International Journal of Offshore and Coastal Engineering
Vol.9 | No. 1 | pp. 15 – 20 | May 2025
e-ISSN: 2580-0914

Submitted: January 10, 2025 | Revised: March 4, 2025 | Accepted: April 25, 2025

Lazy Wave Flexible Riser Dynamic Responses Analysis with Variation of SPM Offset from PLEM on Operation Condition

Muhammad Naufal Hawari[a*], Wisnu Wardhana[a] and Murdjito[a]
[a)] Department of Ocean Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

*Email: naufalhawari123@gmail.com

ABSTRACT
The increasing use of flexible risers in oil and gas exploration projects is a big challenge for engineers to design better riser systems to improve further the efficiency and safety of exploration and production activities in offshore oil and gas fields. SPM is often used as an offloading facility connecting FSO or FPSO as recipients of oil and gas products from subsea templates or wells. Under operating conditions, SPM can move freely following the movement of environmental loads. Drifting or changes in position due to the load on the SPM can threaten the riser response, whereas the riser response can be different whether the SPM is moving or drifting in its stress or bending response. The results in this study also contain the effect of this phenomenon on their fatigue life. As a result, the difference in riser response due to the distance from SPM to PLEM is that the farther the distance from SPM from PLEM, the greater the stress response and bending radius it has. Fatigue life also follows the same results, where the farthest distance from the SPM configuration to PLEM has the lowest fatigue life compared to the closest distance from the SPM to PLEM configuration, with the highest fatigue life at 128.31 years and the lowest at 124.78 years.

Keywords: *Fatigue, Flexible Riser, Offset, Operation, SPM*

1. INTRODUCTION
Flexible risers are an important component in offshore developments because they provide a means to transfer fluids or power between subsea units and floating structures. This riser can withstand the movement of floating structures and can also withstand hydrodynamic loads such as waves and currents. They have high axial stiffness and low bending stiffness so that they can withstand considerable deformation due to waves, ocean currents, or the movement of the structure above them.

According to Yilmaz and Incecik [7], the dynamic response of the structure will be known by calculating environmental loads comprehensively. The purpose of calculating the dynamic response of a structure is to obtain the extreme response of the system. One way to conduct the analysis is to analyze the structural response for an environmental data design such as 100-year significant waves, 100-year wind speed, and 100-year current [8].

With the possibility of a change in the position of the SPM concerning PLEM or TDP, dynamic response analysis of various riser configurations is needed to see if there is a significant effect on the fatigue life of the riser when there is a difference in the position of the SPM. The fatigue life of the riser must also meet or exceed the planned service life or length of operation for the riser to operate optimally.

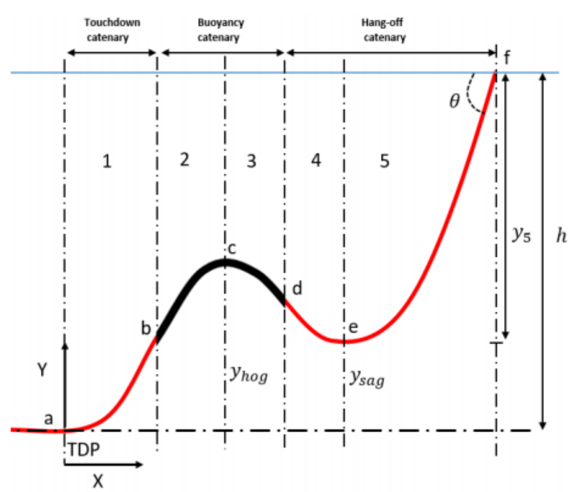

Figure 1. Lazy Wave Riser Configuration

The goal of this paper is to find out the effect of SPM distance or offset from PLEM in their dynamic responses, which consist of tension and bending radius or bending moment. After that, the difference in fatigue life due to their respective variation could be seen from the trendline on riser responses due to SPM distance to PLEM.

