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THE BEHAVIOUR OF HIGH STRENGTH STEEL CIRCULAR HOLLOW SECTIONS UNDER COMPRESSION

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ملخص البحث

منذ أوائل القرن التاسع عشر ، تم تصنيع القطاعات الدائرية المجوفة (CHS) واستخدامها في الإنشاءات مثل الأعمدة والكمرات وعناصر الجمالون، والتي يمكن ان تكون معرضة للضغط او الشد او الانحناء. ولتصميم هذا النوع من القطاعات ، لابد من فهم سلوك القطاعات الدئرية المجوفة في مدي واسع من نسب القطر إلى السماكة (D / t) تحت تأثير الضغط المحوري. ووفقا لذلك ، تم عمل نمذجة لمجموعة من القطاعات قصيرة الطول تحت تأثير احمال الضغط باستخدام طريقة العناصر المحدودة. و تم التحقق من صحة نتائج النماذج باستخدام النتائج العملية. تم فحص 20 عينة نظريا من الاعمدة القصيرة بنسب D/t تتراوح من ١٠ إلى ٢٥٠ لتقييم سلوك القطاعات المجوفة الدائرية عالية الإجهاد تحت تأثير القوي المحورية. و قد أظهرت البيانات التجريبية التي تم جمعها من الأبحاث السابقة والبيانات النظرية لهذه الدراسة أن القطاعات ذات النسب المنخفضة من D/t انهارت مع تشوه محيطي خارجي مع عدم وجود انبعاج محلي واضح. ولكن مع زيادة نسبة D/t يبدا ظهور الانبعاج المحلي قبل الوصول لحمل إجهاد الخضوع. تم دراسة تأثير نسبة D/t والتشوهات الابتدائية باستخدام نموذج العناصر المحدودة.

الكلمات المفتاحية: الضغط المحوري، الاعمدة القصيرة، القطاعات الدائرية المجوفة، حديد عالي الاجهاد، القطاعات الدائرية المجوفة السميكة و القطاعات الدائرية المجوفة النحيفة.

Abstract.

Since early 1800s, circular hollow sections (CHS) have been made and used in constructions as columns, beams, tension members, and truss elements, which are subjected to axial stress and bending moment. To design this kind of elements, it is crucial to understand the behaviour of circular hollow section with a wide range of diameter-to-thickness (D/t) ratios under axial compression. Accordingly, axially loaded short columns modelled using finite element method. The accuracy of the finite element results was validated using some experimental results. Twenty short columns were investigated analytically with D/t ratios ranging from 10 to 250 to evaluate the behavior of axially loaded CHS. The experimental data from previous researches and numerical data of this study showed that tubes with lower D/t ratios collapsed with outward circumferential deformation and without signs of local buckling. However, the local buckling was noticed at the peak load as the D/t ratio increased. In this study, the effects of D/t ratio and the geometric imperfection were investigated using finite element models

Key words: axial compression, stub columns, circular hollow sections, high strength steel, stocky circular hollow sections, and thin-walled tubular sections.

1. Introduction.

Since early 1800s, circular hollow sections (CHS) have been made and used in constructions as columns, beams, tension members, and truss elements [1]. They have become increasingly popular among designers as a result of their appealing aesthetics and advantages against open sections, such as excellent torsional resistance, uni-axial, bi-axial bending resistance, the ability to being filled with concrete, and lower maintenance requirements due to the smaller external area exposed to corrosion [1].

CHS may be exposed to axial compression load, bending moment, or combined axial and bending. The bending, axial capacity, and buckling behavior of CHS depend on the diameter to thickness ratio (D/t). Thus, with the increase of (D/t) ratio, local buckling may affect the bending behaviour of CHS. Steel design specifications present different classes of sections according to the point at which local buckling occurs. For axial compression, AISC-LRFD specifications classify the sections as compact and slender. Cross-section classification is used in current design rules to divide (CHS) into distinct categories based on their sensitivity to local buckling. The EN 1993-1-1 [2], BS 5950-1 [9] can be used for the classification of structural steelwork, EN 1999-1-1 [3] for aluminum, and EN 1993-1-4 [10] for stainless steel in which four cross-section classes are considered. Within the AISC 360 [4] and AS 4100 [5] steel codes, there are no equivalent class 2 cross-sections. The class 3 limit in terms of axial compression distinguishes non-slender cross sections that are able to reach the yield load (i.e. classes 1–3) from those that due to local buckling fail before attaining their yield load (i.e. class 4).

