

Design of Riser System Based on Target Oilfield and Platform

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Abstract: Abstract: Risers are an important component in the development of offshore oil and gas resources, but they are also one of the weakest components. Therefore, the safety of the design of deep-water riser systems plays a crucial role in the development of offshore oil and gas resources. This article focuses on the selection and initial design of riser systems based on the target oilfield and platform. Taking into account both the transportation capacity of oil and gas pipelines and the strength of casing, multiphase flow theory is used to calculate the pressure drop and transportation capacity of the riser. Based on this, the size of the oil pipe and casing is iteratively calculated. The riser design is based on the specifications and professional software Orcaflex, which is mainly used in the design process, is used for stress analysis of the riser, Taking into account the main scale of the FWPSO platform, reservoir and wellhead data, as well as the marine environment data where the riser is located, the selected oil and casing will be subjected to wall thickness design verification.

Keywords: Riser design; TTR; Force Analysis; Orcaflex; the FWPSO platform.

1. Introduction

Based on the sea conditions and platform characteristics of the target oilfield, and taking into account the production capacity of the offshore platform, the oil and gas characteristics of the oilfield are designed to be suitable for the riser system of the target oilfield and platform. At present, the most widely used standards are API RP 2RD developed by the American Petroleum Institute and DNV OS F201 developed by Det Norske Veritas. API RP 2RD is based on the allowable stress method, while DNV OS F201 is based on the reliability analysis load resistance coefficient method. This time, the riser system design will be carried out using API RP 2RD. This article uses the standard riser design process and comprehensively considers the relationship between the oil pipe and the casing. Once again, based on reservoir data, a TTR-SCR riser system was designed to be used in conjunction with the riser system. The multiphase flow theory^[1] was used to calculate the vertical upward pipe flow pressure drop, and hydraulic analysis was performed on the tubing to calculate its corresponding pressure gradient and pressure drop at different flow rates. The inner diameter of the tubing corresponding to the minimum pressure drop was selected as the initial tubing design diameter, and based on API SPEC 5L and API SPEC 5CT, Select materials and determine the size of the oil pipe. Finally, based on the selected riser size and the requirements of API RP 2RD

specification, a minimum wall thickness verification analysis of the riser will be conducted.

2. Target Oilfield Operating Conditions

2.1. Riser design

The design of risers^[2] needs to consider various factors such as production requirements, environmental conditions, and floating platforms. In order to standardize the design of marine risers, many classification societies and petroleum associations have conducted research on the standardization of risers. At present, the most widely used standards are API RP 2RD developed by the American Petroleum Institute and DNV OS F201 developed by Det Norske Veritas. API RP 2RD is based on the allowable stress method, while DNV OS F201 is based on the reliability analysis load resistance coefficient method. This time, the riser system design will be carried out using API RP 2RD.

2.1.1. Sea conditions

For the target oilfield with a water depth of 1000m, FWPSO is used as the operating platform.

Risers are subjected to various environmental loads during their service life. When conducting structural analysis of the riser, it is necessary to combine wind, waves, and currents for design to ensure that the riser meets conditions such as strength and fatigue during its design life^[3].

Table 1. Design condition

sea	wave	current	wind	design condition verification factor
Extreme	100-yr cyclone	100-yr cyclone	100-yr cyclone	1.2
Survival	1000-yr cyclone	1000-yr cyclone	1000-yr cyclone	1.5
Operating	10-yr cyclone	--	--	10.0

Under extreme sea conditions, it is necessary to calculate the motion response of the riser to ensure that the response meets the specified requirements. In survival sea conditions,

it is necessary to ensure that the riser components do not fail or be damaged.

