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An Effectiveness of Mooring lines on Spar Platform

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Abstract:
Single Point Anchor Reservoir (SPAR) platforms is a kind of floating platforms that are used in deep waters. This is a platform that are placed atop a huge hollow cylindrical hull with other end of cylinder descending to a water depth of about 300m.These are mainly used for deep water applications for drilling, production, processing, storage and offloading of ocean deposits. The Spar is modelled as a rigid body connected to sea floor by catenary mooring lines both loose and tight mooring that are attached to the spar at fairleads. Here nonlinear time domain analysis is done for response analysis at different wave angle to solve the dynamic behaviour of a moored Spar platform as an integrated system by iterative incremental Newmark's Beta approach using NAOS software

Keywords: *Catenary mooring lines, Floating platform, Newmark's Beta approach , Nonlinear time domain analysis, Response analysis, Spar platform,*

1. Introduction

Due to ever rising demand for oil and gas in the world today, the global offshore oil and gas industry has been growing by leaps and bounds. The rising cost of oil and gas prices holds great promises for the industry in coming years. There are number of technologies, transportation mediums, and occupations associated with offshore industry. One such technology is the offshore platforms or oil platforms that are giant structures used for the purpose of drilling and extracting gas and oil from wells, located deep beneath the ocean floors. These platforms have onsite processing and storage facilities, as well as provide accommodation for the crew. Offshore platforms are strongly built and are designed to last decades in the harsh environment.

Depending on the requirements, they can either be floating or fixed to the ocean floor. There are different types of platforms that can be operated in a wide range of water depths from 200 to 12,000 ft. Among widely used oil platforms today are: fixed platforms, Compliant Towers, Semi-submersible Platform, Floating Production Systems, Tension Leg Platforms, Drill ships and Spar Platforms.

Here Spar platform is considered for the study that is placed on South China Sea platforms can operate in water depths up to 3,048 m (10,000 ft). In this study the Spar Platform is placed atop a huge hollow cylindrical hull with other end of cylinder descending to a water depth of about 300m. Despite the fact that the cylinder stops far above the ocean bed, the platform stays in place due to the cylinder's weight. These platforms are kept stationed in the ocean environment by using mooring system. These types of platforms operate in water depths up to 3,048m.

The concept of a Spar platform as an offshore structure is not a new idea. A floating instrument platform (FLIP) was built in 1961 to perform oceanographic research, the Brent Spar platform was built by Royal Dutch shell as a storage and offloading platform in the North sea at intermediate water depth. The use of Spar platforms is relatively recent as a production platform. Several studies have been conducted on the analysis of mooring lines and responses of spar platforms. A.K. Agarwal and A.K. Jain[1] had studied the dynamic behaviour of offshore

spar platforms under regular sea waves. From the study of literature it reveals that Spar platforms are one of the most effective compliant platforms used for deep water applications.Response of spar(classic) with different mooring configurations are scarcely studied. Here design of spar platform for water depth 300m is studied. The main objective of the study is that to study

offshore hydrodynamic analysis using NAOS(Non Linear Analysis of Offshore Structures) software and to do the preliminary design of spar supporting loads of an oil drilling platform. Here the study is conducted

on the response of the designed spar platform and its effect of mooring on platform. This project will focuses on

- → Developing a preliminary design for the spar platform with a hull and ballast at bottom for stability at water depth of 300m in South China Sea for normal offshore platform drilling loading condition .

→ Modelling the design spar platform along with catenary mooring lines using NAOS software and study the responses

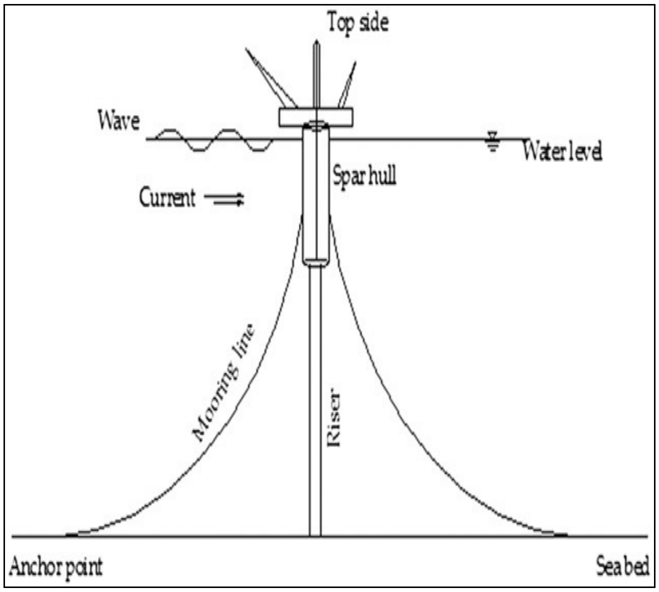


Figure 1: Schematic elevation of Spar (Source: A.B.M. Saiful Islam et al(2012))

2. Methodology

Figure 2 shown below describes the methodology. Environmental factors like site, depth, wave height, wave time period are fixed as preliminary input. Preliminary design is performed from these values by doing many iterations to satisfy the criteria. If the criteria is satisfied , go to dynamic analysis which consist of two parts. One is Eigen value analysis and the other is Non-linear time domain analysis. From these analysis we form results and then leads to conclusion.

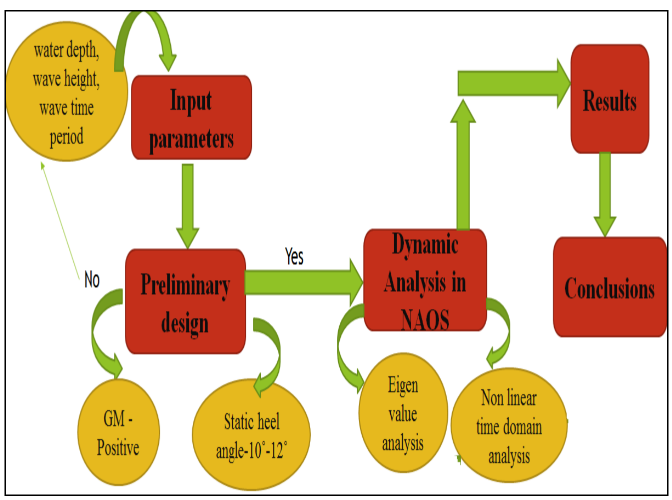


Figure 2: Methodology

3. Input Data

The site is located at 6˚0'54.23''N109˚39'13.55''E, South China Sea. The water depth for the region is300m

