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TESTING AND ANALYSIS OF COLD-FORMED STEEL CHANNEL SECTION WITH NOTCH

*Mohd Syahrul Hisyam Mohd Sani[1], Fadhluhartini Muftah[1] and Muhammad Isha Ismail[1]

[1]Faculty of Civil Engineering, Universiti Teknologi Mara Cawangan Pahang, Kampus Jengka, 26400 Bandar Jengka, Pahang, Malaysia

*Corresponding Author, Received: 16 May 2017, Revised: 5 Sept. 2017, Accepted: 1 Dec. 2017

ABSTRACT: Cold-formed steel (CFS) channel section is a construction material that often been used in the building and still in the research for utilizing in structural element. The advantages of the CFS channel section such as lightweight, anti-corrosion and etc are becoming so interesting in selecting it as a roof purlin, roof truss system and storage rack. For having the structural element with the strong, safe and stable condition, the study of the CFS with the notch is carried out to determine the behavior. The parametric study is taking place to determine the suitability of notch pattern whether the notch depth and spacing are affecting the ultimate load of the CFS channel section column and beam. The study of the CFS channel section is divided into two parts, the first part is to examine the ultimate load of the column in varies of notch depth and the second part is to determine the ultimate load of the beam in varies of notch spacing. By referring the study of the notch depth on CFS channel column section, the result of the ultimate load is obtained to have the reduction about 19-80% of the variation of notch depth when compared with the normal section. Although, the CFS channel beam section with variation notch depth is influenced by approximately 4-14% when compared with CFS channel normal beam section.

Keywords: Cold-formed steel, Notch, Ultimate load, Column, Beam

1. INTRODUCTION

Cold-formed steel (CFS) is a structural and building material that has been introduced broadly in construction such as a roof truss system, wall panel, storage pallet rack and etc. CFS with a lot of advantages in construction such as highest strength to weight ratio, impervious to termites, rot, and mold, recyclable, noncombustibility, cost-effectiveness, and anti-corrosion. Currently, CFS is shifted as a structural element rather than before, for the only non-structural element. There is comprehensive information about the design of the CFS in the codes especially Eurocode 3 or American Iron and Steel Institute (AISI). However, there are having not clear information and design of the CFS as structural element, such as a column or beam with a notch or perforated.

The notch can be referred that steel structure is discontinuities in cross-sectional geometry as example v-shape, semi-circle shape square-shape and etc or non-uniformity of material [1]. Generally, the steel notch is produced to provide some spacing to mechanical and electrical service activity in the building. The study of the steel notch is significant to certify the structure is could be utilized back if there are some failure happened to it. There are two types of the notch counting of V-notch and U-notch in the previous study. Additionally, fatigue of the steel structure exists when the fatigue loading occurred at plastic strain and produced the surface defect such as a notch or cracking. The notch of the steel is the main problem that always been discussed by researchers because of its fatigue issues. It is happened due to the localized or restricted changes of the steel structure with producing the concentration stress on the location of the notch and lastly growth of cracking. Reference [2] has explained about the fatigue design limit for conventional parts are acquired at stress cycles of 10^7 for determining and designing the allowable stress.

There are a lot of researchers studied about the notch which become popular for stopping the failure of the material and structure. Reference [3] has analyzed the fatigue of complex notch that established from welded joints. Welded joint for industries purpose such as offshore, oil and gas, and the building is used as a joint between the structural member to provide safety and stability of the construction [3]. Reference [4] has clarified the tensile residual stresses from the welding activity for steel assemblies is combined with initial stress from steel component is lead to crack initiation. Others researchers that study on the notch made from welded joints are [5] and [6].

Reference [7] has reported the result of compression testing of the concrete filled steel tubular (CFST) short column with notch and the performance of the column when subjected to the material imperfection. So, the notch in the steel tubes is reacted as the material imperfection problem which must be solved to obtain the excellent in the structural integrity and also extended their service life [7]. Besides, the notch length, orientation, and location are proposed for determining the column performance and load-strain response. As the result, the ultimate load of the CFST short column is decreased with increasing of the notch length. Reference [8] has reported the mechanical behavior of the circular concrete-filled steel tube short column subjected to axial concentrated load and also the impact of the steel tubes due to geometry imperfection.

Reference [9] has explored the crack growth resistance of a sharp notch of the high strength rail steels for their mechanical properties. There are three test specimens including smooth, short gauge and pre-cracked single-edged-notched bending specimen that used in the railway industry [9]. Reference [10] explained the structural integrity of the structure is evaluated by assessing the defect condition or flaw assessment procedures derived from the mechanics of fracture approaches such as loading and temperature. Furthermore, many researchers are studied about the notch as a crack and defects of the section or material such as [11], [12], [13] and [14].

