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# Simulation of the Corrosion Point and Repairing Technique at the Crane with Finite Element Analysis

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*Abstract*-**This paper describes the stress analysis for the corrosion area at the hollow pipe crane structure. This crane is used for lifting the load. Finite element analysis was used to investigate the stress concentration at the corrosion point. Three stages had been simulated; first stage simulates the structure without corrosion, second stage simulates the main chord with corrosion and third stage simulates the corrosion point with patch method and clamp shell repair method. The results show that the stress concentrations at the corrosion points were double from the normal point. Clamp shell method reduces the stresses by 28.6%. This technique saves the costs and time to repair the corrosion areas.**

***Keywords***: finite element analysis, corrosion, crane structure, propose repair.

## I. INTRODUCTION

Crane is one of the important structures especially during the constructions of the building or any other civil constructions. Purpose of the crane is to lift the heavy equipment or constructions material from ground to the desired level or floor during the construction process. Figure 1 shows crane in the working conditions in the constructions yard. Crane is always open to the effect of the environment especially corrosion. Corrosion defect at crane structure will reduce the capability of the crane to lift the load. Finite element modelling was used to analyse the corrosion on the crane. Computer modelling is a useful tool for solving the problem [1]. Among numerical techniques, the finite element method is widely used due to the availability of user friendly commercial software in market. The finite element method is a numerical procedure that can be applied to obtain solutions to a variety of problems in engineering [2]. The method can analyse any geometry, and solves both stresses and displacements [3].

Assessment of existing structures is performed in order to extend service life of the facility, as new methods of production and new discoveries may result in a request for life extension. From an economic point of view the continued use of an existing installation will in many cases be preferable, compared to a new installation. This will be preferable for several installations even with major modifications to the structure. Assessment will also be needed after addition of more equipment, more personnel and deterioration and damage to the structure. The purpose of an assessment of existing structure for possible life extension should be to ensure that the probability of structural failure is acceptable. In order to achieve this, several assessment procedures are proposed. A few of these will be presented in the following text. The purpose of a structural analysis is to achieve sufficiently safe and effective structures. Methods of designing structures have developed from "trial and error" to linear elastic design by load and strength calculations and code check [4].

The development of linear elastic design has to some extent been a process of "trial and error". The design against new failure modes have been introduced into the code checks as more experience on incidents and accidents has been collected. Important aspects of this development are the understanding of structural behaviour aspects like brittle cracking and fatigue. Developments on structural loading have also been important, as vortex induced vibrations and wave slamming loads. Linear elastic design and the codes used today for offshore structures are relatively mature. Failures are relatively rare for structures in operation on a field. However, it should be noted that very few offshore structures have been exposed to any loading comparable with the design loading. Hence, very few failures should be expected and the failures that have been seen are rather due to errors in design, fabrication or installation [4].

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Stress corrosion cracking (SCC) is the unexpected sudden failure of normally ductile metals or tough thermoplastics subjected to a tensile stress in a corrosive environment, especially at elevated temperature (in the case of metals). SCC is highly chemically specific in that certain alloys are likely to undergo SCC only when exposed to a small number of chemical environments. The chemical environment that causes SCC for a given alloy is often one which is only mildly corrosive to the metal otherwise. Hence, metal parts with severe SCC can appear bright and shiny, while being filled with microscopic cracks. This factor makes it common for SCC to go undetected prior to failure. SCC often progresses rapidly, and is more common among alloys than pure metals. The stresses can be the result of the crevice loads due to stress concentration, or can be caused by the type of assembly or residual stresses from fabrication (eg. cold working); the residual stresses can be relieved by annealing. The specific environment is of crucial importance, and only very small concentrations of certain highly active chemicals are needed to produce catastrophic cracking, often leading to devastating and unexpected failure [5]. The oxidation of alloying elements such as chromium results in the formation of chromium-depleted areas, and therefore, impairs the corrosion resistance of the coatings employed in various corrosive environments [6-8]. The anodisation will open up application field in our research and it is possible to generate micro-rough surface, then by means of subsequent fixation of hydrophobic organic compounds, super-hydrophobic surface is formed [9-11]. Such surface is of great importance for many industrial applications, and may present a solution to the long-standing problems of environmental contamination and corrosion of metals [12].

