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Numerical Simulation of stresses in welded T tubular structure

A. Fouathia, S. Meziani, M. Gaci

Laboratory of Mechanics, Faculty of Sciences of Technology, University Constantine1
Campus Chaab Ersas, 25000 Constantine, Algeria
Email: fouathiaa@yahoo.fr ; salim.meziani@labomecanique-umc.org

Abstract— **Fatigue failure caused by stress concentrations in tubular welded joints is observed in offshore platforms subjected to cyclic loading in corrosive marine environments. In some junctions, the stress concentration can induce a stress thirty times the nominal stress, and increase the risk of fatigue failure in tubular joints. Therefore, it is necessary to accurately assess the intensity of the stress concentrations to effectively deal with the problem of fatigue damage and lead to reliable tubular joints.**
This work aims to study the stress distribution and location of the "hot" spots in a T welded tubular structure subjected to a combined loading of tension and bending (in-plane bending, out of plane bending and traction) to better simulate the actual loading.

Keywords: **stress concentrations, tubular welded T-joints, hot spots, tension, bending.**

I. INTRODUCTION

The tubular welded joints are widely used in metal buildings, modern bridges, towers and offshore structures such as oil rigs "Offshore" type Jacket for the exploitation of hydrocarbon reserves in the middle sailor. They are classified according to their form in T. Y. X, K, DT, DY, and DK [1].

Platforms "Offshore" are subjected during their service life (20-30 years), various environmental actions such as waves, currents, wind and particularly severe storms and being acted several combined stresses, in particular traction [2], [3]. The in-plane bending and bending out of the plane cause at the junctions of tubes, hot spots or areas of high stress concentrations [4]. In some junctions, the stress concentration can induce a maximum stress at the intersection, 30 times the nominal stress, leading inevitably to a fatigue damage of these structures [5]

Besides the security problem they pose, the fatigue failure cause significant operating losses for the user and costly to repair and redesign high for the manufacturer [6].

It is therefore necessary to assess accurately the intensity of stress concentration to properly address the problem of fatigue damage, and result in reliable tubular junction, and it will pay particular attention to the design and the achievement of welded assemblies. So far, research [7] in the field of fatigue welded tubular nodes was conducted mainly conducted by the offshore oil industry [8].

It is therefore necessary to accurately assess the intensity of the stress concentrations to better assess the fatigue damage and obtain reliable tubular joints.

This study deals with the phenomena of fatigue nodes tubular assemblies of marine metal structures subjected to random forces due to natural elements (waves, wind, current ...).

It aims to study the stress distribution and location of "hot" spots (hot-spot stresses) in critical areas of tubular welded joints, subjected to static loading in tension, in-plane bending, bending out of plan and the combination tension / in-plane bending and tensile / bending out of the plane. It is therefore to find a numerical simulation tool to study and predict the behavior of welded tubular structures by a simple and accurate modeling of the structure. In this study, the simulations were performed using the computer code COMSOL Multiphysics.

II. MODELING OF THE TUBULAR STRUCTURE

A. Steps in the modeling process

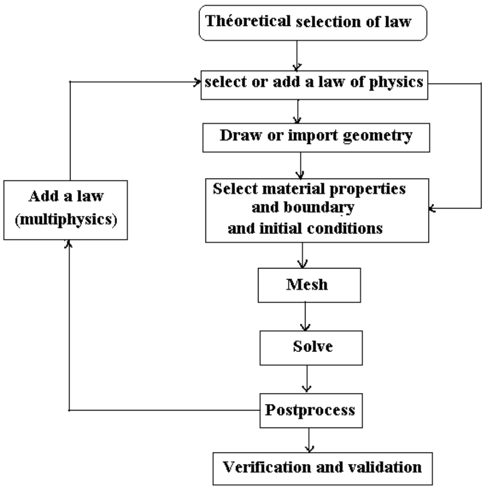

Fig.1 Process Flowchart modeling COMSOL Multiphysics

B. Modeling of a tubular welded structure

The 3D geometry of model was built on SolidWorks and imported into COMSOL (Fig. 2). The mesh is triangular type Lagrangian.