2. THEORY AND METHODOLOGY
2.1 Flexible Riser
The riser system combines components such as tensioning, buoyancy modules, etc. According to the API [1], the riser system usually consists of the riser, top interface, and

bottom interface. In an oil or gas field, there is not only one riser but many riser bodies and interfaces. This is because a reservoir allows for fluid differences in pressure and type. The bathymetry conditions of each well can also be different. This can lead to differences in the design of a riser in a riser system. Hybrid concepts such as SHR or HRT are strong and more resistant to fatigue damage, but operating costs and challenges during installation may be why hybrid types are rarely used in deep sea conditions and harsh environments. Therefore, a Lazy flexible riser and SLWR are the most feasible concepts for deep sea conditions [2]. Flexible pipes usually have high axial tensile stiffness and low bending stiffness. This can be achieved by modifying the pipe wall into a composite construction. This type is more often applied as an unbonded flexible pipe.

2.2 Fatigue Life Analysis

Fatigue is a phenomenon of structural fatigue due to cyclic loading. Fatigue failure is very dependent on the load that occurs and the strength of the structural material itself. In this paper fatigue calculation method used is the S-N curve method, in which the S-N curve approach aims to find out how many stress cycles are needed until a crack occurs, which can trigger failure. DNV RP F204 [3] explains that the components forming the nominal cyclic stress (σ) in pipes are generally a linear combination of axial stress and bending stress, as shown in the following equation.

$$\sigma(t) = \sigma_a(t) + \sigma_m(\theta, t) \quad (1)$$

$$Axial\ Stress = \sigma_a(t) = \frac{T_e(t)}{\pi \, . \left(OD - t_{fat}\right) . \ t_{fat}} \quad (2)$$

$$Bending\ Stress = \sigma_m(\theta, t) = \left(M_y(t)\sin(\theta) + M_z(t)\cos(\theta)\right).\left(\frac{OD - t_{fat}}{2I}\right) \quad (3)$$

The stress range used in calculating accumulated fatigue damage is the value obtained from applying the stress concentration factor and the thickness correction value to the nominal stress range. In this case of riser fatigue analysis, the nominal stress is obtained from the stress generated due to wave forces and ocean currents. This stress range is determined by rainflow-counting, which counts how high the stress could occur and how many times it happened. This method reduces highly variable stress cycles to a more detailed data set. Cycle calculation using the rain flow-counting method uses the analogy of falling water from the roof of a pagoda. Examples of this method's results are shown in the table below.

Table 1. Example of Rainflow-Counting Method Results

Stress Range (MPa)	Total Cycle
10	0
9	0,5
8	1
7	0
6	0,5
5	0
4	1,5
3	0,5
2	0
1	0

From DNV [3], S-N curve for flexible risers are manufactured and specified and cannot be found on any literature. This is because every type of flexible riser was built for specified fields and owner specifications. So there was a good probability that every flexible riser in this world has different specifications. In this paper, however, due to limited data, S-N curve used was based on Chen [4] thesis research which is S-N curve for the armored flexible riser. S-N curve could be expressed as:

$$\log(N) = \log(\bar{a}) - m\log(S) \quad (4)$$

Alternatively, it could be rearranged as:

$$N = \bar{a}S^{-m} \quad (5)$$

Fatigue damage calculation used in this paper is the Miner-Palmgren rule. This rule allowed fatigue damage calculation from several sets of stress range data. Miner-Palmgren rules were stated, such as:

$$D = \sum_{i=1}^{m} \frac{n(S_i)}{N(S_i)} \quad (6)$$

Where fatigue life could be calculated using this equation:

$$T_{life} = \frac{1}{D} \quad (7)$$

From DNV [5] for fatigue analysis, damage calculation should consider design fatigue factor like table below.

Table 2. Design Fatigue Factor

Design Fatigue Factor		
Safety Class		
Low	Normal	High
3.0	6.0	10.0

3. RESULTS AND DISCUSSION

3.1 Floater Modelling and Validation

The following are the SPM properties used in the research.

