A Numerical and Structural Response of FPSO Under Wave Induced Motions

Greeshma George, Sheeja Janardhanan

Abstract**:** ***FPSO (Floating Production, Storage and Offloading) is generally a ship used by oil and gas industry for performing a multitude of tasks and is moored to the ocean bed for the extraction of oils and hydrocarbons. Due to continuously varying cyclic load, FPSO undergoes progressive and localized structural deformations leading to fatigue damage. Structural analysis of the FPSO is important to establish the strength and stability of the structure. A moored FPSO generally has three degrees of freedom viz. heave, roll and pitch, under following sea conditions. In this paper, a numerical study on the FPSO has been conducted with the help of CFD (Computational Fluid Dynamics) analysis under calm sea-stateand the subsequent structural response of the system has been calculated by finite element method. CFD studies have high potential in determining the effect of any complex fluid loading with reasonable degree of accuracy. Geometric modeling and meshing have been carried out in ANSYS ICEM CFD. An unstructured grid system has been used here and the prescribed motions on the hull in heave, roll and pitch have been brought in using user defined function (UDF) module of the commercial CFD solver, FLUENT. Air water interface has been captured using volume of fluid method. The lift and drag forces are calculated from the simulations. Fluid forces have been validated against their analytical counterpart using Linear wave theory and Strip theory. Structural response of 3D hull has been predicted in ANYS Workbench with the forces determined from the CFD solver as input. Equivalent stress distribution and total deformations of the structure have been studied using static analysis.Understanding the behavior of structure under various motions provides an insight and guidance to the design calculations of the FPSO in order to withstand fatigue loading.***

Keywords—FPSO, CFD, Pitch, Heave, Roll, Lift, Drag, Structural Response.

I. INTRODUCTION

FPSO (Floating Production Offloading and Storage) is generallya ship use for the storage of hydrocarbons and oils.

It is a large structure and highly technical as shown in Fig1.It is performing multitude of tasks and can act in wide range of water depths and many environmental conditions especially in harsh environment. It is the best developed system in oil production industry. From the existing well centers it takes oil and through the injection lines the oil is pumbed to the storage unit. Later the oil is offloaded to the tankers.FPSO is acted by repeated loads[2]. The FPSO is acted upon by wave, wind and other environmental loads such as ice in polar regions. Regular inspection and strength analysis is very important [1]. Due to the cyclic loads it can undergo progressive and structural damages. Understanding the strength and stability is a very important criterion for fatigue design. The sea state condition, in which the FPSO acts, cannot be, predicted so the design of this structure is complicated and very challenging for engineers. Due to varying loading and unloading cycles, fatigue assessment of the structure is very important.

Fig .1 FPSO

Wu , have done a noticeable work on the total deformation and equivalent stress caused by still water and vertical wave-induced bending moments for a specific FPSO using finite element analysis . Further, based on cumulative fatigue damage theory and Miner ruler, an empirical formula is proposed to calculate fatigue damage accumulation of FPSO so as to predict the fatigue life of FPSO.Kannah,conducted an experimental investigation on dynamic response of FPSO under regular wave conditions and frequencies. Surge, heave and pitch motions are measured.No much work has been done considering the structural behavior of FPSO using a CFD input of fluid loading during motions.In this paper structural response of FPSO is computed for fluid loading under different motionsfor a range of frequencies and fatigue life is estimated.Generally a floating body such as a ship has six degrees of freedom surge, heave, sway, pitch, roll and yaw[4]. As a moored structure, it has only three degrees of freedom that is heave, pitch and roll.The objective is to compute the structural response of FPSO under heave, pitch and roll motions under calm sea state and to predict the fatigue life. Performing the structural response improves the reliability of designs.

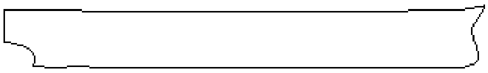

Fig .2 Side View

Revised Manuscript Received on December 22, 2018.

