RESEARCH ARTICLE OPEN ACCESS

# Analysis of Stress in Nozzle/Shell of Cylindrical Pressure Vessel under Internal Pressure and External Loads in Nozzle

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**ABSTRACT**
This work a comparative study of the methods of analysis of stress in vessel/nozzle, due to external loads. The methods of analysis compared are WRC 107, WRC 297 and Method of Finite Elements. To make the comparison between the methods, one model of nozzle has been developed without reinforcement plate. In this nozzle it was applied external loads and after the application of the loads, compared the results of stress for the three methods of analyses considered in this study.
***Keywords –*** stress analysis, WRC 107, WRC 297, finite elements, pressure vessel, nozzle and shell

## I. Introduction

This work analyzes stress in a nozzle connected in the pressure vessel and compares the obtained results through the used methods of calculations for external loads in nozzle.

The importance this work is study methods of stress analysis due external loads on nozzle of pressure vessel for create a comparative between these methods, objectifying develops critical sense of use of each method.

## II. Referential Bibliography

Pressure vessel are recipients waterproof, are able contain pressurized fluid. The important attachment to pressure vessel are nozzles that has finality transfer of fluid and communication between equipments.

A design code, for example, ASME code, establishes values of admissible stress for intersections nozzle/vessel. The stresses are analysis through methods such as WRC 107, WRC 297 and finite methods (MEF).

### 2.1 ASME code

During the centuries XVII and XIV, due industrial revolutions, stream was power supply in the industries, so accidents were very commons. For this, became necessary an elaboration of laws to avoid accidents.

The ASME code had the purpose of standardization the several standards in United Stated of American [1].

### 2.1.1 ASME section VIII division 1

The ASME VIII Division 1 is the norm about pressure vessel most used in Brazil [4] and much of the world.

The ASME VIII divisions 1 show rules for design of the parts of pressure vessels, such as, heads, shell, flanges, nozzle and reinforcement. The code no adopts procedures for avaliation of stress in the pressure vessel due to external loads in nozzle, for this reason its necessary consult other literature for evaluation of them.

### 2.2 Stress analysis

The pressure vessels are subject a several loads and different intensities of stress each component. The category and stress intensities are function of nature from load, of geometry and construction of vessel component.

In accordance with ASME VIII division 1 paragraph UG-22, the loads in pressure vessels are due to, internal or external pressure, weight of equipment, static reactions, welded components, such as, nozzle, pipes, isolations, internal supports, or reactions cyclical or dynamics due to thermal variations, wind loads, seismic forces, impact reactions due to fluid, and temperature gradients [1].

### 2.2.1 Stress category

The stress category as primary, secondary and peak stress. The primary stresses are subdivided in general and load of membrane and bending [5]. The secondary stress are divided are membrane and bending.

### 2.2.1.1 Primary stress

The primary stress can be normal stress or shear stress developed by loading. These stress are characterized by not decrease their values when the structure deforms.

The primary stress are divided in primary general membrane – $P_m$, primary bending stress – $P_b$, and primary local membrane – $P_L$.

**2.2.1.2 Secondary stress**

The secondary stress can be normal stress or shear stress and are characterized by decrease their values when the structure deforms.

The secondary stress are represented for letter Q, and divided in secondary membrane stress and secondary bending stress. Examples of secondary membrane stress, $Q_m$, are loads and moments that developed of thermal expansion. Examples of secondary bending stress that develops at the attachment of body flange to the shell [5]. Another example is bending stress due loads and moments in nozzles and supports.

**2.2.1.3 Peak stress**

The peak stresses, F, are additive stress. [4].

Peak stresses are additive to primary and secondary stresses present at the point of the stress concentration. Peak stresses are only significant in fatigue conditions or brittle materials. Peak stresses are sources of fatigue cracks and apply to membrane, bending, and shear stresses. Examples are: stress at the corner of a discontinuity. [12]

**2.3 Localized stress in nozzle**

External loads applied in nozzle, such as, from pipes, give rise to additives membrane stress, bending stress and shear stress in cylindrical and spherical shells.

