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Lazy Wave Flexible Riser Dynamic Tension Analysis with Variation of Diameter and Buoyancy Module Configuration in Extreme Condition

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ABSTRACT
Oil and Gas Production at floating offshore facilities is growing. It prompted the design of the Flexible Riser as a solution to channel exploration results to floating offshore facilities. In this final project, dynamic stress analysis of lazy wave flexible riser is carried out with variations in diameter and number of buoyancy modules under extreme conditions. This study discusses the maximum tension and minimum bending radius (MBR) on the flexible riser due to variations in diameter and number of buoyancy modules in extreme conditions with two system conditions, namely intact conditions and damage conditions. From the results of the analysis, the larger the diameter of the flexible riser, the greater the maximum tension at the SPM point. While it will be smaller at the PLEM point and the more buoyancy modules used, the smaller the maximum tension at the SPM point, the larger it will be at the PLEM point. The larger the diameter of the flexible riser, the smaller the MBR in the SagBend area. The larger the HogBend area and the more buoyancy modules used, the larger the MBR in the SagBend area, while the smaller the HogBend area.

Keywords: *Flexible Riser, Lazy Wave, Maximum Tension, Minimum Bending radius*

1. INTRODUCTION
Increased oil and gas production activities at floating offshore facilities encourage the design and design of risers. The riser system links the floaters on the water surface and the wellhead or PLEM (Pipe Line End Manifold) on the seabed. The riser is used to distribute exploration results in the form of oil and gas to a floating offshore production facility called offloading. The Flexible Riser is an alternative solution because it is generally less sensitive to the movement of floaters. This floating offshore facility is moored with Single Point Mooring (SPM) while carrying out offloading activities. The flexible riser is one component of SPM. Calculating environmental loads will know the dynamic response of the structure comprehensively. The purpose of the dynamic response calculation is to obtain the extreme response of the system.

One way to carry out the analysis is to analyze the structural response to an environmental data design, such as a 100-year significant wave, 100-year wind speed, and 100-year current. When extreme conditions occur, no floating offshore facilities should be moored in the SPM. The flexible riser is one of the real solutions to face the challenges of deepening operations, so it must be designed in such a way as to be able to withstand extreme environmental conditions.

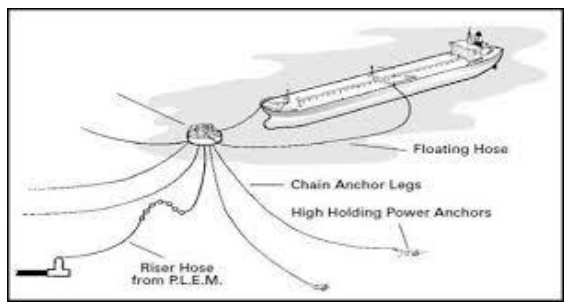

Figure 1. SPM and Flexible Riser Configurationo

In this research, the flexible riser configuration is a lazy wave by adding a buoyancy module to the flexible riser. From this research, it will be obtained the maximum tension and minimum bending radius that occurs in the flexible riser, so that from this research it is found how the dynamic stress that occurs in the flexible riser due to the influence of diameter variations and the configuration of the buoyancy module used during extreme conditions.

2. RESEARCH DESCRIPTION
The steps used in this research are:

2.1 Literature Study
The literature study collected books, codes, previous final assignments, and journals related to lazy wave flexible riser information.

2.2 Data Collection
Data collection required is single point mooring (SPM) data, flexible riser data, and extreme environmental data (100 years) used in West Natuna waters with a depth of 92.5 m.

Table 1. SPM Principle Dimension

Parameter	Unit	Data
Outside Diameter of Body Buoy	m	13.5
Diameter of Skirt	m	16.0
Inner Diameter	m	4.9
Body Buoy Height	m	7.1
Draft	m	4.78

Table 2. Mooring Line Data

Mooring Line Specification			
		Value	
Parameter	**Unit**	**Segment A (at Chain Stopper)**	**Segment B (at Pile)**
Type	-	Chain	Chain
Chain Grade	-	R4	ORQ
Chain Diameter	mm	76	114.3
MBL	te	612	975
Mass per Unit Length	kg/m	118	297.35
Mooring Line Length	m	165	289

