Experimental validation of a finite element model that simulates the collapse and post-collapse behavior of steel pipes

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Abstract

In previous publications CINI presented finite element models that simulated the collapse and post-collapse behavior of steel pipes under external pressure and bending. Those finite element models were used to analyze the effect of different imperfections on the collapse pressure and collapse propagation pressure of the steel pipes. Laboratory tests were carried out at CFER (Edmonton, Canada) in order to obtain experimental results that could be used to validate the numerical models. In this paper we compare the numerical and experimental results for the case of external pressure without bending.

Keywords: External pressure; Bending; Steel pipes; Collapse pressure; Collapse propagation

1. Introduction

In Ref. [1] the calculation of the external collapse pressure of steel pipes using finite element models was discussed. The main conclusions were that the 2D models are not accurate enough and that the 3D models developed using the MITC4 shell element [2–4] are appropriate for the pipe dimensions under analysis (in the cases that we analyze [radius/thickness]>8). It was also presented in Ref. [1] a laboratory device (*"shapemeter"*) that CINI developed in order to map the external surface of the pipe samples.

In Refs. [5,6] the effect of imperfections such as ovality, eccentricity and residual stresses on the collapse and collapse propagation pressure of steel pipes under external pressure and bending, was discussed.

In the present paper we are going to compare CINI finite element results with the experimental results obtained at CFER (Edmonton, Canada) for steel pipes under external pressure only.

2. CFER experimental results

Most of the experimental results available in the literature for the collapse of pipes under external pressure, correspond to aluminum small diameter pipes [7,8] or to structural tests where the collapse pressure was not reached, because their purpose was to demonstrate the structural safety for a given external pressure [9].

The purpose of the laboratory tests, which were performed on TENARIS steel seamless pipes at CFER, was to determine the collapse pressure and to track the post-collapse equilibrium path for external pressure and bending.

In this paper we examine the behavior of the three samples that were subjected to external pressure only. In a following report we will compare the behavior of samples subjected to external pressure and bending with the predictions of finite element models.

In Table 1 we list the seamless pipe samples tested at CFER.

A complete geometrical characterization of the three samples was performed:

- The OD of the samples was properly mapped using the device described in Ref. [1]
- The thickness of the samples was mapped using an ultrasonic gauge.

Table 1
The seamless pipe samples tested at CFER

Sample	OD (mm)	Thickness (mm) (mm)	Nominal yield stress (ksi)
1	323	17.65	65
2	323	20.30	65
3	352	22.00	65

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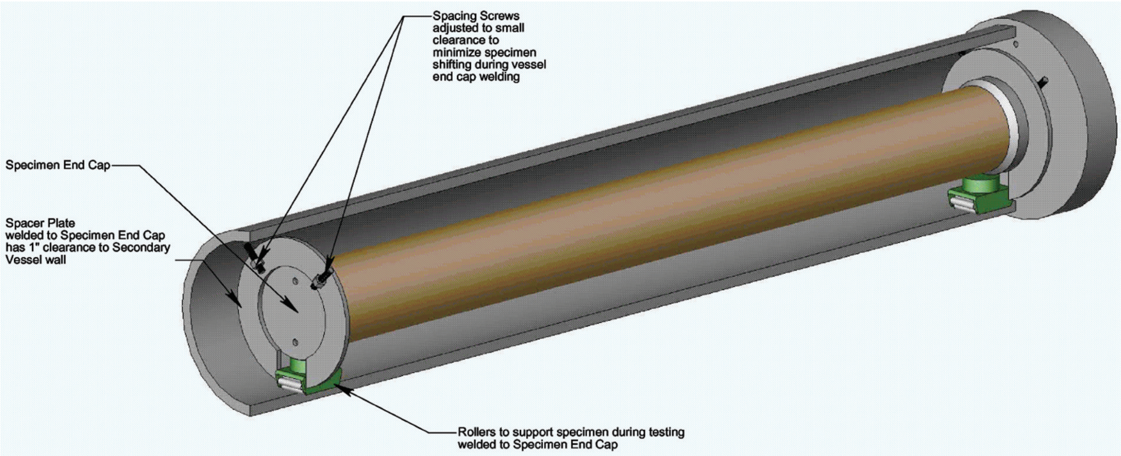

Fig. 1. CFER collapse chamber.

Also a complete mechanical characterization of the three samples was performed. For each pipe sample the following determinations of the yield stress were done:

- Coupons in the circumferential direction, tension tests.
- Coupons in the circumferential direction, compression tests.
- Coupons in the axial direction, tension tests.
- Coupons in the axial direction, compression tests.

For developing the finite element models of the collapse test the value of the compressive circumferential yield stress was used.

The circumferential residual stresses were measured using the slit-ring test [1] (a linear stress distribution through the thickness is assumed).