The sign convention and nomenclature of local loads according to Bulletin WRC 107 and shows in Figure1.

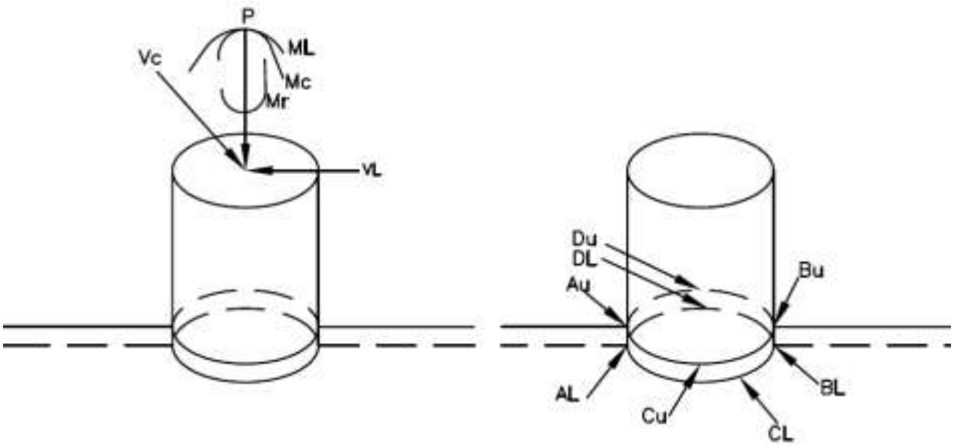


Figure 1 – Convention and Nomenclature of Local Loads

**2.3.1 Evaluation of local stress**

The main procedures of evaluation of local loads are WRC Bulletin 107 and WRC Bulletin 297.

However, due to limitations of these bulletins, local loads also are analyzed from finite elements methods.

(a) Bulletin WRC 107

The Bulletin 107 is parameterized procedure of stress calculation from nozzle [15]. The input values are dimensionless, the stress results due loads are obtained from developed curves from experimental datas.

(b) Bulletin WRC 297

WRC Bulletin 297 is a supplement to WRC 107 and gives data for larger diameter-thickness ratios than WRC 107 [9].

(c) Finite Element Analysis

The finite element method is one way of achieving a approximate numerical solution to specific problem.

The nodal points, or nodes, are typical points the elements like the vertices, the side of middle points, and the element middle point, among others. Because of this choice, the solution representation is strongly the domain geometry.

This method can be used for static analysis, using static loads and know pressure or displacements, and has characteristic static materials and boundary conditions.

To make analysis by finite element method is necessary some datas, such as, geometry, element, material, boundary conditions, loads e solution method.

For pressure vessel the most common type of element is 3D Solid element based on elasticity theory [8]. For each 3D solid element are defined three degrees of freedom: orthogonal displacement: $u_x$, $u_y$, $u_z$.

### 2.4 Methodology of stress analysis

The methodology used to stress analysis in pressure vessel in junction shell and nozzle are experimental, analytical and numerical.

Petrovic [13] analysed stress analysis of a cylindrical vessel loaded by axial and transverse forces on the free end of nozzle. The stress values obtained form the algebric function were within -12.5% and + 12.8% of those from finite elements. The difference between stresses deduced from strain gauge readings on experimental and calculated stress was a maximum of 12%.

Weiss e Joost [14] studied local loads from piping system. In most cases the reaction of the intersection of socket and vessel is unknown. They did study to elastic finite element analyses in combination with experimental investigations and compared the results.

The analytical methodology, that provide equations and solutions based in thin shell theory.[10]

Dekker e Stikvoort [3] made comparison of local load stress calculation methods reveals considerable differences. They made many finite element analyses and the resulted in non-dimensional parameter graphs to determine pressure induced stresses at nozzles.

