ISSN: 2688-8645

Fluid-solid Coupling Analysis of Riser based on CFD

Haifeng Ma*, Xian Qin, Jie Qiu, Wenjie Xie and Zhixu Zhou

School of Mechanical and Electrical Engineering, Southwest Petroleum University, Chengdu 610500, China

Abstract

The riser is the only channel connecting the submarine pipeline oil gas and offshore platform structures, offshore oil and gas development and utilization of lifelines, offshore pipeline system is the weakest vulnerable link. Due to its long and thin structure, the marine riser is easy to failure and failure in the complex working conditions. Marine vibration pipe safety or not directly affects the marine engineering and the surrounding environment and marine biology, in the event of damage, can cause the economic loss and environmental pollution, will result in a casualties, and even cause serious secondary disasters. Therefore, the safety and reliability of marine riser has been the focus of marine oil and gas industry research. In order to ensure the safety and reliability of the marine riser, it is usually necessary to evaluate the safety and reliability of the marine riser. The two-way fluid-solid coupling analysis of the riser system with a water depth of 500m is carried out by Ansys workbench software. The results show that the maximum flow rate of the flow field at the interface between the fluid and the riser occurs in the middle of the riser near the two ends. As time increases, the maximum flow rate will gradually shift from both ends to the middle of the riser, and the maximum value is 0.85m/s; the maximum stress of the riser will appear at the upper and lower end points, the maximum is 81.43Mpa; the lateral displacement of the upper end of the riser reaches the maximum, about 0.69m; indicating that these positions are the vortex induced lateral vibration of the riser dangerous area; therefore, this part can be improved by structural design or protection to increase the working life of the riser.

Keywords

Riser; Fluid-solid Coupling; CFD.

1. Introduction

Marine deepwater drilling is the only way to promote the development of China's petroleum industry. In offshore oil and gas development, risers are one of the most critical and vulnerable components as the link between the rig and the subsea wellhead [1]. The alternating devortexing formed on both sides of the pipe body when seawater flows through the riser will induce periodic vibration of the riser, and the vibration of the riser will disturb the shedding of the vortex of the flow field, etc., and this phenomenon of fluid-solid coupling is called "vortex-induced vibration". Drilling marine environment with the increase of water depth becomes more complex and the force situation of the riser string also becomes more severe and complex, with the increase of water depth, the length of the riser increases, resulting in a decrease in the natural frequency of the riser system, the possibility of vortex-induced resonance is greater, and the vortex-excited resonance of the riser will cause high-frequency alternating stress, continuous vortex-induced vibration is easy to lead to the fatigue of the riser, so that its mechanical properties are reduced, accelerating the fracture of the riser, Whether the riser system is stable directly affects whether deepwater drilling can proceed smoothly. In addition to significant economic losses, the oil and drilling fluids leaked from the marine riser structure can cause catastrophic damage to the marine environment.

The problem of double coupling between the riser and the fluid in deepwater drilling is very complicated, mainly because the hydrodynamic load is difficult to solve. The vibration of the riser by fluid stimulation such as water flow, waves and shock waves or other non-fluid excitation, the flow field around it also changes, and the change of the flow field in turn will change the fluid force received by the riser, which forms the vibration problem of the feedback fluid-riser interaction.

This paper mainly uses the fluid simulation software CFD to analyze the fluid-structure coupling between the marine drilling riser and the fluid, obtains the pressure of the riser, and the simulation of the velocity of the fluid after the movement around the flow, mainly observes the various movement modes and pressure of the fluid after the flow, analyzes the position of the maximum displacement and maximum stress, and solves the problem through theoretical basis for the subsequent in-depth research.

2. Physical Model

The riser is one of the components of underwater appliances. The steel pipes connecting the subsea BOP group and the floating offshore drilling unit are mainly used to isolate seawater, introduce drilling tools and casing, and form the channel for the mud cycle [2]. The model of the riser for deepwater drilling is shown in Figure 1.

