Investigation of the Torsional Capacity of 400MPa+ 76.1mm and 88.9mm Circular Hollow sections

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ABSTRACT: *There is very little research comparing the theoretical and experimental* ***Torsional Capacity*** *of small diameter Circular Hollow Sections (CHS).*
This research paper investigates the experimental torsional capacity of two CHS 76.1mm and 88.9mm in diameter. In theory the torsional capacity of a function of the ***geometry and the yield strength*** *of the section.*
In practice however, the yield strength of the section can be difficult to determine without testing of the specific sample - as steel mills typically undertake yield testing subsequent to ***ageing of the test specimen.***
The geometry of the section can also vary depending on the ***wear of the rollers*** *used to form the section.*
Determining a reliable method to calculate the torsional capacity of a section is particularly important in the screw piling industry as AS2159 [1] requires that the ***structural design strength of the screw pile*** *shall not be less than the design action effect on the pile.*

INTRODUCTION: The Australian and New Zealand residential screw piling market has grown exponentially with the majority of the growth coming from the replacement of concrete bored piers.
With a significant correlation between torque and pile capacity [2] it is critical to not only understand the point at which the pile can perform to the design capacity but also when the pile may reach its elastic and torsional yield capacity.
The actual torsional capacity of screw piles is particularly important as there is no way for the operator installing the piles to detect any twisting of the pile beyond the pile's elastic torsional yield capacity.
This paper explains the factors that should be considered in the calculation of the theoretical elastic torsional yield point in a CHS namely:
Yield strength of the rolled steel - rolling mill testing and certification (rolling mills usually undertake ageing treatment prior to testing of specimens)
Outside diameter and actual thickness of the pipe
The assumed design capacity factor
The theoretical capacity of the two CHS sections was calculated followed by a number of tests in torsion in order to compare what the actual results achieved.
This paper attempts to assist design engineers, residential builders and piling contractors understand how to calculate the torsional elastic capacity and how the theory compares to the actual torsional test results.

THEORETICAL CALCULATION OF TORSIONAL CAPACITY: It is important to note that in the typical stress vs strain curve, the yield point of the steel pile is very difficult to detect during the installation of the pile, hence the reason to understand with some degree of accuracy where is point is to avoid plastic deformation and fracture of the screw pile.

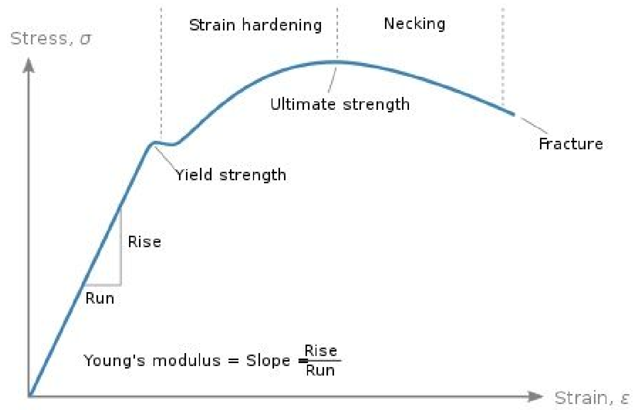

Figure 1: Steel strain vs Stress curve (The Chicago Curve) [3]

There are no design provisions for torsional capacity in AS4100 [4]. Torsion primarily introduces shear on a CHS which is considered to be uniform through the action's cross-section.

The torsional capacity can be calculated as follows [5]

$$\text{Ø}\, Mz = \text{Ø}\, 0.6\, fy\, C$$
$$C = 2J/do$$
$$J = \pi/32\,(do^4 - di^4)$$

Mz = Torsional Moment
fy = Design Yield Stress
C = Torsional Section Modulus
J = Torsional Section Constant
do = Outside diameter
di = Inside Diameter

In the table below is a calculation of the theoretical elastic torsional capacity.
For the 76.1mm section 3.83mm represents the min thickness allowed by AS1163 and 4.0mm represents the nominal thickness.
For the 88.9mm section 5.265mm represents the min thickness allowed by AS1163 and 5.5mm represents the nominal thickness.

Calculated Torsion (Nm)	**76.1x 3.83**	**76.1x 4.0**	**88.9x 5.27**	**88.9x 5.5**
Ø=0.9 350MPa	5656	5867	10327	10701
Ø=1.0 500MPa	8879	9210	14752	16799

Table 1: Theoretical Torsional Yield Capacity by member size, capacity factor and yield strength

TESTING METHODOLOGY: Two groups undertaking their postgraduate masters degrees undertook testing of the 76.1mm and 88.9mm sections. [6] [7]

The test assembly consisted of a 150x150x9 SHS which was secured horizontally to the floor and a 150x150x9 SHS lever arm which was attached to a MTS 244.31 Non-Hydrostatic Hydraulic Actuator with a capacity of 250kN.

