WEB CRIPPLING BEHAVIOUR IN AUSTENITIC STAINLESS STEEL CHANNEL SECTIONS UNDER INTERIOR ONE FLANGE LOADING

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ABSTRACT

This study investigates the web crippling behavior of austenitic stainless-steel channel sections under interior one-flange loading conditions, with a focus on enhancing predictive accuracy through Finite Element Analysis (FEA) using ANSYS 2024 R2. The primary objectives are to develop and validate a detailed numerical model for simulating web crippling and combined bending-crippling failures, and to conduct a comprehensive parametric study to evaluate the influence of key geometric and material properties. A total of 300 simulations were performed to examine the effects of yield strength, inside bent radius, section thickness, and bearing length on structural response. The results reveal that web crippling strength varies linearly with yield strength and bearing length, with increases of 6–7% and 10% observed for respective parameter enhancements. Thickness emerged as the most influential parameter, with a 20% increase resulting in approximately 35% gain in crippling strength. Conversely, an increase in inside bent radius led to a reduction in strength, particularly for thicker sections, likely due to induced eccentricities. The study provides essential insights into the mechanics of web crippling in thin-walled stainless-steel sections and establishes a validated modeling approach for future design optimization and code development.

Keywords: Web crippling, Austenitic stainless steel, Channel sections, Interior one-flange loading, Finite Element Analysis (FEA), ANSYS 2024 R2, Bilinear isotropic hardening, Parametric study, Yield strength, Inside bent radius, Section thickness, Bearing length

INTRODUCTION

Stainless steel, particularly austenitic stainless steel, is increasingly used in structural applications due to its excellent corrosion resistance, high ductility, and impressive mechanical performance over a wide temperature range. Among the various grades, austenitic stainless steels, such as the 300 and 200 series, dominate construction and industrial use due to their non-magnetic nature, weldability, and cold-forming capabilities. Their applications extend from cladding and drainage systems to load-bearing members and structural supports. However, despite their many advantages, the behavior of stainless steel structural sections—especially under localized loading conditions—requires deeper investigation to ensure safety and performance in real-world construction scenarios.

One critical failure mode affecting thin-walled stainless steel members is web crippling, also referred to as web crushing. This localized failure occurs near points of concentrated loads or reactions and is characterized by yielding or buckling of the web portion of the section. In cold-formed and stainless steel channel sections, web crippling is a dominant failure mechanism, particularly in short-span members where shear and localized loads govern behavior more than flexural stresses. Unlike global buckling, web crippling is highly sensitive to local geometric features, load position, and material properties, making it a complex phenomenon to predict and mitigate. This complexity is further compounded in stainless steel sections, where the non-linear stress-strain behavior, anisotropy, and residual stresses from manufacturing processes influence load-bearing capacity.

Given the growing use of austenitic stainless steel channels in modern construction and infrastructure projects, it is essential to develop a robust understanding of their web crippling performance. Accurate prediction of web crippling strength is vital for safe structural design, especially under conditions of interior one-flange loading where only part of the cross-section is engaged. Finite Element Analysis (FEA) offers a powerful tool to model this behavior, allowing for controlled parametric studies that assess the influence of critical parameters such as section thickness, bearing length, yield strength, and inside bend radius. These studies provide the necessary design insights to optimize stainless steel member dimensions, improve design codes, and ensure the safe and efficient use of stainless steel in structural applications where localized loading is significant.

OBJECTIVES

To develop web crippling and bending finite element models for austenitic stainless steel channels under interior one flange loading condition using ANSYS 2024 R2.

To perform parametric study on the effect of variation of parameters such as Section thickness. Bearing length. Inside bent radius and Yield strength.

METHODOLOGY

This study employs a numerical methodology to evaluate the web crippling strength of austenitic stainless steel channel sections under Interior One-Flange (IOF) loading conditions using finite element analysis (FEA). The 3D geometric models were developed in SolidWorks 24 and analyzed using ANSYS 2024 R2, where the material behavior was modeled using a bilinear isotropic hardening approach based on material properties—elastic modulus, yield strength, and ultimate strength. The web crippling capacities were determined through displacement-controlled loading, with fixed bottom supports to simulate realistic boundary conditions. Validation of the numerical model was carried out by comparing the results against experimental data, and upon successful verification, the model was employed for a comprehensive parametric study. This analysis explored the influence of varying parameters such as section thickness, yield strength, inside bend radius, and bearing length on three different channel profiles across two sample lengths.