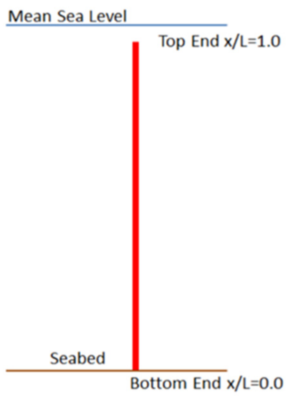


Fig 1. The model of riser

The marine environmental parameters are derived from the relevant information provided by Shenzhen CNOOC, using the annual sea conditions, and the current environmental data under the conditions of typhoons once a year in the South China Sea are shown in Table 1.

Table 1. Seawater environmental factor

Distance from sea level (m)	Current velocity (m/s)
1	1.07
25	1.03
247	0.79
411	0.55
576	0.54
740	0.53
1069	0.52
1233	0.51
1398	0.51
1m from seabed	0.31

ISSN: 2688-8645

When establishing the model, the riser with an outer diameter of 0.5334m and a wall thickness of 0.0317m was selected, with a top tension coefficient of 1.4, an elastic modulus of 210GPa, a density of 7850kg/m^3, and the seawater density of 1250kg/m^3. In this paper, the vortex-induced vibration of a 500m real-size deepwater drilling riser is studied.

3. CFD Analysis Calculation

3.1. Setting up Fluid-solid Coupling

In the ANSYS Workbench platform, bidirectional fluid-structure interaction analysis flows can be easily set up with Fluent, Mechanical and System Coupling modules, as shown in Figure 2. Connect the Fluent and Mechanical Set up processes to System Coupling's Set up, and control the time setting and data exchange information setting for fluid analysis and structural analysis at the same time in System Coupling. Structural analysis and fluid analysis exchange data once after each time step solved, fluid analysis calculates the external load of the structural surface, and transmits it to structural analysis to calculate the deformation response of the structure, and then performs structural solving, structural analysis solves a time step, and then the structural deformation is fed back to fluid analysis, as a new structural boundary of the flow field, this repeated data exchange between the two solvers is automatically completed in System Coupling.

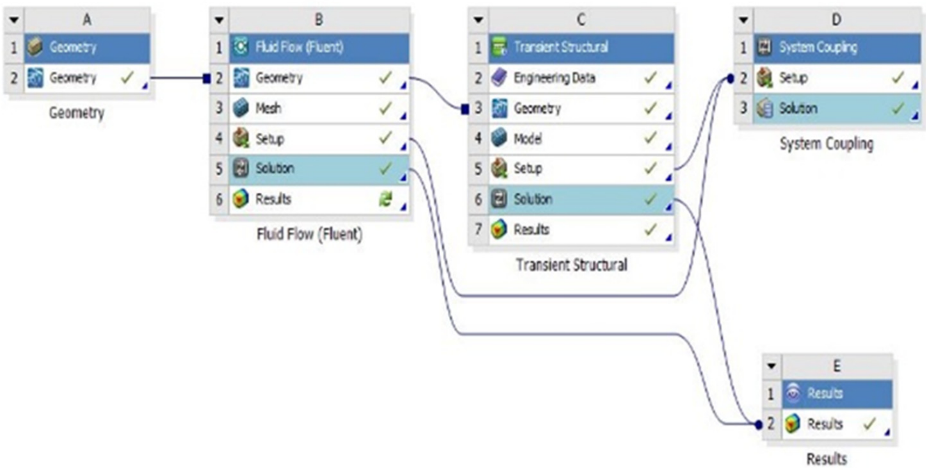


Fig 2. Two-way fluid-solid coupling analysis flow by Workbench

3.2. Modeling and Meshing

Build geometric models in Spaceclaim. Firstly, the length of the riser is 500m, the outer diameter is 0.5334m, and the wall thickness is 0.0317m; the outer flow field is surrounded, and the rectangular outflow field is established, the height of the flow field is 500m, indicating the water depth is 500m, the length of the flow field in the flow direction is 100m, and the width direction is 20m.

