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Collapse of pipes with plain or gouged dents by bending moment

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Abstract

This paper discusses collapse caused by the bending moment of mild steel pipes containing plain or gouged dents.

Five laboratory size pipes were machined with their geometry given by the outside-diameter-to-wall-thickness ratio $D_o/t \cong 40$ and by the length-to-outside-diameter ratio $2L/D_o \cong 12.0$. Defects in the first four pipes had the depth-to-wall-thickness ratio $e/t \cong 0.47$, the length-to-outside-diameter ratio $2c/D_o \cong 0.25$ and the width-to-wall-thickness ratio $2w/t \cong 0.50$. The gouge in the fifth had these ratios given by $e/t \cong 0.23$, $2c/D_o \cong 0.81$ and $2w/t \cong 1.20$.

Specimens were dented with a rigid, hemispherical indenter. The maximum depth of the dent, $(\delta/D_o)_{max}$, varied between 0.15 and 0.23. Dented pipes were collapsed by moment loading whilst subjected to constant internal pressure. This was followed by burst tests. Details about modelling of dents, gouges and the associated FE analyses are provided. Good agreement between experimental and numerical results was obtained in the modelling of denting, but agreement was not so good in the modelling of bending. The FE results underestimated the experimental values of collapse bending moments.

Keywords: Gouged dents; Collapse by bending moment; Pressurised pipes; Burst pressure; Experimental and FE results

1. Introduction

Dents in empty and/or pressurised pipelines have been extensively studied in the past due to perceived risks that these defects could cause to structural integrity of pipelines. As a result, there is a wide body of literature covering the structural integrity of pipes containing dents. Results of both theoretical/numerical and experimental studies are available. Refs. [1–4] can provide some initial background insight to the topic. It is worth noting here that details and references to more than 400 experimental tests on dented pipes are given in [4]. The ratio of pipe-outside-diameter-to-wall thickness, D_o/t, in these experiments varied from 18 to 108. The largest number of tests was carried out for the D_o/t ratio of about 50.

In many instances, e.g. during excavation, falling rocks or ice, dents might suffer a variety of further surface defects including gouges to the wall thickness. This type of defect, i.e. existence of a gouged dent and its influence on the structural integrity of pipelines, has also been addressed in a number of past studies. The amount of work carried out here is much smaller. The open literature suggests that most of the work carried out here was of experimental nature. Ref. [5] provides details about 40 tests on pipes having dents with longitudinal gouges. Tested pipes were either empty or internally pressurised.

The combined effect of internal pressure and bending on the behaviour of dented pipelines is studied numerically in [6]. Interaction diagrams have been developed for closed and open bending moments (with the latter being on the tensile side of the pipe). Magnitudes of collapse bending moment appear to be well defined for closing bending moments (CBMs), whilst for open bending moment one needs to adopt some form of arbitrary criterion for magnitude of collapse load. Experiments on pipes containing local thinning of the wall and being subjected to collapse by open bending moment indicate that the mechanism/magnitude of collapse is well defined, whilst the numerical model is not capable of capturing this phenomenon [7]. It would be desirable to assess this aspect of load versus deflection both from numerical and experimental points of view for dented pipes.

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Nomenclature

$2a$	indenter's diameter (Fig. 6)
c	half-length of axial gouge (Fig. 2)
e	depth of longitudinal gouge (Fig. 2c)
p	internal pressure
t	thickness of pipe
w	half of gouge width (Fig. 2c)
D_o	outside diameter of pipe
$2L$	length of pipe (Fig. 2b)
CBM	closing bending moment (Fig. 12b)
CNC	computer numeric controlled
OBM	opening bending moment (Fig. 12b)

In this study, experimental and numerical collapse bending moments are established for dented and gouged pipes. Work begins with 'perfect' pipes into which axial gouges are introduced, followed by transverse denting. Subsequently, pipes are collapsed by a bending moment. Next, as there is no loss of pressure tightness all pipes are subjected to pressure burst tests. This three-stage experimental process is closely followed by FE analysis. One of the objectives here is to assess the capability of the FE analysis in predicting denting force and the magnitude of the collapse bending moment of the pipes.

