CALCULATION OF STRESS CONCENTRATION FACTOR (SCF) IN SOME TYPICAL TUBULAR JOINTS IN OFFSHORE PLATFORM STRUCTURES BY USE OF FINITE ELEMENT METHOD

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ABSTRACT

This paper introduce a method to analyse tubular joints of the type used in the jacket structure of offshore platforms. Initially, a computer program was developed to define the joint geometry by means of node coordinates. As a second step the generated mesh is checked by the use of pre-processors and then the entire structure is analysed by SAP IV computer program. In this study, shell elements were used to perform the analysis. The results obtained were then compared to some figures found in the literature.

INTRODUCTION

The "oil crisis" has already caused many economical troubles, mainly to those countries which depend directly of the import of that energy source. In Brazil, the crisis has led the government to search for new oil resources to at least balance the constantly increasing oil demand.
One of the advantages of this government policy was the construction for the first time in Brazil, of offshore platforms for the exploration of already known oil fields. However, the design and construction of such platforms require the knowledge of new type of technologies which must be learned from more experienced countries, and, for this purpose, an efficient program of research and development should be established under the government supervision.
In order to help the nucleation of a technological background in this subject, a group in the Department of Naval Architecture and Marine Engineering of Escola Politécnica of University of São Pau

lo, is at present working in a research project, involving the design and construction aspects of stationary offshore platforms. This project work is described in detail in another paper submitted to this Congress and is sponsored by Financiadora de Estudos e Projetos, FINEP.

STUDY OF TUBULAR JOINTS

One of the critical points in the platform structure refers to the design and construction of structural joints, since they have to withstand complex load configurations which can lead to highly stressed areas in the mentioned joints.
The type of joint treated in this paper is the tubular joint. In spite of looking very simple structural components, they are actually fundamental parts of an offshore platform since they promote the connexion between jacket elements, jacket and deck structures, etc. imparting the total structural system the strength and rigidity required for its operation.
A simple failure in one of such a joint can at least cause serious damages to the section to which it belongs, and depending on the conditions it can extend to other points of the structural system. Actually, statistics shows that tubular joints have been responsible for numerous structural failures, consisting in a major cause of damages in stationary offshore platforms. Investigations on the subject have shown that failures in those tubular joints were not always caused by a poor structural design, which can lead to undersizing of the whole joint, but they resulted from more complex mechanisms, such as brittle fracture, fatigue, stress corrosion cracking and problems within the base material or the welded joints.
On the other hand, it is now well recognized that all those material problems are closely related to the existance of critical stress states within the material, which can either start or continue a given failure process. Those stress states can be brought about by,for instance, a lamination problem, residual stresses induced by welding or fabrication processes, or by a physical or metallurgical notches, all of them having the tendency to cause stress concentrations in critical zones of the joint structure.
The type of stress concentration treated in this paper refers to those caused by the so called "geometrical notches", such as abrupt changes in the sectional areas of structural members,sharp bends, and equivalent geometries. Stress concentration problems can adequately be modeled and solved by computer programs and so this paper will describe the steps involved in the development of the solutions.

TYPES OF TUBULAR JOINTS

A typical tubular joint is shown in Figure 1 and it consists basically of three parts, i.e., chord, branch and plugs. They are differentiated with respect to the type of reinforcements as well as their geometries.

Type of reinforcement

Tubular joints can be subdivided in three categories:

- Ordinary tubular joint, as shown in Figure 1, consists in a joint without any structural reinforcement. The stresses acting on these joints are mainly influenced by the value of bending moments.
- Tubular joint with local reinforcement, as shown in Figure 3, has the reinforcements located in the joint area, since this is the weakest point of the structure. In this case, bending moments effects are more severe in the reinforced zone.
- Totally reinforced tubular joint, as shown in Figure 4, in which the stresses are mainly transmitted by membrane action and the bending moment effects are of secundary importance, although they are included in the calculation of Stress Concentration Factor (SCF).