Figure 1: Picture of the crane in the construction yard.

## II. METHODOLOGY

Global model was built using beam elements in Finite Element Modeller (ALGOR™). Specified lifting load and gravitation pull was applied with boundary conditions representing crane pivot points and crane hoist luffing cable. The reactions force and resultant force of the crane hoist were extracted from the finite element model. Currently manual calculations were carried out to verify the finite element model results. Internal forces and moments of structural elements at specific corrosion points were extracted from the finite element model and tabulated. Localised model of corrosion locations were developed using solid modeller (SolidWork™). The models were then transferred to ALGOR for stress calculations. Equivalent loads and boundary conditions were applied to the corrosion model.

## III. FINITE ELEMENT MODELLING

The global model as shown in Figure 2 was built using beam elements where its structural elements were represented according to their thickness, internal and external diameter.

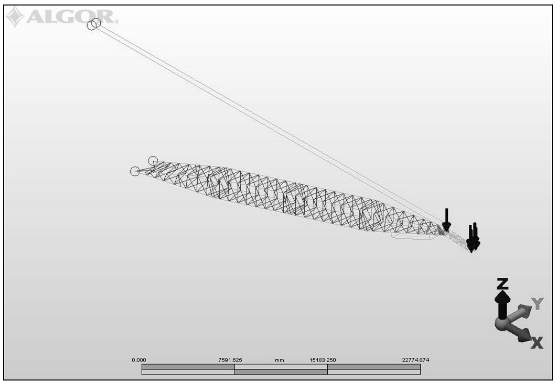


Figure 2: global model.

From the global model, reaction forces at the pivot point and crane hoist were extracted. List of the values are available in Table 1. Manual force and moment calculations were also performed to verify force parameter to be input in finite element global model (Refer to Table 2).

Table 1: Reaction Forces from Finite Element Model

| Resultant Crane Hoist (kN) | Pivot Point (horizontal) (kN) | Pivot Point (vertical)(kN) |
|---|---|---|
| 1124 | -1089 | -37.9 |

Global deformation and main chord internal forces were verified from the finite element model with manual calculation for free body diagram as shown in Figure 3. Gravitational load was studied and shown that crane itself has own stress downward impact of gravity as shown in Figure 4.

Confirmation on reaction forces by manual calculation can be referred in Figure 3.