2. Summary of gathered experimental data.

The results of six experimental tests on CHS stub columns were collected from Lanhui Guo, et al [6] to cover a wide range of cross-section slenderness beside the studied finite element models. Table 1 shows the yield stress of the coupon tests and the cross-section slenderness (λs). The ranges of (λs) in the experimental tests were 60.5≤ λs≤ 242 for CHS [6].

Table 1: Experimental four point bending tests on CHS [6].

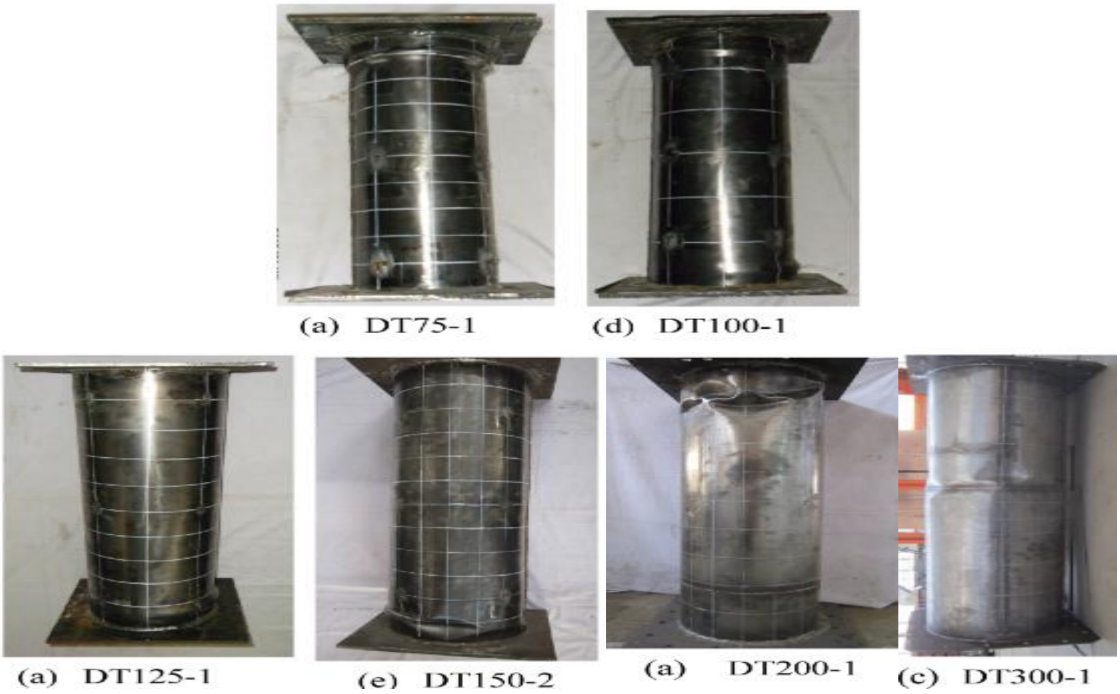
Se	f_y	D	t	L	λs
DT75	190	150	2	450	60.5
DT100	190	200	2	600	81
DT125	190	250	2	750	101
DT150	190	300	2	900	121
DT200	190	400	2	1200	162
DT300	190	600	2	1800	242

In Lanhui Guo, rt al [6] three tensile coupon tests were performed to determine the average properties of stee material. The properties of material are list in Table 2, in which t is the thickness of the tested coupons, fy is the average yield stress, fu is the tensile strength, Es is the modulus of elasticity, ν is the Poisson ratio, and δ is the elongation ratio.

Table 2: Mean Key Results from Tensile Coupon Tests.