Type of geometry

Figure 2 shows 7 basic types of tubular joints: - Fig. (2a)-
Tee joint, (T), Fig. (2e)
Double Tee joint (DT); Fig. (2c) - K joint (K); Fig. (2f)
Double K joint (DK); Fig. (2d) - TK joint (TK); Fig. (2g)
Double TK joint (DTK) and Fig. (2b) - Y joint (Y)

Much information is available for ordinary tubular joints[(1)(2)(3)]
In reference (1) for instance, parametric study on stress concentration factors (SCF)[(1)] was carried out resulting in a series of equations to estimate them, based on the following variables:

D = chord diameter
T = chord wall thickness
d = branch diameter
t = branch wall thickness
L = distance between chord supporting points
θ = angle between chord and branch axis

The results of parametric or experimental studies were always compared to ones obtained by analytical means, by using finite element methods (FEM). For instance TKJOINT and SATE programs were based on shell elements proposed by Johnson and Clough as shown in Figure 5.

In this study concerned only to ordinary joints, SAP IV program[(5)] was employed, by using a plate element as shown in Figure 6.This figure shows a quadrilateral element composed by 4 compatible triangles. The properties of such an element are presented in reference (6). The element itself has 17 degrees of freedom internally, which are reduced only to 5 degrees per node when its stiffness matrix is assembled: 2 degrees of freedom refers to the plane stress behaviour and the other 3 correspond to the plate behaviour of the element.

The element used by Johnson and Clough considers the surface curvature, what does not happen in SAP IV program. This difference however is overcome by taking a finer mesh when using SAP IV computer program.

COMPUTER SUB-ROUTINES FOR THE JOINT GEOMETRY

Even the simpler tubular joint has such a geometry, so that it becomes quite cumbersome to supply the node coordinates to the computer. Therefore, for that purpose it was necessary to devel op two computer routines in order to be incorporated to the main program.
One of them establishes the node coordinates of all elements which belong to the intersection between the chord and a branch, while the second one establishes the coordinates of nodes for all elements belonging to a branch outside the intersection area For the chord. SAP IV has itself the capacity to transform polar into orthogonal coordinates, so that no special problem is involved in this operation.
Figure 7 shows the coordinate systems adapted in this study. There are two orthogonal coordinate systems, namely a global x, y, z system in which the y axis coincides with the chord axis; and a local $\bar{x},\bar{y},\bar{z}$ system, in which the $\bar{y}$ axis coincides with the branch axis.
In the same Figure 7 are presented the geometrical relationship between the two coordinate systems.

APPLICATION EXAMPLE

For the application of the developed computer program an ordinary T joint (T) was studied. Figure 9 shows the joint under consideration and this is the same case study conducted by a group at Southwest Research Institute (SWRI) in San Antonio, Texas. This T joint was selected since stress values along its chord as well as circunferential stresses were all measured and the respective SCF calculated.

Mesh generation

The following procedure was adopted for the mesh generation:

- The sharpest stress gradient occurs in the neighborhood of the intersection between the chord and the branch, so that a finer mesh was utilized in that area.
- Chose to the ends of both chord and branch, rougher meshes will be utilized, since stress values at those points are smaller. However, the mesh size will be such to keep the curvature of the structure.
- The nodes were numbered in such a way to minimize the incidence of elements and so trying to reduce the size of the global stiffness matrix.
- Triangular meshes were also avoided, since they cause some discrepancies in bending moment values.

Due to the double simmetry of the tubular joint, only a quarter of structure was analysed, according to Figure 11. This resulted in utilizing a total of 265 shell elements and 241 nodes. The total load was then equivalently subdivided, and applied in its respective node.

Use of pre-processors

Due to the geometrical complexity of the mesh it will be very hard to an analyst to check the correctness of all input data. Therefore some pre-processor already developed in the Department of Naval Architecture was utilized to check the generation of the mesh. Figures 12 and 13 shown the discretized structure by means of the mentioned pre-processors. In figure 12 some input errors were detected, and they were corrected in Figure 13. The total computer time spent in the analysis was about 30 minutes.

RESULTS OF ANALYSIS

Figures 14 and 15 show results of the analysis and a comparison between the outputs of TKJOINT(1) and SAP IV program, as well as the experimental results obtained in SWRI.

In figure 14, normal stresses along the external surface of chord top sections are plotted against the distance from one of joint ends. The plotted stress values take into account the flexural as well as membrane behaviour of the plate elements. It is noticed in Figure 14 that there is a very good agreement between the results, although in TKJOINT program a finer mesh than that used for SAP IV has been employed. There is a little divergence at the ends of the chord, but this is mainly caused by the effects of the vertical supports on the chord boundaries.

