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Web Crippling Capacity of Cold Formed Steel Channel Sections With and Without Openings

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Abstract - *Steel is an important construction material since ancient days. Among steel, Cold Formed Steel (CFS) are getting more popular due to its advantages including light weight, high strength to weight ratio, resistance to fire etc. These are the sections which are shaped near room temperature. CFS channel sections are commonly used nowadays as bearing and non- load bearing walls, partition walls, in multi-rise buildings, framings. In this channel sections the holes are provided in the web portion for plumbing services and installation of ducts. However such opening made the section more vulnerable to failures including web crippling and web buckling. In this paper various parameters which affect the web crippling capacity of the channel sections are analyzed and the analysis is also done to find the optimum location of web holes in the channel sections.*

Key Words: Cold Formed Steel Sections, Web Crippling, Web Buckling

1. INTRODUCTION

Advanced structures are quite common in nowadays due to growth in construction industry, Due to this advancement many industries are looking forward to develop and use sustainable building materials. Steel is an important construction material using nowadays due to its innumerable advantages which make it as a perfect option for modern building construction. There are mainly 2 types of steel used for the construction purposes. 1) Hot Rolled Steel Sections 2) Cold Formed Steel Sections. As the name indicates, CFS sections are the sections which are rolled, bended, pressed or shaped at near room temperature. We do not need to provide extra heat for shaping them as it is required in hot rolled steel sections. In hot rolling process steel is rolled by providing high temperature which is more than 1700 Fahrenheit. But such hot rolled steel have a tendency to shrink when cool off, thus giving less control on size and shape. Advantages of CFS sections over Hot Rolled Steel Sections includes CFS does not shrink, no heat is required to form shape, light weight, non- combustible, won't absorb moisture, resist fire and termites and high strength to weight ratio. Nowadays openings are provided in the web portion of channel section for ease of installation of electrical or plumbing devices. Such holes result in the sections becoming more vulnerable to failures especially under concentrated loads applied near the web holes. Two common type of failures in CFS sections include 1) Crippling Failure 2) Buckling Failure. Web crippling failure occurred in CFS members at the web flange junction. This failure is mainly seen in the web elements due to the concentrated loads which are delivered through flange of the channel sections. The main reason for this failure is due to the application of static and dynamic loads transversally which causes direct crushing of web. Buckling is another failure mode in CFS sections due to its thin walled cross section causing loss of stability. This failure occurs when the critical buckling stress in web is less than the compressive stress acting vertically. It occurs before yielding.

Fig -1: CFS in Construction Industries

1.1 Aim

To perform the analysis on web crippling capacity of cold formed channel sections with and without opening

1.2 Objective

To understand effect of bearing length, inside bent radius, web depth and flange width on web crippling capacity of channel sections.

To study effect of web opening and web opening locations in the web crippling and buckling capacity of the channel sections

1.3 Methodology

1) Modeling and analysis of channel sections with and without hole in ANSYS Workbench by varying parameters

- Bearing Length
- Inside Bent Radius
- Web Depth
- Flange Width

2) Modeling and analysis of channel sections in ANSYS by varying web holes diameters and web hole locations

3) Comparison of results and graphs of all models for web crippling and web buckling strength.

2. MODELING AND ANALYSIS

Channel sections with and without web holes are modeled in ANSYS Workbench 2022. Material properties and section dimensions are discussed below.

2.1 Material Properties

Steel with the following properties are used for modeling the channel sections.

Poisson's ratio = 0.3

Yield Strength= 450Mpa

Tangent Strength = 0Mpa

2.2 Section Properties

Section used is channel section with and without hole. One loading plate and one supporting plate are provided. The mesh size is 5mm x 5mm mesh for bearing plates and 3mm x 3mm mesh size is adopted for beam. Generally provide the length of bearing plate as 50mm. Boundary Conditions include for loading plate translation in y axis is -8, rotation about x axis is free and all other translations & rotations are fixed and for the supporting plate all movements are fixed whereas rotation about x axis is free

