

2011 ANSYS CONFERENCE & ESSS USERS MEETING

Costão do Santinho Resort - Florianópolis, SC - Brasil
8 a 11 de Novembro de 2011



ASME Stress Linearization and Classification of a WYE piping junction

Miguel Mattar Neto (mmattar@ipen.br)

Carlos Alexandre de Jesus Miranda (cmiranda@ipen.br)

Altair Antonio Faloppa (afaloppa@ipen.br)

Gerson Fainer (gfainer@ipen.br)

Instituto de Pesquisas Energéticas e Nucleares, IPEN – CNEN/SP
CEN – Nuclear Engineering Center

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IPEN Overview

- **IPEN – Nuclear and Energy Research Institute is a State of São Paulo autarchy, associated to the University of São Paulo – USP for educational purposes and supported and operated technically and administratively by the National Nuclear Energy Commission – CNEN, a federal agency of the Ministry of Science and Technology**
- **The Institute was founded in 1956 with the main purpose of doing research and development in the fields of nuclear energy and its applications. It is located at the campus of USP, in the city of São Paulo, in an area of nearly 500,000 m². It has over 1.000 employees and 40% of them have qualification at master or doctor level**
- **IPEN is recognized as a national leader institution in research and development in the areas of nuclear engineering, radiopharmaceuticals, industrial applications of radiation, basic nuclear research, nuclear reactor operation and nuclear applications, materials science and technology, laser technology and its applications**
- **Along with the R&D, it has a strong educational activity, having a graduate program in Nuclear Technology, in association with the University of São Paulo, USP, ranked as the best university in the country. The Federal Government Evaluation institution CAPES, granted to this course grade 6, considering it a Program of Excellence**



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IPEN Overview

- IPEN mission is to improve the Brazilian people quality of life by producing scientific knowledge, developing technologies and services and promoting human resources for nuclear and correlated areas
- The internal organization structure comprehends Research and Development Centers, grouped according to their research, development and innovation activities. CEN, the Nuclear Engineering Center, is one of them
- CEN has several areas such as Structural Mechanics, Reactor Physics, Nuclear Fuel Engineering, Instrumentation and Control, Thermal Hydraulics, etc.
- The CEN Structural Mechanics Area has worked on the development of mechanical equipment stress analysis using numerical tools like ANSYS since 1980

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Introduction

- The ASME code, particularly in its Section III, the nuclear one, has specific requirements on how to assess the results from the stress analyses to make the necessary verifications to avoid failure. These requirements apply to those equipments (valves, pumps, vessels, piping, etc.) which are part of the pressure boundary
- The components, as well as the piping in a nuclear power plant, should be classified accordingly to its nuclear safety classification, as Class 1, Class 2, Class 3 or Class NN (non nuclear). The project of nuclear equipments classified as Class 1, 2 or 3 should follow the recommendations given in the code sub-sections NB, NC and ND, respectively
- The present work deals with the structural and stress analysis of Class 1 equipment which structural project should be verified “by analysis” using usually the finite element method
- Generally speaking, a Class 1 piping analysis should be performed and its results analyzed accordingly to NB 3600, Section III, of the ASME Code while the analyses of Class 1 equipment as the Vessels in general (Reactor Pressure Vessel, Steam Generator, Pressurizer, et.) should follow NB-3200 and NB-3300

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Introduction

- To analyze equipment, one uses a model made basically by shell and solid elements (2D, 3D or axi-symmetric ones)
- To analyze a piping, besides the general straight and the curved pipe elements, the analyst has to model some standard parts or fitting as valves, short radius and long radius curves, Tees, etc. Supports and anchors are also used
- Standard curves and Tees, for instance, have specific stress indices (that behave like stress concentration factors) which are experimentally determined as function of the fatigue life reduction with respect to the straight tube fatigue life. These factors are given by the applicable code, specifically, in NB-3600 for Class 1 nuclear piping