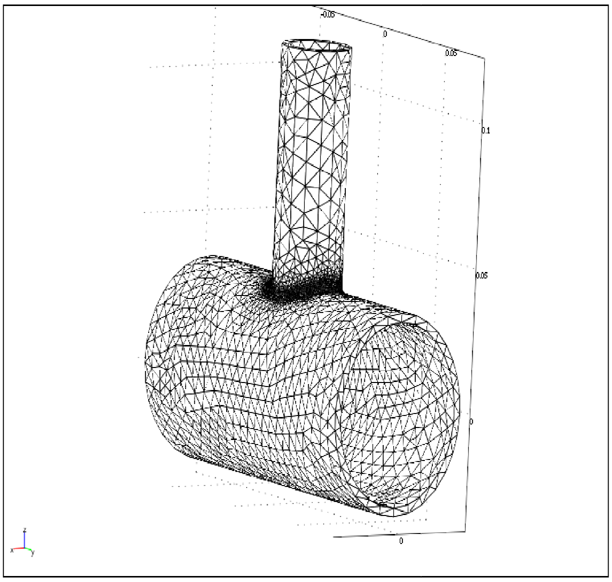

Fig. 2. Refined mesh of model

The mesh in the most sought joint area was more refined.

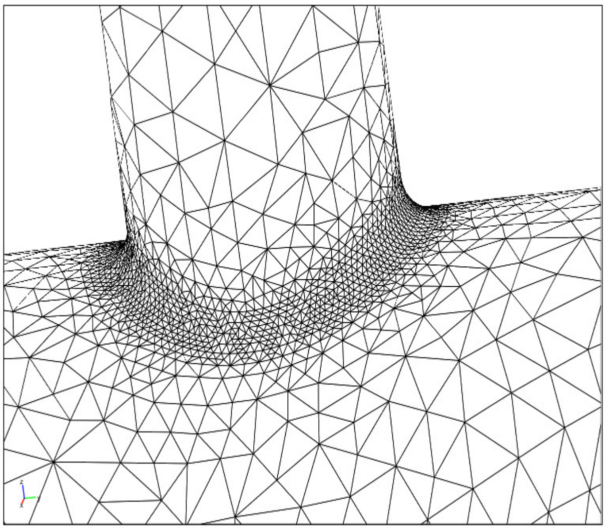

Fig 3. Zoom on the (very fine mesh) weld

III. RESULTS AND DISCUSSION

A. Stress distribution

Von Mises stresses are calculated in the center of gravity of the element.

The results of the simulation model under tension, we note the existence of two zones in the spacer (Fig. 4):

- Zone 1 where the stresses decrease abruptly, is located above the weld seam in the immediate vicinity of the latter,
- Zone 2 in which the stresses decrease gradually, while having a small variation in place to achieve substantially constant values at the upper end of the spacer.

σ_N is the nominal stress Measured in zone 2. σ_{N1}, σ_{N2} are the nominal stress taken at the edge of the "hot" area located above the two hot spots corresponding to two points at a nearby high (D + d) / 2 points from the saddle point. σ_{max} is chosen as the largest of the values σ_{N1} and σ_{N2}. Either: $\sigma_{max} = \sup(\sigma_{N1}, \sigma_{N2})$

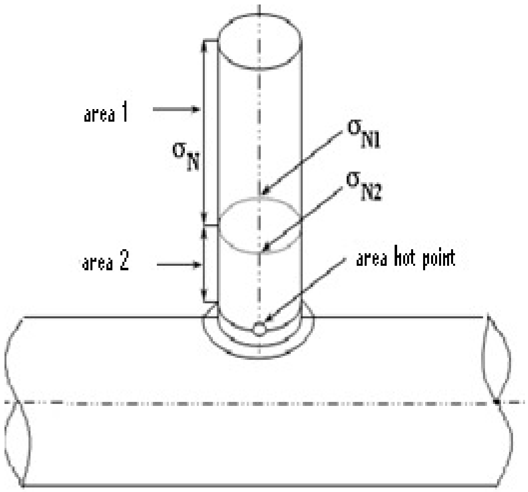

Fig.4: Areas of stress distribution

Fig. 5 shows the evolution of the Von Mises stress along the periphery of the spacer. We note the presence of two explained zones.

