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Fatigue Analysis of Spread Mooring Line

Chanhoe Kang, Changhyun Lee, Seock-Hee Jun, Yeong-Tae Oh

***Abstract*—**Offshore floating structure under the various environmental conditions maintains a fixed position by mooring system. Environmental conditions, vessel motions and mooring loads are applied to mooring lines as the dynamic tension. Because global responses of mooring system in deep water are specified as wave frequency and low frequency response, they should be calculated from the time-domain analysis due to non-linear dynamic characteristics. To take into account all mooring loads, environmental conditions, added mass and damping terms at each time step, a lot of computation time and capacities are required. Thus, under the premise that reliable fatigue damage could be derived through reasonable analysis method, it is necessary to reduce the analysis cases through the sensitivity studies and appropriate assumptions. In this paper, effects in fatigue are studied for spread mooring system connected with oil FPSO which is positioned in deep water of West Africa offshore. The target FPSO with two Mbbls storage has 16 spread mooring lines (4 bundles x 4 lines). The various sensitivity studies are performed for environmental loads, type of responses, vessel offsets, mooring position, loading conditions and riser behavior. Each parameter applied to the sensitivity studies is investigated from the effects of fatigue damage through fatigue analysis. Based on the sensitivity studies, the following results are presented: Wave loads are more dominant in terms of fatigue than other environment conditions. Wave frequency response causes the higher fatigue damage than low frequency response. The larger vessel offset increases the mean tension and so it results in the increased fatigue damage. The external line of each bundle shows the highest fatigue damage by the governed vessel pitch motion due to swell wave conditions. Among three kinds of loading conditions, ballast condition has the highest fatigue damage due to higher tension. The riser damping occurred by riser behavior tends to reduce the fatigue damage. The various analysis results obtained from these sensitivity studies can be used for a simplified fatigue analysis of spread mooring line as the reference.

***Keywords*—**Mooring system, fatigue analysis, time domain, non-linear dynamic characteristics.

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I. Introduction

CONSISTENTLY the demand for offshore energy development with regard to oil and gas resources has increased and the field has required the state of the art technologies and concepts for better engineering productivity. In particular, for ultra-deep water above 1000m depth the sustained drive to improve the harvests from offshore oil exploration, production and transportation has led to the specific needs on the various floating structures like FPSO, SPAR, etc. Also, most of the offshore floaters have been required to meet the rigorous design requirements in term of the structural strength and fatigue in order to reduce the potential invisible risk levels.

Offshore floating structures require mooring systems to maintain the station keeping under surrounding environment actions such as current, wind, and wave. Mooring systems are composed of specially designed devices for the purpose and widely applied to the most floaters. Therefore, the mooring systems have to provide such station keeping capability and high global performance to ensure allowable excursions against environmental loads. The performance characteristics of mooring systems is typically a function of the type and size of floater, the operational water depth, environmental loads, seabed condition, and the arrangement and weight of mooring components.

Besides, unlike general trading ships, offshore floaters stay at a fixed position for their whole life without regular dry docking for inspection and repair. The mooring lines have to be designed to withstand severe weather conditions since they shall be in place without any failure of mooring lines during life-time. Especially the various environmental loads during operation of floaters lead to increasing fatigue damage in their mooring lines.

This paper deals with fatigue analysis of permanent mooring line under the various environmental conditions. As permanent moorings are normally applied for floating production systems such as FPSO with design lives of over 20 years, mooring system fatigue is an important design factor. And since it has non-linear dynamic characteristics, fatigue analysis should be performed through time domain analysis [1].

The spread mooring system of deep water FPSO installed in West Africa offshore is chosen in this study. It has the chain-wire-chain structure. Using the mooring design data of West Africa offshore, various sensitivity studies were performed in accordance with the effect of fatigue damage for spread mooring lines. The studied parameters for sensitivity are environmental loads, type of responses, vessel offsets, mooring position, loading conditions and riser behavior.

To perform fatigue analysis, tension time series of mooring lines were calculated through dynamic analysis with OrcaFlex [2]. The rain-flow counting method proposed by Matsuishi and Endo [3] was applied to calculate number of cycles of mooring line tension. And then fatigue damages of mooring lines were obtained using the T-N curve and the Miner linear cumulative law model which is the commonly used calculation method of fatigue damage.