Table 3. Flexible Riser Data

Flexible Riser Properties				
Items	**Unit**	**Value**		
		8 Inch	**10 Inch**	**12 Inch**
Inner Diameter	m	0.203	0.254	0.305
Outer Diameter	m	0.300	0.356	0.396
Bending Stiffness	kN.m^2	75.73	120.00	177.30
Mass per Unit Length	te/m	0.131	0.182	0.233
Minimum Bending Radius	m	2,938	3.272	3.66
Max. Allowable Tension	kN	1741.3	2291.1	2454.4

Table 4. Buoyancy Module Data

Buoyancy Module Specification		
Parameter	**Units**	**Value**
Element Diameter	mm	1290
Element Length	mm	1160
Shell Thickness	mm	12
Module Weight in air	kg	517.57
Initial Buoyancy Module	kg	630

Table 5. Wave Data

100-Year Wave Data									
		Heading (deg)							
Items		0˚	45˚	90˚	135˚	180˚	225˚	270˚	315˚
Hs	m	5.1	6.7	5.0	3.2	4.1	4.6	3.8	4.7
tp	m	9.9	11.3	9.8	7.9	8.8	9.3	8.5	9.5
Tz	m	7.7	8.8	7.6	6.1	6.9	7.3	6.6	7.4

Table 6. Current Data

100-Year Current Data								
	Current Speed (m/s) vs. Heading (deg)							
Depth (m)	0˚	45˚	90˚	135˚	180˚	225˚	270˚	315˚
0	0.6	0.6	0.6	1.0	1.1	0.9	0.4	0.5
23.1	0.4	0.4	0.4	0.8	0.9	0.8	0.3	0.3
46.3	0.2	0.2	0.3	0.7	0.8	0.6	0.2	0.2
69.4	0.2	0.1	0.2	0.6	0.7	0.5	0.1	0.1
91.5	0.1	0.1	0.1	0.4	0.4	0.3	0.1	0.1

3. RESEARCH METHODOLOGY

3.1 Modeling Using Software

SPM is modeled using software based on the data that has been obtained. The modeled SPM is only the body buoy. This SPM model will be run to obtain hydrostatic output properties, wave drift force, RAO, added mass, and damping, taking into account the load experienced by the SPM itself in the directions 0˚, 45˚, 90˚, 135˚, 180˚, 225˚, 270˚, and 315˚.

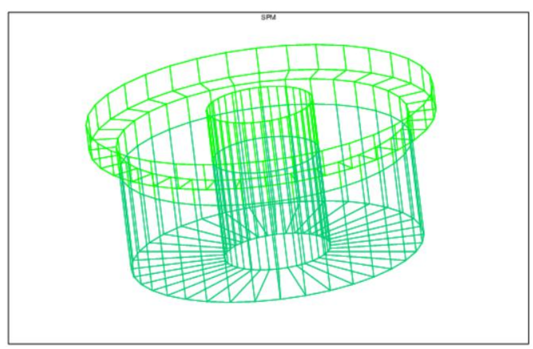

Figure 2. SPM modeling with Dynamic Software

3.2 Modeling Using Dynamic Software

The modeling performed on software is SPM, mooring line, lazy wave flexible riser, and PLEM. SPM modeling on dynamic software is done by entering the hydrodynamic behavior of the output, and the parameters consist of the following:

- RAO movement SPM (displacement RAO) obtained from the results of the analysis

- 1st order wave force as a panel wave frequency load obtained from the analysis
- *Quadratic Transfer Function* (QTF) non-dimensional as the transfer function of wave force of order-2
- Matrix 6 x 6 added mass and damping

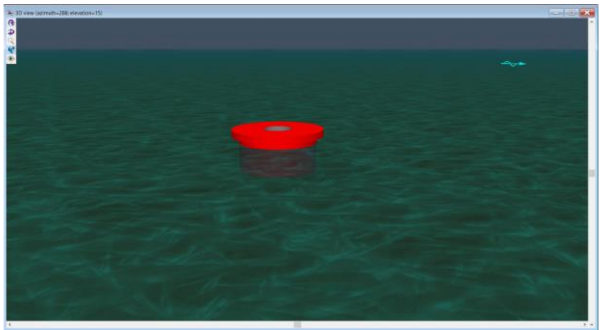

Figure 3. SPM modeling with Dynamic Software

Then proceed with modeling the flexible riser and PLEM on dynamic softaware. The Flexible Riser installed on the SPM is a Lazy Wave Flexible Riser configuration type with a riser length of 200.43 meters. The Buoyancy Module will be placed along the flexible riser in the buoyant section, where the buoyant section is 46 meters long.