T	F_y (Mpa)	F_u (Mpa)	E_s (Mpa)	ν	δ
2	190	315	1.88x10^{5}	0.36	0.51

Lanhui Guo, et al [6] studied the behaviour of short columns of the circular hollow steel sections under axial compression. The six short columns were investigated, with slenderness ratio λs ranging from 60.5 to 242, as shown in Table 1. The length of the specimens was chosen to be equal three times the diameter to avoid failure by global buckling. Yield strength of 190 MPa, the initial geometric imperfection, and the initial residual stress were taken into consideration. Based on their experimental study, it was conducted that tubes with λs ratio of 60.5 and 80.64 were able to attain yield load and no local buckling was observed. For tubes with λs of 100.8 and 121, the circumferential outward deformation was noticed on the steel specimens. The buckling deformation was smooth. For tubes of with λs ratios of 161.3 and 242 were recognized as inward and outward bulge like chequer-board, which start at the peak load, accompanied by a fast drop in load-carrying capacity and the vertical strain rapidly increased. The failure modes of λs from 60.5 to 242 are presented in Figure 1.


(a) DT75-1 (d) DT100-1

(a) DT125-1 (e) DT150-2 (a) DT200-1 (c) DT300-1

Figure 1. Failure mode of specimen λs =60.5 to λs =242 (Lanhui Guo, Yong Liu, Hui Jiao, and shilong 2016).

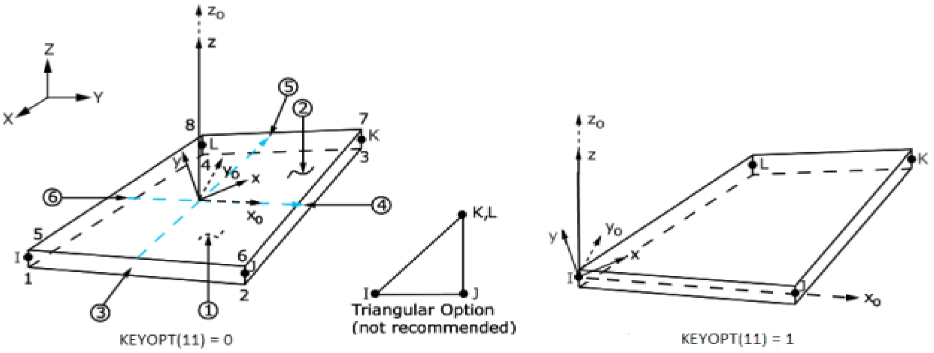
3. Analytical verification.

3.1. Finite element modeling.

Although the experimental work is reliable technique to investigate the behavior of any structure, it is more expensive than the analytical solution and numerical model. The last decade has seen widespread of good commercial finite element software for an extensive range of applications. Hence, finite element computer software has become widely used in almost all branches of engineering. ABAQUS, COSMOS, and ANSYS software packages are among the most common finite element programs which can be applied for various structural analysis purposes. Because of its capacity to tackle difficult structural engineering issues, the ANSYS structural analysis software [7] package is trusted by enterprises all over the world. FEA (finite element analysis) tools from ANSYS version 19.0 general-purpose finite element program provides many new functions that have the ability to simulate and analyze every structural aspect. In this research, the ANSYS software package is used to build three-dimensional finite element models to study the behavior of circular hollow steel sections subjected to different straining actions. This verification is necessary to ensure the model capabilities for representing the behavior of the studied pipes so that parametric study can be performed.

3.2. Model geometry.

Shell elements SHELL 181 [8] are used to create the model, as illustrated in Figure 2. This shell element type is a four-node element with six degrees of freedom at each node translations and rotations around the x, y, and z-axes. In addition, SHELL181 is ideal for nonlinear, linear, big rotation, and/or large strain applications. Nonlinear analyses take into consideration changes in shell thickness. Both complete and limited integration techniques are supported in the element domain. SHELL181 accounts for distributed pressure follower (load stiffness) effects. The meshing step is done by generating a mesh size of D/20, which is suitable for the simulation of local buckling of the model.



x_0 = Element x axis if element orientation (**ESYS**) is not specified.

x = Element x axis if element orientation is specified.