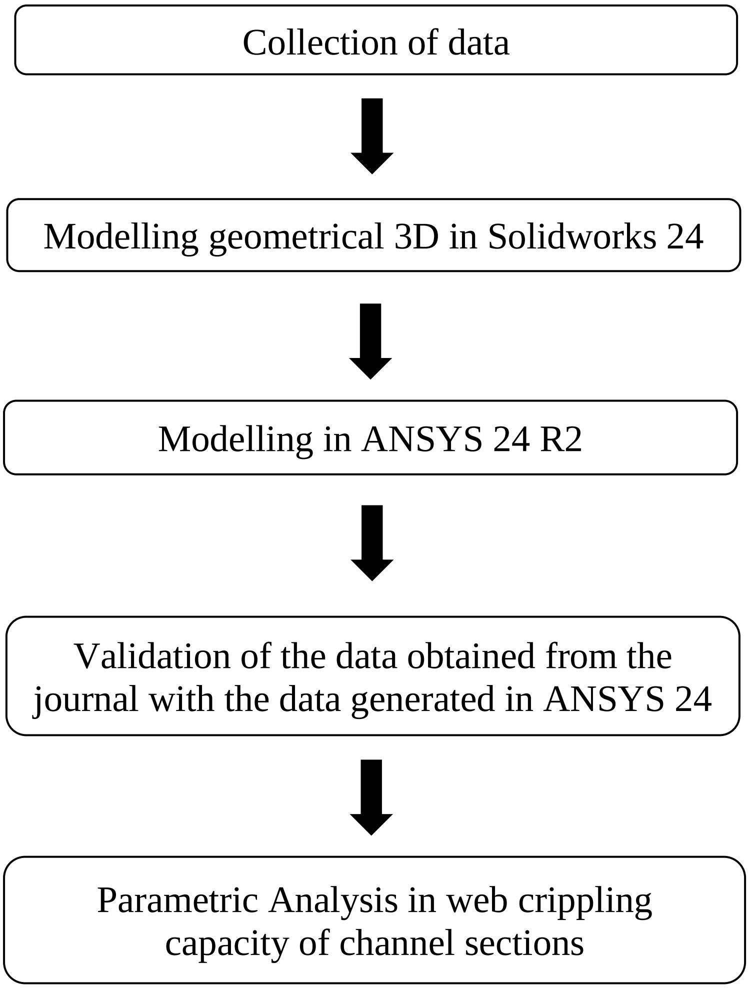

Figure 1: Flow chart of Methodology

FEA MODELLING OF AUSTENITC STAINLESS STEEL CHANNEL SECTION UNDER INTERIOR ONE FLANGE LOADING FOR PARAMETRIC STUDY

For the numerical study, the finite element analysis package ANSYS 2024 R4 is used. In order to simulate the web crippling behaviour of the austenitic stainless steel channel sections, the channels, supporting blocks, as well as the applied loading condition including the bearing plates and support blocks were modelled. The geometric models of all specimens were created using the CAD software package Solidworks 24. All parts were created without merging each other, in order to properly defining the contacts between each components of the experimental setup.The 3D solid model of the channel section generated in Solidworks 24 is converted to a 3d surface model in ANSYS SpaceClaim by using the mid surface generation., as the model of the channel section needed to be modelled as a surface

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for using the SHELL181 for discretization of the model.

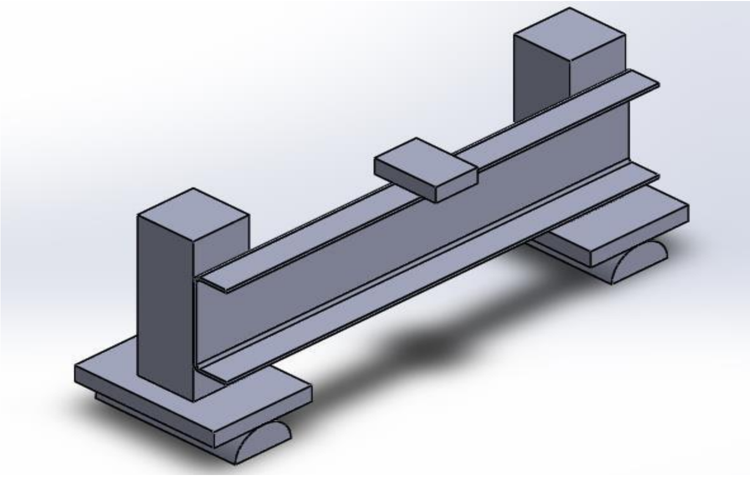


Figure 2: Geometry of the model in Solidworks 24

The channel sections were fabricated using Stainless steel (NL) material, available in the general non-linear material library of ANSYS. The plasticity characteristics for the model were provided by using bilinear isotropic hardening property. In bilinear isotropic hardening model the stress-strain curve of a material can be achieved by inputting two parameters, yield strength and tangent modulus. The yield strength is one of the parameters considered in this study. The bearing plates were designed using the default structural steel available in ANSYS 2024 R4. The supporting blocks, loading plates and half rounds were modelled as rigid bodies. The cross sectional details and material properties of the specimens in the experimental procedures are shown in table 1 and 2 respectively.

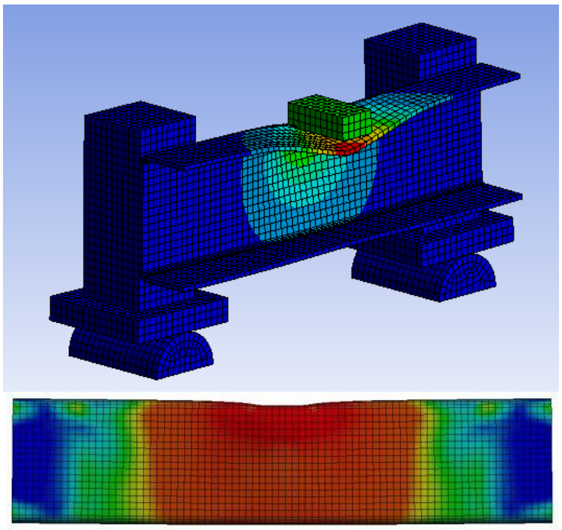
Table 1 Cross section details of Specimen Considered

Specimen dimension	**d (mm)**	**bf (mm)**	**N (mm)**	**t (mm)**	**r (mm)**	**L (mm)**
175x60x6	177.91	59.77	50	6.02	5.48	774.67
200x75x4	201.55	74.89	100	4.09	3.59	900.01

Table 2 Material properties of specimen considered

Specimen dimension	**Elastic modulus (MPa)**	**Yield strength (MPa)**	**Ultimate yield strength (MPa)**
175x60x6	220,000	245	639
200x75x4	220,000	265	669

The total deformation in both experimental as well as finite element study was observed to be same. Also an almost equal web crippling strength versus displacement graph is obtained



.Figure 3: Failure pattern in ANSYS

From the FEM analysis, it is understood that only 1 to 2 % variation has occurred from the experimental study for the two specimens.