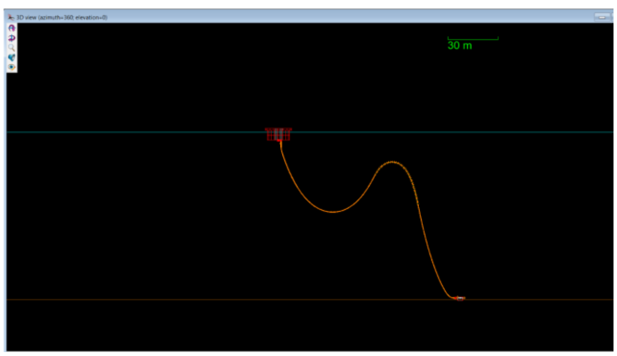

Figure 4. Flexible Riser Modeling with Dynamic

After the SPM and flexible riser are modeled on Dynamic Software, the next step is to model the mooring line according to a predetermined configuration with an angle interval of 60˚.

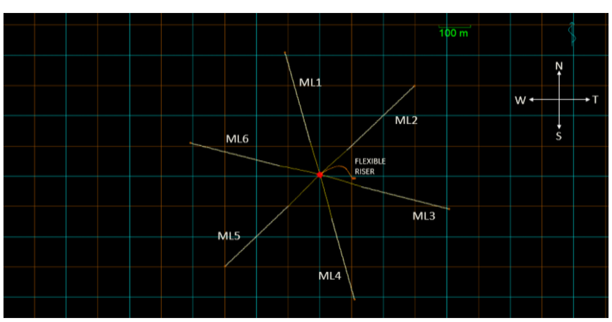

Figure 5. Mooring Line modeling with Software

The following is a flexible riser model with one diameter variation for each variation in the number of buoyancy modules that will be analyzed.