Greeshma George, Civil Engineering Department,SCMS School of Engineering and Technology, Karukutty, Ernakulam
SheejaJanardhanan, Mechanical Engineering Department, SCMS School of Engineering and Technology, KarukuttyErnakulam, India

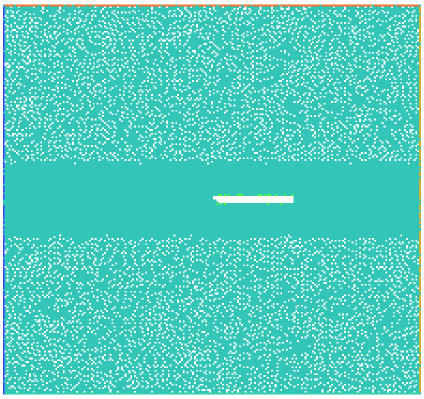

Fig. 3 Side view meshed

II. NUMERICAL METHODOLOGY

Computational Fluid Dynamics (CFD) is the best method to analyze fluid interactions with the structure especially when the structure is undergoing wave-induced motions. The details of FPSO are shown Table I. The FPSO has been scaled down in the simulation (Scale ratio = 1:30)

TABLE I FPSO PARTICULARS

DESCRIPTION	DIMENSION
Length	248 m
Breadth	42 m
Depth	27.1 m
Draft	21 m
Freeboard	7.1 m

A.GeometricModeling and meshing

The 2D model of the ship has been created using ANSYS ICEM CFD. Figure 3 and Figure 4 shows the meshed model of the FPSO. 2D model was also created to find out the behavior of the ship hull towards the wave simulation.The domain extends are 2L from the inlet boundary, 3L from the outlet and IL each from the top and bottom boundaries. Meshing is carried out as patch independent with a maximum mesh size of 0.6 units.Triangular elements with a minimum size of 0.005 in the y direction are chosen as this value satisfies the CFL criteria. Fine mesh is created around the hull portion in order to capture the air water interface.Modelling and meshing has been carried out in front and side views of a ship. This facilitates simulation of heave (sinusoidal z-translation in x-z plane), roll (sinusoidal rotation about x-axis in y-z plane) and pitch (sinusoidal rotation about y axis in x-z plane). Modeling and meshing in these views are shown in Figs 2 through 5.

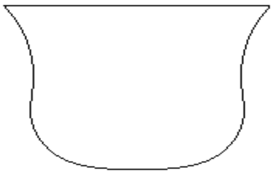

Fig .4Front view

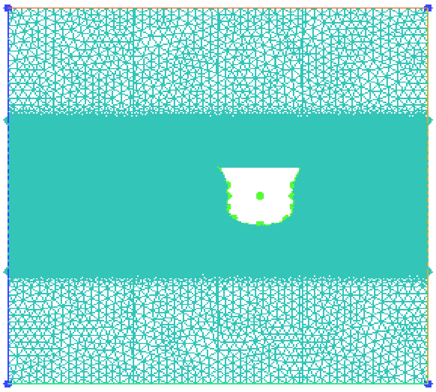

Fig. 5Front view meshed

C. CFD Simulations and Results

ANSYS Fluent 18.1 is launched with a transient and pressure- based solver. Gravity is activated in the negative y-direction. Volume of fluid method is adopted for modeling the air-water interface.It is a free surface tracking technique for effectively capturing its deformations. The boundary conditions for present study are given in Table II.