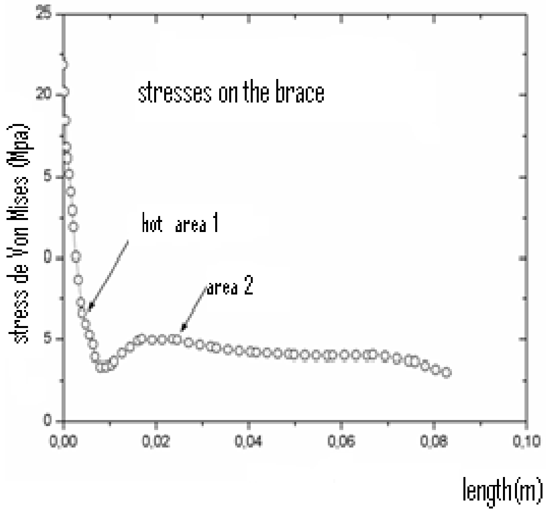

Fig. 5. Distribution of stress on the brace

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Applying a pulling force on the spacer, the structure undergoes a deformation whose general shape is shown in Fig. 6. Note that the deformation is located largely in the middle of the frame just below the spacer. Also the spacer is deformed but in lower proportion relative to the frame. The deformation is mainly longitudinal.

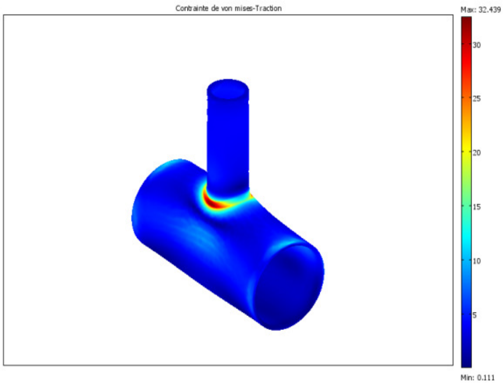

Fig. 6: Field of stresses in the structure with distorted.

B. Constraints in the junction

In the case of tensile stress, concentration around the junction is symmetrically distributed. It is largely visible in the vicinity of two points in the neighborhood party, which favors the appearance of the hot spot in these two points. In Fig. 7 we can see the stress concentration. The maximum point value is 32.4 MPa and the minimum value is 0.11 MPa

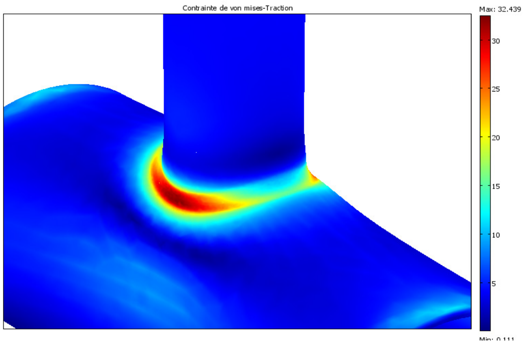

Fig. 7: Concentration of stresses in the Weld.

For reasons of symmetry, we consider only half of the welded structure. The study therefore focus on the portion between the saddle point ($\Phi=0°$) () and Crown Point ($\Phi=90°$).

Fig. 8a and 8b shows the distribution of the stress intensity factor k_t in the structure. We see that the concentration increase gradually from the saddle point up to the maximum value at the crown point ($k_t = 6.4$).

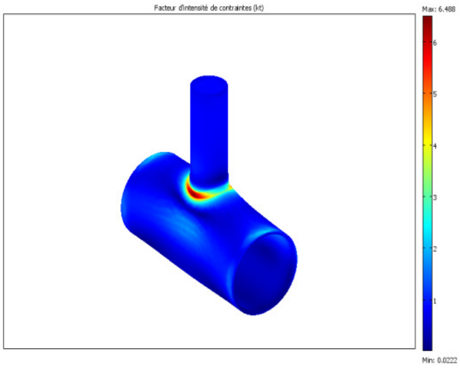

Fig. 8a: stress intensity factor in traction

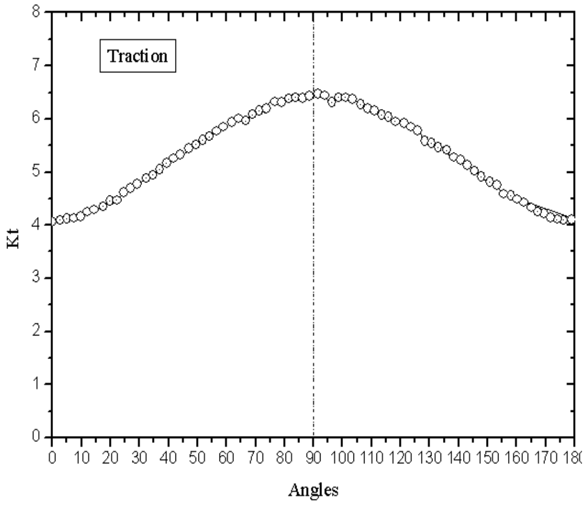

Fig. 8b: Change k_t according Φ_i

C. Out of plane Bending

In the case of a bending stress from the plane, the structure deforms transversely. This deformation is localized mainly on the frame. A part of the structure will undergo a pull and the other a compression (Fig. 9).