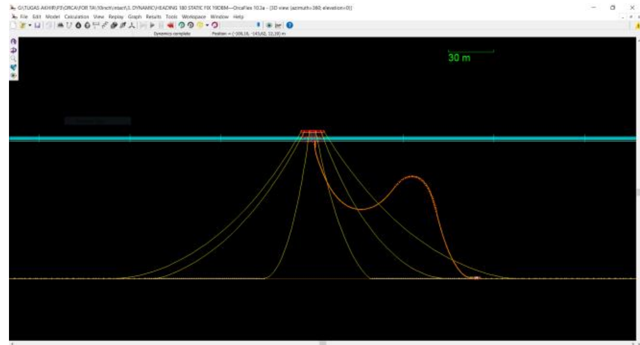

Figure 6. 10 Inch Lazy Wave Flexibler Riser 19 DBM

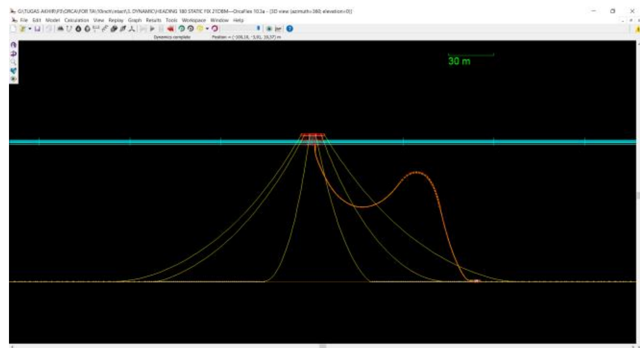

Figure 7. 10 Inch Lazy Wave Flexibler Riser 21 DBM

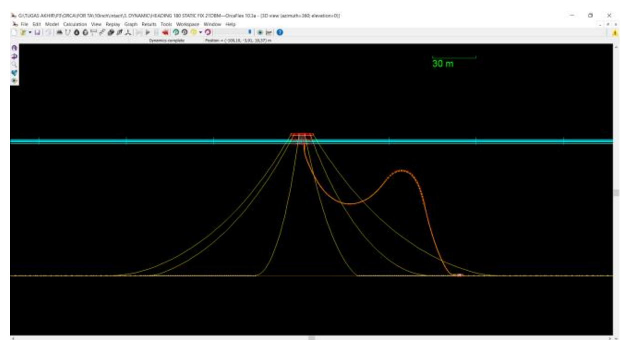

Figure 8. 10 Inch Lazy Wave Flexibler Riser 23 DBM

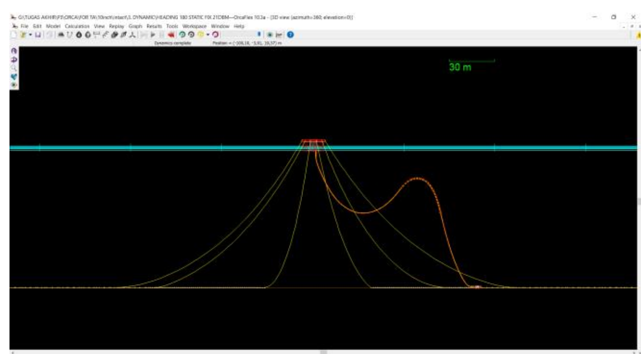

Figure 9. 10 Inch Lazy Wave Flexibler Riser 25 DBM

4. ANALYSIS AND DISCUSSION

4.1 Analysis of SPM Movement Characteristics due to Regular Wave Excitation

The analysis of the SPM buoy movement is the movement at the time of free-floating on the regular wave from the output. The output generated from the motion analysis is an RAO (Response Amplitude Operator) graph with loading directions 0˚, 45˚, 90˚, 135˚, 180˚, 225˚, 270˚, and 315˚. The RAO produces six degrees of freedom surge, sway, heave, roll, pitch, and yaw.