There is no information about CFS with a notch for column and beam in design, standard and previous study. Besides, there are a lot of studies about steel notch as an imperfection, welding and cracking effect but no information about the steel notch as an initial work before being the curve of the steel component. CFS is cut with same notch spacing and width but varieties of notch depth as a preliminary study to form CFS curved section. Cut-curved method is one of the methods that's been utilized in the curving process and other methods are a cold-curved and hot-curved process. Cut-curved method is chosen due to the simple way of process and also avoids using the skill workers, high technology machine, and high-cost equipment. For producing the CFS curved section, the notch depth must be studied to determine the physical effect of the section before being curved, ultimate load and also the load-deformation behavior. Reference [15] has stated that the mitered bends by cut-curved are produced the smooth bends for impractical circumstances such as uneconomical and limited space factor.

Usually, many studies are only emphasized on the tensile load either flat or coupon tensile specimen but for column and beam structure in actual size or small scale is still deficient. Additionally, there is no standard and experimental method that's been utilized in evaluating the performance of the structure with the notch. Hence, the objective of the study is to investigate the mechanical behavior especially the ultimate load of the CFS column and beam section with a variety of notch depth under concentrated load. Finally, the paper determines the behavior of the CFS with a notch to propose some new information and understanding of the production of the CFS cut-curved.

2. SPECIMEN PREPARATION AND TEST SETUP

A CFS channel section with lipped and double intermediate web stiffener is chosen and clean. A CFS channel section with double intermediate web stiffener is selected to avoid the local buckling on early stage and as a reference to the cut limit. The cross-section and section dimension of the CFS channel section are tabulated in Fig. 1 and Table 1. Besides that, the section dimension of the testing specimen is taken because the section is easy to get from construction material suppliers. The initial geometric imperfection and residual stress of the section are ignored. The ratio between the section and element is tabulated in Table 1 for checking the appropriateness of the section dimension due to deformation ability and allowable stability.

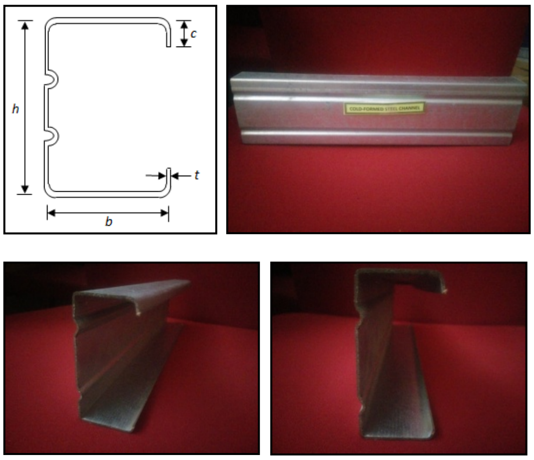


Fig. 1 The cross-section of the CFS channel section

Table 1 The section dimension and properties of CFS channel section

Section dimension			
Notes	Value	Notes	Value
Web, *h*	75 mm	Flange, *b*	34 mm
Lipped, *c*	8 mm	Thickness, *t*	1 mm
Area, *A*	148 mm^2	Yield Strength, f_y	550 MPa
Second Moment of Area			
I_{xx}	0.135 x 10^6 mm^4	I_{yy}	0.025 x 10^6 mm^4
Second Modulus			
Z_{xx}	3.605 x 10^3 mm^3	Z_{yy}	2.240 x 10^3 mm^3
Radius of Gyration			
R_x	30.22 mm	R_y	12.94 mm
Geometrical Ratio			
b/t	34.0	*b/c*	4.25
h/b	2.21	*h/t*	75.0
h/c	9.38	*c/t*	8.0

The section is cut by using an electric saw with notch width of 3 mm and notch spacing which measured center to center of 100 mm as a constant value. There are two experiments are arranged, the first experiment is a column specimen with varies of notch depth and the second experiment is still a variation of notch depth but for beam specimen. The first experiment is obtained three column specimens with difference notch depth and profile is illustrated in Table 2 and Fig. 2. The section is cut according to three parts of notch depth for column and beam specimens. The first part, the section is cut from the bottom flange until bottom intermediate web stiffeners with 14 mm of notch depth from the bottom of the CFS channel section. The second part, the section is cut to half of the total height of the CFS channel section with a notch depth of 37.5 mm. The section is cut from the bottom flange until upper intermediate web stiffeners with a notch depth of 60 mm for the last part. The notch depth of 14 mm, 37.5 mm and 60 mm are compared with an overall depth of the CFS channel section without a notch is roughly about 81.3 %, 50 %, and 20 %, respectively. The height of the column is 400 mm and the length of the beam is 250 mm.

