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Local Analysis of The Padeye-Brace Clamp Structure Strength during Installation of Riser-Spool at Offshore Platform

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ABSTRACT

The need for natural gas in Indonesia has developed very rapidly, thus encouraging the construction of many production support facilities. One of them is the Wellhead Platform B (WHP-B) in West Pangkah waters, East Java. This production platform is in shallow water conditions with a depth of less than 5 m and a distance of less than 5 km from the shoreline. Therefore, when the pipe installation process is carried out, a crane barge or construction vessel type cannot be used. To be able to connect the gas flow from the well to the production platform (WHP-B), it requires a supporting structure in the form of a spool and riser. The size of the spool and riser that will be installed on WHP-B is 16" and 6" with the condition that the riser and spool are connected. A crawler crane carried by a barge can be used for the installation process to occur efficiently. For the 16"-6" riser-spool to be lowered simultaneously, it requires a temporary structure that serves to clamp the two pipes so that they can be installed simultaneously. This structure is a modification between the padeye and the brace clamp. The process of lowering the 16"-6" riser-spool experienced a critical condition when it was in the splash zone. Based on the global analysis results, it is known that the UC that occurs is 0.97 with a vertical bending stress of 172.36 MPa in the 3rd padeye-brace clamp structure. After conducting local analysis on the 3rd brace clamp, it is known that the clamp structure is still in a safe condition with a maximum von Mises stress of 2.42 MPa and a maximum deformation of 0.0096 cm.

Keywords: *Riser, Spool, Splash Zone, Von Mises Stress, Deformation*

1. INTRODUCTION

The term spool or spool piece is often used in the oil and natural gas industry to refer to a rigid pipe segment with connectors at both ends [1]. In general, rigid or tie-in spools connect facilities such as risers on jacket platforms, X-mas trees, and manifolds [2]. The use of spools is very wide, causing spool installation activities to become a part of marine operations that we often encounter in offshore contractor companies. The tools used to lift and attach the spool offshore depend on the size and configuration of the spool itself.

The shape of the spool is generally in the form of a slender and long structure, so it requires a large area for the installation process compared to the problem with the weight of the spool itself. Usually, the use of construction vessels or crane vessels is a common choice for the process of transportation and installation of spools at a lower cost [1]. However, there are conditions where construction vessels cannot be used due to cost considerations and environmental conditions that do not allow this to impact the lifting method used [3]. This occurs in the case of the 16" and 6" spool installation process for the B-Wellhead Platform (WHP-B) located in Pangkah Barat waters, East Java, as seen in Figure 1. The location is approximately 5 km from the shoreline (onshore) with a sea depth of less than 5 m. Due to the shallow water depth, the spool installation process cannot be carried out with a construction vessel, which requires deeper waters.

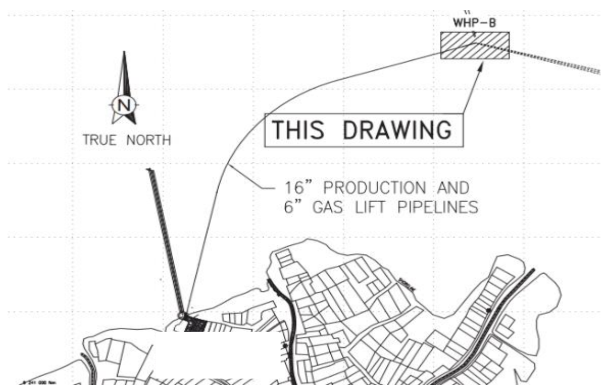

Figure 1. Riser-spool installation location 16"-6"

Therefore, we need an alternative way that is more efficient, namely by using a crawler crane that is transported by a barge. However, the use of this modified crawler crane has weaknesses, namely, the crane boom has limited movement and the wire rope is not corrosion-resistant. The process of installing a spool with a modified barge also has its own constraints, namely the limited variety of rigging configurations that can be carried out due to considerations of barge stability, cost, and effectiveness [4]. Therefore, in this case, only rigging is used (with one hook) without the help of a spreader bar or spreader truss. In the case being analyzed, the process of lowering to the seabed in the WHP-B area was carried out simultaneously between 16" and 6" spools with 16" and 6" risers.