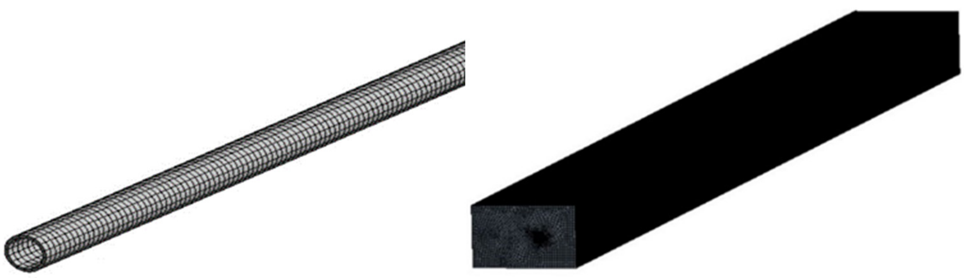


Fig 3. Meshing riser and flow field

During the Fluent meshing phase, the structural model is suppressed. The first boundary layer thickness is 1mm, a total of 10 boundary layers are divided, the overall mesh size is set to 0.5m, and the two-way fluid-structure interaction analysis is performed in Workbench, which is modeled in SpaceClaim; and the fluid model is suppressed in the Mechanical meshing stage. The cylindrical shell is divided into 32 equal parts along the circumferential direction, and one unit every 1m in the axial direction. The meshing results of the flow field and the riser are shown in Figure 3.

3.3. Loads and Boundary Conditions

3.3.1. Fluid Settings

In Fluent, specify the transient analysis type; The material of the fluid domain is set to water; The water flow speed is set to 0.8m/s, that is, the speed inlet is selected and the inlet speed is set, and the outlet is the pressure outlet; The effect of gravity on the fluid is not taken into account. Set the fluid-solid interface to the dynamic grid region, and the moving mesh adopts the Diffusion algorithm in the Smoothing option, which is more robust in large deformation problems, and specifies the dynamic mesh region option as the System Coupling option setting. In the time setting, specify a time step size of 0.005s and a time step of 200, that is, the total simulation time is 1s.

3.3.2. Structure Settings

In Mechanical, the transient structural analysis type is used, and the time step and simulation time are exactly the same as Fluent; Constrain the translational degrees of freedom at the upper and lower ends of the riser, specify the fluid-solid interface as the outer surface of the riser, receive the fluid pressure calculated by Fluent, and map the fluid pressure to the structural grid by load mapping technology, as shown in Figure 4.

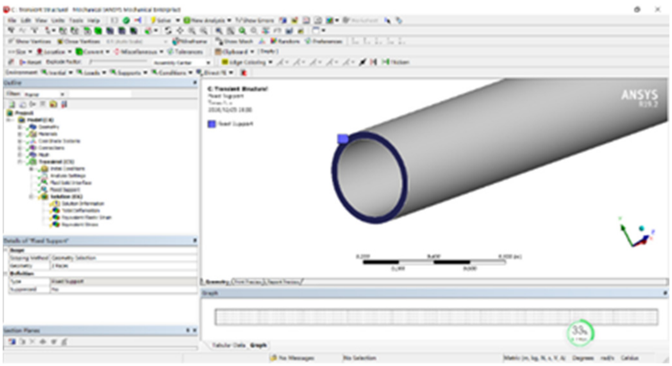


Fig 4. Setting riser structure

3.4. Calculate the Solution

Fluid-structure interaction setup with bidirectional fluid-structure interaction. In System Coupling, set the total simulation time and time steps to 1s and 0.005s, respectively. In the setting of data exchange, the structural boundary pressure of the fluid analysis is transferred to the fluid-solid interface specified by the structural analysis; At the same time, the structural deformation obtained by structural analysis is transferred to the riser boundary of the fluid analysis, and the analysis is carried out until the calculation is solved.

