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Review

A review of literature for the structural assessment of mitred bends

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Abstract

This paper presents a state-of-the-art review of literature available for the structural assessment of all types of mitred pipe bends. Compared with smooth bends, the volume of literature available for mitres is less extensive and its scope is not as wide. Historically, this reflects a reduced application level, as well as a less demanding range of applications, such as non-high temperature use. There is also the issue that an analysis of a mitred bend is complicated by discontinuity stresses, as well as those due to cross-section ovalisation. This fact delayed the development of non-linear analysis of mitred bends. Nevertheless, there is now a substantial body of work on mitred bends. This review tabulates and characterises all publications to date in chronological order. The details of experimental specimens are highlighted, with a view to these perhaps providing useful verification data for any future finite element analysis for example. Issues of particular interest to pipework designers are discussed, including the effects of combinations of loading, out-of-circularity, tangent pipe length and flanges. Failure characteristics and loads are discussed where relevant. Topics for further research are also noted. For example, comprehensive design curves do not exist for the elastic and plastic behaviour of all mitre types, over a practical range of geometry and loading parameters. Similarly, there is still scope for further work on the effect of combined loading, end effects and out-of-circularity. Limit, collapse and burst loads are not yet available across the entire spectrum of bends and loading parameters either. Creep and optimisation represent virgin territory as far as mitred bends are concerned and given that unforeseen vibration is a common source of high-cycle fatigue failure in pipework, there must also be scope for vibration-induced fatigue studies.

Keywords: Mitred pipe bend; Literature review; Structural assessment

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1. Introduction

Mitred bends are widely used in industry. In particular, applications include large-diameter pipework or ducting in chemical complexes, desalination plants, water supply and nuclear power stations, where the manufacture of smooth bends may be either impractical or uneconomical. In many cases, designers will prefer to utilise smooth pipe bends due to the lack of discontinuity, the relatively smaller stress concentration and the more favourable flow characteristics. However, in large-diameter applications or applications with restricted space or a tight budget, mitred bends still find application.

A detailed review and assessment of every document published on mitred bends is obviously not possible within the scope of this paper. The main aim of this review therefore is to draw attention to the information available in the open literature, to give the reader an indication of scope, to highlight specific topics of interest to the designer and to identify possible areas for further research, the challenge being to try and summarise this research in a useful manner to industry and academia today.

While such a chronological presentation of Refs. [1–101] in Tables 1–3 is no doubt interesting from a historical viewpoint, it is perhaps true to say that most of the early theoretical work, in particular, will hold little real interest. Much of the early theoretical work, which was clearly ground-breaking at the time, related to the development and subsequent refinement of fundamental theoretical details. This activity was often informed by comparisons with experiments. For example, early theories assumed the un-reinforced segment of a multi-mitre to have a uniform flattening and the intersection of a reinforced mitre to be rigidly constrained. Later theories relaxed these constraints and involved series expansions to allow for the decay of cross-sectional ovalisation, postulating the existence of long and short decay lengths. This not only improved comparison with experiment, but also allowed consideration of the effects of end constraints. It is also apparent from the early documents that the development of the theory and general topics of interest had much in common with smooth pipe bends. This is not surprising given that the basic behaviour of these components is similar. This includes the fact that both develop an increase in flexibility and local stress levels due to cross-section ovalisation. The mitre obviously has the added complexity of discontinuity stresses at the intersection. In the early theoretical work, an edge solution was developed for this case, which was then superimposed on the flattening analysis.

The later papers invariably contain the refined theories and provide best comparisons with experiment in general. However, today the real relevance to industry of even these later theories must be questionable. Interestingly, as far back as 1970, Sobieszczanski [22] felt that the finite element method was the ‘analytical tool’ that should be used and that his theoretical concept of an ‘equivalent smooth bend’ should be abandoned. Today, the finite element method has a dominant role in the study of engineering structures and components in general and most organisations faced with the need to examine a mitred pipe bend will almost certainly use this as the preferred approach. In the general area of ‘design by analysis’ of pressure vessels and components, finite element analysis is now generally preferred to hand calculations using shell theory. The mitred bend also represents a very challenging theoretical problem and this is why it has kept numerous researchers busy for decades. The number of engineers, in general, who can understand such theories and apply them is almost certainly in decline. Even Kitching, who had spent many years developing and refining his theoretical solutions, turned to finite element analysis with his research students, when examining non-linear behaviour. It should be recognised, however, that these theoretical developments also had an influence on code guidelines and rules over the years and their contribution to understanding of the subject and industrial practice should not be underestimated. Even though today finite element analysis is the preferred approach, there is no doubt that having a knowledge of the various relevant issues in the behaviour of such components will be invaluable. Many of these issues were identified in the development of the theory and it is these issues that will provide a focus for this review of literature.

Unlike the theoretical development, the extensive (and no doubt expensive) experimental testing carried out over the years is generally still highly relevant today. The issue of validation of finite element models is perhaps surprisingly still as important today as it ever was. It is widely recognised that benchmarking finite element results against quality experimental data is a valuable exercise—both in terms of the education of the analyst and also in terms of validating the model. A study of the significance of real-world variables relating to geometry, material and boundary conditions can be an enlightening experience for analysts. As finite element analysis moves into more complex combined physical phenomena (e.g., fluid–flexible structure interaction), where no theoretical benchmark is available, the importance of experimental validation increases.