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Finite Element Analysis of Mooring Cable

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ABSTRACT
The Mooring refers to the means for providing the connection between the structure and the seafloor. It is used for securing the structure against the environmental forces. Moorings typically have three basic components anchor, chain or cable and floating devices. The mooring system relies on the strength of the anchors, digging depth and the soil properties. The mooring lines run from the structures to the anchors on the seafloor these are made up of synthetic fiber rope, wire and chain or a combination of these. The catenary mooring system is the most commonly used system and at the seabed, the mooring cable lies horizontally. The rope comes in at 30- 45 degree angle with the seabed. The different forces are acting on the mooring cable under tidal and climatic conditions such as current force, wave force and wind force.
In this analysis studied the behaviour of mooring cable attached to buoy and spar platform under environmental forces using FEA package ANSYS 10.0. The application of CFRP material as a mooring cable instead of existing steel and fibre rope mooring cables is studied.
Keywords – Buoy, Offshore, Spar, Vessels, Wave.

I. Introduction

A Mooring refers to any permanent offshore structure to which a vessel or platform may be secured. Moorings typically have three basic components an anchor, chain or line and flotation devices. The mooring cables run from the vessel to the anchors on the sea floor. The rope comes in at a 30-45 degree angle with the seabed. The mooring system relies on the strength of the anchors, digging depth and the soil properties. The forces acting on the mooring cables are gravity force, drag force and wave force. Environmental factors wind, waves and currents determine which materials make up the mooring system.

D.T. Brown and S. Mavrakos [4] presented a comparative study on the dynamic analysis of suspended wire and chain mooring lines. M.A Vaz and M.H. Patel [5] formulated the governing equations to analyze the three-dimensional behaviour of segmented elastic mooring line catenaries. Jason I and Mark A [7] presented an empirical model for the dynamic tension due to vertical motions at the top of a catenary mooring. YU Long and TAN Jia-hua [11] studied about mooring cable using two-dimensional finite element model for different water depths. Iordan C [13] studied about the static configuration of mooring cable using new mathematical model and numerical method based on finite differences.

This paper illustrates the behaviour of mooring cable under the environmental forces. The forces acting on mooring cable is self weight due to the weight of cable, drag forces due to current and wind, line tension due to wave load and shock/snatch. In this study spherical buoy and spar platform moored using mooring cable are considered. The cable anchored at the sea bed.

When the floating bodies experiences the different motions under environmental forces such as surge, heave and sway (i.e. translation in x, y and z axis), roll, yaw and pitch (i.e. rotations in x, y and z axis). The main objective of this study is to find the behaviour of the mooring cable under environmental force. The numerical investigation of behaviour of mooring cable is found out by using ANSYS 10.0.

II. Mooring Cable

A mooring line or cable is a thick rope or cable which is used to anchor a structure in place. A typical mooring system is shown in Fig: 1.

The completely submerged mooring line configuration is considered as a catenary curve. The co-ordinate for the catenary curve has been found out using the standard mathematical equations and calculations. The co-ordinates of catenary is given by the equation

$$y = a \cosh (x/a) \quad (1)$$

The length of mooring cable is given by the equation

$$S = a \sinh (x/a) \quad (2)$$

where y=vertical co-ordinate; S= length of mooring cable; x=horizontal co-ordinate in reference to the lowest point; a=height of the lowest point on the chain from the horizontal reference line.

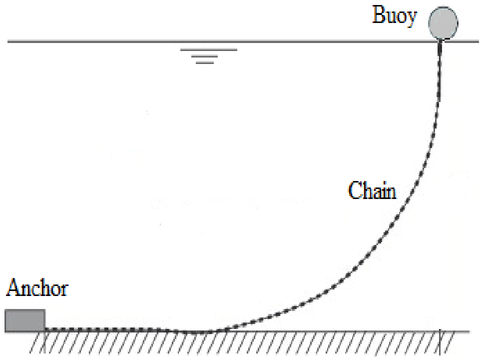

Fig.1 Typical mooring system [12]

For this study select the buoy and spar platform anchored by using mooring cable. Its response is calculated by using different mooring cable materials and combinations. The environmental conditions and cable properties are identified for this study.

III. Buoy

From the different buoys available a typical spherical buoy is considered for present the study. One end of the mooring cable is attached to the buoy and other end is attached to the seabed. For the study consider the buoy is anchored at Arabian sea. Table 1 shows the details of the environmental data in Arabian sea.