Table 2. Current

Current (m/s)	1-yr cyclone	10-yr cyclone	100-yr cyclone	1000-yr cyclone
Water (m)				
0	1.57	1.85	2.49	2.80
55	1.17	1.45	2.09	2.40
166	0.86	1.01	1.36	1.58
239	0.73	0.85	1.15	1.34
313	0.68	0.81	1.09	1.26
Sea bed above 1m	0.49	0.58	0.78	0.91

2.1.2. Riser material

One of the initial steps in riser design is to choose the materials used for the riser, and commonly used materials^[4] for marine risers include carbon steel, alloy steel, etc. The strength and fatigue characteristics of different steels vary. When selecting steel, it is necessary to consider its cost,

weight, corrosion performance, strength, fatigue characteristics, etc. Generally speaking, the higher the grade of steel, the better the mechanical properties of the material, but the higher the cost. Therefore, the selection of steel should be based on factors such as cost, riser working environment, and work requirements. For top tensioned risers, the commonly used steels are X65 steel and x80 steel^[5].

Table 3. Material parameters

Material type	Minimum yield limit (MPa)	Maximum yield limit (MPa)	Minimum ultimate tensile strength (MPa)	Maximum ultimate tensile strength (MPa)
X80	552	690	621	827
X65	448	600	531	758

2.2. Stress verification method

The wall thickness of a deep-water riser has a significant impact on the force it bears under internal and external loads during installation and operation, and also affects the cost of the riser. Choosing the appropriate wall thickness^[6] is of great significance in ensuring the strength of the riser structure and achieving safe installation and operation, while reducing production and installation costs.

For the design of riser wall thickness, it is sufficient to follow the specifications. At present, the main specifications for deepwater risers include DNV-OS-F201 and API RP 2RD. According to regulations, the wall thickness of deep-water risers should ensure that the verification results of the combined stress and buckling and crushing stress of the riser meet the requirements.

Firstly, calculate the Von Mises combined stress as

$$\sigma_e = \sqrt{(\sigma_r - \sigma_\theta)^2 + (\sigma_\theta - \sigma_z)^2 + (\sigma_z - \sigma_r)^2} / \sqrt{2}$$

Among them:

σ_e is the Von Mises equivalent stress, σ_r is the radial stress, σ_θ is the circumferential stress, and σ_z is the axial stress.

Verification criteria:

$$(\sigma_p)_e < C_f \sigma_a$$

$$(\sigma_p + \sigma_b)_e < 1.5 C_f \sigma_a$$

Among them, σ_p is the membrane stress, corresponding to the average stress of the cross-section, σ_b is the stress caused by bending, $\sigma_a = C_a \sigma_y$ is the allowable stress parameter, $C_a = 2/3$, σ_y is the yield strength of the material.

C_f is the design operating condition parameter, which can be obtained by looking up the table (API RP 2RD).

For ordinary circular pipes, as lateral shear and torsion can be ignored, they only need to be checked according to

Namely:

$$(\sigma_p)_e = \sqrt{(\sigma_{pr} - \sigma_{p\theta})^2 + (\sigma_{p\theta} - \sigma_{pz})^2 + (\sigma_{pz} - \sigma_{pr})^2} / 2 < C_f \sigma_a$$

Among them:

$$\sigma_{pr} = -\frac{P_o D_o + P_i D_i}{D_o + D_i}$$

$$\sigma_{p\theta} = (P_i - P_o) \frac{D_o}{2t} - P_i$$

$$\sigma_{pz} = \frac{T}{A} + \frac{M}{I} (D_o - t)$$

P_i is the pressure inside the pipe, P_o is the pressure outside the pipe, D_o , D_i is the outer diameter and inner diameter of the riser, t is the wall thickness of the riser, A is the cross-sectional area of the riser, T is the axial force of the riser, M is the section bending moment, I is the moment of inertia of the cross-section.

2.3. Wall thickness design

For the design of TTR production riser systems, the first step is to clarify their functions, which helps deepen the designer's understanding of the entire design process and helps them better complete the design. The TTR production riser system mainly has the following functions^[7]:

1) Transport liquids produced from oil reservoirs from underwater wellheads, Christmas trees, or manifolds to floating production equipment.