RESULTS AND DISCUSSIONS

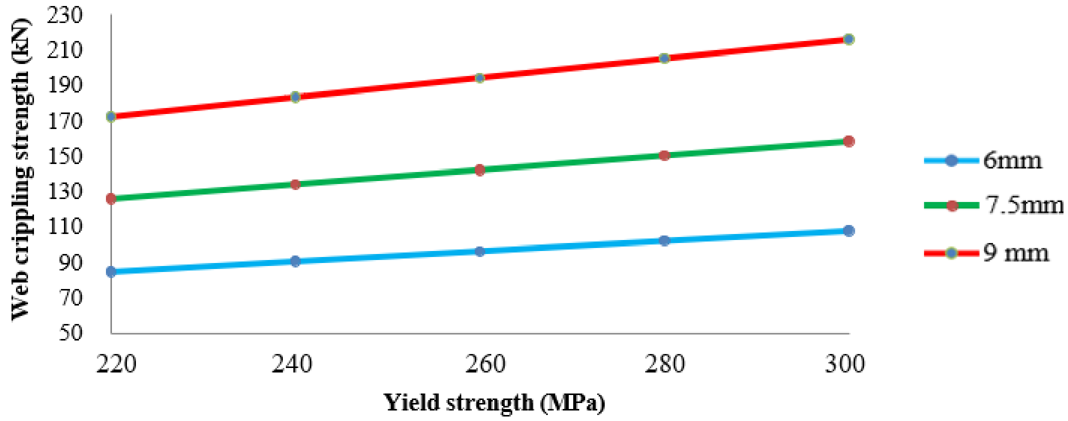
A comprehensive parametric investigation was conducted to study about the effect of variation of various parameters on the web crippling strength of the stainless steel channel section using the validated finite element model. The parametric study was conducted on a total of 270 samples. The influences of parameters yield strength**,** inside bent radius**,** Section thickness and Bearing length were studied.

EFFECT OF VARIATION OF YIELD STRENGTH

Effect of variation of yield strength on web crippling capacity of stainless-steel channel sections under IOF loading condition was studied by varying the yield strength of the stainless-steel channel section. Total of five different yield strengths were considered, for the purpose of investigating the effect of variation of this parameter. The yield strength was varied in regular interval of 20 MPa, starting from 220 MPa to reach at 300 MPa. The study was conducted in 90 samples, out of which 45 samples for studying the variations of web crippling strength with yield strength and the rest 45 samples to analyse the effects of yield strength on combined effect of bending and web crippling strength. In order to obtain both the above-mentioned failure strengths, two different lengths of specimens were considered, i.e., 600 mm and 1000 mm samples. Three channel sections with three varying thicknesses with inside bent ratio (r/t) fixed to unity and bearing length of 50 mm were considered for the research of this parameter. The details of the web crippling strengths of the specimens obtained from the finite element analysis are presented in table 3 and corresponding graphs are represented in Figure 4

Table 3 Variation of web crippling strength with yield strength for 600 mm sample

Specimen dimension	Yield strength (MPa)				
	220	240	260	280	300
130x65x6	82.71	90.325	95.945	101.53	107.83
130x65x7.5	124.35	132.49	140.44	148.21	156.34
130x65x9	169.15	180.1	190.95	201.78	212.4
150x75x6	84.104	90.098	95.904	101.71	107.33
150x75x7.5	125.36	133.69	141.86	149.97	158.03
150x75x9	171.57	182.79	193.86	204.81	215.66
160x80x6	86.452	92.298	98.091	103.84	109.16
160x80x7.5	128.41	137.26	145.59	153.82	162.04
160x80x9	177.52	188.91	200.54	211.87	223.18



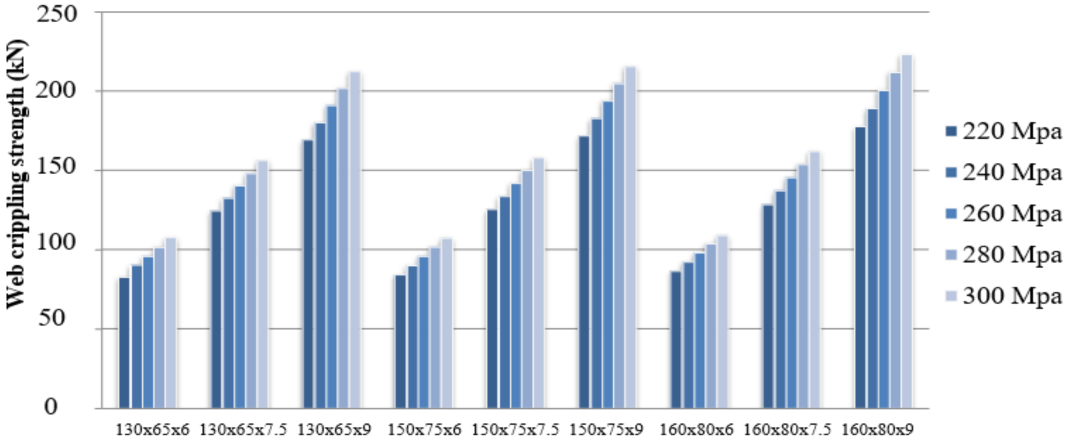
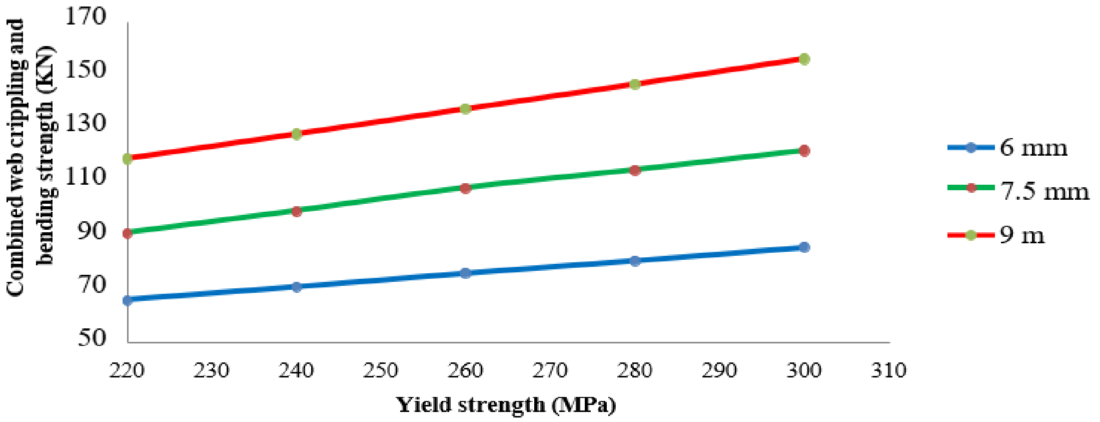


Figure 4: a) Variation of web crippling strength with yield strength for 130 x 65 sample b) Variation of web crippling strength with yield strength for 600 mm length samples

The details of the combined web crippling and bending obtained from the finite element analysis is tabulated below in table 4 and corresponding graphs are represented in Figure 5.