Table 3. SPM Main Dimension

Parameter	**Unit**	**Value**
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
Weight	MT	550.70

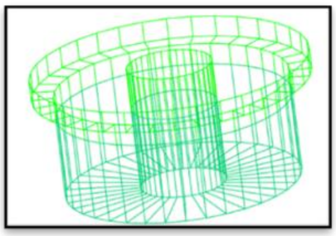

Figure 2. SPM Model

Table 4. FSO Main Dimension

Parameter		**Unit**	**Value**
LOA	Helideck End	m	297.54
	Centerline of Buoy	m	314.64
Length Between Perpendicular (LBP)		m	272.00
Breadth Moulded		m	43.40
Depth Moulded		m	20.60
Draft	Ballasted	m	8.49
	Fully Loaded Condition	m	12.88
Disp.	Ballasted	MT	82245.64
	Full Load	MT	127410.90

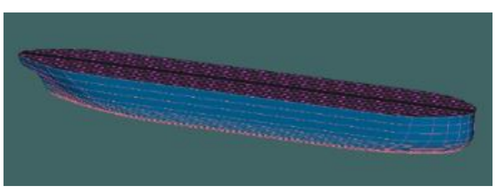

Figure 3. Maxsurf FSO Model

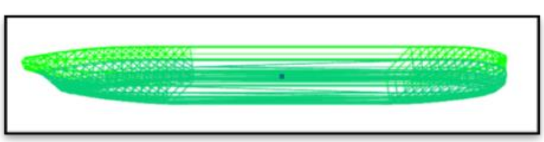

Figure 4. FSO Model

From ABS 2021 [6], model in software should be validated based on printout or handout data. Below are validation of model in this paper from the stated data above.

Table 5. Floater Validation Check

Parameter	Unit	Maxsurf	Moses	Gap (%)	Check
Displacement	Tons	127410.0	129536.9	1.67%	OK
LCB	m	132.4	129.8	1.95%	OK
KB	m	6.6	6.6	0.09%	OK
KMT	m	18.5	18.6	0.59%	OK
BMT	m	11.9	12.0	0.98%	OK
BML	m	428.3	430.9	0.60%	OK
TPc	Tonne /cm	108.7	108.4	0.24%	OK

From software, both floater model will be simulated to obtain hydrodynamics parameter that needed to be an input in software modelling in the next step. This parameter consists of RAO, wave drift force, added mass, and damping.

3.2 Software Modelling

In this step, results from past steps in software were used as input data to create our model in software. Another addition is riser system data and environment data. For environment data, wildly wave and current data were used at each loading, in which used in this paper used 8 directions loading every 45° to achieve in-line and between-line simulation. For wave and current used area combination of 100 years return period data, each direction has its wave and current data.

In this paper, a variation of SPM location from PLEM also varied to see the effect of the distance riser span on their responses, including the fatigue life. The variation is far, nominal, and near, where the nominal is 0m variation as a control variable. Far and near means the SPM will change their position in line with the riser span 15m away or closer to the PLEM coordinates.

3.3 Dynamic Simulation Results

The results of the dynamics simulation of each variation are shown in each table below.

Table 6. Nominal Dynamic Response Result

Lazy Wave Flexible Riser Effective Tension (kN)								
Connection	Headings							
	0°	45°	90°	135°	180°	225°	270°	315°
SPM	136.46	105.59	101.79	107.52	135.17	109.46	127.72	104.18
Sagbend Section	36.90	30.48	23.19	24.14	25.55	23.56	22.92	16.00
Hogbend Section	23.42	20.10	17.45	16.80	20.76	16.97	23.48	15.44
PLEM	20.02	10.46	15.70	18.85	24.74	23.00	25.55	25.98
Highest E.Tension	136.46	105.59	101.79	107.52	135.17	109.46	127.72	104.18
Allowable Check <1530 kN	OK	OK	OK	OK	OK	OK	OK	OK

Lazy Wave Flexible Riser Minimum Bending Radius (m)								
Connection	Headings							
	0°	45°	90°	135°	180°	225°	270°	315°
SPM	3153.33	4361.66	6515.23	4998.18	5606.19	5389.41	6652.25	11020.63
Sagbend Section	18.28	18.37	13.98	14.67	15.97	13.66	10.33	13.08
Hogbend Section	5.19	4.67	4.01	4.21	4.58	4.06	3.75	4.64
PLEM	712.86	663.90	776.16	787.17	755.35	953.74	983.11	1169.10
Highest E.Tension	5.19	4.67	4.01	4.21	4.58	4.06	3.75	4.64
Allowable Check >3.926 kN	OK	OK	OK	OK	OK	OK	Fail	OK