2) Transport completion fluid, repair fluid or kill fluid, and other repair fluids from floating production systems to underwater production equipment.

3) Provide and maintain necessary full control over the wellhead and production fluid under all operational and emergency conditions.

4) Minimize pressure drop and throttling between underwater equipment and floating production systems.

5) Capable of withstanding the maximum operating pressure of underwater equipment and floating production system process equipment

6) Provide complete monitoring and visual inspection methods during installation and service

7) Capable of withstanding design loads under normal operations, emergency situations, and survival conditions

2.3.1. Basic Specification for Riser Design

The main design specification is API RP 2RD, while other specifications and standards are used for design reference and material and size selection^[8]:

APIRP 2RD "Design of Risers for Floating Production Systems (FPSs) and Tension Leg Platforms (TLPs)", First Edition, 1998.

ABS Guide for Building and Classing Undersea Pipelines and Risers, 2001.

APISpec 5L: "Specification for Line Pipe", 2010.

APISpec 5CT: "Specification for Casting and Tubing", 2011.

(1) Equivalent stress verification method

The axial stress of the riser is,

$$\sigma_{pz} = \frac{T_{tw}}{A_o - A_i} + \sigma_b = \frac{T_{tw}}{A_s} \pm M(D_o - t)/2I$$

In the formula, A_o is the area of the outer diameter circle of the riser; A_i is the area of the inner diameter circle of the riser; A_s the cross-sectional area of the riser; σ_b is the bending stress of the riser.

$$\sigma_b = \pm M(D_o - t)/2I$$

T_{tw} is the true tension of the pipe wall considering the end effect of effective tension and internal and external pressure.

$$T_{tw} = (P_i A_i - P_o A_o) + T_e$$

P_i and P_o represents internal and external pressures respectively; T_e is the effective tension of the riser.

The circumferential stress of the riser is,

$$\sigma_{p\theta} = \frac{(P_i - P_o)D_o}{2t} - P_i$$

The radial stress of the riser is,

$$\sigma_{pr} = \frac{P_i D_i + P_o D_o}{D_i + D_o}$$

According to the yield criterion, the equivalent stress of these three principal stresses is,

$$\sigma_{vm} = \sqrt{\frac{(\sigma_{pz} - \sigma_{p\theta})^2 + (\sigma_{pr} - \sigma_{p\theta})^2 + (\sigma_{pz} - \sigma_{pr})^2}{2}}$$

Verify according to the coefficients given in API RP 2RD,

$$\sigma_a = C_f C_a \sigma_y$$

In the formula, σ_a is the allowable stress; C_f is the design factor, taken as 0.667; σ_y is the minimum yield limit. C_a is the allowable factor, with an air traffic control state of 1.2, a production state of 1.0, and a static water test state of 1.35.

(2) Collapse verification method

API RP 2RD provides a simplified evaluation method for collapse verification, which is applicable to risers installed on general floating structures to ensure that they do not collapse under external pressure^[7].

Permissible net external pressure for crushing verification:

$$P_a \leq D_f P_c$$

In the formula, D_f is the safety factor given by the specification, generally taken as 0.75.

P_c is the minimum crushing pressure,

$$P_c = P_\infty (gf - s/s_0)$$

In the formula, P_∞ Pressure for crushing circular pipes.

$$P_\infty = \frac{P_e P_y}{\sqrt{P_e^2 + P_y^2}}$$

In the formula, P_y is the yield stress considering the effect of uniform tension.

$$P_y = \frac{2Y_r t}{D_o}$$

P_e is the elastic yield stress,

$$P_e = [2E/(1 - \nu^2)](t/D_o)^3$$

(3) Equivalent method for riser

The riser in this design is a double-layer casing structure, which includes: production tubing, inner casing, and outer casing. Once the inner casing fails, the outer casing is designed to maintain the flow of the internal medium, thus maintaining the pressure balance of the oil well.