Figure 2: Torsion test assembly

The test system was restrained to ensure there was minimal movement of the components of the system other than the rotation of the lever arm applying a torsional force to the specimen being tested.

Restraints are indicated in figure 3 below.

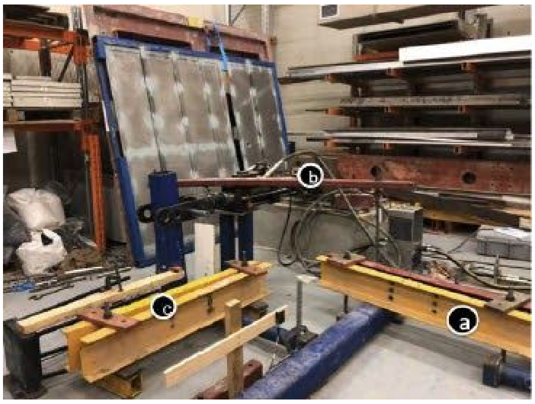

Figure 3: Restraints applied to the testing system

During the test the actuator force was measured along with the displacement and rotation of the test specimen.

TEST RESULTS:

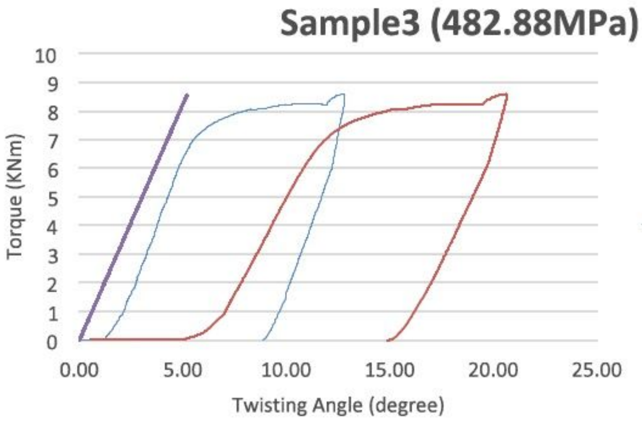

Figure 4: The predicted twisting angle, the measured twisting angle and the twisting angle of the actuator.

Figure 4 demonstrates a significant correlation between the predicted and actual twisting angle - a representation of a stress / strain or the Young's Modulus.

Table 2 summarises the range of theoretical Torsional Capacities - minimum compared to maximum for the variables of thickness, yield and capacity factors and compares the final experimental result of the testing.

For the 76.1mm CHS: 3 specimens from 6 heats (i.e. 6 different yield strengths) were tested. In total 18 specimens were tested. These specimens indicated the correlation of results within each heat.

For the 88.9mm CHS: 5 specimens from 1 heat (i.e. 1 yield strength) were tested. These specimens indicated the variation that could be expected within a single heat.

Torsion (Nm)	76.1x 4.0	76.1x 4.0	88.9x 5.5
Mill tensile yield - aged test (MPa)	438	482	468
Theoretical Torsion (Nm) Ø=0.9	7345	8094	14310
Theoretical Ø=1.0 Nm	8071	8895	15725
Melbourne Uni tensile yield - no ageing (MPa)	369	396	405
Theoretical Torsion (Nm) Ø=0.9	6198	6646	12410
Theoretical Torsion (Nm) Ø=1.0	6886	7385	13789
Experimental Elastic yield (Nm)	7400	7967	12820*

Table 2: Summary of the theoretical and experimental test results *Ave 5 results

OBSERVATIONS:

- specimen aging increased the yield strength of the specimens by 18.7%, 21.7% and 15.6%
- a capacity factor of 0.9 together **with aged tensile** testing predicted a very accurate result for the 76.1mm CHS.
- A capacity factor of 0.9 together with a tensile test with **no ageing** predicted an accurate result for the 88.9mm CHS.
- The tested yield of the 88.9mm specimens was closer to the ageing test as this pipe was allowed to age for a longer period than the 76.1mm specimens.

Samples	76.1x 4	76.1x 4	88.9x 5.5
Experimental Plastic Yield (Ep) Nm	7638	8068	13800*

Table 3: Summary of the Plastic Yield of the specimens. *Ave 5 results

INPUTS TO CALCULATE TORSIONAL CAPACITY AND PRACTICAL CONSIDERATIONS:

Yield strength:
Section 14.4 in AS1163 [8] requires ageing treatment of the steel prior to tensile or impact testing. Test pieces to be aged by heating between 150-200 deg C for a period not less than 15min.
Aged treatment by steel mills attempts to predict the increase in yield strength of steel over time.

