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Influence of a cutout on circular steel hollow sections under cyclic loading

Tohid Ghanbari Ghazijahani *, Hui Jiao, Damien Holloway

School of Engineering, University of Tasmania, Hobart, Australia

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ABSTRACT

Due to extensive applications of circular hollow sections (CHS) as structural members, these steel elements are always in the focus of interest of investigators. This study reports on the effect of circular openings on the fatigue behavior of CHS members. Circular cutouts were made near the area of maximum tension stress of tube specimens. The failure mode as well as the fatigue life was explored. It was found that fatigue life and failure modes strongly depend on the position and the diameter of the opening. It was interesting that, due to the distribution of the stress concentration, a cutout with an optimal diameter helped to extend the fatigue life of a tube compared to those without the cutouts.

1. Introduction

For various applications, cutouts in the form of circular holes are sometimes found in circular hollow sections. Towers door openings (see Fig. 1), cable entrance holes of overhead traffic signs or any transition or secondary element attachments can be instances of the application of the cutout in such structural elements. There are a multitude of papers in the literature regarding structural behavior of cylindrical shells among which only a few papers reflected the tubes with cutout under static loading. To the knowledge of the authors, there is no reference exploring tubes with circular opening under cyclic loading.

The plastic limit load of cylindrical shells with cutouts subject to pure bending moment was investigated in [2]. In this research analytical estimations of lower bound limit load and finite element calculations of thin-walled cylindrical shells with a central circular opening of various geometric parameters were studied and the results were compared with experimental values. The elasto-plastic buckling of cylindrical shells with a cutout under pure bending was investigated analytically and experimentally [3]. It was found that the limiting buckling moment of a shell was smaller when a cutout was on the compression side of the shell than on the tension side. The buckling load of oblique loaded steel cylindrical shells with elliptical cutout was reported [4]. Results of this study showed that the critical load increased with the increase of deformations before the critical buckling load. The buckling load of mild steel cylindrical shells of various D/t and L/D ratios (D, t and L are diameter, thickness and length respectively) with elliptical cutouts in different positions was determined [5]. Critical areas of the bulking of thin cylindrical shells under bending were determined [6,7]. It was believed that any geometrical discontinuities such as cutouts should be avoided in the most critical areas. Analysis and design of a prototype of a steel 1-MW wind turbine tower with opening was evaluated considering different loadings and phasmatic analysis [8]. Moreover, the plastic behavior of an elasto-plastic cylindrical shell with circular and rectangular cutouts under bending moment was investigated numerically and experimentally [9]. It was found that the limiting buckling moment of a shell with a cutout increased when the cutout was located toward one of the clamped ends.

In the present study, tests were conducted to examine the fatigue life and the failure modes of the tubes with circular cutouts. The effect of the opening size on the fatigue life and the stress concentration was investigated in this research.

2. Experimental program

2.1. Features of test rig and loading condition

Eight cantilever beam specimens were tested by means of a MTS-810 machine under cyclic unidirectional loading. The machine was calibrated by Australian Calibrating Services (ACS) before the tests. Different components of the test apparatus are shown in Fig. 2.

In this set of experiments, the loading was not a reversal loading and was applied as a maximum stress and unloaded up to a minimum stress. Stress ratio of 0.1 (maximum stress/minimum stress) was adopted for all specimens. The applied maximum stress was about 50% of the calculated yield limit of the intact tubes. Note that although the cutout diameter of each specimen was different from the others, the stress ratio was kept 0.1 for all specimens.

* Corresponding author. Tel.: +61 469 311 896.
E-mail addresses: tohid.ghanbari@utas.edu.au, tohidghanbari@gmail.com (T. Ghanbari Ghazijahani).

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Fig. 1. Entrance opening in a tower [1].

2.2. Specimen preparation and perforation process

Mild-steel tube specimens were used in this research. These specimens were accurately prepared and cut into desired lengths. One end of each specimen was machined in a lathe to ensure that the specimen was welded quite perpendicular to the end plate. This was conducted to avoid the influence of non-alignment of a specimen on the fatigue life. The welding of the specimens was carried out using an automatic rotating machine which allowed the welding to be conducted at a uniform speed.

