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SRGE	TITLE: REQUIREMENTS FOR STRESS ANALYSIS BY FINITE ELEMENT METHOD (FEM)		INTERNAL
			ESUP

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SUMMARY

1 SCOPE

This Technical Specification establishes minimum and complementary requirements for stress analysis by the Finite Element Method (FEM) of pressure vessels parts and components.

The requirements herein listed may be used for performing FEA for other equipment components and parts, when so specified by BUYER.

Whenever a Finite Element Analysis (FEA) is required, the stress analysis report shall be submitted to BUYER for approval.

2 NORMATIVE REFERENCES

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

2.1 CLASSIFICATION SOCIETY

2.1.1 SELLER shall perform the design conforming to the requirements of Classification Society.

2.1.2 SELLER 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

2.2.2 When performing FEA for parts and components for equipment with design codes other than the above mentioned, the applicable design code recommendations and requirements shall be considered.

2.3 ABBREVIATIONS

FEM – FINITE ELEMENT METHOD

FEA – FINITE ELEMENT ANALYSIS

3 STRESS ANALYSIS REPORT CONTENT

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

3.1 ANALYSIS DESCRIPTION

Shall describe:

- The equipment and/or component part being analyzed, which may be represented by drawings or sketches.
- 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.

3.2 REFERENCE DOCUMENTS

All reference documents used in the analysis shall be listed, such as: equipment design code and addenda; drawings, data sheets, calculation reports, catalogs, material standards, and so on.

3.3 ANALYSIS DATA

3.3.1 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, operation and design (or evaluation temperature, if other), or the transient temperature curve.
- Upset conditions of temperature and/or pressure, informing the holding time.
- Static head from fluids or bulk materials (e.g., catalyst).
- Fluid specific gravity.
- Loads for all different analysis conditions including those that are a function of time.
- Wind loads.
- External loads.
- Acceleration loads.
- Bolt loads.
- Corrosion/mechanical allowances.
- Material specifications, including refractory linings and thermal insulation.
- Material specifications for overlay/clad/lining, with its main characteristics and properties.
- Allowable stresses as determined by the design code (at room temperature and at evaluation temperature).
- Elasticity Modulus (at room temperature and at evaluation temperature).

- Yield Strength (at room temperature and at evaluation temperature).
- Ultimate Tensile Strength (at room temperature and at evaluation temperature).
- Joint efficiency.
- Material fatigue curve.
- Thermal expansion, thermal conductivity and thermal diffusivity coefficients (varying with temperature, when applicable).
- Strain limits.
- Film coefficient (varying with temperature when applicable).
- Internal and external heat transfer coefficients, with the respective bulk temperatures.
- Materials densities and Poison's ratio.

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

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

3.3.4 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.

3.3.5 If the refractory or insulation weight is considered by applying an equivalent density for the metal, a table with these values shall be elaborated.

3.4 TYPE OF ANALYSIS PERFORMED

3.4.1 The report shall describe all types of analyses performed, justifying why they were chosen. All conceptual simplifications and hypothesis considered shall be detailed.

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

3.4.3 When performing the analysis for equipment designed as per ASME BPVC code, the report shall be explicit on the failure modes included in the analysis (plastic collapse, local failure, buckling and cyclic loading). The report shall present a justification for any excluded failure mode.

3.4.4 When performing the analysis for equipment designed as per ASME BPVC code, the report shall be explicit on the analysis method applied (elastic stress analysis method, elastic-plastic stress analysis method, and limit load analysis method). The report shall present a justification for the chosen analysis method.

3.5 ALLOWABLE STRESSES

3.5.1 For parts of the equipment designed according to ASME BPVC Section VIII Division 2, the allowable stresses to be used in the stress analysis shall be obtained from Tables 2A, 2B, 5A and 5B of ASME BPVC Section II Part D.

3.5.2 For parts of the equipment designed according to ASME BPVC Section VIII Division 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.

