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Cover Page Footnote

This paper is prepared with support of the Directorate of Oil and Gas Engineering and Environmental, Directorate General of Oil and Gas and PT Multi Solusi Enjinering, which allowed to use the data from a project related to the failure of rig mast based on requirements of API - "American Petroleum Institute".

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Abstract. During a move to the new drilling location, two braces of the upper mast section on a 550 HP oil and gas rig were damaged. When damage is discovered, the rig operating company should conduct a risk analysis related to the damage using the standard used to determine rejection criteria and follow-up repairs. The strength of the rig mast is calculated using Finite Element Analysis (FEA) with initial conditions (before damage occurs) where all braces are installed and extreme conditions where neither brace is repaired. The calculation results are then used to assess the risk of reducing the rig mast strength. The integrity analysis results will show the rig mast's FEA and the distribution pattern of stress ratio values, which is the ratio between the stress that arises and the allowable stress of the material on the mast parts due to loading.

Keywords: Structural Integrity, Rig Mast Failure, Finite Element Analysis, Oil and Gas Regulation

INTRODUCTION

Installations used in oil and gas exploration and exploitation must have an Operational Fitness Approval, with the Rig being one type of installation. [1] The four types of accidents in the oil and gas industry are worker, installation, environmental, and general interference. Accidents involving oil and gas companies must be reported to the Directorate General of Oil and Gas. [2] The labor-intensive nature of the drilling operation exposes the drilling crew to many potentially hazardous situations and work procedures. Many operations are physically demanding and depend on the coordinated activity and timing of each member of the crew for their effectiveness and ultimate safety. [3] The rig owner and operating company are fully responsible for the rig installation's oil and gas safety (installation/equipment safety, environmental safety, worker safety, and public safety). According to the Operational Fitness Approval issued by the Directorate General of Oil and Gas, if the damage is discovered, the rig operating company must first conduct a Risk Analysis related to the damage as mentioned above, referring to the standard used (API 4G) to determine rejection criteria and follow-up repairs. Implementation of Risk Analysis and improvement to ensure that it is carried out by a company that meets the requirements of the laws, regulations, and applicable standards.

Each mast of each rig mast represents a new and unique structure with unique geometry for the maximum hook load to which it will be subjected during the work. It depends on several factors, such as expected weather conditions, winds, possible earthquakes, the structure of the truck chassis for transportation to the location and work, etc. [4] When working in the wellbore, the installation and its mast must deal with various cases of simultaneous loads, such as: maximum hook load and wind; working hook load and wind; wind expected to act like a hurricane, working in the event of an earthquake, etc. The API 4F standard provides all these possible loading cases. [5, 6]

Rig installation requires a strong foundation to support the rig installation's weight, and many supporting devices are needed. Onshore rig installation requires several heavy transportation equipment to move from one drilling location to another. Safety which will be discussed in writing regarding the feasibility analysis of this rig installation, will prioritize the mast structure. In addition to the preliminary visual inspection, chemical analysis of the chain link material, magnetic particle inspection of welded joints, mechanical testing, fractographic analysis, and detailed finite element analysis using software packages form the different steps of this investigation to identify possible causes of failure of the tower structure. [7, 8] In the event of a failure, it is sometimes essential to investigate the root cause of failure in terms of design, material quality, fabrication procedure, or operational error in handling. [7] The max defection is observed at the side of the structure, so it is recommended that cross-links should be used to reduce the deformation. The maximum bending moment is observed at the base of the tower. Reinforcement can be added to minimize the maximum bending moment. [9, 10]

To overcome this crucial problem in oil and gas business activities, the government must start monitoring the schedule for the maintenance and operation of this installation through audit activities that describe a general diagnosis of the work to be carried out while optimizing production. [11] Inappropriate rig checks in inspection or maintenance activities on rigs can lead to unexpected production losses not due to routine work but due to shut down due to integrity that is not maintained.