Table 2 The profile of CFS with notch

Notes	Value Data
Notch width, *a*	3 mm
Notch spacing, *s*	100 mm
Notch depth, *d*	14 mm, 37.5 mm, 60 mm
Ratio	
a/t	3.0
s/t	100
d/h	0.19, 0.50, 0.80

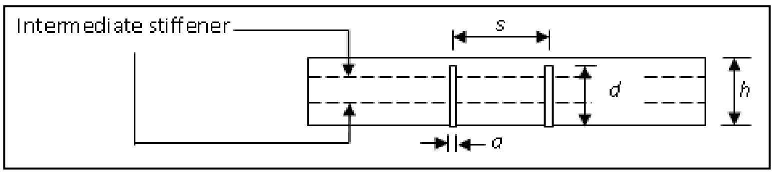


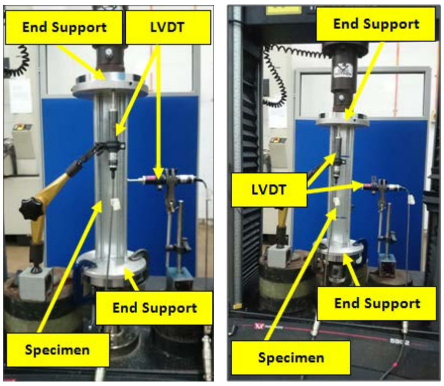
Fig. 2 The schematic diagram of CFS channel section with the notch.

Table 3 is represented the specimen profiles and labels for column and beam specimen. The compression test of the CFS channel section of column and beam with the variety of notch depth is tested by using the Universal Testing Machine (UTM) with a capacity of 100 kN. The end support condition for column specimens is acknowledged as a semi-rigid end support which utilizes the steel plate 6 mm that attached to the compression steel jigs. The column specimen is situated on the surface of the steel plate at the upper and bottom side of the support by using a self-drilling screw and monitored the fixity of the specimen to avoid the move. Two of the linear variable deformation transducers (LVDT) is placed in the middle of the column height of flange and web element, and one LVDT is located on the steel plate to measure the axial shortening of the specimen as shown in Figure 3 (a) and (b). The height of the CFS channel column section is 400 mm.

Meanwhile, the end support condition for beam specimens is also recognized as a semi-rigid end support condition. Two plates and one steel rod are used for every end support to avoid the move. Two LVDTs are located on mid-span of the web beam and end of the flange beam. The 50 mm extensometer is also being used for determining the mid-span flange deformation as shown in Figure 4. The length of the CFS channel beam section is stated of 250 mm. Both specimens are utilized the pacing rate of the loading of the UTM is 1 mm/min. All LVDTs is connected to a data logger to acquire the value of the web and flange deformation.

Table 3 Specimen profile and label for a CFS channel section for both experiments

Specimen profile	Label
Experiment One - Column	
CFS without notch section	CFS-CC0
CFS with notch depth of 14 mm	CFS-CC1
CFS with notch depth of 37.5 mm	CFS-CC2
CFS with notch depth of 60 mm	CFS-CC3
Experiment Two - Beam	
CFS without notch section	CFS-CB0
CFS with notch depth of 14 mm	CFS-CB1
CFS with notch depth of 37.5 mm	CFS-CB2
CFS with notch depth of 60 mm	CFS-CB3



(a) (b)

Fig. 3 The compression testing arrangement and setup of the CFS channel section column specimen (a) without a notch and (b) with the notch.

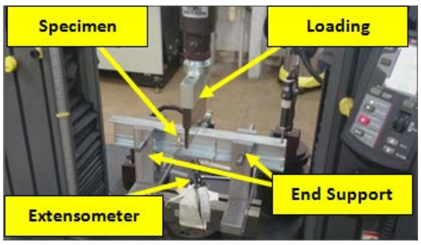


Fig. 4 The flexural testing arrangement and setup of the CFS channel section beam specimen.

3. RESULT AND DISCUSSION

The mechanical behavior of the column and beam specimen with difference notch depth is calculated and analyzed. The LVDTs is recorded the deformation of the column and beam specimen and extensometer equipment that is used in flexural testing is to calculate the deformation of the beam at mid-span.