Moore and Moffat [11] studied a general theory for the construction of best-fit correlations equations for multi-dimensioned sets of numerical data. The theory is based on the mathematics of n-dimensional surfaces. The authors suggest the studied parameters used for minimize works and obtain a more efficient design.

Liu and other [6] developed a modified elastic compensation method (MECM) for nozzle-to-cylinder junctions. The author studied three different models and calculated solutions and compared with results from the elastic-plastic analysis method.

Dekker and Brink [2] compared internal pressure stresses at nozzle/vessel junctions based on thin shell theory. The authors concluded are that outward weld areas offers little reinforcement and analyses based in thin shell theory are acceptable.

Ming and others [7] created three different 2-D axi-symmetric finite elements models, with different vessel radii modeled 1, 1.5 and 2 times the actual vessel radius. The calculate stress intensity results are compared with those predicted from a realistic 3-D simulation model. They concluded if a simplified 2-D axi-symetrical model is used to simulate stress behavior of nozzle-vessel structure, obtained a conservative membrane and membrane plus bending stress intensity at the nozzle-vessel junction section.

## III. Methodology

The methodologies used for this work are comparison stress analysis using three different methods of analysis: WRC 107, WRC 297 and Finite Elements Methods.

### 3.1 Model – vessel/nozzle

For this study will be analysis a nozzle in pressure vessel due external loads. This model is a nozzle without reinforcement plate, welding in pressure vessel. The pressure vessel applied internal pressure and the external loads in nozzle.

The nozzle analyzed is connected a horizontal pressure vessel, show in Figure 2. The dimensions and design datas shows in Table 2.

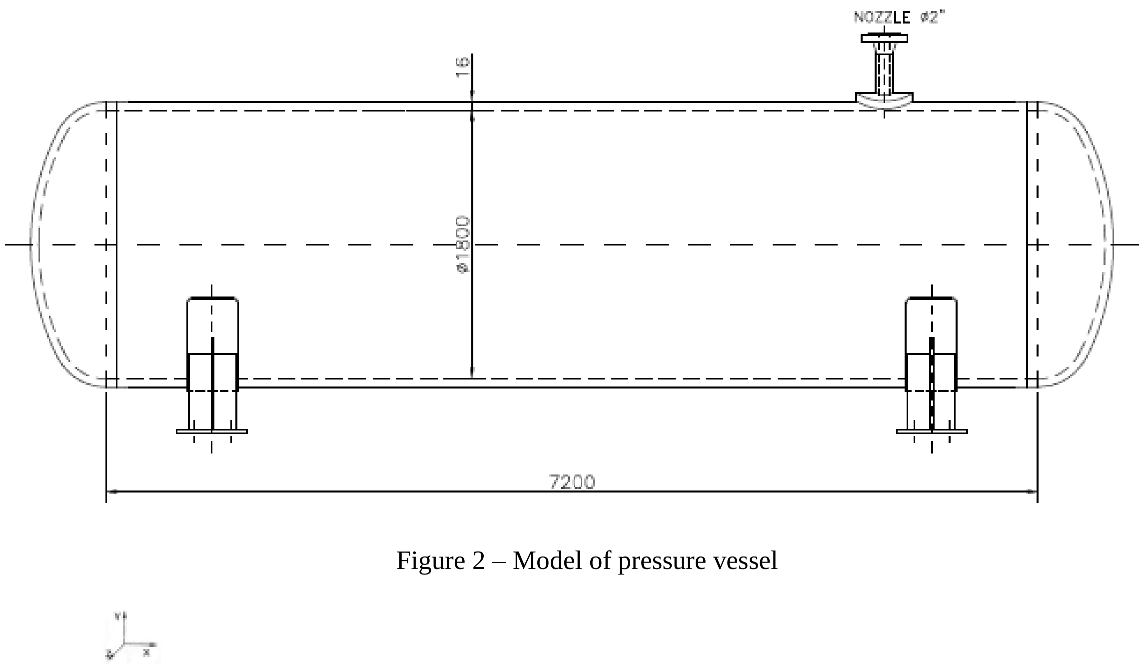


Figure 2 – Model of pressure vessel

TABLE 2 Design data - pressure vessel

| Design Data | |
|---|---|
| Code | ASME SEC. VIII, DIV. 1 |
| Edition / Adenda | 2004 / 2006 |
| Design Pressure [MPa] | 1.47 |
| Design Temperature [°C] | 68 |
| Internal Diameter [mm] | 1800 |
| Length Tangents [mm] | 7200 |
| Welding Efficiency - Shell [%] | 100 |
| Welding Efficiency -heads [%] | 100 |
| Corrosion [mm] | 3 |