Table 1 Environmental data in Arabian sea

Data	
Water depth (h)	52.00 m
Current speed (v)	1.02 m/s

The mooring cable diameter is taken as 250 mm and buoy diameter is 1.84 m. Current force acting on the mooring cable is considered for this study and it is calculated by the equation

$$F_C = 1/2\ \rho\ C_d\ D\ v^2 \qquad (3)$$

where F_C=current force; ρ=density of sea water; C_d =drag coefficient; D=diameter of mooring cable; v=current speed.

Table 2 Co-ordinates of mooring cable for buoy

X Co-ordinates	Y Co-ordinates
00.00	00.00
05.00	01.28
10.00	05.43
15.00	13.52
16.50	16.99
20.00	27.61
22.50	37.95
25.00	52.00

IV. Spar Platform

For the present study a typical offshore structure Classic Spar is identified. One end of the mooring cable is attached to the Spar with the other end is attached to the seabed. For the study consider the spar located in Malaysian sea. Table 3 shows the details of the environmental data in Malaysian sea.

Table 3 Environmental data in Malaysian sea [15]

Data	
Water depth (h)	1018 m
Current speed (v)	0.50 m/s
Significant wave height(H)	6.00 m
Time period (T)	14.00 s

For this study 4 numbers of 200 mm diameter mooring cables is used for anchoring the spar platform. The wave and current forces are considered for this study. The wave force is calculated by using Froude-Krylov Theory. The wave force on cylindrical structure is given by the equations

$$(F_{Wa}) = C_H\ \rho V \frac{2J_1\,(k_a)}{k_a} \frac{\sinh(kl/2)}{(kl/2)}\ \mathring{u}_0 \qquad (4)$$

where F_{Wa}=horizontal wave force; ρ=density of sea water; C_H =horizontal force coefficient; V=submerged volume of the structure; k_a=diffraction parameter; k=wave number; l=submerged depth; $\mathring{u}_0$=horizontal acceleration.

Table 4 shows the details of dimensions of spar platform

Table 4 Dimensions of spar structure [15]

Dimensions	
Length	213.04 m
Diameter	40.54 m
Draft	198.12 m

Table 5 shows the details of the catenary mooring cable co-ordinates for spar structure.

Table 5 Co-ordinates of mooring cable for spar structure

X Co-ordinates	Y Co-ordinates
00.00	00.00
50.00	05.08
100.0	20.52
150.0	46.95
200.0	85.47
250.0	137.6

300.0	205.6
350.0	292.8
400.0	401.0
450.0	536.4
500.0	704.1
550.0	911.5

V. Vessel

Floating bodies such as oil tanker is considered in the present analysis. The floating body is treated as a plane element. For this analysis consider the homogeneous mooring cable is connected to the stern and bow side of the tanker. The vessel is modelled as Plane42 element. For the study consider the tanker is berthed at Cochin port. The loads on the vessels and mooring cable are studied and apply the loads on the structures. Table 6 shows the details of the environmental data in Cochin port.

Table 6 Environmental data in Malaysian sea

Data	
Water depth (h)	14 m
Current speed (v)	1.029m/s
Wind speed	3.00 m/s

VI. Load Calculation

6.1 Forces Acting on Mooring Cable for Buoy

Current Force on Mooring Cable:
Drag coefficient (C_d) = 1.8
Density of water (ρ) = 1025 kg/m³
Current force (F_C) = $1/2\ \rho\ C_d\ D\ v^2$ = 243.72 N/m

6.2 Forces Acting on Mooring Cable for Spar Platform

Current Force on Mooring Cable:
Drag coefficient = 1.8
Current force (F_C) = $1/2\ \rho\ C_d\ D\ v^2$ = 46.12 N/m
Current Force on Spar Platform:
Drag coefficient (C_d) = 1.8
Density of water (ρ) = 1025 kg/m³
Current force (F_C) = $1/2\ \rho\ C_d\ D\ v^2 = 9.35\times10^3$ N/m
Wave Force on Spar Platform:
Froude-Krylov Theory
Horizontal wave force

$$(F_{Wa}) = C_H\, \rho V \frac{2J_1(k_a)}{k_a} \frac{\sinh(kl/2)}{(kl/2)}\, \dot{u}_0$$

$$= 7187\times10^3 \text{ N}$$

6.3 Forces Acting on Vessel

Current Force:
Drag coefficient (C_d) = 0.8
Current force on barge (F_C) = $1/2\ \rho\ C_d\ A\ v^2$
= 13127.9 N

Wind force:
Drag coefficient (C_d) = 0.8
Wind force on deck of barge (F_{Wi}) = $1/2\ \rho_1\ C_d\ A\ v^2$
= 6386.6 N

Wind force on hull of barge (F_{Wi}) = $1/2\ \rho_1\ C_d\ A\ v^2$
= 3193.3 N

VII. Finite Element Analysis

In ANSYS 10.0 the following elements plastic23, plane42, shell63 are used for the analysis.