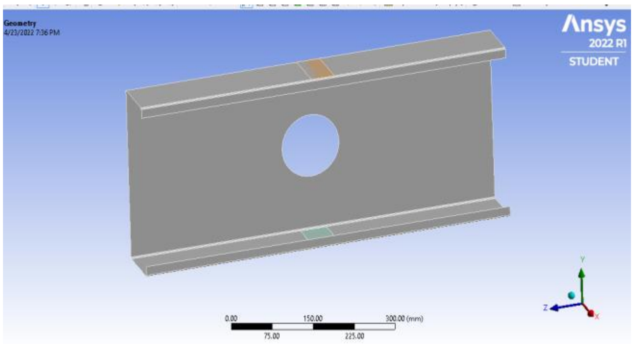

Fig -2: Channel Section With Hole

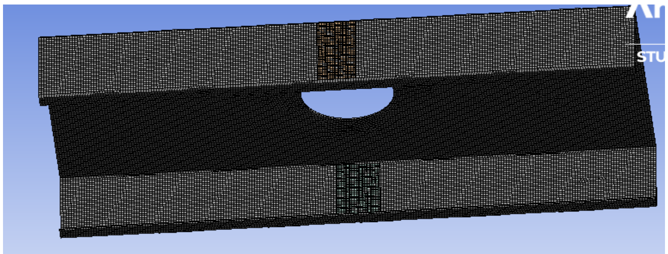

Fig -3: Meshing

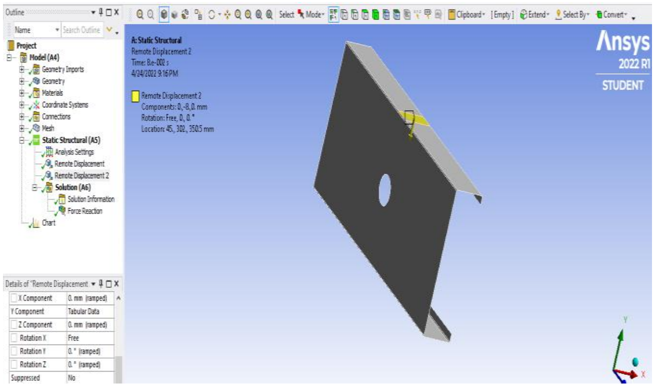

Fig -4: Boundary Conditions for Loading Plate

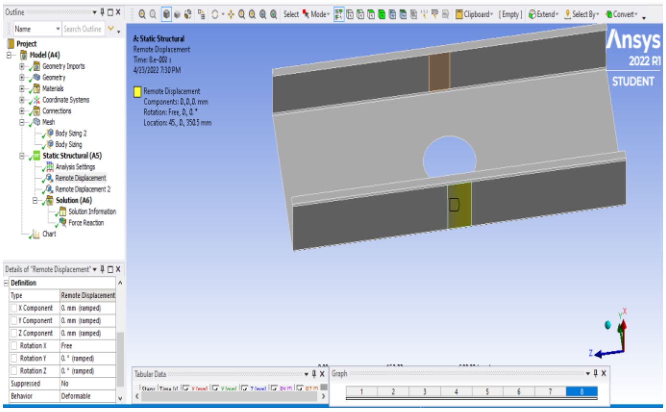

Fig -5: Boundary Conditions for Supporting Plate

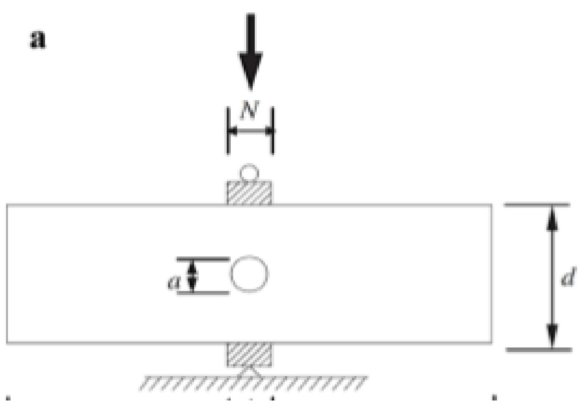

Fig -6: Schematic diagram of modeled channel section

2.3 Varying Bearing Length

Bearing plate is used to transfer concentrated compressive forces between two structural elements. Bearing length is the length along the beam under which a high concentration of stresses is transferred to the supporting structure below.

Section used – 150x45x13mm

i) without hole

ii) with hole (diameter of hole = 60 mm)

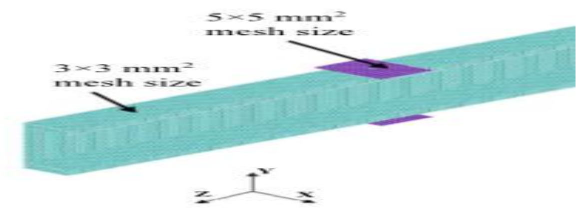

Fig -7: Section with bearing plates

The above mentioned channel sections are modeled by varying bearing length from 20 mm to 60 mm in order to find the effect of bearing length on the strength of the channel sections. The tabular data showing the results are given below.