Source: Research data

### 3.2 Vessel/nozzle model – general characteristics

#### 3.2.1 Material and mechanical properties

The material used for cylindrical shell is ASME SA-516 60 steel and nozzle ASME SA-106 B steel. The mechanical properties steel are showed in Table 3.

TABLE 3 Mechanical Properties of Materials

| Material | Yield Strength (MPa) | Tensile Strenght (MPa) | Yield Stress (GPa) |
|---|---|---|---|
| SA-516-60 | 220.6 | 413.7 | 210 |
| SA-106-B | 241.3 | 413.7 | 210 |

Source: AMERICAN BOILER AND PRESSURE VESSSEL CODE VIII - Division 1, 2007

#### 3.2.2 Loads

The values of loads applied in nozzle are shows in Table 4.

TABLE 4 Loads applied in nozzle

| Class | | 150# | |
|---|---|---|---|
| Nominal Diameter (pol/mm) | Axis | Force (N) | Moment (N.m) |
| 2 / 60,3 | X,Z | 667 | 343 |
| | Y | 804 | 284 |

Source: Research data

### 3.3 Model

The nozzle geometry is presented in Figure 3

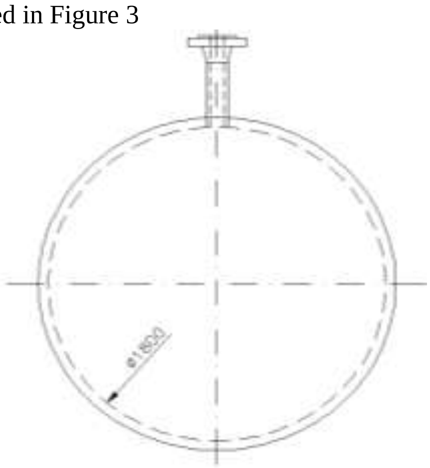


Figure 3 – Nozzle 2”

**3.4 Analysis form finite method element**

For finite elements methods, the material of vessel and nozzle were considered with mechanical properties according to Table 3. Was assumed elastic linear analysis with isotropic and homogeneous material.

# IV. Results

The values of stress obtained from WRC 107, WRC 297 and MEF are listed in Table 5.

TABLE 5
Comparative table from analyses methods for Nozzle 2".

| Analysis Method | Obtained Stress (MPa) | Location |
|---|---|---|
| WRC 107 | 167.72 | Nozzle |
| WRC 297 | 167.00 | Nozzle |
| MEF | 166.80 | Nozzle |

Source: Research data

**4.1 Results – bulletin WRC 107**

The Table 5 shows the external loads applied in nozzle and Table 6 show values obtained from Bulletin WRC 107.

TABLE 6
Sum of stress – Nozzle 2"

| Stress | | Stress Value [MPa] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Type | Load | Au | Al | Bu | Bl | Cu | Cl | Du | Dl |
| Circumferential | Pm | 112 | 114 | 112 | 114 | 112 | 114 | 112 | 114 |
| Circumferential | PL | -2 | -2 | 3 | 3 | 0 | 0 | 1 | 1 |
| Circumferential | Q | -23 | 23 | 33 | -33 | -41 | 41 | 53 | -53 |
| Longitudinal | Pm | 56 | 56 | 56 | 56 | 56 | 56 | 56 | 56 |
| Longitudinal | PL | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 |
| Longitudinal | Q | -40 | 40 | 53 | -53 | -23 | 23 | 33 | -33 |
| Pm | | 112 | 114 | 112 | 114 | 112 | 114 | 112 | 114 |
| Pm + PL | | 110 | 112 | 116 | 118 | 112 | 114 | 114 | 116 |
| Pm + PL + Q | | 87 | 136 | 150 | 84 | 72 | 156 | 168 | 63 |

Source: Research data

**4.2 Results – bulletin WRC 297**

The Table 7 lists the values of stress and loads founds from reading dimensionless curves and parameters of calculations contained from Bulletins WRC 297.