TABLE II Boundary Conditions

Boundary	Type
Inlet	Slip wall
Outlet	Slip wall
Sky	Slip wall
Seabed	Slip wall
Hull	No slip wall

The boundary conditions represented in Table II are typical to a tank. Hence the simulations are performed in a numerical tank. Dynamic mesh scheme is adopted with smoothing and remeshing.A user-defined function (UDF) is used to describe the motion of the ship. The UDF is a C program which specifies the boundary conditions and imposes prescribed motions on the hull. The body motions follow the sinusoidal function [6] for velocity as given in Eq. (1)

$r = ra\cos\omega t$(1)

ω is frequency of oscillation in radians per sec is 0.5rad/s. For the wave generation the simulation was done for a certain time step. ris the time dependent velocity and ra is the velocity amplitude. The time step is computed such that the CFL criteria are satisfied. The time step here is 0.001s.The time period is calculated as shown by Eq. (2).

$$T = \frac{2\pi}{\omega} \quad (2)$$

T is the time period I seconds. The computational runtime for the analysis was 37 seconds, corresponding to 3 cycles for frequency 0.5rad/sec and the amplitudeof lift and drag forces of steady state oscillation condition are recorded. Simulation for pitching motion for 0.5 rad/sec is shown in Fig 6.

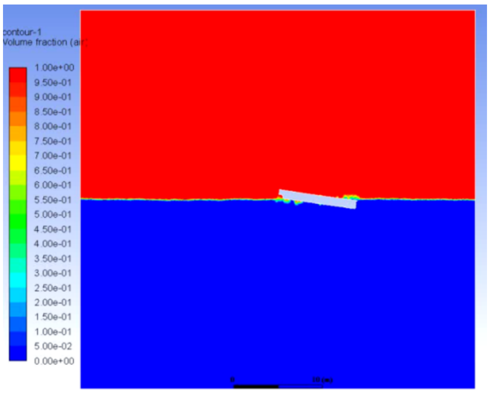

Fig .6 Simulation of pitching motion of FPSO at 0.5rad/sec

The up and down motion of ship along x axis is simulated using ANSYS FLUENT.Motion amplitude is 0.104 radians.

Drag force from CFD analysis is 1726.05N/m and lift force from CFD analysis is 11188.1N /m.Simulation for rolling motion for 0.5 rad/sec is shown in Fig 7.

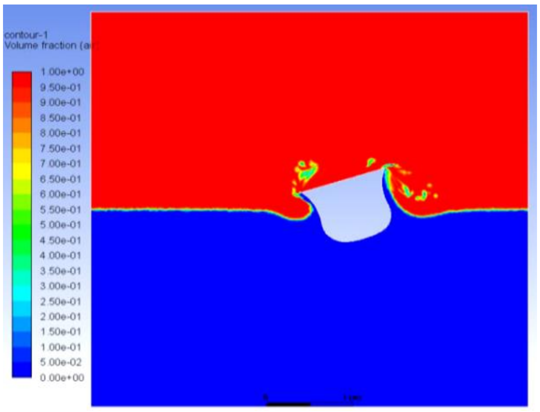

Fig .7 Simulation of rolling motion of FPSO 0.5rad/sec

Rolling is, the rotation about x axis. Motion amplitude is 0.18 radians. Drag force from CFD analysis is 0.011N/m and lift force from CFD analysis 0.002N /m.Simulation for rolling motion for 0.5 rad/sec is shown in Fig 8.

Fig .8 Simulation of heaving motion of FPSO 0.5rad/sec

Thelinear vertical up and down motion. Motion amplitude is 0.1 radians thatis taken as the height of the ship to be heaved.Drag force from CFD analysis 59.6 N/m and lift force from CFD analysis is 18028.73N /m

In order to predict realistic wave loading, a 3D model has been created in ANSYS ICEM CFD with the parameters mentioned in Table I. The model is created with help of points, curves and surfaces. The 3D model is then imported to structural solver and the forces are imposed. Figure 9 shows the 3D model.

