CILAMCE 2017
Florianópolis - Santa Catarina - Brazil

DEVELOPMENT OF COMPUTATIONAL TOOLS FOR THE MODELING AND ANALYSIS OF CORROSION DEFECTS IN PRESSURE VESSELS.

Gustavo Lima do Nascimento

Ingrid Thayse Pereira Lourenço Agra

Antonio Almeida Silva

gustavoliman@hotmail.com

agraingrid@gmail.com

antonio.almeida@ufcg.edu.br

Academic Unit of Mechanical Engineering (UAEM).Federal University of Campina Grande – UFCG. Av.Aprígio Veloso, 882 - Universitário, 58429-900, Campina Grande - PB, 58429-900

Abstract. *This article intends to develop computational model in order to represent generalized corrosion defects. Softwares based on Finite Elements Method (FEM) were used to build and analyze a tubular model where the defect have an elliptic rounded borders form in way to better examine the thickness loss with less computational cost. The maximum principal stress of the model without defect were found and has the value of 67,314 MPa to an internal pressure of 2,07 MPa. Through FFS methodology were found a new Maximum Allowable Working Pressure for the given thickness loss. The level 1 assessment obtained a pressure of 1,17MPa generating a maximum principal stress of 117.67 MPa. On level 2 assessment was obtained a pressure of 1,30MPa presenting a maximum principal stress of 130,74MPa. The allowable tensile stress was 120,06MPa, putting the pressure vessel in safety only in the first case. The last phase has to find out a pressure that cause a maximum stress close to the pressure without the lost thickness, wich value was 0,67MPa. The analysis by the use of computational tools was necessary to evaluate the service conditions and operating safety.*

Keywords: *Computational modeling, Structural integrity, Pressure vessels, FEM, Corrosion defect.*

INTRODUCTION

Analyze the structural integrity of a pressure vessel is a big concern of mechanical engineers at process industry, motivated for the sensibility of these equipment and the risk associated to their failure.

Corrosion is considerate a big damage mechanism and when it works associated to mechanical solicitations can reduce drastically the life expectation of the piece. The norm API 579/ASME FFS-1 evaluate through the methodology Fitness-for-Service (FFS) if components under pressure could keep working even they have some structural damage. To evaluate the defects was used computational models based on numeric methods, being necessary a good model created for an engineer with good knowledge of the problem to ensure the relevance of simulation. When carefully created it is a good and economical option to study and predict the comportment of the vessels with corrosion defects and if they still can work, creating accurate results.

When subjected to internal pressure thin-wall tubes, where radius has at least 10 times the thickness, feature the circumferential stress (σ_c) and longitudinal (σ_l). Your structure as shown in Fig. 1, where the distribution of stress from internal pressures will present major stresses on the surface inside than on the outside surface and can be standardized as decreasing the thickness.

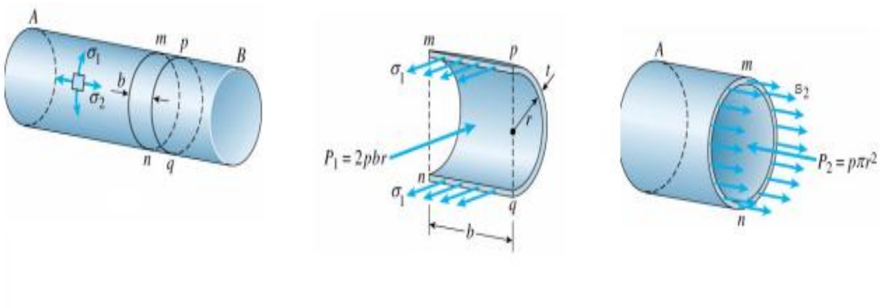

Figure 1. Tensions generated in pressure vessels due to internal pressures.

These tensions are functions of the internal pressure (Pi) in which the vessel submitted, the radius of the circumference of the cylinder (r) and thickness (t).An important variable to obtain in a project of pressure vessels is Maximum Allowable Working Pressure intake (MAWP), pressure that able to cause maximum stress that a material can withstand. The MAWP is given by construction standards of pressure vessels and generally obtained as a function of the geometry and by the mechanical properties of pressure vessels.