Table 7. Far Dynamic Response Result

FAR VARIATION Lazy Wave Flexible Riser Effective Tension (kN)								
Connection	Headings							
	0°	45°	90°	135°	180°	225°	270°	315°
SPM	135.03	106.11	103.80	108.60	139.27	111.05	134.83	106.55
Sagbend Section	45.70	37.14	29.57	29.68	33.69	28.98	34.57	22.09
Hogbend Section	31.61	25.39	21.60	22.03	25.42	21.98	31.07	21.26
PLEM	26.72	17.47	20.39	23.31	29.42	26.73	31.04	28.81
Highest E.Tension	135.03	106.11	103.08	108.60	139.27	111.05	134.83	106.55
Allowable Check <1530 kN	OK	OK	OK	OK	OK	OK	OK	OK

FAR VARIATION Lazy Wave Flexible Riser Minimum Bending Radius (m)								
Connection	Headings							
	0°	45°	90°	135°	180°	225°	270°	315°
SPM	3056.33	4182.29	6194.87	4793.14	5533.74	5427.73	5809.94	11468.68
Sagbend Section	23.08	22.48	16.71	17.96	20.57	17.83	14.11	17.75
Hogbend Section	5.83	5.62	4.89	5.04	5.36	4.78	4.45	5.49
PLEM	731.12	699.02	844.42	854.25	834.09	974.23	1054.24	1229.46
Highest E.Tension	5.83	5.62	4.89	5.04	5.36	4.78	4.45	5.49
Allowable Check >3.926 kN	OK	OK	OK	OK	OK	OK	OK	OK

Table 8. Near Dynamic Response Result

NEAR VARIATION Lazy Wave Flexible Riser Effective Tension (kN)								
Connection	Headings							
	0°	45°	90°	135°	180°	225°	270°	315°
SPM	135.59	105.62	100.27	107.58	131.42	108.39	129.14	102.76
Sagbend Section	30.15	24.90	18.24	18.89	19.40	18.48	15.18	11.36
Hogbend Section	17.59	15.70	13.03	12.29	17.77	14.70	17.41	13.14
PLEM	15.10	4.26	12.48	14.57	21.97	21.18	22.25	23.99
Highest E.Tension	135.59	105.62	100.27	107.58	131.42	108.39	129.14	102.76
Allowable Check <1530 kN	OK	OK	OK	OK	OK	OK	OK	OK

NEAR VARIATION Lazy Wave Flexible Riser Minimum Bending Radius (m)								
Connection	Headings							
	0°	45°	90°	135°	180°	225°	270°	315°
SPM	3223.66	4495.19	6781.13	5149.59	5649.84	5354.38	6540.31	10695.39
Sagbend Section	15.06	15.29	11.28	11.83	12.40	10.26	7.88	9.95
Hogbend Section	4.57	4.03	3.40	3.50	3.78	3.14	3.22	4.10
PLEM	692.81	613.58	684.88	697.04	661.66	866.13	945.52	1116.70
Highest E.Tension	4.57	4.03	3.40	3.50	3.78	3.41	3.22	4.10
Allowable Check >3.926 kN	OK	OK	Fail	Fail	Fail	Fail	Fail	Fail

Focusing the results in 90° and 270° loading directions parallel with the riser span, the comparison of each connection at three variations could be seen as having a uniform trendline in decline, shown better in the graph below.

Figure 5. Effective Tension Comparation at 90° Loading

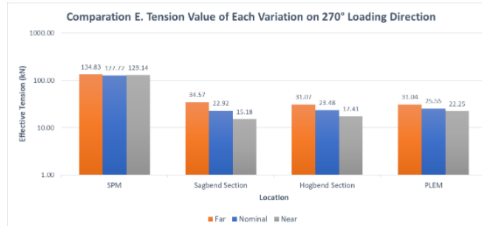

Figure 6. Effective Tension Comparation at 270° Loading

For minimum bending radius comparison are follows.