For each case CFER determined the collapse pressure and the collapse propagation pressure using the experimental apparatus shown in Fig. 1.

3. The finite element models

For each of the three tested samples we developed a finite element model using the MITC4 shell element in the ADINA general-purpose code [10].

In Fig. 1 we presented a scheme of a tube sample inside the pressure chamber at CFER. It is obvious that the external pressure acts on the lateral surface of the pipes and also that it introduces an axial compression on them.

The numerical models were developed using a material and geometrical nonlinear formulation [11] and they incorporate the following features:

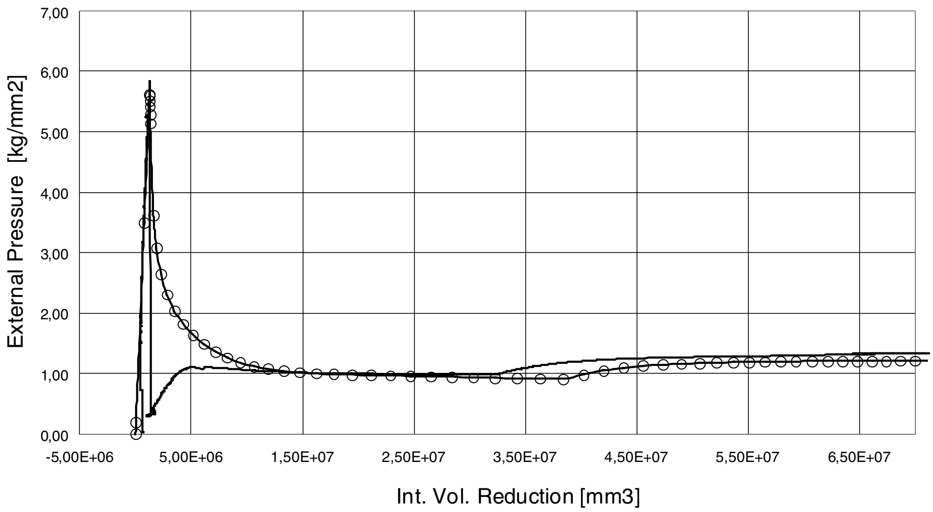

Fig. 2. Sample #1: external pressure vs. internal volume reduction; finite element curve (line and symbols) and experimental results (solid line).

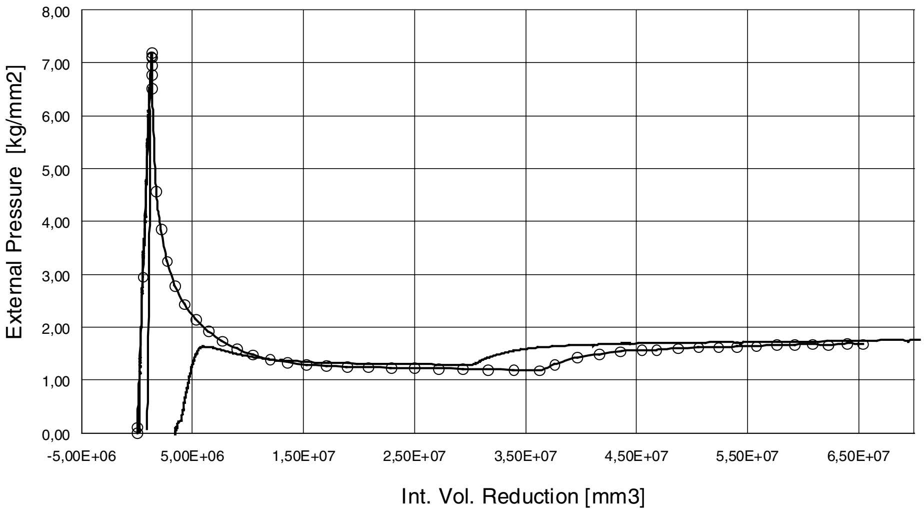

Fig. 3. Sample #2: external pressure vs. internal volume reduction; finite element curve (line and symbols) and experimental results (solid line).