Table 4: Variation of combined web crippling and bending strength with yield strength for 1000 mm sample

Specimen dimension	Yield strength (MPa)				
	220	240	260	280	300
130x65x6	65.817	70.69	75.845	80.63	85.703
130x65x7.5	90.894	99.13	107.71	114.43	121.63
130x65x9	118.76	127.91	137.26	146.49	156.01
150x75x6	74.92	79.82	85.06	90.21	95.715
150x75x7.5	101.91	109.94	119.45	128.32	136.4
150x75x9	128.39	137.88	147.78	157.13	166.75
160x80x6	74.12	79.72	85.29	90.73	96.39
160x80x7.5	109.79	117.74	126.09	133.78	141.84
160x80x9	136.29	147.62	158.97	170.39	181.82



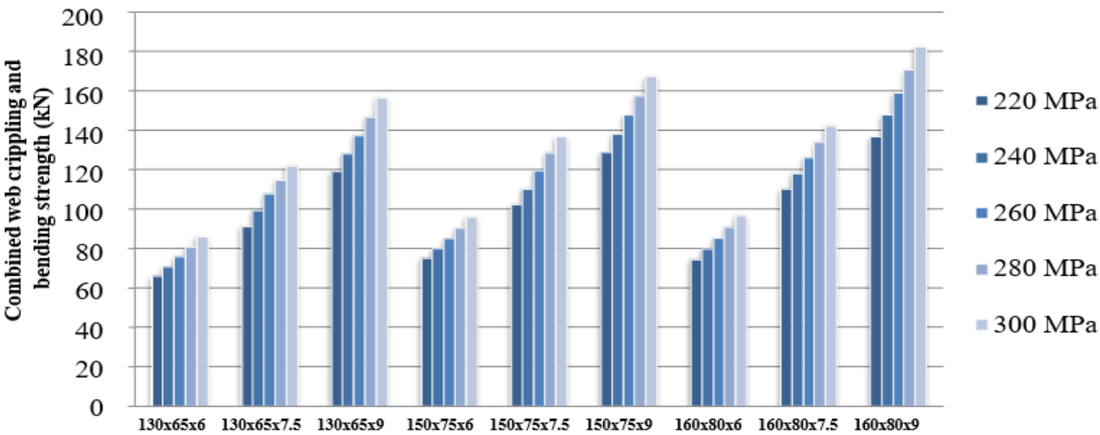


Figure 5: a) Variation of combined web crippling and bending strength with yield strength for 130x65 sample b) Variation of combined web crippling and bending strength with yield strength for 1000 mm sample

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The influence of yield strength on web crippling strength and combined effect of bending and web crippling strength is graphically represented in figure 4 and 5 respectively. For both kinds of strengths, the variation shows linear behavior. Also, the web crippling strength was found to be more than the combined bending and crippling strength for specimens having same cross section. The slope of the graph is found increasing as the thickness of the section increases. For all the specimens, three different thicknesses were also considered. In both failure cases, observed an increase of 6-7% in strength for an increase of yield strength by 20 MPa.

EFFECT OF VARIATION OF INSIDE BENT RADIUS

The inside bent radius or the fillet radius is one of the cross-sectional parameters considered in this study. The inside bent radius variation in the model is incorporated by varying the ratio of inner bend radius to thickness of the channel section (r/t). For finding the effect of variation of inside bending radius on web crippling strength and combined bending and web crippling strength under IOF loading, five different r/t ratios were considered.

Same as in the previous parametric study, a total of 90 samples were considered. 45 were modelled with 600 mm length for studying the effect on web crippling strength and 45 samples with 1000 mm sample for investigation the effect on combined web crippling and bending effect. The yield strength of all samples was chosen as 240 MPa. The bearing length adopted for all the models were 50 mm length.The web crippling strengths obtained from the finite element study are presented in table 5 and corresponding graphs are represented in Figure 6.

Table 5 Variation of web crippling strength with inside bend radius for 600 mm length sample

Specimen dimension	**Inside bend radius (r/t)**				
	0.6	**0.8**	**1**	**1.2**	**1.4**
150 x 75 x 6	97.58	93.54	90.098	86.406	82.72
150 x 75 x 7.5	138.67	135.51	133.69	131.77	129.29
150 x 75 x 9	187.3	185.61	182.79	179.6	176.4
160 x 80 x 6	100.24	95.446	92.298	88.1	85.67
160 x 80 x 7.5	143.8	138.88	137.26	135.34	133.43
160 x 80 x 9	195.59	191.9	188.91	185.87	182.51
130 x 65 x 6	95.023	91.088	90.325	84.567	79.7
130 x 65 x 7.5	137.23	133.62	132.49	127.06	124.08
130 x 65 x 9	186.07	183.67	180.1	176.07	172.98

