PVP - Vol. 136

Codes and Standards and Applications for Design and Analysis of Pressure Vessel and Piping Components

Contributing Editors
R. Seshadri
W. R. Mikesell
J. P. Breen
S. Y. Zamrik

Coordinating Editor
G. L. Hollinger

Library of Congress Catalog Number 88-71186

Printed in U.S.A.

FOREWORD

The Design and Analysis Committee, the Codes and Standards Technical Subcommittee, and the Education Chairman of the ASME Pressure Vessels and Piping Division are pleased to present this volume of technical papers whose principal theme is aligned with the theme of the Pittsburgh Conference—Codes and Standards – Key to Progress with Safety. The ASME Boiler and Pressure Vessel Code and the Piping Codes have enjoyed a long history of technical progress which has steadily increased the safety record of the operation of boilers, pressure vessels and piping systems. Such a record has been possible by the technical expertise and contributions of many of engineers in the past hundred or so years. Such expertise and contributions continue to be an important, strong link with the ASME Boiler and Pressure Vessel and Piping Codes. The technical progress of the Codes is careful and measured—the Code's heritage of safety. Progress is a careful balance of "what has succeeded in the past" with "what is useful for the future." The papers in this volume discuss various topics and ideas that could, with such balanced considerations, bear on future directions of portions of the Codes.

G. L. Hollinger

SECTION I

INTRODUCTION

CLASSIFICATION OF STRESSES AND DEFORMATIONS FOR CODE DESIGN EVALUATIONS

R. Seshadri

When complex pressure components are analyzed by the finite element method, it is often difficult to classify the stresses and deformations. Stresses are frequently categorized conservatively, if the classification process is unclear. This section deals with papers in the areas of simplified methods for the evaluation of inelastic problems, classification of stresses in components experiencing elastic follow-up, issues pertaining to post-processing of finite element results, and applications of the ASME Code stress-classification procedures to practical problems in the iron and steel industry as well as power plants.

The authors of the papers presented in this section deal with some state-of-the-art issues in the area of stress-classification.

D. L. Marriott deals with design situations where the classification of stresses by inspection alone is difficult and for which inelastic analysis could be quite expensive or sometimes unnecessary. Aspects pertaining to the decomposition of mechanical stresses and elastic follow-up are examined. Lower bound analysis of components based on simple "strength of materials" approach and iterative application of linear elastic finite element evaluations are discussed. A tentative set of design rules that is suitable for classifying finite element stresses is presented.

J. T. Boyle and J. Mitchell examine the basic nature of elastic follow-up in piping systems. Various classification schemes for elastic follow-up that have appeared in the literature are compared and contrasted. A case is made for a purely geometrical nature of elastic follow-up in complex piping systems. In the light of the geometrical nature, the suitability of various classification schemes is re-examined.

The ASME Code failure criteria are based on the fundamental assumptions of beam theory which are that membrane and bending stresses act on a plane, and that plane sections remain plane. J. L. Hechmer and G. L. Hollinger examine several options with regard to linearization of component-stresses that are obtained by finite element analysis. From a detailed study of the options, the most logical linearization options, which are cconservative yet consistent with the "bending" concepts of the Code, are then recommended.

N. V. L. S. Sarma, G. L. Narasaiah and G. Subhash discuss the numerical and computational approaches pertaining to the classification of axisymmetric finite element stresses according to ASME stress categorization.

C. A. Schacht describes an analytical method which characterizes the level of thermal expansion stress in refractory lined cylindrical vessel shell. A limit for the total primary plus secondary stress range in the vessel shell, in which the secondary stress is induced by expansion of the refractory lining, is recommended.

In the final paper of this section, K. Desai and P. B. Warren use finite element analysis to determine the effects of stresses on the internals of the power plant deaerator which have experienced cracking.

EVALUATION OF DEFORMATION OR LOAD CONTROL OF STRESSES UNDER INELASTIC CONDITIONS USING ELASTIC FINITE ELEMENT STRESS ANALYSIS

D. L. Marriott, Associate Professor
Department of Mechanical and Industrial Engineering
University of Illinois at Urbana-Champaign
Urbana, Illinois

ABSTRACT

It is often difficult to judge stress classes under the rules of the ASME Pressure Vessel Code using finite element results. This can be needlessly constraining if it is necessary to classify a secondary stress as primary, for instance.