7.1 Mooring Cable Attached to Buoy

Some of the assumptions are made for the finite element analysis of buoy.

- Mooring cable does not stretch under tension. i.e. elongation will be neglected.
- Current direction has only horizontal component.
- Current is in contact along the mooring cable length.
- Mooring cables are flexible.

Boundary Conditions:
The one end of the mooring cable is attached to the seabed (i.e. all translations and rotations are arrested). And the other end is attached to buoy.
Mooring Cable Materials for Analysis

- Steel Chain
- Synthetic Fibre Rope
- Carbon Fibre Reinforced Plastic (CFRP)
- Steel Chain + Fibre Rope (50% of total mooring cable length)
- Steel Chain + CFRP (50% of total mooring cable length)

The buoy along with the catenary mooring is analyzed for the loads acting on the mooring line and the buoy. The Fig. 1 and Fig. 2 show the modeling and displacement diagram of steel chain mooring cable attached to buoy.

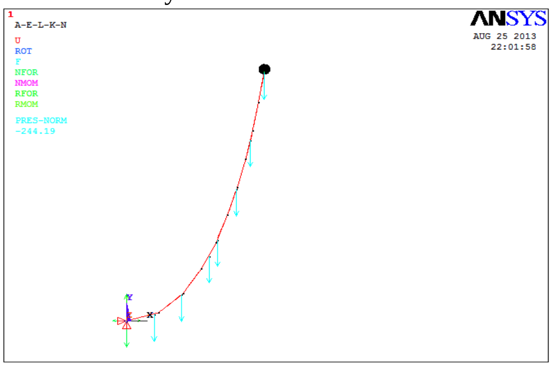

Fig. 2 Load and boundary conditions applied to the mooring cable with buoy

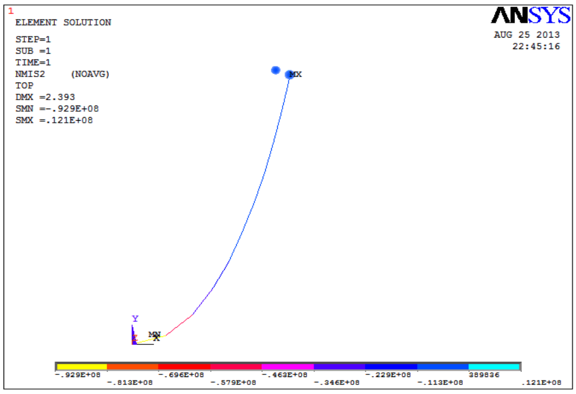

Fig. 3 Maximum horizontal displacement of the Buoy

7.1.1 Results and Discussion

Table 7 Maximum horizontal displacement and stress

Mooring cable materials	Max. buoy displacement (m)	Max. stress (N/m^2)
Steel chain	2.39	0.2×10^8
Synthetic fibre	4.49	0.2×10^8
CFRP	2.24	0.2×10^8
Steel chain + Synthetic fibre	3.44	0.2×10^8
Steel chain + CFRP	3.17	0.2×10^8

Linear static analysis mooring cable was carried out for three different mooring cables and its combinations with spherical buoy. The horizontal displacement of buoy under the force is reduced by using CFRP material. The analysis shows that the use of CFRP material can reduce the displacement of buoy.

7.2 Mooring Cable Attached to Spar Platform

For the present study a typical offshore structure Classic Spar is identified. The Spar is modelled as shell63 element and mooring cable is modelled as plastic23 element. The loads on the Spar and mooring cable are studied and apply the loads on the structure. For this study mooring cable of different material such as combinations of steel chain and synthetic fibre, steel chain and CFRP is considered.

Boundary Conditions:

One end of the mooring cable is attached to the Spar with the other end is attached to the seabed.

Mooring cable materials for analysis

- Steel chain + Synthetic Fibre
- Steel chain + CFRP

The Fig. 4 and Fig. 5 show the modeling and displacement diagram of combination of steel chain and synthetic fibre mooring cable attached to spar platform.