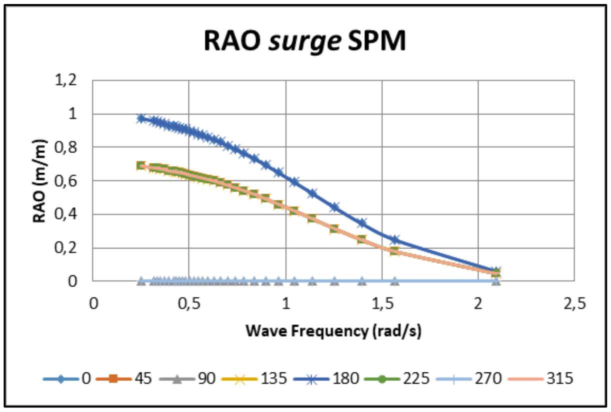

Figure 10. Graph of RAO surge on SPM

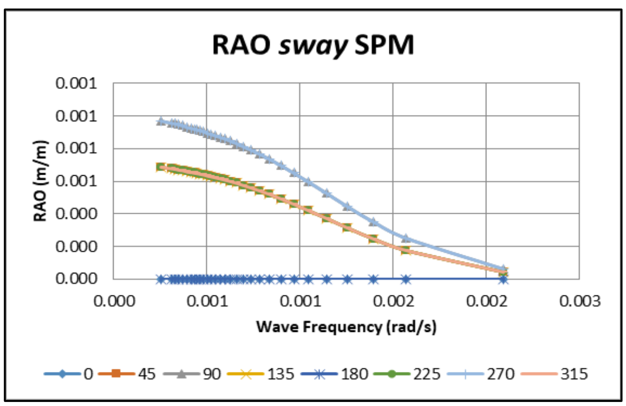

Figure 11. Graph of RAO sway on SPM

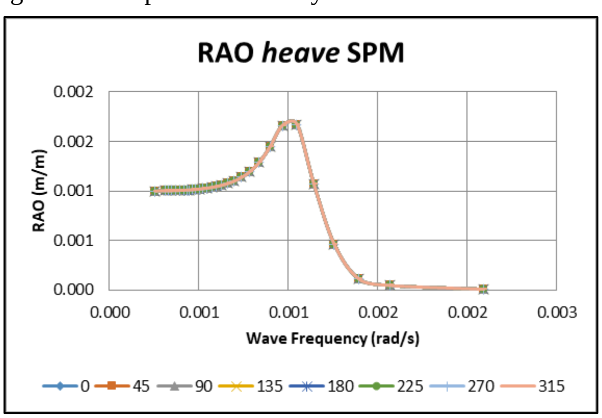

Figure 12. Graph of RAO heave on SPM

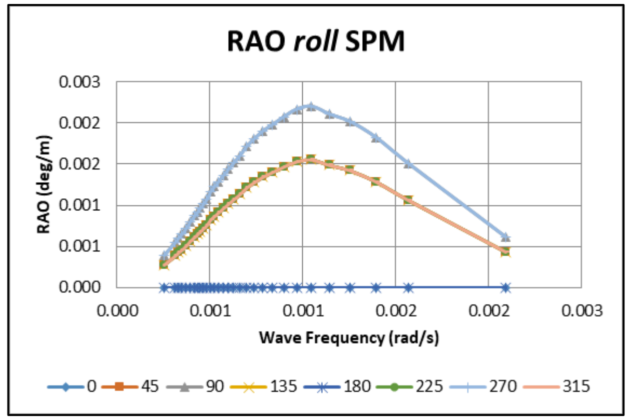

Figure 13. RAO roll graph on SPM

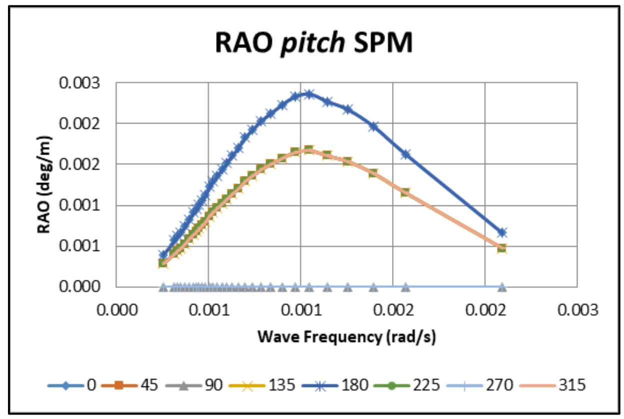

Figure 14. Graph of RAO pitch on SPM

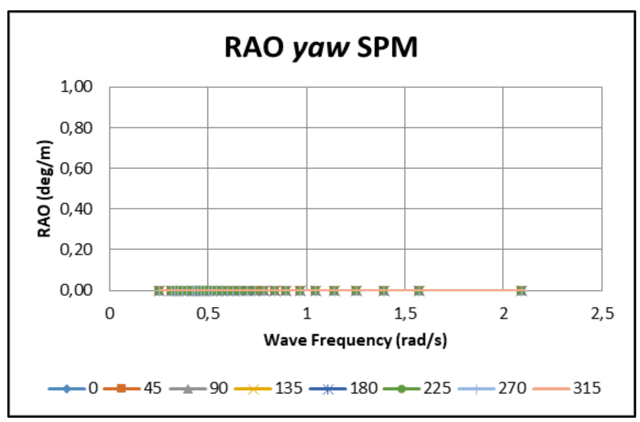

Figure 15. RAO yaw graph on SPM

The movement response of Single Point Mooting in the self-floating condition as seen from the graph of the six degrees of freedom movements, for translational movement, it can be concluded that the largest surge values occur at heading 0˚ and 180˚ with a value of 0.976 m/m at a frequency of 0.251 rad/s. In contrast, the greatest value for sway movement occurs at heading 90˚ and 270˚ with a value of 0.976 at a frequency of 0.251 rad/s. For heave movement, the greatest value occurs in all loading directions, with a value of 1.762, which occurs at a frequency of 1.047 rad/s. For rotational movement, the highest roll value occurs at heading 90˚ and 270˚ with a value of 3,078 deg/m at a frequency of 0.739 rad/s. For pitch movement, the highest value occurs at heading 0˚ and 180˚ with a value of 5,864 deg/m at a frequency of 0.739. rad/s, while for yaw movement.

4.2 Static Analysis Software

Static analysis using dynamic software software is carried out to obtain the model's equilibrium position and the most significant loading direction from the eight available loading directions.