4. Preliminary Calculation

4.1. Initial Proportioning

The proposed spar for a water depth of 300m has been designed as per static stability requirements and in accordance with API RP 2FPS and 2SK code. The method for initial sizing is discussed below:

1. Trial values for diameter and draft are selected
2. Thickness (t_s) is calculated based on hydrostatic stresses as follows (*Mohamed El-Reddy*):

$$fh = \frac{pD}{2t} \leq \frac{Fhc}{SFh} \text{ for D/ts<300}$$

Where f_h = Hoop stress due to hydrostatic pressure
p = Hydrostatic pressure = p∫g

SF_h = Safety factor against hydrostatic collapse =2 (API RP 2A)
F_{hc} = Critical hoop buckling stress =(2*Ch*E* t)/D
3. Calculation of total weight of spar platform
4. Calculation of buoyancy force
5. Calculation of centre mass of platform
6. Calculation of centre of buoyancy of platform
7. Check the stability of platform from step 5 and step 6. The platform will be stable when centre of buoyancy is greater than centre of mass
8. Calculation of Metacentric height of platform. If spar is stable then metacentric height is positive.
Metacentric height GM = KB – KG + I/▼
Where ▼= Hull displacement in volumetric units
KB= Distance from keel to centre of buoyancy
KG= Distance from keel to centre of gravity
I = Moment of inertia of the water plane
9. Calculate angle of heel which is determined by the resultant moment caused by coupling between the steady environmental forces (wind and wave) and the resisting force of the mooring lines. The static heel angle (*Subrata chakrabarti*)is computed as

$$\Theta_{env} = \frac{Menv}{Mr}$$

Where Menv = Moment due to environmental force = Fenv (KFenv - KFmoor)
Where Fenv = Total wind force and wave force
KFenv= Distance from keel to centre of action environment forces
KFmoor= Distance from keel to fairlead elevation
Mr = GM*Δ
Where Δ = hull displacement in force units
The static heel angle computed θenv should be within 10˚-12˚ for the preliminary design. Many iterations are done until the required conditions are satisfied.

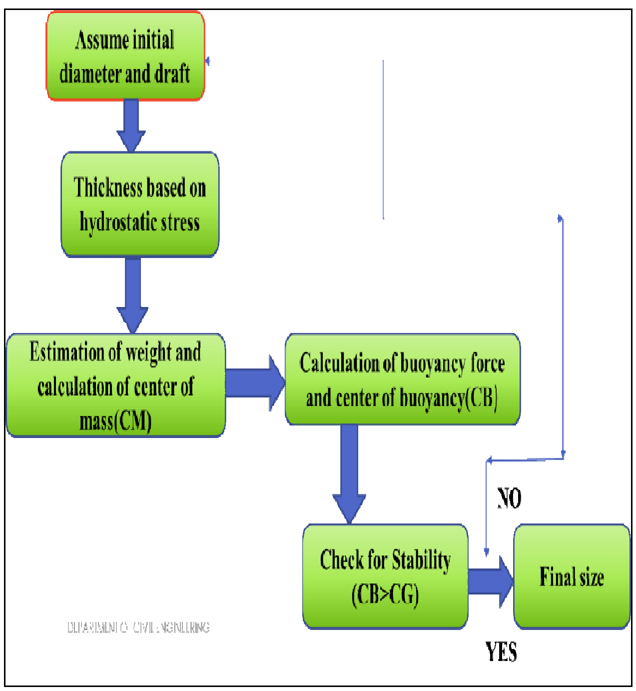


Figure 3: Flowchart of initial sizing of spar

4.2. Mooring Lines
The stiff moorings and loose moorings are attached to the Spar platform that are inclined at 30^0 and 60^0 with the Spar. Mooring lines are modelled as beam elements with small crossections and low modulus of elasticity. The angle between the mooring lines are 120^0 each as shown in figure

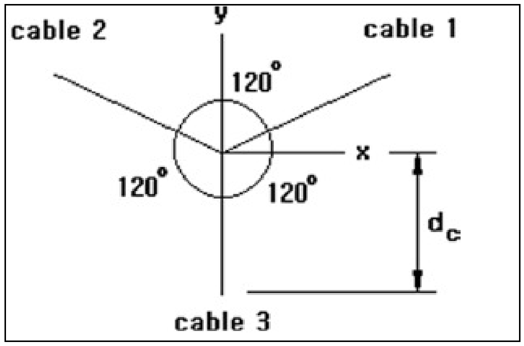


Figure 4: Alignment of three equal catenary lines
(Source: S.H.Jeon et al(2013)

4.3. Model Obtained from Preliminary Calculation

Description	
Diameter	10m
Draft	115m
Free board	10m
Water depth	300m
Total weight	6857106Kg
Total buoyancy force	90377000N
CM	46.85m
CB	57.5m
GM	11m
Platform load	360000kg