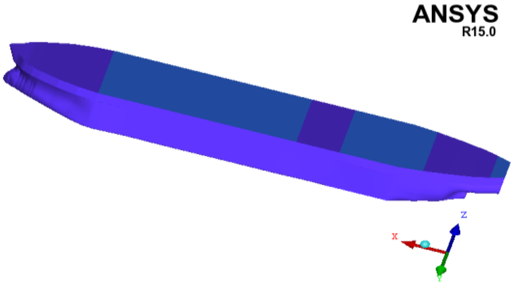

Fig .9 3D model of FPSO

D. Analytical Method

The forces from CFD are verified analytically by means of linear wave theory. The theory assumes that the flow is irrotational and inviscid.The theory is used for small amplitude waves for two-dimensional bodies. Total force is the summation of static and dynamic force [6].Drag force is calculated from the Eq. (4).

$$F=\left\{\int_{-Z_1}^{-Z_2} \rho g z\, dz + \int_{-Z_1}^{-Z_2}\int_0^l (\rho g a e^{kz}\cos(\omega t - kx))dxdz)\right\} b \times c \quad (3)$$

Where

F=Drag force in N
P= Pressure
ρ = Water density
g= Acceleration due to gravity
z1 = vertical coordinate in left side

z2 = vertical coordinate in right side
a= wave amplitude
k = wave number
x = horizontal coordinate
ω = wave frequency
λ= wave length
t= time at any instant
b= width of ship
l= length of ship at bottom
c = Block coefficient

In case of pitching motion, drag force is 1781.5 N/m.The numerical results of drag force for pitch varies 3% .In case of heave the static force is zero. The dynamic force obtained from the equation is 58.42N/m.The numerical results for heave vary 2.5% from analytical results and the variation is within permissible limits.

The lift force due to pitching and heaving is computed with the help of strip theory. In this theory ship is assumed to be divided into many strips .The two-dimensional flow problem is found by integrating the forces or hydrodynamic characteristics along the ship knowing the mass and radiation, and dampingcoefficients for each strip. Assume that the ship is forced to oscillate in calm water with theamplitude,$\hat{\eta}$and the angular frequency, ω.The vertical reaction force acting on the body from the water can be computed after integrating thetwo dimensional reaction forces, along the ship [6]is calculated from the Eq. (4) and (5).below ,

$$\eta = \hat{\eta}\cos(\omega t) \quad (4)$$

$$F = -(A_{33} + m)\ddot{\eta} - B_{33}\dot{\eta} - C_{33}\eta_3 \qquad (5)$$

Where F represents the lift force, m the mass and the coefficients A33, B 33 and C33are the integrated or summed quantities along the ship. Theoretically value of lift force in case of heave is 17602.73 N/m and for pitch is 12014.5N/m.The numerical results of lift force vary 2.3% in case of heave and 6.87% in case of pitch from analytical results.The variation is due to use of coarser grid, negligence of viscous effect.

III. STRUCTURAL RESPONSE COMPUTATION

The aim of structural analysis and design is to develop a structure that will be able to withstand all loads and deformations.FPSO is designed forlife with a suitable margin of safety. FPSO as it is subjected to harsh environment its safety has to be thoroughly checked.ANSYS provide many comprehensive simulation sets and solve wide range of problems[5].3D model of the FPSO from ANSYS ICEM CFD is imported to ANSYS Workbench15.0 for structural analysis is shown in Fig 10 and meshed model of structure is shown in Fig 11.