Figure 2. Element type SHELL181, geometry [26].

3.3. Model restraints and material properties.

The support conditions and the introduction of applied loads received particular attention, and the use of so-called kinematic linear constraints has been made to ensure a “plane-sections remain-plane” behavior of the end sections. Following ideal simply-supported support conditions, one end of the cross-section restrained against axial and circumferential displacements, the other end only restrained against circumferential displacements. Thus, the two ends are free to rotate about weak and strong axis. These assumptions were considered to resemble the experimental study conducted by Lanhui Guo, et al [6] so that the analytical model verification can be obtained. It is worth mentioning that elastic perfectly plastic stress-strain curve is used for the steel material with an elasticity modulus (E) equals to 1.88 E+08 kN/m2 as shown in Figure 3.

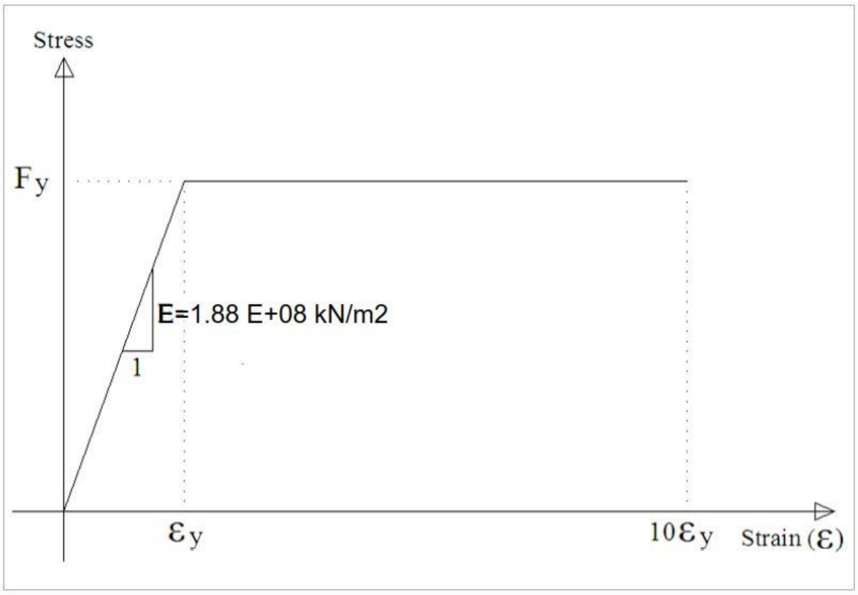


Figure 3. Stress-Strain curve for steel material.

3.4. Analysis type.

ANSYS provides both linear and nonlinear types of analysis. In this research, it is significant to implement nonlinear analysis to simulate the cross-sectional behavior of CHS under compression and consider the effect of increasing deformations called geometric non-linearity. In addition, it is required to fix the loads that leading to failure, which is called material non-linearity.

4. Comparison of results.

The Comparison between the failure modes of the experimental tests by Lanhui Guo, et al and the ANSYS models are presented in Figures 4 and 5. In addition, the load-deflection curves of the experimental tests and the ANSYS models are presented in Figures 6 and 7. From these figures, it is clear that the failure loads resulted from experimental tests are in a high degree of agreement with those resulted from ANSYS models. The ratio between the analytical and experimental results is presented in Figure 8. The validated study shows that the adopted finite element (FE) models could produce accurate predictions of load-carrying capacity and accepted failure mode compared with failure modes of the experimental study. Thus, the validated FE models will be used in a comprehensive parametric study to investigate the behavior of circular hollow sections (CHS).