Table -1: Web Crippling Load (KN) in Channel Section without hole corresponding to different bearing length

Deflection (mm) \ Bearing Length (mm)	20	30	40	50	60
1	6.2725	8.0638	9.3404	10.699	12.017
2	8.2736	11.15	12.91	14.788	16.546
3	9.1381	12.722	14.737	16.955	19.021
4	9.6725	13.82	16.013	18.436	20.698
5	10.063	14.686	17.023	19.615	22.02
6	10.37	15.426	17.894	20.634	23.16
7	10.622	16.081	18.668	21.545	24.183
8	10.835	16.656	19.358	22.364	25.105

Table -2: Web Buckling Load (KN) in Channel Section without hole corresponding to different bearing length

Deflection (mm) \ Bearing Length(mm)	20	30	40	50	60
1	3.241	2.82	2.64	2.46	2.33
2	4.27	3.9	3.65	3.4	3.21
3	4.72	4.45	4.16	3.9	3.69
4	4.99	4.83	4.52	4.24	4.01
5	5.2	5.13	4.81	4.51	4.27
6	5.397	5.358	5.06	4.78	4.49
7	5.62	5.48	5.27	4.95	4.62
8	5.52	5.5	5.47	5.14	4.87

Table -3: Web Crippling Load (KN) in Channel Section with hole corresponding to different bearing length

Deflection (mm) \ Bearing Length (mm)	20	30	40	50	60
1	6.0348	7.6925	8.8885	10.169	11.392
2	8.0738	10.873	12.545	14.351	16.04
3	8.9832	12.528	14.505	16.675	18.673
4	9.5389	13.666	15.836	18.23	20.456
5	9.9443	14.555	16.87	19.438	21.817
6	10.261	15.311	17.758	20.477	22.978
7	10.52	15.981	18.546	21.404	24.019
8	10.74	16.569	19.25	22.237	24.958

Table -4: Web Buckling Load (KN) in Channel Section with hole corresponding to different bearing length

Deflection (mm) \ Bearing Length(mm)	20	30	40	50	60
1	2.11	1.59	1.39	1.21	1.51
2	2.83	2.25	1.96	1.71	1.62
3	3.15	2.59	2.27	1.98	1.89
4	3.34	2.83	2.48	2.17	2.07
5	3.49	3.07	2.64	2.31	2.21
6	3.6	3.17	2.78	2.441	2.32
7	3.69	3.31	2.9	2.552	2.43
8	3.77	3.43	3.01	2.65	2.52

2.4 Varying Flange Width

In order to determine the effect of flange width on the web crippling capacity of the channel sections four models of channel sections with and without holes are modelled and analysed. In this section the flange width is varied between 28 mm to 64 mm.

Sections modelled include

-150 x28x13 mm

- 150x34x13mm

- 150x45x13mm

- 150x64x13mm

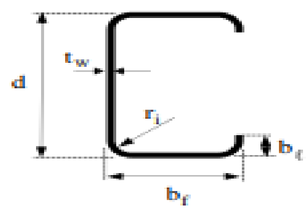

Fig -8: Channel section with bf= flange Width

Table -5: Web Crippling Load (KN) in Channel Section without hole corresponding to different flange width

Deflection (mm) \ Flange width (mm)	28	34	45	64
1	19.274	15.675	10.697	5.0725
2	23.667	20.077	14.784	9.242
3	26.722	22.575	16.949	11.197
4	29.338	24.581	18.429	12.422
5	31.657	26.355	19.607	13.294
6	33.757	27.917	20.625	13.988
7	35.556	29.309	21.535	14.58
8	36.656	30.595	22.353	15.108

Table -6: Web Buckling Load (KN) in Channel Section without hole corresponding to different flange width

Deflection (mm) \ Flange width (mm)	28	34	45	64
1	0.66	1.19	2.46	3.54
2	0.81	1.52	3.4	6.46
3	0.91	1.71	3.9	7.82
4	1	1.87	4.24	8.68
5	1.08	2	4.51	9.27
6	1.16	2.12	4.79	9.77
7	1.22	2.23	4.95	10.19
8	1.26	2.32	5.14	10.56

Table -7: Web Crippling Load (KN) in Channel Section with hole corresponding to different flange width

Defection (mm) \ Flange width (mm)	28	34	45	64
1	18.448	14.985	10.165	4.8398
2	23.245	19.672	14.347	8.8882
3	26.349	22.26	16.671	10.842
4	28.982	24.288	18.228	12.154
5	31.312	26.073	19.436	13.081
6	33.41	27.652	20.475	13.812
7	35.241	29.055	21.402	14.428
8	36.388	30.341	22.235	14.971

Table -8: Web Buckling Load (KN) in Channel Section with hole corresponding to different flange width

Deflection(mm) \ Flange width (mm)	28	34	45	64
1	0.49	0.54	1.21	2.22
2	0.62	0.71	1.71	4.09
3	0.7	0.8	1.99	4.99
4	0.78	0.87	2.17	5.59
5	0.84	0.94	2.32	6.02
6	0.89	0.99	2.44	6.35
7	0.94	1.04	2.55	6.41
8	0.97	1.09	2.65	6.89

2.5 Varying Bent Radius

Section used – 150x45x13mm

i) Without hole

ii) with hole (diameter = 60mm)

Inner bent radius is varied between 1.5 mm to 3.5 mm in this analyse.