Table 1

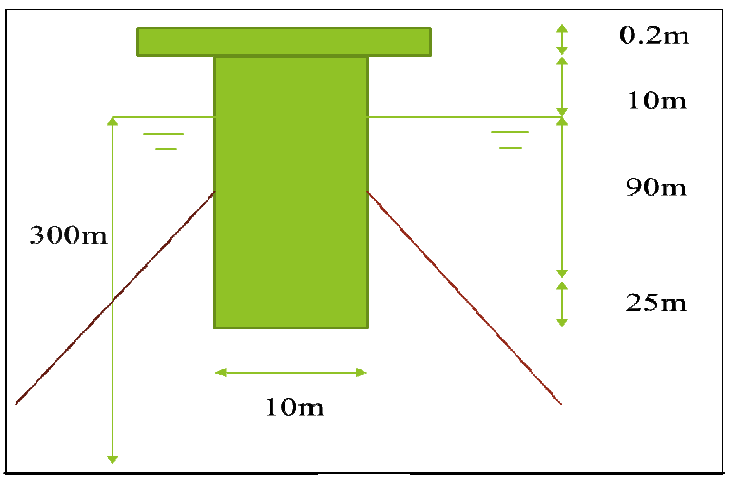


Figure 5

5. Numerical Modeling

Here Spar is modeled as a rigid cylinder with six degrees of freedom connected to the sea floor by stiff or loose catenary mooring lines that are attached to the Spar at fairlead position in NAOS software. The six degrees of freedom are three displacement degrees of freedom- surge,sway and heave along the X,Y, and Z axes and three rotational degrees of freedom that is roll, pitch and yaw along the X,Y, and Z axes at its centre of gravity. The spar is assumed to be closed at its keel. Depending on number of mooring lines attached near the centre of gravity of the Spar the stability and stiffness is provided for low dynamic positioning of the Spar platforms. The movement of the platform will take place in a plane of symmetry of the mooring system, when it deflects and the resultant horizontal force formed will also occur in this plane. The resultant behaviour of the platform will be two dimensional. For the overall analysis of the platforms, it is the force and displacement (excursion) at this attachment point is of fundamental importance. The development of Spar platform model for dynamic analysis forms the formulation of a nonlinear stiffness matrix considering mooring line tension fluctuations due to variable buoyancy and other nonlinearities.

5.1. Stiff Mooring

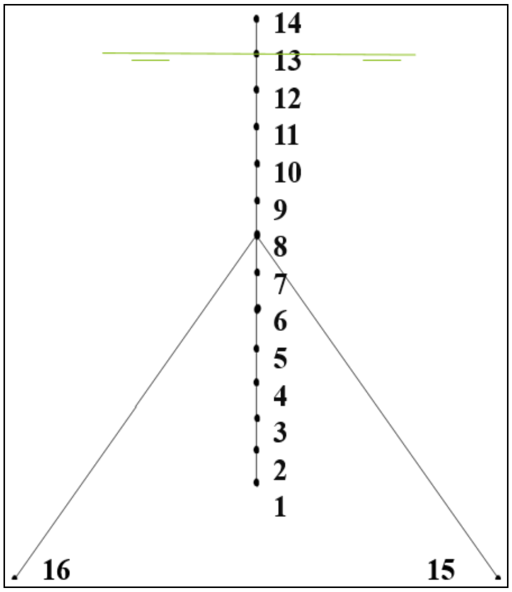


Figure 6

The stiff mooring attached with Spar consists of a total seventeen nodes. Only node fourteen is above water. There are sixteen beam elements. 8-15,8-16,8-17 are beam elements acting as mooring lines & 15,16,17 nodes fixed at bottom of sea. The platform load are given as nodal mass in node 14. 3D coupled spring at node 13 were provided for water piercing elements

5.2. Loose Mooring

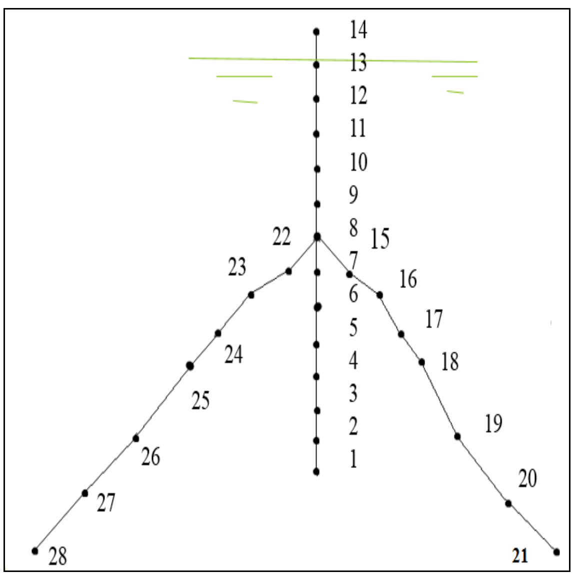


Figure 7

Here loose moorings have a total thirty five nodes. Only node fourteen is above water. There are thirty four beam elements. 8-21,8-28,8-35 include different
beam elements as mooring lines & 21,28,35 nodes are fixed at bottom of sea. The platform load act as nodal mass in node fourteen. 3D coupled spring at node 13 were provided for water piercing elements

6. Results and Discussions

6.1. Eigen Value Analysis
The results of eigen value obtained from NAOS software for stiff mooring is given below

	FREQUENCY(Hz)	TIME PERIOD(S)
mode1	0.605	1.651
mode2	0.149	0.670
mode3	0.605	1.651
mode4	0.149	0.670
mode5	0.506	0.197
mode6	0.538	0.185

Table 2

The results of Eigen value obtained from NAOS software for loose mooring is given below

	FREQUENCY(Hz)	TIME PERIOD(S)
mode1	0.284	0.351
mode2	0.284	0.351
mode3	0.285	0.351
mode4	0.669	0.149
mode5	0.668	0.149
mode6	0.670	0.149

Table 3

There are two modes. They are rigid mode that is mode values is less than four. The second mode is soft mode in which mode value is greater than 25s (*S.K Chakrabarti*). Here the obtained value is within the rigid mode. So safe.

6.2. Non Linear Time Domain Analysis

6.2.1. Response of Spar of Stiff Moorings That Are Inclined At 30^0 With Spar For Different Wave Angle

6.2.1.1. At Wave Angle 0^0

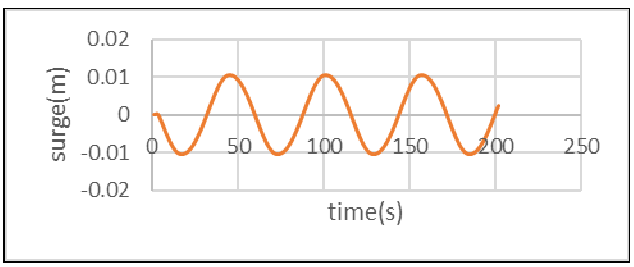


Figure 8: Surge response is at 1cm for wave angle of zero degree.