Therefore, in the minimum wall thickness design stage, it is necessary to perform equivalent conversion on the double-layer casing structure. According to the requirements of API RP 2RD, the equivalence principle for overall analysis is^[9]:

The outer diameter of the equivalent tube is the same as the outer diameter of the outer tube,

$$D_{out} = D_{equ}$$

The cross-sectional area of the equivalent tube is equal to the sum of the cross-sectional areas of the three layers of tubes,

$$A_{out} + A_{inner} + A_{tube} = A_{equ}$$

The inertia moment of the equivalent pipe is equal to the sum of the inertia moments of the inner and outer sleeves,

$$I_{out} + I_{inner} = I_{equ}$$

The weight of an equivalent tube is equal to the sum of the weights of three layers of tubes,

$$W_{out} + W_{inner} + W_{tube} = W_{equ}$$

2.3.2. Riser design results

According to the above method, the design parameters of the riser based on the sea conditions of the target oilfield and the target platform are shown in the table below.

Table 4. Riser parameters

Function	Type	Diameter mm	Wall Thickness mm	Material
Production	Inner TTR	224.5	10.16	API 5L X80
	Outer TTR	323.8	12.7	API 5L X80
	Tubing TTR	114.30	101.60	API 5L X80
Meg	SCR	356	20.7	API 5L X65

Based on the annual sea conditions in the South China Sea, a circular FPSO was designed using the TTR riser for inter

riser collision analysis. The analysis software used was Orcaflex11.2, which has been widely used in engineering.

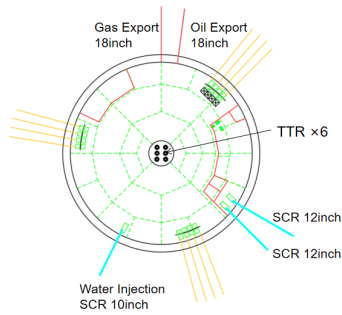


Figure 1. Platform riser layout

The target oilfield is located at a water depth of 1000m, with an environmental load of once in a year production condition, wave data, and ocean current environment. The platform drift distance is set to 7% of the water depth, which is 70m. The TTR top tension is set to 1.5 times the weight of the riser, which is 1461KN for a single riser^[4].

Based on the annual sea conditions in the South China Sea, the circular FPSO was subjected to stress analysis using the designed TTR riser. The analysis software used was Orcaflex11.2, which has been widely used in engineering.

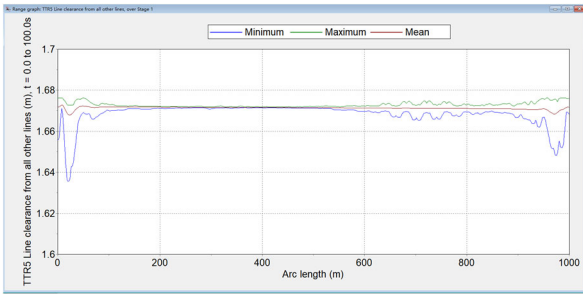


Figure 2. TTR riser spacing variation chart with water depth

According to the analysis results, it can be seen that the minimum distance between the risers is greater than 1.63m and there will be no collision, and vortex induced vibration will not occur at this distance, which can ensure that a safe distance is always maintained between the risers.