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Introduction

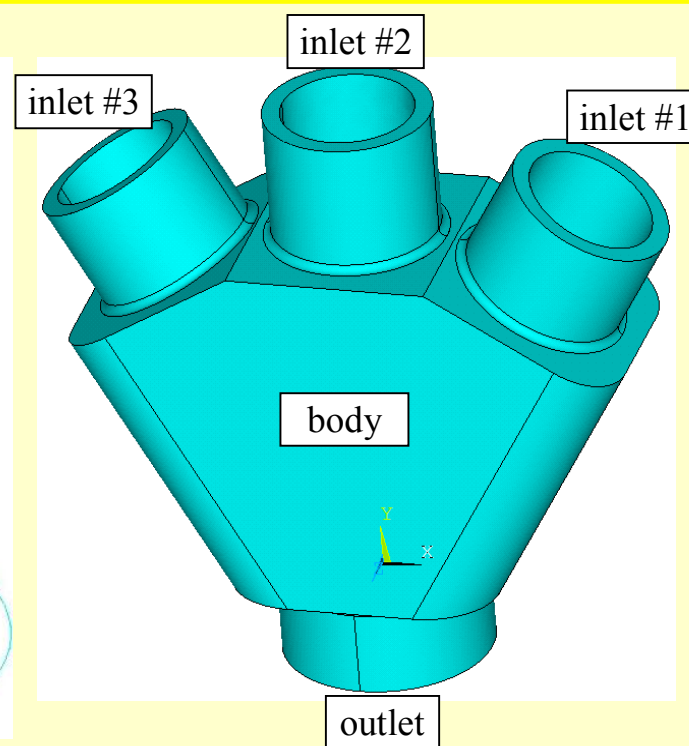
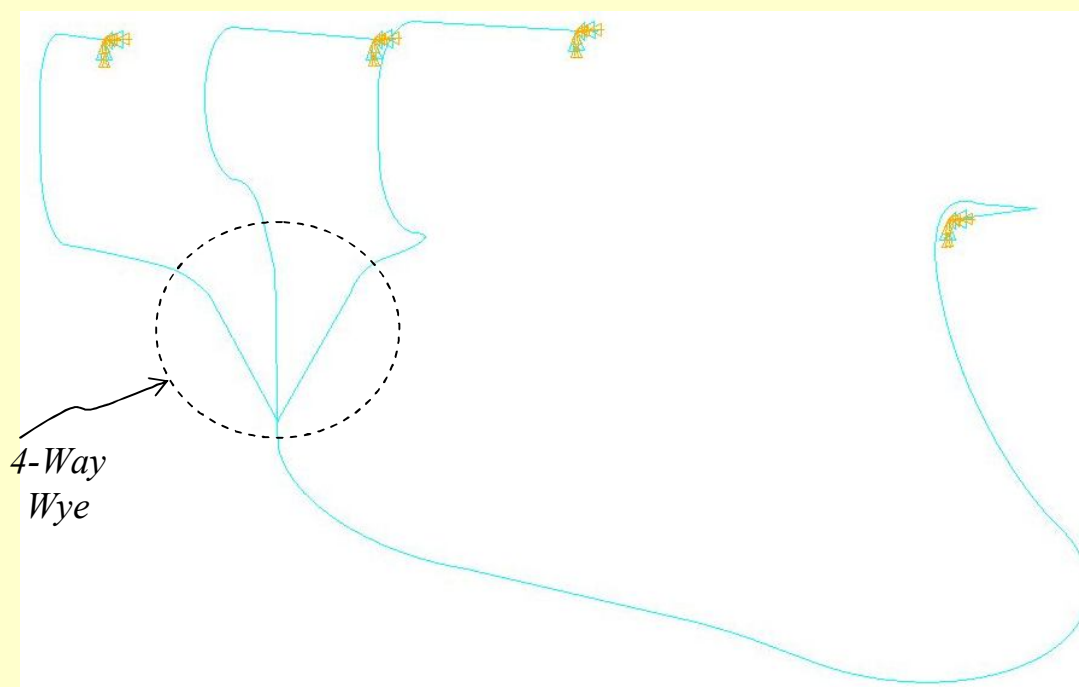
- In some plants the space restriction imposes a compact lay-out with the use of non-standard fittings
- For those special piping items with non-standardized geometry the piping analysis can not capture the actual stress state and, therefore, a specific analysis should be performed using the requirements of NB-3200/NB-3300
- In this situation, usually the analysis is performed in two steps
 - Firstly, the piping is analyzed (and modeled) as usual where the special item is modeled by rigid straight tubes (with an equivalent cross section and density to introduce its mass in the model). All model results, except by the special item, should attend NB-3600 limits
 - In the second step the special item is modeled as equipment, with shell and/or solid elements **and the piping stiffness and mass introduced as super-elements**. The results (stresses in general) from the special item, but not the piping super-element results, should be verified against NB-3200 limits