The installation process experienced a critical condition when the 16”-6” riser-spool was in the splash zone condition. This is due to the influence of environmental loads and the movement of the crane boom which causes the stress on the structure and rigging equipment to increase. Based on the results of numerical analysis with the help of the SACS program, the maximum UC value occurs in the 3rd BRC member of 0.97. While the maximum joint deflection in the 3rd BRC member occurs in the BR06 joint with the x direction of 21.962 cm, the y direction of -10.7669, and the z direction of 3.6963 cm. It is necessary to conduct a local analysis to ensure the integrity of the temporary structure during operation to ensure the condition of the 3rd brace clamp structure is safe [5]. With the help of the ANSYS program, it is known that the structure of the 3rd brace clamp is still in a safe condition with a maximum von Mises stress of 2.42 MPa in the clamp bolt hole area of 16". Whereas the maximum deformation that occurs is 0.0096 cm in the 16” flange plate clamp area.

2. METODOLOGY

2.1 Literature Study

The literature study aims to find out more information about the structural strength of the padeye-brace clamp temporary structure. The collection of environmental data includes primary data and secondary data. Primary data in the form of a general drawing of lifting riser-spool 16”-6”, material take off, and data of rigging equipment catalog. Secondary data in the form of literature studies in the form of journals and proceedings. In addition, it is also supported by standards or codes in the form of API and DNV.

2.2 Global Structure Modeling

The 16” and 6” riser-spool structures will be modelled with the help of the SACS program. The lifting-lowering analysis in the SACS program uses the gap element approach to member slings. So, the output of the lifting analysis that will be used is sling tension. With the help of the SACS program, you can also analyze the integrity of the structure in the form of Unity Check (UC) [6-7]. By following the following equation:

$$UC = \frac{\sigma_m}{\sigma_{Rd}} \tag{1}$$

where,
σ_{ud} = *Actual stress* (kN)
$\sigma_{rigging}$ = *Allowable sress* (kN)

In addition to checking the UC value, an analysis of the axial load that occurs related to the critical load (P_{cr}) is also carried out based on Euler's buckling theory [8]. The equation used is as follows:

$$P_{cr} = \frac{\pi^2 EI}{L_e^2} \tag{2}$$

where,
E = Elastic modulus (Pa)
I = Moment of inertia (m^4)
L_e = Effective length (m)

Modeling the riser-spool geometry will follow the general drawing data in Figure 2. Structures that cannot be modeled with the SACS program, such as coating layers and anodes, will be converted into non-generated dead loads based on data from Table 1. To obtain the weight of the pipe structure accurately.

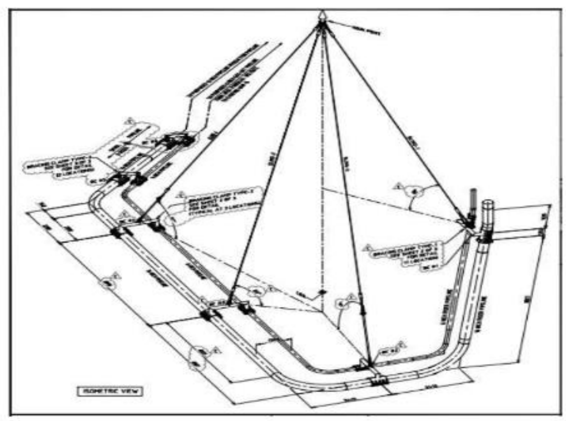

Figure 2. *General drawing lifting-lowering riser-spool* 16”-6”

Based on Figure 2, for modeling the 16”-6” riser-spool geometry will also be modeled along with the padeye-brace clamp structure which will be modeled as a joint load. The results of the lifting riser-spool modeling will be carried out using 4 lifting points, if the UC value exceeds 1 the number of slings will be added to 5 lifting points. The results of the16”-6” riser-spool lifting modeling can be seen in Figure 3.

