Inelastic behaviour of steel circular hollow sections under cyclic loading – Executive Summary

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Introduction

This Executive Summary outlines the execution of the above-named project which has received generous funding by the Institution of Structural Engineers Research Award Scheme. The experimental and numerical work programme was carried out between January and June 2019 at the Imperial College Structures Laboratory in South Kensington, London.

In the United States, seismic design of tubular steel piles used in piers and wharves is carried out according to ASCE 61-14 (2014), a displacement-based design standard that specifies a material strain limit at a localised plastic hinge as the primary performance criterion for a given level of seismic hazard. However, ASCE 61-14 (2014) is largely silent on the effect of inelastic buckling on the deformation capacity and moment resistance of tubular steel piles, known to lead to premature failure for more slender cross-sections. In particular, the codified strain limits corresponding to different performance levels are not currently dependent on any measure of the cross-sectional slenderness.

Contrary to the relatively large pool of test results exploring the monotonic bending response of steel tubes, the dataset of critical longitudinal strains established on the basis cyclic bending tests remains quite small. The chief aim of this project was thus to expand the database of critical strains obtained through cyclic bending tests and supporting simulations with ABAQUS (2017), and to this end seven tube specimens were successfully brought to failure in a series of three-point cyclic bending tests. The focus was on tubes with external diameter to thickness (*D*/*t*) ratios from 20 to 60, typical of applications as piles in piers and wharves.

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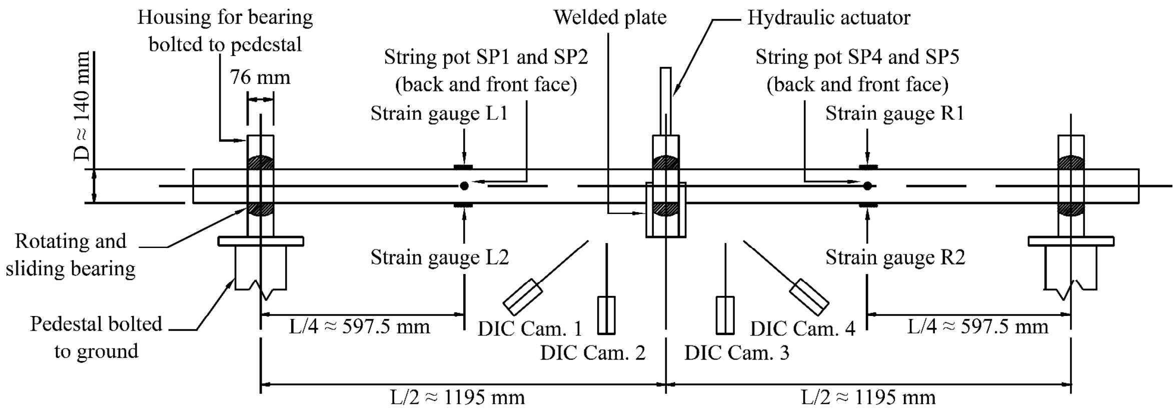
Experiment setup

A schematic of the test rig used to perform the cyclic three-point bending is illustrated in Fig. 1a. The specimens were restrained inside roller bearings at each end (Fig. 2b) which permitted the tube ends to undergo transverse rotations due to a lubricated interface between the inner and outer bearing rings (Fig. 2c). A slight gap between the inner bearing surface and the tube surface was made up with a lubricated filler material which permitted relatively frictionless sliding. The midspan load was introduced into the tube by a lubricated bearing ring inside a clamp-housing which moved vertically together with the hydraulic actuator (Fig. 2d). The bearing restrained cross-sectional distortion at midspan but permitted rotation in the event of an asymmetrical response. The instrumentation included strain gauges, string potentiometers and four-camera Digital Image Correlation (DIC) system to track the deformations at the midspan plastic hinge locations. A displacement-controlled cyclic load protocol was applied consisting of triads of integer multiples of the first yield displacement (using the 0.2% proof stress).

a) Schematic of test setup in elevation



b) Detail of tube in the end bearing

c) Detail of a rotated bearing

d) Detail of tube in the central bearing

Fig. 1 – Schematic of test setup with instrumentation locations and various details.

Main results

Observed and simulated critical longitudinal strains at inelastic buckling failure are summarised in Fig. 2, contextualised against the existing database of monotonic and cyclic bending test results and proposed design equations by various authors. The critical strain depends on the method through which the mean cross-sectional curvature at failure is estimated (DIC and two hinge models), and a range of values are reported. A proposed lower-bound for strain limits at the Life Safety seismic performance level is $\varepsilon_{cr} = 10(D/t)^{-2}$ (Harn *et al.*, 2019), dependent on slenderness for the first time.

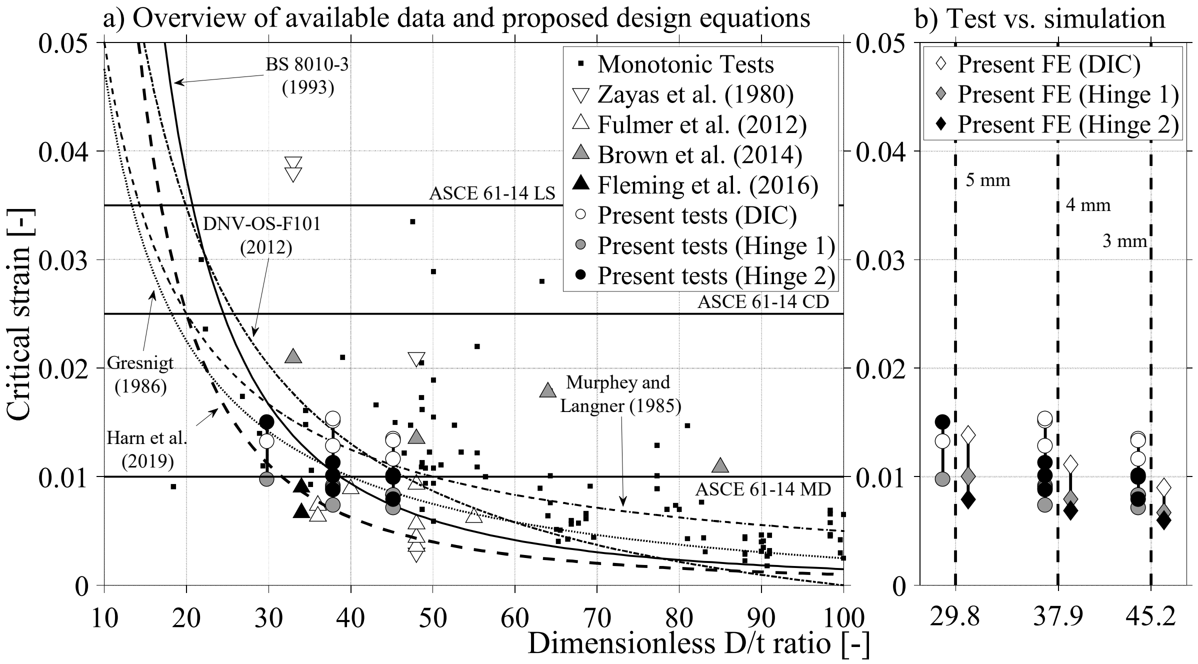


Fig. 2 – Currently available test data and various proposed design equations.

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