# ASME PTB-5-2019

# ASME Boiler and Pressure Vessel Code, Section VIII, Division 3, Example Problem Manual

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# ASME BOILER AND PRESSURE VESSEL CODE, SECTION VIII, DIVISION 3, EXAMPLE PROBLEM MANUAL

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During the 1980s, ASME's Special Working Group on High Pressure Vessels was established for the purpose of creating a standard dealing with the construction of high-pressure vessels, which generally operate at a pressure above 10,000 pounds per square inch ("psi"). This was done on the basis of recommendations made by the Operations, Applications, and Components Technical Committee of the ASME Pressure Vessel and Piping Division (the "Committee"). The ASME Boiler and Pressure Vessel Code ("BPVC"), Section VIII, Division 3, titled "Alternative Rules for Construction of High Pressure Vessels" was first published in 1997; the Committee continues to refine and develop this code.

Some of the innovative concepts which began with BPVC Section VIII, Division 3 include:

- Use of elastic-plastic finite element analysis in design of pressure equipment;
- One of the lowest design margins (originally published at 2.0 and then lowered to 1.8);
- Use of high strength materials in manufacturing of high-pressure equipment;
- Stringent requirements on fracture toughness for materials used in construction;
- Complete volumetric and surface examination after hydrotest;
- The use of fracture mechanics for evaluation of design life assessment in all cases where "leak-before-burst" cannot be shown; and
- Consideration of beneficial residual stresses in the evaluation of the design life of vessels.

This publication is provided to illustrate some of the design calculations and methodologies used in the BPVC Section VIII, Division 3. It is recognized that many high-pressure designs are unique and quite innovative and therefore, this example problem manual cannot cover all design aspects within the scope of BPVC Section VIII, Division 3. This is an attempt at covering some of the most common ones.

Established in 1880, ASME is a professional not-for-profit organization with more than 127,000 members promoting the art, science, and practice of mechanical and multidisciplinary engineering and allied sciences. ASME develops codes and standards that enhance public safety, and ASME provides lifelong learning and technical exchange opportunities benefiting the engineering and technology community. Visit www.asme.org for more information.

STLLC is a not-for-profit limited liability company, with ASME as the sole member, formed in 2004 to carry out work related to new and developing technologies. STLLC's mission includes meeting the needs of industry and government by providing new standards-related products and services, which advance the application of emerging and newly commercialized science and technology, and providing the research and technology development needed to establish and maintain the technical relevance of codes and standards. Visit http://asmestllc.org/ for more information.

To develop this Example Problem Manual, STLLC contracted with Structural Integrity Associates, Inc. to perform the work.

## EXECUTIVE SUMMARY

An introduction to the example problems in this publication is described in Part 2 of this publication. The remaining parts of this publication contain the example problems. The remaining Parts of this publication coincide with the following sections of BPVC Section VIII Division 3:

- Part 2 Parts KM - Materials,
- Part 3 - KD-2 General Design Issues,
- Part 4 - KD-3 Fatigue Assessment,
- Part 5 - KD-4 Life Assessment Using Fracture Mechanics,
- Part 6 - KD-5 – Residual Stresses using Autofrettage,
- Part 7 KD-6 – Closures and Connections,
- Part 8 – KD-8 Residual Stresses in Multiwall Vessels,
- Part 9 – KD-9 Wire Wound Vessels,
- Part 10 – KT-3 - Determination of Hydrostatic Test Pressure, and
- Part 11 – Appendix E – Determination of Blind End Dimensions and Thread Load Distribution.

The example problems in this manual follow the calculation procedures in BPVC Section VIII, Division 3. It is suggested that users of this manual obtain a copy of "Criteria of the ASME Boiler and Pressure Vessel Code Section VIII, Division 3" [2], which contains the original criteria on its use when it was first published.

It should be noted that BPVC Section VIII, Division 3 requires the use of API 579-1/ASME FFS-1 [3] for some calculation procedures. When reviewing certain example problems in this manual, it is recommended that a copy be obtained of this standard for this purpose.

It is noted that many analysis techniques are covered in this manual as examples. Some of these modelling techniques are problem specific and are not requirements of the BPVC Section VIII, Division 3, but are provided herein as examples of methods of compliance with the code requirements. Alternative techniques may be used, as appropriate for certain problems, where complete guidance is not mandated in the BPVC Section VIII, Division 3.