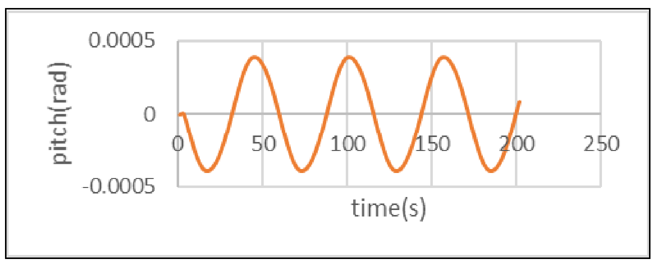


Figure 9: Pitch response of zero wave angle is 0.04cm

6.2.1.2 At Wave Angle at 30^0

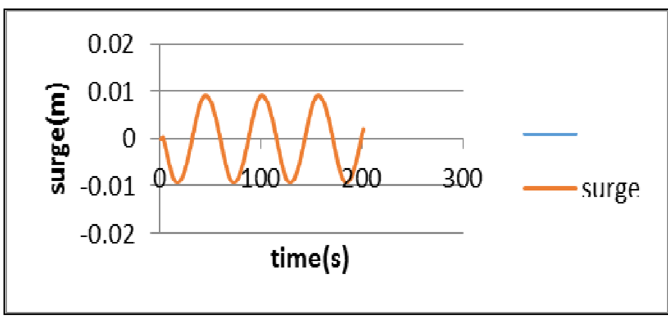


Figure 10: Surge response for thirty degree wave angle is 0.9cm

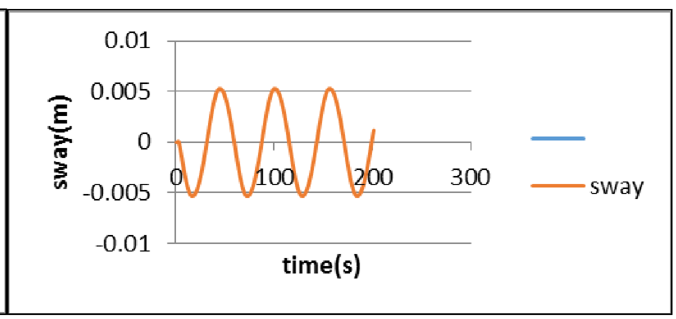


Figure 11: Here sway response is .5cm for thirty degree wave angle

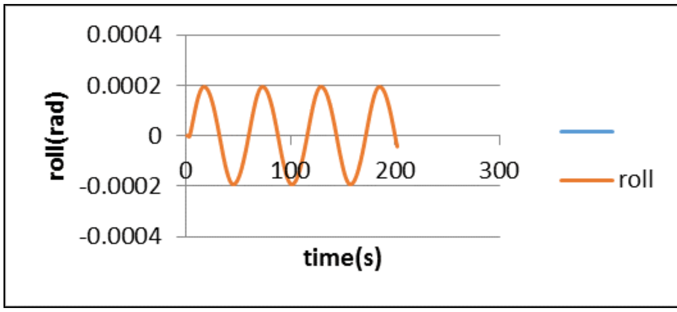


Figure 12: Roll response is 0.02cm

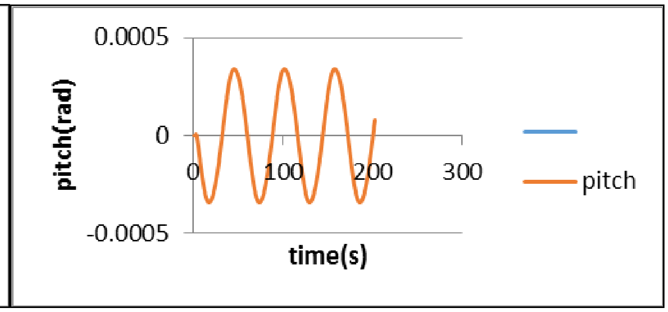


Figure 13: Pitch response is 0.032cm

6.2.1.3 At wave angle 60^0

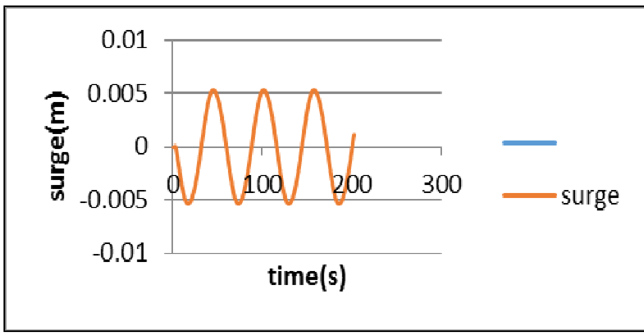


Figure 14: Surge response for sixty degree wave angle is 0.52cm

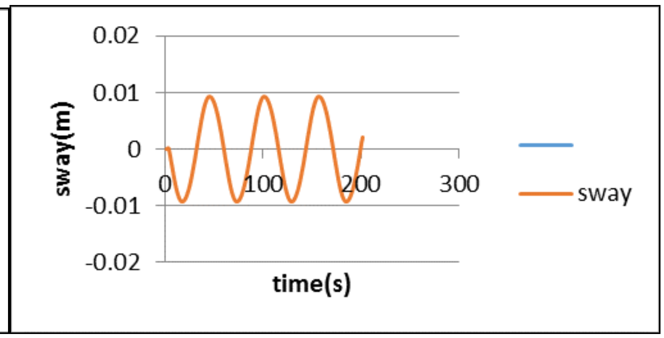


Figure 15: Response of sway is0.9cm

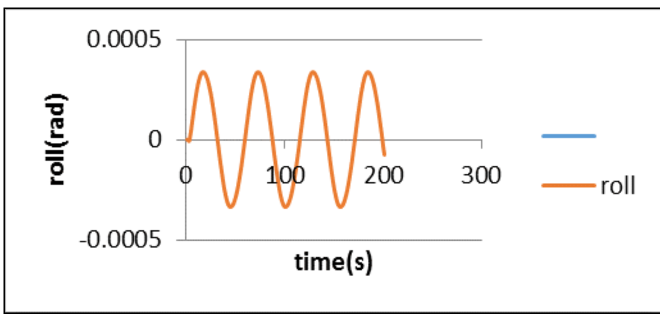


Figure 16: Roll response is 0.035cm

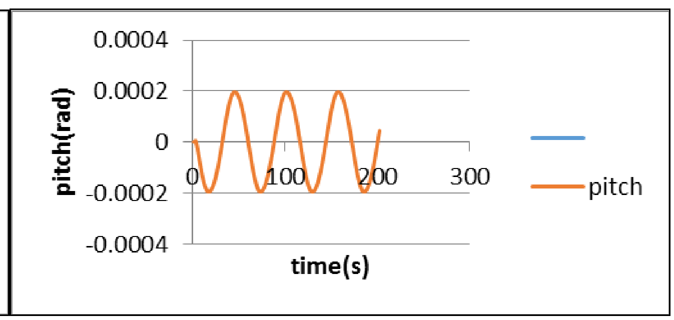


Figure 17: Pitch response is .02cm

6.2.1.4. At wave angle 90^0

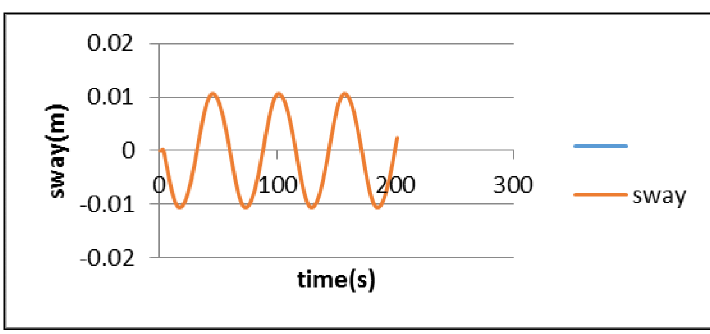


Figure 18: Sway response obtained is 1.1cm

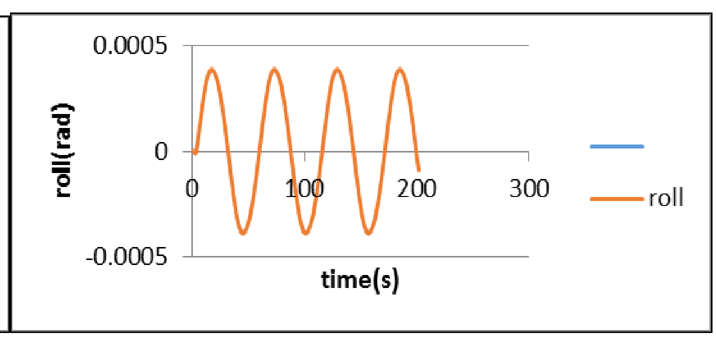


Figure 19: Roll response for ninety degree wave angle is .04cm

6.2.1.5 Discussions

Here surge response and sway response varies from 0.5cm to 1.1cm. At 90^0 there is no surge response, roll response and pitch response and at 0^0 there is no sway response and roll response. The roll response for other wave angle considered varies from 0.02cm to .05cm. Also there is no yaw and heave response for tight mooring inclined at 30^0 at spar.