II. FPSO Platform Model and Environmental Conditions

A. FPSO Platform

In this paper, the FPSO installed in West Africa offshore was considered. The installation field has approximately 1200m

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water depth and seabed conditions with a regular slope in global south-west direction of 2%. The main characteristic parameters of the FPSO platform model are listed in Table I. Three kind of loading conditions have been studied in fatigue analysis.

TABLE I
PARAMETERS OF FPSO PLATFORM

Parameters	Value		
Length (m)	305		
Breath (m)	61		
Depth (m)	32		
Loading conditions	Ballast	Intermediate	Full
Draft (m)	11.69	17.46	23.04
Displacement (metric ton)	205573	312441	417645
COG from the stern (m)	162.35	161.85	158.34
COG from the keel (m)	22.85	20.59	18.47
Roll gyration radius (m)	25.55	21.81	22.04
Pitch gyration radius (m)	85.67	80.46	80.69
Yaw gyration radius (m)	85.9	80.47	81.24

B. Mooring System

The heading of FPSO is 22.5deg from true north in east direction as shown in Fig. 1. The FPSO is installed by spread mooring system. Mooring system consists of 16 mooring lines around FPSO. The 4 mooring lines are composed as a bundle. The mooring lines are arranged with 1600m pattern radius. As shown in Fig. 2, mooring lines of the FPSO are made up of three components which are top chain, wire rope and bottom chain. The range of mooring line is from FPSO fairlead point to TAP (so-called Theoretical Anchor Point). Top chain is connected at the fairleads of the FPSO with chain stopper and bottom chain is linked to the suction anchor on seabed. The buried parts of bottom chains to suction anchoring point are not considered in mooring analysis. The mooring line properties are listed in Table II.

C. Environmental Conditions

Global responses of mooring line connected with FPSO were calculated under sea state conditions such as wind, current, and wave loads. The sea state condition was selected from the measured data of West Africa offshore. The long-term sea state usually consists of a number of short-term sea states. The chosen sea states are listed in Tables III-V. The Ochi-Hubble wave spectrum and KAIMAL wind spectrum was used for each sea state.

D. Riser Effect

FPSO platform has been connected with a lot of risers which are necessary to consider the mooring analysis. In this paper, the effect of risers is compared in view of the calculated fatigue damage of mooring lines.

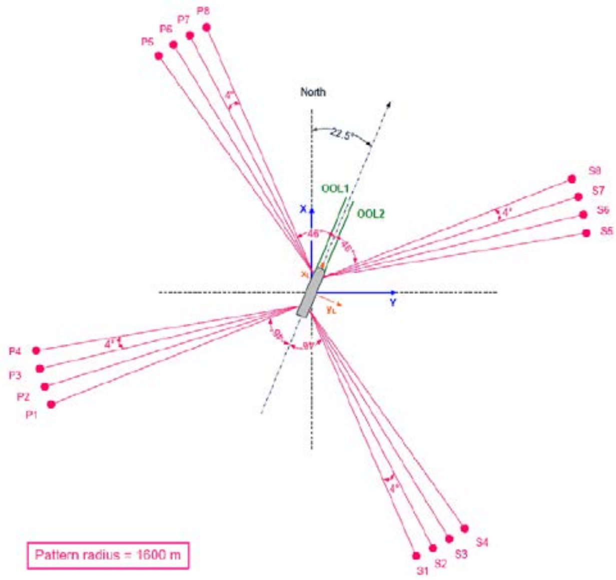

Fig. 1 Arrangement of mooring system

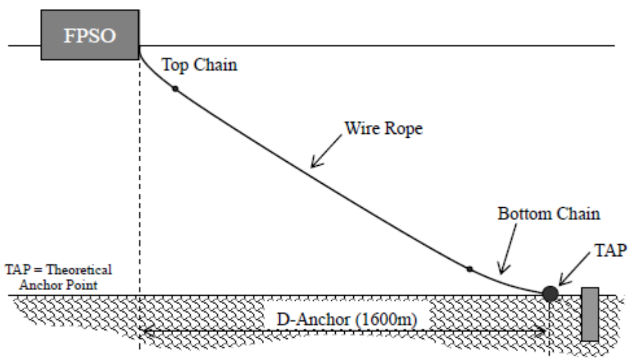

Fig. 2 Configuration of mooring line

TABLE II
MOORING LINE CHARACTERISTICS

Component	Characteristics	Value
Top chain	Property of material	R3 Studless Chain
	Nominal diameter	147 mm
	Line length	27 ~ 62 m
	Breaking strength	15536 kN
	Line axial stiffness	1319.26 MN
	Line weight in water	380.0 kg/m
Wire rope	Property of material	Spiral Strand Wire Rope
	Nominal diameter	111 mm
	Line length	1850 m
	Breaking strength	12500 kN
	Line axial stiffness	1200.48 MN
	Line weight in water	50.68 kg/m
Bottom chain	Property of material	R3 Studless Chain
	Nominal diameter	132 mm
	Line length	190 m
	Breaking strength	14508 kN
	Line axial stiffness	1189.06 MN
	Line weight in water	306.0 kg/m