1 METHODOLOGY

Figure 2 shows a detailed flowchart of activities for the development of the model and analysis of results presented by numerical simulation. The first step was definition of a geometry model to analyze the defect in pressure vessel. Then, was necessary to mesh the model in order to obtain the convergence of the results. Therefore is necessary to evaluate the results found in level 1 and 2 assessment of the standard API 579.

Proceedings of the XXXVIII Iberian Latin-American Congress on Computational Methods in Engineering
P.O. Faria, R.H. Lopez, L.F.F. Miguel, W.J.S. Gomes, M. Noronha (Editores), ABMEC, Florianópolis, SC, Brazil, November 5-8, 2017.

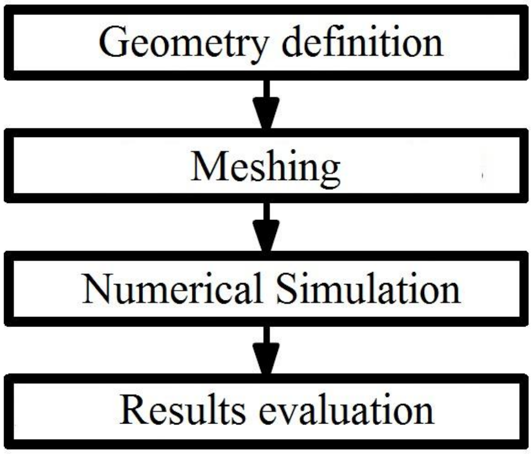

Figure 2. Flow chat of steps at evaluation

Procedures of CENPES/PETROBRÁS led the methodology used to meshing the geometry model at this problem. In this case, the mesh go through a transition to conciliate valid results with the less computational costs. The mesh is thinner at defect region and gets to a bigger one outside the critical space.

The evaluation of the process made from API579/ASME – FFS1/ Section 4 are based on a thickness averaging approach because the corrosion defects causes a thickness loss. Through this norm is possible to obtain a methodology to determine the assessment procedure to be used in the evaluation of the model.

2 RESULTS

2.1 GEOMETRY DEFINITION

The working conditions of the model developed was based on the conditions of construction of the ASME code, Section VIII, Division 1. The model data used are shown in Table 1.

Table 1: Operating conditions and dimensions of pressure vessel

Data	Value
Pressure (P):	2.07 [MPa]
Diameter (D):	1219.2 [mm]
Thickness (t):	19.5 [mm]
Allowable Pressure (S)	120.06 [MPa]

The dimensions of defect geometry are shown in Table 2, where was used a thickness corroded of 52% of the thickness of pressure vessel.

Table 2: Defect geometry data.

Geometry data	Value
Circumferential length:	228.600 [mm]
Longitudinal length:	228.600 [mm]
Minimum thickness:	9.144 [mm]
Fillet radius:	50.000 [mm]

Due to the symmetry conditions was used a model shown in Figure 3, associating reliable results to low computional cost. The amount of elements was reduced by 4 times when compared with the complete model, as shown below.

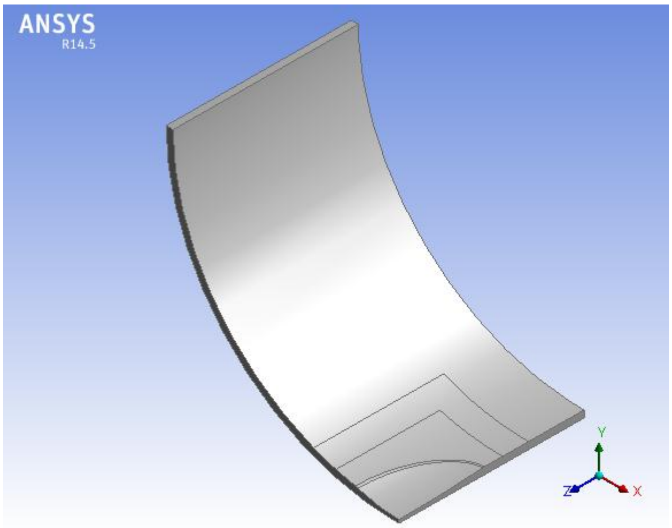

Figure 3. Isometric view from geometry model

In the Figure 3 is possible to view the parabolic approximation adopted, useful to avoid stress concentrators. The divisions near the defect was used to give a better transition of the mesh.

