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Fatigue Analysis of Pedestal-mounted Crane on Offshore Fixed Platform Using Finite Element Method

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Abstract

The crane is one of the production support facilities on the offshore platform. During operation, it receives a large load, both from the environment and the crane's operational load, so the crane's strength and operational safety need to be maintained. Cyclic loading can cause the crane structure to experience fatigue. This evidence shows the importance of analyzing the crane pedestal. How much the load affects the fatigue life of the structure. A previous study on the crane loading effect on the Floating Production Storage and Offloading (FPSO) was provided as a comparison. Local fatigue analysis was performed on the pedestal crane using the Finite Element Method (MEH) and ANSYS Workbench 19.1 software. The validation stage was carried out by comparing the value of the reaction force, moment, and maximum equivalent stress (Von-Mises) on the crane pedestal between the simulation results and hand-calculation. Furthermore, a static simulation was carried out to obtain the stress value as the basis for cyclic loading. A dynamic simulation was carried out based on the stress obtained from the static simulation to determine the structure's critical point and fatigue life. The fatigue analysis was carried out based on the Palmgren-Miner Theory. It is found that the load that has the most significant influence on crane pedestal fatigue is the operational load with a contribution of 80.7%, wind load of 19.3%, and wave load of 0%. The minimum estimated fatigue life of the crane pedestal structure is 96.5 years or close to 5 times the design life. Compared to the crane in the FPSO in previous studies, the most significant difference lies in the contribution of wave loads, where the wave load on the FPSO has the most considerable contribution to crane structure fatigue (97.8%).

Keywords: Fatigue life analysis, finite element method, offshore fixed platform, pedestal-mounted crane

1. Introduction

Offshore structures have developed a lot with different development objectives [1]. One of the offshore structures currently operating in Indonesia is a wellhead type fixed offshore platform in the Madura Strait, which is operated by Husky-CNOOC Madura Limited (HCML). This platform produces crude oil using wells as the outlet for crude oil and gas and injection wells to inject water. This pavilion is located offshore in the Madura Strait, East Java. The platform was installed at a depth of about 316.4 feet measured from the mean sea level.

In operation, fixed offshore platforms are subject to significant loads from the surrounding environment. Therefore, the fatigue analysis of offshore buildings and the supporting equipment components therein is essential to be carried out. The crane that is used as a material transfer tool is one of the facilities on the offshore platform that has a significant enough chance of experiencing fatigue, so it is necessary to maintain its structural strength so that it is safe during operation. The crane used on the platform can be seen in Figure 1.

In this study, a crane pedestal fatigue due to environmental and operational loads on a fixed offshore platform was carried out and the influence of each load on the structure's fatigue life. In addition, the effect of loading on the fatigue life of offshore platform cranes is also compared to that of previously studied FPSO cranes.

Structural analysis was carried out on the crane pedestal structure with the help of ANSYS Workbench 19.1 software based on FEM [2] and Palmgren-Miner Theory for the calculation of fatigue life.

Figure 1. Pedestal crane on a fixed offshore platform.

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2. Research Methodology

2.1. Structural Model

The specifications and configurations of the analyzed crane pedestal cylinders [3], can be seen in Table 1 and Table 2. Figure 2 shows the pedestal crane configuration. The crane and the beam on the deck that acts as a clamp for the crane pedestal are modeled as in Figure 3. Only pedestal and top ring modeling were used, ignoring the five existing beams. The boundary condition given to the object being analyzed was fixed support on the top of the crane pedestal's top ring. The boundary conditions in modeling can be seen in Figure 4.

2.2. Material

Steel and other structural materials were determined according to standard Structural Materials Specifications or from the data contained in the relevant drawing [3, 4]. The properties of the materials used for the design are shown in Table 3 and Table 4.

Table 1. Pedestal crane specification.