This paper shows examples where it is difficult to determine the stress class by inspection alone, and for which inelastic analysis is a costly proposition. It is shown how a purely elastic analysis can be used to distinguish between load- and deformation-controlled stress states.

Alternatively limit load analysis is used to discriminate between stress classes. This is illustrated by an example. A simple method of estimating limit loads by elastic finite element analysis will also be demonstrated.

1. INTRODUCTION

According to the rules of the ASME Pressure Vessel and Piping Code [1], stresses are given different weights according to the application. Stresses required to satisfy equilibrium under external mechanical load are subject to more severe limitation than self-equilibrating stresses caused, for instance, by thermal gradients, or by enforcing compatibility at discontinuities.

Depending on whether the stress is primary membrane or bending the limit is between approximately 2/3Sy and Sy. On the other hand, the only constraint on secondary stress is that the range due to transient conditions should not exceed 3Sm, or about twice the yield stress, Sy. Clearly it is possible to suffer a severe penalty if stresses are classified as primary when they are actually secondary, due to uncertainty as to their cause.

A classical example illustrating the difference between primary and secondary stresses is a nozzle in a shell, with area compensated reinforcement according to the Area Replacement Rule, as shown in Fig. 1. In this case, despite significant bending in the shell adjacent to the nozzle, only the membrane stresses are primary, because only the membrane stress in the shell and the loop stress in the nozzle reinforcement are necessary to satisfy equilibrium under internal pressure. In this case the distinction between primary and secondary categories is clear. In other cases however, it is not so apparent.

The general adoption of computer dependent finite element analysis (FEA) for design has made the task of stress classification more difficult, if anything, than in earlier days when design was based largely on hand calculations.

In hand computation it is usually easy to identify primary membrane and bending stresses, because these are the nominal stresses obtained from "strength-of-material" calculations. The same goes for residual, discontinuity or thermal stresses, which are easily classed as secondary as result of the way they were calculated. In Code terms, Peak or F, stresses are associated with stress concentrations or very local

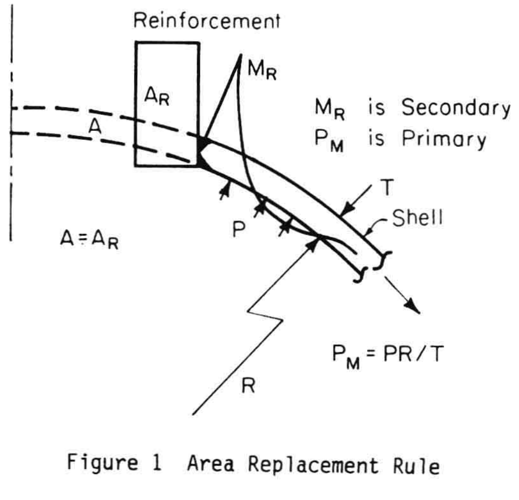

Figure 1 Area Replacement Rule

thermal gradients. Once again, it is clear from the hand calculation procedure, which stresses fall into this category.

In contrast, a finite element analysis simply provides the total stress, which must then be decomposed into the different stress categories.

A technique permitted by the Code, which is consistent with the underlying rationale for stress classification, is the practice of stress linearization on individual sections. This enables portions of the total stress distribution to be identified as membrane, bending and peak respectively (see Fig. 2). Depending on circumstances both membrane and bending stresses can be classified as either primary or secondary and the appropriate stress limits applied. The Code offers guidance on classification for common geometries found in pressure vessel construction.

The process of linearization is actually conservative as far as primary stresses are concerned. Although it is not very clear on this point, the rationale for primary and secondary stresses, as used by the ASME Code, is actually based on concepts derived from inelastic analysis. Linear elastic analysis, with the added adjustment of linearizing stresses on individual sections, is a practical means of constructing an admissible lower bound solution to the component limit load. It a conservative procedure because it does not take advantage of the redistribution of section forces and bending moments from one section to another. As a design procedure this is probably a sensible approach, because it trades off a degree of conservatism for the convenience of reducing the computation to a more or less standard algorithm.