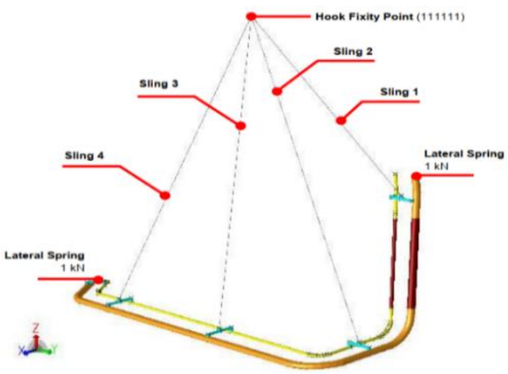

Figure 3. Modeling the 16”-6” riser-spool lifting with the SACS program

Table 1. *Material take off spool*

Description	Unit	Value		
		16” Spool Riser	6” Spool Riser	6” Bracing Clamp
Nominal Pipe Size (NPS)	-	16	6	6
Outside Diameter (OD)	mm	406.4	168.3	
Wall Thickness (WT)	mm	14.3	11	
Material Type	-	CS API 5L X 65, NACE	CS API 5L Grade B	
Manufacturing Process	-	HFW/ERW		
SMYS	MPa	450	250	
SMTS	MPa	535	415	
Density	kg/m^3	7850		
Poisson’s Ratio	-	0.3		
Young’s Modulus	MPa	207000		
Thermal Expansion Coefficient	1/ °C	1.17×10^5		
Pipe Joint Length	m	12.2		

2.3 Calculation of DAF Factor and Application of Rigging Factor

Furthermore, for calculating the DAF value based on standard [9], assuming the installation location is in a coastal area by following the following equation:

$$DAF = 1.07 + 0.05\sqrt{\frac{100}{W_{ud} + W_{rigging}}} \tag{3}$$

where,
DAF = Dynamic Amplification Factor
W_{ud} = Dry weight riser-spool (MT)
$W_{rigging}$ = Weight rigging equipment (MT)

Equation 3 is used for air installation conditions, while for splash zone and submerged conditions, the DAF value is conservatively 1.75 to 2 [10-11]. Next is to determine the safety factors for rigging, such as the CoG envelope factor, Weight contingency factor, and Consequence factor as shown in Table 2.

Table 2. Rigging factors for lifting riser-spool 16”-6”

Description	Coefficient	Value
CoG envelope factor	Υ_{CoG}	1.10
Weight contingency factor	Υ_{f}	1.10
Consequence factor	Υ_{C}	1.30

2.4 Local Structure Strength Analysis

Analysis of the local structural strength of the temporary brace structure will be carried out with the help of the ANSYS program. The geometry modeling in the SACS program is not detailed, so it needs to be done with the ANSYS program to determine the stress distribution that occurs [12] along with the deformations. The structure in the form of a bolt-nut will be modeled on each clamp with the addition of pretension. So, there are differences in constraints between global and local analysis. The structure of the brace clamp will be modeled by clamping the 16” and 6” spool pieces to resemble actual conditions. The minimum length of the spool piece will follow the standard from previous research [13], which is 6OD. In local analysis, the bolt-nut structure in each clamp will be given pretension. The goal is that the clamp can clamp the 16” and 6” spools. The pretension values that work on spools 16 "and 6" can be seen in Table 3.

Table 3. Pretension acting on 16”-6” clamp

Pretension Clamp 16” (kN)	**Pretension Clamp 6” (kN)**
130	145

The bolt-nut structure will be modeled with a friction contact type with a coefficient of friction (μ) of 0.2. So, the numerical analysis that works uses the gap element approach because it is non-linear using the Newton-Rhapson method approach [14]. The type of contact that works on the structure can be seen in Table 4.

Table 4. Contact type working on 16”-6” clamp

Contact-Target	**Type**
Bolt-Flange Plate	friction
Nut-Flange Plate	friction
Bolt-Nut	friction

2.5 Finite Element Analysis Method

In general, the equation models used in numerical analysis are equilibrium equations. Based on the discretization results of the structural model, a stiffness matrix will be formed. The more complex the model, the greater the matrix order must be solved. The results of stress and deformation analysis on local structures will follow Hooke's law for linear analysis according to the following equation:

$$\begin{Bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ . \\ . \\ . \\ f_n \end{Bmatrix} = \begin{bmatrix} k_{11} & k_{12} & k_{13} & . & . & . & . & k_{1n} \\ k_{21} & k_{22} & k_{23} & . & . & . & . & k_{2n} \\ k_{31} & k_{32} & k_{33} & . & . & . & . & k_{3n} \\ k_{41} & k_{42} & k_{43} & . & . & . & . & k_{4n} \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ k_{n1} & k_{n2} & k_{n3} & . & . & . & . & k_{12} \end{bmatrix} \begin{Bmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ . \\ . \\ . \\ d_n \end{Bmatrix} \tag{4}$$