Type	Fixed Length Box Boom Cylinder Crane
Operating Weight	27.5 ton
Safe Working Load	5 ton
Length	16.490 m
Height	9.673 m (up to boom)
Maximum Work Radius	13.7m
Minimum Work Radius	3.1m
Design life	20 years

Table 2. Geometry and property of cylinder material crane pedestal

Cylinder	I	II	III
Outer Diameter (OD)	1.04 m	1.04 m to 1.41 m	1.41 m
Thickness (t)	31.75 mm	31.75 mm	31.75 mm
Height (h)	3.05 m	0.55 m	0.50 m
Modulus of elasticity		29,733 ksi	
Steel density		490.00 lb/ft^3	
Pedestal yield stress		50 ksi	

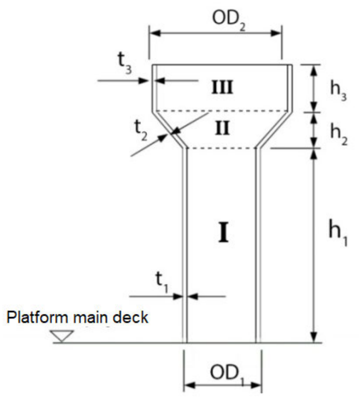


Figure 2. Crane pedestal configuration.

Figure 3. Geometry modeling of crane pedestal.

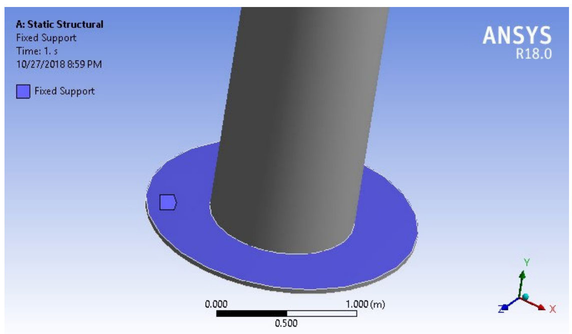


Figure 4. Fixed support boundary conditions on the top ring pedestal base.

Table 3. Material properties for design.

Material	Property	Value
Steel	Density	8.653E-09 ton/mm^3
	Modulus of elasticity	206,843 MPa
	Shear modulus	76,923 MPa
	Poisson's ration	0.3
	Coefficient of thermal expansion	1.17E-5/°C
	Design yield strength	Type I (Mild Steel) – 248 MPa Type II (High Stength Steel) – 345 MPa

Table 4. Allowable stress based on the number of cycles.

Number of Loading Cycles		Allowable Stress Range (MPa)
From	To	
20,000	100,000	193
100,000	500,000	110
500,000	2,000,000	69
Over 2,000,000		48

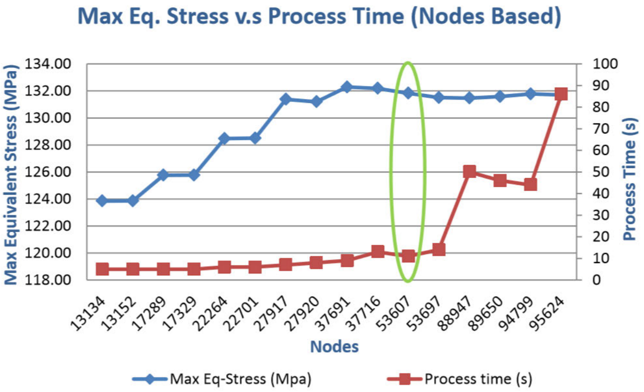


Figure 5. Convergence test results as a function of the number of the nodes.

Table 5. Wind loading condition.

Load Condition	9	10	11	12	13
Wind speed (m/s)	5.5	8	10	13.9	17.3
$F_{24.08}$ (N)	80.15	169.95	309.6	512.12	794.21
$F_{24.63}$ (N)	17.06	36.15	65.82	108.93	168.85
$F_{25.13}$ (N)	17.9	37.95	69.17	114.54	177.44
M_{boom} (Nm)	2,560	5,422	9,880	16,351	25,342
F_{boom} (N)	384.26	814.04	1,483	2,455	3,805
$F_{selfweight}$ (N)	231E+03	231E+03	231E+03	231E+03	231E+03
$M_{selfweight}$ (Nm)	1.543E+06	1.543E+06	1.543E+06	1.543E+06	1.543E+06
Cycle (Hours)	70,720	88,860	14,380	1,260	60