In Figure 15, normal stresses along the external surface of circumferential sections are plotted against the distances from the intersection between joint chord and joint branch. From the results, one can also notice the chose agreement between the compared results.

Since the maximum stress value occurs at the exact point lying on the intersecting line between the chord and branch,its values was obtained by extrapolation in Figure 15, for the plotted values are supposed to occur at the middle of each element, as shown in Figure 16. The extrapolated value was 190 Kpsi. The nominal stress value σ_o, acting on that point would be:

$$\sigma_o = \frac{4 \times P}{\pi(D^2 - d^2)} = 21,83 \text{ Kp/in}^2 \qquad (1)$$

So that the SCF will result in

$$SCF = \frac{190,00}{21,83} = 8,70 \, , \qquad (2)$$

very close to that obtained in reference (1) which is equal to 9,10.

FINAL COMMENTS

Just as a final comment, one can say that the method developed by the project group to analyse tubular joints by FEM technique, presents good results when compared to other existing either computacional or experimental methods. The analysis carried out has only considered a very simple ordinary T joint, however, this study was further advanced in order to expand the capacity to other type of more sophisticated joints. The intention of this effort is to find shortly a reliable method to analyse reinforced joints since a parametric study for those types becomes much more complex.

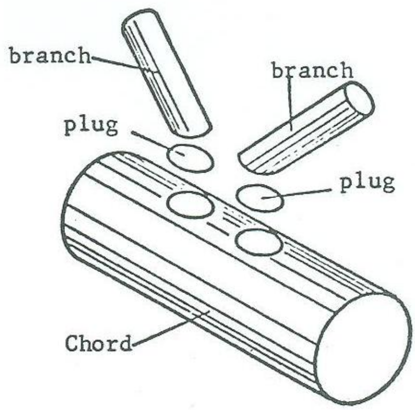


Fig.1 - Components of a tubular joint

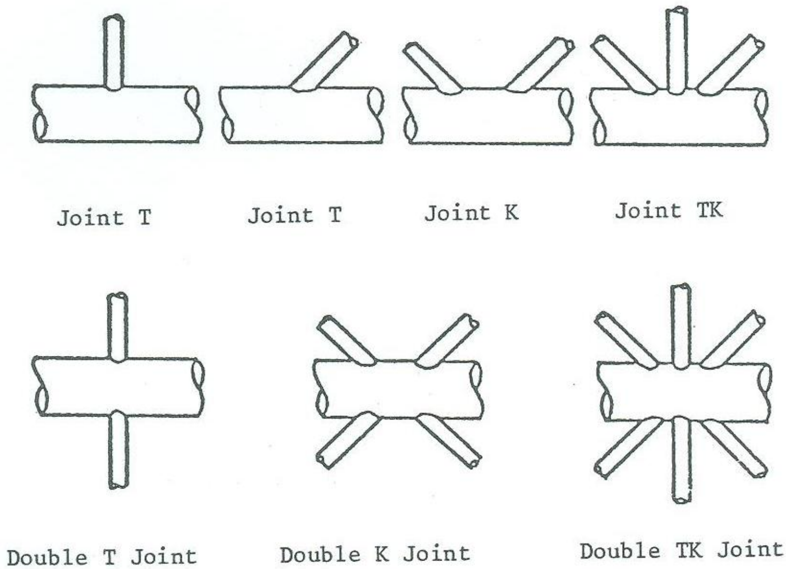


Fig.2 - Ordinary Tubular Joints

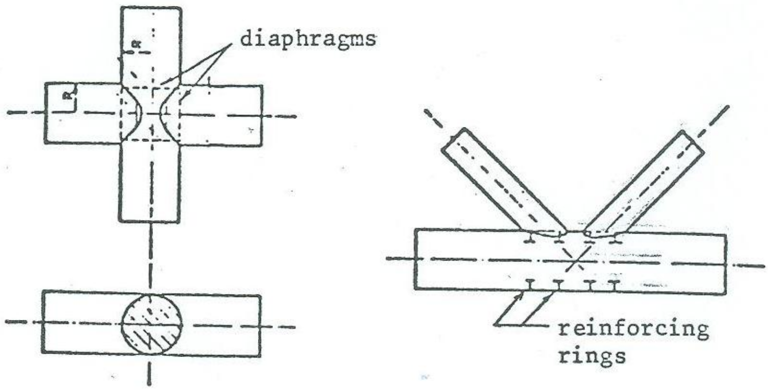


Fig.3 - Locally reinforced tubular joint

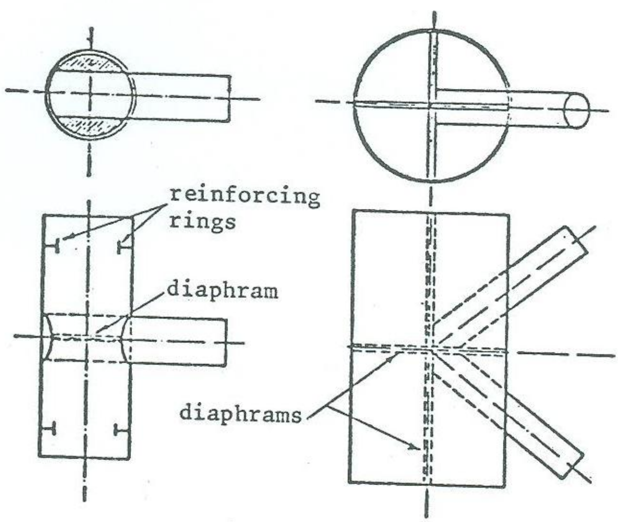
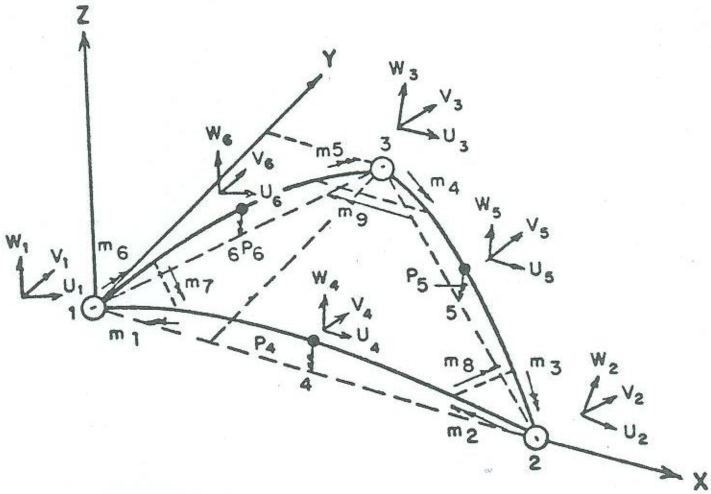


Fig.4 - Completely reinforced tubular joint



U,V - displacement in XOY plane
W - displacement normal to XOY plane
m - moments
XOY - reference plane for the shell

Fig.5 - A shell triangular element (Johnson and Clough)

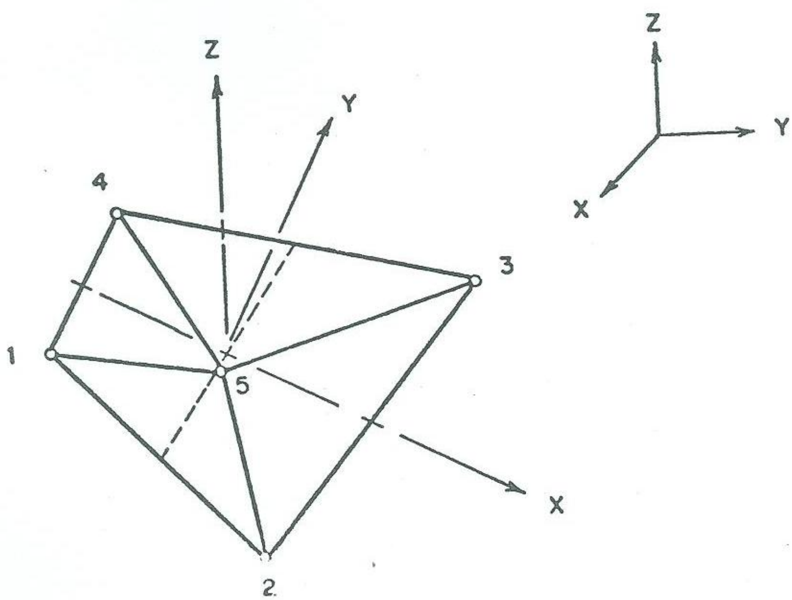


Fig.6 - A shell triangular element (Fillipa and Clough)