TABLE 7
Stress intensities circumferential plane - nozzle 2"

| Type of Stress | Au Top (outside) | Al Top (Inside) | Bu Bottom (outside) | Bl Bottom (inside) |
|---|---|---|---|---|
| Stress Intensity | 53 | 142 | 167 | 50 |

Source: Research data

**4.3 Results – finite element method**

The Figure 4, 5 and 6 was copied from ALGOR software.
The Figures 5 and 6 shows the three dimensional model of junction nozzle/vessel.
The Figure 6 show the stress value obtained from MEF

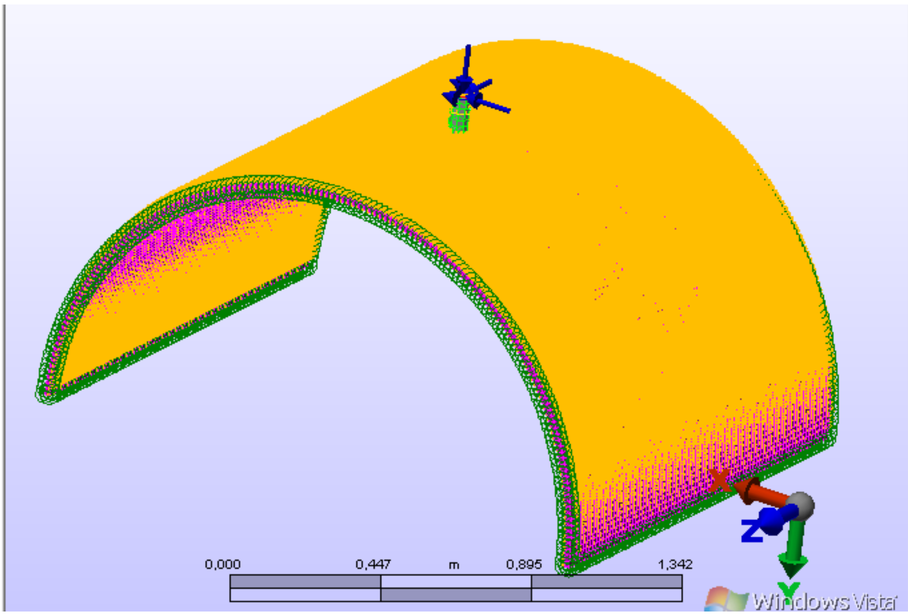

Figure 4 –Nozzle 2" – MEF

The Figure 4 show the nozzle 2" analyzed by MEF with application: external loads, internal pressure and boundary conditions.

Due to geometry symmetry of vessel and loads in longitudinal plane of junction, only one quarter of vessel was modeled. Therefore boundary conditions were imposed everybody nodes localized in symmetric plane.

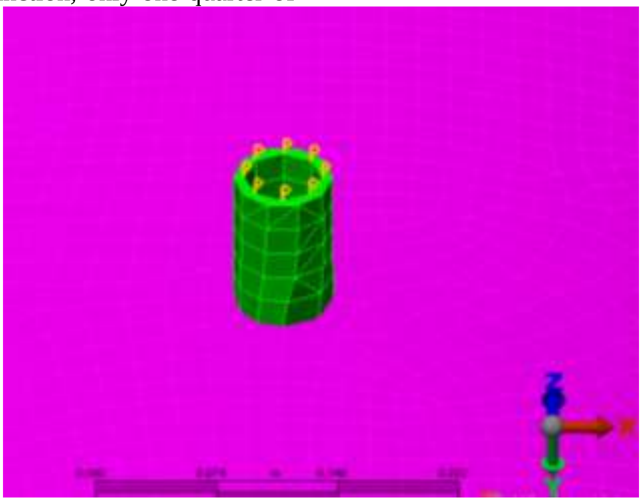
Figure 5 - Perspective view of junction nozzle/vessel – Nozzle 2"

The Brick solid element by ALGOR DESIGN CHECK computational platform was used for mesh generation.