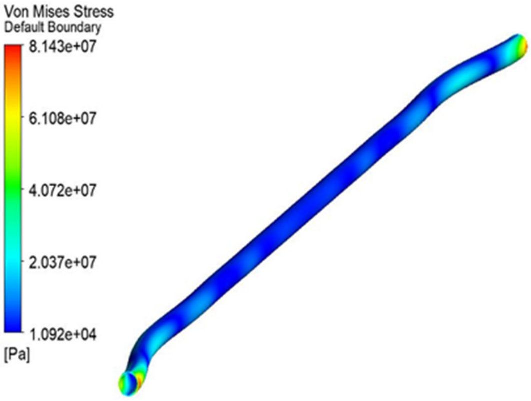
4. Result Analysis

4.1. Analysis of Riser Motion Characteristics

For post-processing analysis, the motion characteristics of the riser pipe can be viewed in CFD-post, as shown in Figures 5 and 6, respectively, the Mises stress distribution on the riser and

ISSN: 2688-8645

the velocity cloud of the riser. It can be seen that the stress at both ends of the riser is large, the maximum value is 81.43Mpa, and the movement speed in the middle of the riser is large, and the maximum value is 0.85m/s.



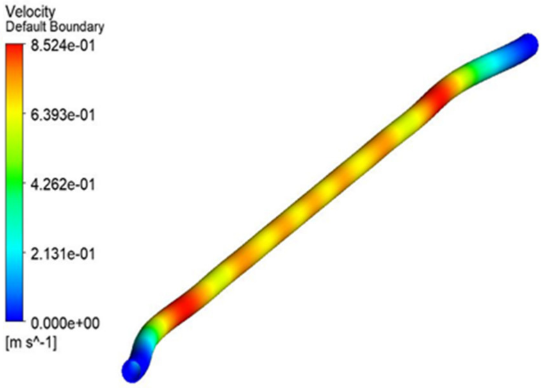
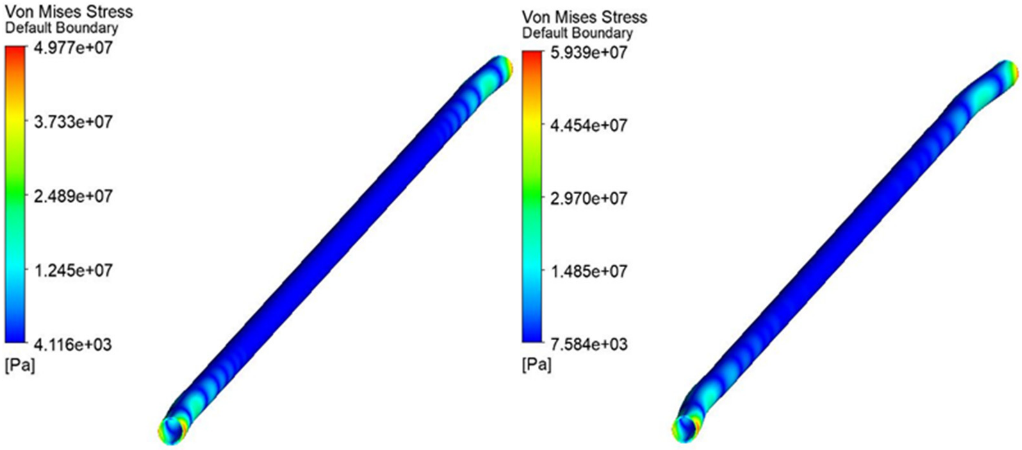
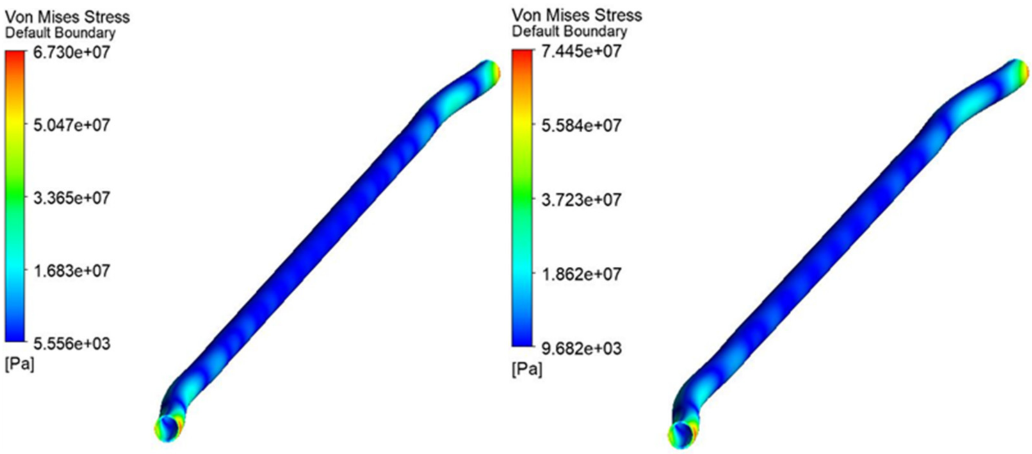