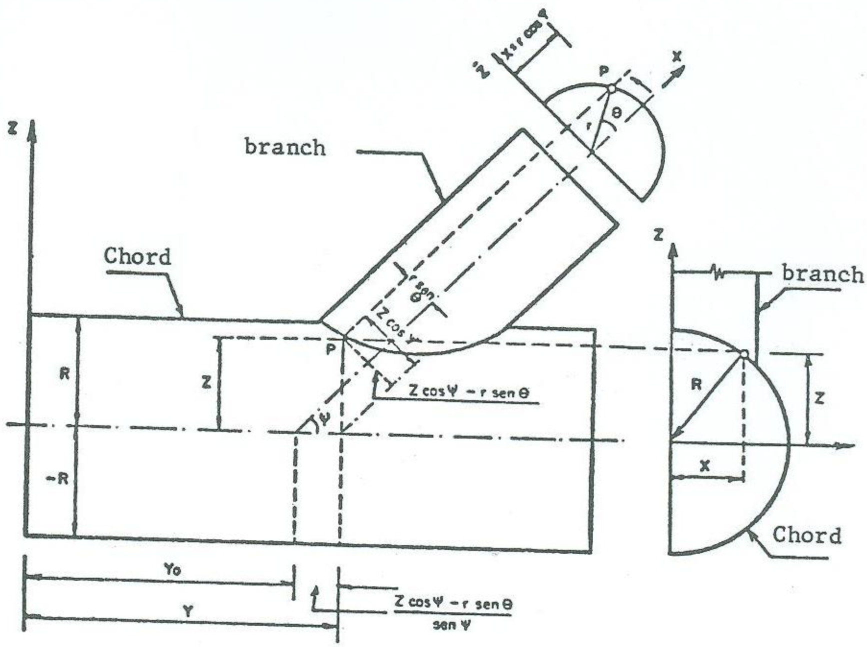


Fig.7 - Coordinates belonging to a point on the intersection

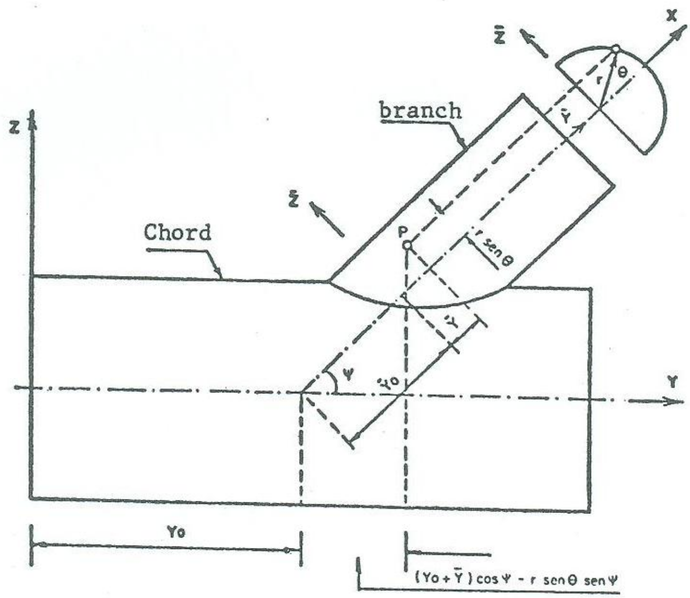


Fig.8 - Coordinates of a point outside the intersection

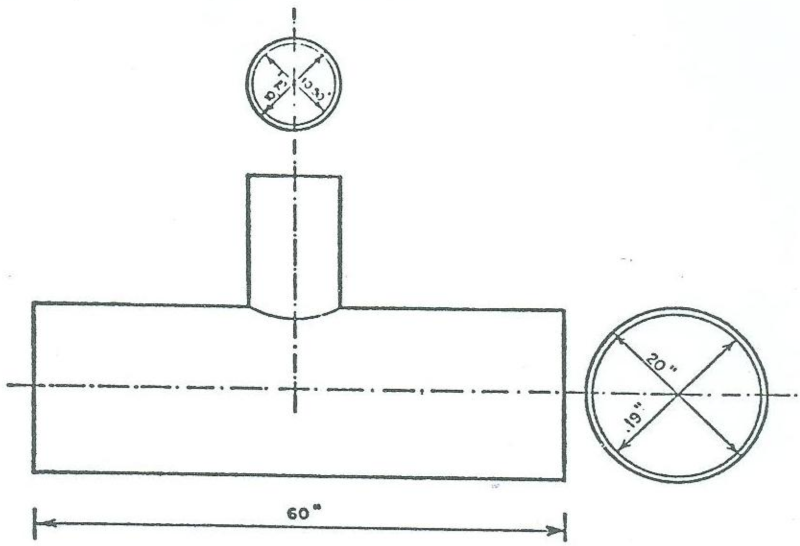