2. Test models

2.1. Geometry

Five test models were CNC-machined from an oversized mild steel pipe. The starting piece of the pipe for each model was about 600 mm long, its wall thickness was 5.7 mm and the outside diameter was 89 mm. The initial length was cut into three pieces P1, P2 and P3 as depicted in Fig. 1a. The middle section had a nominal length of $3D_o$ and wall thickness t. The remaining parts P1 and P3 had lengths of $1.5D_o$ and the wall thickness remained the same, i.e. t. The reason behind cutting the pipe into the set of three was dictated by the need of machining in order to obtain models with the D_o/t ratio ≈ 40. Machining was carried out on the inside and outside surfaces and it was easier to proceed with shorter pieces of the pipe. Axial gouges were introduced to the middle part, P2. After that all three pieces were welded together. Further extensions were welded to both ends. Their wall thickness was 6.75 mm and both were capped with flat discs. A sketch showing these arrangements is depicted in Fig. 1b, whilst the resulting test model after welding all parts together is shown in Fig. 1a. The measured geometry of five models, designated as SP2, SP3, SP4, SP5 and SP6, is provided in Table 1. It is seen that the outside diameter-to-wall-thickness ratio D_o/t is ≈ 40, and the total-length-to-outside-diameter $2L/D_o$ is ≈ 6.

Table 1
Geometry of tested models, values of internal pressure during denting and indication whether the model was gouged/bent

Model	D_o (mm)	t (mm)	L (mm)	$p_{denting}$ (MPa)	Gouged	Bent
SP2	84.10	2.10	504.6	11.2	No	Yes
SP3	84.08	2.08	504.5	11.2	No	Yes
SP4	84.06	2.09	504.4	5.6	Yes	Yes
SP5	84.08	2.08	504.5	5.6	Yes	Yes
SP6	83.97	2.08	503.8	5.6	Yes	Yes

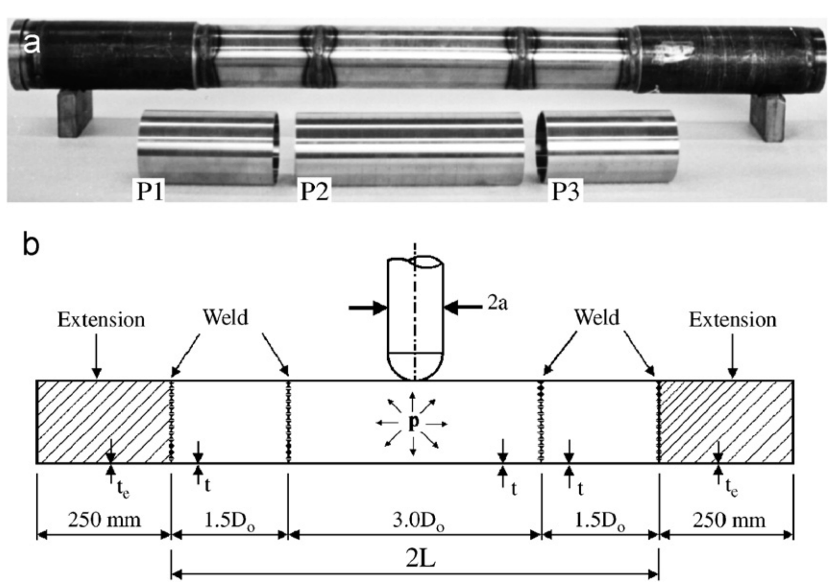

Fig. 1. View of three machined pipe parts P1, P2 and P3. Also, photograph of a test model after welding of P1, P2, P3 and two end extensions (a). Sketch depicting dimensions and mid-span application of transverse indenter (b).