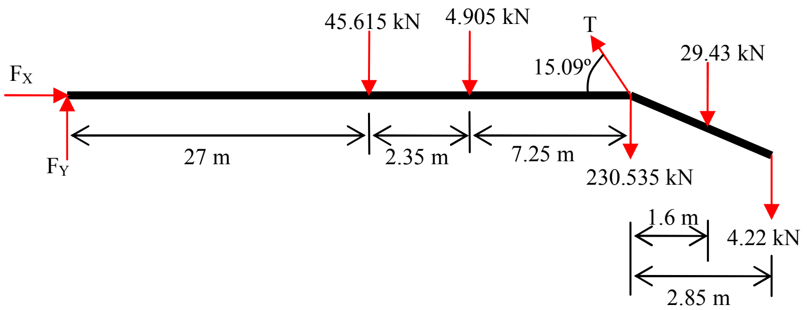


Figure 3: Free Body Diagram

$$\circlearrowleft \sum M_F = 0$$

$$-(45.615)(19.3)-(4.905)(29.35)-(230.535)(36.6)-(29.43)(38.2)-(4.22)(39.45)$$

$$+T\sin(15.09^\circ)(36.6)=0$$

$$T = 1165.36kN$$

$$\Uparrow \sum F_Y = 0$$

$$F_Y - 45.615 - 4.905 + 1165.36\sin(15.09^\circ) - 230.535 - 29.43 - 4.22 = 0$$

$$F_Y = 11.32kN$$

$$\Rightarrow \sum F_X = 0$$

$$F_X - 1165.36\cos(15.09^\circ) = 0$$

$$F_X = 1125.17kN$$

$$F = \sqrt{F_X{}^2 + F_Y{}^2} = 1125.23kN$$

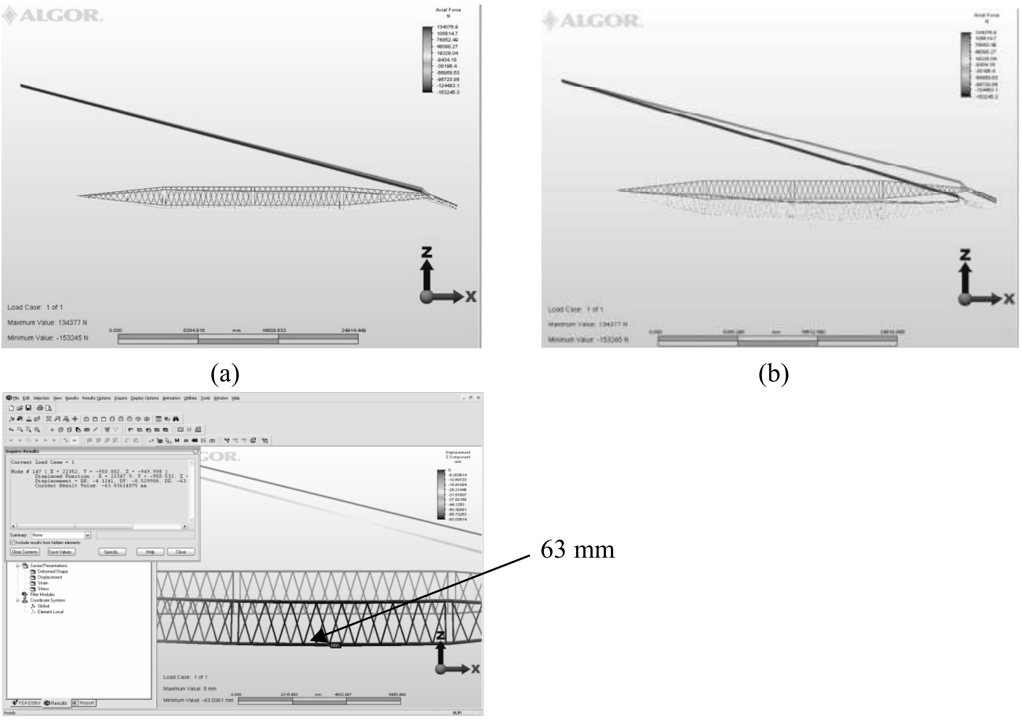
Table 2: Reaction Forces from Manual Calculations

| Resultant Crane Hoist tension(kN) | Pivot Point (horizontal) (kN) | Pivot Point (vertical) (kN) |
|---|---|---|
| 1165 | -1125 | -11.32 |

Calculations on stresses at uniform cross section internal axial forces and bending moment were extracted from the global finite element model. Stress values were calculated manually for areas away from the corrosion areas. The manual calculation is based on classical stress formula for axial load and bending moment.

$$\sigma = \frac{P}{A} \pm \frac{My}{I} \tag{1}$$

Where, σ is a stress, P is an axial load, A is a net sectional area, M is a bending moment, y is a maximum radius and I is a second moment of area. It was found that bending moment contribution towards resultant stress is minimal.



(a) (b)

(c)

Figure 4: Gravitational load on the crane structure results in bending deformations. Maximum deflection due bending is 63mm in the Z-axis direction. a) actual, b) exaggerated view (5 times), c) maximum deflection

The bending deformation as shown in Figure 5 of the crane structure is further verified by checking the internal forces of the main chords. It is confirmed that the top two main chords are in compression and bottom main chords are in tension. A typical four-node tetrahedral element and four-node quadratic shell element, and their coordinate systems are illustrated in Figure 6 [13].