The range of yield strength for a 400+ MPa steel from 350MPa (no ageing treatment of steel prior to testing) to 500MPa (results of tensile yield testing after ageing by the rolling mill)

Dimensional tolerances:
AS1163 - allowable limits:
8.2 **Cross-section** - thickness +/- 10%
On the Cross-section min thickness a steel mill would be allowed to produce steel min 3.96mm in thickness
8.2 **Outside diameter** +/- 0.01 do
9 **Mass** > 0.96 times specified mass

Considering the above dimensional constraints, a steel mill would typically be able to produce steel with a min thickness of 3.83mm. This is where only a nominal thickness specified i.e no min thickness specified.

CONCLUSIONS AND RECOMMENDATIONS:
The exact yield point during the testing was difficult to determine. Chattopadhyay [9] provided a method to approximate the elastic yield point using a 0.2% offset.

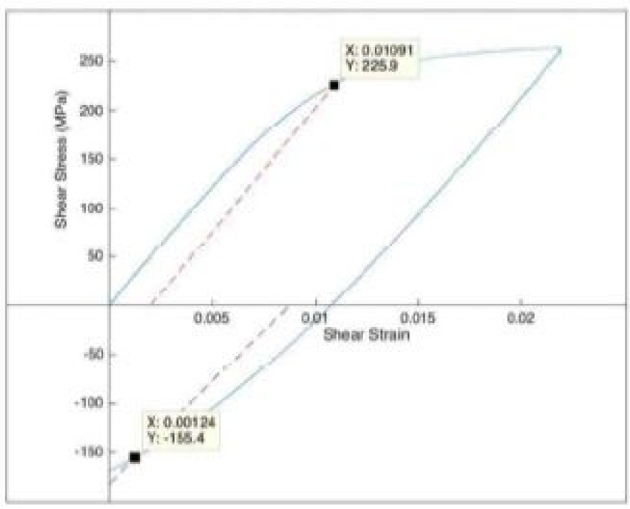

Figure 4: Prediction of elastic yield by using a 0.2% offset

The Young's Modulus elastic behaviour was very close to what was expected for all the samples tested.

The 76.1mm samples that were tested were confirmed to have a thickness of 4.0mm
In theory, the range of torsional yield expected was between 5656Nm and 9210Nm.
For the 76.1mm CHS and using Ø=0.9 the theoretical result was very close to the experimental result. Theoretical result 7345Nm vs experimental result of 7400Nm and a calculated of 8094Nm vs experimental result of 7967Nm for the lowest and highest yield yield strengths respectively.

The 88.9mm samples that were tested were confirmed to have a thickness of 5.5mm

In theory, the range of torsional yield expected was between 10,327Nm and 16,799Nm.

For the 88.9mm CHS and using Ø=0.9 the theoretical result was 10% more than the experimental result. Theoretical result 14,310Nm vs experimental result of 12,820Nm.

Factors which may have resulted in a lower experimental result for the larger 88.9mm CHS were the relative capacity of testing equipment, the strength of the welds on the ends of the test specimens and the relative rigidity of the test assembly used to test the specimens. Further testing may provide clarification of the experimental result for the 88.9mm CHS.

It can be assumed with ageing of the steel, that these are minimum values and torsional yield will continue to increase with ageing/time.

There is minimal deformation of the section beyond the elastic yield point and along the strain hardening section of the stress/strain curve.

Plastic failure of screw piles is sudden and up to that point, while the pile does rotate there is only a small loss in section capacity due to the eccentricities introduced by the deformation due to the rotation.

Figure 5: Figure showing deformation of specimens

The CHS of screw piles is typically designed with significantly more capacity than the design action effect on the pile.

If the CHS of the screw pile is designed with significantly more capacity than the design action effect, then as long as the pile does not reach its plastic yield point, its structural design strength should still be significantly more than the design action effect on the pile.

[1] AS2159 Piling - Design and Installation
[2] Howard A Perko. Helical Piles A Practical Guide to Design and Installation. (2009) 177
[3] Bieber C, Bjelkengren C, Ryu J and Varga A. Plastic deformation in material processing. (2006)
[4] AS 4100 Steel Structures
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[6] Shi J, Li M, Lu M, Gao F. Tube torsion capacity investigation for Screw Piles. (2019)
[7] Sze E, He J, Cicco S, Luo X. Tube Torsional Capacity Investigation for Screw Piles. (2019)
[8] AS 1163 Cold-formed structural steel hollow sections
[9] Chattopadhyay S, Qu J, Nuri A, Hasan S A, Kundu N. Torsion Tests to Study Plastic Deformation in Ductile Materials.