3.1 Mechanical Behaviour of CFS Channel Column Section with Difference Notch Depth

The result of the compression behavior of a CFS channel column section especially ultimate load, axial shortening, and failure mode shape is represented in Table 4. From the table, the CFS-CC1 is the largest value of the ultimate load and lowest value of axial shortening at ultimate load when compared with another CFS-CC specimen with the notch. The percentage difference from ultimate load between CFS-CC1 with CFS-CC2 and CFS-CC3 is approximately 5.51% and 8.52%, respectively. The ultimate load of the specimen is decreased with increasing of the notch depth. The ultimate load of the CFS-CC specimen is not extensively affected and influenced even if the notch depth in a high percentage. The percentage difference of the ratio notch depth over the section web between CFS-CC without notch and CFS-CC1, CFS-CC2 and CFS-CC3 is 19%, 50%, and 80%, respectively. 56.85% of the ultimate load percentage difference between CFS-CC0 with CFS-CC1 is recorded. Furthermore, the difference of axial shortening at ultimate load between CFS-CC0 with CFS-CC1, CFS-CC2, and CFS-CC3 in percentage is represented roughly 17.44%, 18.08%, and 18.39%, respectively. The axial shortening at ultimate load for CFS channel section with the notch is not showing significant changes in all specimens. This is because the specimen is no longer having the compression deformation but the specimen is demonstrated to have the small rotation or known as distortional buckling. Besides, the notch depth is getting smaller when a compression load is applied and the peak at both sides of the notch is touching each other. Lastly, the axial shortening at ultimate load is increased when the notch depth is increased. Failure mode shape for all specimens is reported having local and distortional buckling. All specimens are stated to meet the local buckling in early loading and finally shifted to distortional buckling with the movement of both flange from the origin.

Table 4 Compression behavior testing of CFS channel section with and without notch depth

Specimen	Ultimate Load (N)	Axial shortening (mm)	Failure mode shape
CFS-CC0	42,410.55	2.13	L & D
CFS-CC1	18,299.17	2.58	L & D
CFS-CC2	17,290.63	2.60	L & D
CFS-CC3	16,739.64	2.61	L & D

Note: L-Local buckling and D-Distortional buckling

The detail of the specimen from initial applied load to failure load with compression deformation is illustrated in Fig. 5. The initial stiffness of CFS-CC0 is higher than other specimens and CFS-CC1 is higher than CFS-CC2 and CFS-CC3. CFS-CC2 and CFS-CC3 are illustrated having the same pattern of load-deformation behavior because the notch depth is located more than 50% of the web depth and percentage difference of notch depth between them is 37.5%. Therefore, the initial stiffness is decreased when the notch depth is increased. Some example of the failure of the CFS-CC0 and CFS-CC3 is shown in Fig. 6. Circle line in the figure is shown the location of the critical failure which has proven the local and distortional buckling exists. The flange element is more critical to deflect and buckle when compared to the web element. However, the CFS-CC channel section with the notch is capable to avoid the large deformation at the flange and cause the overall column structure to bend to the weak axis.

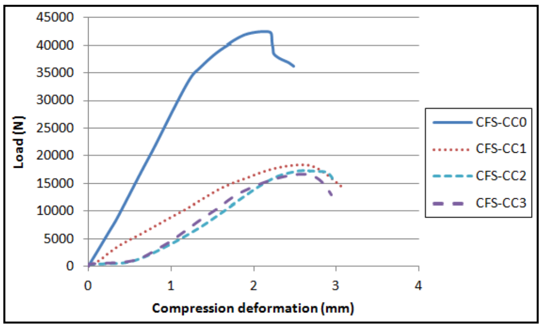
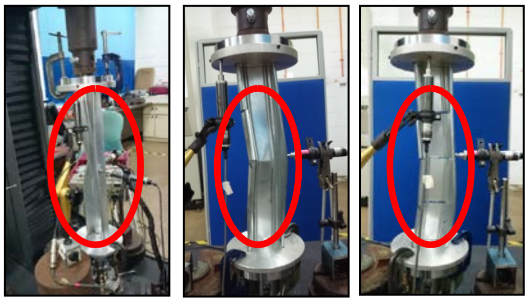


Fig. 5 Applied load versus compression deformation graph.