where,

$$\{f\} = [k]\{d\} \tag{5}$$

Based on Equation 5, the von Mises stress can be found by following the following equation:

$$\sigma_e = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_3 - \sigma_1)^2]} \tag{6}$$

where,

σ_e = Von Mises stress (MPa)
σ_1 = Stress field 1 (MPa)
σ_2 = Stress field 2 (MPa)
σ_3 = Stress field 3 (MPa)

Equation 5 will be used to find the maximum von Mises stress value in the local model. Based on the general drawing data from Figure 2, 3 padeye-brace clamp structures are used for the lifting process. This clamp structure is divided into 3 types, as seen in Figure 4. The differences in this structure are based on padeye position and brace dimensions.

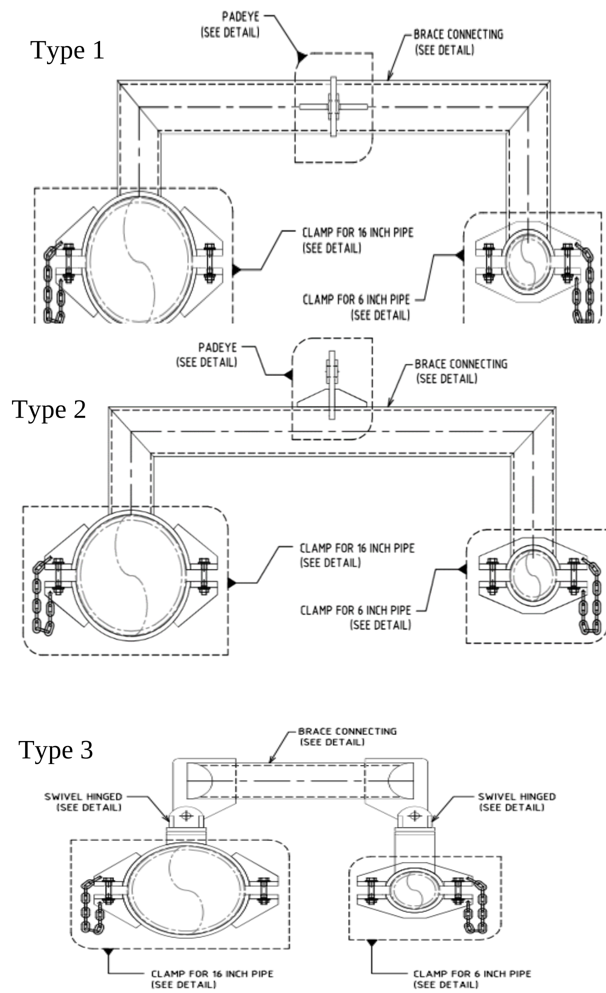

Figure 4. Local structure of padeye-brace clamp type 1, type 2 and type 3

This study will focus on the brace clamp structure, which is experiencing the most critical stress. In addition to von Mises stress, maximum deformation is also considered in this study.

2.6 Validation

At the validation stage, check the suitability of the structural model made with the original conditions and structural data. The aspect that is reviewed in this validation stage is the dry weight of the riser-spool where the difference must be less than 5% between the numerical model and the original structure. For structural weight validation, the Mean Absolute Error (MAPE) method [15] is used as seen in following equation:

$$MAPE = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \times 100 \tag{7}$$

where,

A_t = the value of the experimental results (primary data) at time t
F_t = value of modeling results (numeric) at time t
n = lots of data/amount of data

3. RESULT AND DISCUSSION

3.1 UC Analysis and Joint Deflection during 16”-6” Riser-Spool Installation

The results of the analysis of UC values and joint deflection on the 16”-6” riser-spool structure when the installation process was carried out using the SACS program based on API standards can be seen in Figure 5. The results of the structural integrity analysis showed that the riser-spool experienced a critical condition during the splash zone condition, with the maximum UC value occurring in the 3rd BRC member.