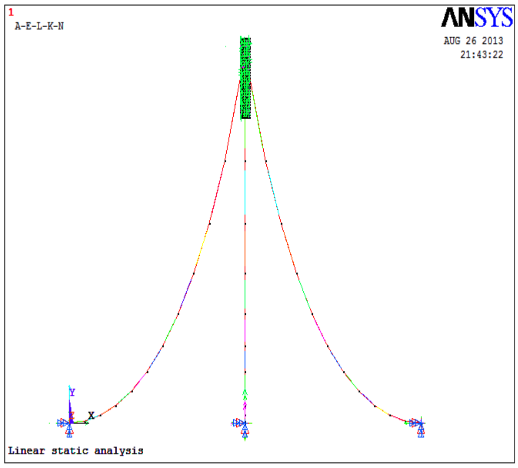

Fig. 4 Load and boundary conditions applied to spar platform

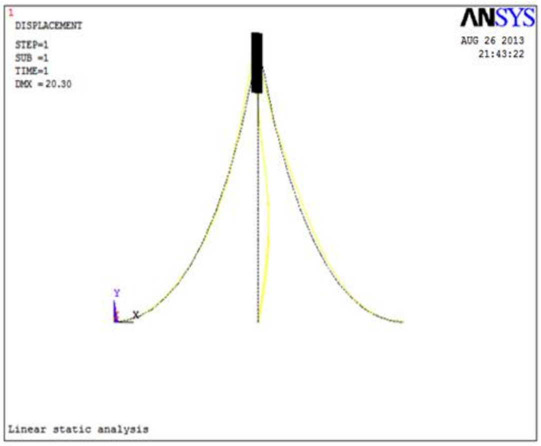

Fig. 5 Maximum horizontal displacement of the Buoy

7.2.1 Results and Discussion

Table 8 Maximum displacement of spar platform

Mooring cable materials	Max. displacement (m) Horizontal	Vertical
Steel chain + Synthetic fibre	20.30	3.40
Steel chain + CFRP	15.67	2.24

Linear static analysis mooring cable was carried out for different mooring cable combinations with spar platform. The displacements of spar under the forces are reduced by using CFRP material.

7.3 Calculation of Number of Mooring Cables for Spar Platform

For the present study a typical offshore structure Classic Spar is selected. One end of the spring element (i.e.combin14) is attached to the spar cylinder and other end is taken 1 m from the cylinder and treated as fixed. The forces calculated are applied to the structure and the response is found out. The analysis is repeated to find a suitable stiffness value such that the displacement element comes down to zero. So for the same stiffness the number of mooring cable attached can be found out by dividing the stiffness value of each mooring cable. The Fig. 6 and Fig. 7 show the modeling and displacement diagram of spar platform connected to spring element.

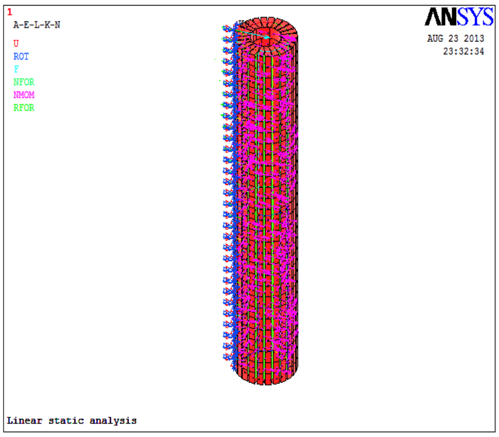

Fig. 6 Load and boundary conditions applied to spar platform Connected to spring element

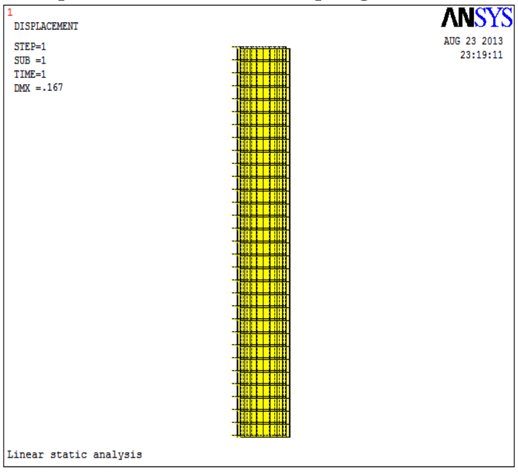

Fig. 7 Maximum displacement of the spar platform

7.3.1 Results and Discussion

Table 9 Max. displacement and stiffness of spar platform

Structure	Max. displacement (m)	Stiffness (N/m)
Spar platform	0.16	5.42×10^{10}

Total stiffness required = 5.42×10^{10} N/m

Fibre Rope Mooring Cable

Diameter of mooring cable = 230 mm
Stiffness mooring cable = EA/L = 4.65×10^{9} N/m
Number of mooring cable = $5.42\times10^{10}/4.65\times10^{9} = 12$
From the analysis 12 numbers of 230 mm diameter fibre rope mooring cables is required for spar structure mooring system.