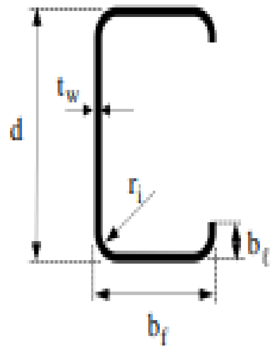

Fig -9: Channel section with Ri = Bent Radius

Table -9: Web Crippling Load (KN) in Channel Section without hole corresponding to different bent radius

Deflection(mm) \ Bent Radius (mm)	1.5	2	2.5	3	3.5
1	11.357	11.168	10.699	9.6011	9.1024
2	14.3	14.444	14.788	12.526	12.059
3	15.578	15.815	16.955	13.817	13.375
4	16.301	16.625	18.436	14.554	14.166
5	16.809	17.185	19.615	15.053	14.719
6	17.197	17.562	20.634	15.432	15.144
7	17.509	17.816	21.545	15.724	15.487
8	17.744	18.004	22.364	15.945	15.767

Table -10: Web Buckling Load (KN) in Channel Section without hole corresponding to different bent radius

Deflection (mm) \ Bent Radius (mm)	1.5	2	2.5	3	3.5
1	2.49	2.62	2.46	3.23	3.19
2	3.14	3.39	3.4	4.22	4.23
3	3.42	3.71	3.9	4.66	4.7
4	3.58	3.9	4.24	4.9	4.97
5	3.69	4.03	4.51	5.07	5.17
6	3.79	4.12	4.78	5.2	5.32
7	3.84	4.18	4.95	5.3	5.44
8	3.89	4.23	5.14	5.37	5.54

Table -11: Web Crippling Load (KN) in Channel Section with hole corresponding to different bent radius

Deflection (mm) \ Bent Radius (mm)	1.5	2	2.5	3	3.5
1	10.885	10.693	10.169	9.1687	8.661
2	13.886	14.107	14.351	12.147	11.676
3	15.352	15.607	16.675	13.556	13.104
4	16.138	16.476	18.23	14.362	13.96
5	16.674	17.071	19.438	14.891	14.543
6	17.077	17.475	20.477	15.285	14.982
7	17.403	17.747	21.404	15.592	15.336
8	17.652	17.945	22.237	15.825	15.623

Table -12: Web Buckling Load (KN) in Channel Section with hole corresponding to different bent radius

Deflection (mm) \ Bent Radius (mm)	1.5	2	2.5	3	3.5
1	1.4	1.46	1.21	1.84	1.94
2	1.78	1.93	1.71	2.44	2.62
3	1.97	2.13	1.98	2.72	2.94
4	2.07	2.25	2.17	2.88	3.13
5	2.14	2.33	2.31	2.99	3.27
6	2.2	2.39	2.44	3.07	3.36
7	2.24	2.43	2.55	3.13	3.44
8	2.27	2.45	2.65	3.17	3.51

2.6 Varying Height of the Web Portion

Slenderness of the web portion plays important role in the strength of the channel section. In order to know the effect of height of the web portion in web crippling capacity, six channel sections are modeled by varying web height from 100mm to 150mm. Sections modeled are

- 100x45x13 mm
- 110x45x13 mm
- 120x45x13 mm
- 130x45x13 mm
- 140x45x13 mm
- 150x45x13 mm

Table -13: Web Crippling Load (KN) in Channel Section without hole corresponding to different web height

Deflection (mm) \ Web height (mm)	100	110	120	130	140	150
1	10.974	10.895	10.847	10.78	10.771	10.697
2	15.042	14.958	14.95	14.87	14.899	14.784
3	17.143	17.072	17.098	17.018	17.086	16.949
4	18.601	18.533	18.574	18.493	18.581	18.429
5	19.77	19.702	19.754	19.671	19.775	19.607
6	20.781	20.713	20.775	20.689	20.812	20.625
7	21.679	21.612	21.687	21.598	21.74	21.535
8	22.487	22.42	22.505	22.414	22.574	22.353

Table -14: Web Buckling Load (KN) in Channel Section without hole corresponding to different web height

Deflection (mm) \ Web height (mm)	100	110	120	130	140	150
1	5.79	4.847	4.073	3.44	2.89	2.46
2	7.94	6.655	5.614	4.75	4.00	3.40
3	9.05	7.596	6.421	5.43	4.59	3.90
4	9.824	8.246	6.975	5.90	4.99	4.24
5	10.44	8.766	7.41	6.28	5.320	4.51
6	10.97	9.216	7.802	6.61	5.59	4.74
7	11.44	9.61	8.14	6.90	5.84	4.95
8	11.876	9.97	8.45	7.16	6.07	5.14

