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Trunnion Structure Analysis with Rigging Variations at The Loadout Stage During Lifting Jacket Platform Process

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ABSTRACT

An offshore structure is a structure that is operated at an offshore base and has the general function of oil and gas exploitation and exploration. The making process of this structure is called the fabrication process. Fabrication is the process which is covered the whole activities to produce the structure. Lifting is a process that is included in this fabrication step.Many important lifting items correspond to the requirement to let the lifting process is working. A trunnion is a tubular member that helps lift the structure because it is where slings can be convoluted. Trunnion can be called lifting lugs, depending on the engineer at the company used.In this research, the trunnion that must be analyzed is the trunnion that has the general function for the jacket-to-lifting processes. In contrast, the researcher analyzed the effect of various rigging configurations. The considered variable of rigging configuration is the shape and amount of the spreader bar.

Keywords: *Trunnion, Loadout, Lifting, Jacket*

1. PRELIMINARY

An offshore structure is a structure that functions for many operating activities in offshore areas. Depending on the application, the general offshore structure is used for oil and gas exploitation and exploration activities. From the general specification, some of them consist of a deck dan framing structure [1]. The deck function is for the placement to accommodate all activities, such as human and equipment operation, and the framing deck is for refraining the deck as long and as strong as possible.

The production of the jacket is called the fabrication process. This process includes the assembling process to make a complete structure. The jacket type that will be fabricated at the site is based on the requirement needed that corresponds to the place condition and what the jacket is used for.

Loadout is a process that transports the jacket structure from the site to the barge, and several methods can be used to make the process work, such as the skidding method, the self-propelled module transport (SPMT) method, and the lifting method. In general uses around the world, the most used method for this process are skidding and lifting. Need to be noted that the lifting method is the most dangerous method among the other methods. However, it can be the most effective method depending on the better analysis result and the better the field practice.

A trunnion is a welded tubular member that is connected to the chord. The trunnion is placed where slings can be convoluted because the general function of this structure is to make horizontal lifting for the jacket [2]. Before the lifting process, the engineer must have detailed calculations for each analysis. Many factors influence the result from trunnion analysis based on the exercised rigging configuration.

2. BASIC THEORY

2.1 Jacket

Along with the growing demand for oil and gas, the number of exploration and exploitation activities for oil and gas also increases. Therefore, the production of offshore buildings also increases. During the fabrication process, many processes are also carried out, one of which is lifting. This lifting can be carried out horizontally and vertically depending on actual conditions. The lifting process is very risky; therefore, in-depth calculations are needed regarding the analysis of the strength of the structure of the jacket and the *trunnion* itself.

2.2 Loadout

Loadout is the stage where moving a structure to a means of transportation from the port. There are various methods in loadout, namely skidding, self-propelled modular transport, and lifting. Skidding is where the jacket is pushed using a hydraulic system over a skidway that extends from the yard to the barge. The self-propelled modular transport method transports the jacket structure from one moving place to another using a wheel system or so-called dollies. Lifting is a method where the jacket is moved to the barge by lifting it using a crane. In general, the loadout method still uses skidding and lifting.

2.3 Load

Load is one of the important factors in designing the building, considering the various analyses that will be carried out. Based on the analysis to be carried out, there are two types of loading, namely static and dynamic. The static load is the load or dead weight of the jacket structure itself. Loads can be modeled, but some are not, so it is necessary to transform these loads into loads that will act on the associated beam. Dynamic loads are loads caused by environmental factors such as wind that affect the jacket structure during the lifting process. Referring to *DNV-OS-H205-Sect.3,* dynamic loads are generated from parameters such as configuration rigging, type crane, procedure, structure jacket, and environmental conditions. The DAF (Dynamic Amplification Factor) approach is used in this research, where dynamic loads can be transformed into static loads. The value of the DAF in the lifting process is distinguished based on the condition where the structure is lifted and the weight lifted.

Table 1. *Dynamic Amplification Factor*

Gross Weight, W, in tons	Offshore	Onshore	Onshore (Moving)	Onshore (Static)
W ≤ 100	1.30	1.15	1.15	1.0
100 < W ≤ 1000	1.20	1.10	1.10	1.0
1000 < W ≤ 2500	1.15	01.05	01.05	1.0
W > 2500	1.10	01.05	01.05	1.0

2.4 Tubular Stress

Tubular stress is the stress that occurs in a pipe-shaped structure. The stress that occurs in the tubular includes normal stresses, shear stresses, and bending stresses. After that, there are allowable stresses where the criteria for compression and buckling loads, allowable stresses include axial stresses, column buckling, bending stresses, and shear stresses [3].