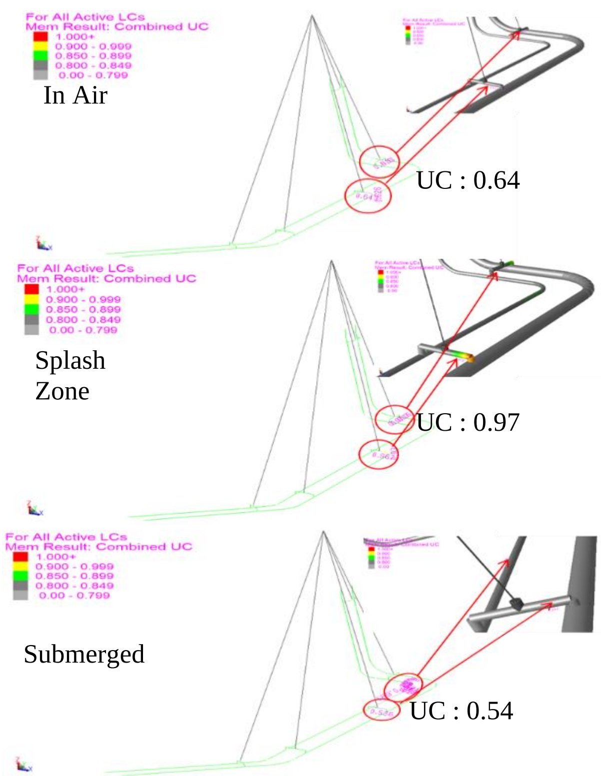

Figure 5. The results of the analysis of the maximum UC value when in water, splash zone, and submerged conditions

As for the joint, the maximum deflection occurs in the BR06 joint with the x direction of 21.9262 cm, the y direction of -10.7669 cm, and the z direction of 3.6963 cm. The results of the joint deflection analysis during the splash zone conditions can be seen in Figure 6.

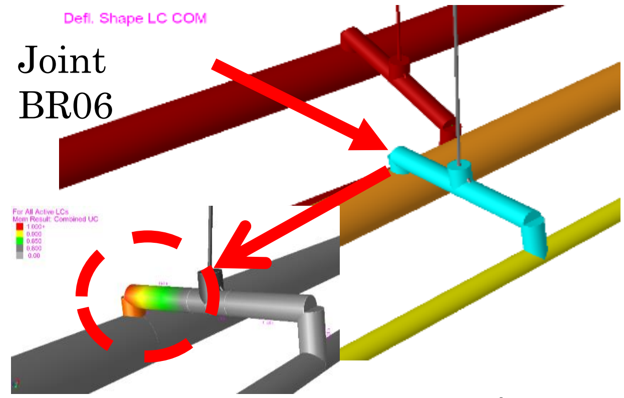

Figure 6. Maximum deflection results in the 3rd BRC member during the splash zone condition

3.2 Padeye-Brace Clamp Geometry Modeling

Making the padeye-brace clamp geometry model will use the AutoCAD program. Due to the limitations of the SACS program, a local analysis was carried out to determine the effect of pretension on the flange plate. After modeling the 3rd BRC member, it is continued by providing constraints.

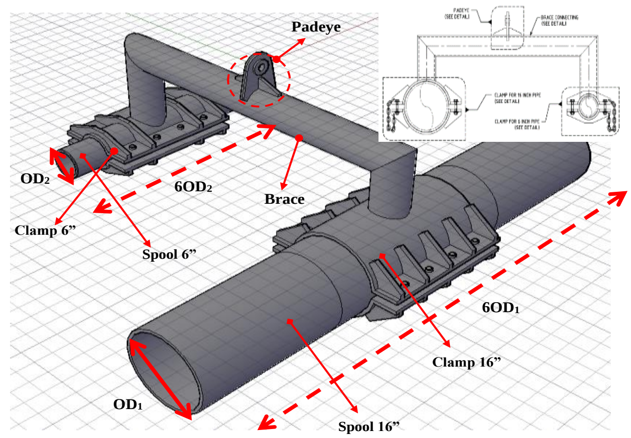

Figure 7. Padeye-brace clamp geometry modeling on the 3rd BRC member

3.2 Cell Size Sensitivity Analysis

Before removing the cell parameters in the form of von Mises stresses and deformations, it is necessary to calibrate the local model discretization results. The aim is to determine whether the discretization results have converged, which can be seen based on the error value of the output. In this study, the parameter analyzed was the von Mises voltage concerning the increase in the number of cells. The results of the sensitivity of the meshing on the local model are acceptable because it has an error value of <5% when the cell size is in the range of 500000-700000 elements.

