	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	
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		ESUP	


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INDEX OF REVISIONS

REV.	DESCRIPTION AND/OR REVISED SHEETS
0	ORIGINAL ISSUE
A	REVISED WHERE INDICATED ACCORDING TO CONSISTENCY ANALYSIS


	REV. 0	REV. A	REV. B	REV. C	REV. D	REV. E	REV. F	REV. G	REV. H
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	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	REV.: A
	-	SHEET: 2 de 10	
	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)	INTERNAL	
		ESUP	

SUMMARY

1	SCOPE	3
2	NORMATIVE REFERENCES	3
2.1	CLASSIFICATION SOCIETY	3
2.2	CODES AND STANDARDS	3
2.3	GOVERNMENTAL REGULATION	3
2.4	REFERENCE DOCUMENTS	4
2.5	CONFLICTING REQUIREMENTS	4
3	DEFINITIONS AND ABBREVIATIONS	4
3.1	DEFINITIONS	4
3.2	ABBREVIATIONS	4
4	STRESS ANALYSIS REPORT CONTENT	4
4.1	ANALYSIS DESCRIPTION	4
4.2	REFERENCE DOCUMENTS	5
4.3	ANALYSIS DATA	5
4.4	TYPE OF ANALYSIS PERFORMED	6
4.5	FINITE ELEMENT MODEL	6
4.6	RESULTS	8
4.7	RESULTS VIEW	10
4.8	CONCLUSIONS	10
4.9	RECOMENDATIONS	10
4.10	REFERENCES USED ON ANALYSIS	10
4.11	ANNEXES	10

	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	REV.: A
	-	SHEET: 3 de 10	
	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)	INTERNAL	
		ESUP	

1 SCOPE

This Technical Specification establishes minimum and complementary requirements for stress analysis by the Finite Element Method (FEM) of Pressure Vessels used in PETROBRAS facilities. Whenever a Finite Element Analysis (FEA) is required, the stress analysis report shall be submitted to PETROBRAS for approval.

“Pressure Vessels” are defined in I-ET-3010.00-1200-540-P4X-001 – REQUIREMENTS FOR PRESSURE VESSELS DESIGN AND FABRICATION.

This Technical Specification is based on Part 5 of ASME BPVC Section VIII Division 2 hereinafter referred to as ASME VIII-2. For parts of the equipment designed according to ASME BPVC Section VIII Division 1, hereinafter referred to as ASME VIII-1, the allowable stresses to be used in the stress analysis shall be obtained from Tables 1A and 1B of ASME BPVC Section II Part D, hereinafter referred to as ASME II-D.

2 NORMATIVE REFERENCES

Pressure Vessels designed according to this Technical Specification shall be in agreement with the following references, where applicable:

2.1 CLASSIFICATION SOCIETY

2.1.1 PACKAGER/MANUFACTURER shall perform the design conforming to the requirements of Classification Society.

2.1.2 PACKAGER/MANUFACTURER is responsible for submitting to the Classification Society all documentation in compliance with stated Rules.

2.2 CODES AND STANDARDS


2.2.1 The following codes and standards include provisions for this specification. The latest issue of the references shall be used unless otherwise agreed. Other recognized standards may be used, provided it can be shown that they meet or exceed the requirements of the standards referenced below:

- ASME BPVC Sec. VIII – Rules for Construction of Pressure Vessels
- TEMA – Standards of the Tubular Exchanger Manufacturers Association

2.3 GOVERNMENTAL REGULATION

NR-13 - Secretaria de Trabalho do Ministério da Economia (Brazilian Economy Ministry) – Norma Regulamentadora Nº 13 (NR-13) – "CALDEIRAS, VASOS DE PRESSÃO, TUBULAÇÕES E TANQUES METÁLICOS DE ARMAZENAMENTO"

Brazilian Government regulations are mandatory and shall prevail, if more stringent, over the requirements of this specification and other references herein.

	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	REV.: A
	-	SHEET: 4 de 10	
	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)	INTERNAL	
		ESUP	

2.4 REFERENCE DOCUMENTS

All reference documents used in the analysis shall be listed, such as:

I-ET-3010.00-1200-540-P4X-001 - REQUIREMENTS FOR PRESSURE VESSELS DESIGN AND FABRICATION

2.5 CONFLICTING REQUIREMENTS

As a general guideline, in case of conflicting requirements between this Technical Specification and other cited references, the most stringent shall prevail. If necessary, the PACKAGER/MANUFACTURER may revert to PETROBRAS for clarification.