Here is the equation for normal stress.

$$\sigma = \frac{P}{A} \tag{1}$$

σ is the normal stress of axial stresses divided by the impacted area.

$$\boldsymbol{f_V} = \frac{V}{0.5\,A} \tag{2}$$

f_V is shear stress, V is shear force, and A is an area of the impacted area.

$$\boldsymbol{f_b} = \frac{M\,.\,y}{I} = \frac{R}{S} \tag{3}$$

$\boldsymbol{f_b}$ is bending stress, **M** is the bending moment, **y** is the gyration radius, **I** is the inertia moment, and **S** is the modulus.

$$\boldsymbol{f_a} = 0.6\,f_y \tag{4}$$

$\boldsymbol{f_a}$ is allowable axial stress and $\boldsymbol{f_y}$ is yield stress

$$\mathrm{F_a} = \frac{\left[1 - \frac{\left({}^{\mathrm{Kl}}/_{\mathrm{r}}\right)}{2\mathrm{C}_\mathrm{c}^2}\right]\mathrm{F_y}}{\frac{5}{3} + \frac{3\left({}^{\mathrm{Kl}}/_{\mathrm{r}}\right)}{8\mathrm{C_c}} - \frac{\left({}^{\mathrm{Kl}}/_{\mathrm{r}}\right)^3}{8\mathrm{C_c}^3}}$$

$$\mathrm{F_a} = \mathrm{F}'_\mathrm{e} = \frac{12\pi^2\mathrm{E}}{23\left({}^{\mathrm{Kl}}/_{\mathrm{r}}\right)^2} \tag{5}$$

E is elastic modulus, **K** is the effective length factor, **L** is the length of the member, **r** is the radius of gyration, **Fy** is yield strength, **Fe** is Euler stress, **D** is diameter, and **t** is wall thickness.

$$\boldsymbol{f_b} = 0.75\,f_y \tag{6}$$

$\boldsymbol{f_b}$ is allowable bending stress and $\boldsymbol{f_y}$ is allowable yield strength.

$$\boldsymbol{f_v} = 0.4\,f_y \tag{7}$$

$\boldsymbol{f_v}$ is allowable shear stress and $\boldsymbol{f_y}$ is allowable yield strength.

2.5 Rigging Arrangement

Rigging Arrangement is a component of equipment used to complete the requirements for the installation of configurations rigging. Examples of tools generally found in rigging include shackles, slings, spreaders, bars, and crane hooks.

Figure 1. Rigging Basic Equipment

3. ANALYSIS

3.1 Structure Modelling

The jacket is modeled horizontally with the help of the software. Modeling begins by placing the *jacket* in a horizontal position. The following data member properties are in the modeling.

Table 2. General Material Specification

Properties	**Value**	**Unit**
Young Modulus Elastic (E)	29000	Ksi
Shear Modulus (G)	11200	Ksi
Yield Stress (Fy)	50	Ksi

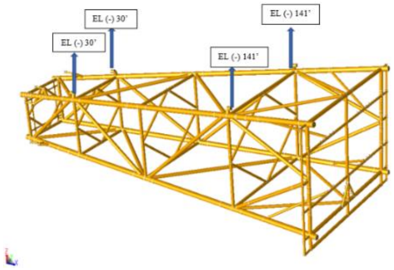


Figure 2. Jacket Model with Horizontal Condition

After designing in general specifications, the author performs modeling based on the configuration rigging. The following is an attachment from the results of one of the jacket models with a configuration of one spreader bar.