Engineering calculations are useful for determining the actual static hook load of the mast and the strain that occurs in each structural mast using Finite Element Analysis, as the input data are structural dimensions and tensile material and verified by load test results. From the results of engineering calculations, a static hook load mast will be obtained. This method is the most economical and fast way but requires expertise and experience from the manufacturer. Load spectrum samples are suggested to be made by animating the loads or stresses received by equipment components using a computer's Finite Element Analysis (FEA) model.

BACKGROUND

It was reported to the Directorate General of Oil and Gas in September 2022 that a 550 HP rig suffered mast damage during a move to a new location. It happened when the mast section had to be removed from the rig carrier due to the extremely long distance. When attempting to remove or lift the mast from the rig carrier, it was discovered that it could not be lifted. After further investigation, it was discovered that the pin was either stuck or had not been completely released. Furthermore, the slings used to lift the mast became entangled in its diagonal support, causing it to bend and crack.

TABLE 1. Technical specifications for the damaged rig

Items	Data
Rig Type	Mobile Rig
Mast Model	118-250K
Power	550 HP
Mast Height	36 Meter
Manufacture Hook Load Capacity	113.4 Metric Ton
Maximum Allowable Work Load	113.4 Metric Ton
Year Build	2001

The integrity of the rig mast was analyzed to assess the condition of the mast strength following repairs to the two damaged diagonal braces in the upper mast section, which are located directly beneath the crown block beam. The repair was completed by replacing the two damaged braces without any documentation, namely the material mill certificate, the welding process, and the WPS and standards used in the repair. A 2"x2" square tube with a thickness of 5.8 mm was used to replace the two damaged diagonal braces, replacing the original damaged square tube material with dimensions of 2" x 2" and a thickness of 4.85 mm.

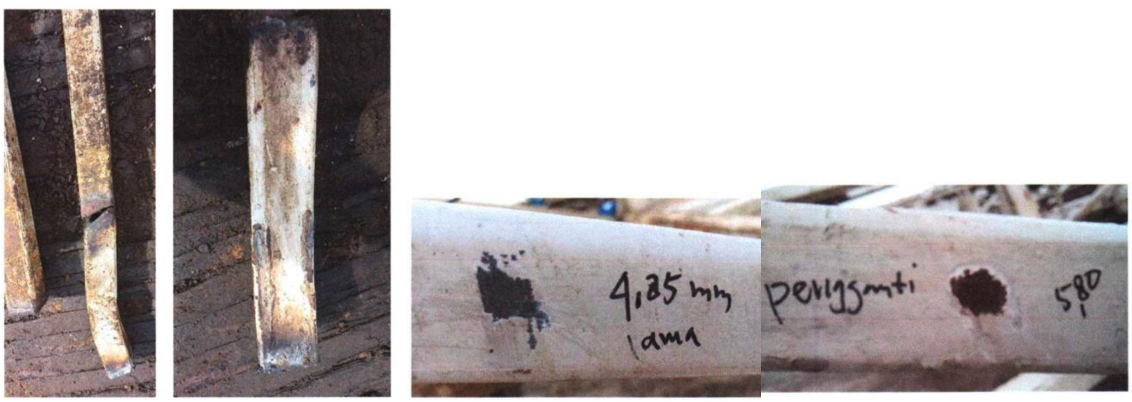

FIGURE 1. Damaged and Replacement Braces

There is no evidence that repairs were carried out in accordance with API 4F and API 4G or other equivalent standards in the absence of the aforementioned recording documents. A comparison of the mast's strength before and after the repair was made using an extreme case in which the two braces replaced were deemed not installed to assess the integrity of the mast after repair.

Inspection Criteria and Mast Repair

The level of inspection on rig components is categorized as follows:

Category I

Visual observation of rig equipment/components during normal operation and routine maintenance for indications of operating abnormalities.