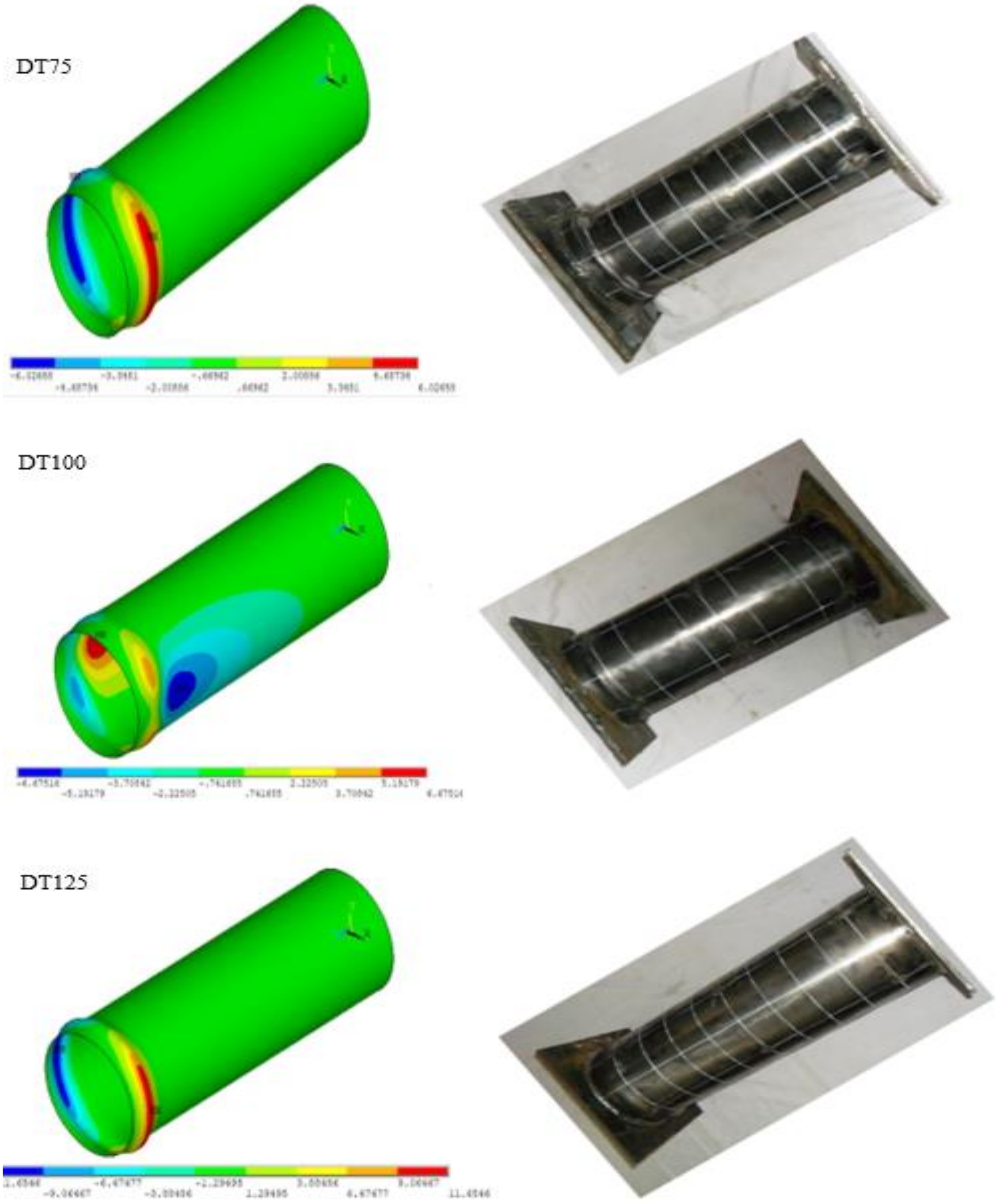


Figure 4: failure modes of numerical and experimental specimens

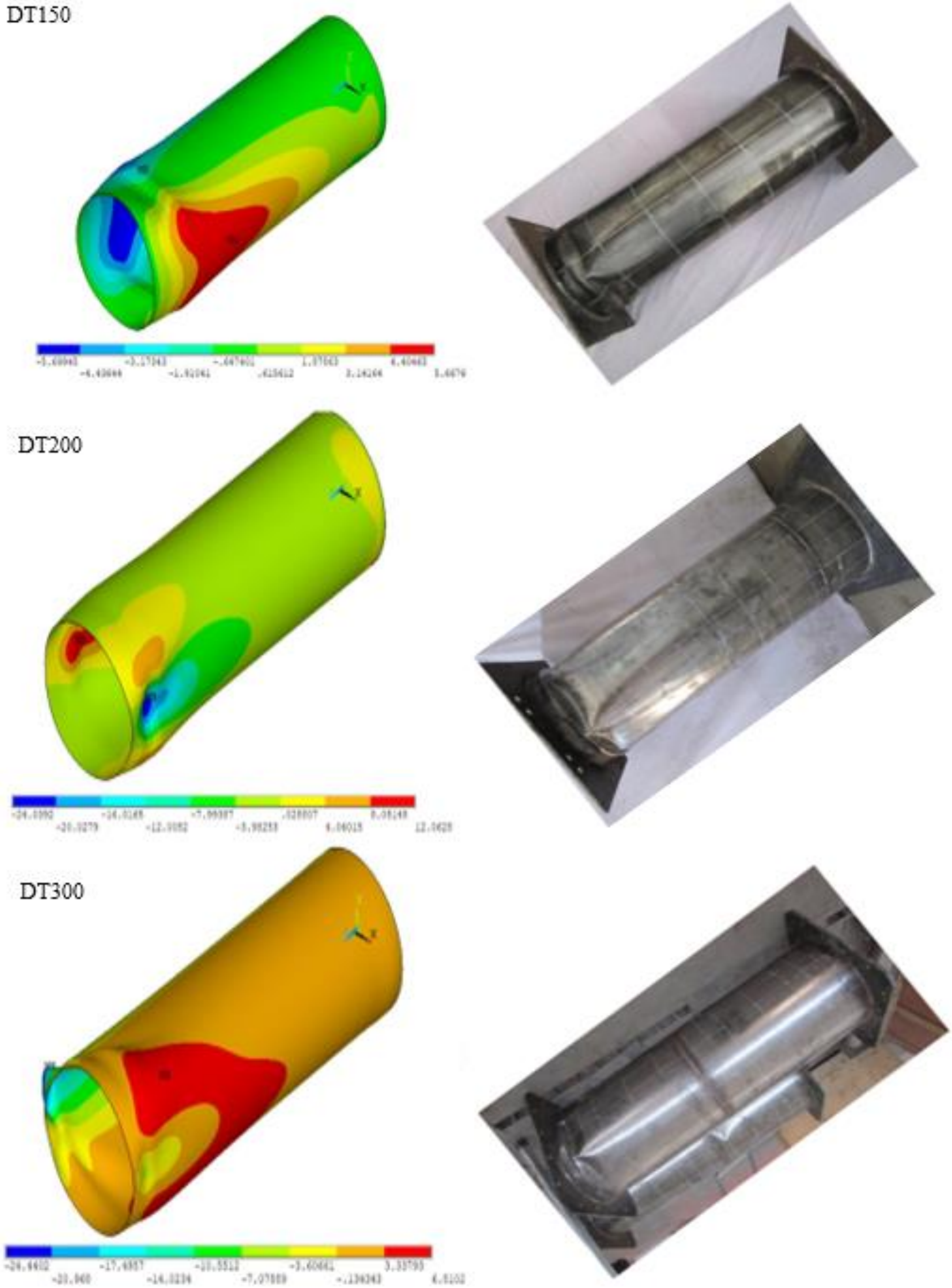


Figure 5: failure modes of numerical and experimental specimens

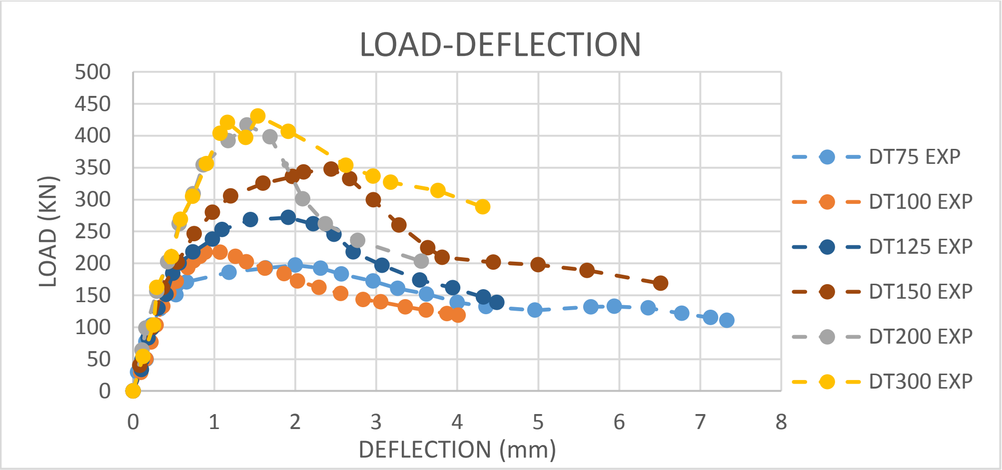


Figure 6: Load-deflection curve from test

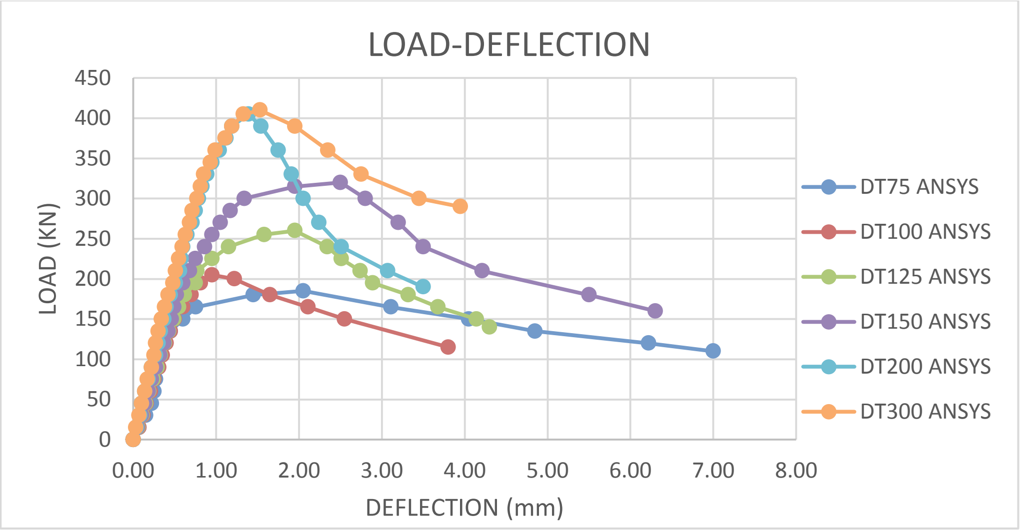


Figure 7: Load-deflection curve from ANSYS

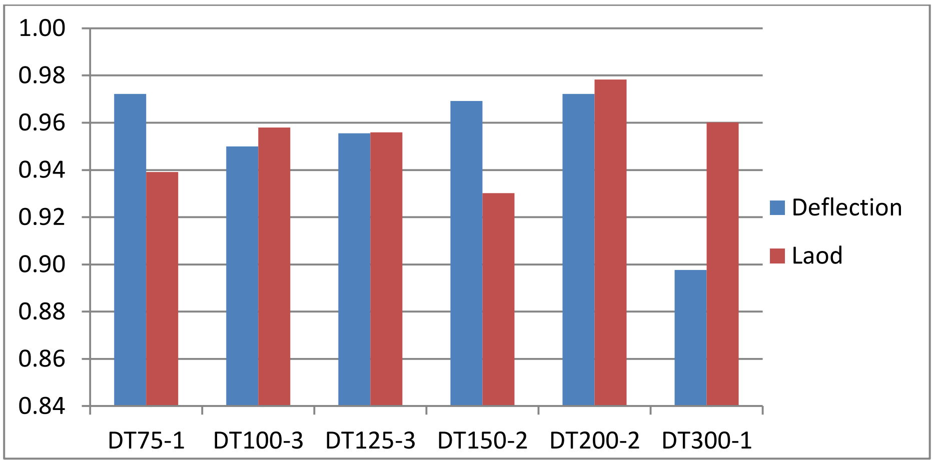


Figure 8: ANSYS model accuracy

5. Cases and parameters considered.

Twenty finite element models were conducted to study the effect of three-parameter on the behavior of circular hollow sections. The 20 models with a twenty value of diameter to thickness (D/t) ratio of high-strength steel. Length to diameter ratio is equal to 3 for all models. Group (LC1) of 20 models were analyzed under pure compression.

6. Finite element results and discussion.