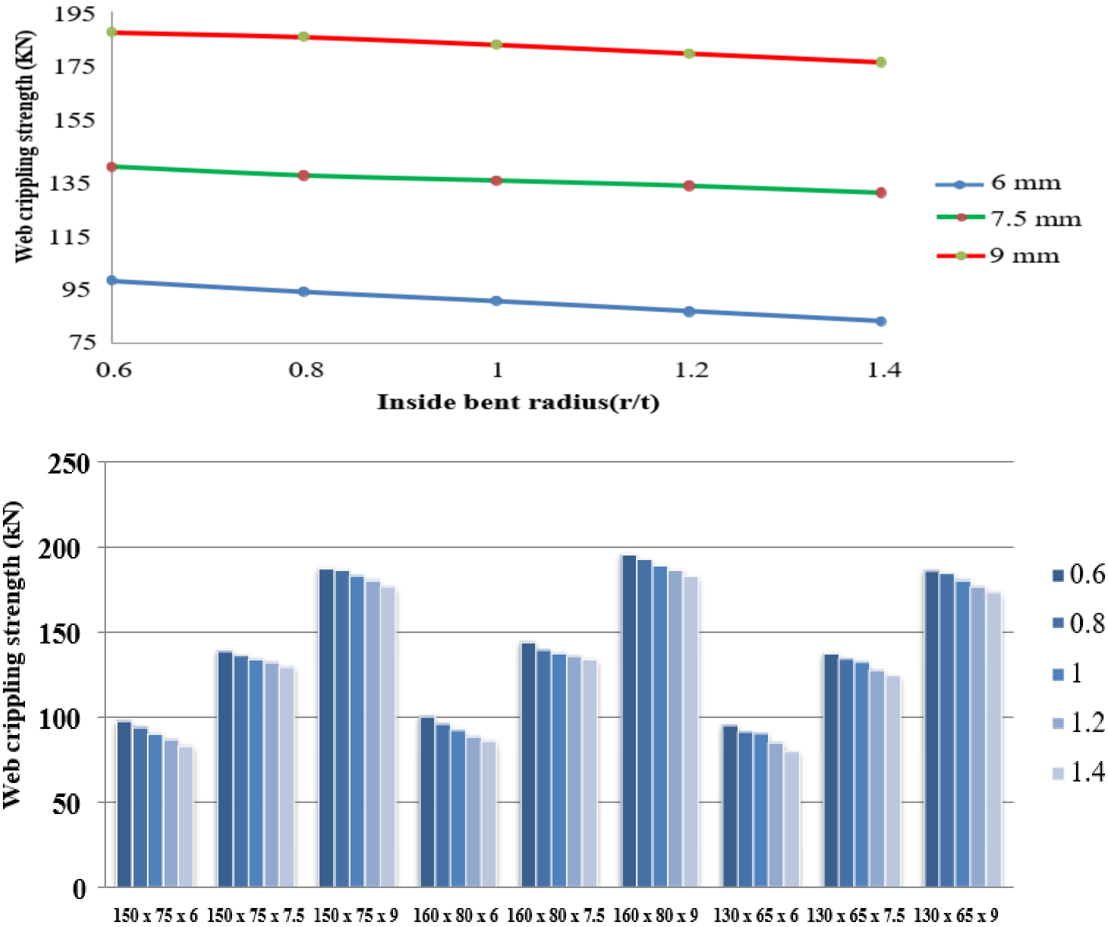
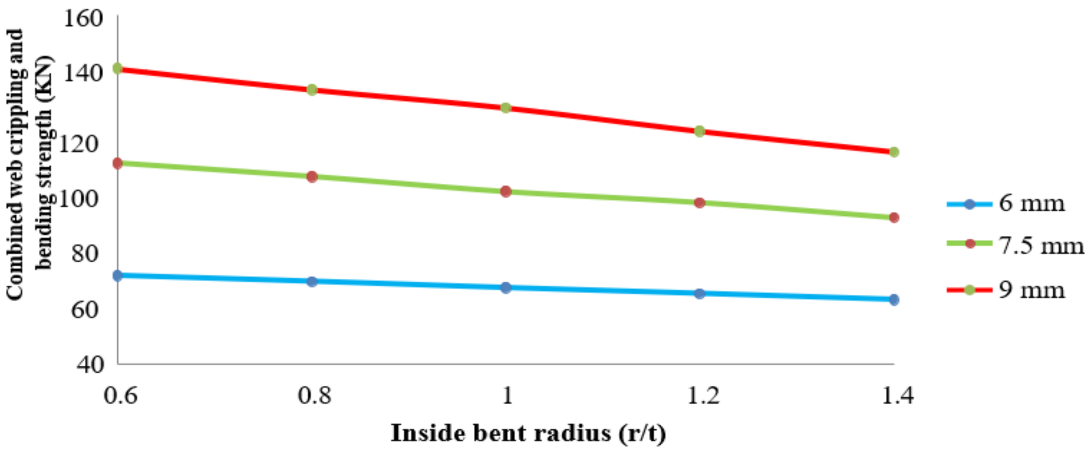


Figure 6: a) Variation of web crippling strength with inside bend radius for 130x65 sample b) Variation of web crippling strength with inside bend radius for 600 mm samples

The details of the combined web crippling and bending obtained from the finite element analysis is tabulated below in table 6 and corresponding graphs are represented in Figure 7.

Table 6 Variation of combined web crippling and bending strength with inside bend radius for 1000 mm length sample

Specimen dimension	Inside bend radius (r/t)				
	0.6	0.8	1	1.2	1.4
130 x 65 x 6	70.34	68.29	66.08	64.06	61.96
130 x 65 x 7.5	108.93	104.31	99.13	95.36	90.21
130 x 65 x 9	141.33	134.19	127.91	119.86	112.75
150 x 75 x 6	75.06	72.91	70.69	68.23	65.73
150 x 75 x 7.5	117.13	113.24	109.94	103.95	98.79
150 x 75 x 9	146.11	140.83	137.88	133.19	128.36
160 x 80 x 6	85.244	82.31	79.82	76.35	73.92
160 x 80 x 7.5	125.97	121.49	117.74	113.63	109.48
160 x 80 x 9	160.28	153.67	147.62	141.61	135.69