Category II

Examination at Level 1 plus further inspection for corrosion, permanent deformation, missing or lost components, adequacy of lubrication, cracks on the outside, and others.

Category III

Category II inspection plus further inspection, including NDT on critical exposed areas and measuring component wear that exceeds the manufacturer's tolerances.

Category IV

Category III inspection plus a further inspection, where the equipment is disassembled for a thorough NDT inspection of all main load receiving components. NDT is performed by ASNT Level II NDT inspectors.

As for the inspection frequency period, the schedule follows table 2.

TABLE 2. Inspection Types and Frequencies [10]

Category	Frequency	Documentation
I	Daily	Optional
II	At Rig Up	Optional
III	Every 730 operating days[a]	Equipment File
IV	Every 3650 operating days[a]	Equipment File

[a] One operating day equals 24 operating hours

Structural repair of a drilling or well servicing structure shall be carefully planned before initiating work. The manufacturer or qualified person shall be consulted to approve materials and methods, utilizing accepted engineering practices to supervise the required repairs. The following recommendations shall be followed when undertaking structural repairs of a drilling or well servicing structure. Repair or replace any damaged members in accordance with table 3.

TABLE 3. Inspection Criteria [12]

Deviation	Rejection Criteria
Legs	¼ in. (6.4 mm) bow in 10 ft (3 m)
Braces	½ in. (12.7 mm) bow in 10 ft (3 m)
Overall alignment of structure	¾ in. (19.1 mm) out of square
Pins	1/16 in. (1.6 mm) under specified diameter
Pin holes (I.D)	3/16 in (4.8 mm) over specified pin diameter (for pins less than 3 in. [76.2 mm] diameter)
	¼ in. (6.4 mm) over the specified pin diameter (for pins 3 in. [76.2 mm] diameter or greater
Corrosion	10% reduction in cross-sectional area
Structural members and wire rope	Sharp kink or bend in a local area
Connections and fittings	Loose connections or fittings
Bolts, pins and safety keys	Missing components or assemblies
Structural members	Missing members
Sheaves, rollers, and bearings	Do not turn freely, have cracks detected, sheave groove out of gage, or groove depth greater than allowed by the sheave manufacturer.
Structural members	Line cuts or abrasions from wire rope
Exposure to heat	In excess of 500°F (260°C)

Analysis Method

The method used is to calculate the strength of the mast using Finite Element Analysis (FEA) on two FEA models of the mast, each with initial conditions (before damage occurs) where all braces are installed and extreme conditions without both braces being repaired. The results of the calculations are then used to assess the risk of a decrease in the strength of the mast due to the untraced ability. [5] To meet the API 4F strength criteria, the mast strength is calculated against three load cases, namely:

1. Maximum Static Hook Load
2. Wind Speed Maximum
3. Erection Loads

INTEGRITY ANALYSIS RESULTS

Figure 2-3 shows the FEA of the rig mast, while figure 4-10 will show the pattern of distribution of stress ratio values, namely the ratio between the stress that arises and the allowable stress of the material on the parts of the mast due to loading.