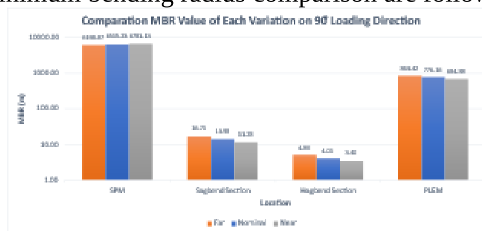

Figure 7. MBR Comparation at 90° Loading

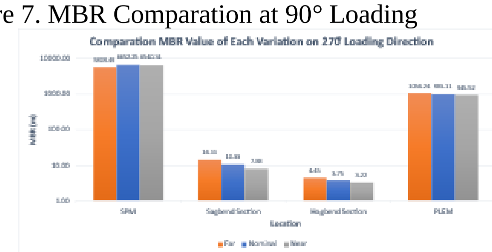

Figure 8. MBR Comparation at 270° Loading

A trendline graph was created to better visualize the effect of SPM distance from PLEM on riser dynamics responses, and it could be seen that there is declining trendline if SPM position is closer to the PLEM at each response.

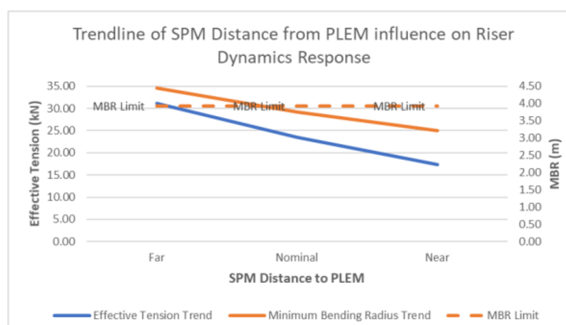

Figure 9. Trendline of SPM Distance from PLEM influence on Riser Dynamics Response

3.4 Focus Point of Fatigue Analysis

Before calculating fatigue damage, the location on which the fatigue analysis focused should be selected. In this paper, the criteria used to select the appropriate location of fatigue analysis is by comparing the nominal stress along the risers and select the biggest one to be the location of fatigue analysis.

The results found in this paper stated that the selected point or location along the riser that will be the fatigue analysis location is at 0.05m from the hang-off connection at the SPM-Riser connection. At this point of every variation, the biggest nominal stress was located in the risers. This point will be the location stress range and cycle counting focusing on in the next step of the analysis.

3.5 Stress Range and Cycle Counting Calculation

From the dynamics simulation before we will have a time history data of riser response. From this time history data, we could calculate the stress range and cycle at each range by using rainflow-counting methods. Using software, we could find the stress range and cycle from nominal stress at each loading direction of each variation. This result, however, was not adjusted with the probability of wave occurrence at each loading direction or wave scatter. By adjusting the cycle value with the probability at each direction, we will have the result with adjusted value according to the table below.

Table 9. Adjusted Rainflow Counting Results

Probability Rainflow Counting Results									
Stress Range (Mpa)	0	45	90	135	180	225	270	315	Total
2	4.65E+06	3.77E+07	5.07E+06	3.59E+06	1.38E+07	1.05E+07	1.41E+06	7.43E+05	7.75E+07
4	3.57E+05	2.82E+06	6.38E+05	8.28E+04	1.35E+06	4.00E+05	8.57E+04	2.55E+04	5.76E+06
6	7.20E+04	5.19E+05	1.13E+05	1.18E+04	4.20E+05	6.61E+04	7.66E+03	6.94E+03	1.22E+06
8	4.38E+04	2.12E+05	0.00E+00	0.00E+00	2.72E+05	2.78E+04	0.00E+00	9.26E+02	5.57E+05
10	9.39E+03	2.36E+04	0.00E+00	0.00E+00	1.42E+05	1.39E+04	0.00E+00	4.63E+02	1.90E+05
12	1.56E+04	0.00E+00	0.00E+00	0.00E+00	1.05E+05	0.00E+00	0.00E+00	0.00E+00	1.21E+05
14	3.13E+03	0.00E+00	0.00E+00	0.00E+00	4.95E+04	0.00E+00	0.00E+00	0.00E+00	5.26E+04
16	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.47E+04	0.00E+00	0.00E+00	0.00E+00	2.47E+04
18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.24E+04	0.00E+00	0.00E+00	0.00E+00	1.24E+04
20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	6.18E+03	0.00E+00	0.00E+00	0.00E+00	6.18E+03
22	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.85E+04	0.00E+00	0.00E+00	0.00E+00	1.85E+04
24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