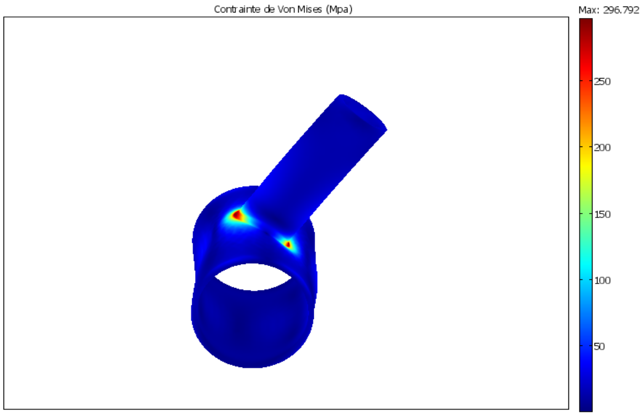

Fig. 9. Stress concentration in bending out of plane

1) Constraints at the junction

In this case the loading can be distinguished a similarity in the distribution of stress concentration with the tensile. Concentration is located at the two crown points. The concentration changes in the same way as in the case of tension, unless the values are lower. For reasons of symmetry we only consider the portion between the saddle point and the Crown Point (Fig. 10).

The minimum value is located at the saddle point at the angle $\Phi=0°$, while the maximum value is at a crown point ($\Phi=90°$), in the range of 296.7Mpa.

We note that in the case of Out of plane bending, the stress value of the hot spot is larger than that of traction.

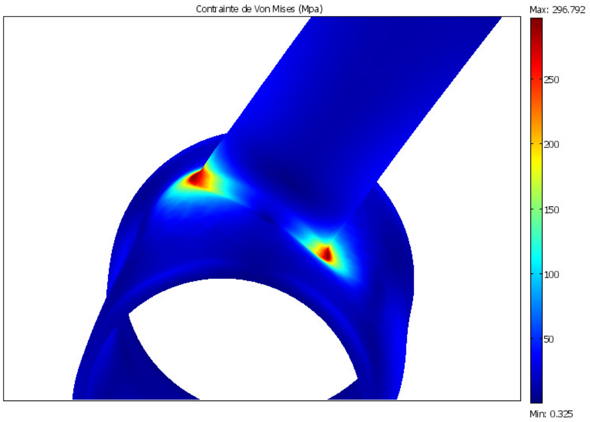

Fig. 10. Distribution of stress in the welded joint.

The Fig. 11a and 11b shows the distribution of stress intensity k_t of the tubular structure, according to the positioning angle factor. It has the same shape as the stress-strain curve. Concentration increases gradually from saddle point until it reaches the maximum value at the Crown Point in the range of 7.8 MPa.