Fig 5. The von mises stress of riser at 1s **Fig 6.** The velocity of riser at 1s

As shown in Figure 7, the Mises stress distribution cloud of 0.2s, 0.4s, 0.6s, and 0.8s is extracted for one cycle. Shows that stress increases over time.



0.2s 0.4s

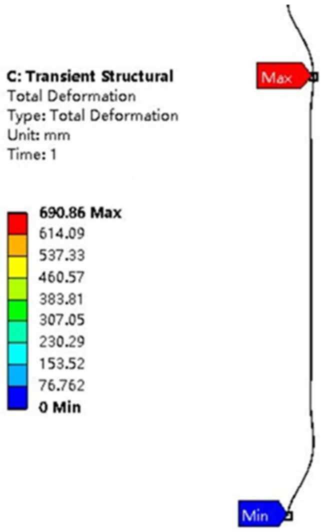


0.6s 0.8s

Fig 7. The von mises stress of riser in 1s

Figure 8 shows the static deformation of the riser, and the lateral displacement of the upper end of the riser reaches a maximum value, about 0.69m. The upper and lower ends are connected by hinges, so the lateral displacement is almost constant. Figure 9 shows the equivalent force cloud diagram of the riser, and the maximum value of the equivalent force of

81.4Mpa will appear at the upper and lower ends of the riser, indicating that these positions are the danger zone of vortex-induced lateral vibration of the riser.



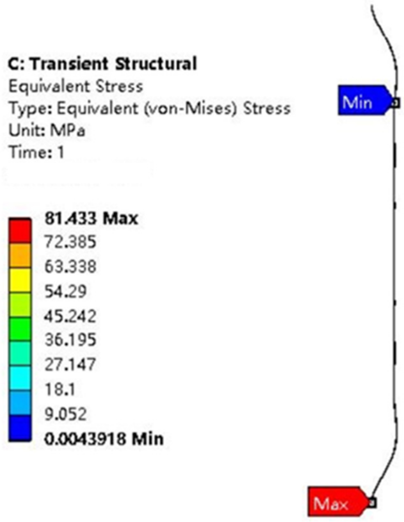


Fig 8. The Displacement of riser at 1s **Fig 9.** The von mises stress of riser at 1s

Select a point at the largest displacement in CFD-post, obtain the Mises stress change curve of the point with time, as shown in Figure 10, it can be seen that the stress gradually increases with time, and shows a trend of up and down oscillation, if the calculation time increases, the oscillation amplitude will be larger.