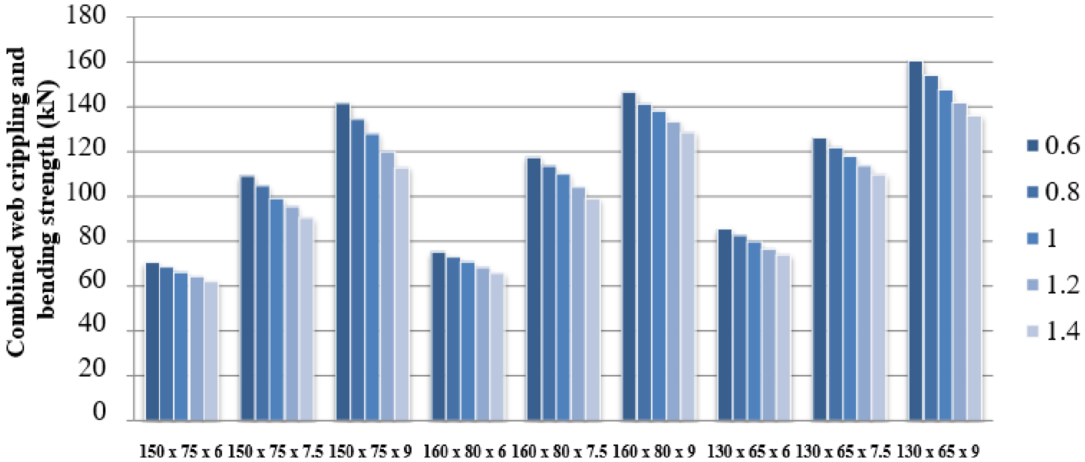


Figure 7: a) Variation of combined web crippling and bending strength with inside bend radius for 130x65 sample b) Variation of combined web crippling and bending strength with inside bend radius for 1000 mm samples

The variation in inside bent radius was achieved by varying the ratio of inside bent radius to thickness (r/t). The linear varying trend was observed for both web crippling as well as combined bending and crippling strengths. Apart from the increasing trend by yield strength, the inside bent radii exhibit negative slopes. In all cases the web crippling strength was the dominant. The strength decreased by an average of about 5% for an increase of r/t ratio by 0.2. The strength was found to be decreasing at higher rate for the specimens with high thicknesses.

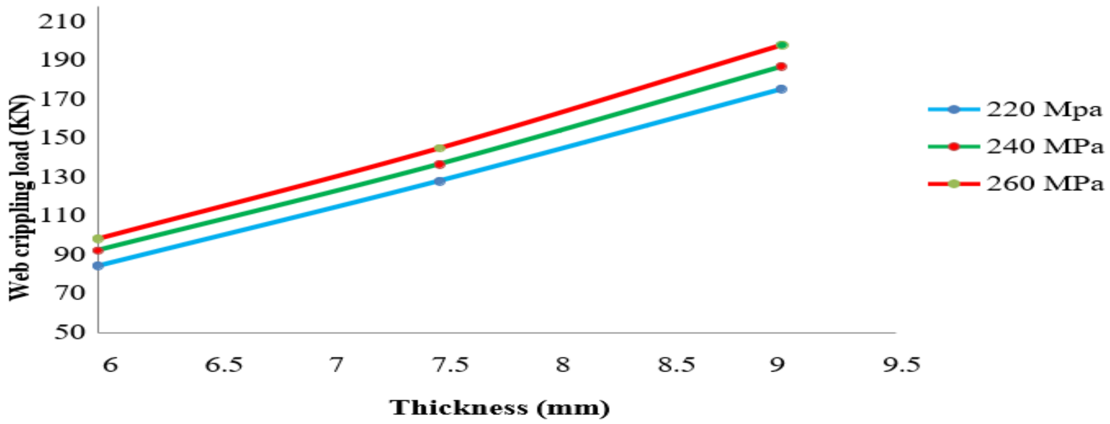
EFFECT OF VARIATION OF SECTION THICKNESS

The thickness of the channel section is one of the important parameters considered in this study. Three different channel sections were considered for studying the effect of variation of thickness on the web crippling strength and combined effect of bending and web crippling strength. The bearing length is taken as 50 mm and the inside bent ratio is fixed as unity. For each channel sections considered three different thicknesses as well as three yield strengths were also considered.

A total of 54 numbers of samples were studied considering the above-mentioned variations. Both the failure strengths were studied by varying the lengths of the specimens. The web crippling strengths and combine web crippling strengths obtained from the finite element analysis is consolidated and presented in table 7 and the graph represented in Figure 8.

Table 7 Variation of web crippling strength with thickness for 600 mm length sample

Specimen dimension	Thickness (mm)		
	6	7.5	9
130 x 65 (220)	82.71	124.35	169.15
130 x 65 (240)	90.325	132.49	180.1
130 x 65 (260)	95.945	140.44	190.95
150 x 75 (220)	84.104	125.36	171.57
150 x 75 (240)	90.098	133.69	182.79
150 x 75 (260)	95.904	141.86	193.86
160 x 80 (220)	86.452	128.41	177.52
160 x 80 (240)	92.298	137.26	188.91
160 x 80 (260)	98.091	145.59	200.54