6.2.2. Response of Spar of Tight Moorings That Are Inclined at 60^0 with Spar for Different Wave Angle

6.2.2.1 At wave angle 0^0

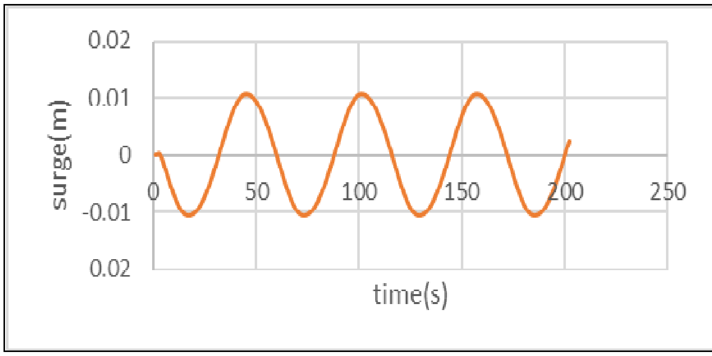


Figure 20: Response of surge is 1.1cm

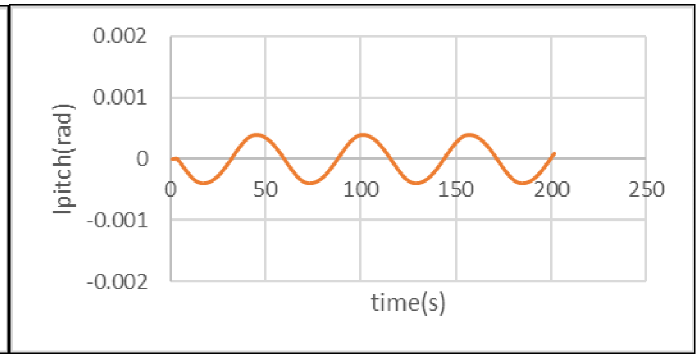


Figure 21: Pitch response is .04cm for zero degree wave angle

6.2.2.2At wave angle 30^0

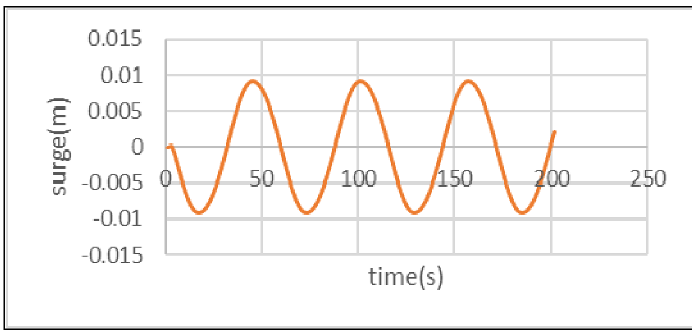


Figure 22: Surge response is 0.9cm for wave angle thirty degree

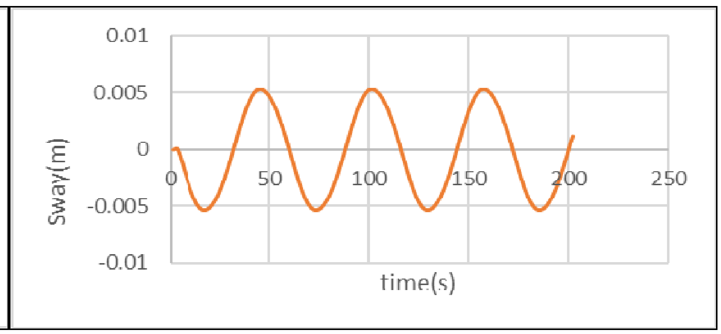


Figure 23: Here sway response obtained is 0.51cm