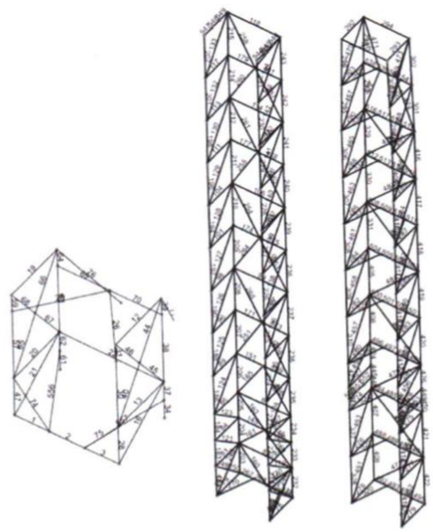

FIGURE 2. FEA Model of Rig Mast

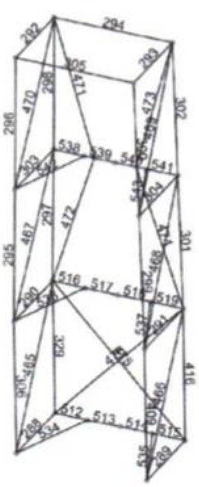

FIGURE 3. FEA Model of Upper Rig Mast near the Damage Braces

In the pictures above, the intensity of the stress ratio that arises is also displayed in color to facilitate observation where the red color indicates a stress ratio value that exceeds the value of 1, which means that the stress that arises is very high because it is greater than the allowable stress value, according to American Institute of steel construction

(ASD-89) which is the reference required by the API 4F standard for strength calculations for drilling masts and workover rigs.

TABLE 4. Static Hook Load Condition

Items	Data
Hook Load	113.4 Metric Ton
Travelling Block Load	1.1 ton
Crown Block Assembly Load	550 kg
Dead Line and Fast line Load	0.148 x 113.4 = 16.8 ton
With eight active configurations	(fast line factor = 0.148)

Maximum Static Hook Load

In this load case, the Mast is given a hook load of 113.4 metric tons. The calculation results are shown in Figures 4 and 5.

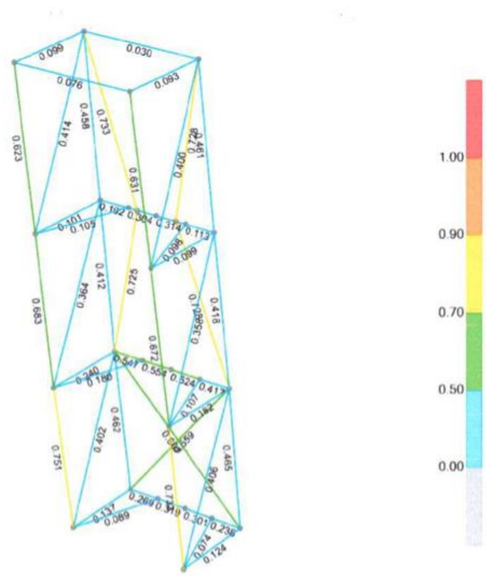

FIGURE 4. Stress Ratio Distribution Pattern on the Mast Around the Repair Site with All Braces Installed

By not installing the two braces, the stress ratio value on the other frames around the not installed brace increases slightly, but the value is still below 1, while the maximum stress ratio value was initially 0.758 on frame no. 539 in the upper mast experienced relaxation and decreased to 0.747.

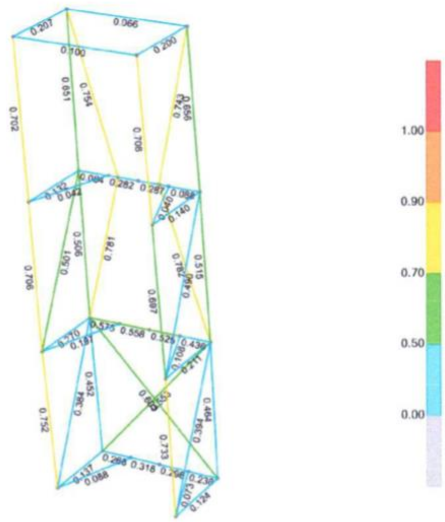

FIGURE 5. Stress Ratio Distribution Pattern on the Mast Around the Repair Site Without Two Braces Installed

Wind Speed Maximum

In this load case, the Mast is given a wind speed of 60 knots with a traveling block load condition of 1.1 tons. The calculation results are shown in Figures 6 and 7.