TABLE III
WIND SCATTER DIAGRAM

Vw [a] (m/s)	Direction from North (Deg)															
	0	22.5	45	67.5	90	112.5	135	157.5	180	202.5	225	247.5	270	292.5	315	337.5
0.5	0.01	0.01	0.00	0.01	0.01	0.00	0.02	0.02	0.03	0.03	0.01	0.02	0.01	0.01	0.01	0.00
1.5	0.05	0.03	0.06	0.05	0.09	0.15	0.23	0.38	0.49	0.49	0.47	0.34	0.17	0.09	0.05	0.06
2.5	0.04	0.03	0.06	0.07	0.14	0.35	0.70	1.62	2.54	2.86	2.03	1.08	0.50	0.25	0.11	0.07
3.5	0.02	0.01	0.01	0.01	0.06	0.20	0.81	2.93	6.65	7.07	3.96	1.43	0.45	0.12	0.06	0.01
4.5			0.01	0.01	0.01	0.06	0.39	2.90	9.42	10.35	4.88	1.28	0.27	0.06	0.01	0.01
5.5				0.00	0.00	0.01	0.12	1.27	6.09	8.45	3.97	0.86	0.10	0.01	0.01	0.01
6.5				0.00			0.01	0.26	1.83	3.77	2.08	0.28	0.01			
7.5								0.02	0.24	0.69	0.42	0.07	0.01			
8.5								0.01	0.01	0.07	0.04	0.01				
9.5										0.00	0.00					

[a] Vw = averaged wind velocity for one hour

TABLE IV
CURRENT SCATTER DIAGRAM

Vcr [a] (m/s)	Direction from North (Deg)								Vcr [a] (m/s)	Direction from North (Deg)							
	0	45	90	135	180	225	270	315		0	45	90	135	180	225	270	315
0.01	0.11	0.12	0.09	0.10	0.10	0.08	0.09	0.07	0.37	0.25	0.30	0.30	0.19	0.05	0.06	0.20	0.44
0.03	0.33	0.29	0.32	0.29	0.27	0.28	0.28	0.32	0.39	0.26	0.21	0.32	0.17	0.02	0.05	0.18	0.37
0.05	0.50	0.58	0.57	0.49	0.40	0.38	0.46	0.47	0.41	0.24	0.13	0.18	0.10	0.01	0.03	0.11	0.33
0.07	0.69	0.84	0.78	0.64	0.57	0.56	0.58	0.57	0.43	0.15	0.08	0.11	0.03	0.01	0.02	0.11	0.25
0.09	0.84	1.11	1.01	0.78	0.74	0.63	0.71	0.60	0.45	0.16	0.08	0.10	0.04		0.01	0.09	0.18
0.11	0.88	1.18	1.21	0.84	0.73	0.74	0.73	0.71	0.47	0.11	0.05	0.07	0.02		0.01	0.07	0.16
0.13	0.96	1.31	1.33	0.88	0.80	0.69	0.75	0.81	0.49	0.11	0.04	0.05	0.01		0.00	0.07	0.15
0.15	0.99	1.54	1.27	1.01	0.93	0.62	0.72	0.80	0.51	0.10	0.04	0.03			0.01	0.06	0.13
0.17	0.97	1.41	1.39	0.98	0.85	0.67	0.74	0.75	0.53	0.08	0.01	0.03	0.01		0.01	0.04	0.08
0.19	0.98	1.28	1.37	0.90	0.75	0.54	0.66	0.81	0.55	0.07	0.01	0.04	0.00			0.03	0.07
0.21	0.84	1.32	1.22	0.94	0.60	0.42	0.56	0.78	0.57	0.03	0.01	0.03				0.02	0.05
0.23	0.73	1.00	1.16	0.93	0.58	0.39	0.48	0.67	0.59	0.03		0.05	0.00			0.02	0.05
0.25	0.61	0.97	1.10	0.71	0.47	0.32	0.44	0.61	0.61	0.01		0.05				0.01	0.04
0.27	0.54	0.81	0.99	0.67	0.39	0.26	0.39	0.64	0.63	0.01		0.02				0.01	0.06
0.29	0.51	0.77	0.97	0.55	0.28	0.22	0.42	0.58	0.65	0.00		0.02					0.05
0.31	0.46	0.56	0.76	0.50	0.19	0.15	0.35	0.57	0.67			0.01				0.00	0.01
0.33	0.42	0.50	0.55	0.41	0.13	0.12	0.25	0.55	0.69			0.01					0.01
0.35	0.35	0.35	0.41	0.33	0.07	0.12	0.20	0.53	0.71			0.00					0.00