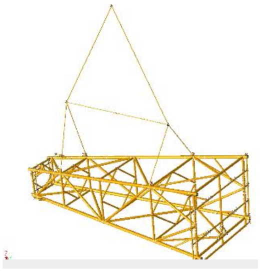


Figure 3. One Spreader Bar Configuration Model

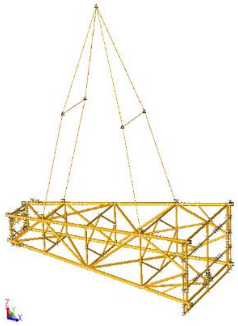


Figure 4. Two spreader bar configuration model

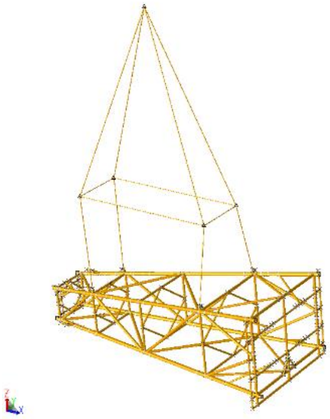


Figure 5. Frame spreader bar configuration model

3.2 Modelling Analysis

This analysis is carried out on the rigging configuration, including the rigging geometry, sling tension, maximum joint displacement, buckling, member UC and Joint UC. The geometry analysis is carried out by looking for the specifications of rigging equipment required as slings and spreaders bars. On Sling tension analysis is done by finding the tension in the tension sling obtained based on the load on the lifting points. The joint displacement is done with the help of software, where the greatest value of the change in the joint location is found when the structure is jacket lifted with a certain configuration. At buckling done with the help of software, the author seeks behavior than jacket specification, which is experiencing the buckling, to see the value UC of output software. On members and joints, UC is done with the help of software to see the results of strength in members and joints UC currently when jacket in lifting conditions.

After the author has conducted various analyses, the author compares the results of the analysis that has been carried out based on each rigging configuration. The following results are from the largest value in each analysis performed on each rigging configuration.

Table 3. Sling tension result comparison

Rigging configuration	**Sling Tension (kN)**	**Max. Joint Displacement (cm)**	**Member UC**	**Joint UC**	**Buckling UC**
R#1	1546.31	5.804	0.36	0.83	0.184
R#2	1678.53	5.458	0.57	0.76	0.184
R#3	1465.81	1.483	0.44	0.84	0.182

Table 4. Maximum joint displacement result comparison

	Maximum Joint Displacement					
Rigging Configuration	**X (in)**	**X (cm)**	**Y (in)**	**Y (cm)**	**Z (in)**	**Z (cm)**
R#1	0.622	1.579	0.175	0.398	-2.29	5.804
R#2	0.494	1.254	0.242	0.614	-2.19	-5.458
R#3	-6.21	-15.78	-1.46	3.701	-2.38	-6.045

Table 5. Buckling unity check result comparison

Rigging Configuration	Kategori Member	Member	UC
R#1	Primary Framing EL.141 ft	M116-M067	0.91
		M370-M321	0.85
		M106-M057	0.85
R#2	Primary Framing EL.141 ft	M116-M067	0.88
		M370-M321	0.79
		M106-M057	0.8
R#3	Primary Framing EL.141 ft	M116-M067	0.86
		M370-M321	0.11
		M106-M057	0.8

Table 6. Member and joint result comparison

Rigging Configuration	Member	UC (Member)	Joint	UC (Joint)
R#1	M380-M331	0.91	M370	0.85
	M370-M321	0.85	M057	0.84
	M116-M067	0.91	M176	0.85
R#2	M380-M331	0.87	M370	0.83
	M370-M321	0.84	M057	0.81
	M116-M067	0.82	M176	0.85
R#3	M380-M331	0.86	M370	0.79
	M370-M321	0.82	M057	0.78
	M106-M067	0.81	M176	0.84

3.3 Trunnion Structure Analysis

This analysis was carried out on the trunnion structure that received the greatest sling tension in each rigging configuration. The trunnion to be analyzed is on lifting point 3 on one configuration spreader bars and lifts point 1 on configuration two and frame spreader bars. The analysis includes the stress Von Misses in the structure, stresses in joints trunnion, shear stresses, bending stresses, and axial stresses. Trunnion specifications to be analyzed are as follows.

Table 7. Trunnion Specification

Structure Properties			
Outside Diameter	OD	24	in
Inside Diameter	ID	23	in
Wall Thickness	wt	1	in
Area	A	9.29E+02	in^2
Inertia	I	4.14E+07	In^4
Material Properties			
Material Propoerties		API 2H GR50	
Yeild Strength		345	MPa

At this stage, the authors researched the trunnion structure in each rigging configuration. In the first stage, the author performs various trunnion structure models in a single spreader bar configuration.