Fig. 3 shows a welded specimen. Cutouts were made on the tension side using a precise drilling method by which an accurate circular opening was obtained. Two specimens after perforation are shown in Fig. 4. The geometric specifications of all specimens are shown in Figs. 5–7 and Tables 1 and 2.

2.3. Material properties

A tensile test was conducted to obtain the material properties, i.e. the Young's modulus, the yield and ultimate strength in accordance with Australian Standard AS-1397. The results are tabulated in Table 3.

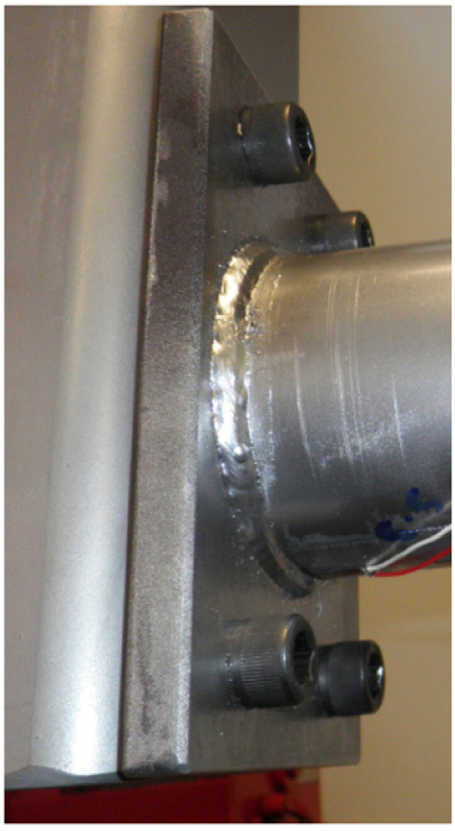

Fig. 3. Welding and connections of the tube specimen.

3. Test observations

3.1. Failure modes

Two failure modes of "*brace-tension-side*" and "*cutout-crack-failure"(CCF)* were observed from this set of specimens.

3.1.1. Brace-tension-side failure

Failure occurred along the welding for specimens QWE.5 and QWE.7 (no holes). Fig. 8 shows the development of the crack in these intact

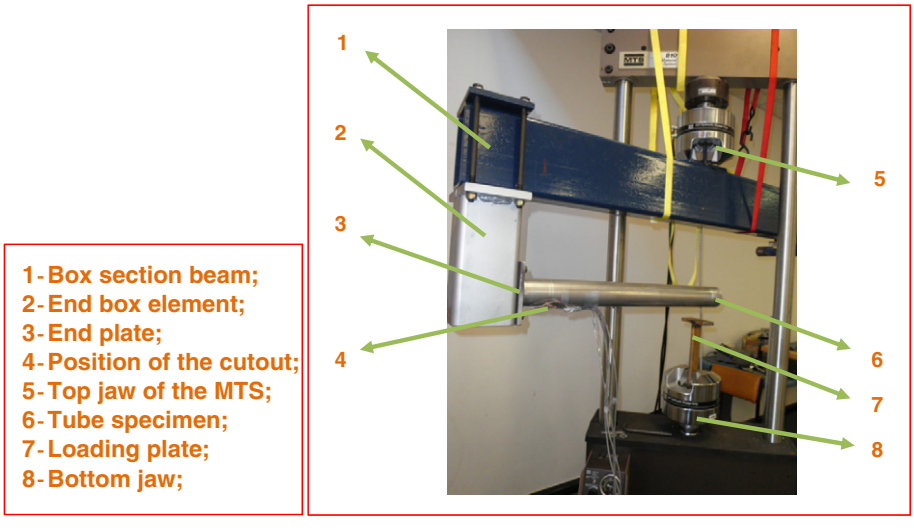

Fig. 2. Overall view of the MTS machine and the apparatus.