Annex J (NORMATIVE)

Finite Element Analysis (FEA) Requirements regarding the use of FEA to support a pressure equipment design submission

Note: This informative Annex has been written in normative language to facilitate its adoption where users of the standard or regulatory authorities wish to adopt it formally as additional requirements to this standard.

J.1 General

The analysis method requires extensive knowledge of, and experience with pressure equipment design, FEA fundamentals, and the FEA software involved.

The FEA software selected by the designer shall be applicable for pressure equipment design.

J.2 Submission Requirements

FEA may be used to support pressure equipment design where the configuration is not covered by the available rules in the ASME code. The designer should check with the Regulatory Authority whether the usage of FEA is acceptable. When using this method for justifying code compliance of the design, requirements in J.3 to J.10 shall be met.

J.3 Special Design Requirement

The FEA analysis and reports shall be completed by individuals knowledgeable and experienced with FEA methods. The FEA report shall be certified by a Professional Engineer.

J.4 Report executive summary

The report shall contain an executive summary, briefly describing how the FEA is used to support the design, the FEA model used, the results of the FEA, accuracy of the FEA results, validation of results, and the conclusions relating to the FEA results supporting the design submitted for registration.

J.5. Report Introduction

The report introduction shall describe the scope of the FEA analysis relating to the design, the justification for using FEA to support the design calculations, a complete description of the material properties used in the analysis, and assumption used for the FEA modeling, the FEA software used for the analysis (i.e. static, dynamic, elastic, plastic, small deformations, large deformations, etc.), a complete description of the material properties used in the analysis, and assumptions used for the FEA modeling.

J.6 Model description

J.6.1 This section of the report shall describe the FEA model used for the analysis. The description shall include dimensional information and/or drawings relating the model geometry to the actual pressure equipment geometry. Simplification of geometry shall be explained and justified as appropriate. The mesh and type (h, p, 2D, 3D), shape, degrees of freedom, and order (2nd order or above) of the elements used must be described. If different types of elements (mixed meshes) are used, as description of how the different elements were connected together is required. When using shell elements, describe the top or bottom orientation with plots of the elements and indicate if they are thick or thin elements.

J.6.2 The model description shall include a list of all assumptions.

J.6.3 The turn angle of each element used on inside fillet radii shall be indicated.

J. 6.4 The method used to select the size of mesh elements with reference to global or local mesh refinement shall be indicated.

J.6.5 When items in contact (e.g. flange joints, threaded joints) are modelled, the model shall describe how two separate areas in contact are linked. Adequate mesh size shall be used to assure that elements are small enough to be able to model contact stress distribution properly.

J.6.6 Boundary conditions such as supports, restraints, loads, contact elements, and forces shall be clearly described and shown in the report (present the figures). The method of restraining the model to prevent rigid body motion shall also be indicated and justified. When partial models are used (typically based on symmetry), the rationale for the partial model shall be described with an explanation of the boundary conditions used to compensate for the missing model sections.

J.6.7 The FEA report shall include validation and verification of FEA results. Validation should demonstrate that FEA results correctly describe real-life behaviour of the pressure equipment, and verification should demonstrate that a mathematical model, as submitted for solution with FEA, has been solved correctly.

J6.8 The accuracy of the FEA results shall be included in the FEA report, either by the use of convergence studies or by comparison to the accuracy of previous successful in-house models.

An error of 5% or less from conversion study is acceptable.

Note: FEA inaccuracy usually consists of discretization errors, which are resulted from matching geometry and displacement distribution due to the inherent limitation of elements, and computational errors, which are round-off errors from the computer floating-point calculation nd the formulations of numerical integration scheme.

J.7 Acceptance criteria

The criteria for acceptance of the FEA results shall be based on the code of construction and factor of safety established under that code. The FEA methodology may be based on another code. The acceptance criteria and code reference shall be presented in the report.
Note: For example, if the code of construction is Section VIII, Div.1 of the ASME code, the allowable stress values from Section VIII, Div.2 of the ASME code (Fig.5.1).

J.8 Presentation of Results

J.8.1 The following information and figures in coloured prints shall be presented:
1) Resultant displacements (plot);
2) deformed shape with un-deformed shape superimposed;
3) Stress plot with mesh, that will:
    a) show fringes using discrete colour separation for stress ranges or plots;
    b) allow comparison between the size of stress concentrations and the size of the mesh.
4) plot with element stress and a comparison of nodal (average) stress vs. element (non-averaged) stress;
5) reaction forces compared to applied loads (free-body diagrams);
6) stress linearization methodology and the stress values in the area of interest;
7) accuracy of the FEA results.

The results shall be plotted to graphically verify convergence. The x axis of this plot shall show some indication of mesh density in the area of interest (number of elements on a curve, elements per unit length, etc.). This is necessary to show true convergence over apparent convergence that is due only to a relatively small change in the mesh.

J.8.2 When plots or figures are presented, an explanation relating to each figure shall be included to describe the purpose of the figure and its importance. Overall model results, including areas of high stress and deformation, shall be presented with acceptance criteria. The analysis shall include a comparison of the results with acceptance criteria.

J.9 Analysis of results

Overall model results, including areas of high stress and deformation, shall be presented with acceptable criteria. The analysis shall include a comparison of the results with acceptance criteria.
Results that are to be disregarded shall be identified, and the determination to disregard them shall be justified.

J.10 Conclusion

As a minimum, a conclusion shall include:
1) a summary of the FEA results in support of the design,
2) comparison of the results and the acceptance criteria, and
3) overall recommendations.