3 DEFINITIONS AND ABBREVIATIONS

3.1 DEFINITIONS

PACKAGER: The organization responsible for design, fabrication, testing, assembly, and furnishing of the PACKAGE.

PACKAGE: An assembly of equipment supplied interconnected, tested and ready to operate, requiring only the Unit available utilities for operation.

MANUFACTURER: The organization responsible for design, fabrication, and testing of the PRESSURE VESSEL.

3.2 ABBREVIATIONS

FEM – FINITE ELEMENT METHOD

FEA – FINITE ELEMENT ANALYSIS


4 STRESS ANALYSIS REPORT CONTENT

The stress analysis report shall include, but is not limited to, the following items namely:

4.1 ANALYSIS DESCRIPTION

The PACKAGER/MANUFACTURER shall describe:

- The equipment and/or component part to be analyzed, which may be represented by drawings or sketches;
- The reason for using FEA, justifying why an analytical analysis is not satisfactory;
- The structural-mechanical behavior of the component part analyzed;
- The types of analysis performed;
- All loads and load case combinations considered in the analysis;
- The name of the commercial finite element software used and its version.

	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	REV.: A
	-	SHEET: 5 de 10	
	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)	INTERNAL	
		ESUP	

4.2 REFERENCE DOCUMENTS

All reference documents used in the analysis shall be listed, such as:


- The equipment Construction Code and Addenda;
- The drawings or data sheets (indicating the revision) used to build the geometry of the finite element model and to acquire the materials properties at operation and design conditions;
- Other sources of information used to elaborate the finite element model and/or to set the check conditions, e.g., data sheets with external loads on nozzles, standards, catalogs, fax messages, e-mails, etc., shall be included in the Annexes.

4.3 ANALYSIS DATA

4.3.1 The following input data, when applicable, shall be summarized in a table, with their values and source of information:

- Operation pressure, design pressure and MAWP (Maximum Allowable Working Pressure), or the pressurization curve;
- Temperatures: initial (Summer or Winter), operation and design, or the transient temperature curve;
- Upset conditions of temperature and/or pressure, informing the holding time;
- Static head from liquid or bulk materials (e.g. catalyst);
- Liquid specific gravity;
- Loads in all different analysis conditions including those that are a function of time;
- Wind loads;
- Loads on nozzles;
- Corrosion allowance;
- Material specification, including refractory linings and thermal insulation;
- Allowable stresses from ASME II-D (room temperature and evaluation temperature);
- Elasticity modulus (room temperature and evaluation temperature);
- Yield strength (room temperature and evaluation temperature);
- Ultimate tensile strength (room temperature and evaluation temperature);
- Joint efficiency;
- Material fatigue curve;
- Thermal expansion coefficients (varying with temperature when applicable);
- Film coefficient (varying with temperature when applicable);
- Internal and external heat transfer coefficients, with the respective bulk temperatures;
- Poison's ratio.

4.3.2 A table with the external loads for each load case shall be presented.

	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	REV.: A
	-	SHEET: 6 de 10	
	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)	INTERNAL	
		ESUP	

4.3.3 For nonlinear analysis, the material property model selected shall be justified, and the commercial package software commands and parameters values used shall be described.

4.3.4 For linear elastic analysis a table summarizing all allowable limits for primary and secondary stresses shall be elaborated to check every load case conditions evaluated.

4.3.5 If the refractory or insulation weight is considered by the use of equivalent density for the metal, a table with these values shall be elaborated.

4.4 TYPE OF ANALYSIS PERFORMED

4.4.1 The PACKAGER/MANUFACTURER shall describe all types of analyses performed, justifying why they were chosen and shall explain all conceptual simplifications and hypothesis considered.

4.4.2 For load cases with temperature gradients, a thermal analysis is required to obtain the temperature profile resulting from either axial or through-wall gradients on the component part evaluated in order to perform a coupled structural-thermal analysis.