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Modeled Piping and The Non-Standard Fitting



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Non-Standard Fitting Material Properties

- Young modulus $E = 180 \cdot 10^9 \text{ N/m}^2$
- Poisson's ratio $\nu = 0,3$
- Mass density $\rho = 8.500 \text{ Kg/m}^3$
- The reference stress and the yield stress are, respectively:
 $S_m = 110,0 \text{ MPa}$ and $S_y = 122,7 \text{ MPa}$ @ $T_{des} = 350 \text{ }^\circ\text{C}$
- Thermal expansion coefficient $\alpha = 17,6 \cdot 10^{-6} \text{ mm/mm}^\circ\text{C}$
- To consider the dead weight for instance, the water and thermal isolation should be considered besides the steel density. To do so, an equivalent density should be calculated and it can reach values around $\rho_{eq} = 11.000 \text{ Kg/m}^3$.)

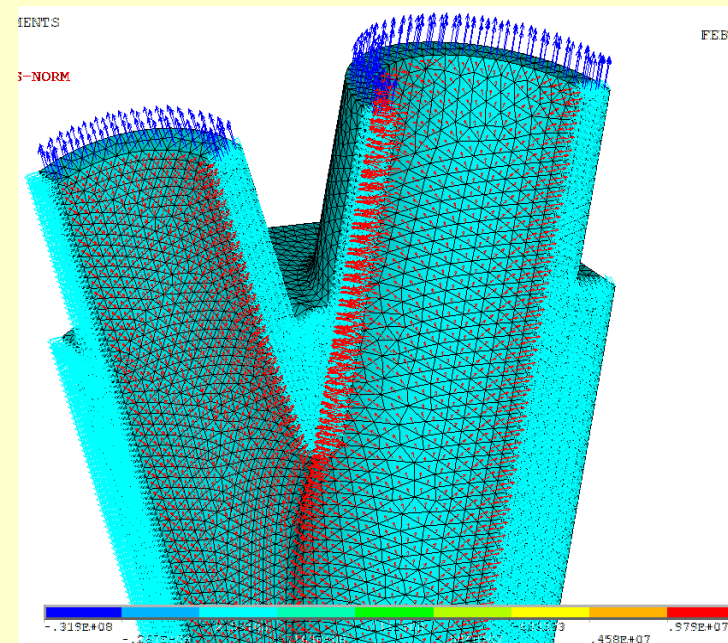
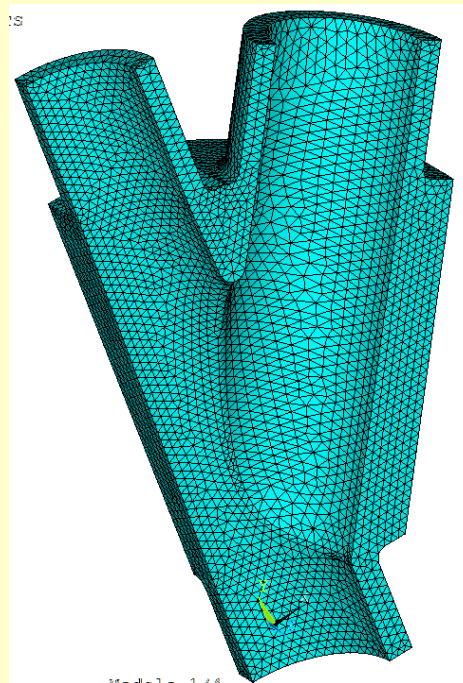
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Loads