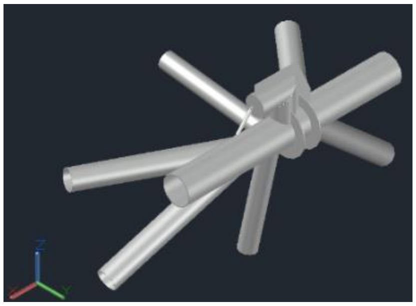


Figure 6. Trunnion LP-03 modeling at one spreader bar

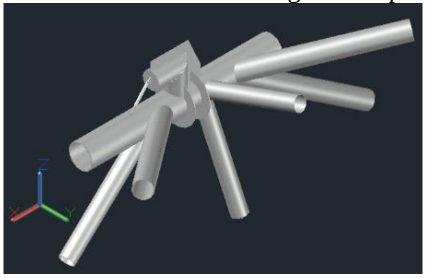
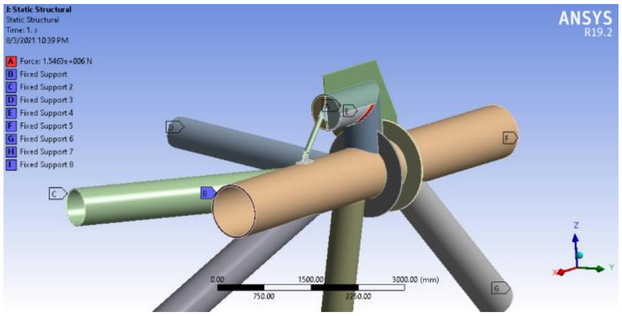


Figure 7. Trunnion LP-01 modeling at two and frame spreader bar

Next, the author determines several types of boundaries condition on the structure trunnion in the software ANSYS.



J: Static Structural
Static Structural
Time: 1. s
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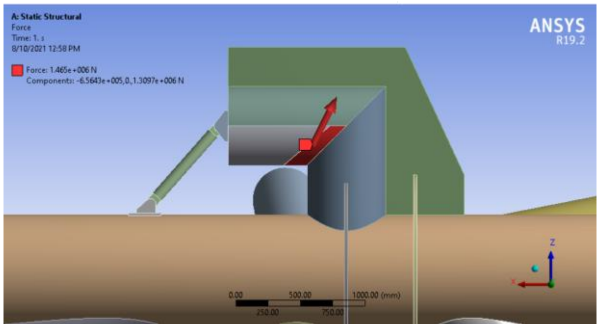
A Force: 1.5463e+006 N
B Fixed Support
C Fixed Support 2
D Fixed Support 3
E Fixed Support 4
F Fixed Support 5
G Fixed Support 6
H Fixed Support 7
I Fixed Support 8

Figure 8. Boundary Condition Trunnion Analysis



A: Static Structural
Force
Time: 1. s
8/10/2021 12:58 PM

Force: 1.465e+006 N
Components: -6.5643e+005,0.,1.3097e+006 N

Figure 9. Load modeling

a. **Purple Label**, *Fixed Support*, the command used to show pieces of the leg structure and bracing on the jacket. Based on the attached image, a transparent label is also included in the command Fixed Support.
b. **Red Label**, *Force*, the command used to apply the area of the loaded structure. The total inputted load is the sling voltage that occurs, namely 1546kN on R#1, 1678 kN on R#2, and 1465kN on R#3 by inputting the distribution of each load in the x, y, and z directions on the component command in the ANSYS software which will then also form a force direction that matches the direction of the force rather than the sling.

After the analysis, the author determines the type of element and meshing size of the trunnion structure, which is used to analyze the ANSYS software. The type of element used by the author is *quadrilateral*. The following is the result of *meshing* each trunnion structure.