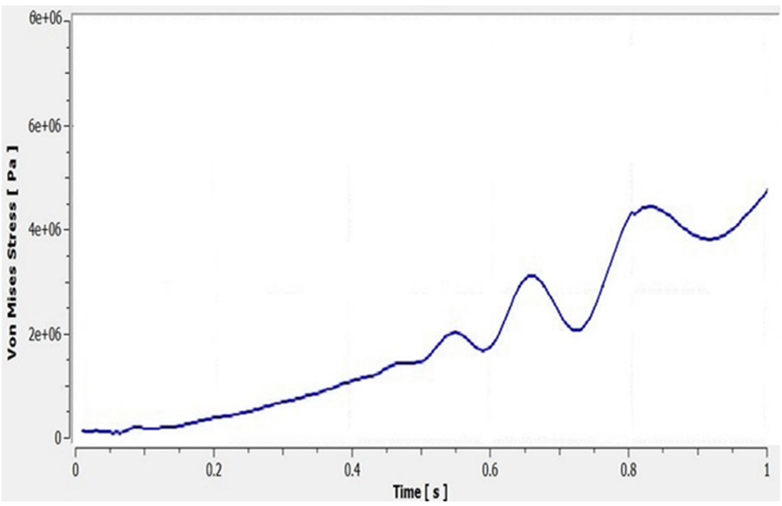
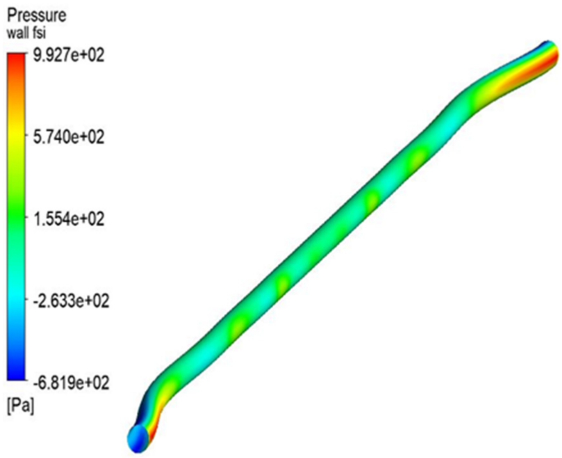


Fig 10. Stress curve at the point of maximum displacement as a function of time

4.2. Analysis of Flow Field Characteristic

After the fluid analysis, a cloud of fluid pressure and fluid velocity analysis can be viewed in CFD-post. Figure 11 and 12 are the pressure and velocity distribution clouds of the interface between the fluid and the riser, that is, the Fluid Solid Interface, respectively. It can be seen that the most stressed parts on the interface are the upper and lower ends of the flow side, with a maximum pressure value of 992.7pa; the area with the largest flow rate is the middle of the interface, with a maximum pressure of 0.85m/s.

ISSN: 2688-8645



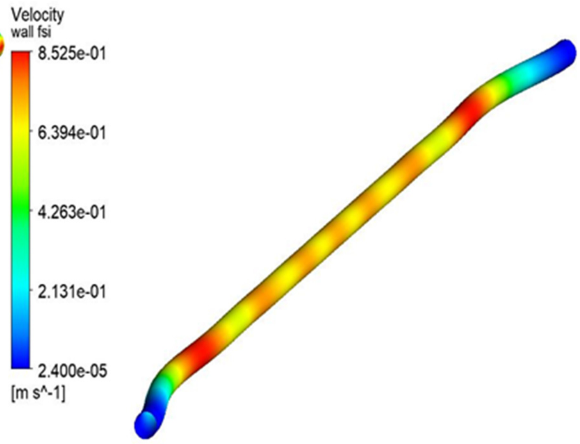


Fig 11. The von mises stress of FSI at 1s **Fig 12.** The velocity of FSI at 1s

The FSI pressure and fluid velocity clouds of 0.2s, 0.4s, 0.6s, and 0.8s were extracted for one cycle, as shown in Figures 13 and 14, respectively. It can be seen that with the increase of time, the maximum pressure at both ends of the FSI interface gradually decreases, because when the fluid begins to flow, the two ends of the riser are articulated by hinges, and the pressure at both ends is the largest, and with the increase of time, the pressure at the interface gradually shifts to the middle, so that the pressure at both ends gradually decreases, and the maximum flow rate at the interface gradually increases with the increase of time.

