STP-PT-070

# DESIGN GUIDELINES FOR THE EFFECTS OF CREEP, FATIGUE & CREEP-FATIGUE INTERACTION

## WITH DESIGN-BY-ANALYSIS AND NONDESTRUCTIVE INSPECTION ACCEPTANCE CRITERIA



ASME STANDARDS TECHNOLOGY, LLC

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# FOREWORD

A task group of ASME Boiler and Pressure Vessel Committee on Power Boilers initiated a project through the ASME Pressure Technology Codes (PTCS) and Standards Committee to identify, prioritize and address technology gaps in the PTC Codes. The key aspect of this project was to review an extensive selection of current Codes and Standards which relate to power boilers and develop guidelines for component design and flaw acceptance criteria. These rules were to be used for the design of new advanced supercritical boilers operating at higher steam cycle conditions. This main focus of this project is to evaluate the current state of understanding with regard to creep-fatigue interaction for intended boiler materials to support the development of effective design by analysis (DBA) rules.

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# ABSTRACT


As part of the modernization of Section I – Rules for Construction of Power Boilers of the ASME Boiler and Pressure Vessel Code (Section I), a project was established to develop design guidelines for the effects of creep-fatigue interaction and flaw size acceptance criteria within the overall framework of Design-By-Analysis (DBA). The existing methods within Section I, which are based around Design-By-Rule/Formula and do not explicitly consider creep, fatigue or their interaction. The oversimplifications involved are such that the safety of boilers operating at higher steam cycle conditions, and under cyclic service, has been questioned. Design-By-Analysis (as an alternative to Design-By-Rule/Formula) is gaining acceptance as a viable approach for design of components that will experience cyclic loading and which will operate at elevated temperatures where creep may occur. Such Design-By-Analysis approaches have been introduced into other international codes, including other sections of the ASME Boiler and Pressure Vessel Code (ASME Code) and the EN Code.

This report has been prepared to recommend design guidelines for components in Section I - Power Boilers. As such, it does provide a comprehensive review of issues. However, to properly introduce the context of the recommendations, some background is provided to a number of philosophical topics that surround Design-By-Analysis, Design-By-Formula, Design-For-Safety and Design-For-Lifetime. As several other recognized Codes and Standards have approaches that are relevant to Design-By-Analysis, or which provide methods for including creep-fatigue interaction effects, a summary of these documents is provided. In particular, the summary compares and contrasts key aspects to provide insight into benefits and shortcomings (or inconsistencies) associated with particular approaches. From this review it is evident that no single Code or Standard has a method that can be universally adopted, particularly when the methods have to be used in the context of other Sections of Codes, such as material properties, or standardized design features. That is, a particular Design-By-Analysis methodology needs to be developed that could be used within the overall context of the ASME Code (particularly Section I).

To that end, a Design-By-Analysis approach is recommended that is both relevant and technically consistent, and which considers the key modes of structural behavior and material response. Some features of the recommended approach are:

- It provides design checks for the structural failure modes relevant to modern Power Boiler, including cyclic service with checks on local creep and fatigue damage as well as the possibility of creep-fatigue interaction.
- It requires minimal material data (most of which is already available within Section II - Materials, Part D of the ASME Boiler and Pressure Vessel Code (Section II, Part D), or which is a logical extension of that based on Section III, Rules for Construction of Nuclear Facility Components Subsection NH of the ASME Boiler and Pressure Vessel Code (Section III, Subsection NH)).
- All design checks are accomplished with an elastic or elastic-perfectly-plastic material representation (thereby avoiding the need for complex constitutive models or analytical procedures).
- It incorporates weld strength reduction factors where weldments operate in the time dependent (creep) regime.

The recommended approach is based on validated methods and the explanation of the methodology highlights where particular features are adopted or adapted from other Codes (most particularly from Section VIII, Rules for Construction of Pressure Vessels Division 2 of the ASME Boiler and Pressure Vessel Code (Section VIII, Div. 2), Section III, Subsection NH and from EN13445-3, Annex B). The approach includes all aspects of a Design-By-Analysis methodology because without considering the

complete design procedure any proposals on specific aspects, such as creep-fatigue interaction, may not be technically consistent with the overall framework.

Flaw size criteria and previous work in this area are reviewed to provide context to the development of future methods. While flaw size criteria can be developed based on engineering mechanics considerations, this can invoke arbitrary assumptions which limit the generality and practical value of the results. Because of this it is highlighted that flaw size criteria should primarily be defined by workmanship quality standards; as is the approach adopted in many other Codes. It is also recognized that if flaw size criteria are to be established using engineering mechanics then this can be accomplished independently of the overall approach to Design-By-Analysis.

In addition to the complexities highlighted by the outline of a Design-By-Analysis methodology, the implications for the overall structure and implementation of Design-By-Analysis methods within Section I are documented as a basis for future discussions to facilitate reaching consensus among the technical community on the best approach for specific aspects, and for the overall approach to adoption within the ASME Code.

# 1 INTRODUCTION

The objective of this document is to summarize the various practices used by various US and International Codes with respect to "Design-By-Analysis" (DBA) methods, particularly in the context of creep, fatigue and creep-fatigue interaction with the aim of identifying elements of these Codes that can provide beneficial input during the modernization of Section I [1]. The document also includes a discussion of flaw size acceptance criteria and provides recommendations on how this should be incorporated in an overall framework.

Development and implementation of procedures for "Design-By-Analysis" should consider relevant experience from research and practice. However, as will become evident in this document, there is currently no universally accepted or consistent approach. Thus, compromises have to be made between the practicality of the methods for use at design and the fidelity of the analysis for particular failure modes. In many cases, certainly within the realm of creep-fatigue interaction, there are a very broad range of scenarios that can occur and the development of analytical methods continues to be a very active area ongoing research. The intent here is not to delve in great depth into those details but rather to provide a practical review of techniques and methods that could be implemented as part of the Section I modernization.

This document is structured into a number of sections that address particular aspects associated with "Design-By-Analysis". The document begins with a preamble which covers background to some of the conceptual aspects associated with "Design-By-Analysis" and the associated aspects of material and structural behavior, such as creep-fatigue interaction. The next section, Section 3, provides a review of a number of International Codes and Standards that incorporate "Design-By-Analysis" approaches and provides some commentary to compare and contrast these. The focus of this comparison is on methods for creep and fatigue damage and their subsequent combination in circumstances of creep-fatigue interaction. Following that, Section 4 discusses the development of a "Design-By-Analysis" approach and provides an outline of a methodology and describes some of the challenges that need to be addressed if this is to be incorporated into an update of Section I. Section 5 discusses flaw acceptance criteria. Section 6 provides a summary of some key recommendations and needs for future work. Section 7 provides a summary of some key implications and changes for the ASME Code if the "Design-By-Analysis" method were implemented. Finally, in Section 8 a collection of key references is summarized.