FY16 ASME High Temperature Code Activities

Nuclear Engineering Division
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ABSTRACT

One of the objectives of the ASME high temperature Code activities is to develop and validate both improvements and the basic features of Section III, Division 5, Subsection HB, Subpart B (HBB). The overall scope of this task is to develop a computer program to be used to assess whether or not a specific component under specified loading conditions will satisfy the elevated temperature design requirements for Class A components in Section III, Division 5, Subsection HB, Subpart B (HBB). There are many features and alternative paths of varying complexity in HBB. The initial focus of this task is a basic path through the various options for a single reference material, 316H stainless steel. However, the program will be structured for eventual incorporation all the features and permitted materials of HBB. Since this task has recently been initiated, this report focuses on the description of the initial path forward and an overall description of the approach to computer program development.
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1 Introduction

One of the objectives of the ASME high temperature Code activities is to develop and validate both improvements and the basic features of Section III, Division 5, Subsection HB, Subpart B (HBB). To accomplish this, it is usually necessary to provide a comparison between the proposed improvement and the reference rules in HBB. HBB is also used to assess components in comparative design studies. However, there are many features and alternative paths of varying complexity in HBB and even the most direct can be costly to evaluate. Also, because of the complexities of HBB, there can be difficulty in the correct interpretation of the requirements. For these evaluations in accordance with HBB, it would be advantageous to have the rules incorporated in a computer program to achieve economical and correct solutions. Because of the many features and alternative paths of varying complexity in HBB, the initial focus of this task is a basic path through the various options for a single reference material, 316H stainless steel. However, the program will be structured for eventual incorporation all the features and permitted materials of HBB.
2 Scope

2.1 Design Rules and Limits for Load-Controlled Stresses

HBB provides rules for both design Loadings and Level A, B, C and D Service Level Loadings. The rules cover both base material and bolting. Factors are provided to account for deterioration of materials in service and strength of weldments. The requirements for design by analysis are provided in HBB-3200. Additional, component specific rules are provided in HBB-3300, -3400, -3500 and -3600 for vessels, pumps, valves and piping, respectively.

For this initial phase, Design Loadings and Level A, B, and C Service Level Loadings will be included but not Level D because these conditions are usually extreme, short-term conditions that do not involve time dependent creep properties. Both base materials and weldments will be considered but not bolting which is not usually part of the elevated temperature boundary. As an initial implementation, the component specific rules will not be included at this time. However, provisions for deterioration of materials in service will be included.

Material properties required for implementing the design rules, i.e. allowable stress values, are provided in Appendix HBB-I-14. Again, for this initial phase, only the properties for 316H stainless steel will be included.

2.2 Design Rules and Limits for Deformation Controlled Stress and Strain

The strain, deformation and fatigue limits are provided in Appendix HBB-T, which also includes the requirements for evaluation of instability and bucking. There are two sets of design rules in Appendix T. In one case, these rules are based on the use of inelastic analysis, which requires constitutive equations describing the materials response. In the second case, the rules are based on the use of elastic analysis with various adjustments and procedures to account for the actual inelastic response.

The procedures based on inelastic analysis will not be included in this phase nor will the buckling limits, which are not usually applicable to pressurized components. Thus, the Appendix T strain limits based on elastic analysis (HBB-T-1320) and simplified inelastic analysis (HBB-T-1330) will be included except for HBB-T-1333, which is seldom, if ever used. The evaluation of creep-fatigue limits in T-1400 will be based on elastic analysis (HBB-T-1430) and will not include the equivalent stress quantities in HBB-T-1411 for inelastic analysis. The requirements for welds in HBB-T-1710 are included.

The material properties used for evaluation of deformation controlled stress and strain, e.g. fatigue design curves and isochronous stress-strain curves are provided in HBB–T-1420-1 and HBB-T-1800 respectively. However, again, only 316H stainless steel is being included in this first phase.
3 Computer Program Features and Approach

The program framework relies heavily on two elements of modern programming: (1) the program is event driven and (2) the program is object oriented. Thus, it may be necessary to be somewhat familiar with some terminology associated with the programming techniques. In order to differentiate terms used in the ASME BPV code from similar terms used in programming, programming terms are represented in boldface. Names given to programming structures are set in italics.

Most modern codes take full advantage of object-oriented programming through class structures. Visual Basic for Applications adds the event driven aspects through the interface with Microsoft Excel. For example, a command button object may be placed on a worksheet. When the button is pressed, an event occurs and a routine is run within VBA. Event based programming can be constructed in other codes as well.

3.1 Definitions

Class: A programming structure used to group together a set of variables (properties) and routines (methods) that may call for multiple instances of these classes (collectively called objects) in the execution of the program. For example, in object-oriented finite element analysis, there may be a class called element that has properties such as volume, coordinates, stresses, and so forth.

Object: A particular instance of a class. In the above case, “element 47” may be a particular element object with its own unique set of properties.

Properties: the variables that characterize an object such as length, color. Properties may be other objects. For example, the material property of a finite element object may refer to an object of the material class.

Method: Is a subroutine associated with a particular class. The method may refer to an action done on or by a particular object.

Collection: is programmatic unit that consists of (or contains) a set of objects, usually of the same or consistent class. For example, the elements collection would refer to all elements in a finite element model.

As an example of how these various objects can interact. The class element_set may be defined as an object that has as a property, name, and a collection, elements, of element objects. Its methods may consist of commands like delete which empties elements and sort which orders elements in some manner.