Fig.9 - T Joint model studied at SWRI

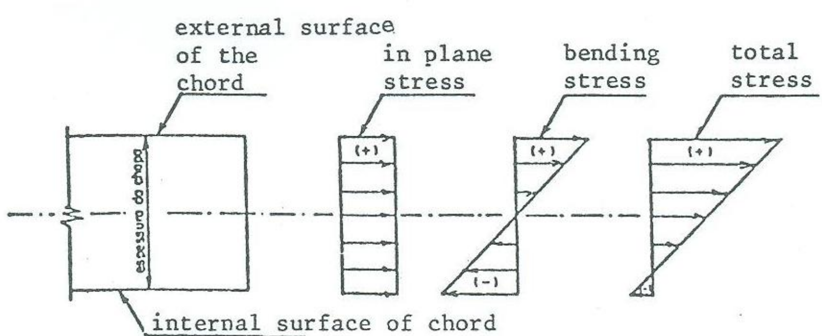


Fig.10 - Stress component in the plate

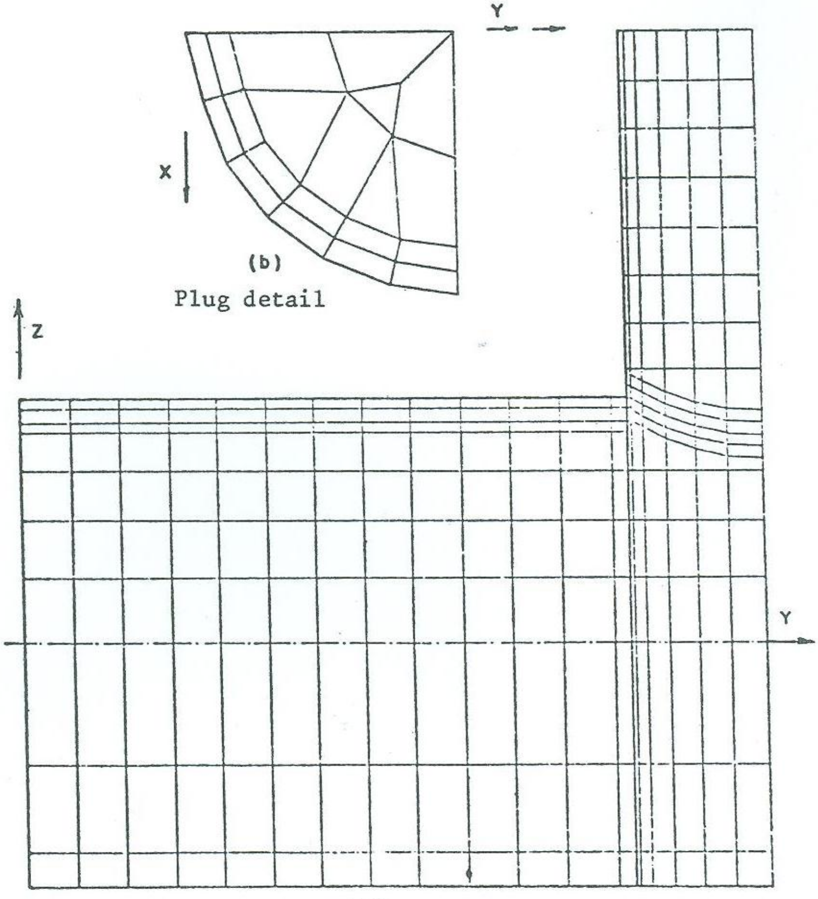


Fig.11 - Modeled structure

D I M 3 — N D P N

* ANALISE DE UMA JUNTA DE 20.0 x 10.75 * DISCRETIZACAO