Table 7. Mooring Line Tension Results

Heading	Mooring Line Effective Tension							
	0°	45°	90°	135°	180°	225°	270°	315°
ML1	206.02	205.99	205.86	204.37	204.30	204.78	205.86	205.98
ML2	206.04	205.79	205.60	204.57	204.27	206.50	205.98	205.96
ML3	205.68	205.76	205.60	205.15	207.74	206.82	205.98	205.93
ML4	210.59	210.63	210.77	212.48	212.51	211.99	210.76	210.63
ML5	205.68	205.93	206.12	207.20	207.74	205.33	205.74	205.76
ML6	206.04	205.96	206.12	206.78	204.27	204.92	205.74	205.79

Table 8. Lazy Wave Flexible Riser Tension Result

Heading	Attachment Points	Effective Tension (kN)
		Flexible Riser Effective Tension
0˚	SPM	69.69
	PLEM	12.53
45˚	SPM	62.30
	PLEM	11.20
90˚	SPM	68.90
	PLEM	9.62
135˚	SPM	68.93
	PLEM	5.80
180˚	SPM	71.20
	PLEM	15.47
225˚	SPM	71.36
	PLEM	20.34
270˚	SPM	70.05
	PLEM	14.40
315˚	SPM	69.91
	PLEM	13.82

Table 9. Minimum Bending Radius Tension Result

Heading	MBR(m)
0˚	4.86
45˚	4.82
90˚	4.86
135˚	5.43
180˚	5.90
225˚	5.28
270˚	4.83
315˚	4.84

The results of Software static analysis found that the most significant loading direction was heading 180˚ (S).

4.3 Dynamic Software Dynamic Analysis

Dynamic analysis on dynamic foftware aims to obtain the maximum mooring line tension, offset from SPM, flexible riser maximum tension, and minimum bending radius (MBR) due to the influence of environmental loads (waves and currents), variations in flexible riser diameter and the number of buoyancy modules on the flexible riser.

Table 10. Load Case Matrix

Riser System	Environment	Direction	Riser Diameter	DBM	System Condition
Initial	100 YW-100 YC	South (180°)	8 inch 10 inch 12 inch	19 21 23 25	Intact System Damage System (Broken Mooring Line)
1x	1x	1x	3x	4x	2x
Tabel No of Load Case: 24					

1. Analysis of Mooring Line Maximum Tension Results
a. *Mooring Line Maximum Tension (Intact)*

Table 11. Mooring Line Maxumum Tension (Intact)

Intact		Mooring Line Maximum Tension (Kn)						Max.SPM OFFSET (m)	
		ML1	ML2	ML3	ML4	ML5	ML6	X	Y
8 inch	19 DBM	591.71	605.74	476.20	1178.91	796.78	416.78	0.56	18.29
	21 DBM	582.16	602.02	457.48	1179.39	793.44	418.46	0.62	18.28
	23 DBM	597.57	615.30	473.56	1178.88	794.18	419.60	0.68	18.28
	25 DBM	581.93	613.27	474.58	1176.62	800.55	421.26	0.73	18.28
10 Inch	19 DBM	671.54	566.45	458.83	1202.28	798.39	415.53	0.56	18.35
	21 DBM	662.93	562.89	471.14	1212.19	801.68	417.81	0.63	18.34
	23 DBM	647.14	566.38	463.16	1232.63	808.45	419.55	0.70	18.35
	25 DBM	626.82	567.15	473.02	1188.74	803.15	421.08	0.77	18.34
12 Inch	19 DBM	646.83	558.89	459.78	1257.92	818.89	414.42	0.53	18.27
	21 DBM	648.04	573.85	461.11	1254.43	819.91	417.21	0.61	18.23
	23 DBM	652.89	573.21	460.01	1251.54	822.47	419.24	0.69	18.19
	25 DBM	659.59	567.60	456.02	1250.87	825.85	421.01	0.78	18.21

b. Mooring Line Maximum Tension (Damage)

Table 12. Mooring Line Maxumum Tension (Damage)