TABLE 5. Wind Load Condition

Items	Data
Wind Speed	60 knots
Travelling Block Load	1.1 ton
Crown Block Assembly Load	550 kg

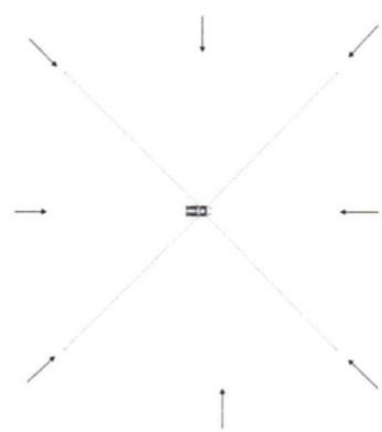

FIGURE 6. Wind Direction on Rig Mast (Top View)

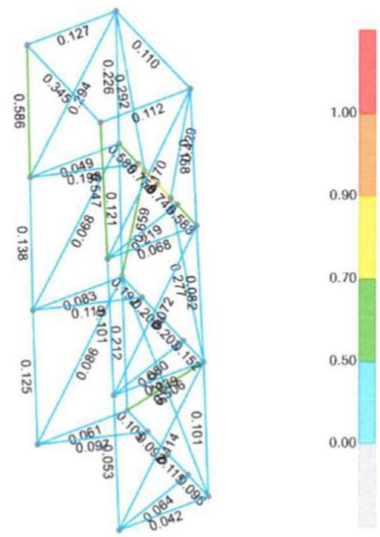

FIGURE 6. Wind Load Stress Ratio Distribution Pattern with All Braces Installed

By not installing the two braces, the stress ratio value on the other frames around the brace that is not installed increases slightly, but the value is still below 1, which indicates that the mast was still strong enough to withstand a maximum wind speed of 60 knots. This is partly because the design of the Mast uses a fairly high safety factor value.

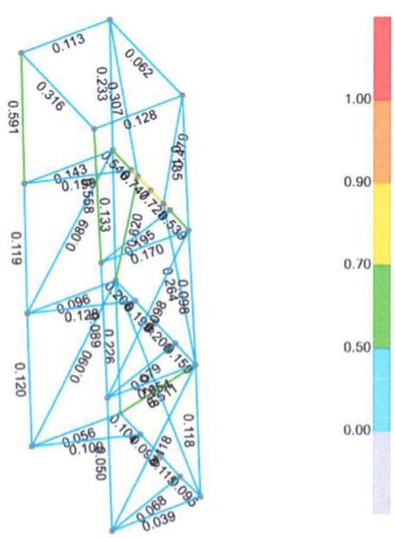

FIGURE 7. Wind Load Stress Ratio Distribution Without Two Braces Installed

Erection Load

The calculation is carried out on the position of the mast which causes the greatest load, namely at the beginning of the mast erection process where the upper and middle mast positions are still horizontal. The calculation results are shown in Figures 9 and 10.