2.7 Varying Diameter of the Web Hole

Opening are provided in the web portion for installation of ducts, electrical and plumbing services. However such holes can reduce the strength of the channel sections to some extent. In order to know the effect of holes in the web crippling capacity of the channel section, sections are modeled by providing holes with varying diameter under the bearing plate and the analyses are conducted on. The diameter used in these analyses is varied between 0mm to 60 mm and the channel section used is 150 x50 mm x 13 mm

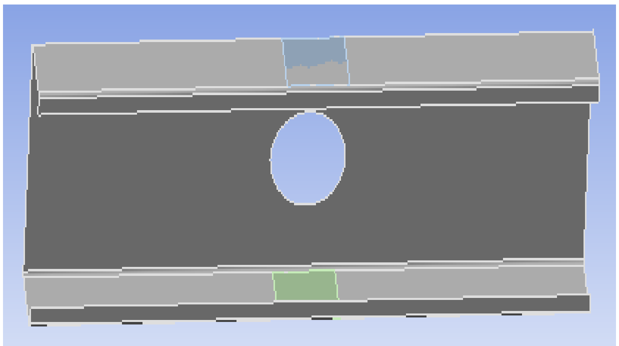

Fig -10: Modeled Figure in ANSYS

Table -15: Web Crippling Load (KN) in Channel Section without hole corresponding to different web height

Deflection (mm) \ Dia(mm)	0	10	20	30	40	50	60
1	8.6865	8.6773	8.6399	8.5783	8.4919	8.3855	8.2576
2	12.94	12.931	12.896	12.838	12.755	12.651	12.525
3	15.016	15.009	14.986	14.946	14.888	14.811	14.711
4	16.409	16.404	16.386	16.355	16.31	16.25	16.174
5	17.53	17.525	17.51	17.484	17.445	17.394	17.328
6	18.482	18.478	18.464	18.441	18.406	18.36	18.3
7	19.307	19.303	19.291	19.27	19.238	19.195	19.14
8	20.044	20.041	20.03	20.01	19.981	19.941	19.889

Table -16: Web Buckling Load (KN) in Channel Section without hole corresponding to different web height

Deflection (mm) \ Dia(mm)	0	10	20	30	40	50	60
1	2.84	2.74	2.48	2.21	1.967	1.74	1.54
2	4.23	4.08	3.71	3.3	2.95	2.64	2.33
3	4.9	4.74	4.31	3.85	3.44	3.09	2.74
4	5.36	5.18	4.71	4.21	3.77	3.39	3.01
5	5.73	5.53	5.04	4.5	4.03	3.62	3.23
6	6.04	5.83	5.31	4.75	4.25	3.838	3.41
7	6.31	6.09	5.55	4.96	4.44	4	3.57
8	6.55	6.32	5.76	5.15	4.62	4.16	3.71

2.8 Varying Locations of Web Hole

Locations of web holes have a great effect in determining the strength of the channel sections. In order to know the effect of the locations of web holes in the channel sections different models are analyzed by varying the distance of web holes from the bearing plates. The distance from the bearing plates (x) to height of the channel section (h) is varied from 0 to 0.6

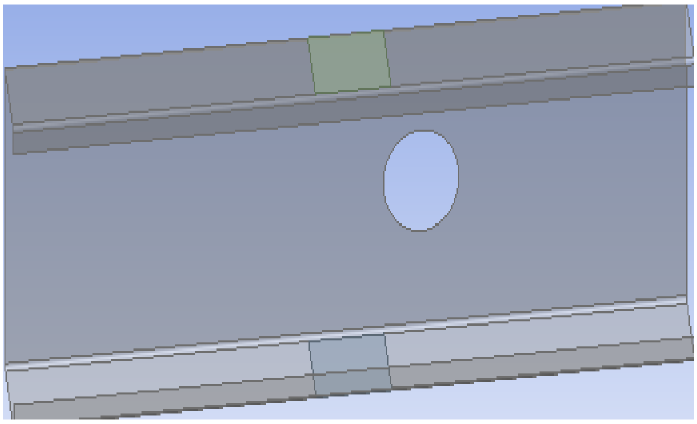

Fig -11: x/h = 0

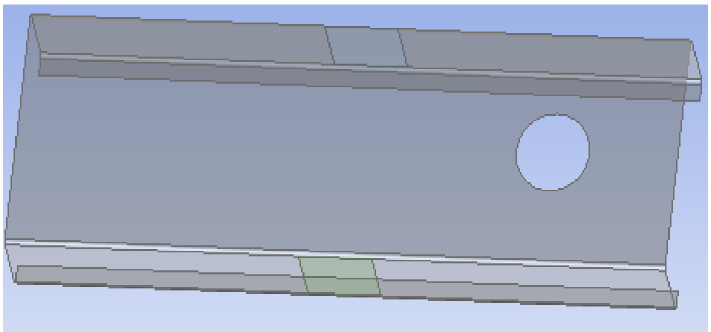

Fig -12: x/h=0.6

Table -17: Web Crippling Load (KN) in Channel Section corresponding to different x/h ratio