3.2 Object Classes in the HBB Software

In order to understand how the HBB software is intended to work it is necessary to understand the fundamental object classes of the program.

Stress Classification Line (SCL). This serves as the interface between the structural analysis program and the HBB software. The SCL essentially holds all the information in the first two columns of Table HBB-3217-1. Stress Classification Lines will be composed of the following...
properties.

- **LineType** (an enumeration “1” for points along a line, “2” for two-dimensional, “3” for three-dimensional, and “0” for pre-processed results).
- **Number of Points**
- **Coordinates**: coordinate locations, not used for pre-processed results
- **Vessel Component Type** (cylindrical or spherical shell, flat head, etc.)
- **Location** (remote from discontinuities, near nozzle, etc.)
- A **collection** of **Results** objects for the SCL
- A **collection** of **Cycles** the SCL is involved in
- A **collection** of **Analysis Cases** the SCL is involved in

**Results.** These objects hold the stress results in terms of raw components, linearized stresses and strains, or both for a given SCL. Properties include

- **Analysis Case object**
- Stress Components
- Strain Components (Appendix T calculations)
- Mean, Bending, and Peak Stress
- Temperatures (uniform or varying)

**Analysis Case.** Essentially this object holds the information in column 3 of table HBB-3217-1

- Case Description (Origin of Stress)
- Temperature (for isothermal case) and/or other descriptive properties

**Cycle.** Are used for Appendix T calculations.

- Number of **Analysis Cases** in a given cycle
- A **collection** of **analysis case objects**
- A **collection** of SCLs defined for this cycle

**Material.** The material properties consist of data from tables in mandatory appendix I-14, allowable stress intensity as a function of time and temperature. Various charts from Appendix T will also be included as properties of the material.

- Stress limits: $S_0$, $S_m$, $S_T$, …
- Yield strength from table Y-1

**Analysis.** The **object** that contains all the more basic **objects** associated with the analysis (SCL, Results, Materials, Analysis Cases, Cycles, and Materials) as a single unit and includes the HBB evaluations as **methods**. Only one instance of this **object class** is anticipated.

Properties of the **Analysis class** include
• A collection of each the fundamental object classes

• The HBB Evaluations as methods

• An array, Evaluations, of Boolean variables corresponding to the HBB evaluations which can be turned on and off

• The “main program” as a method called from the spreadsheet which branches off to the various evaluations to be performed.

Evaluations refers to the various procedures to determine the acceptability of a design. The methods in the evaluation range from simple (as in FIG HBB-3221-1) to complex in Appendix T. For example paragraph T-1430, “LIMITS USING ELASTIC ANALYSIS” represents an evaluation. Evaluations may be broken down into individual Tests where acceptability can be demonstrated by multiple equations (see for example HBB-T-1322, HB-T-1323, and HB-T-1324).

3.3 Excel Interface

Excel will serve as the interface for both the input and the results tabulated output and display.

Separate worksheets will hold the information about the analysis, stress classification lines, and material data. Arrangement of information on these worksheets is still to be determined and development is incorporated in later tasks in this program. The most difficult of these input cases is the data intensive SCL. Geometry data and results data will be stored on separate sheets for compactness and readability of the critical information. A user input dialog will be used to assist with the creation and editing of the SCL.

Output for each evaluation will reported on individual sheets and a summary on the main worksheet.

3.4 Flow Diagrams and HBB Software

The naming and description of the object classes suggests how these object classes relate. The flow diagrams, therefore, closely follow the analysis flow diagrams in Division 5 HBB. All of the Load-Controlled Stress Limits evaluations rely on the same initial linearization and categorization steps shown below in Figure 1 and only need to be performed once for a given analysis. Each evaluation will have a separate programmatic flow diagram and these tend to be short and simple for stress limits. Strain limit and creep-fatigue interaction evaluations involve the manipulation of cycles to determine strain ranges. More detailed flow diagrams will be developed for these cases.

An example of Satisfaction of Strain Limits (T-1322 and T-1323) is given here as shown in Figure 2. Most load-controlled stress limits are assessed by simply comparing the classified stresses with the allowable stress intensity values for the material.
for each SCL (i)

for each result (j)

Linearization (if Required)

Classification

\[ X_{i,j} = (P_L + P_b / K_t) \]

next result

next SCL

SCL includes all information about the component and includes the value of \( K_t \)

Results link to the analysis case from which they are taken. For example “Origin of Stress” is “External Load or Moment”

For some input types, linearization may have already been completed. Otherwise generates “membrane,” “bending,” and “peak.” This is also required for strains

Determine \( P_m, P_L, P_b, F, \) and \( Q \) based on the linearization, the location of the SCL, and the Origin of Stress

**Figure 1. Initial Programming Step, Linearization and Classification**
Figure 2. Example Flow Diagram Satisfaction of Strain Limits Using Elastic Analysis (Test A-1 and A-2)
4 Summary

The rules of Section III, Division 5 Subpart HBB are intended for the evaluation of the design of pressure vessels and components operating in the elevated temperature regime. In this regime time dependent inelastic effects must be accounted for. In order to avoid complex analysis with detailed material constitutive models HBB provides rules for elastic and simplified inelastic analysis methods. The current project aims to develop software to help implement these rules. The basic framework of the software relies on object-oriented programming methods and a Microsoft excel interface. The basic object classes include Stress Classification Lines, Materials, Cycles, and other classes that correspond to the methods of analysis in HBB. Flow diagrams for the different evaluations for stress limits and strain limits are currently being developed.
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