- Internal pressure with a typical value, $P_{\text{int}} = 15 \text{ MPa}$ applied on all internal surfaces (+ coherent closing forces)
- Dead weights
- Seismic loads



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Stress Classification and Linearization

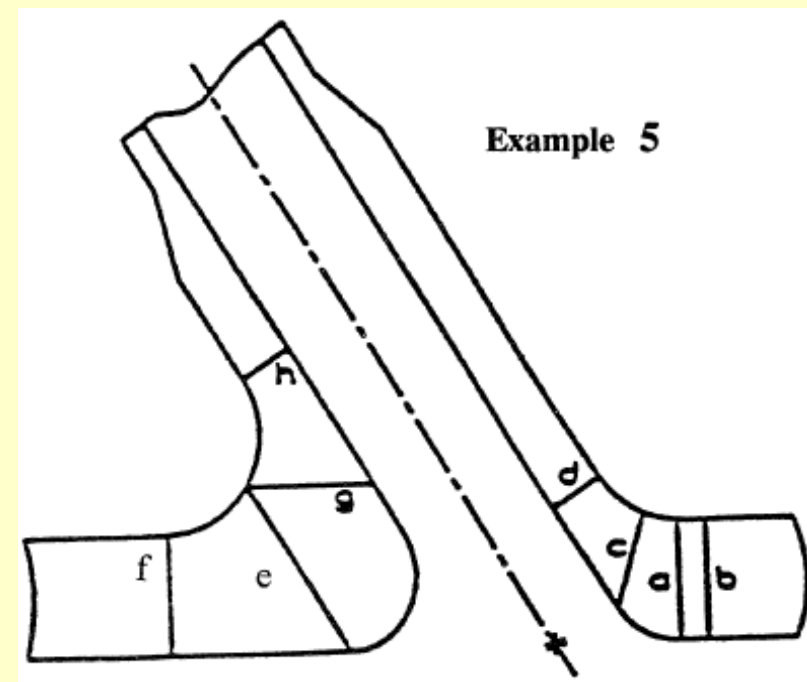
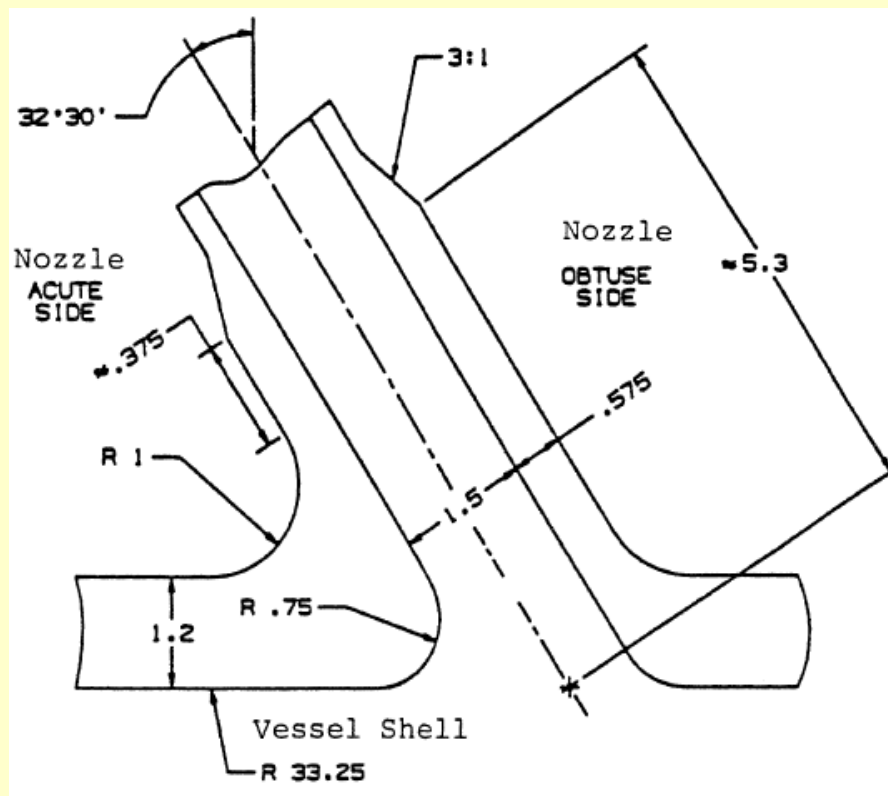
- The stress classification is done to identify, basically, the “Primary” (P) and the “Secondary” (Q) stresses (The former are directly related with the equilibrium equations while the later are related with the compatibility equations)
- The stresses should be linearized to obtain the generalized (Pm) or localized (PL) membrane component, the bending (Pb) and the Peak (F) stress
- This linearization should be done along a cross section of the piping or equipment (but in the discontinuities this section is not so clear)
- The stress linearization is done along a line, the SCL – Stress Classification Line
- The stress linearization procedures are not straight forward mainly in 3D models which are very common nowadays
- The stress classification adopted in the present work, for those sections or SCL where the stresses were verified, follows the ASME NB Table-3217-1d and to chose the SCL the recommendations from WRC Bulletin 429