2.3. Meshing

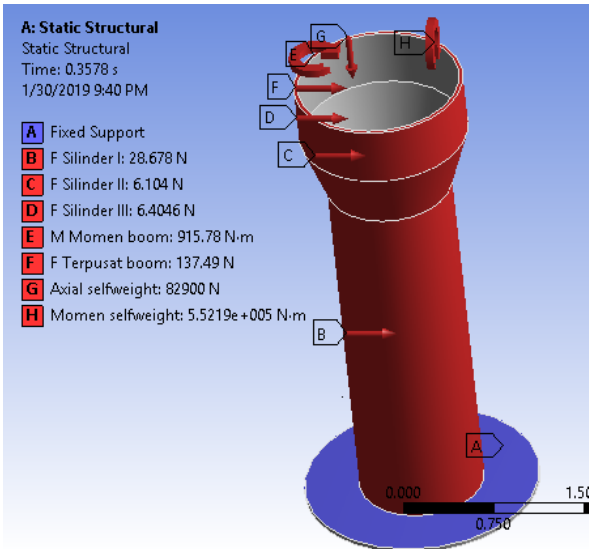
The convergence test was done by comparing the meshing results using the span angle coarse and medium. After the results of each test were obtained, the two were compared by sorting the number of nodes. Then, the meshing with the smallest number of nodes was selected at the point where the object's equivalent stress began to converge. The method used is Hex Dominant with Adaptive size function and Fine relevance center. The results of the tests can be seen in Figure 5. The final meshing method used medium span angle and element size of 50 mm, with the total number of nodes of 53,607 or total number of cells of 10,236 and the average mesh metrics was 0.68039. Calculation of the effect of cumulative damage on platforms using the S-N curve for tubular joints [5], regardless of the corrosion effects.

2.4. Loading Condition

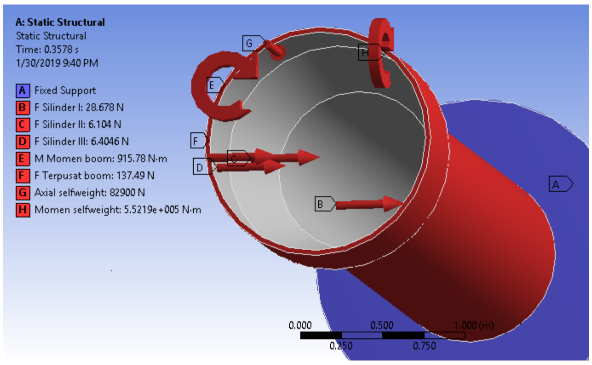
The input of wind loading in ANSYS Workbench 19.1 software is the axial force due to self-weight, wind force, and moment due to wind force. Input to the software can be seen in Figure 6. The wind loading conditions with variations in wind speed based on crane pedestal elevation and boom is obtained as in Table 5.

The operational loading input on ANSYS Workbench

19.1 software is an axial force due to self-weight and moment due to crane lifting force. The input parameter to the software can be seen in Figure 7. The operational loading conditions with variations in the working radius of the boom in conditions without and with crane lifting loads is shown in Table 6.