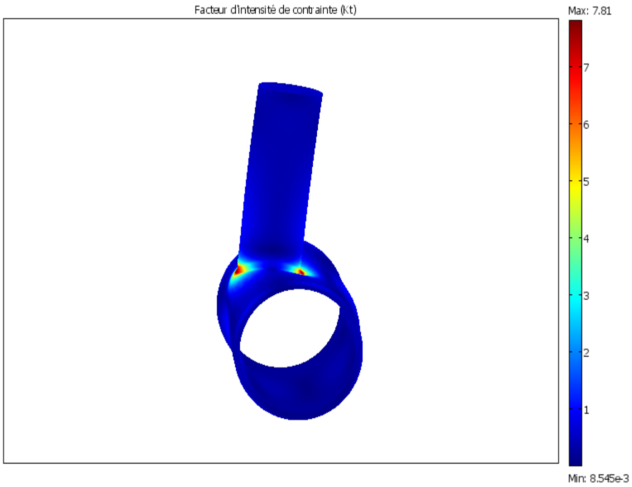

Fig. 11a. Stress intensity factor in traction

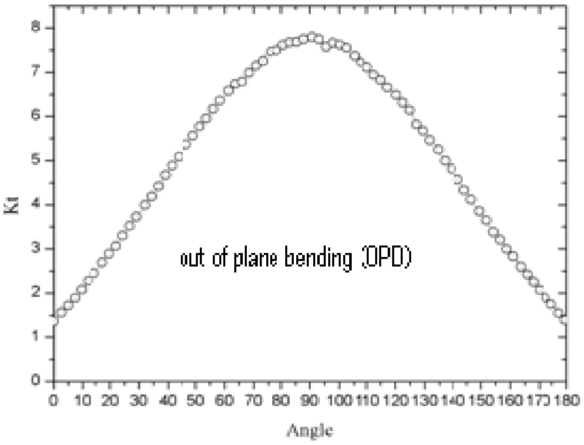

Fig. 11b. Curve of variation of kt based Φi

2) Bending in the plane

We apply in this case a bending in the plane of the frame creating a deformation made by compression on one side and pulling in the other. We note that most of the deformation is located on the chord near the junction between the two tubes. The spacer undergoes deformation also, but in but small size (Fig. 12).

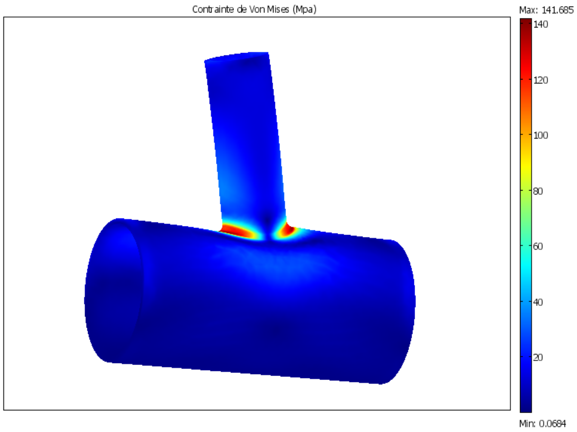

Fig. 12. Distribution of stresses in the structure

3) Constraints at the junction

The Fig. 13 shows the stress distribution in the structure. Unlike the previous two cases of loading, stress concentration is not located near the Crown Point but it is deflected toward the saddle point. It is in the range of 141.6 MPa.

In the two previous cases we note the presence of two distinct hot spots; in this case we also notice the same think.

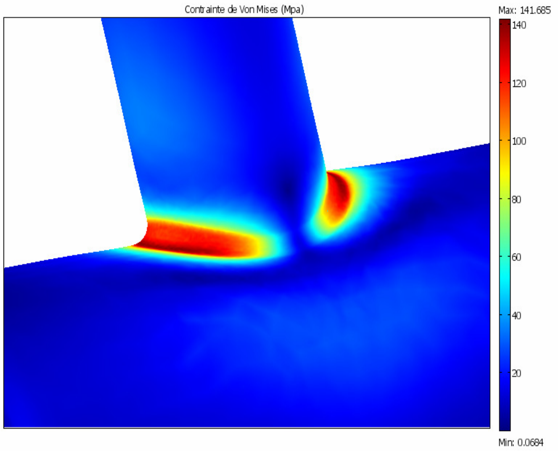

Fig. 13. Concentration of bending stresses in the plane.

In this case the concentration change gradually from the saddle point to a maximum value (k_t = 5.06) at an angle Φ=90° and then begins to decrease until Crown Point. We note that the hot spot is not located at the Crown Point as the other two cases, but in the saddle point (Fig. 14).

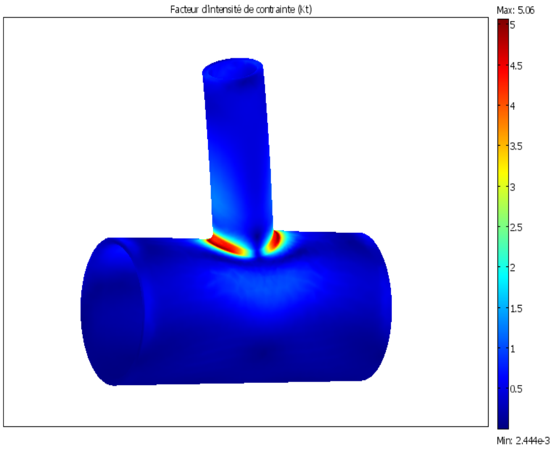

Fig. 14. Factor intensity of traction stresses.