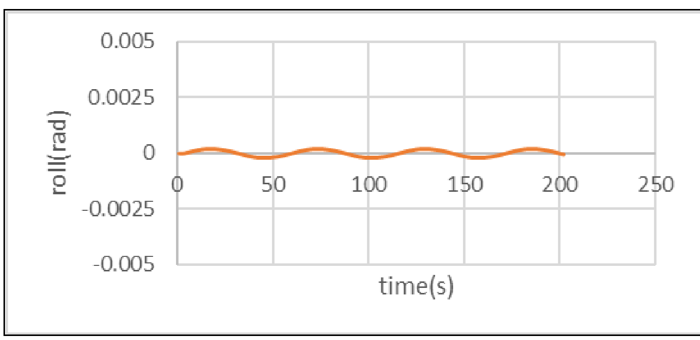


Figure 24: Roll response obtained is 0.05cm

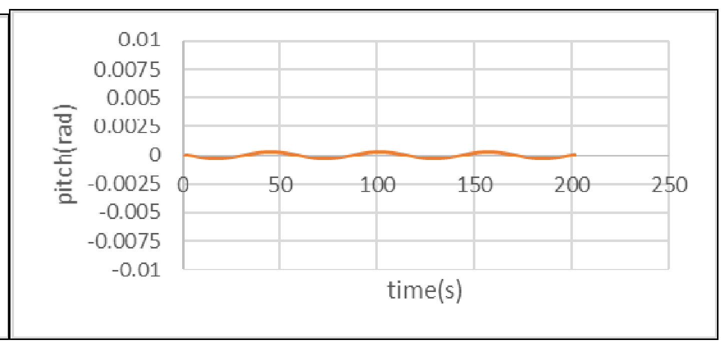


Figure 25: Pitch response obtained is -.05cm

6.2.2.3 At wave angle 60^0

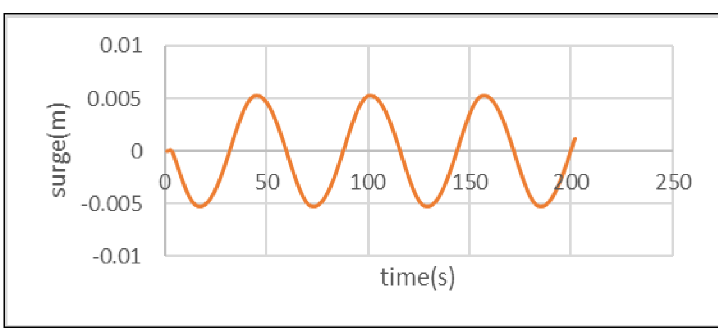


Figure 26: Surge response is 0.5cm for wave angle is sixty angle

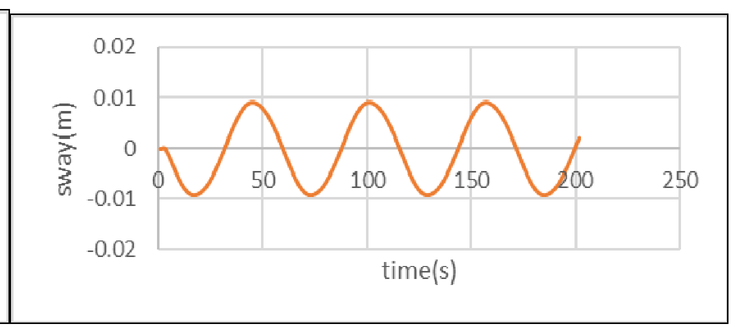
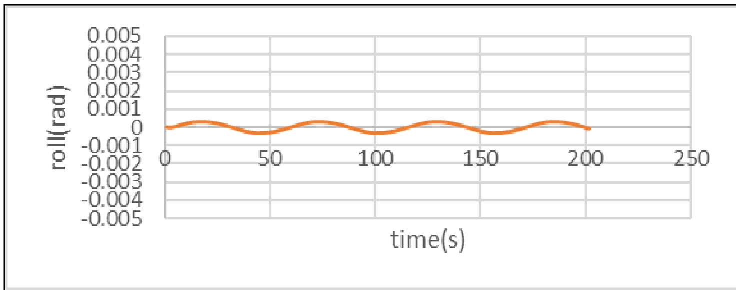


Figure 27: Sway response obtained is 0.9cm



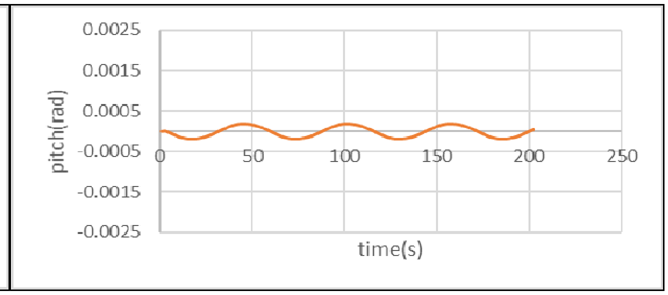
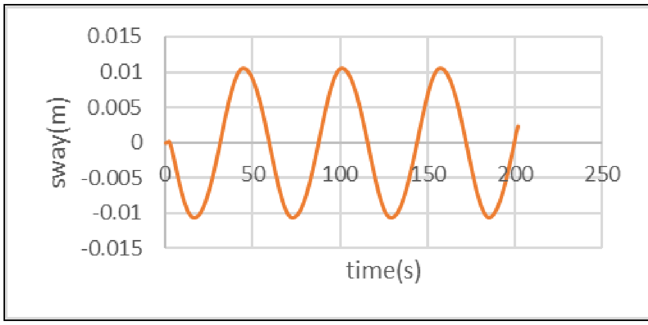