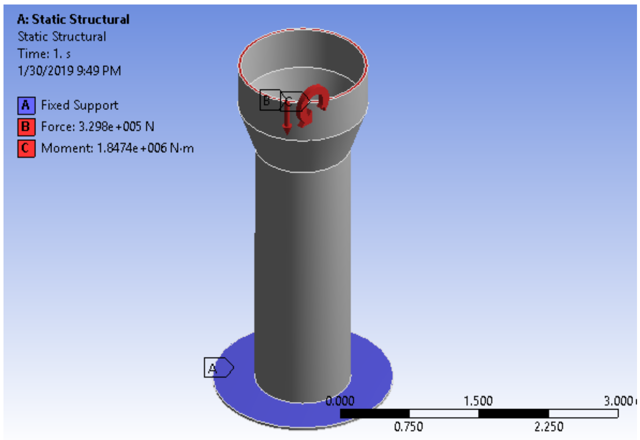


(a) Side view

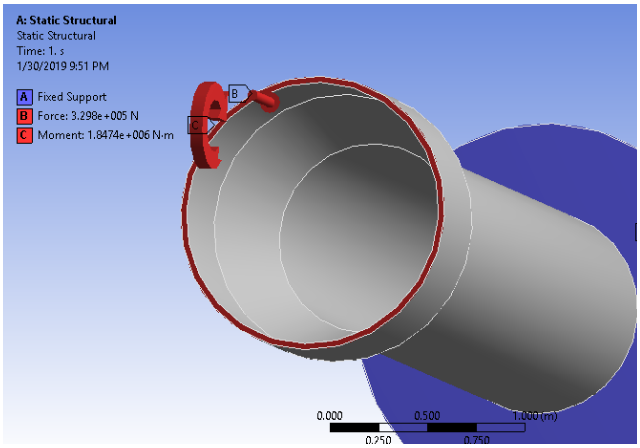


(b) Top view

Figure 6. Wind loading input on the crane.



(a) Side view



(b) Top view

Figure 7. Operational loading input on the crane.

Table 6. Operational Loading Condition.

Load Condition	Load (Ton)	Radius (m)	Force (N) Without Lifting Load	Momen (Nm) Without Lifting Load	Cycle
1		3.1	231,695	1,543,297	518,400
2		6	231,695	1,543,297	518,400
3		10	231,695	1,543,297	518,400
4		13.7	231,695	1,543,297	518,400
	10		**With Lifting Load**	**With Lifting Load**	
5		3.1	329,795	1,847,407	518,400
6		6	329,795	2,131,897	518,400
7		10	329,795	2,524,297	518,400
8		13.7	329,795	2,887,267	518,400

3. Result and Discussion

3.1. Wave Load

In operation, the platform is subjected to loads from sea waves. Several design criteria must be met to ensure the platform's structural integrity and serviceability, such as local and global deflections in the horizontal and vertical directions [3], as shown in Table 7. For the relevance of this study, the criterion that needs to be considered is the global deflection of the platform to the horizontal on the leg.

When a crane is placed on a mobile structure, it can experience inclination. The movement of the structure where the crane is anchored causes the crane base to experience two rotational motion modes, namely heel, and trim. Both of these movements cause a moment of inertia that acts on the crane base and can be calculated using the equation $M = I \times \alpha$, where α is the amount of acceleration at the crane base. The two modes of rotational motion are illustrated as in Figure 8.

Analysis of simulation results with the help of offshore structure analysis software (SACS) conducted by the company shows that the maximum deflection that occurs due to working loads, including environmental loads such as ocean waves, is 4.07" (= 102.16mm) [3]. The deflection that occurred in the B2 leg of the bridge resulted in a vertical inclination of 0.054. The deflection is described in Figure 9.

Meanwhile, according to API, the value of horizontal acceleration due to crane inclination varies depending on the placement of the crane. Horizontal crane acceleration as in [5], can be seen in Table 8. The platform is fixed with an inclination angle that does not exceed 0.5° in the heel and trim direction, accelerated by 0.0 ft/s^2, as required by API-2C. Thus, it can be concluded that there is no moment of inertia that occurs on the crane base due to the movement of the platform. This indicates that the wave load results in the possibility of movement on the offshore-fixed platform and the contribution of the loading to the reduction of the platform's jacket leg fatigue life but does not have a significant effect on the crane pedestal fatigue life. So that in this study, the simulated loading was only wind and operational loads.

Table 7. Offshore platform deflection limit.

Component	Deflection Limit
Legs/columns	The maximum horizontal/lateral deflection from the mudline to the top of the platform structure is the maximum sway with a height of H/200.
Crane Pedestal	The maximum tilt angle is not more than 0.5°.