# ABBREVIATIONS AND ACRONYMS

| Abbreviation \| Acronym | Description |
|---|---|
| *2c/a* | Assumed Crack Aspect Ratio |
| $A_B$ | Cross-Sectional Area of Vessel Normal to Vessel Axis through Internal Threads |
| $A_C$ | Cross-Sectional Area of Vessel Normal to Vessel Axis through External Threads |
| API | American Petroleum Institute |
| ASME | American Society of Mechanical Engineers |
| *b* | Assumed Seal Width |
| BPVC | ASME Boiler and Pressure Vessel Code |
| $C_M$ | Combined Flexibility Factor of Body and Closure |
| $C_T$ | Flexibility Factor of the Threads |
| CTOD | Crack Tip Opening Displacement |
| CVN | Charpy V-Notch |
| D | Diameter |
| *D* | Dead Weight Applied as Acceleration *1g* in Finite Element Model |
| $D_i$ | Inside Diameter |
| $D_{if}$ | Diameter Interface between Cylinder and Winding |
| $D_{if}$ | Interface Diameter Between Cylinder Layers |
| $D_o$ | Outside Diameter |
| $D_{o.1}$ | Liner Outside Diameter |
| $D_{o.2}$ | Outer Body Outside Diameter |
| $D_p$ | Pitch Diameter of the Threads |
| $D_s$ | Opening Seal Diameter |
| $D_w$ | Instantaneous Applied Outside Diameter of Winding |
| E | Elastic Modulus |
| *El* | Elongation |
| $E_y$ | Modulus of Elasticity |
| FFS | Fitness-for-Service (ASME) |
| ft-lbf | Foot-Pounds, Force |
| FTT | Fracture Toughness Testing |
| in | Inch(es) |
| $in^2$ | Square Inches |
| $in^3$ | Cubic Inches |
| ISO | International Organization for Standardization |
| $J_{Ic}$ | Fracture Toughness Testing |
| $K_{Ic}$ | Fracture Toughness Testing |
| $K_{Ic}$ | Critical Stress Intensity Factor |
| $K_{Ic}$ | Material Fracture Toughness |
| $K_r$ | Surface Roughness Factor |
| ksi | Kilopounds per Square Inch |
| L | Length |
| lb | Pound(s) |
| *m* | Seal Factor |
| MAWP | Maximum Allowable Working Pressure |
| Min. | Minimum |
| Mo | Molybdenum |
| *n* | Number of Threads |
| NDE | Non-Destructive Examination |
| Ni | Nickel |
| OD | Outside Diameter |
| *P* | Pressure Load |
| $P_A$ | Autofrettage Pressure |
| $P_b$ | Primary Bending Stress Intensity |
| $P_D$ | Design Pressure |
| $P_{D.Dual}$ | Design Pressure for Dual Wall |

| Abbreviation \| Acronym | Description |
|---|---|
| $P_{if}$ | Interface Pressure |
| $P_L$ | Local Primary Membrane Stress Intensity |
| $P_m$ | General Primary Membrane Stress Intensity |
| psi | Pounds per Square Inch |
| $P_T$ | Hydrostatic Test Pressure |
| $P_T$ | Thread Pitch |
| PTCS | ASME Pressure Technology Codes and Standards |
| $Q$ | Secondary Stress Intensity |
| $RA$ | Reduction in Area |
| $R_c$ | Inside Corner Radius |
| $S`_a$ | Alternating Stress Component |
| $S_{alt\ i,j}$ | Alternating Stress Intensities |
| $S_{ij}$ | Stress Intensities |
| STLLC | ASME Standards Technology, LLC |
| $S_u$ | Tensile Strength |
| $S_y$ | Yield Strength |
| $t_w$ | Wall Thickness |
| $\sigma_{uts}$ | Tensile Strength |
| V | Vanadium |
| W | Weight |
| $x_1$ | Any Diameter of the Cylinder |
| $x_2$ | Any Diameter of the Winding |
| $Y$ | Diameter Ratio, $D_o$ / $D_i$ |
| $Y_i$ | Liner Wall Ratio |
| $Y_o$ | Outer Body Ratio |
| $\varepsilon_{ys}$ | Offset Strain |
| $\Delta\Delta L$ | Elongation in Each Yoke Plate |
| $\delta$ | Diametral Interference |
| $\varepsilon$ | Longitudinal Strain in Each Side of Yoke |
| $\nu$ | Poisson's Ratio |
| $\nu_t$ | Poisson's Ratio for Liner |
| $\nu_o$ | Poisson's Ratio for Body |
| $\rho$ | Density |
| $\sigma_{n\ i,j}$ | Associated Mean Stress |
| $\sigma_{n\ i,j}$ | Stress Normal to the Plane of Maximum Shear |
| $\sigma_{nm\ i,j}$ | Associated Mean Stress |
| $\sigma$ | Longitudinal Stress on Each Side of Yoke |
| $S\_(eq\ i,j$ | Equivalent Alternating Stress Intensity |
| $\epsilon\_L$ | Limiting Triaxial Strain |
| $\epsilon\_cf$ | Cold Forming Strain |

# PURPOSE AND USE

The BPVC Section VIII, Division 3 [1] contains mandatory requirements, specific prohibitions, and non-mandatory guidance for the design, materials, fabrication, examination, inspection, testing, and certification of high-pressure vessels and their associated pressure relief devices. This Example Problem Manual is based on the 2019 edition of the BPVC Section VIII, Division 3, and all paragraph references herein are to this same edition.

## Scope

Example problems illustrating the use of the analysis methods in BPVC Section VIII, Division 3 are provided in this publication.