4.5 FINITE ELEMENT MODEL

4.5.1 The PACKAGER/MANUFACTURER shall describe the finite element model elaborated and its dimensions, justifying and explaining all the simplifications hypothesis, and assumptions adopted in the geometry creation, such as: symmetry, plane stress, plan strain, etc. Furthermore, it is necessary to explain the behavior hypothesis considered, like contact conditions/type, constraint equations, equivalent heat transfer coefficients, etc.


4.5.2 The PACKAGER/MANUFACTURER shall list all types of elements used and their names on the software elements library. Each type of element chosen shall be justified.


4.5.3 The report shall contain a table describing the model, with the following columns:

- Name given to each component of the model;
- Type of element adopted for each component and its reference number in the model;
- Reference name in the software elements library;
- Real Constant defined to each component, when applicable, and its reference number in the model;
- Component material and its reference number in the model;
- Number of elements of each component.

4.5.4 The report shall contain a table of Real Constants, when applicable, with the following columns:

- Reference number of each Real Constant associated with the component;

	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	REV.: A
	-	SHEET: 7 de 10	
	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)	INTERNAL	
ESUP			
<ul style="list-style-type: none"> • Thickness, in case of shell elements; • Cross-section properties, in case of beam elements; • Location of each Real Constant associated to the component. <p>4.5.5 The report shall contain a material table, with the following columns:</p> <ul style="list-style-type: none"> • Reference number of the component material; • Material specification; • Modulus of Elasticity as temperature function (when applicable); • Other properties (thermal expansion coefficient, thermal conductivity, etc.), as temperature functions, when applicable. <p>4.5.6 The report shall contain at least the following graphical displays (color contour plotting) of the geometry model:</p> <ul style="list-style-type: none"> • The elements with the associated materials; • The elements with their associated types; • The elements with the associated Real Constants; • The surfaces showing their normal vector, in case of shell elements model; • The elements mesh, showing the refined regions. <p>4.5.7 The PACKAGER/MANUFACTURER shall inform the elements mean size at regions of interest and the complete description of the mesh refinement criteria used, justifying the quality of the mesh discretization, showing the energy error within each finite element and expressing this error in terms of a global error energy norm.</p> <p>4.5.8 Applying Loads</p> <p>4.5.8.1 All applied loads and load combination in each load-step evaluated shall be listed, including those that are a function of time.</p> <p>4.5.8.2 It is necessary to describe and justify how the following loads are applied to the finite element model:</p> <ul style="list-style-type: none"> • Pressure; • Temperature and/or temperature gradient; • Wind loads; • External loads on nozzles; • Weight of internal or external parts; • Pressure end load applied on the edge of the model to simulate the longitudinal stress, when applicable; • Concentrated loads; • Other surface thermal loads (ex.: convection, heat flux); • Inertia loads such as gravitational acceleration, angular velocity and angular acceleration; 			

	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	REV.: A
	-	SHEET: 8 de 10	
	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)	INTERNAL	
		ESUP	

- Imposed displacements.

4.5.8.3 The PACKAGER/MANUFACTURER shall depict graphical displays (color contour plotting) to show how the above-mentioned loads are applied to the model.

4.5.9 Applying Boundary Conditions

4.5.9.1 The PACKAGER/MANUFACTURER shall justify all boundary conditions (degree-of-freedom constraints) adopted in each load case, explaining how they were applied to the model.

4.5.9.2 The symmetric and antisymmetric degree-of-freedom constraints on the model shall be justified, and the graphical displays (color contour plotting) showing the regions, planes and faces of symmetry/antisymmetry shall be presented.

4.5.9.3 If the analysis considers the contact between parts, describe the type of contact used and the behavior expected for the model.

4.5.9.4 If constraints equations for coupling degrees of freedom are used, describe how it was used (methods of generating constraint equations) and justify the behavior expected for the model after loading.

4.5.9.5 Graphical display (color contour plotting) of the applied boundary conditions and degree-of-freedom constraints shall be provided to show that they were applied properly.


4.5.10 In case of nonlinear or transient analysis, the PACKAGER/MANUFACTURER shall describe all control settings defined, such as: type of equation solver, the use of small or large displacements, pre-stress effects, iteration method, number of load-steps, number of iterations, loading application conditions (stepped or ramped), convergence criteria, termination criteria, etc.