3.6 Fatigue Life Calculation

Using SN-curve data below we could calculate the damage using Miner-Palmgren rule.

$$\log(N) = 12.5 - 3\log(S) \quad (8)$$

Table 10. Nominal Variation Fatigue Calculation

Nominal Fatigue Calculation						
Stress Range (MPa)	Cycle Factor	N Calculation > 10^6 m = 3	Log(A)=12.5	N	Damage	D.DFF
2	7.75E+07	1.16E+01	3.95E+11	3.95E+11	1.96E-04	1.96E-03
4	5.76E+06	1.07E+01	4.94E+10	4.94E+10	1.17E-10	1.17E-03
6	1.22E+06	1.02E+01	1.46E+10	1.46E+10	8.31E-05	8.31E-04
8	5.57E+05	9.79E+00	6.18E+09	6.18E+09	9.01E-05	9.01E-04
10	1.90E+05	9.50E+00	3.16E+09	3.16E+09	5.99E-05	5.99E-04
12	1.21E+05	9.26E+00	1.83E+09	1.83E+09	6.60E-05	6.60E-04
14	5.26E+04	9.06E+00	1.15E+09	1.15E+09	4.56E-05	4.56E-04
16	2.47E+04	8.89E+00	7.72E+08	7.72E+08	3.20E-05	3.20E-04
18	1.24E+04	8.73E+00	5.42E+08	5.42E+08	2.28E-05	2.28E-04
20	6.18E+03	8.60E+00	3.95E+08	3.95E+08	1.56E-05	1.56E-04
22	1.85E+04	8.47E+00	2.97E+08	2.97E+08	6.24E-05	6.24E-04
24	0	8.36E+00	2.29E+08	2.29E+08	0.00E+00	0.00E+00
				Total Damage year		7.90E-03
				Fatigue Damage (Years)		126.55

By multiplying the damage before summing up with DFF at high safety class with the value of "10". The total damage for nominal variation at 0.05m from the hang-off connection is at 7.90E-03 or with the fatigue life at 126.55 years. Using the same methods, we could have the rest of the variation fatigue life as follow.

Table 11. Far Variation Fatigue Calculation

Far Fatigue Calculation						
Stress Range (MPa)	Cycle Factor	N Calculation > 10^6 m = 3	Log(A)=12.5	N	Damage	D.DFF
2	7.68E+07	1.16E+01	3.95E+11	3.95E+11	1.94E-04	1.96E-03
4	5.51E+06	1.07E+01	4.94E+10	4.94E+10	1.11E-04	1.11E-03
6	1.23E+06	1.02E+01	1.46E+10	1.46E+10	8.39E-05	8.39E-04
8	5.59E+05	9.79E+00	6.18E+09	6.18E+09	9.04E-05	9.04E-04
10	1.90E+05	9.50E+00	3.16E+09	3.16E+09	5.99E-05	5.99E-04
12	1.21E+05	9.26E+00	1.83E+09	1.83E+09	6.60E-05	6.60E-04
14	4.02E+04	9.06E+00	1.15E+09	1.15E+09	3.49E-05	3.49E-04
16	3.71E+04	8.89E+00	7.72E+08	7.72E+08	4.80E-05	4.80E-04
18	1.24E+04	8.73E+00	5.42E+08	5.42E+08	2.28E-05	2.28E-04
20	0.00E+00	8.60E+00	3.95E+08	3.95E+08	0.00E-00	0.00E-00
22	1.85E+04	8.47E+00	2.97E+08	2.97E+08	6.24E-05	6.24E-04
24	6.18E+03	8.36E+00	2.29E+08	2.29E+08	2.70E+05	2.70E+04
				Total Damage year		8.01E-03
				Fatigue Damage (Years)		124.78