[a] Vcr = current velocity

III. FATIGUE ANALYSIS

A. S-N Curve

According to API RP 2SK [4], S-N curve presents the number of cycles to failure for a specific mooring component as a function of a constant normalized tension range, based on the results of experiments. For mooring lines, *T-N* approach which only considers the tension fatigue and ignores the bending fatigue is normally used. Equation (1) presents the *T-N* curve:

$$NR^{M} = K \tag{1}$$

where N is the number of cycles, R is the ratio of tension range to reference breaking strength, and M and K are material parameters in the *T-N* curve.

According to Miner's linear cumulative damage rule, the annual cumulative fatigue damage D can be summed up from the fatigue damage D_i arising in a set of short-term sea states as shown in (2):

$$D = \sum_{i=1}^{n} D_i \tag{2}$$

The fatigue damage D_i in the i-th short-term sea state is calculated from (3):

$$D_i = \sum_{j=1}^{N} \frac{n_j}{N_j} \tag{3}$$

where n_j is number of cycles within the j-th tension range, N_j is allowable number cycles at the j-th normalized tension range given by *T-N* curve.

For fatigue analysis, the values of $M = 3.0$ and $K = 316$ for chain, and $M = 5.05$ and $K = 10^{(3.25 - 3.42\,Lm)}$ for wire, were chosen from [1]. L_m is the ratio of mean load to reference breaking strength for wire rope.

B. Numerical Simulation

For fatigue analysis, cyclic loading of mooring line needs to be obtained firstly. To calculate dynamic tension of mooring line, dynamic analysis was performed to generate a time simulation of 6 DOF motions of model using equation of motion. The equation of motion applied is shown in (4):

$$M(p,a) + C(p,v) + K(p) = F(p,v,t) \quad (4)$$

where *M(p,a)* is the system inertia load, *C(p,v)* is the system damping load, *K(p)* is the system stiffness load and *F(p,v,t)* is the external load. Also *p*, *v*, *a* and t are the position vectors, velocity vectors, acceleration vectors and simulation time, respectively.