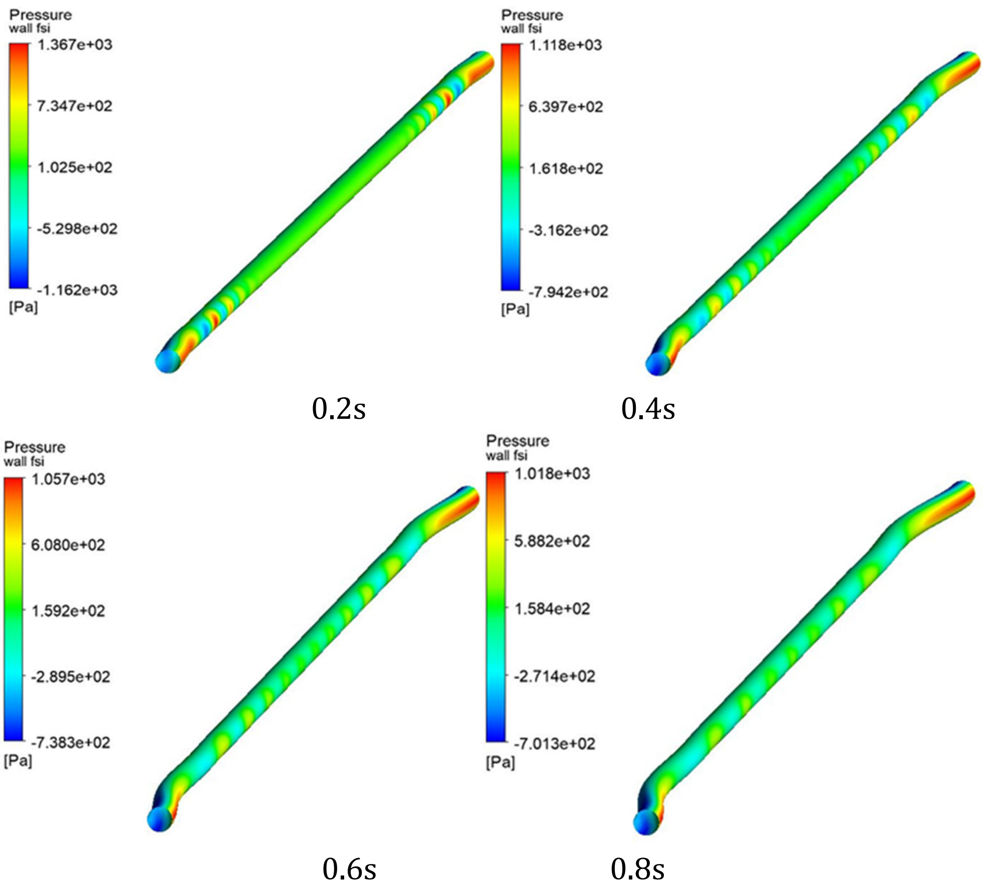


Fig 13. The von mises stress of FSI in 1s

ISSN: 2688-8645

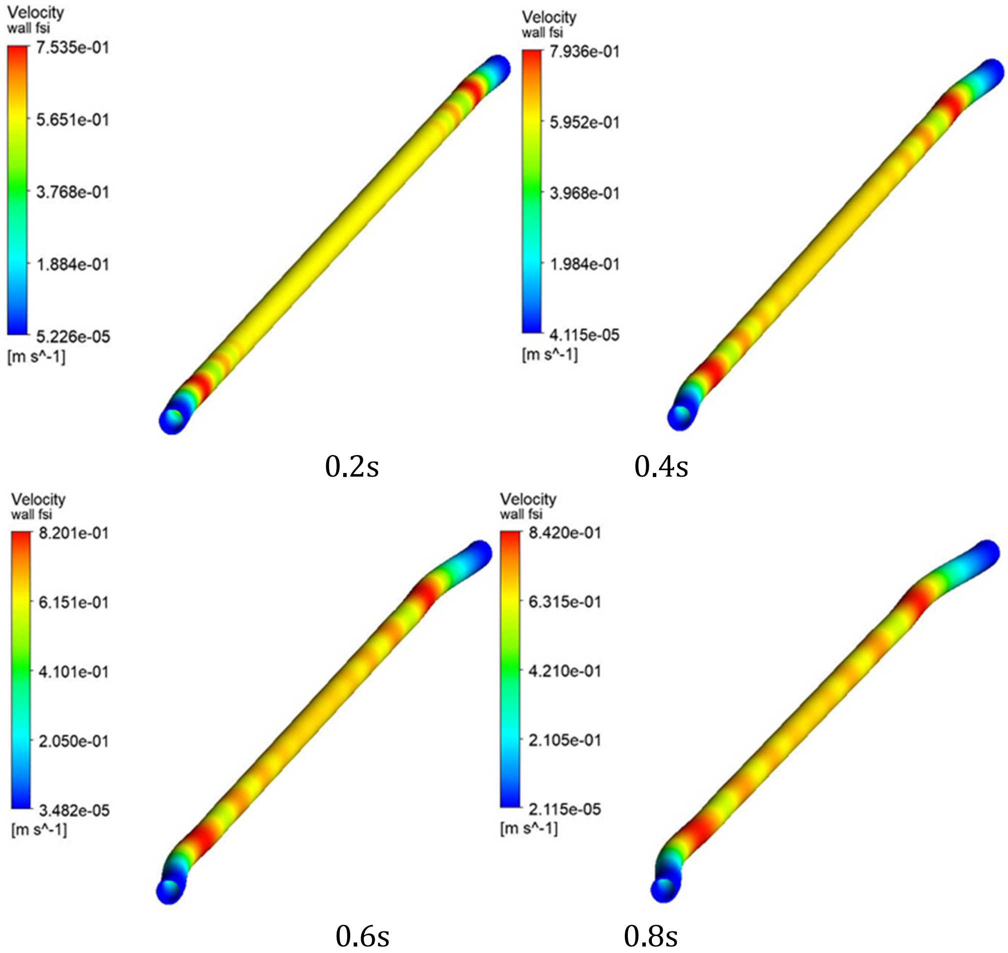


Fig 14. The velocity of FSI in 1s

5. Summary

Bidirectional fluid-structure interaction analysis of a 500m water depth riser shows that:

1. The lateral displacement of the upper end of the riser reaches the maximum value, about 0.69m, and the von Mises stress at the maximum point of displacement gradually increases with the increase of time, and shows a trend of oscillation up and down, which is extremely unstable, indicating that the point is dangerous.

2. The maximum value of the von Mises stress of the riser will appear at the upper and lower endpoints, and the maximum value is 81.43Mpa, indicating that these positions are the danger zone of vortex-induced lateral vibration of the riser.

3. The largest pressure at the interface between the fluid and the riser is the upper and lower ends of the flow side, with the increase of time, the maximum pressure at both ends of the interface gradually decreases, because when the fluid begins to flow, the two ends of the riser are articulated by a hinge, the pressure at both ends is the largest, with the increase of time, the pressure at the interface gradually shifts to the middle, so that the pressure at both ends gradually decreases, and the maximum pressure value is 992.7pa.