2.2 MESHING

From the geometry definition was used a method of convergence of the results to choose a mesh. Initially was placed a very refined mesh to achieve the convergence of the results and then was reducing the amount of nodes and elements in the model in order to obtain results that converge and submit a lower computational cost.

The first mesh adopted was the hexahedron because the bigger number of nodes per element. However, tetrahedral mesh was used used because it managed to converge the results with lower computational cost. The mesh was a SOLID187 element, which is a tetragonal element with 10 nodes and 3 degrees of freedom at each node.

Figure 4 details the discretization of the geometry, where the defect region presents a greater accumulation of nodes in relation to the rest of the geometry, since the analysis in this region must be more precise. Was given a reduction of 5 mm on each of the delimitations for transition of the mesh: 20 mm; 15mm; 10mm; 5 mm.

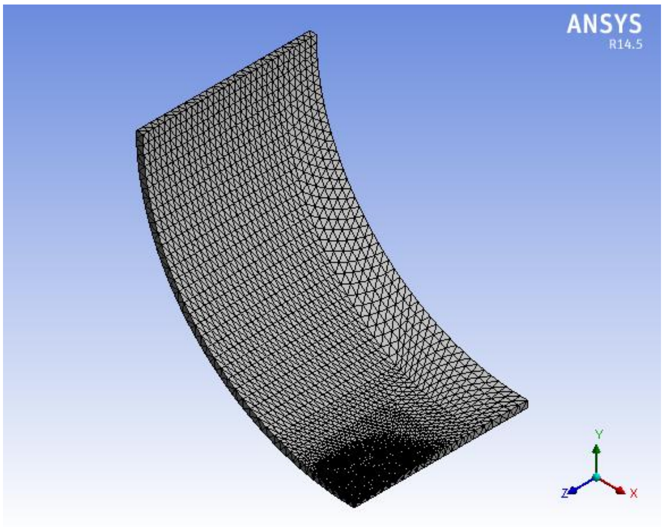

Figure 4.Mesh used in the model.

2.3BOUNDARY CONDITIONS

The boundary conditions used for input data because of to the symmetry of the model are shown in Figure 5 and represents the pressure applied on all the internal parts of the pressure vessel. B, C and D represents the conditions of 0 offset in x, y, and z directions, respectively. That offset 0 was used to apply the conditions of symmetry.

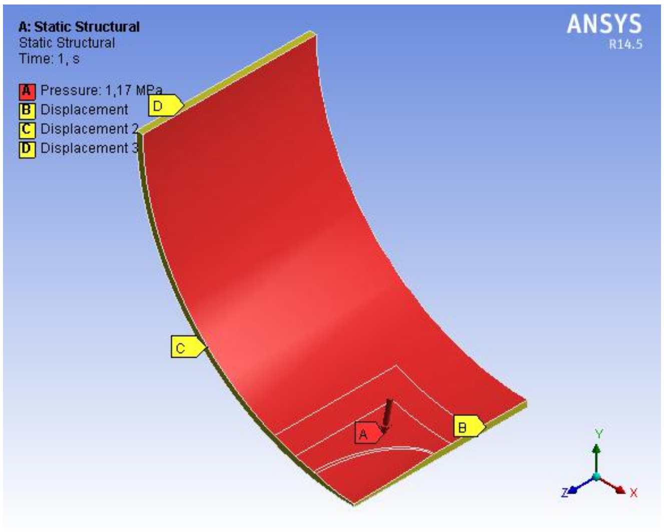

Figure 5.Boundary conditions applied on the model.

2.4 MODEL VALIDATION

Model validation through the analysis of pressure vessel without corrosion defect was obtained. The analytical value of the maximum principal stress in a differential element of the model was $\sigma = 66{,}24$ MPa. Figure 11 shows the maximum principal stress in the vessel without thickness loss. Was found a maximum stress of 67.314 MPa.