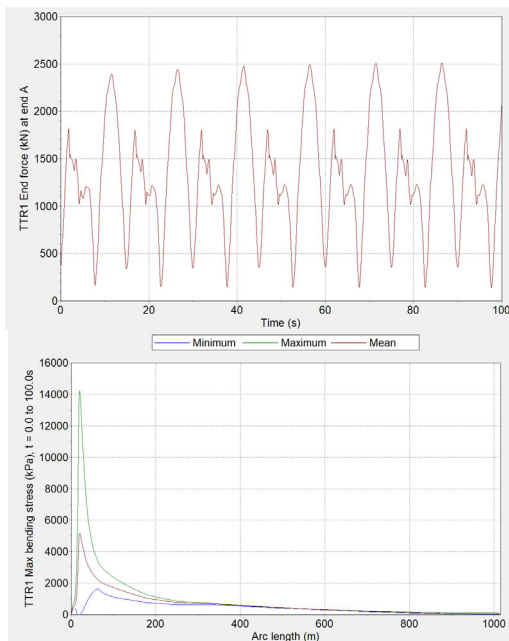


Figure 3. Time variation curve of TTR riser top load and bending stress

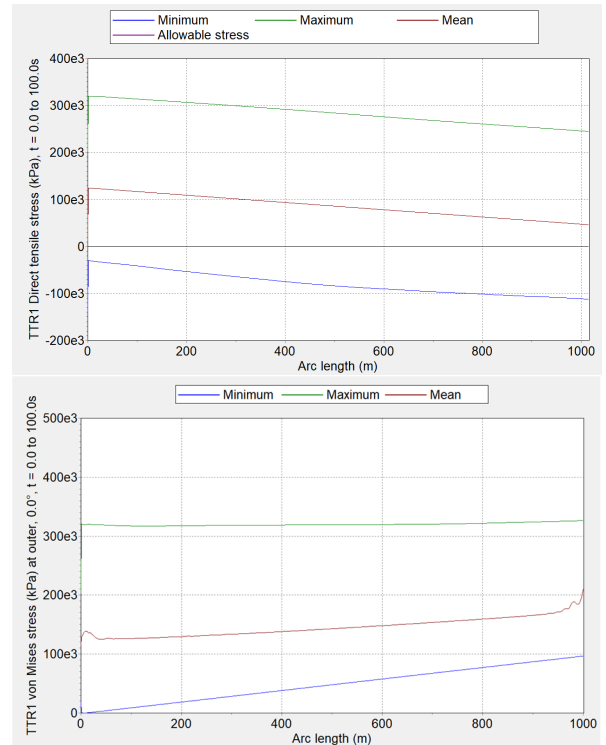


Figure 4. TTR riser axial stress and total stress variation chart with water depth

Vertical pipe size verification, in accordance with the requirements of API RP 2RD specification, checks the combined stress and crushing stress of TTR vertical pipes in three states: empty pipe, production, and static water pressure testing. The results show that the combined stress of each layer of casing and tubing meets the specification requirements, and the utilization coefficient is less than 0.8. Therefore, this design can be used for the target oilfield and corresponding working conditions.

2.4. Impact of TTR spacing

The various risers used in the process of offshore oil and gas development are prone to vortex induced vibration under the action of ocean currents, causing structural damage. Vortex induced vibration is an important factor in riser failure. The flow field around the two columns was divided into four regions based on the parallel rigid cylindrical wake structure^[10, 11].

When the single vortex street area is $1.0 < T/D < 1.2$ (T is the distance between the centers of the two cylinders, D is the outer diameter of the cylinder), only a single vortex street is formed behind the two cylinders, and the gap flow between the cylinders is very weak; Strouhal number S_t of two cylinder $S_t \approx 0.07 \sim 0.09$, gap flow affects S_t has almost no impact.

When the bistable region is $1.2 < T/D < 2.2$, the gap flow between two cylinders will deflect, The two columns correspond to wide and narrow wake regions respectively, and the gap flow exhibits bistability; Wide wake zone corresponds to low S_t , corresponding to high S_t in the narrow wake region, These two types of S_t The t -number is very sensitive to and leads to S_t , which means that for one of the cylinders, there will be two types of vortex discharge frequencies.

When the coupling vortex block is $2.2 < T/D < 4.0$, the two column vortices are distributed simultaneously on both inner and outer sides; Number S_t is equal, just like an isolated column, $S_t \approx 0.2$.