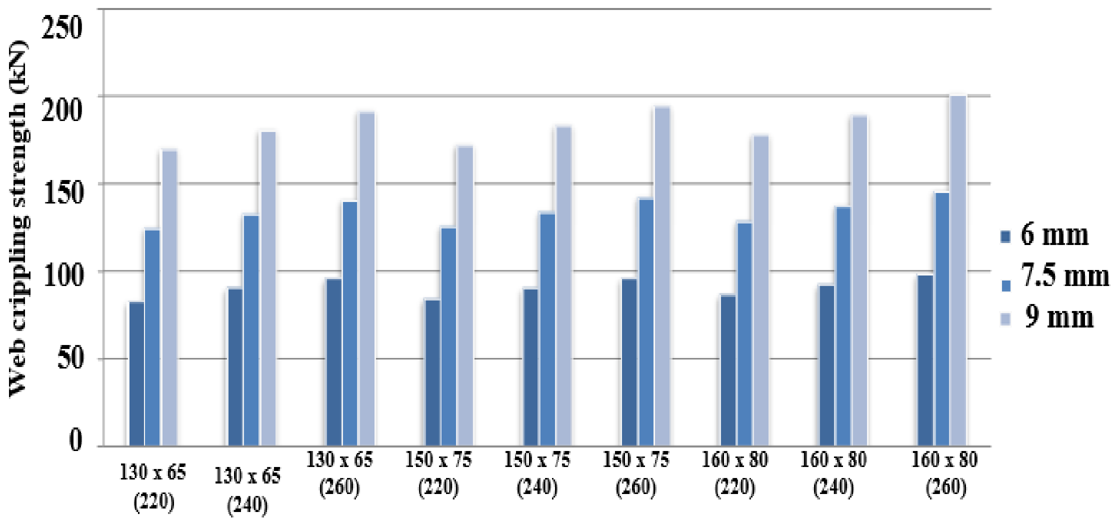
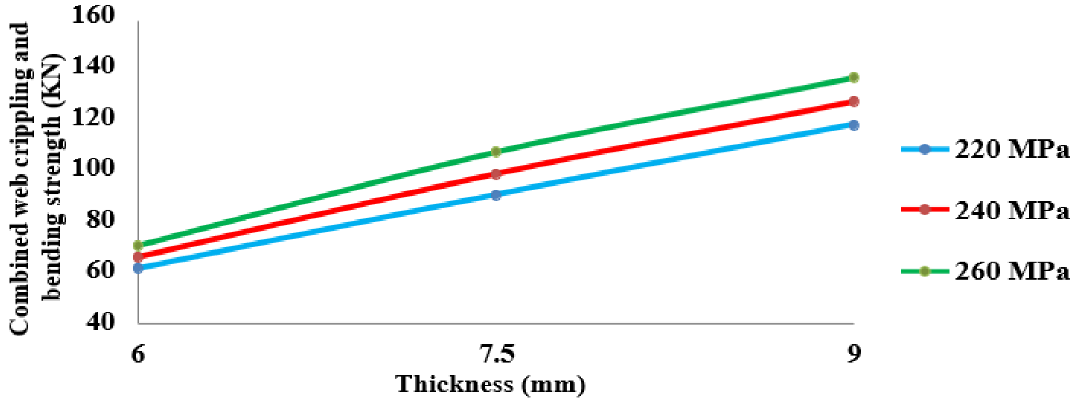


Figure 8: a) Variation of web crippling strength with thickness for 130x65 sample b) Variation of web crippling strength with thickness radius for 600 mm samples

The details of the combined web crippling and bending obtained from the finite element analysis is tabulated below in table 8 and corresponding graphs are represented in Figure 9.

Table 8 Variation of combined web crippling and bending strength with thickness for 600 mm length sample

Specimen dimension	**Thickness**		
	6	**7.5 mm**	**9 mm**
130 x 65 (220)	61.686	90.894	118.76
130 x 65 (240)	66.08	99.13	127.91
130 x 65 (260)	70.631	107.71	137.26
150 x 75 (220)	65.817	101.91	128.39
150 x 75 (240)	70.69	109.94	137.88
150 x 75 (260)	75.845	119.45	147.78
160 x 80 (220)	74.92	109.79	136.29
160 x 80 (240)	79.82	117.74	147.62
160 x 80 (260)	85.06	126.09	158.97



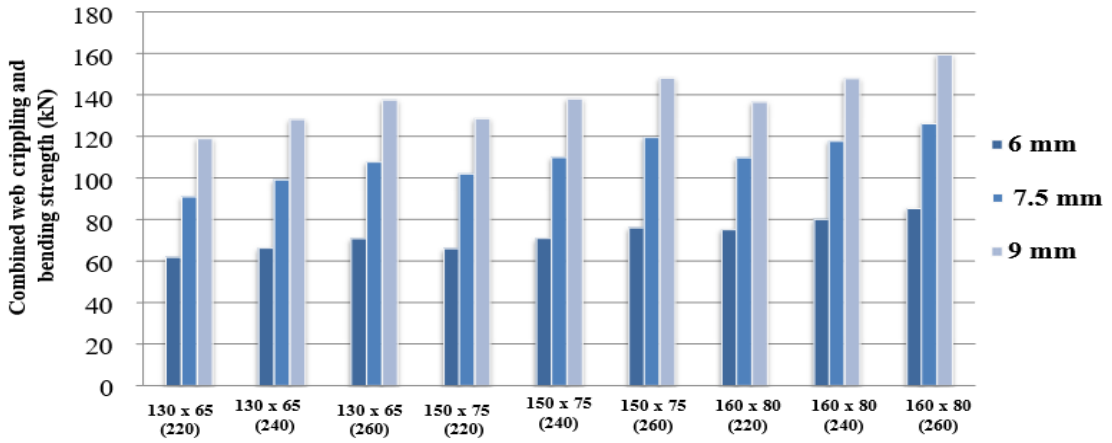


Figure 9: a) Variation of combined web crippling and bending strength with thickness for 130x65 sample b) Variation of combined web crippling and bending strength with thickness for 1000 mm samples