Deflection (mm) \ x/h ratio	0	0.2	0.4	0.6
1	8.5702	8.6461	8.6712	8.6802
2	12.808	12.886	12.918	12.93
3	14.911	14.968	14.995	15.005
4	16.319	16.365	16.388	16.398
5	17.447	17.487	17.508	17.518
6	18.405	18.44	18.46	18.469
7	19.236	19.266	19.284	19.293
8	19.978	20.004	20.021	20.03

Table -18: Web Buckling Load (KN) in Channel Section corresponding to x/h ratio

Deflection (mm) \ x/h ratio	0	0.2	0.4	0.6
1	2.01	2.48	2.75	2.81
2	3	3.7	4.1	4.19
3	3.5	4.3	4.76	4.86
4	3.83	4.7	5.2	5.31
5	4.09	5.02	5.5	5.68
6	4.32	5.3	5.86	5.98
7	4.51	5.5	6.12	6.25
8	4.68	5.75	6.36	6.49

3. GRAPHS AND DISCUSSIONS

3.1 Effect of Bearing Length

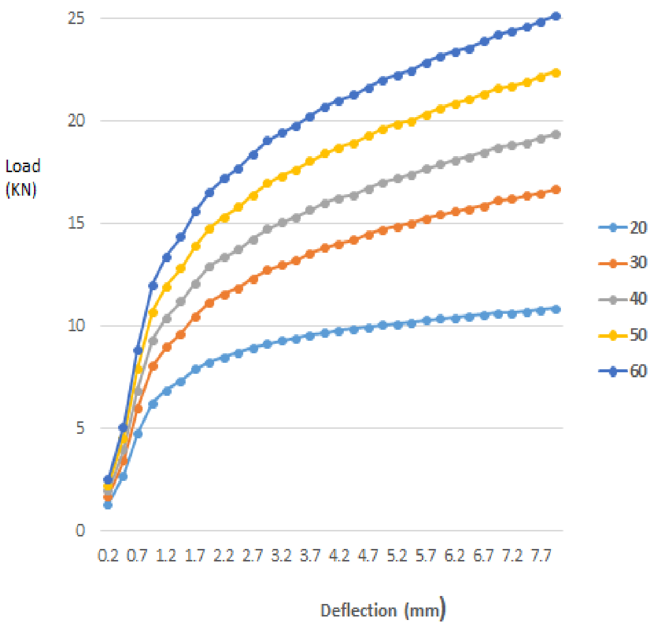

Chart -1: Effect of Bearing Length in Web Crippling Load of Channel Section Without Hole

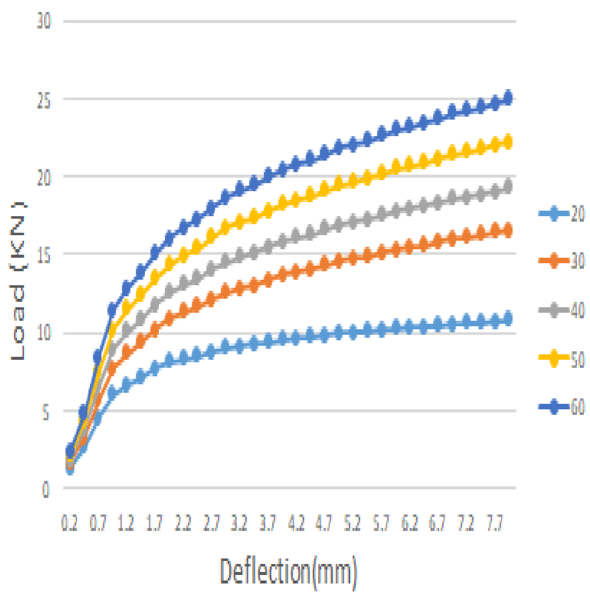

Chart -2: Effect of Bearing Length in Web Crippling Load of Channel Section With Hole

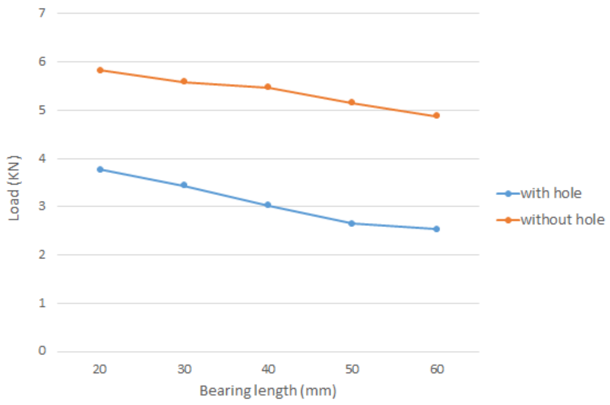

Chart -3: Effect of Bearing Length in Web Buckling Load

Bearing length plays an important role in determining the web crippling capacity of the channel section. With the increase in the bearing length the web crippling capacity of the channel section increases. From the analysis it was cleared that web crippling capacity of channel sections with bearing length 60 mm is greater than 20 mm. The buckling strength of the channel sections decreases with increase in the bearing length. By providing the web holes the strength of the channel sections decreases , so there is a huge decrease in web buckling strength of the channel section with hole compared with the sections without hole