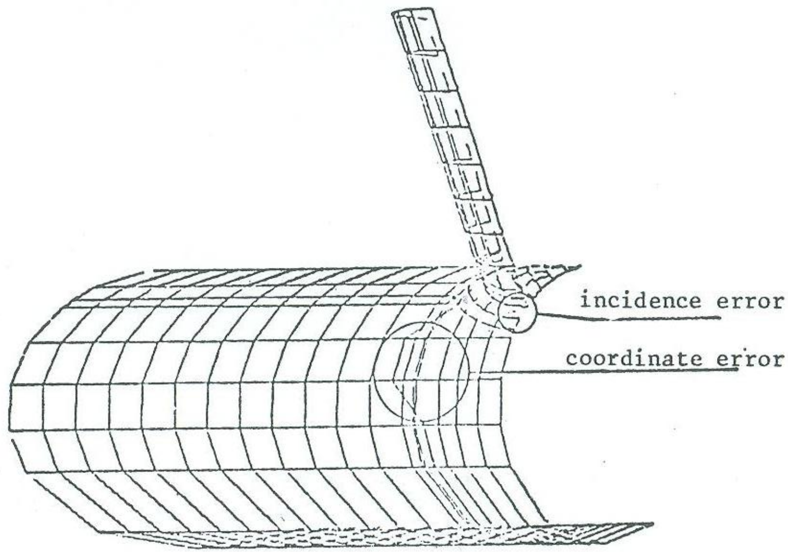


Fig.12 - Mesh generations with errors

D I M 3 — N D P N

* ANALISE DE UMA JUNTA DE 20.0 x 10.75 *   DISCRETIZACAO

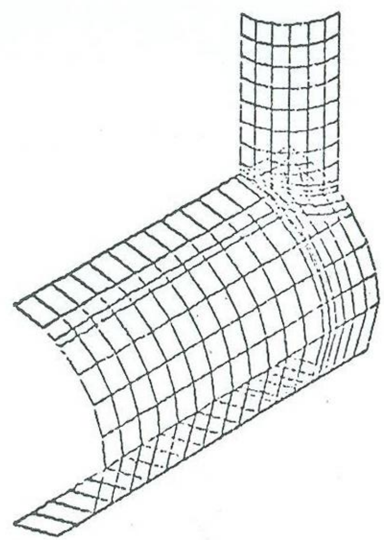


Fig.13 - Corrected mesh

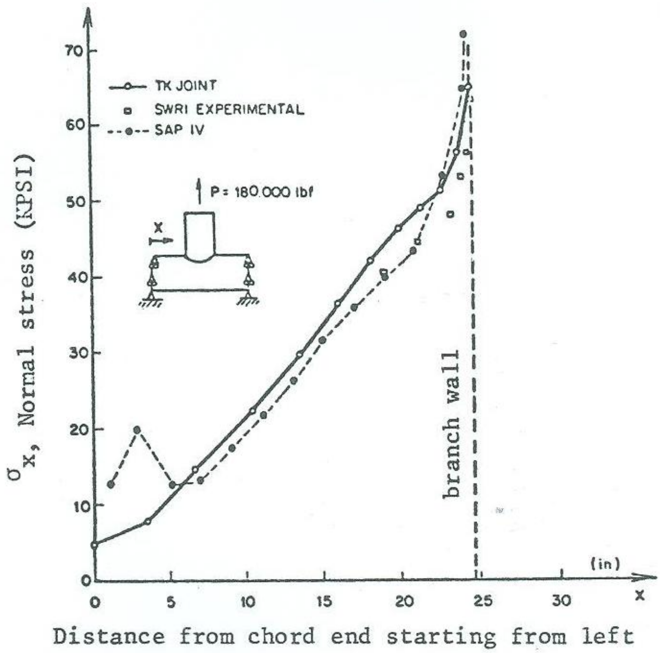