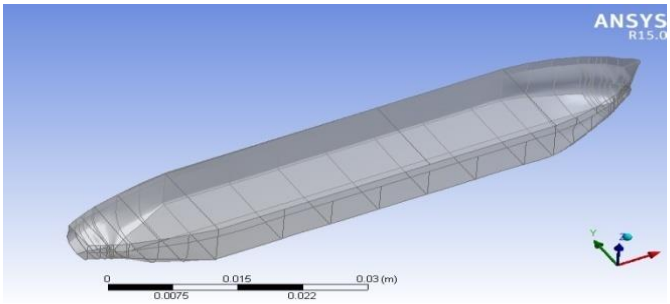

Fig .10 3Dmodel in ANSYS Workbench

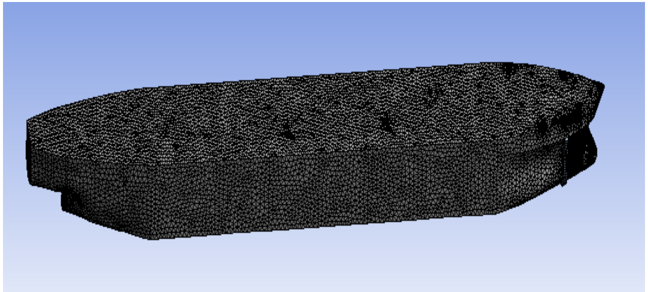

Fig .11 3D meshed model in ANSYS Workbench

Static structural analysis is taken as load is not varying with respect to time.High grade strength steel is taken as material for FPSO. The thickness provided is 20mm. The modulus of elasticity and Poisson's ratio for the ship building grade steel is 2.1x1011 N/m2 and 0.3 respectively. The tensile strength of steel is 250MPa.Forces are provided transversely and axially.Drag force is applied axially and lift force is applied transverse to the bottom of hull. Total deformations and stresses are also shown in figures below respectively indicating the region of higher deformation and stress. Two cases have been taken to carry out the ship structural analysis that ispitching and heaving.Because the two loading conditions are different. Structural responses due to pitching and heaving motions are shown below.

Response due to pitching effect

The lift force 11188.1 N/m is applied vertically upwards on the bottom surface and drag force 1726.05N/m is applied axially against the flow direction. Total deformation diagram and equivalent stress diagram is shown in Fig.12 and Fig.13

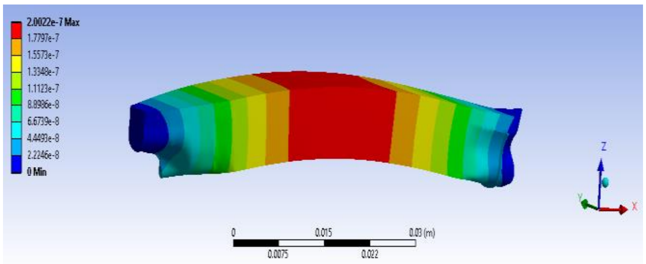

Fig .12Total deformation diagram under pitching effect

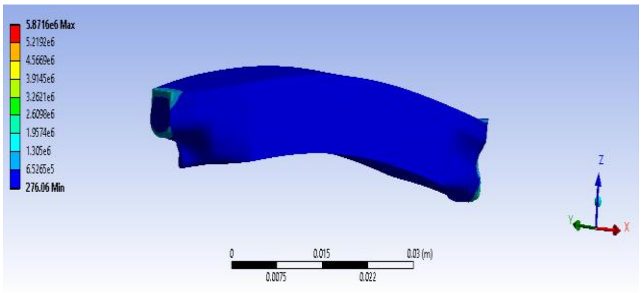

Fig .13 Equivalent stress diagram under pitching effect

B.Response due to heaving effect

The lift force 18028.7 N/m is applied vertically upwards on the bottom surface and drag force 59.5N/m is applied axially against the flow direction. Total deformation diagram and equivalent stress diagram is shown in Fig.14 and Fig.115.