4.6 RESULTS

4.6.1 The PACKAGER/MANUFACTURER shall present graphical displays (color contour plotting) of the deformed shape of the model for each load-step, comparing and commenting each deformed shape plots with its expected appearance with regard to the direction of application and type of loading for each load-step. The plots legend must show the percent error in structural energy norm (SEPC), which indicates the quality of the mesh refinement, and its value shall be less than 10% in the regions of interest.


4.6.2 The PACKAGER/MANUFACTURER shall check if the reaction loads at constrained nodes (support reactions) for each load-step are consistent with the applied loads. The sum of the reaction loads in each direction shall be equal to the sum of the applied forces in that direction. Unexpected reaction loads, not complying with the directions of the applied loads, shall be checked.

4.6.3 The PACKAGER/MANUFACTURER shall present, for each load-step, graphical displays (color contour plotting) of displacement UX, UY e UZ, when applicable, in

	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	REV.: A
	-	SHEET: 9 de 10	
	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)	INTERNAL	
		ESUP	

an adequate plotting coordinate system. The points to be considered relevant in the plots of displacement results demonstrating the compliance with the loadings applied shall be identified and commented. The maximum displacements obtained shall be checked in order to satisfy their defined allowable values, when applicable.

- 4.6.4 The PACKAGER/MANUFACTURER shall present, for each load-step, graphical displays (color contour plotting) of membrane and bending stress distributions for SX, SY, SZ, S1, S2 and S3 in an adequate plotting coordinate system. The points to be considered relevant in the plots of displacement results demonstrating the compliance with the loadings applied shall be identified and commented.
- 4.6.5 The PACKAGER/MANUFACTURER shall demonstrate that the results of FEA performed comply with simplified analytical calculation, data based on experimental studies, or data in the literature.
- 4.6.6 The PACKAGER/MANUFACTURER shall present, for each load-step, graphical displays (color contour plotting) of von Mises equivalent stress (membrane and bending) distribution, categorizing the stresses according to ASME VIII-2, in case of elastic stress analysis method. The maximum values shall be indicated and compared to associated limiting values.
- 4.6.7 In case of transient analysis, used to determine the dynamic response of a structure under the action of any general time-dependent loads, the PACKAGER/MANUFACTURER shall present time-varying graphs of stress, displacements, forces and temperature (when applicable) of specific locations (nodes) in the model. The chosen nodes shall be justified and the time-varying graphs commented. The maximum values shall be indicated and compared to the associated limiting values.
- 4.6.8 When fatigue analysis is required, it shall be made on the basis of the number of applied cycles of a stress or strain range at specific locations (nodes) in the component. The controlling stress for the fatigue evaluation is the effective total equivalent stress amplitude calculated for each cycle in the loading histogram. The chosen nodes shall be justified, the cycle counting methods explained, and the controlling stress range commented.
- 4.6.8.1 The PACKAGER/MANUFACTURER shall check whether the directions of the principal stresses at the point being considered change during the stress cycle.
- 4.6.8.2 The PACKAGER/MANUFACTURER shall present time-varying graphs of the component stresses at specific locations (nodes) evaluated.
- 4.6.9 The report shall contain tables summarizing the results for each load step, with the following columns:
- Name given to the component part;
 - Material;
 - Temperature;
 - Stress categorization;

	TECHNICAL SPECIFICATION	Nº: I-ET-3010.00-1200-540-P4X-003	REV.: A
	-	SHEET: 10 de 10	
	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)	INTERNAL	
		ESUP	

- Allowable limits;
- von Mises equivalent stress.

4.7 RESULTS VIEW

Each load case results shall be commented and analyzed comparing outputs with the expected results.

4.8 CONCLUSIONS

The conclusions of the stress analysis performed for all load cases shall be reported.

4.9 RECOMENDATIONS

The recommendations relevant to the analysis shall be informed.

If the analysis performed shows that it is necessary to reinforce some component part, increase thicknesses or reduce/limit some type of loadings, this modifications shall be clearly informed and pointed out.

4.10 REFERENCES USED ON ANALYSIS

All reference sources used in the stress analysis report, such as, articles, books, etc. shall be informed.

4.11 ANNEXES

All documents containing data used in the FEA report, such as: data sheets with external loads on nozzles, excerpts of standards, excerpts of catalogs, fax messages, e-mails, shall be attached.