4. The maximum flow rate of the flow field at the interface of the fluid and the riser occurs in the middle of the riser near both ends, and with the increase of time, the maximum flow rate will gradually shift from both ends to the middle of the riser, and the maximum value is 0.85m/s.

ISSN: 2688-8645

References

[1] ZHANG Xiaodong, WANG Haijuan. Progress and outlook of deepwater drilling technologies[J]. Natural Gas Industry, 2010, 30（9）: 46-48, 54.

[2] HANG Yuanjiang, DUAN Menglan. Design and operation of marine drilling riser: A case history of deepwater drilling in the south china sea[J]. Natural Gas Industry, 2014, 34（5）: 106-111.

[3] HAN Chunjie, CHEN Mingming, YAN Tie. The riser lateral free vibration analysis of deepwater environment[J]. Journal of Applied Mechanics, 2012, 29（3）: 341-344,359.

[4] LIU Qingyou, ZHOU Shouwei, JIANG Wei, et al. A dynamic model of marine risers/pipes under the drilling operation condition and sea environment[J]. Natural Gas Industry, 2013, 33（12）: 6-12.

[5] WANG Mao-cheng. Finite elemental method[M]. Beijing: Tsinghua University Press, 2003.

[6] ANSYS CFX Reference Guide. ANSYS CFX ANSYS Release 11.0[R]. ANSYS Inc., Canonsburg, USA, 2007.

[7] YU Haoyang. The research of Marine riser coupling and in hibition device[D]. Northeast Petroleum University, 2017.

[8] LIU Shanshan. Coupling Mechanical Analysis and Numerical Simulation of Deepwater Drilling Rieser[D]. Northeast Petroleum University,2016.

[9] Yao Shichong. Numerical simulation study on vortex-induced vibration response of marine riser[D]. Southwest Petroleum University,2017.