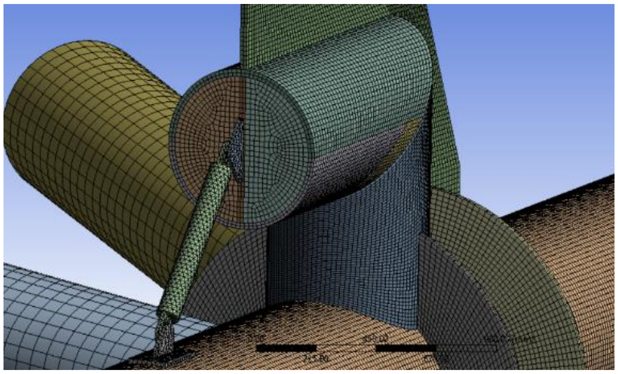


Figure 10. Meshing Model, Trunnion Structure LP03 R#1

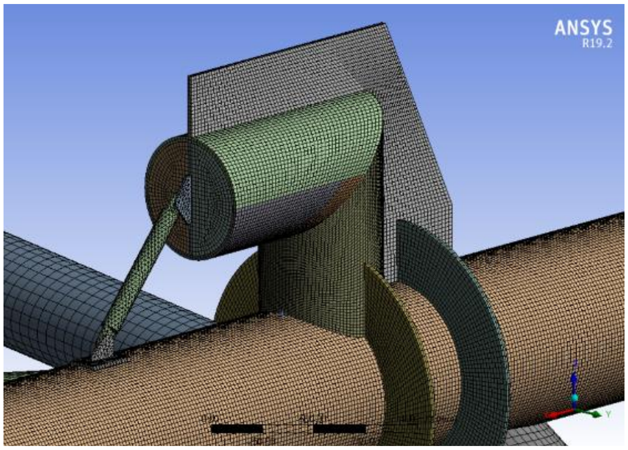


Figure 11. Meshing Model, Trunnion Structure LP01 R#2 and R#3

Then the author starts a meshing sensitivity analysis used to determine the quality of the output generated from the analysis. The following are the results of the analysis of the meshing sensitivity of the trunnion structure for each rigging configuration.

Table 8. Trunnion LP03 R#1 Meshing Sensitivity Analysis Result

Size Mesh (mm)	Nodes	∑ (Element)	Von Mises Stress (MPa)	Diff
60	156948	24571	83.59	-
50	182208	28285	77.67	7.08%
40	225363	34818	70.28	9.52%
35	262432	40482	120.12	70.93%
30	319709	49215	87.83	26.88%
25	592830	107198	85.41	2.76%
24	629418	114121	91.42	7.04%
23	680998	124164	107.89	18.02%
22	733952	135333	110.45	2.37%
21	798014	147404	112.34	1.71%
20	870854	161788	117.75	4.82%

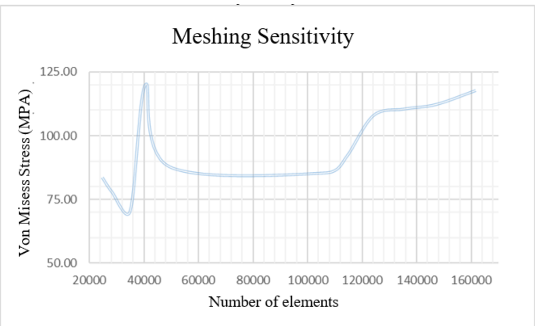


Figure 12. Graph of Trunnion LP03 R#1 Meshing Sensitivity Analysis Result

Table 9. Trunnion LP01 R#2 Meshing Sensitivity Analysis Result

Size Mesh (mm)	Nodes	∑ (Element)	Von Mises Stress (MPa)	Diff
60	151,435	23,931	64.03	-
50	176,530	27,499	66.72	4.20%
40	219,499	34,017	97.74	46.50%
35	256,996	39,741	94.26	3.56%
30	293,418	43,730	101.48	7.66%
25	552,489	98,571	125.21	23.33%
24	624,537	113,362	103.37	17.44%
23	676,115	123,375	104.62	1.21%
22	733,863	134,548	99.04	4.47%
21	790,632	144,541	103.68	3.74%
20	864,653	160,925	105.6	1.85%

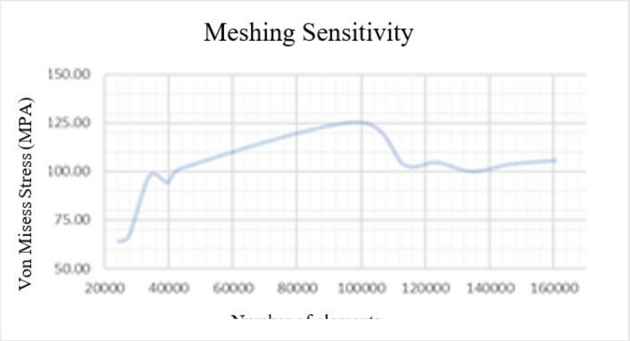


Figure 13. Graph of Trunnion LP01 R#2 Meshing Sensitivity Analysis Result

Table 10. Trunnion LP01 R#3 Meshing Sensitivity Analysis Result

Size Mesh (mm)	Nodes	∑ (Element)	Von Mises Stress (MPa)	Diff
60	151665	23943	51.91	-
50	176549	27497	54.95	5.86%
40	219676	34027	55.02	0.12%
35	256762	39702	79.32	44.17%
30	319688	49204	87.04	9.73%
25	587617	106491	111.18	27.73%
24	624863	113383	78.40	29.49%
23	676438	123343	83.17	6.08%
22	733885	134356	81.84	1.60%
21	792655	146634	84.13	2.80%
20	818178	147941	85.93	2.14%