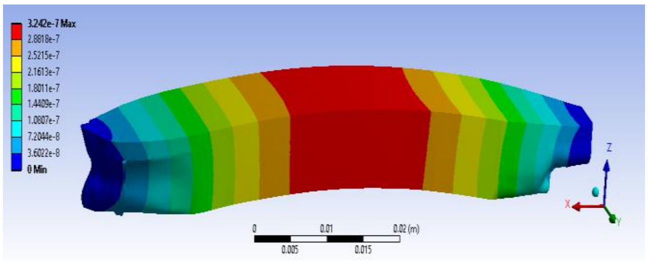

Fig .14 Total deformation diagram under heaving effect

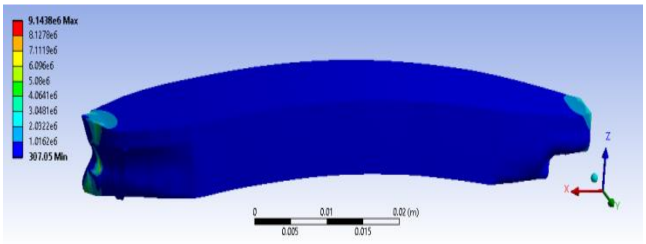

Fig .15 Equivalent stress diagram under heaving effect

The midship section shows the maximum deformation in all the cases so it has to be strengthened more specially with stiffeners. The deformation is maximum in the case of heaving and minimum in the case of pitching. The stress is also maximum for heaving and minimum for rolling. The yield stress of material is 250MPa and the obtained values are within the limit. In the case of rolling drag and lift force obtained is very less and so it is neglected.

III. CONCLUSIONS

Structural behaviors of FPSO under calm sea state conditions are analysed.CFD simulations are carried out for heave, pitch and roll motions of FPSO.Deformations in air water interface is captured and lift and drag forces are calculated. Forces from CFD are comparable with linear wave theory and strip theory. In this paper total deformation and equivalent stress diagram caused by heaving and pitchingare studied by finite element analysis. Rolling is neglected since the forces obtained are less. The forces effect for rolling motion is in a negligible level.The FPSO has maximum stress and deformation under heaving motion.The stress obtained is within the yield stress of material.CFD and structural response computation method adopted here proved to be a better method in analyzing the FPSO behavior.

REFERENCES

1. Lei yu et al. (2017)" Study on the remaining fatigue life of FPSO based on spectral analysis", International Conference on Ocean, Offshore and Arctic Engineering.
2. Yingguang Wang ,(2010)" Spectral fatigue analysis of a ship structural detail – A practical case study, "International journal of Fatigue 32 (310-317)"
3. Lei Wu, et al (2017) "Interaction and combination method for estimation of still water and wave-induced bending moments on FPSO",World congress on Advances in Structural Engineering and Mechanics.
4. DamithaSandaruwanet.al (2010), "A Six Degrees of Freedom Ship Simulation System for Maritime Education", The International Journal on Advances in ICT for Emerging Regions 2010 03 (02) :34 – 47.
5. Emil Mathews et.al (2013), "Fatigue life estimation of ship structure ", International Journal of Scientific & Engineering Research, Volume 4, Issue 5, May.
6. Lars Bergdahl,(2009) "Wave-Induced Loads and Ship Motions"Department of civil and environmental engineeringdivision of water environment technology, Chalmers university of technology.
7. . Rajesh Kannahet.al, (2006) "Experimental study on the hydrodynamics of a Floating, Production, Storage, and Offloading", Journal of Waterway, Port, Coastal, and Ocean Engineering, Vol 132, No. 1.
8. Rajesh, M., and J. M. Gnanasekar. "Path Observation Based Physical Routing Protocol for Wireless Ad Hoc Networks." Wireless Personal Communications 97.1 (2017): 1267-1289.
9. Rajesh, M., and J. M. Gnanasekar. "Sector Routing Protocol (SRP) in Ad-hoc Networks." Control Network and Complex Systems 5.7 (2015): 1-4.
10. Rajesh, M. "A Review on Excellence Analysis of Relationship Spur Advance in Wireless Ad Hoc Networks." International Journal of Pure and Applied Mathematics 118.9 (2018): 407-412.
11. Rajesh, M., et al. "SENSITIVE DATA SECURITY IN CLOUD COMPUTING AID OF DIFFERENT ENCRYPTION TECHNIQUES." Journal of Advanced Research in Dynamical and Control Systems 18.
12. Rajesh, M. "A signature based information security system for vitality proficient information accumulation in wireless sensor systems." International Journal of Pure and Applied Mathematics 118.9 (2018): 367-387.