TABLE 5. Erection Load Condition

Items	Data
Travelling Block Load	1,1 ton
Crown Block Assembly Load	550 kg

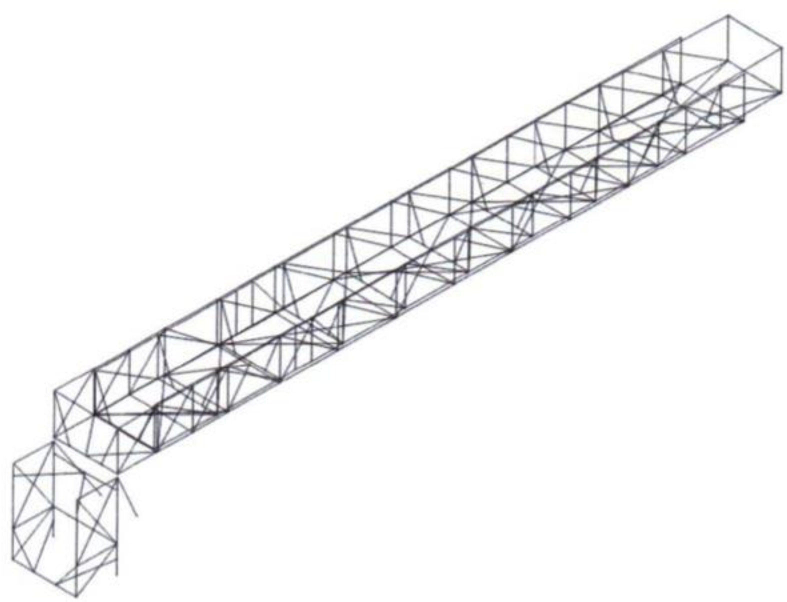

FIGURE 8. FEA Model of Rig Mast on Erection Process

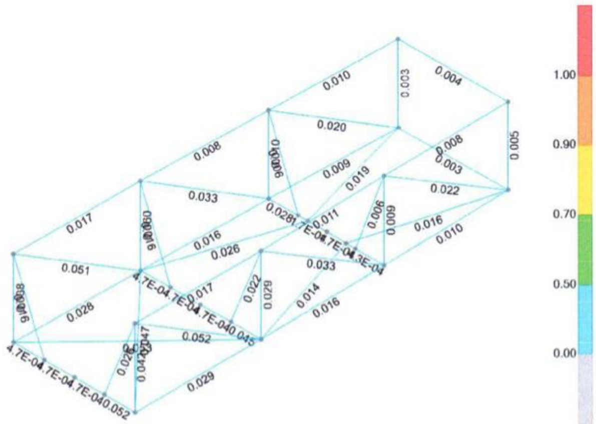

FIGURE 9. Erection Load Stress Ratio Distribution Pattern with All Braces Installed

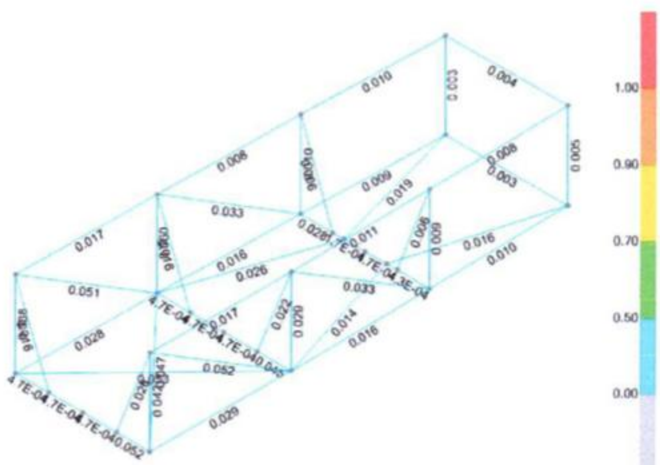

FIGURE 10. Erection Load Stress Ratio Distribution Pattern Without All Braces Installed

By not installing the two braces, the stress ratio value on the other frames around the brace that is not installed practically does not change. This is partly because during the erection process, the upper mast rides on top of the middle mast so it does not receive the load.

RECOMMENDATIONS

From the results of the analysis, we can give the recommendations:

1. The actual strength of the mast is also affected by the physical conditions of the mast, such as corrosion, permanent deformation, wear, and tear, and other physical conditions that are not included in the scope of the calculation.
2. Suggestions follow API RP 4G requirements regarding guy-wire and pre-tension installation.

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CONCLUSION

The results of the analysis concluded that:

1. Without the two damaged braces, the mast can withstand a maximum static hook load even though the stress ratio value has increased slightly but is still below the value of 1.
2. Without the two damaged braces, the mast can withstand a wind speed of 60 knots even though the stress ratio value has increased slightly but is still below the value of 1.
3. Without the two damaged braces, the mast can still withstand the load caused by the erection process because the upper mast, where the two braces are located, does not support the load due to the erection process.
4. Analysis results in points 1-3 are extreme conditions where the strength of the two replacement frames is not considered. In practice, the two replacement frames also support the load so that the change in the strength of the mast is smaller than the calculation results.

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