TABLE V
WAVE SCATTER DIAGRAM

No.	Inc1	Hs1	Tp1	Inc2	Hs2	Tp2	Inc3	Hs3	Tp3	Occ	No.	Inc1	Hs1	Tp1	Inc2	Hs2	Tp2	Inc3	Hs3	Tp3	Occ
1	225	1.3	13	203	0.8	9	180	0.3	7	230	43	225	0.3	11	203	0.8	9	203	0.3	5	46
2	203	1.3	13	203	0.8	9	203	0.3	5	228	44	225	1.3	15	203	1.3	9	203	0.8	7	46
3	203	0.8	11	203	0.8	7	180	0.3	5	218	45	203	1.3	15	203	1.3	11	180	0.8	9	44
4	203	1.3	11	0	0.0	0	0	0.0	0	198	46	203	0.8	9	203	0.8	7	203	0.8	5	43
5	225	0.8	13	203	0.3	9	180	0.3	5	184	47	203	0.3	11	203	0.3	9	180	0.3	5	42
6	225	0.8	13	203	0.8	9	180	0.3	5	184	48	225	1.8	15	203	0.8	9	203	0.3	9	42
7	225	1.3	13	203	0.3	7	158	0.8	5	179	49	203	0.3	17	203	0.8	11	180	0.3	9	40
8	203	0.8	11	203	0.3	7	338	0.8	5	146	50	225	0.3	17	225	0.8	11	180	0.3	5	40
9	225	0.3	15	203	0.8	11	203	0.3	5	146	51	203	1.3	13	180	0.3	7	180	0.3	7	39
10	203	1.3	9	0	0.0	0	0	0.0	0	141	52	203	2.3	15	0	0.0	0	0	0.0	0	39
11	203	0.8	13	203	0.8	9	180	0.3	7	131	53	225	0.8	15	225	0.8	11	203	0.8	7	39
12	203	1.3	13	0	0.0	0	0	0.0	0	126	54	203	0.3	13	203	0.3	9	203	0.3	5	38
13	203	1.3	11	203	0.8	7	180	0.3	5	102	55	225	0.3	15	225	0.3	11	203	0.3	7	38
14	225	0.3	13	203	0.8	9	203	0.3	5	102	56	203	1.3	13	180	0.8	9	180	0.3	5	36
15	203	1.3	13	203	0.3	7	180	0.3	5	91	57	225	0.3	13	203	1.3	9	180	0.3	7	36
16	225	0.8	11	203	0.8	7	135	0.8	5	90	58	225	1.8	13	0	0.0	0	0	0.0	0	36
17	203	0.8	13	203	0.3	9	203	0.3	5	88	59	203	1.8	13	203	0.8	9	203	0.3	7	35
18	203	1.3	11	203	0.3	5	225	0.3	5	88	60	225	1.3	15	203	0.3	9	180	0.3	9	35
19	203	1.3	13	203	1.3	9	180	0.3	9	85	61	203	0.8	11	180	0.3	7	180	0.3	5	34
20	225	0.8	15	203	0.8	9	180	0.3	9	85	62	203	1.3	11	225	0.3	5	203	0.3	5	34
21	225	1.3	15	203	0.8	9	203	0.3	9	85	63	225	0.8	13	203	1.3	9	225	0.3	5	34
22	203	1.8	13	0	0.0	0	0	0.0	0	84	64	225	1.3	13	180	0.8	7	203	0.8	5	34
23	225	0.3	15	225	0.8	11	203	0.3	5	83	65	225	2.3	15	0	0.0	0	0	0.0	0	34
24	225	0.3	15	203	1.3	11	203	1.3	9	79	66	203	2.3	13	0	0.0	0	0	0.0	0	33
25	203	0.8	9	203	0.3	7	203	0.3	3	77	67	225	1.3	13	180	0.3	7	203	0.3	5	33
26	225	1.3	13	203	1.3	9	90	0.8	5	75	68	203	0.8	9	0	0.0	0	0	0.0	0	31
27	225	0.8	11	203	0.3	7	180	0.3	5	74	69	203	0.8	11	0	0.0	0	0	0.0	0	31
28	225	1.3	13	0	0.0	0	0	0.0	0	73	70	203	1.3	11	180	0.3	7	225	0.3	5	30
29	203	0.8	13	203	1.3	9	203	0.3	7	70	71	203	0.8	11	225	0.3	7	180	0.3	7	29
30	203	0.3	15	203	0.8	11	203	0.3	7	67	72	203	1.8	15	0	0.0	0	0	0.0	0	29
31	203	1.3	15	203	0.8	9	203	0.8	9	58	73	203	0.3	15	203	0.3	11	203	0.3	7	28
32	225	0.3	17	203	0.8	11	180	0.3	7	58	74	225	0.8	15	203	1.3	9	180	0.8	7	27
33	225	0.3	13	203	0.3	9	203	0.3	5	56	75	225	1.3	11	203	0.3	7	90	0.8	5	27
34	225	1.8	15	0	0.0	0	0	0.0	0	56	76	225	1.8	13	203	0.8	7	225	0.3	7	27
35	225	0.8	15	203	0.3	9	203	0.3	7	53	77	203	0.8	15	203	1.3	9	180	0.8	9	26
36	203	0.8	15	203	0.8	11	203	0.8	7	51	78	203	2.3	11	0	0.0	0	0	0.0	0	26
37	203	0.3	13	203	1.3	9	203	0.3	7	48	79	203	1.8	15	203	1.3	9	0	0.0	0	25
38	203	0.3	15	203	1.3	11	203	0.3	9	48	80	225	0.3	17	203	1.3	11	203	0.8	9	25
39	203	0.3	11	203	0.8	7	180	0.3	5	47	81	225	1.3	17	225	0.8	13	180	0.8	9	24
40	203	0.3	13	203	0.8	9	180	0.3	7	47	82	203	1.8	15	203	0.8	7	203	0.8	9	23
41	203	1.8	11	0	0.0	0	0	0.0	0	47	83	225	0.8	15	225	0.3	11	203	0.3	7	23
42	225	0.3	15	203	0.3	11	203	0.3	7	47	84	203	0.3	15	225	0.8	11	203	0.3	7	22

Inc = wave heading, Hs = significant wave height, Tp = peak period, Occ = occurrence.