In the same way as in the other two loads we give the curve representing the evolution of the stress intensity factor based on Φ_i . We notice that the shape of the curve is completely different from the other two. But we can see the appearance of symmetry (Fig. 15).

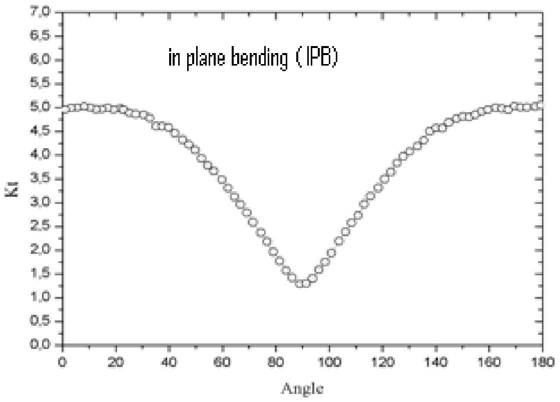

Fig. 15. Curve of variation of Kt based Φi Solicitation of the structure IPD

4) Comparison of results

In Table I we compared the results of our calculations and those obtained by parametric formulas and numerical calculations of different researchers [9.

Table I : Comparison of results

Load cases	Kuang & al.	Gibstein	Hel& al	F.E.M	our calculation
Traction	9.6	11.2	6.7	8.6	6.48
IPD	3.3	3.4	2.8	3.2	5.06
OPD	8.6	11.3	6.1	9.1	7.81

We find that the results of our calculations are closer to those obtained in particular by Hel and al, in general, and by other researchers, for the same loads.

C. Combined Loading

1. Combination pull-OPD-IPD

Applying a combined loading of traction and bending out of plane and bending in plane with the same load of 4 MPa, we note that the stress concentration at the junction between the chord and the brace is located in the vicinity in two points of crown. Given the combination of loads, the chord is extremely distorted (Fig. 16 and 17).

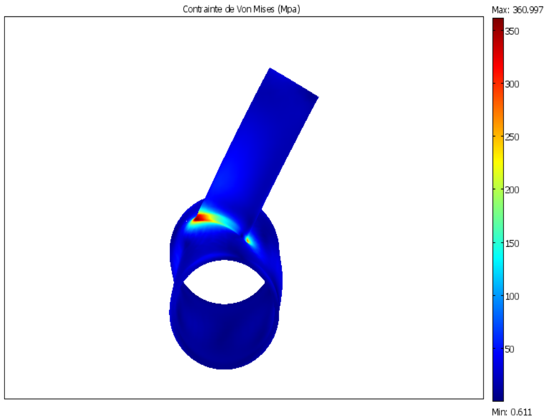

Fig. 16. Concentration of stresses in traction-IPD-OPD.

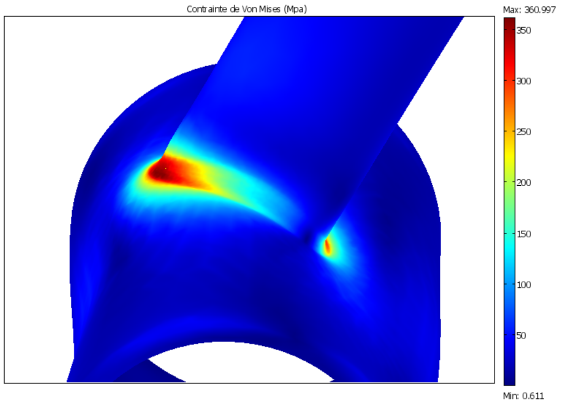

Fig. 17. Distribution of stress in the welded joint.

This stress concentration is not symmetric. It starts with a maximum value 6.3 to Crown Point, Φ=0° angle and begins to increase until it reaches the value of 10.3 at Φ=72° angle. Then the constraints will gradually decrease until it reaches the value of k_t = 3.6 to angle Φ = 143 °, from this point it increases to the value of k_t=6.3 in the second crown point at the angle Φ=180°. The curve representing the evolution of the stress concentration factor k_t based on the positioning angle Φ_i is shown in Fig. 18 and 19.