Fig.14 - σ_x stress on external surface of chord top

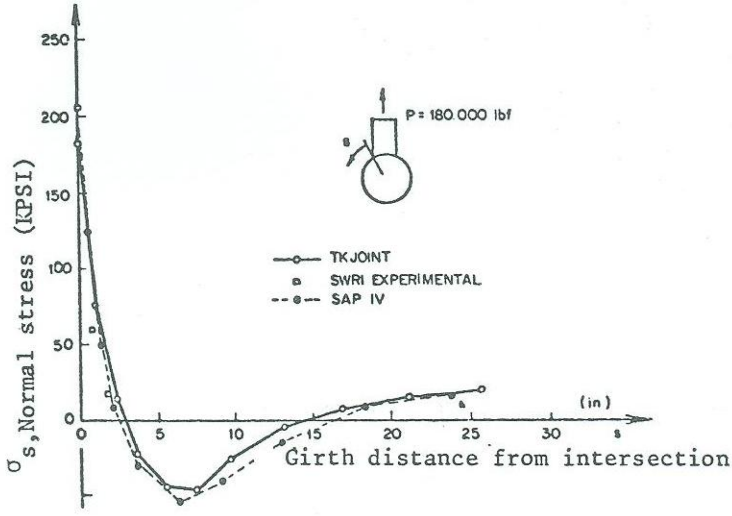


Fig.15 - σ_s stress on external surface of chord structure

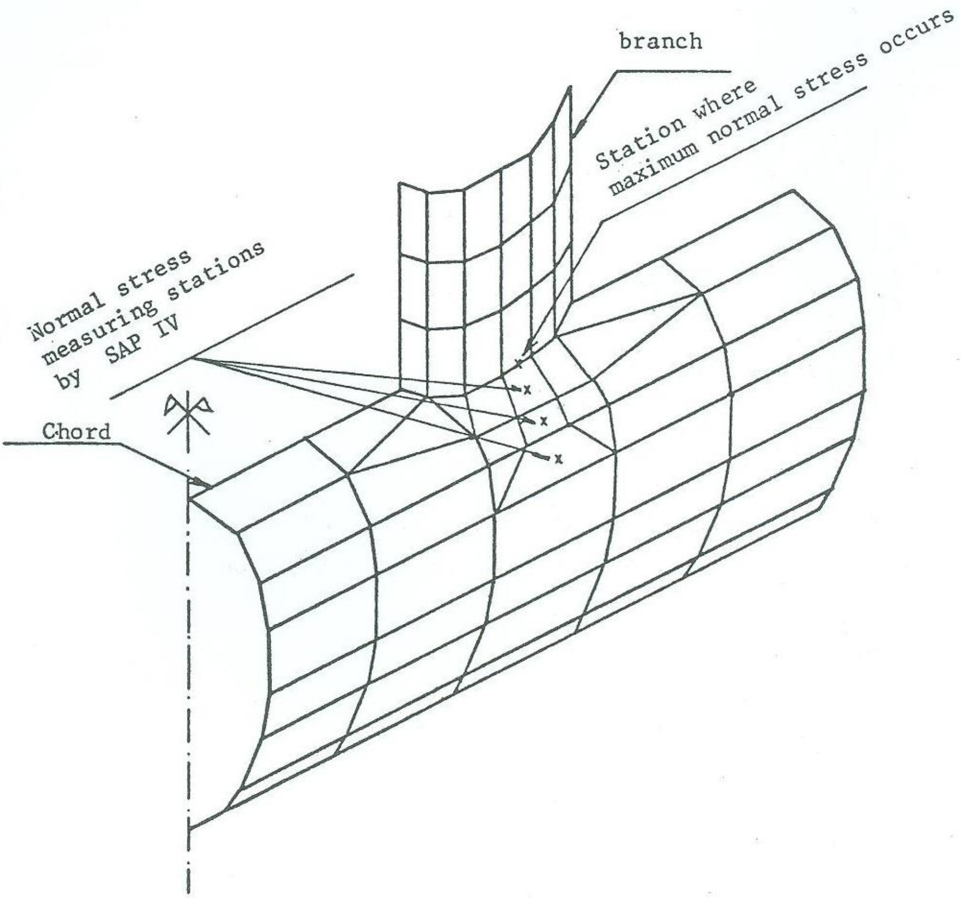


Fig.16 - Location of normal stress measuring stations