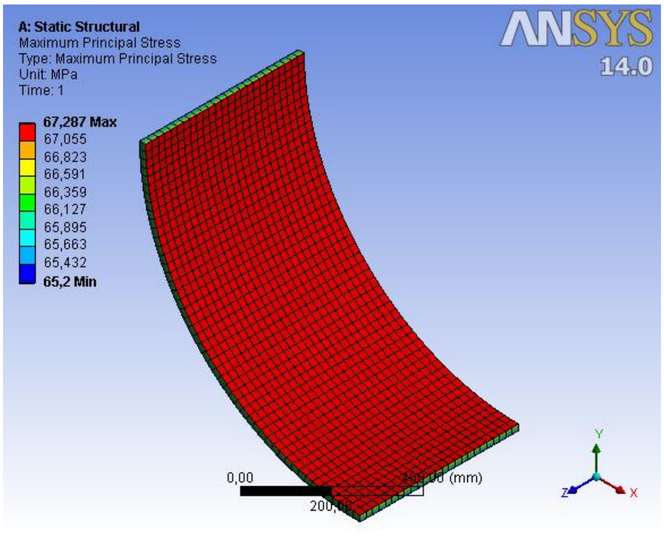

Figure 6.Numerical analysis of pressure vessel without corrosion.

The numeric result was 67.314 MPa againstthe value of 66.24 MPa from analytical result. This equivalent error of 1.62% shows the accuracy of the software used.

2.5PERFORM IN THELEVEL 1 AND 2 OF THE API 579 ASSESSMENT

The API 579 methodology to general metal loss can be used to establish a new MAWP, if the flaw found is unacceptable. Initially was determined the minimum required thickness that is 12,26mm.

The second step was to locate the regions of metal loss on the pressure vessel and determine the type of thickness and data that would be recorded. The Fig. 7 shows the details about the grid utilized to obtain the thickness of the model. The grid was placed to analyze the entire corroded region.

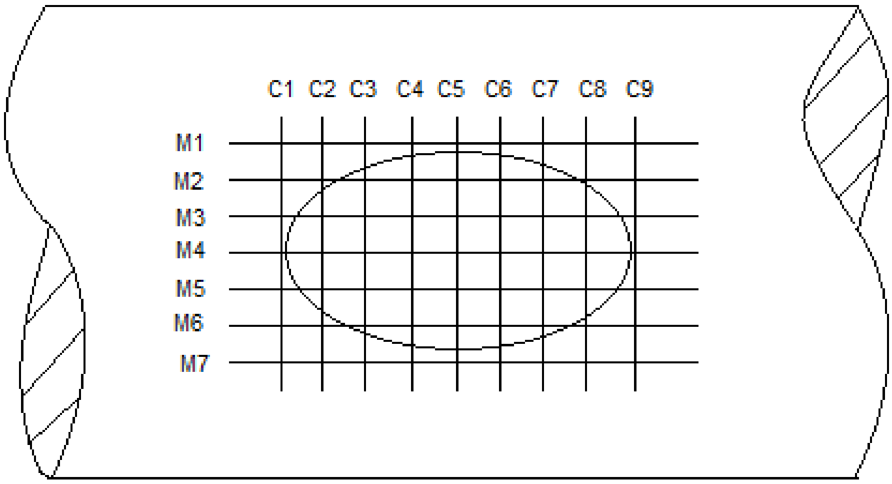

Figure 7. Grid for thickness verification.

The Table 3 shows the values of the thickness found on the model.Was utilized a step of 50 mm in circumferential direction and 60 mm in longitudinal direction on the corrosion profile. The inspection of the thickness was made in the computational model. So each point on the Tab. 3 was found in the elliptical approach.

Table 3: Values of the thickness of the defect in the model

Inspection Plane (mm)	C1	C2	C3	C4	C5	C6	C7	C8	C9
M1	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05
M2	19.05	19.05	19.05	17.71	17.09	17.71	19.05	19.05	19.05
M3	19.05	17.33	13.92	11.87	11.19	11.87	13.92	17.33	19.05
M4	19.05	15.29	11.08	9.83	9.14	9.83	11.08	15.29	19.05
M5	19.05	17.33	13.92	11.87	11.19	11.87	13.92	17.33	19.05
M6	19.05	19.05	19.05	17.71	17.09	17.71	19.05	19.05	19.05
M7	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05	19.05

Based on these data was possible to determine the minimum thickness measured. This thickness has the value of 9.144 mm and was located in the center of the grid in points C5 and M4.