3.5.3 For other design codes the allowable stresses shall be as therein defined.

3.6 FINITE ELEMENT MODEL

3.6.1 The report 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, plane strain, etc. Furthermore, it is necessary to explain the behavior hypothesis considered, like contact conditions/type, constraint equations, equivalent heat transfer coefficients, etc.

3.6.2 The report shall list all types of elements used and their names on the software elements library. Each type of element chosen shall be justified.

3.6.3 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.

3.6.4 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.
- Thickness, in case of shell elements.
- Cross-section properties, in case of beam elements.
- Location of each Real Constant associated to the component.

3.6.5 The report shall contain a material table, with the following columns:

- 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.

3.6.6 The report shall contain at least the following graphical displays (color contour plotting) of the geometry model:

- 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.

3.6.7 The report 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.

3.6.8 Applying Loads

3.6.8.1 All applied loads and load combination in each load-step evaluated shall be listed, including those that are a function of time.

3.6.8.2 It is necessary to describe and justify how the following loads are applied to the finite element model:

- Pressure.
- Temperature and/or temperature gradient.
- Wind loads.
- External loads.
- Bolt loads.
- Weight of internal or external parts.
- Pressure thrust loads.
- Support reaction loads.
- Concentrated loads.
- Other surface thermal loads (ex.: convection, heat flux).
- Inertia loads such as gravitational acceleration, angular velocity and angular acceleration.
- Imposed displacements.

3.6.8.3 The report shall depict graphical displays (color contour plotting) to show how the above-mentioned loads are applied to the model.

3.6.9 Applying Boundary Conditions

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

3.6.9.2 The symmetry and anti-symmetry (when applicable) 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/anti-symmetry shall be presented.

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

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

3.6.9.5 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.

3.6.10 In case of nonlinear or transient analysis, the report 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.

3.7 RESULTS

3.7.1 The report 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.

3.7.2 The report shall show if the reaction loads at constrained nodes (support reactions) for each load-step are consistent with the applied loads.

3.7.3 The report shall present, for each load-step, graphical displays (color contour plotting) of displacement UX, UY e UZ, when applicable, 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. The maximum displacements obtained shall be checked in order to satisfy their defined allowable values, when applicable.

3.7.4 The report 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.

3.7.5 The report shall present for each load-step graphical displays (color contour plotting) of von Mises equivalent stress (membrane and bend) distribution, categorizing the stresses according to ASME VIII-2, in case elastic stress analysis method. The maximums shall be indicated and compared to associated limiting values.

3.7.6 The report shall demonstrate that the results of FEA performed comply with simplified analytical calculation, data based on experimental studies, or data in the literature.

3.7.7 The report shall include a method used to validate the numerical model (i.e., mesh sensitivity review and equilibrium check for finite element analysis, e.g., check of hoop stress in a component away from structural discontinuity and a check to ensure that global equilibrium is achieved between applied loads and reactions at specified boundary conditions).

3.7.8 In case of transient analysis, used to determine the dynamic response of a structure under the action of any general time-dependent loads, the report 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.

3.7.9 When fatigue analysis is required, it shall be made based on 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.

3.7.9.1 The report shall show whether the directions of the principal stresses at the point being considered change during the stress cycle.

3.7.9.2 The report shall present time-varying graphs of the component stresses at specific locations (nodes) evaluated.

3.7.10 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.
- Allowable limits.
- von Mises equivalent stress.

3.8 RESULTS VIEW

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

3.9 CONCLUSIONS

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

3.10 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, these modifications shall be clearly informed and emphasized.

3.11 REFERENCES USED ON ANALYSIS

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

3.12 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, e-mails, shall be attached.

Electronic file for the full model shall be submitted along with the report. This electronic file shall be a “ready to run” version of the evaluation, with all materials, symmetries, construction geometries, meshing rules, boundary conditions, and loads properly applied.