Table 12. Near Variation Fatigue Calculation

Near Fatigue Calculation						
Stress Range (MPa)	Cycle Factor	N Calculation > 10^6 m = 3	Log(A)=12.5	N	Damage	D.DFF
2	7.58E+07	1.16E+01	3.95E+11	3.95E+11	1.92E-04	1.92E-03
4	6.07E+06	1.07E+01	4.94E+10	4.94E+10	1.23E-04	1.23E-03
6	1.30E+06	1.02E+01	1.46E+10	1.46E+10	8.88E-05	8.88E-04
8	5.22E+05	9.79E+00	6.18E+09	6.18E+09	8.45E-05	8.45E-04
10	1.65E+05	9.50E+00	3.16E+09	3.16E+09	5.21E-05	5.21E-04
12	1.21E+05	9.26E+00	1.83E+09	1.83E+09	6.60E-05	6.60E-04
14	5.26E+04	9.06E+00	1.15E+09	1.15E+09	4.56E-05	4.56E-04
16	2.47E+04	8.89E+00	7.72E+08	7.72E+08	3.20E-05	3.20E-04
18	1.24E+04	8.73E+00	5.42E+08	5.42E+08	2.28E-05	2.28E-04
20	1.24E+04	8.60E+00	3.95E+08	3.95E+08	3.13E-05	3.13E-04
22	1.24E+04	8.47E+00	2.97E+08	2.97E+08	4.16E-05	4.16E-04
24	0	8.36E+00	2.29E+08	2.29E+08	0.00E+00	0.00E+00
				Total Damage year		7.79E-03
				Fatigue Damage (Years)		128.31

From the calculation of every variation above, there is a trend in which the closer the SPM to PLEM, the fatigue life of riser will increase, but this is not always permissible due to the result on riser response before, stated that the closer SPM to PLEM the dynamic response will exceed the allowable criteria such as effective tension and minimum bending radius. The visualization of this trend can be seen in this graph below.

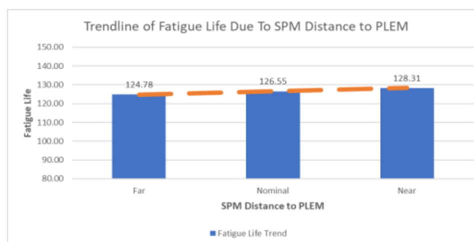

Figure 9. Trendline of SPM Distance from PLEM influence on Fatigue Life

4. CONCLUSION

Based on the result above, the conclusion of this paper is as followed:

1. According to the results of the previous trendline graph, it can be concluded that the farther the SPM is from PLEM, the average effective tension value is greater than the nominal and near variations. This also applies to the minimum bending radius, which will increase in value as the distance between SPM and PLEM increases. The largest effective tension value in the nominal configuration is 136.46 kN in the 0° loading direction and the smallest MBR at 3.75 m in the 270° loading direction. For the far configuration, the largest effective tension was found at 139.27 kN in the 180° loading direction and the smallest MBR at 4.45m in the 270° loading direction. For the near configuration, the largest effective tension was found at 135.59 kN in the 0°

loading direction and the smallest MBR at 3.22 m in the 270° loading direction.

2. For the nominal stress value which is the resultant axial stress and bending stress, where the axial stress result is influenced by the effective tension and the bending stress is influenced by the bending moment, the results of each of the largest nominal stresses experienced by each configuration are as follows: For the largest nominal stress value obtained in the Far configuration or the farthest distance from SPM to PLEM with a value of 22.79 MPa. The smallest value is obtained in the Near configuration with a value of 21.53 MPa where in this configuration the value of effective tension produced is smaller than the other configurations, resulting in a smaller nominal stress. The nominal configuration is between the other two configurations with a value of 21.87 MPa

3. The fatigue life obtained from the results of this study shows that the farther the distance from the SPM to the PLEM or the more interested the riser configuration, the smaller the fatigue life compared to the more compressed riser configuration or the distance from the SPM to the PLEM is smaller. This is proven by the fatigue life of the Far configuration at 124.78 years for the nominal configuration at 126.55 years and the Near configuration at 128.31 years.

ACKNOWLEDGEMENTS

The author would like to thank to Ocean Engineering Department and all parties involved in carrying out this research both directly and indirectly, so that this research can be completed and could be utilized responsibly for a wide range of audience.