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Stress Classification and Linearization



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Limits and Verifications

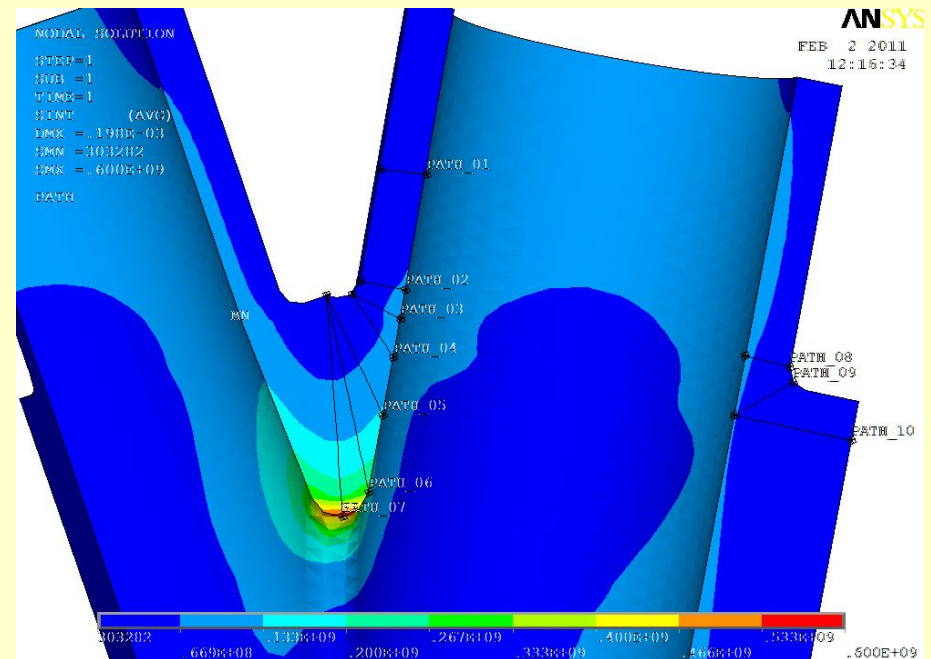
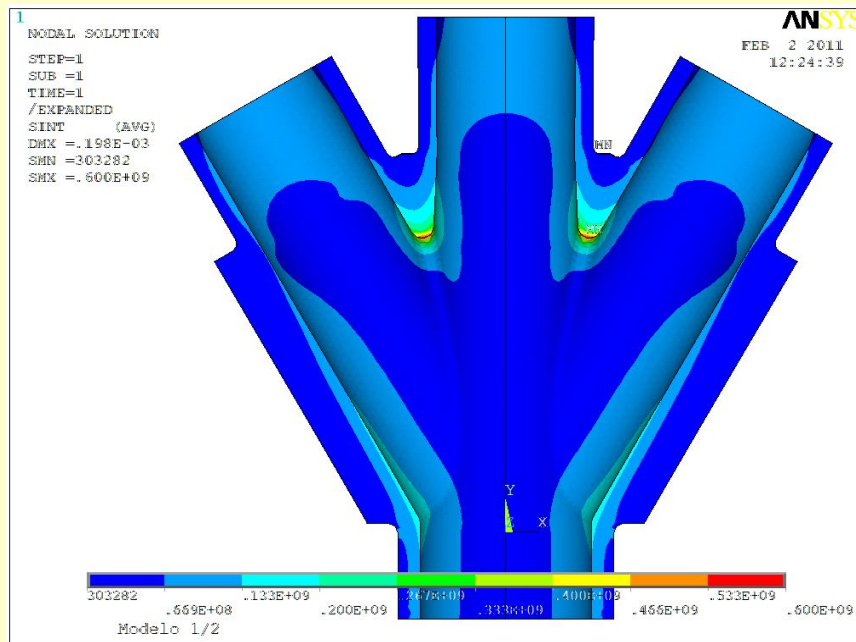
- The allowable values for each type of stress (P_m or PL , $PL \pm Pb$, $P+Q$, $PL \pm Pb + Q + F$) are derived from the basic allowable - S_m - at the working temperature
- $P+Q$ and $PL \pm Pb + Q + F$ involves secondary stress (Q) and are related with the compatibility equations and fatigue, respectively
- To stay within the scope of this work and to be coherent with the applied load (pressure), only the primary stress (P_m , PL and $PL \pm Pb$) will be verified
