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Ultimate Limit States of Pipes Under Tension and Bending

Yong Bai*
Det Norske Veritas Industry, Høvik, Norway

Ragnar T. Igland
SINTEF Structures and Concrete, Trondheim, Norway

Torgeir Moan
The Norwegian Institute of Technology, Trondheim, Norway

ABSTRACT

Experimental and numerical databases are presented for thick pipes ($10<D_0/t<40$) under pure bending and combined tension and bending loads. Equations to predict collapse moment, critical curvature, moment-tension and curvature-tension interactions are proposed based on the databases. The model uncertainty analyses have confirmed that the proposed equations are accurate.

INTRODUCTION

The paper presents numerical and experimental databases and ultimate limit states of thick pipes ($10<D_0/t<40$) subjected to pure bending and combined tension and bending loads. The study is motivated primarily by the development of design codes for pipelines, risers and TLP (tension leg platform) tendons, but is also relevant for thick-walled tubulars used in buildings, offshore platforms, piping systems and other engineering structures.

The collapse behaviour of thick pipes is strongly influenced by mean diameter to thickness ratio D_0/t, material properties (yield stress and strain-hardening parameters), and initial imperfections. For pipes under pure bending, two failure modes have been observed:

(1) Bifurcation buckling, where ripples and a kink occur in the compressed region of the pipe.

(2) Limit load, where failure occurs due to ovalization of cross-section.

The bifurcation type of failure with ripples and a subsequent kink on the compression side of the pipe looks very similar to the plastic buckling of an axially compressed pipe (Timoshenko and Gere, 1961). The limit load type of failure is caused by increased ovalization of the pipe. Brazier (1927) solved a limit load type of instability of long elastic pipes in pure bending due to ovalization of the cross-section. The solution was extended by Ades (1957) for long elastic-plastic pipes in pure bending by assuming that the cross-section always ovalizes into an elliptical form.

The D_0/t value which separates limit load instability and bifurcation buckling is dependent on the material properties of the pipes. Experiments conducted by Corona and Kyriakides (1988) and Kyriakides and Ju (1992) show that this D_0/t value is around 35 for typical pipeline material. The present study, therefore, only deals with the limit load type of instability, and the ultimate capacity is defined as the point at which the limit load type of instability occurs.

Collapse of pipes under pure bending has been investigated by many researchers. Earlier research was mainly devoted to laboratory tests of structural tubular members (Schilling, 1965; Sherman, 1976, 1984; Korol, 1979; Reddy, 1979; Enosawa and Nomoto, 1985; and Bai, 1989). Recently tests have been accomplished for pipeline applications (Wilhoit et al., 1971; Jirsa et al., 1972; Corona and Kyriakides, 1988; Fowlers, 1990; and Kyriakides and Ju, 1992).

However, most theoretical investigations have been devoted to pipes with D_0/t larger than 35. There is no publication available which extensively investigates parametric sensitivities to various factors affecting collapse moment and curvature for thick pipes under pure bending. To our knowledge, there is a lack of experimental and numerical investigations on the collapse behaviour of thick pipes under combined tension and bending loads. Wilhoit and Merwin (1971) extended Ades' procedure to include axial tension. However, the effect of loading path, which is important for the response of thick pipes under combined tension and bending, has not been accounted for in their analysis. Dyau and Kyriakides (1992) conducted combined experimental and analytical investigation on pipeline under combined tension and bending, with emphasis on the spooling of a pipeline onto a reel and the pulling of a pipeline through a J-tube.

In the present study, systematic finite element analyses have been carried out on pipe collapse under pure bending and under combined tension and bending loads (Bai et al., 1993b), using an experimentally validated model (Bai et al., 1993a). Experimental and numerical databases are then established. Finally, ultimate limit states are proposed in terms of ultimate moment, critical curvature, ultimate tensile strength and their interactions; and model uncertainties of the proposed equations are assessed.

COLLAPSE UNDER PURE BENDING

Numerical Database

The elastic-plastic large deflection analysis of pipes under tension and bending shown in Fig. 1 is carried out by means of the finite element program ABAQUS (1992), as described in Bai et

*ISOPE Member.

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KEY WORDS: Collapse, thick pipes, pure bending, combined tension and bending, finite element analysis, experimental database, equations, model uncertainty.