3.2Effect of Flange Width

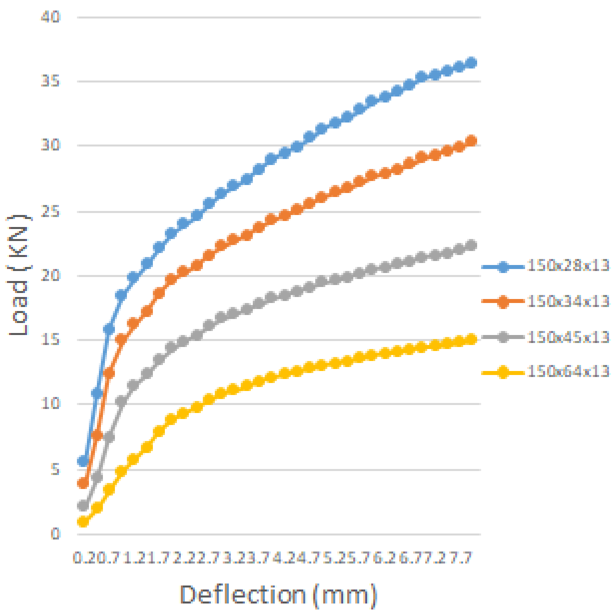

Chart -4: Effect of Flange Width in Web Crippling Load of Channel Section

Flange width affect the web crippling capacity of the channel sections. Web crippling capacity is high for 150x28x13 mm and is very low for 150x64x13 mm. From the analyses it is clear that with increase in the flange width of the channel section web crippling capacity decreases. With the increase in the flange width web buckling strength increases.

3.3 Effect of Bent Radius

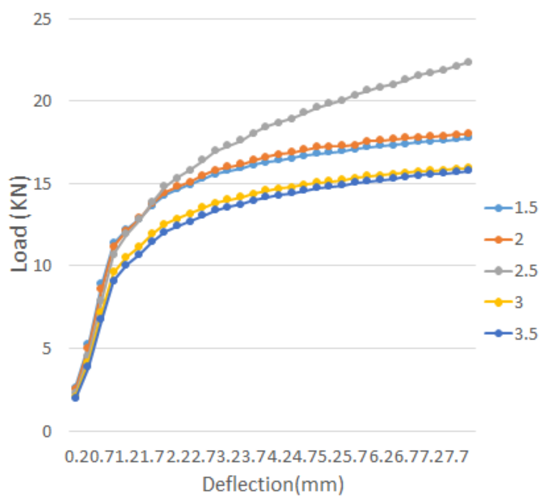

Chart -5: Effect of Bent Radius in Web Crippling Load of Channel Section

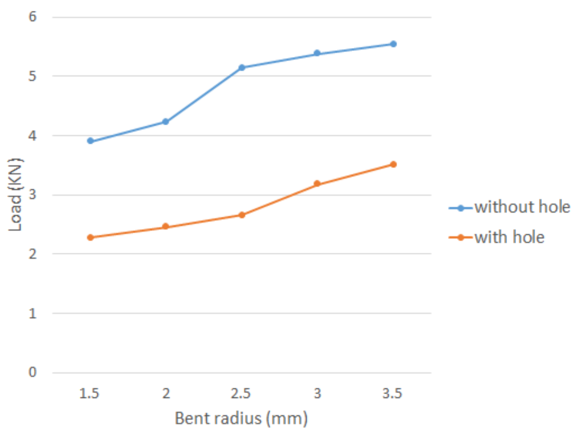

Chart -6: Effect of Bent Radius in Web Buckling Load of Channel Section

In the analysis with the bent radius of the channel sections is varied between 1.5 mm to 3.5 mm. From the analysis it is clear that the channel sections with bent radius 2.5mm show high web crippling capacity compared to other sections. The web crippling capacity of the channel sections increase from 1.5 mm to 2.5 mm. Beyond 2.5 mm the web crippling capacity of the channel section increase