The dynamic behavior of mooring lines can be split into two modes as shown in Fig. 3; wave frequency (WF) from the six degrees of freedom of vessel motion, and low frequency (LF) due to second order drift forces [5].

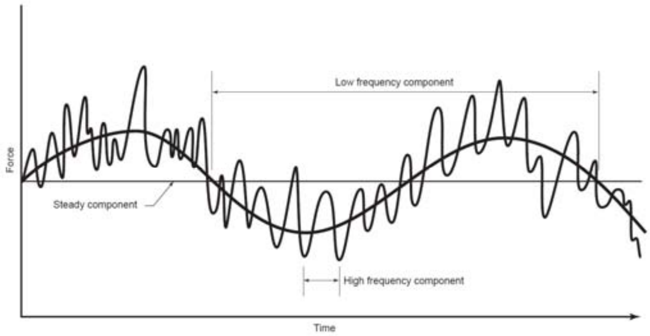

Fig. 3 Typical dynamic behavior of wave frequency and low frequency

To perform dynamic analysis, OrcaFlex was applied in this study. The model for dynamic analysis of the FPSO platform and its mooring lines is shown in Fig. 4.

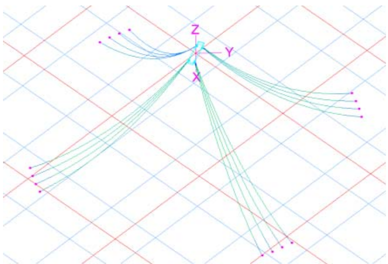

Fig. 4 Dynamic analysis model

Fig. 5 shows a tension time series of the representative P1 mooring line calculated from dynamic analysis. Line tension loads were captured at the first chain link position from fairleads of FPSO under wave scatter diagram No. 183. The rain-flow counting method is employed to count the calculated mooring line tension. The time domain cycle counting is generally considered to be the most accurate method for fatigue damage calculation, and then resultant fatigue damages of mooring lines were calculated for each condition.

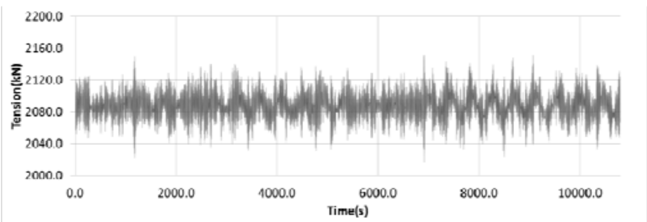

Fig. 5 Tension time series of P1 mooring line for wave scatter No. 183

IV. Sensitivity Study

Spread mooring system of FPSO installed in West Africa offshore was considered in this sensitivity studies. Based on the sea states of target installation field, several governing parameters applied to the sensitivity studies were investigated the effects of fatigue damage. In fatigue analysis, because of the most critical point, first chain link connected with fairleads of FPSO was selected as the target segment. In this study, the only representative intermediate condition was mainly taken into account for sensitivity study.

A. Environmental Loads

Fatigue analysis of mooring system should consider the environmental conditions of wind, current, and wave. Reflecting the sea states of West Africa offshore, fatigue damages at the first chain link position from fairleads of FPSO were calculated as shown in Fig. 6. The fatigue damage in wave is much higher than others. And fatigue damage in current is significantly smaller than that of wind. In terms of mooring line fatigue, the contribution of environmental forces from wind and current acting on the mooring lines is relatively small.