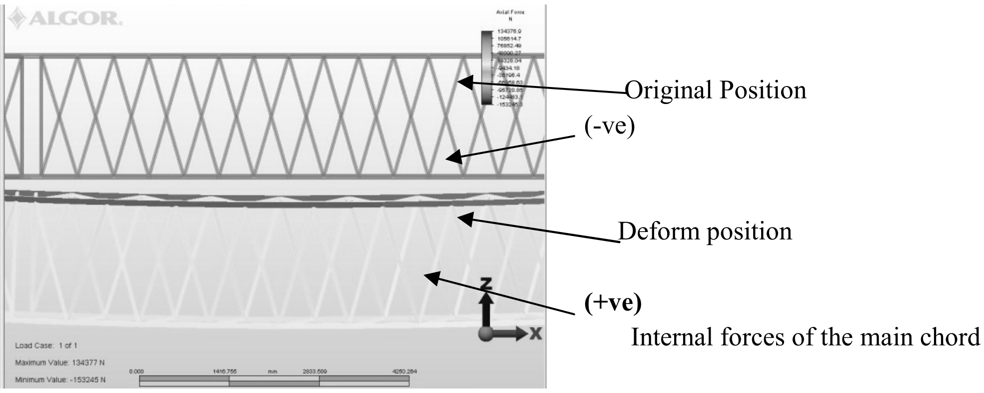


Figure 5: bending deformation

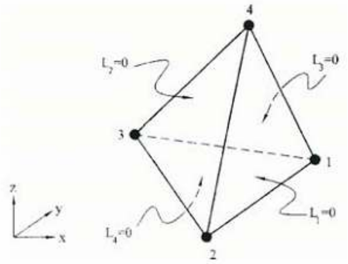
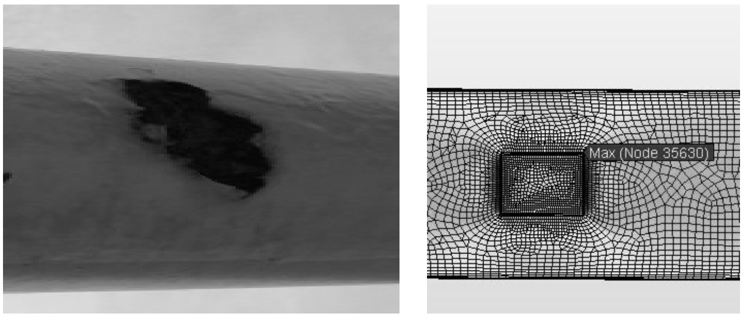


Figure 6: -node tetrahedral element

## IV. RESULTS AND DISCUSSION

Stress corrosion simulation result shows that the stress at the corrosion point is 350MPa which is double from area without corrosion defect (~170MPa). Figure 7(a) shows corrosion point at the crane structure while Figure 7(b) explains the corrosion point in term of finite element analysis. The corrosion area indirectly affects the strength of the crane itself and its capability. It will reduce the function of the crane to lift the load by half. There are two simple way to repair the corrosion point which is patch method and clamp shell method. Patch method is simpler than clamp shell method. Patch method will use half round and covered just the corrosion area affected. Half round metal will be welded to the corrosion area. Clamp shell method will be more difficult to realize but more effective to repair and reduce the stress compare to patch method. Figure 8 and 9 shows of both patch method and clamp shell method to repair the corrosion.



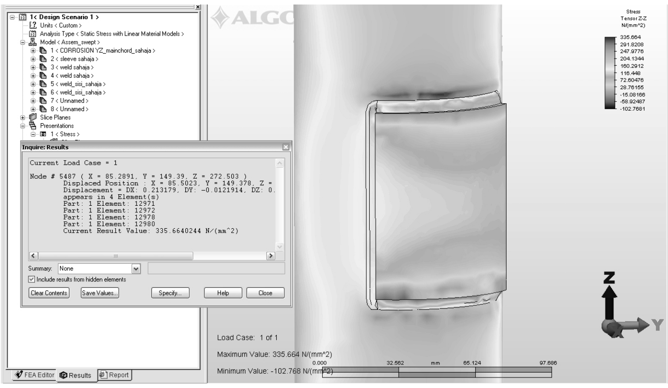
(a) (b)

Figure 7: Crane structure with corrosion effect. a) corrosion, b) finite element model

Repairing technique by patch method will reduce the stress from 350 MPa to 335MPa as shown in Figure 8. Therefore, the effectiveness of the patch method could be calculated in the following manner.

$$\text{Percentage of effectiveness} = \left(\frac{350-335}{350}\right)\times 100\% = 6\%$$