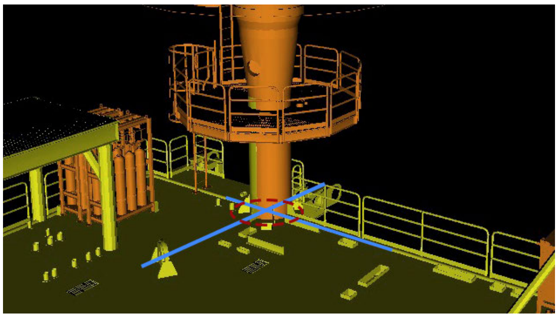


Figure 8. Inclination direction of crane based on fixed platform.

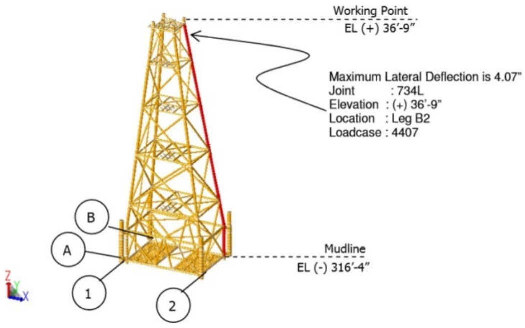


Figure 9. Maximum lateral deflection.

Table 8. Horizontal acceleration and inclination angle based on where the crane is placed [6].

Crane mounted on:	Crane Static Inclination Angle (°) Heel	Crane Static Inclination Angle (°) Trim	Crane Dynamic Horizontal Acceleration (g)
Fixed Platform	0.5	0.5	0.0
Tension Leg Platform (TLP)	0.5	0.5	$0.007 \times H_{sig} \geq 0.03$
Spar	0.5	0.5	$0.007 \times H_{sig} \geq 0.03$
Semisubmersible	1.5	1.5	$0.007 \times H_{sig} \geq 0.03$
Drillship	2.5	1	$0.007 \times (H_{sig})^{1.1} \geq 0.03$
FPSO	2.5	1	$0.007 \times (H_{sig})^{1.1} \geq 0.03$

3.2. Wind Load

Static analysis was carried out by finding the Equivalent (Von-Mises) stress value at each wind speed according to load conditions 9 to 13, where one wind speed at four different elevations is considered to occur at the same time. An example of static simulation results with the greatest Equivalent (Von-Mises) stress value, namely at the highest wind speed (17.3 m/s), can be seen in Figure 10. The static simulation results at each wind speed are presented in Table 9.

Furthermore, a dynamic simulation was carried out to find the value of life and damage with a predetermined cycle according to the Table. The type of loading used is Zero-Based, and can be seen in Figure 11. An example of dynamic simulation results with the largest damage value and the smallest fatigue life, namely at a wind speed of 8 m/s, can be seen in Figure 12. The dynamic simulation results at each wind speed are presented in Table 10. Dynamic calculations showed that the total damage ratio due to crane wind loads at five different wind speeds is 0.039944.

Table 9. Static simulation results of wind loading.

Wind speed (m/s)	Maximum Equivalent (von-Mises) Stress (Pa)
5.5	1.355216E+08
8.0	1.355229E+08
10.8	1.355251E+08
13.9	1.355291E+08
17.3	1.355357E+08