Figure 28: Roll response obtained is 0.05cm

Figure 29: Pitch response is 0.025cm for wave angle sixty degree

6.2.2.4.At wave angle 90^0



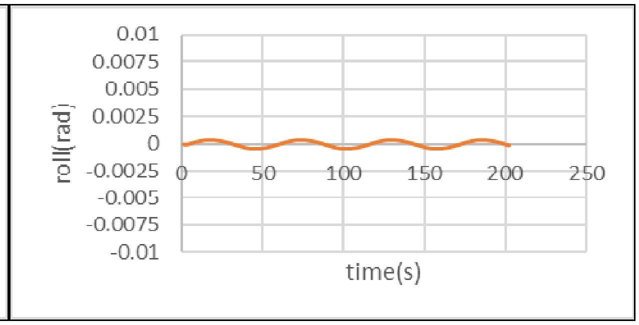


Figure 30: Sway response obtained here is 1.1cm

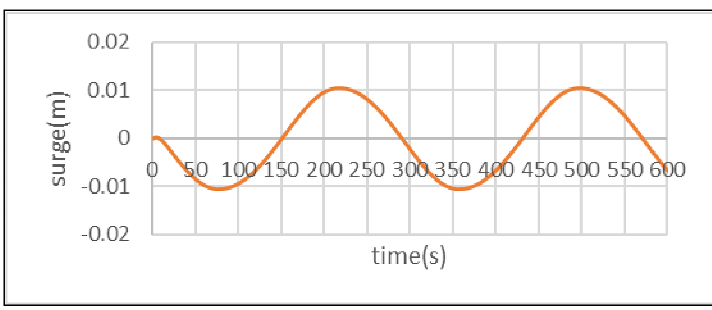
Figure 31: Roll response for wave angle is 0.06cm

4.2.2.5. Discussions

The surge and sway response of tight mooring inclined at 60 ^{0} with the spar varies from 0.5cm to 1.1cm.There is no heave and yaw response. The roll response varies from 0.03 to 0.05 cm and pitch response varies from -0.02 to -0.05cm. At 0^0 there is no response for sway and roll and at 90^0 there is no response for surge and pitch. When compared with first case there is slight increase in the response. So as the wideness between mooring line and spar increases there is increase in response.

<u>6.2.3. Response of Spar of Loose Moorings That Are Inclined at 30^0 with Spar for Different Wave Angle</u>

6.2.3.1 At wave angle 0^0



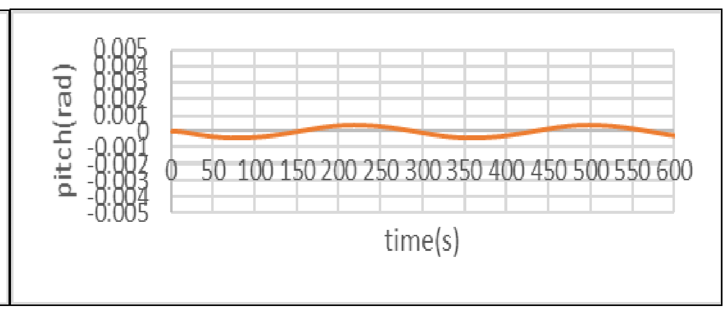
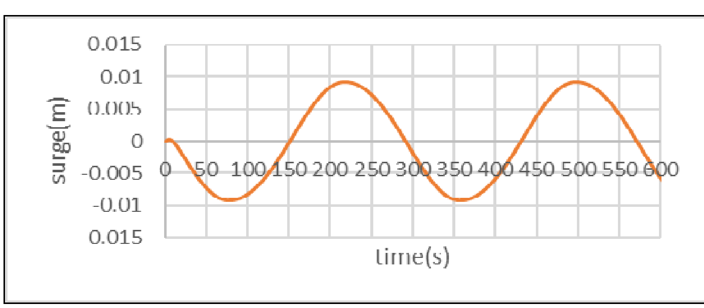