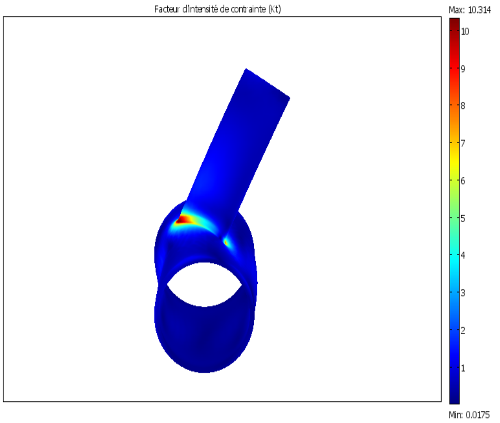

Fig. 18: Factor intensity of traction

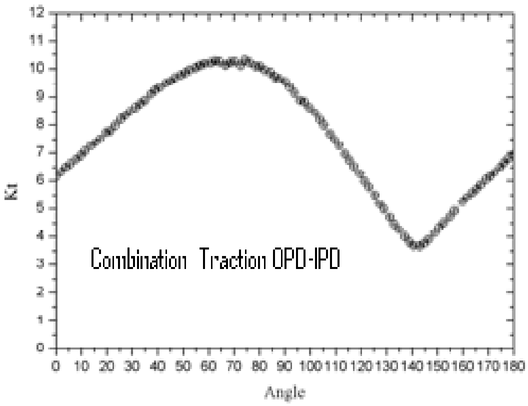

Fig. 19: Curve of variation of Kt based Φi.

D. Discussed and recommendations

1) In case traction

The dominant stresses in the welded T tubular structure under axial loading are produced by bending, as a result of the overall deformation of the chord. Any modification of these constraints has a significant influence on the values of the k_t coefficient and reduces the deformation of the chord.

The best way to reduce the deformation of the chord is to add a stiffener where the chord is deformed. Research [9] [10] have proven that this method can reduce the maximum value of hotspot up to 40%. Using this principle, Baker Jardine [13] came to reducing the maximum value of the hot spot of 5.25 to 3.15.

2) In case of bending in the plane

In the case of bending in the plane, the stresses at the junction spacer ribs are produced by local bending of the chord.

Acting in the same way as in the case of tension, adding a stiffener in the frame, you can get a slight reduction in the maximum value of kt, however, this value is low due to the deformation direction of the chord.

3) In case of bending out of plane

The out of plane bending is similar to the case of traction; the overall deformation remains the main factor to generate the constraints at the spacer chord junction. As in the case of traction, any reduction in the overall deformation results in the reduction of the values of k_t factor. With the same principle as the stiffening traction, the maximum values of k_t can be reduced to 30%. The calculation of stress concentration factors can bring pieces of information on the distribution of stresses in the structure designed according to the type of stress

Given the complexity due to many parameters in particular the geometry of the intersection curve, there is no fairly simple method to take into account the stress distribution in the vicinity of the weld. Only the finite element method can give any part of the answer.

Some research work, namely those conducted by the CTICM [12] (Industrial Technical Centre of Metal Construction, France), have established the variation of stress concentration factor according to each geometric parameter, as a function exponential type. The work carried out on cylindrical notched loaded in tension, have to take into account the exponential increase of the stress distribution.

The fact remains that this possibility is being ruled out of tubular structures, except in tension [12]. Therefore, the expression of stress concentration factor is given by the ratio of the maximum stress σ_{max} to the hottest point on the nominal stress σ_{nom} near the weld, both on the side of the spacer as that of the chord. We consider for each finite element of the structure, and for each stress, the Von Mises stresses, in order to obtain the stress concentration factors respectively. Constraints are taken into account the constraints of so-called "skin" for thin shell elements [11].

But we can say the existence of a zone of symmetry between the saddle point and the Crown Point; in this area the factors of stress concentration are identical, and are found to increase with as we advance the saddle point to Crown Point. The hot spot changes position depending on the geometry of the node and the nature of the solicitation.

IV. CONCLUSION

This study allowed us to show that the hot spots are usually located at points in the neighborhood when loading tensile, bending out of the plane and pulling / bending combination out of the plane with the values of the factors that can kt reach respectively (8.99, 10.36, 13.98) and are satisfactory compared to those found by other researchers (9.62, 10.45, 18.0).

In the case of in-plane bending and tensile / bending combination in the plan values are respectively equal to: (4.94 to 58.5 °, 72 ° 11.01). They are close to those obtained by other researchers (3.11 at 45 °, 9.8 to 67.5 °). It was found that the maximum stresses in the hot spots also vary depending on the type of loading

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