CFRP Mooring Cable

Diameter of mooring cable = 230 mm
Stiffness mooring cable = EA/L = 9.97×10^{9} N/m
Number of mooring cable = $5.42\times10^{10}/4.65\times10^{9} = 6$
From the analysis 6 numbers of 230 mm diameter fibre rope mooring cables is required for spar structure mooring system.
From this analysis found that number of mooring cables could minimize by using the CFRP material.

7.4 Mooring Cable Attached to Vessel

Floating bodies such as oil tanker is considered in the present analysis. For this analysis consider the homogeneous mooring cables are connected to the tanker. The tanker is berthed at the port.
Boundary Conditions:
One end of the spring element (i.e.combin14) is attached to the vessels deck and other end is taken 1 m from the deck and treated as fixed. The forces calculated is applied to the structure and the response is found out.

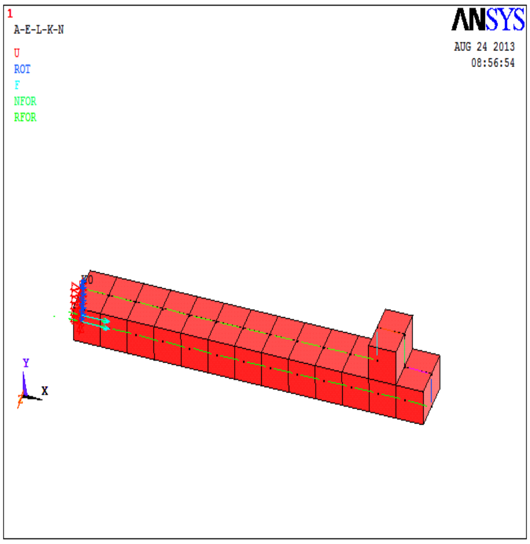

Fig. 8 Load and boundary conditions applied to tanker

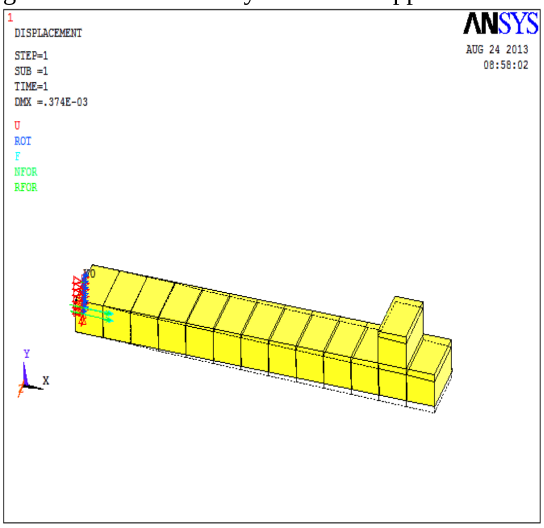

Fig. 9 Maximum displacement of the tanker

7.4.1 Results and Discussion

Table 10 Max. displacement and stiffness of tanker

Structure	Max. displacement (m)	Stiffness (N/m)
Tanker	0.0003	4.45×10^9

Total stiffness required = 4.45×10^9 N/m
Fibre Rope Mooring Cable:
Diameter of fibre rope mooring cable = 80 mm
Stiffness fibre rope mooring cable = EA/L
= 5.62×10^8 N/m
Number of mooring cable = $4.45\times10^9/5.62\times10^8$
= 8 Nos
From the analysis 8 numbers of 80 mm diameter fibre rope mooring cable is required for berthing of tanker.
CFRP Mooring Cable:
Diameter of CFRP mooring cable = 80 mm
Stiffness CFRP mooring cable = EA/L
= 1.20×10^9 N/m
Number of mooring cable = $4.45\times10^9/1.20\times10^9$
= 4 Nos
From the analysis 4 numbers of 80 mm diameter CFRP mooring cable is required for berthing of barge.

VIII. Conclusions

The study was focused on mooring cable, which is widely used in the marine and offshore industry. The two structures where mooring cable used are selected (i.e. buoys and offshore structures).
A typical analysis was carried out on a floating buoy using FEA software ANSYS. The loadings on the buoy were calculated and their effect on the structure was found out for different materials and different combinations of mooring cable. From the analysis found that CFRP mooring cable is more effective for reducing the displacement of buoy than other steel chain and synthetic fibre mooring cable.
A spar structure and oil tanker were taken for the study and response of spar structure was found out by using different mooring materials. In deep water, combination of steel chain and CFRP mooring cable is effectively reducing the response of the structure than the steel chain and synthetic fibre combinations. The required stiffness of altogether for the spar is found out using FEA. The structure mainly experience heave motion, to reduce these motions the required numbers of mooring cable and its dimensions were found subsequently.

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