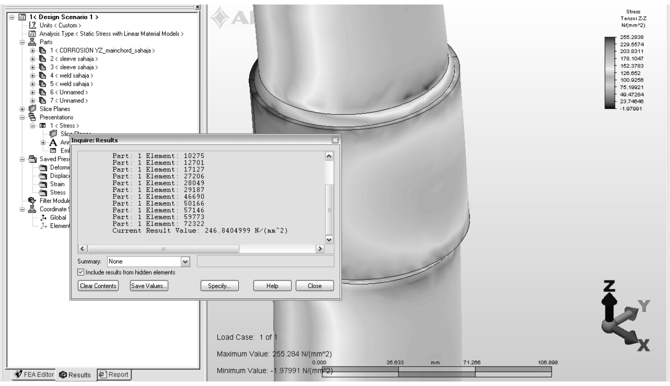
The patch method could reduce the stress level by 6%. The reduction is too small.



```
Current Load Case = 1

Node # 5487 ( X = 85.2891, Y = 149.39, Z = 272.503 )
        Displaced Position : X = 85.5023, Y = 149.378, Z =
        Displacement = DX: 0.213179, DY: -0.0121914, DZ: 0.
        appears in 4 Element(s)
        Part: 1 Element: 12971
        Part: 1 Element: 12972
        Part: 1 Element: 12978
        Part: 1 Element: 12980
        Current Result Value: 335.6640244 N/(mm^2)
```

```
Load Case:  1 of 1
Maximum Value: 335.664 N/(mm^2)
Minimum Value: -102.768 N/(mm^2)
```



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        Part: 1 Element: 10275
        Part: 1 Element: 12701
        Part: 1 Element: 17127
        Part: 1 Element: 27206
        Part: 1 Element: 28049
        Part: 1 Element: 29187
        Part: 1 Element: 46690
        Part: 1 Element: 50166
        Part: 1 Element: 57146
        Part: 1 Element: 59773
        Part: 1 Element: 72322
        Current Result Value: 246.8404999 N/(mm^2)
```

```
Load Case:  1 of 1
Maximum Value: 255.284 N/(mm^2)
Minimum Value: -1.97991 N/(mm^2)
```

Figure 8: Repair by patch method

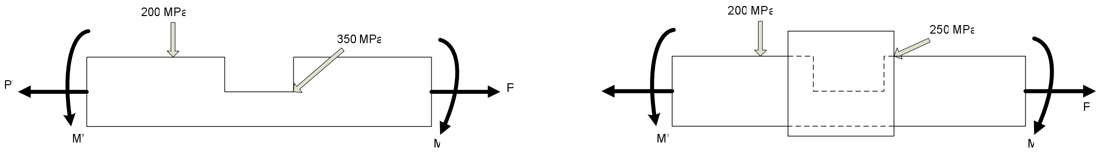
Figure 9: Repair by clamp shell method.

Completed shell method will result lower stress which is 246 MPa at the highest stress area which is in between repair shell and original crane structure as shown in Figure 9. Corroded area length: 100 mm, Clamp shell length = (2 x shoulder) + corroded area = (2 x 100) + 100 = 300 mm

The effectiveness of clamp shell method is assessed by comparing the stress values in critical areas. In this idealised case the stress concentration in the corroded area is 350 MPa. However with the clamp shell attached, the maximum stress is reduced to 250 MPa. The location of worst stress has now moved to the fillet area instead of the corroded area. Therefore, the effectiveness of the clamp shell method could be calculated in the following manner;

Percentage of effectiveness = $\left(\frac{350-250}{350}\right)\times 100\% = 28.6\%$

The clamp shell method could reduce the stress level by 28.6%. Figure 10, shows that the comparison between corrosion without clamp shell and corrosion with clam shell. The amount of reduction is directly influenced by the length of the ‘clamp shell’ length. Even though the relationship is proportional, a repair exercise would never reduce the stress concentration value to the original level when the crane structure brand new.



(a) (b)

Figure 10: Corrosion with and without clamp shell, a) corrosion without clamp shell, b) corrosion with clamp shell

## V. CONCLUSIONS

The analysis has identified weaknesses in the crane structure due to corrosions. Corrosion areas have higher stress due to discontinuities cause by the corrosions. The analysis was also able to infer the original margin of safe working stress based on ration of worst effective working stress to material’s yield strength specified by the manufacturer. In addition a study on repair method has also been completed. The repair method should follow the clamp shell method. The method could reduce stress concentrations at corrosion points by 28.6%. Finite element analysis is an effective tool to investigate the deformations and stress trend in the corroded structure.

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