3.4 Effect of web Height

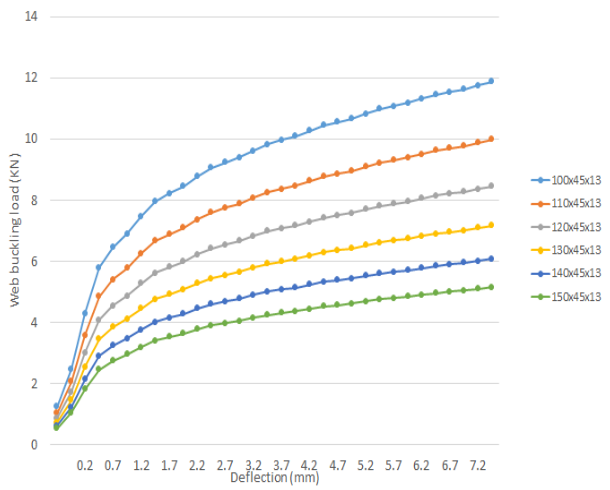

Chart -7: Effect of height of Web in Web Buckling Load of Channel Section

Web Height affects the strength of the channel sections. In the analysis the web height of the channel sections is varied between 100mm to 150 mm. From the analysis it is cleared that the channel sections having more web height is more vulnerable to failure. The web buckling load of 100x45x13 mm channel section is very high compared to that of the section having dimensions 150x45x13 mm.

3.5 Effect of diameter of web hole

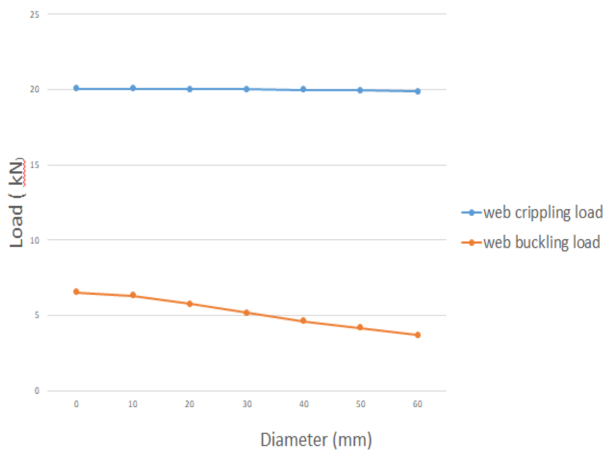

Chart -8: Effect of Diameter of Holes in Web Buckling Load of Channel Section

In the analysis the web holes with various diameters is provided at the center of the channel section, under the bearing plate in order to know how it affects the strength of the channel section. Diameter of hole used in the section is varied between 0 mm to 60 mm. From the analysis it is clear that providing holes directly under the bearing plate do not make a huge effect in reducing the web crippling capacity of the channel sections. However it has a drastic effect in reducing the buckling strength of the channel sections. By increasing the diameter of web holes the buckling strength of the channel sections is reduced.

3.6 Effect of location of web holes

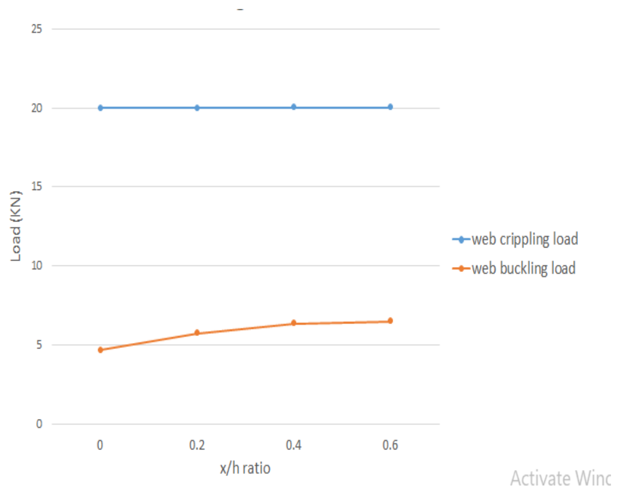

Chart -9: Effect of Location of Web Holes in Web Buckling Load of Channel Section

From the analysis it is clear that the location of web holes does not affect the web crippling capacity of the channel sections. But at the same time it affects the web buckling strength of the channel sections. The model with x/h ratio 0.6 having high buckling strength compared to the section with x/h ratio 0. By increasing the distance of web holes from the bearing plate the web buckling strength of the channel sections increase.

4. CONCLUSION

This paper is mainly aimed to know more about the web crippling capacity of the channel sections. Different parameters like length of the bearing plate, inner bent radius, web height, flange width, diameter of web hole and location of web holes varied in channel sections in order to know how it affect the web crippling and web buckling strength of the sections and came to the conclusion that web crippling capacity of the channel sections increases with increase in bearing length and bent radius up to 2.5 mm. With the increase in the flange width of the channel section the web crippling capacity decreases. However the diameter of web hole , location of the web holes and height of the web portion do not affect the web crippling capacity in a large extent but affect the web buckling strength. Decrease in the holes diameters and increase in the x/h ratio can increase the web buckling strength of the channel sections. At the same time increase in the web height can decrease the strength of the channel sections.

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