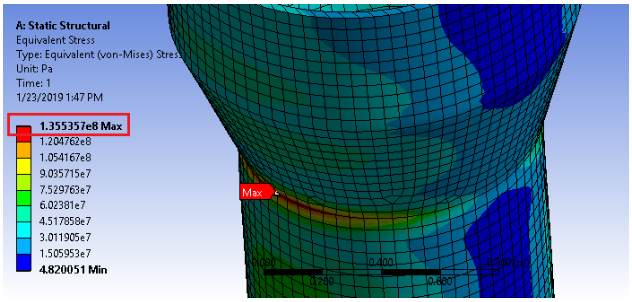


Figure 10. The equivalent (Von-Mises) stress value at wind speed 17.3 m/s

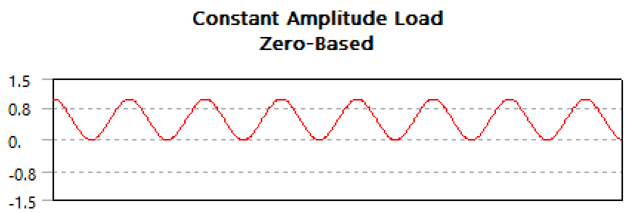
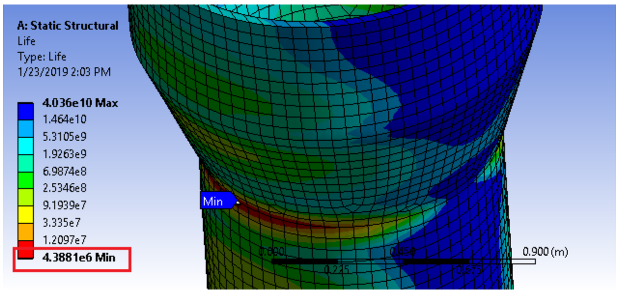
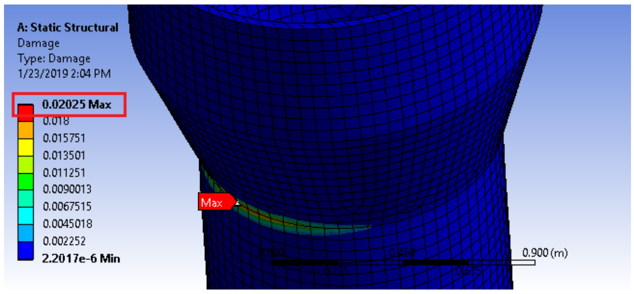


Figure 11. Zero-Based type loading



(a) Minimum life value



(b) Maximum damage

Figure 12. At wind speed of 8 m/s.

Table 10. Dynamic simulation results of wind loading.

Wind speed (m/s)	ni	Minimum Life (Ni)	Maximum Damage (ni/Ni)
5.5	70,720	4.3882E+06	1.6116E-02
8	88,860	4.3881E+06	2.0250E-02
10.8	14,380	4.3879E+06	3.2772E-03
13.9	1,260	4.3875E+06	2.8718E-04
17.3	60	4.3868E+06	1.3677E-05
		Total	**3.9944E-02**

3.3. Operational Load

In a static simulation of operational loading, a minimum and maximum stress value are required from two different loading conditions, namely maximum equivalent (Von-Mises) stress when the crane is not loaded as minimum stress, and maximum equivalent (Von-Mises) stress when the crane lifts the load of 10 Tons as the maximum stress, because the type of loading used is ratio.

The maximum equivalent (Von-Mises) value of the crane without load based on the static simulation results can be seen in Figure 13. Whereas an example of static simulation results with the largest Maximum Equivalent (Von-Mises) value, namely when lifting a maximum load of 10 tons with the largest radius of 13.7 m, is shown in Figure 14. The static simulation results for each radius are presented in Table 11.

Furthermore, a dynamic simulation was carried out to find the value of life and damage with a predetermined cycle according to Table 10. The type of loading used is the ratio. The type of loading ratio (R = 0.8297) on the Fatigue Tool can be seen in Figure 15.

This ratio is then used in dynamic simulations to calculate life and damage using the crane loading conditions to lift the maximum load. Each ratio was used under four loading conditions with different radii, according to the minimum and maximum stresses in the radius. An example of dynamic simulation results with the smallest life value and the most significant damage, namely at the largest radius (13.7 m), can be seen in Figure 16. The dynamic simulation results for each radius are presented in Table 12. The dynamic simulation results showed that the total ratio of cumulative damage due to crane operating loads at four different radii is 0.16722.

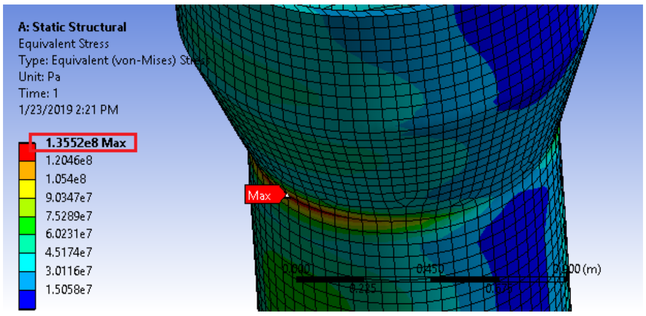


Figure 13. Equivalent (von-Mises) stress without load.