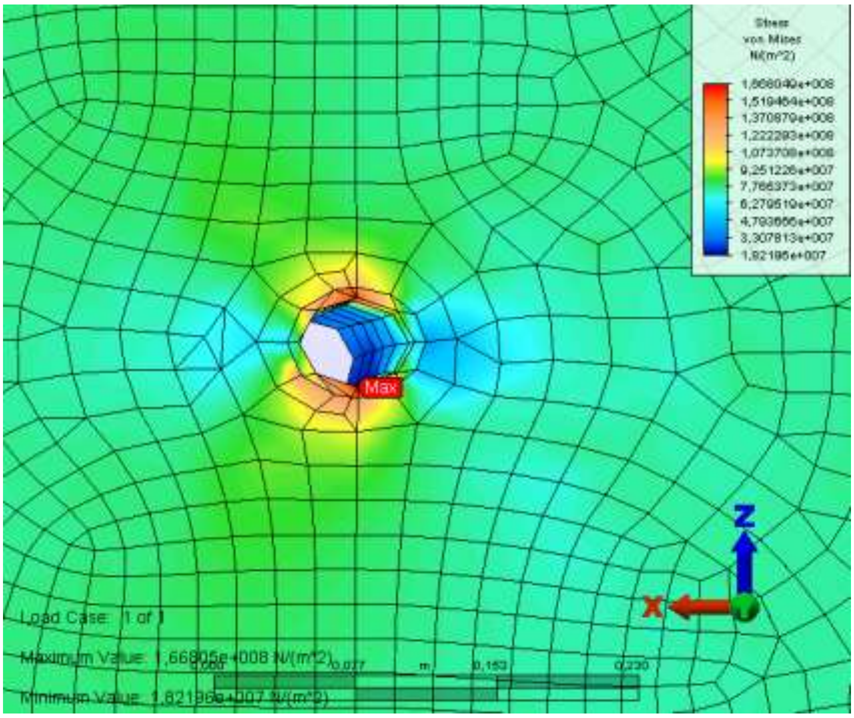


Figure 6 – Stress in nozzle - 2”

For the analyzed model in this work, used for three-dimensional solid elements of eight nodes and three freedom degrees per node, by mesh generation of vessel and nozzle.

A extremity of model was assumed like fixed support, while another was axially free, only sustain per cylindrical support.

As can be seen in Figure 6, the maximum stress value is 166.8 MPa.

## V. Conclusion

Accordance with Table 5 the stress results obtained from three methods of stress analysis are very closed. The MEF value was less to WRC 297 and WRC 107.

The values difference found by WRC 107 to WRC 297 was 0.43% and MEF to WRC 107 was 0.55%. The value difference MEF to WRC 297 was 0.12%.

On analyzed nozzle, the stress value obtained from MEF was more approximated the WRC 297 values than values WRC 107.

Finally, the stress values are reliable for pressure vessel and nozzle that fit into bulletins WRC 107 and WRC 297.

## VI. Acknowledgements

The authors thank the financial support of the Conselho Nacional de Desenvolvimento Científico e Tecnologico-CNPq-“National Counsel of technological and scientific Development”, the Fundação de Amparo a Pesquisa de Minas Gerais-FAPEMIG-“Foundation for Research Support of Minas Gerais” and the Coordenaçao de Aperfeiçoamento de Pessoal de Nivel Superior-CAPES-“Coordination of Higher Education Personnel Training”.

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