REFERENCES

1. API: *Recommended Practice for Flexible Pipe*. API RP 17B 3rd Ed., American Petroleum Institute, Washington, DC, USA, 2002
2. Agusta, A.: Structural Design of Steel Catenary Riser with the Environmental Contour Line Method for Operation in Indonesian Water. *Master Thesis*, Department of Marine Technology, NTNU, Trondheim, Norway,2014
3. DNVGL: *Riser Fatigue*. DNVGL RP-F204 Oct. 2017 Ed., Det Norske Veritas Germanischer Lloyd, Oslo, Norway, 2017
4. Chen, M.: Fatigue Analysis Of Flexible Pipes Using Alternative Element Types And Bend Stiffener Data. Master Thesis, Department of Marine Technology, NTNU, Trondheim, Norway,2011
5. DNV: *Dynamic Risers*. DNV OS-F201 Oct. 2010 Ed., Det Norske Veritas, Oslo, Norway, 2010
6. ABS: *Mobile Offshore Unit: Part 3 Hull Construction and Equipment.* ABS MOU Part 3, Jan. 2021 Ed., American Bureau of Shipping, Spring, TX, USA, 2021
7. Yilmaz, O. and Incecik, A..: Hydrodynamic Design of Moored Floating Platforms. *Journal of Marine Structures*, 1994
8. Wibowo, Y. A.: Analisis Pengaruh Variasi Jarak Horizontal Antara FSRU dan LNGC Saat Side by side Offloading Terhadap Perilaku Gerak Kapal dan Gaya Tarik Coupling Line. Final Year Project. Department of Ocean Engineering, ITS, Surabaya, Indonesia, 2014 (in Bahasa Indonesia)
9. Bahari, M. K.: Strength Analysis of Catenary Offshore Buoyancy Riser Assembly Riser due to Hydrodynamic Load. *Journal of Subsea and Offshore* Vol. 10, 2017
10. Bai, Y. and Bai, Q.: *Subsea Pipelines and Risers*., Elsevier, Houston, 2005
11. Bai, Y. and Bai, Q.: *Subsea Pipeline Design, Analysis, and Installation*., Elsevier, Oxford, 2014
12. Buberg, T.: Design and Analysis of Steel Catenary Riser Systems for Deep Waters. Master Thesis, Department of Marine Technology, NTNU, Trondheim, Norway,2014
13. Erestio, R. C.: Analisis Kekuatan Dan Sensitivitas Steel Catenary Riser Akibat Pergerakan Semi-Submersible. Final Year Project. Department of Ocean Engineering, ITS, Surabaya, Indonesia, 2016 (in Bahasa Indonesia)
14. Gemilang, G.: Feasibility Study of Selected Riser Concepts in Deep Water and Harsh Environment. Master Thesis, Offshore Technology, University of Stavanger, Stavanger, Norway,2015
15. Karegar, S.: Flexible Riser Global Analysis for Very Shallow Water. Master Thesis, Offshore Technology, University of Stavanger, Stavanger, Norway,2013
16. Karunakaran, D., Subramanian, S., and Baarholm, R Steel Lazy Wave Riser Configuration for Turret Moored Fpso With Disconnectable Turret In Deepwater. *Proceedings of the ASME 2015 34th International Conference on Ocean, Offshore and Arctic Engineering*, St. John, NL, Canada, 2015
17. Keprate, A.,and Ratnayake, R. M. C.: Riser Concept Selection For Fpso In Deepwater Norwegian Sea: A Case Study. *Proceedings of the ASME 2018 37th International Conference on Ocean, Offshore and Arctic Engineering*, Madrid, Spain, 2018
18. Lekkala, M. R. et al.: A practical technique for hydrodynamic coefficients modification in SHEAR7 for fatigue assessment of riser buoyancy modules under vortex-induced vibration. *Journal Ocean Engineering* 217: 107760, 2020
19. Mahanani, D. F.: Analisa Time-Domain Pengaruh Spread Mooring Dengan Variasi Jumlah Line Terhadap Tension Pada Flexible Riser. Final Year Project. Department of Ocean Engineering, ITS, Surabaya, Indonesia, 2017 (in Bahasa Indonesia)
20. Yue, B., Campbell, M., Walters, D., Thompson, H., dan Raghavan, K.: Improved SCR Design for Dynamic Vessel Application. *Proceedings of the ASME 2010 29th International Conference on Ocean, Offshore and Arctic Engineering*, Shanghai, China, 2010