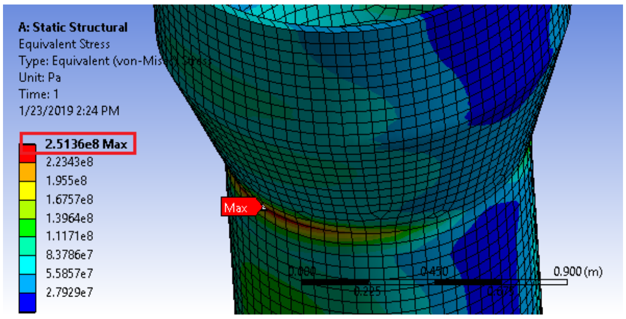


Figure 14. Equivalent (von-Mises) maximum load stress at a radius of 13.7 m.

Table 11. Static simulation result of operational loading.

Radius (m)	Maximum Equivalent (von-Mises) Stress (Pa) without load	Maximum Equivalent (von-Mises) Stress (Pa) with load
3.1	1.3552E+08	1.6333E+08
6	1.3552E+08	1.8741E+08
10	1.3552E+08	2.2063E+08
13.7	1.3552E+08	2.5136E+08

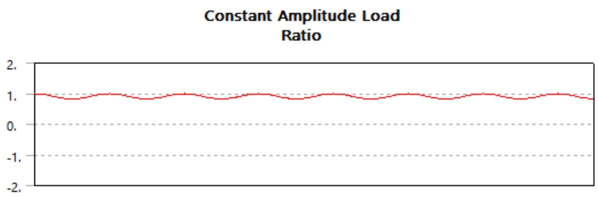
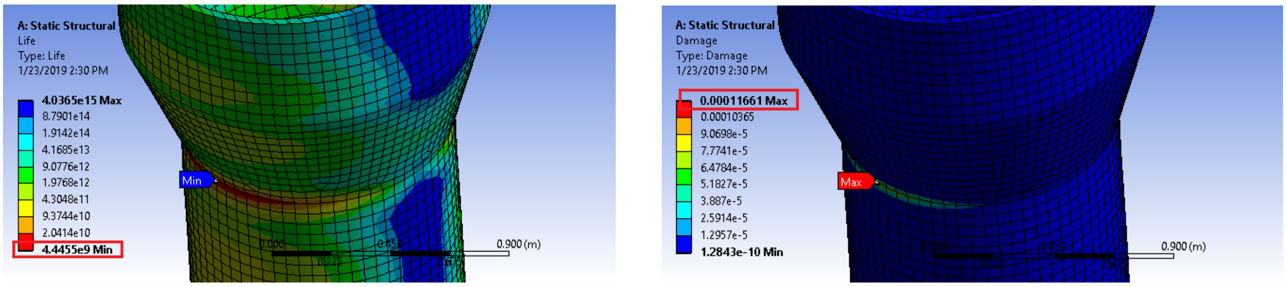


Figure 15. Type of loading ratio (R = 0.8297).



(a) Minimum life value

(b) Maximum damage

Figure 16. Dynamic simulation result at radius of 13.7 m.

Table 12. Dynamic simulation result

Radius (m)	Ratio	ni (cycle/year)	Ni (Min Life)	ni/Ni (Max Damage)
3.1	0.82973	581,400	4.4455E+09	1.1661E-04
6	0.72312	581,400	1.7790E+08	2.9140E-03
10	0.61424	581,400	1.2848E+07	4.0349E-02
13.7	0.53915	581,400	4.1860E+06	1.2384E-01
			Total	**1.6722E-01**

Table 13. Total fatigue analysis results.

Cumulative Damage Ratio	0.20716
Fatigue Life	96.54 years
Safety Factor	4.827

Table 14. The percentage of the contribution of loading to the fatigue of the crane pedestal structure.