- So, accordingly to Fig. NB-3221-1 and NB-3222-1 of the ASME NB the due verifications and their limits are:
 - $P_m \leq S_m = 110,0 \text{ MPa}$
 - $PL \leq 1,5S_m = 165,0 \text{ MPa}$
 - $PL \pm Pb \leq 1.5S_m = 165,0 \text{ MPa}$

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Sections to Linearize, Classify and Verify the Stresses

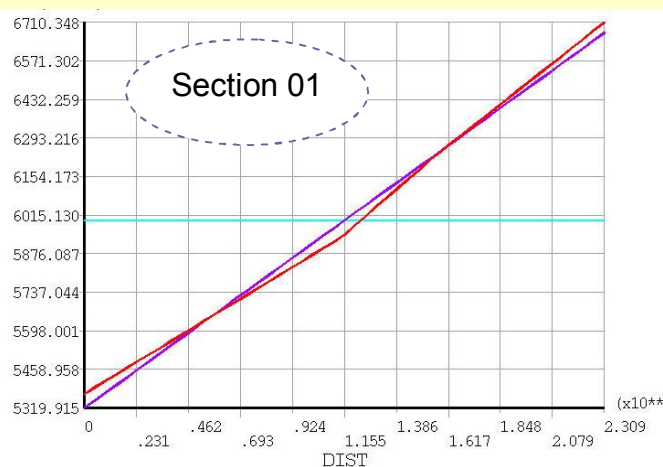


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Primary Stresses Verification



Stress Verification (MPa)

Section #	1	2	3	4	5	6	7	8	9	10	Limit
P_m	60.0	---	---	---	---	---	---	---	---	---	110,0
P_L	---	54.8	57.7	60.5	67.9	106.	128.	55.8	48.0	24.2	165,0
$P_L \pm P_B$	67.7	---	---	---	---	---	---	---	---	---	165,0
$\sigma_{actual}/\sigma_{limit} (\%)$	55 41	33	35	37	41	64	78	34	29	15	-----