When $T/D > 4.0$ in the undisturbed zone, the wake flow field of the two cylinders is completely the same, there is no interference between the two cylinders, and the release form of the vortex is no different from that of an isolated cylinder.

When the spacing T is $1.2 \sim 2.0D$, although the parallel risers are symmetrical in structural space, the wake flow field exhibits asymmetry. This flow that occurs in a completely symmetrical structure and leans towards one side is called a bistable phenomenon, and the smaller the spacing, the more obvious this asymmetry is. The wake range of one side of the riser is narrower, and the wake range of the other side of the riser is narrower.

2.5. Analysis of riser simulation results

From the above simulation results, it can be seen that the

maximum stress of the riser always occurs at the top and bottom of the riser. This is because the top of the riser is connected to the platform, and the platform undergoes movements such as heave and roll with the waves, resulting in large stress fluctuations at the top of the riser. The large stress fluctuations at the bottom of the riser are due to the connection between the bottom of the riser and the wellhead, and the bottom of the riser cannot move.

The simulation results of the riser include analysis results of stress, tension, riser spacing, etc. It can be seen from the results that in this design result, the TTR riser spacing meets the design requirements, there will be no collision, and vortex induced vibration will not occur at the minimum spacing. The stiffness and strength of TTR and SCR risers can meet the requirements for use.

Table 5. Three Scheme comparing

Working Condition	Scheme 1	Riser	Max von Mises stress	Max Blending stress	Minimum spacing/m
ProductingCondition	100-yr cyclone	TTR SCR	324MPa 308MPa	293MPa 268MPa	1.63 --

3. Conclusion

This article designs a riser system suitable for the target oilfield based on its sea conditions and platform parameters, including the layout and size of SCR/TTR risers. Using Orcaflex to verify the design results, analyze the stress on the riser, the spacing between the risers under production conditions, etc., it is concluded that the riser system designed in this article can meet the requirements of the target platform.

References

- [1] PHAM D, SRIDHAR N, QIAN X, et al. A review on design, manufacture and mechanics of composite risers[J]. *Ocean Engineering*, 2016,112: 82-96.
- [2] Michael M. Bernitsas. Problems in Marine Riser Design[J]. *Marine Technology*, Vol. 19, No. 1, Jan. 1982, pp. 73-82
- [3] Ben G. Burke, Chevron Oil Field Research Co, et al. An Analysis of Marine Risers for Deep Water[J].
- [4] CABRERA-MIRANDA J M, PAIK J K. On the probabilistic distribution of loads on a marine riser[J]. *Ocean Engineering*, 2017,134: 105-118.
- [5] Carl F. Baxter, Ronald W. Schutz, and Christopher S. Caldwell, et al. Experience and Guidance in the Use of Titanium Components in Steel Catenary Riser Systems[J]. *Offshore Technology Conference*, April-3 May 2007.
- [6] GUESNON J, GAILLARD C, RICHARD F. Ultra Deep Water Drilling Riser Design and Relative Technology[J]. *Oil & gas science and technology*, 2002,57(1): 39-57.
- [7] KIRK C L, ETOK E U, COOPER M T. Dynamic and static analysis of a marine riser[J]. *Applied Ocean Research*, 1979,1(3): 125-135.
- [8] MAO L, LIU Q, ZHOU S, et al. Deep water drilling riser mechanical behavior analysis considering actual riser string configuration[J]. *Journal of Natural Gas Science and Engineering*, 2016,33: 240-254.
- [9] Chicago Bridge and Iron Co, Plainfield, IL 60544, USA. Review of riser analysis techniques[J].
- [10] WONG E W C, KIM D K. A simplified method to predict fatigue damage of TTR subjected to short-term VIV using artificial neural network[J]. *Advances in Engineering Software*, 2018,126: 100-109.
- [11] E.R. Fontaine, J. Rosen, H. Marcollo, et al. Using Model Test Data to Assess VIV Factor of Safety for SCR and TTR in GOM [J].