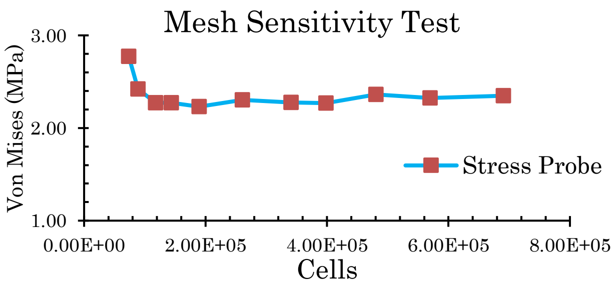

Figure 8. Meshing sensitivity results

3.3 Results of Von Mises Stress Analysis and Local Model Deformation

Constraints were given to the brace clamp local model in the form of sling tension, fixed supports, pretensions, and friction-type contacts. The aim is to determine the von Mises stresses and deformations that occur in the local model using the finite element approach. The maximum von Mises stress output from the local model is 2.42 MPa at the bolt holes. Whereas the maximum deformation occurs on the flange plate in the 16” clamp section of 0.0096 cm. The results of the brace clamp local model analysis can be seen in Figure 9 and Figure 10.

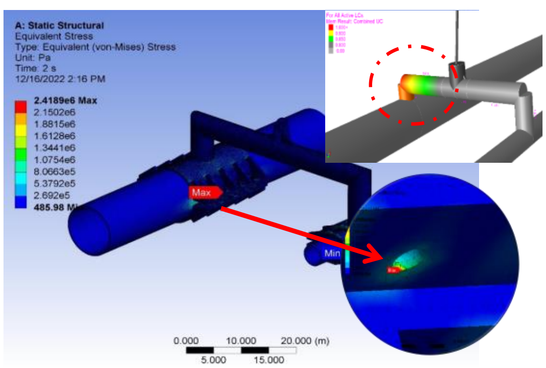

Figure 9. Results of the von Mises stress on the local model

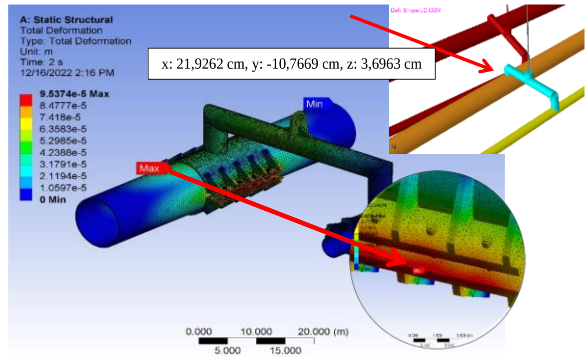

Figure 10. Deformation results on the local model

Based on the results of stress and deformation analysis using the ANSYS program, the accurate location of critical areas can be identified.

4. CONCLUSION

Based on the research that has been done, the conclusions are as follows:

1) Based on the global analysis results with the SACS program, the 16”-6” riser-spool structure experiences the most critical conditions during the splash zone conditions. With a maximum UC value of 0.97 for the 3rd BRC member. Whereas the maximum deformation occurs at the BR06 joint with the x direction of 21.9262 cm, the y direction of -10.7669 cm, and the z direction of 3.6963 cm.

2) Based on the results of the local analysis with the ANSYS program, the largest von Mises stress is 2.42 MPa, which occurs in the bolt-nut model at Clamp 16”. While the maximum deformation occurs in the flange plate structure of the 16" brace clamp of 0.0096 cm. With local analysis using the ANSYS program, it can show areas that are experiencing stress and deformation compared to the SACS program in more detail.

3) The results of numerical analysis on the local model show that the brace clamp structure (3rd BRC) is still in a safe condition even though it has a UC value of 0.97. Differences in global and local analysis occur due to differences in constraints and geometric models. In the SACS program, there are problems in modeling the actual shape of the padeye-brace clamp geometry. So, a local analysis must be done to ensure the stress and deformation conditions in the local model.

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