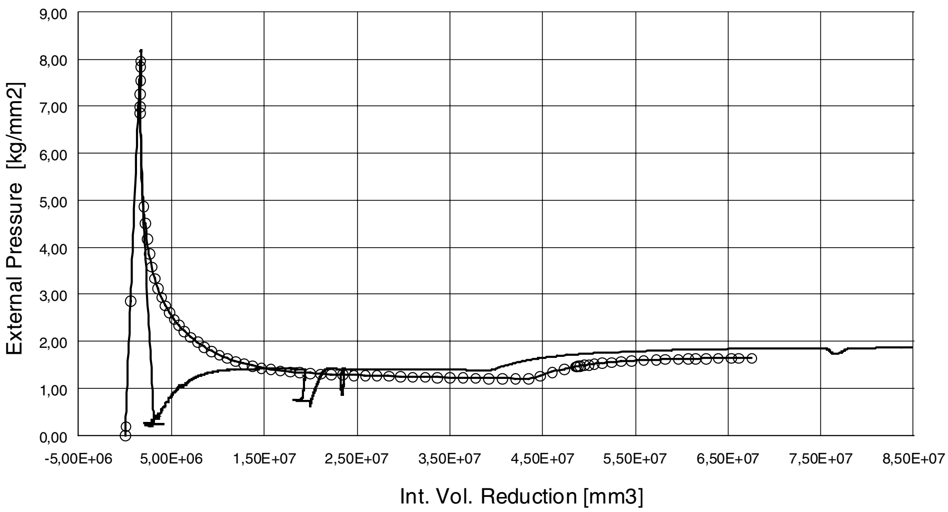

Fig. 4. Sample #3: external pressure vs. internal volume reduction; finite element curve (line and symbols) and experimental results (solid line).

- Geometry as described by the OD mapping and by the thickness distribution, those were determined as discussed above.
- Von Mises elastic: almost perfectly plastic material model with the yield stress corresponding to the samples hoop yield stress in compression. In this model we neglect the plastic anisotropy of the material.
- Residual stresses as reported above.
- Contact elements on the pipe inner surface [11] in order to prevent its inter-penetration in the post-collapse regime.
- The nonlinear equilibrium path was tracked using the algorithm described in Ref. [12].

In Figs. 2, 3 and 4 we compare, for the three samples the experimentally and numerically determined *[External Pressure vs. Internal Volume Reduction]* diagrams.

The experimental and numerical diagrams are practically coincident, except in the interval that goes from immediately after the pipe collapse to the point at which the experimentally and numerically determined curves merge again [1]. Hence, we can assess that the post-collapse re-

[1] In the experimental test, after collapse the chamber is abruptly depressurized and water must be pumped to regain pressure. Hence, the *[external pressure–internal volume reduction]* experimental path is different from the numerical one.

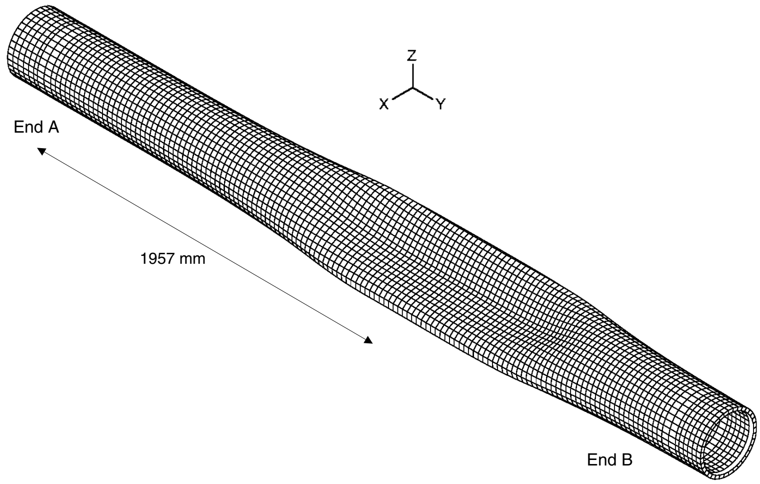

Fig. 5. Sample #1; post-collapse; isometric view.

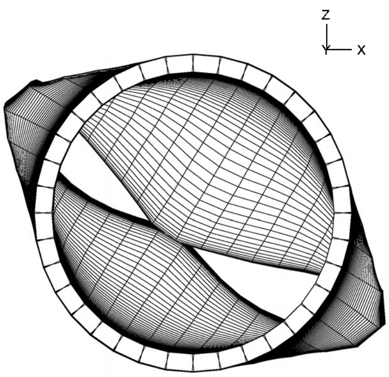

Fig. 6. Sample #1; post-collapse; end view.

sponse of the finite element model, specifically the path in which the collapse propagates, has an excellent match with the experimental results.

For the first sample, in Figs. 5 and 6 we present the deformed finite element mesh corresponding to a certain point of the collapse propagation.

4. Conclusions

The agreement between the finite element predictions and the laboratory observations, both in the pre- and post-collapse regimes is excellent; hence, the finite element models can be used as a reliable engineering tool for analyzing the effect of different imperfections on the collapse and collapse propagation pressure of steel pipes.

An important aspect that needs further analysis is the prediction of the collapse mode: since there are more than one collapse modes that present almost identical collapse pressures, small perturbations either + in the experimental or numerical models, can produce in both cases a branching into one of the possible collapse modes.

Acknowledgement

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