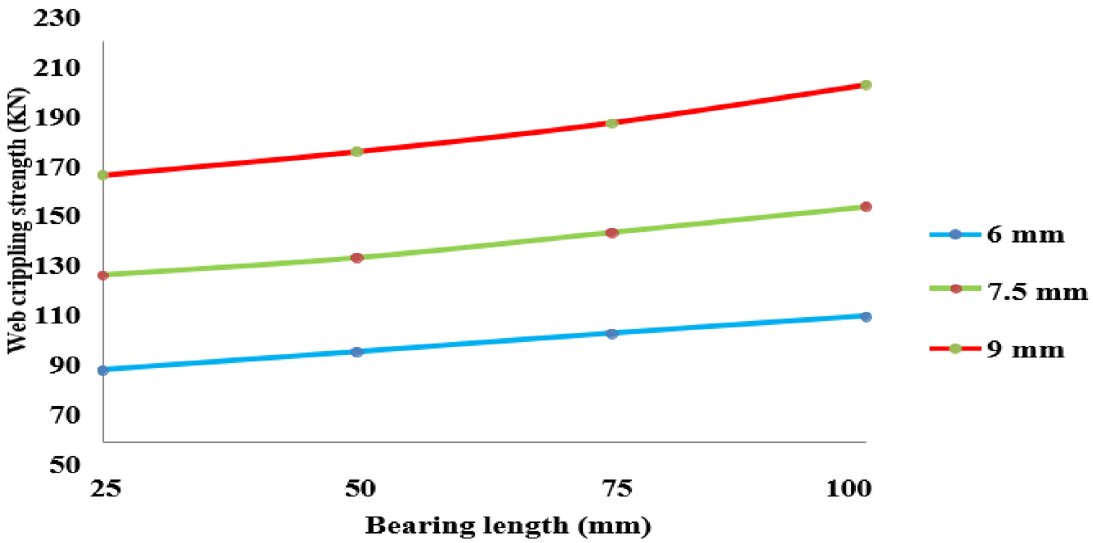
Thickness is the parameter, observed with more influence on web crippling and combined effect of crippling and bending. For all specimens, the web crippling strength dominates over combined strength. On an average increase of 20 % in the thickness of the section, web crippling strength as well as the combined strengths had an increment of 35%.

EFFECT OF VARIATION OF BEARING LENGTH

To study the influence of load bearing plate lengths, 36 different models were analysed under IOF loading condition. Four different bearing lengths were considered for the study, i.e., 25-, 50-, 75- and 100-mm loading plates. The yield strength of all the samples under consideration were fixed as 240 MPa. The inside bent radius is fixed as unity. The effect of web crippling strength with the variation of bearing length is presented in table 9 corresponding graphs are represented in Figure 10.

Table 9 Variation of web crippling strength with bearing length for 600 mm length sample

Specimen dimension	**Bearing length (N)**			
	25 mm	**50 mm**	**75 mm**	**100 mm**
130x65x6	82.281	90.325	98.6	106.4
130x65x7.5	124.67	132.49	143.87	155.42
130x65x9	169.51	180.1	193.01	210
150x75x6	84.541	90.098	98.917	105.93
150x75x7.5	123.22	133.69	145.68	152.18
150x75x9	173.25	182.79	199.49	205.58
160x80x6	86.34	92.298	101.29	107.6
160x80x7.5	125.39	137.26	149.56	158.05
160x80x9	174.63	188.91	205.68	216.39



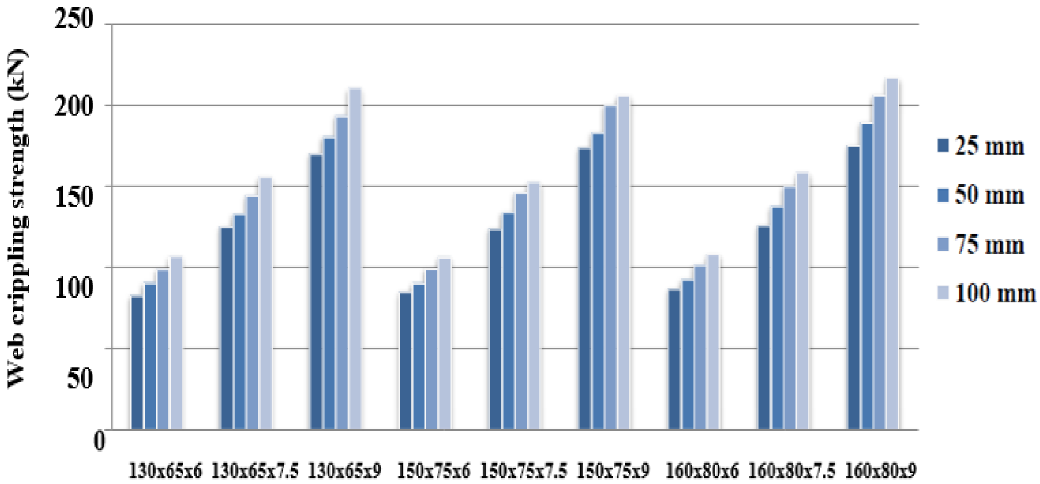


Figure 10: a) Variation of web crippling strength with bearing length for 600 mm samples b) Variation of combined web crippling and bending strength with thickness for 600 mm samples

The effect of web crippling strength with the variation of bearing length was observed linear. In all the cases the specimens with highest bearing length shows the highest web crippling strength. For every 25 mm increment in the bearing length the web crippling capacity increased by 10%.

CONCLUSIONS

A finite element model for austenitic stainless-steel channels was developed using ANSYS 2024 R2 in this study. Bilinear isotropic hardening property of the material was considered. Using the developed model, an extensive parametric study was conducted by varying the yield strength, inside bent radius, thickness of channel section and bearing length. Nearly three hundred samples were studied numerically by varying the mentioned parameters. In all the cases, the trend lines were drawn and compared with numerical results to understand the variation of web crippling strength with the parameters under consideration.

From the study, it was found that web crippling strength and combined bending and web crippling strength of austenitic stainless steel channel sections under interior one flange loading condition varies linearly with the variations of yield strength. It was observed that the combined bending and crippling strength is lower than the web crippling strength. In both failure cases, an increase of 6-7% observed in strength for an increase of yield strength by 20 MPa.

The effect of variation of web crippling strength and combined bending and crippling strength with inside bent radius was observed linear. Both the strengths decreased by the increase of inside bent radius. This effect is more prominent for the sections with higher section thicknesses and can be due to the presence of eccentricity caused by the inside radius leading to an additional moment generated. From the parametric study, it was observed that thickness is the highest influential parameter. The numerical study exhibit almost straight line variations. On an average increase of 20 % in the thickness of the section, web crippling strength as

well as the combined strengths had an increment of 35%.
As per the parametric study, the web crippling strength increases as the bearing length increases. For an increase of 25 mm of bearing length, web crippling strength increased by an average of 10%.

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