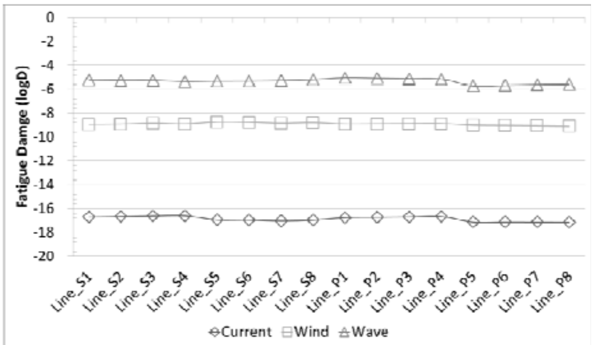

Fig. 6 Fatigue damage of mooring lines under each environmental loads

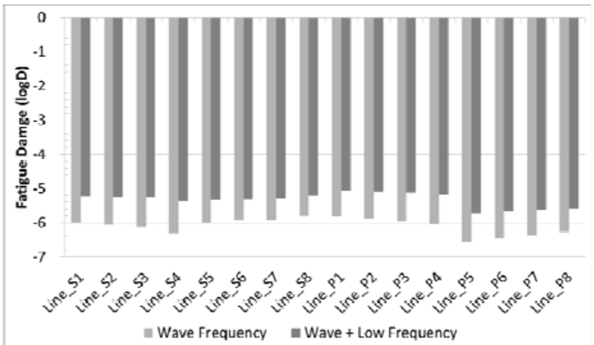

Fig. 7 Fatigue damage of mooring lines for mode of dynamic behavior

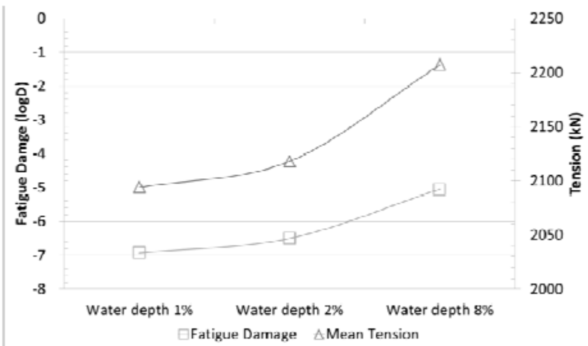

Fig. 8 Fatigue damage of P1 mooring line for vessel offsets

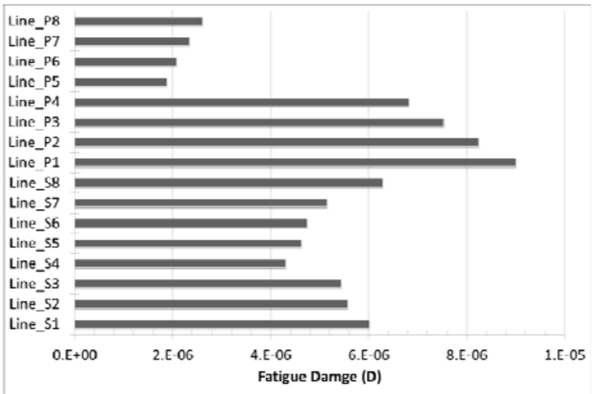

Fig. 9 Fatigue damage of each mooring positions for wave loads

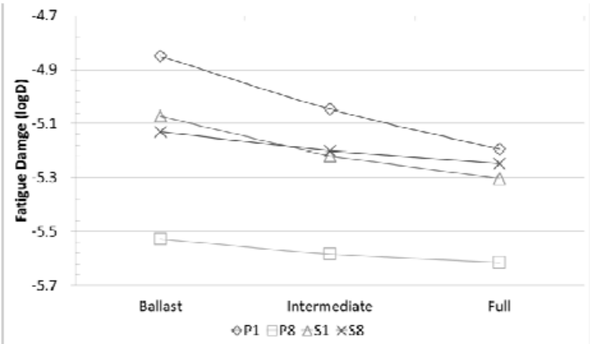

Fig. 10 Fatigue damage of mooring lines for loading conditions

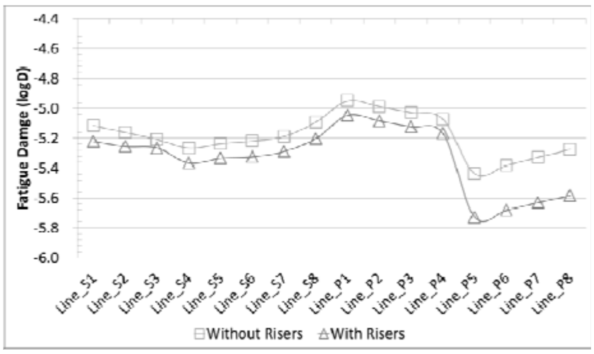

Fig. 11 Fatigue damage of mooring lines for riser behavior

B. Type of Responses

Global responses of moored vessel have WF motions and LF Motions. The dynamic behavior of mooring lines would be also occurred into combination of WF and LF modes. In this study, the effect of fatigue damage calculated from two modes of response was compared respectively. To find out wave frequency effect in term of fatigue, two cases were studied. Firstly, fatigue analysis by WF and LF case was carried out and secondly only WF motion case was dynamically simulated in the state which the vessel position was fixed at static equilibrium position and the resultant fatigue damages were calculated. As shown in Fig. 7, fatigue damages by the only WF motion were not much different with the fatigue damages by WF and LF motions. The fatigue damage of WF mode is more significant than that of LF mode. Therefore, fatigue damage of mooring lines is highly impacted by wave frequency motions.

