions without considering the environmental load effect; (2) Environmental load, refers to the load acting on the piping system which is generated by the wind, waves, currents, ice and earthquakes and other environmental phenomena; (3) Accidental load, refers to the load on the piping system under abnormal and unexpected circumstances(DNV-OS-F101, 2005).According to the DNV standard requirements, combined with the actual project load, the following design load conditions need to be considered for covering the adverse load case of the subsea product process piping stress analysis: (1) Functional loads; (2) Design environmental load and functional load acting simultaneously; (3) Hydrostatic test or stop/restart. Conservativelythe safety factors as shown in Table 3 will be used in the piping stress UC check.

Table 3Safety factors for different load conditions

Load condition	(1)	(2)	(3)
Safety factor	0.5	0.67	0.9

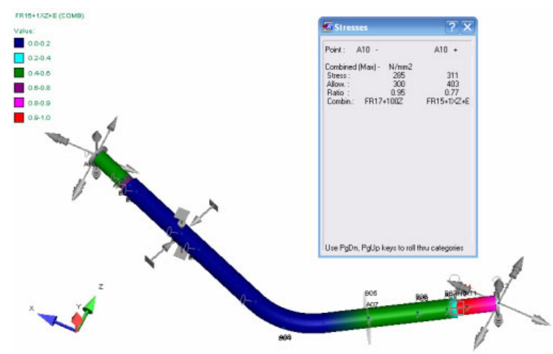
SDRB process pipingis connected to the rigid subsea pipeline and theflexible riserthrough the flanges.Interface data such as the acting load, acting moment and acting mode need to be provided by the other system for piping stress checking. The flexible riser arrangement scheme is checked based on the extreme condition of thefloating production facilities being offset with one chain broken. Taking into account the tolerance and internal stiffness effects of the flexible pipe,the forces at the SDRBpiping flange end with dynamic response consideration are provided from the flexible riser analysis. In order to make the limit conditions cover all the subjected forces from the flexible risers, the ultimate loadsare given without direction.

Based on the results of the analysis andassuming a rotational symmetric structural capacity, the tension, the torque, the shear force and the bending moment will be applied simultaneously.The shear force to act in the conservative direction in combination with the bending moment willobtain a total of 16 load components.

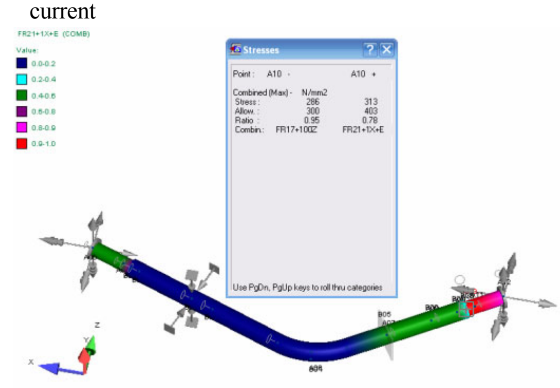
Additionally, we took into account the different direction approaches of the waves and currents, with thermal reactions from the pipeline.There are a total of 10 load components and resultswith the 10 load combinations. Through combining piping flange end forces respectively, a total of 160 load cases exist. Considering the complexity of the project load case conditions, the model adjustment will increase the pre-processing and post-processing workloads. Based on the sub-portfolio approach to extracting the 25 load points, and further optimizing the permutations and combinations, ultimately thecompact model will achieve the purpose of reducing the workload.

3 SDRB process piping stress analysis results

AutoPIPE software is adopted to establish the SDRB PIP piping stress analysis model, and the bulkhead used for the PIP pipe transiting to a single pipe is simulated as the rigid connection. According to the DNV standards, the stress of the carrier pipe and the jacket pipe has been checked at the different load conditions, and the maximum stress UC of the SDRB process piping is shown in Fig. 10.The UC values have already been considered regarding the corresponding safety factors.



(a) PIPE 1—load combination(2) with *XZ* direction wave and current



(b) PIPE 2—load combination(2) with *X* direction wave and current

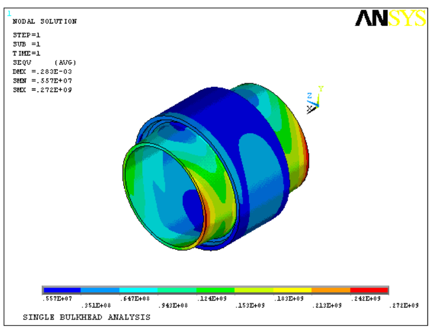
Fig. 10 Stress UC distribution of the SDRB process piping

As can be seen in Table 4, the maximum stress UC value of thecarrier pipe and jacket pipe are both less than 1, and meet the design requirements. Among them, the maximum stress UC value of thecarrier pipe is greater than that ofthejacket pipe.

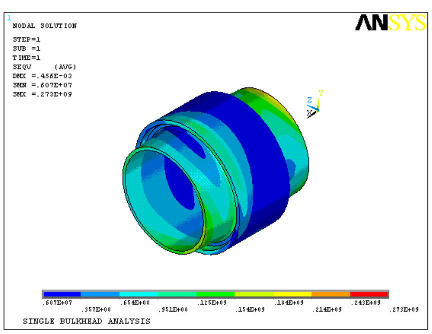
The bulkhead is a complex structure, so there may appear to be discontinuities when transferring the load, and detailed analysis of the bulkhead via the 3D finite element model is needed. As can be seen from Table 4, the maximum stress UC value of the bulkhead is 0.95, less than 1. As shown in Fig. 11, the bulkheadstress reaches the maximum UC value of 0.91 when the stress value is 273MPa, still meeting the design requirements.

Table 4Maximum stress UC of the SDRB process piping

PIPE No.	Location	Max. Stress UC
PIPE 1	Carrier pipe	0.86
	Jacket pipe	0.42
	Bulkhead	0.95
PIPE 2	Carrier pipe	0.89
	Jacket pipe	0.46
	Bulkhead	0.95



(a) PIPE 1—load combination(2) with *XZ*direction wave and current



(b) PIPE 2—load combination(2) with *X*direction wave and current

Fig. 11Stress distribution of bulkhead

4 Conclusions

1) Obtained from the stress analysisphilosophy of the topside piping and subsea pipeline, the stress analysis procedure of the subsea product is given**.** For the PIP piping stress analysis, first check as a whole system, and then check the key components such as the bulkhead, *etc*., through use of the general finite element software ANSYS.

2) Regarding the process piping for the SDRB carrying the forces from the dynamic riser system and static loads from expanding the rigid pipeline at the same time, fixing the piping support at the riser side and guidingthe piping support at the pipeline side are recommended. As typhoons should be especially considered in the South China Sea, interface loads from the riser system contribute most of the piping stress which should be paid attention to.

3) SDRBasa subseapipeline terminal product is recommendedto carry out the process piping stress check in accordance withDNV standards.

4) SDRB is a typical subsea product, and the stress analysis technology of theprocess piping is an important element of the product design.The design idea and method of this instance will provide reference for other similar subsea product designs.

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