It is worth noting that the ASME Code does not mandate elastic analysis as the only method of analysis. Section NB-3228.1 permits the use of a less conservative limit analysis if one can be done. This point is discussed later in this paper.

2. PROBLEMS IN STRESS CLASSIFICATION

Two major difficulties are experienced in classifying stresses.

a. Decomposition of mechanical stresses
In dealing with sections where there is no easy alternative to finite element analysis it may be very difficult to determine what proportion of the linearized membrane and bending stresses are secondary. This leads to their being classified as primary as the only safe option.

b. Elastic Follow-up
Thermal and other residual stresses are generally classified as secondary, the exception being when relaxation of the residual stress would impose large deformations on part of the system, e.g. a highly stresses pipebend in a long piperun. At one extreme, elastic deformations of the surrounding structure require thermal stresses to be classified as primary. A local hot spot on the surface of a thick plate, is clearly a peak stress. Between these extremes there is a region of uncertainty where follow-up deformations are not negligible, but are still small enough to offer little danger of causing local collapse.

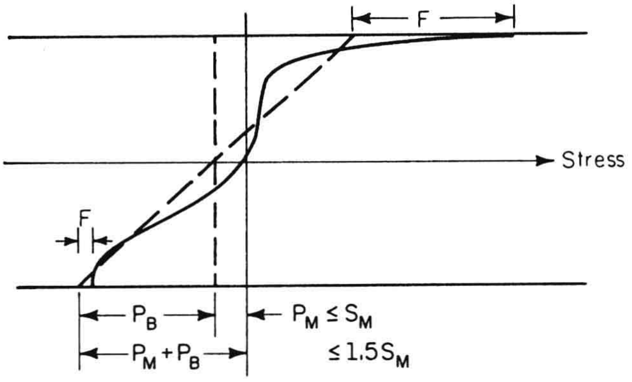

Figure 2 Definition of Linearized Stresses

This paper does not claim to offer definitive solutions to either of the above problems, but by reference to an example it presents some ideas on how the problem can be resolved by practical manipulation of the standard tool of design - elastic finite element analysis - without resorting to the complication of full inelastic analysis.

3. IDENTIFICATION OF PRIMARY STRESS COMPONENTS

3.1 The Problem

This problem is illustrated by a case study. The component illustrated in Fig. 3 is a welded fabrication in Type 316 stainless steel. Its operating temperature is 550°C. According to Code Case N-47 [2], the allowable stress, Sm, at this temperature, is 106 MPa. For simplicity in this example, time dependency is ignored, which does not affect any of the conclusions drawn here.

The main load on the component is a thermally induced systems load, P, of 10 kN acting as a longitudinal shear on the centerline spacer. Very high stresses are developed on the section marked A as shown in Fig. 4.

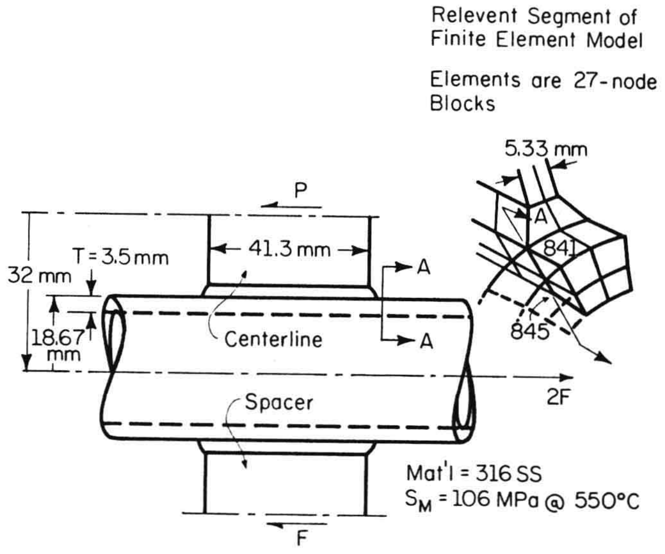

Figure 3 Schematic Drawing of Component

H00420