Damage		Mooring Line Maximum Tenxion (KN)						Max.SPM OFFSET (m)	
		ML1	ML2	ML3	ML4	ML5	ML6	X	Y
8 Inch	19 DBM	779.14	430.04	343.63	871.34	818.90	INACTIVE	6.56	16.59
	21 DBM	776.03	419.99	336.23	870.93	815.99		6.68	16.63
	23 DBM	799.81	463.10	350.53	876.45	827.40		6.78	16.68
	25 DBM	734.71	487.27	347.66	873.23	829.94		6.89	16.69
10 Inch	19 DBM	782.76	446.57	352.11	873.86	813.32		6.57	16.86
	21 DBM	773.23	441.73	350.55	870.99	813.13		6.66	16.84
	23 DBM	763.76	418.50	350.78	874.62	821.36		6.75	16.89
	25 DBM	785.23	421.55	335.94	872.93	825.82		6.84	16.88
12 Inch	19 DBM	804.11	422.76	346.95	876.66	800.86		6.45	16.59
	21 DBM	805.99	435.12	344.36	876.30	801.21		6.57	16.63
	23 DBM	796.70	425.01	341.70	874.99	836.89		6.68	16.41
	25 DBM	790.65	414.31	352.24	873.75	818.84		6.80	16.56

2. Analysis of Flexible Riser Maximum Tension

a. *Flexible Riser Maximum Tension (Intact)*

Table 13. Flexible Riser Maximum Tension results at the SPM (Intact) point

Intact	Max. Tension (kN)		
	8 Inch	10 Inch	12 Inch
19 DBM	110.86	138.51	165.81
21 DBM	109.83	136.13	160.01
23 DBM	108.74	128.36	154.80
25 DBM	107.05	127.93	150.63
Criteria (kN)	< 1741.3	< 2291.1	< 2454.4
	OK	OK	OK

Table 14. Results of Flexible Riser Maximum Tension at the PLEM (Intact) point

Intact	Max. Tension (kN)		
	8 Inch	10 Inch	12 Inch
19 DBM	19.72	16.57	14.83
21 DBM	21.87	20.17	16.51
23 DBM	23.62	23.46	19.43
25 DBM	25.06	26.15	23.03
Criteria (kN)	< 1741.3	< 2291.1	< 2454.4
	OK	OK	OK

b. *Flexible Riser Maximum Tension (Damage)*

Table 15. Flexible Riser Maximum Tension results at the SPM (Damage) point

Damage	Max. Tension (kN)		
	8 Inch	10 Inch	8 Inch
19 DBM	102.22	130.92	164.43
21 DBM	100.34	126.39	158.98
23 DBM	98.98	121.11	154.54
25 DBM	97.78	119.97	148.7
Criteria (kN)	< 1741.3	< 2291.1	< 2454.4
	OK	OK	OK

Table 16. Flexible Riser Maximum Tension results at the PLEM (Damage) point

Intact	Max. Tension (kN)		
	8 Inch	10 Inch	12 Inch
19 DBM	18.25	15.08	14.65
21 DBM	20.12	18.54	15.57
23 DBM	21.52	21.78	17.77
25 DBM	22.73	24.34	20.85
Criteria (kN)	< 1741.3	< 2291.1	< 1741.3
	OK	OK	OK

3. Flexible Riser Minimum Bending Radius (MBR) Analysis

a. *Flexible Riser Minimum Bending Radius (Intact)*

Table 17. Results of Flexible Riser Minimum Bending Radius in the SagBend (Intact) area

Intact	Minimum Bending Radius (m)		
	8 Inch	10 Inch	12 Inch
19 DBM	19.55	15.87	12.88
21 DBM	20.03	17.36	13.84
23 DBM	21.21	18.81	15.03
25 DBM	22.41	19.2	16.27
Criteria (m)	> 2.94	> 3.27	> 3.66
	OK	OK	OK

Table 18. Results of Flexible Riser Minimum Bending Radius in the HogBend (Intact) area

Intact	Minimum Bending Radius (m)		
	8 Inch	10 Inch	12 Inch
19 DBM	4.83	5.60	6.41
21 DBM	4.30	5.10	5.86
23 DBM	3.78	4.67	5.46
25 DBM	3.32	4.22	4.37
Criteria (m)	> 2.94	>3.27	> 3.66
	OK	OK	OK

b. *Flexible Riser Minimum Bending Radius (Damage)*

Table 19. Results of Flexible Riser Minimum Bending Radius in the SagBend (Damage) area