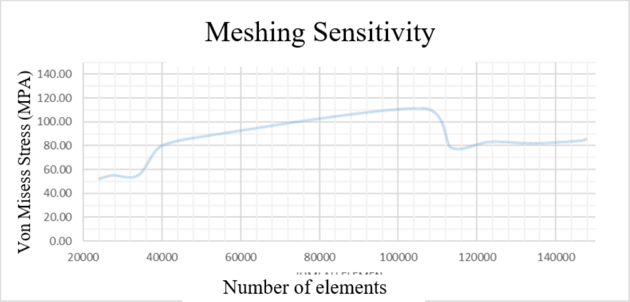


Figure 14. Graph of Trunnion LP01 R#3 Meshing Sensitivity Analysis Result

6. CONCLUSIONS

Based on the results of research on the analysis of the trunnion structure with variations in the rigging configuration of the loadout stage during the lifting jacket platform process, the results of the analysis on the rigging configuration model show that normal loading in LP-01 is 1465.24 kN, LP-02 is 1458.71 kN, LP-03 is 1276.48 kN and LP-04 of 1267.67 kN. Then for the shifting condition, the load results for each lifting point are in shifting conditions **(X+Y+)** LP-01 of 1384.89 kN, LP-02 of 1490.84 kN, LP-03 of 1250.38 kN and LP-04 of 1335.65 kN. For shifting conditions **(X+Y-),** LP-01 is 1495.16 kN, LP-02 is 1538.07 kN, LP-03 is 1207.77 kN, and LP-04 is 1240.82 kN. For shifting conditions **(X-Y+),** LP-01 is 1545.59 kN, LP-02 is 1426.59 kN, LP-03 is 1302.59 kN, and LP-04 is 1199.70 kN. For shifting conditions **(XY-),** LP-01 is 1435.32 kN, LP-02 is 1379.36 kN, LP-03 is 1345.20 kN, and LP-04 is 1294.53 kN.

Based on the analysis of the members and the Joint UC done when the jacket is done in the process of lifting the configuration, R # 1 showed a maximum of *members UC* on *members* 402L-L001 and 402L-L002 are 0.342, and *Joint TheUC* maximum on the *joint is* M3700.838. In the R#2 configuration, the maximum results obtained are *members UC* on *members* 402L-L001 and 402L-L002 is 0.57, and *The UC* maximum on the *joint is* M3700.757. In the R#3 configuration, the maximum results obtained are *members UC* on *members* 402L-L001 and 402L-L002 is 0.44, and *The UC* maximum at the *joint is* M0570.84.

Based on the stress analysis on the trunnion structure carried out with the help of ANSYS software and the structure *trunnion* analyzed only from the structure *trunnion* that received the greatest sling stress in each rigging configuration, namely *trunnion. LP03* on single configuration *spreader bar* and *Trunnion* LP01 in dual and configurations *frame spreader bars*. Based on the results of research on *trunnion LP03* in a single configuration *spreader bar* maximum stress of *von misses* that occurred was 179.46 MPa, with the result of the unity check of 0.776 and the von *misses stress* at the connection that occurred was 179.46 MPa. On *trunnion LP01* in a two-configuration *spreader bar*, the maximum stress *von misses* that occur is 185.22 MPa, with the result of the *unity check being* 0.777 and the voltage is *von misses* at the connection that occurs is 100.99 MPa. On *trunnion LP01* in the configuration *frame spreader bar* maximum stress *von misses* that occur is 119.46 MPa, with the result of the *unity check being* 0.523, and the voltage is *von misses* at the connection that occurs is 51,776 MPa.

Based on the results of the analysis that has been carried out, including global analysis carried out on *jackets* such as the *Sling Tension*, *Maximum Joint Displacement*, *Member UC*, *Joint UC*, and *Buckling* with local analysis on the *trunnion* that is the maximum stress *Von Misses*, the configuration with the best analysis results is the configuration *frame spreader bar* where most of the analyzed values are dominantly smaller than the results of other configuration analyzes.

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