Figure 32: Response for surge obtained is 1.3cm

Figure 33: Pitch response for zero degree wave angle is .055cm

6.2.3.2 At wave angle 30^0



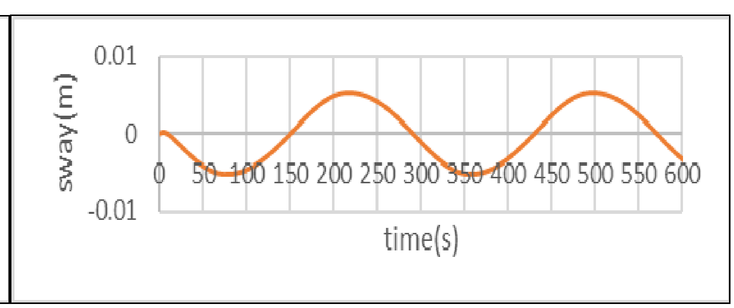


Figure 34: Surge response for thirty degree wave angle is 0.95cm

Figure 35: Here response for sway obtained is 0.52cm

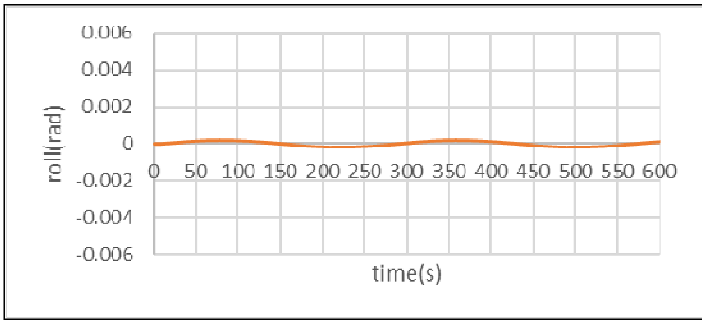


Figure 36: Roll response obtained is 0.022cm

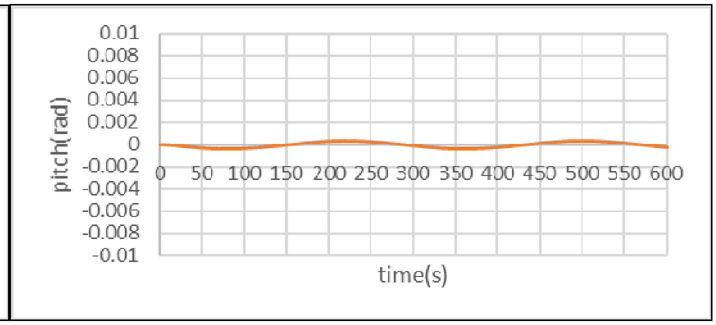


Figure 37: Here pitch response is -0.02cm

6.2.3.3 At wave angle 60^0

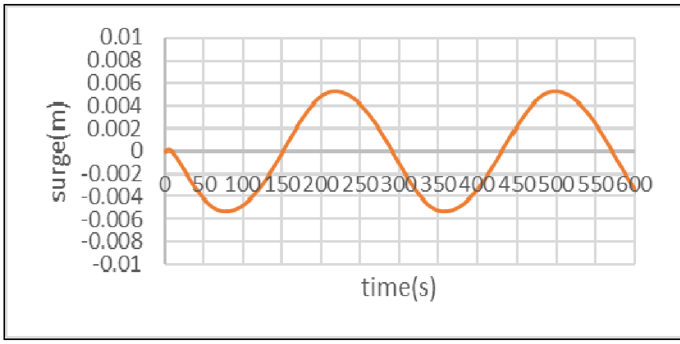


Figure 38: Surge response obtained is 0.55cm

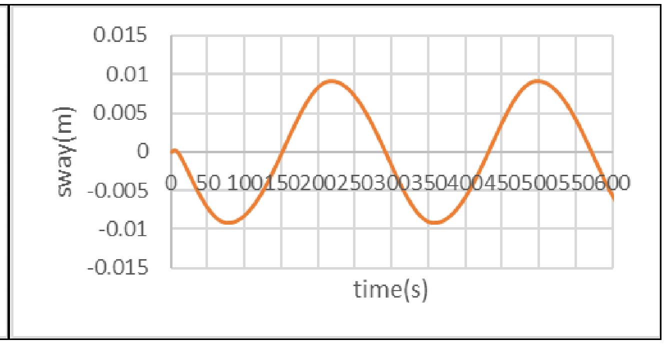


Figure 39: Here sway response for the wave angle is .093cm

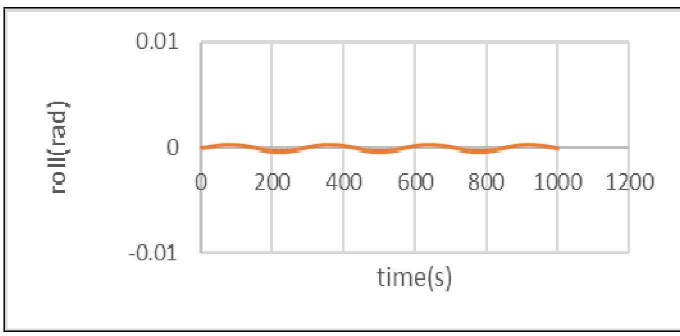


Figure 40: Roll response for wave angle sixty degree is 0.02cm

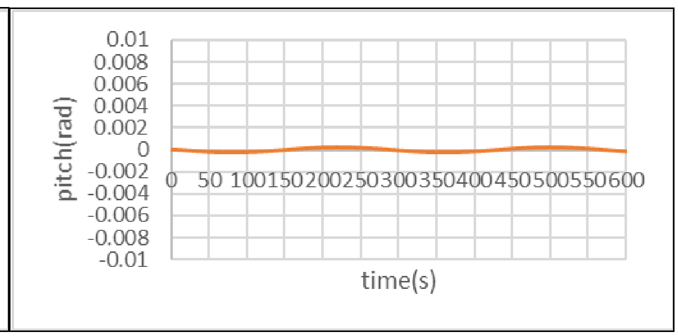


Figure 41: Pitch response obtained is -.02cm

6.2.3.4. At wave angle 90^0

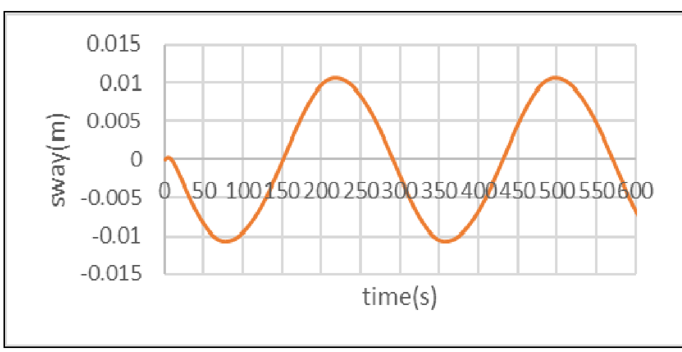


Figure 42: Sway response is 1.3cm

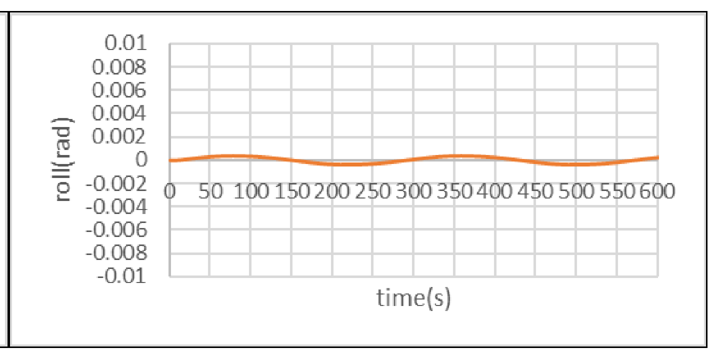


Figure 43: Roll response obtained is 0.04cm

6.2.3.5 Discussions

For loose mooring inclined at 30^0 with the spar, the surge response varies from 0.55cm to 1.3cm and sway response varies from 0.95cm to 1.1cm. Here also no heave and yaw response. At 0^0 there is no response for sway and roll and for 90^0 surge and pitch response is nil. The pitch response varies from -0.02cm to -0.06cm. As compared to stiff mooring, the response of loose mooring is slightly greater.

7. Conclusion

In this, study was conducted on different configurations of mooring line both stiff as well as loose mooring for different wave angles of regular wave. The following are the conclusions are drawn:

- whatever be the wave angle and mooring configurations no heave and yaw response are prominent because the spar is positioned to a deeper depth and has no projections in it.
- As the distance between spar and mooring lines become wider, the response will increase
  The loose moorings have slightly greater 10%-40% response than tight moorings even if it is inclined at 30˚and 60˚ with the spar. This is because in case of loose moorings they are free to move depending on wave approach angle but in stiff moorings the spar are not so free to move.
- The spar platform modelled is unconditionally stable because centre of buoyancy is greater than centre of gravity and also the metacenric height obtained is positive. So it was found that there is no significant effect of wave approach angle on the response of spar even if it is stiff moorings or loose moorings for different wave angle. In this cases, the mooring lines fixed to platform are preferred only to maintain the position of spar on ocean bed .

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