C. Vessel Offsets

The primary purpose of mooring system is to maintain an FPSO on station within a specified tolerance, typically based on an offset limit determined from the configuration of the risers. The mooring system provides a restoring force that acts against the surrounding environmental loads as wind, current and wave. The horizontal components of the mooring line tension give such restoring force. Until horizontal restoring forces by mooring lines are balanced from environmental loadings, the FPSO will be offset as shown in Fig. 12.

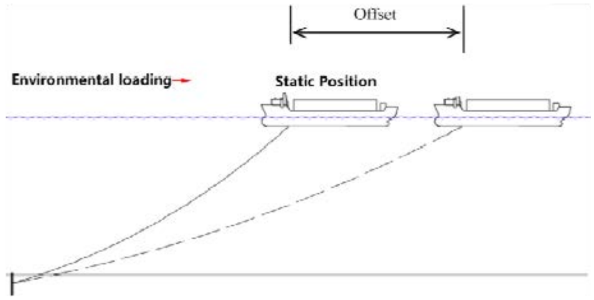

Fig. 12 Vessel offsets and tension effect

The fatigue damages for P1 mooring line were calculated at a fixed offset position according to the level of vessel offset in the most tensioned direction of mooring line. According to Fig. 8 which shows the results for 1%, 2%, and 8% offsets of water depth, the longer offset is horizontally moved due to the environmental loadings, the higher mean tension of the mooring line is occurred. The higher mean tension of the mooring line causes the larger fatigue damages.

D.Mooring Positions

The fatigue damages of mooring lines for wave loads were obtained from fatigue analysis. As shown in Fig. 9, external lines of P1, P8, S1 and S8 were the more damaged ones in each mooring bundles. According to the sea state of West Africa offshore, swell component which mainly has the direction in longitudinal axis of FPSO is predominant. These wave loads give an effect on the pitch motion of FPSO. External mooring lines positioned at the bow and stern side would be more damaged by the larger heave motion of fairleads due to vessel pitch motion.

E. Loading Conditions

Floating production systems such as FPSO installed at field has been positioned during a long life-time. FPSO platform has various loading conditions for operation. To compare the effect of loading conditions, it is assumed that each loading condition has 100% of the life-time for fatigue calculations. The calculated fatigue damages of external mooring lines were presented in Fig. 10. The highest fatigue damage occurred at the ballast condition with lower draft which has higher mean tension.

F. Riser Behavior

FPSO platform is connected with risers for production and injection in addition to mooring lines. The dynamic effects for the risers were considered through a coupled analysis that all interactions among mooring lines, risers and vessel are modelled directly [6]. As shown in Fig. 11, from the results of fatigue analysis, it is found that the dynamic effects of the risers give lower fatigue damages than without risers. In case of mooring analysis model including risers, mean drift loads on risers and mooring lines are sufficiently accounted. And also, for weakly damped systems such as moored vessels, the damping effects from the mooring and riser systems give the influence in accordance with response of low frequency motion.

V. Conclusion

This paper deals with sensitivity study for the various parameters which affect the fatigue damage of the mooring lines. Mooring lines connected with spread moored FPSO in the West Africa field have been studied through this research and the following results from fatigue analysis of mooring line are summarized,

1) A wave load in view of fatigue is a governing parameter among environmental loads such as wind, current, and wave.
2) Fatigue damage of mooring lines is highly impacted by WF motions of moored vessel.
3) Wave frequency fatigue analysis at larger vessel offset position leads to the higher fatigue damage when it is applied with the equivalent environmental loads.
4) In the West Africa offshore, swell component which mainly orientated into the direction in longitudinal axis of spread moored FPSO gives the higher fatigue damage of external mooring lines by the larger heave motion of fairleads due to vessel pitch motion.
5) Regarded with loading conditions, the lower draft results in the higher mean tension of mooring line. These high line tensions produce the more fatigue damage.
6) Regarding riser behavior, mean drift loads and damping effect of riser gives the good vessel LF motions and good fatigue performance.

Based on these sensitivity studies, mooring fatigue analysis can be made as a simplified approach to reduce a lot of load cases and computation time regarded with the effects of design parameters. However, simplified fatigue analysis method of spread mooring line should only be applied for initial scantlings.

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