Damage	Minimum Bending Radius (m)		
	8 Inch	10 Inch	12 Inch
19 DBM	19.85	16.73	12.12
21 DBM	21.08	16.79	13.72
23 DBM	22.28	17.81	14.4
25 DBM	23.37	18.88	15.35
Criteria (m)	> 2.94	>3.27	> 3.66
	OK	OK	OK

Table 20. Results of Flexible Riser Minimum Bending Radius in the HogBend (Damage) area

Damage	Minimum Bending Radius (m)		
	8 Inch	10 Inch	12 Inch
19 DBM	4.43	5.35	5.95
21 DBM	3.99	4.89	5.58
23 DBM	3.56	4.46	5.19
25 DBM	3.13	3.99	4.78
Criteria (m)	> 2.94	>3.27	> 3.66
	OK	OK	OK

4. CONCLUSION

From the analysis that has been done, conclusions can be drawn that can be summarized from this research:

1. The movement response of Single Point Mooting in the self-floating condition as seen from the graph of the six degrees of freedom movements, for translational movement, it can be concluded that the largest surge values occur at heading 0˚ and 180˚ with a value of 0.976 m/m at a frequency of 0.251 rad/s. In contrast, for sway movement, the greatest value occurs at heading 90˚ and 270˚ with a value of 0.976 at a frequency of 0.251 rad/s. For heave movement, the greatest value occurs in all loading directions, with a value of 1.762 at a frequency of 1.047 rad/s. For rotational movement, the highest roll value occurs at heading 90˚ and 270˚ with a value of 3,078 deg/m at a frequency of 0.739 rad/s. For pitch movement, the highest value occurs at heading 0˚ and 180˚ with a value of 5,864 deg/m at a frequency of 0.739. rad/s, while for yaw movement,
2. *Mooring Line Maximum Tension* in the direction of loading 180˚ (south) is in ML4 for each Variation of Diameter and Number of Buoyancy Modules in Intact and Damage conditions.
3. *Maximum tension* The results obtained are in the form of maximum tension at the SPM and PLEM points for intact conditions and damage conditions with variations in the diameter of the flexible riser and the number of buoyancy modules as follows:

a. For intact condition, the larger the Flexible Riser Diameter, the greater the maximum tension at the SPM point, with an increase of 44.87%, while it will be smaller at the PLEM point with a decrease of 18.79%. The more Buoyancy Modules are used on the Flexible Riser, the maximum tension that occurs at the SPM point will be smaller, with a decrease of 6.50%, while it will be even greater at the PLEM point, with an increase of 42.76%.

b. For damage conditions, the larger the Flexible Riser Diameter, the greater the maximum tension at the SPM point, with an increase of 56.88%, while it will be smaller at the PLEM point with a decrease of 17.01%. The more Buoyancy Modules are used on the Flexible Riser, the maximum tension that occurs at the SPM point will be smaller, with a decrease of 7.42%, while it will be even greater at the PLEM point, with an increase of 42.76%.

4. *Minimum bending radius* The results obtained are MBR in the SagBend and HogBend areas for intact conditions and damage conditions with variations in the diameter of the flexible riser and the number of buoyancy modules as follows:
   a. For intact conditions, the larger the Flexible Riser Diameter, the MBR that occurs in the SagBend area will be smaller, with a decrease of 30.39%. In comparison, the MBR that occurs in the HogBend area will increase by 41.76%. The more Buoyancy Modules are used, the MBR that occurs in the SagBend area will be greater with an increase of 20.64%, while the MBR that occurs in the HogBend area will be smaller with a decrease of 25.45%.
   b. For damage conditions, the larger the Flexible Riser Diameter, the MBR that occurs in the SagBend area will be smaller, with a decrease of 35.89%. In

comparison, the MBR that occurs in the HogBend area will increase by 43.17%. The more Buoyancy Modules are used, the greater the MBR that occurs in the SagBend area, with an increase of 15.83%, while the MBR that occurs in the HogBend area will be smaller with a decrease of 24.81%.

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