The following step was the determination of the remaining thickness ratio,R_t in order to calculate the length for thickness averaging, L. Therefore, the approximate value of L was 120 mm.

To determine the average measured thickness from the grid analyzedwas made the arithmetic mean between the length that corresponds to the C4, C5 and C6 points in M4.

$$t_{am} = \frac{9.83 + 9.144 + 9.83}{3} = 9.60mm \qquad (1)$$

With these values, the level 1 and 2 assessment can be analyzed to determine the new MAWP and determine if the pressure vessel is acceptable for continued operation. By the level 1. For these conditions, only one criteria is acceptable. Thus, if the vessel is derated, the new MAWP based on level 1 assessment is:

$$MAWP^c = \frac{S \times E \times t_c}{R_c + 0{,}6 \times t_c} = \frac{120.06 \times 0.85 \times 7.06}{612.14 + 0.6 \times 7.06} = 1.17MPa \qquad (2)$$

Similarly, the level 2, was accepted only by one of these criteria, giving a new MAWP for this case as shown below.

$$MAWP^{c} = \frac{S \times E \times \frac{t_c}{RSF_a}}{R_c + 0.6 \times \frac{t_c}{RSF_a}} = \frac{120.06 \times 0.85 \times \frac{7.06}{0.9}}{612.14 + 0.6 \times \frac{7.06}{0.9}} = 1.30MPa \quad (3)$$

By level 2 assessment the new MAWP has the value of 1.30MPa.

2.6 PERFORM ALEVEL 3OF THE API 579 ASSESSMENT

With the new values of the MAWP the level 3 assessment is required to evaluate the stress distribution in the model. Through these operations conditions is possible to analyze if the pressure vessel is on safe working conditions.

By level 1 assessment, where MAWP has the value of 1,17 MPa, the maximum principal stress has the value of 117,67 MPa in the region of lower thickness. This value is inferior of the allowable tensile stress of the shell material evaluated, but he works next to the rupture stress. The Fig. 8 (a) shows details of the stress distribution at model.

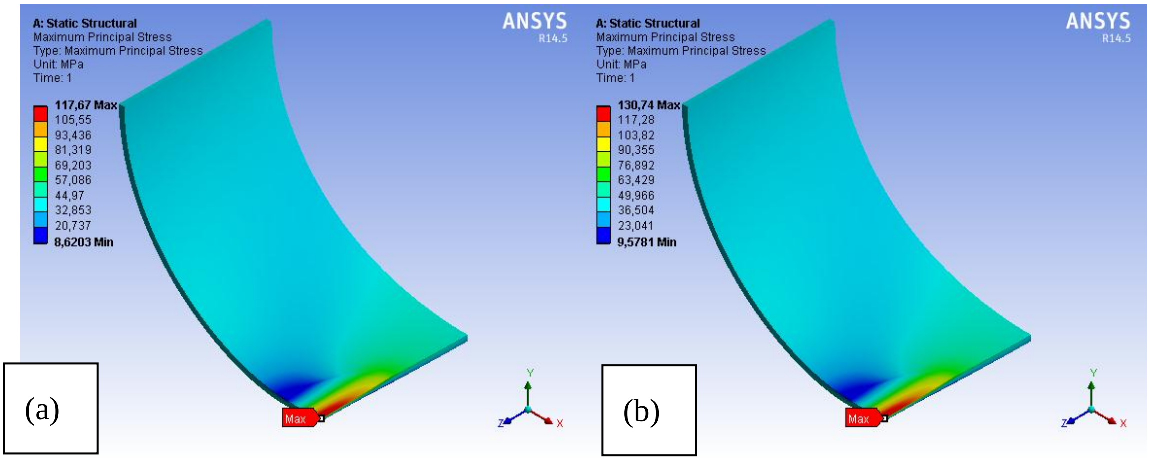

Figure 8. (a) Stress distribution to 1,17 MPa pressure; (b)Stress distribution to 1,30 MPa pressure.