Most of the specimens failed at the position of approximately D/4 away from the two ends supports, but some specimens of too slender sections of D/t higher than 200, failed through the full length of the tube, which coincides with the experimental failure modes in the literature as indicated in Figure 9.

For specimens with D/t of 10 to 50 the outward circumferential displacement appeared as a typical failure mode of all specimens in this range of D/t. specimens in this range of D/t can exceed their yield stress up to ultimate stress. The out-ward deformation was like an elephant’s foot buckle, i.e., one notable outwards circumferential buckle occurred at the two ends of the tube All specimens in this range of D/t were able to reach their yield stress and exceed it through their full length.

For Specimens with D/t of 60 to 100 the outward circumferential displacement appeared as a typical failure mode of all specimens in this range of D/t. specimens in this rang of D/t. specimens in this range of D/t can just reach their yield stress. The out-ward deformation was like a circumferential bulge occurred at the two ends of the tube All specimens in this range of D/t were able to reach their yield stress and exceed it through their full length. This shape of buckling was the typical failure mode of noncompact tubes with D/t below 100.

For Specimens with D/t of 110 to 250 The sharp out-ward deformation was like an elephant’s foot buckle occurred at the two ends of the tube. All specimens in this range of D/t were not able to reach their yield stress. the sharp outward circumferential displacement was the typical failure mode of slender tubes with D/t above 110.

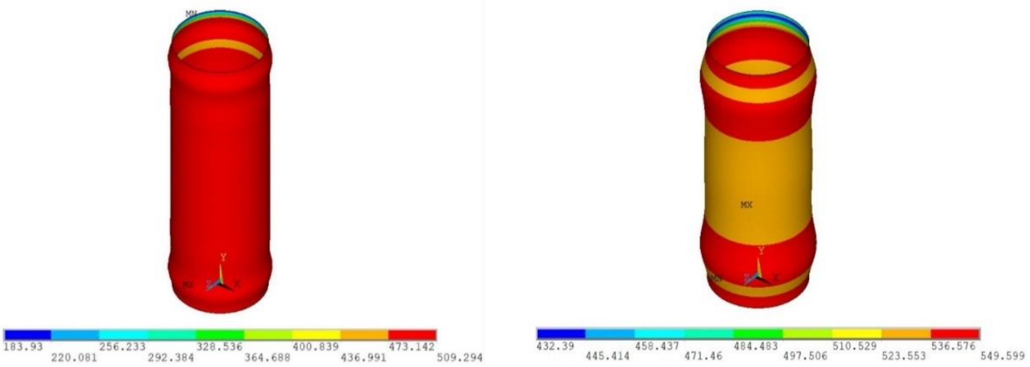


Figure 9: stress through tube length and typical failure modes of specimens

7. Summary and Conclusions.

Finite element model using ANSYS software was conducted to resemble the failure mode and load-carrying capacity of circular hollow section CHS, which are conducted through an experimental study by others. The analytical models have shown high degree of agreement with the experimental results in both load-carrying capacity and failure modes of the specimens. Based on the analytical study and the gathered experimental data, the following conclusion can be drawn:

- Most of the specimens failed at the position of approximately D/4 away from the two ends supports.
- Too slender sections with D/t higher than 200 failed through the full length of the tube.
- The outward deformation appeared as a typical failure mode of all specimens.
- The ductility decreases with the increase of D/t.

8. References.

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