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Conclusions

- The paper described a nuclear piping analysis with a non-standard fitting modeled as a 3D solid with its verification done according to NB 3200 of the ASME Code instead of NB-3600 one
- The used geometry is one that can be found in many plants, from petrochemical to nuclear however, the 'nuclear focus' was adopted
- Only the primary stresses due to the internal pressure were considered once the scope is to emphasize some of the issues that arise from the stress classification and linearization in discontinuities, which are common in the nuclear area and it is still an open issue
- Along with the modeling, analysis and verification a discussion on how to perform the Code verifications was presented, pointing some differences between the present (simplified) analysis, just one load – pressure, and an actual one, with several applied loads
- To stay within the scope of this work and to be coherent with the applied load (pressure), only the primary stress (P_m , PL and $PL \pm Pb$) were verified

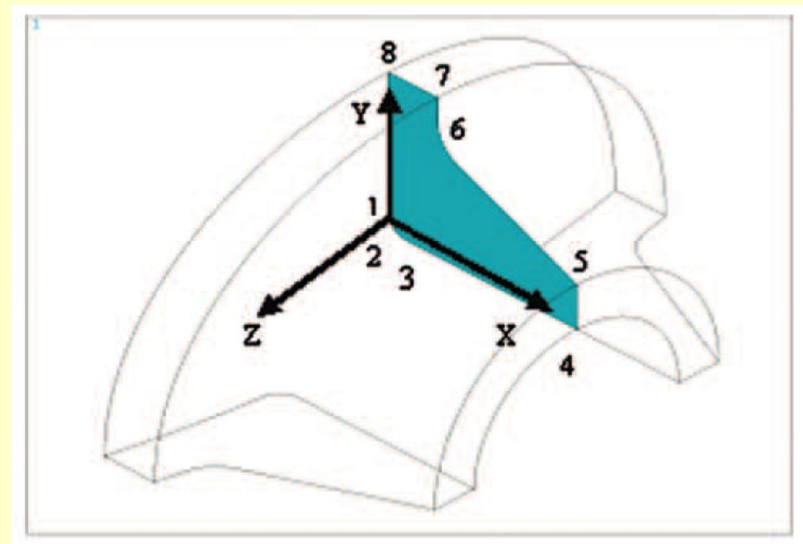
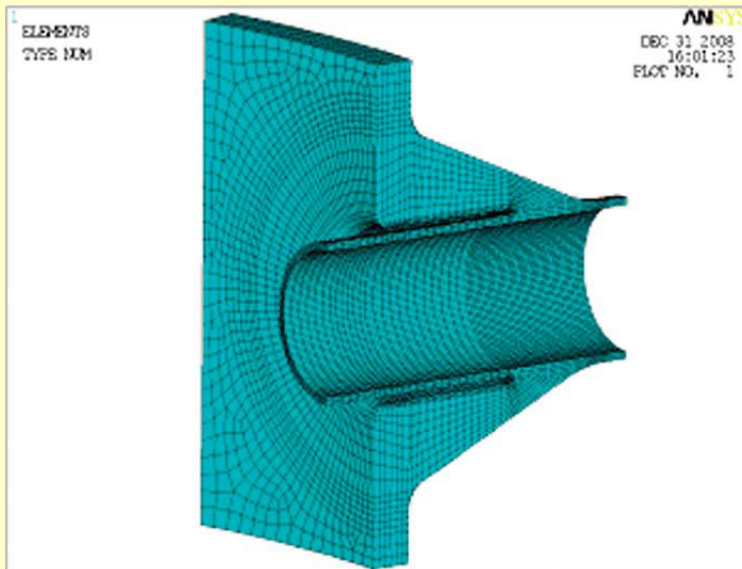
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Future Works

- Stress Categorization on Planes (P. B. Godbole & Supak Pore, A New Method for Stress Categorization on Planes, Journal of Pressure Vessel Technology, DECEMBER 2010, Vol. 132, p. 1-6)



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