Similarly to the level 1, the level 2 has a MAWP with the value of 1.30 MPa. The maximum principal stress has the value of 130.74 MPa. This stress is located at the region with lower thickness and is superior than the allowable tensile stress. The Fig. 8 (b) shows detail of the stress distribution.

From this computational toll, it is possible to find a working pressure that can offer a maximum principal stress found to the vessel without the loss of thickness of 67.314 MPa. Was used the method of attempt, where was tested in the model some pressure until the stress was found.The value found was 0.67 MPa.

3 CONCLUSIONS

Through this work, it is possible to demonstrate the importance of the use of computational tools for the analysis of pressure vessels with the presence of generalized corrosion defects, since empirical methods often do not show results that will carry the components pressurized to safety conditions, as was the case of level 2 assessment. However, the most conservative assessment, level 1, presented results that would take the component not to collapse, but the tensions found are approaching the maximum allowable tensile stress value for the pressure vessel. With the use of computational tools was also possible verification of a new PMTA to the pressure vessel can be in service with maximum principal stress similar those that do not present the corrosion defect.

Another important factor is the use of simplified models, which may offer a faster solution to the problem showing results converge to closest models of reality. This simplification demand a less computational cost associated with a shorter time to evaluation of real models.

ACKNOWLEDGEMENTS

The presente workwascarried out with thesupportof CNPQ (ConselhoNacional de DesenvolvimentoCientífico e Tecnológico – Brasil).

The authors also thank to the support of the Laboratory of Modeling and Simulation (LMS), the UAEM Academic Unit of Mechanical Engineering (UAEM) and the CCT-UFCG (Center of Science and Technology – UFCG).

REFERENCES

AMERICAN PETROLEUM INSTITUITE – API. API 579/ASME FFS-1. FITNESSFOR SERVICE. 2016.

ALVES, AVELINO F. *ELEMENTOS FINITOS: A BASE DA TECNOLOGIA CAE*. ÉRICA, 2003. 294P.

AMERICAN SOCIETY OF MECHANICAL ENGINEERS – ASME, Section VIII, Division1. Rules for Construction of Pressure Vessels. 2013.

AZEVEDO, D.F.O. *Análiseestrutural com Ansys Workbench: StaticStructural*. Mogi das Cruzes,2016. 180p.

GENTIL, V. *Corrosão,* 6ª Edição. Rio de Janeiro: LTC, 2011.

LACERDA JUNIOR, J. A. *Apontamentos de Aula do Engº Mecânico*, Volume 2, Disciplina: Mecânica dos Materiais 2. 197p.

TELLES, P. C. S. *Vasos de Pressão*. 2ª Edição, Rio de Janeiro: LTC. 2005.

BATHE, K. J. *Finite Elements Procedures*. Ed. Prentice-Hall. 1996.

ALMEIDA, J. I. L. *Análise numérica da integridade estrutural de vasos de pressão com corrosão usando a norma API 579*. 131p. Dissertação (Mestrado em Engenharia Mecânica) – Universidade Federal da Paraíba (UFPB). 2012.

CABRAL, H. L. D. *Desenvolvimento de ferramentas computacionais para modelagem e análise automática de defeitos de corrosão em dutos*. 140p. Dissertação (Mestrado em Engenharia Mecânica) – Universidade Federal de Pernambuco (UFPE). 2007.

FRANCESCHINI, A. S. *Avaliação do fenômeno de união de trincas induzidas pelo hidrogênio e sua influência na integridade estrutural de um vaso de pressão*. 118p. Dissertação (Mestrado em Engenharia Mecânica) – Universidade Federal do Rio Grande do Sul. 2011.

ROCHA, R. S. *Avaliação do alívio mecânico de tensões residuais devido a sobrecarga provocada por teste Hidrostático*. 87p. Dissertação (Mestrado em Engenharia Metalúrgica) – Universidade Federal do Rio Grande do Sul (UFRGS). 2009.