Load	Contribution
Wave	0%
Wind	19.3%
Operational	80.7%

3.4. Total Fatigue Analysis

After obtaining the damage ratio due to each wave, wind, and operational loading, the three damage ratios were added to get the total cumulative damage ratio. Then from the damage ratio, the fatigue life and safety factor were obtained.

The results of the total fatigue analysis are presented in Table 13. The fixed platform has a design life of 20 years. Based on API RP2A, the platform's design life taking into account the safety factor 5.0 is 100 years. Based on the calculation results obtained in this study, the crane is feasible to operate because it has a fatigue life approaching the fatigue life of a fixed platform, which is 96.54 years.

3.5. Contribution of Loading

The effect of each load on the fatigue life of the crane pedestal is known from the analysis. The magnitude of the effect of the load is presented in Table 14. Based on the simulation results, it was found that the fatigue that occurs in the crane pedestal structure due to cyclic loads are most influenced by operational loads, which is 80.7%, followed by wind loads of 19.3%, and wave loads have no significant effect on the fatigue of the crane pedestal structure at fixed platform.

3.6. Comparison of Fatigue Analysis Results

Table 15 shows the comparison of data and loading analysis between crane manufacturing design limitations on a fixed platform as the object of the current study, actual crane loading, and previous research with crane research objects in Floating Production, Storage, and Offloading (FPSO).

While the comparison of the results of the analysis between the crane on a fixed platform as the object of the current study with the crane at the FPSO as the object of previous research is presented in Table 16.

The most significant difference between the results of the analysis between the current study and previous research lies in wave loads contribution. The last study shows that the wave load on the FPSO had the most significant contribution to the crane structure fatigue (97.8%). In wind and operational loading, the difference between the previous research and this study is due to the difference in wind speed in the fixed platform area and operating FPSO, the size and weight of each crane, and the lifting load and the number of cycles.

Table 15. Data comparison and crane loading analysis.

Parameter	Fixed platform design limitation	Fixed platform Current study	FPSO Previous research [7]
Design life	20 Years	20 Years	30 Years
Effect of wave loads on the object of research	The inclination angle does not exceed 0.5°	The inclination angle is 0.054° and the acceleration is **0.0 m/s^2**	Acceleration **1,456 m/s^2** in heave direction and **3,389 rad/s^2** in roll direction
Wind Speed	Crane operating wind speed **28.3 m/s**	**28.11 m/s**	**14.08 m/s**
Force due to wind load	Max **31,000 N**	**3,804.57 N**	**1,456.25 N**
Lift load	SWL **5 Ton**	**10 Ton** (SF=2.0)	**50 Ton**
Axial force due to operational load	Max **370,000 N**	**329,795 N**	**2,953,352 N**
Moment due to operational load	Max **3,200,000 Nm**	**2,887,267 Nm**	**2,448,580 Nm**

Table 16. Comparison of analysis results.

Analysis Result	Fixed platform	FPSO [7]
Damage ratio due to wave load	0.00	0.269
Damage ratio due to wind load	0.03994	7.22E-10
Damage ratio due to operational load	0.16722	0.00593
Total cumulative damage ratio	0.20716	0.2749
Estimated fatigue life	96.54 Years	109.309 Years
Safety Factor	4.827	3.644
Contribution of wave loads to structural fatigue	0%	97.8%
Contribution of wind loads to structural fatigue	19.3%	0.000000263%
Contribution of operational loads to structural fatigue	80.7%	2.2%

4. Conclusion

Based on the analysis that has been done, the following conclusions can be drawn. Loads that affect the fatigue life of crane pedestals on fixed platforms are sorted from those that have the most significant influence is operating loads and wind loads. The wave load only affects the fixed platform, but the movement that occurs on the platform does not significantly affect the fatigue of the crane pedestal structure.

The contribution of the effect of each loading to the fatigue that occurs in the crane pedestal structure is the operational load of 80.7%, the wind load of 19.3%, and the wave load of 0%. The minimum estimated fatigue life of the crane pedestal structure is 96.54 years or close to 5 times the design life, under the fixed platform's design with the safety factor (SF) = 5.0.

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