3.2 Mechanical Behaviour of CFS Channel Beam Section with Difference Notch Depth

The result of the flexural behavior of a CFS channel beam section, for instance, ultimate load and the moment is tabulated in Table 5. The ultimate load of CFS-CB without a notch is recorded to have 6,931.42 and the highest value of the ultimate load among of the CFS-CB with the notch is 6,598.15.



(a) (b) (c)

Fig. 6 The schematic diagrams of (a) CFS-CC0, (b) CFS-CC1 and (c) CFS-CC3 after fail.

The percentage difference between them is expressed around 4.80%. It showed that the notch depth with less than 50% of the cut along the web depth is not influenced the ultimate load and the moment of the section. This is because the beam is categorized as a short beam with less of deformation and bending condition when compared to the slender beam. 16.93% and 35.14% of comparison percentage between CFS-CB1 with CFS-CB2 and CFS-CB3, respectively is reported. Additionally, the percentage difference between the CFS-CB0 with CFS-CB2 and CFS-CB3 is noted having 20.93% and 38.26%, respectively. Lastly, a summary that can be designated is that when the notch depth is increased, the ultimate load of the beam decreased.

The failure mode shape of the CFS-CB is tabulated in Table 5. All specimens are observed having a local buckling in the early stage of loading and shifted to distortional buckling in the middle period of loading. Table 5 also mentioned about the flexural deformation of mid-span flange at ultimate load and flexural deformation of the overall beam at mid-span under the applied load. The flexural deformation of mid-span flange is noted to have nonuniform and uncertain data because of the location and depth of the notch. When the notch depth is not achieved the second web stiffener or middle of the section, the flexural deformation is still in a stable condition but if the notch depth is reached the second web stiffener, the beam has lost its stability and strength. The percentage difference between the CFS-CB0 with CFS-CB1 and CFS-CB2 is recorded to meet about 4.14% and 11.90%, respectively. The load-flexural deformation graph at mid-span flange is illustrated in Fig. 7 and showed that the initial stiffness and line pattern of CFS-CB0 and CFS-CB1 are same. Meanwhile, the initial stiffness and stability of the CFS-CB are decreased with increasing of the notch depth. The percentage difference between CFS-CB3 with CFS-CB0 is

14.07%. In addition, the flexural deformation of overall bending at mid-span is increased when the notch depth is increased. The percentage difference between the specimen with the lowest value, CFS-CB3 and the specimen with the highest value is 99.31%. Fig. 8 is shown applied load versus the flexural deformation of overall bending at mid-span. From the figure, the initial stiffness of the CFS-CB without a notch is higher when compared with CFS-CB with the notch. This is because the CFS-CB has lost its stability, strength, toughness, and stiffness if the section is cut vertically though small by following the direction of the applied load.

Table 5 The result of CFS channel beam section under three pinned bending

Specimen	Ultimate Load (N)	Moment (Nmm)	Flexural deformation at mid-span (mm)		Failure mode shape
			Flange at ultimate load	Overall bending	
CFS-CB0	6,931.42	433,213.75	5.80	0.05	L & D
CFS-CB1	6,598.15	412,384.38	5.56	0.85	L & D
CFS-CB2	5,480.94	342,558.75	5.11	2.40	L & D
CFS-CB3	4,279.27	267,454.38	6.75	7.26	L & D

Note: L – Local buckling and D – Distortional buckling

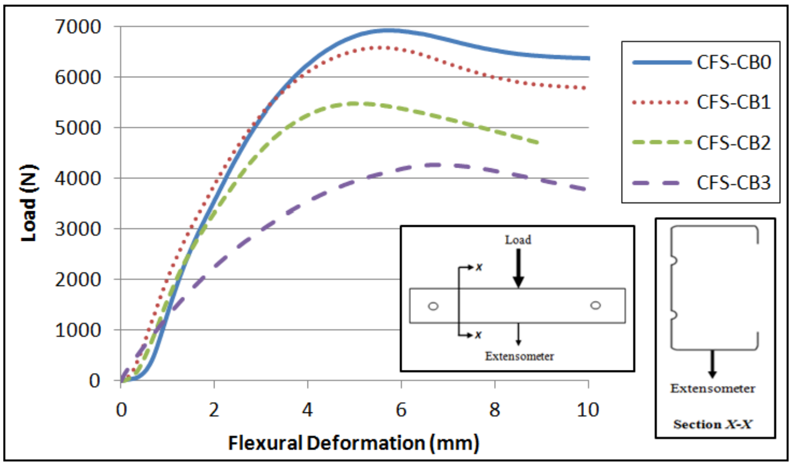


Fig. 7 Applied load versus flexural deformation of mid-span flange under load graph.

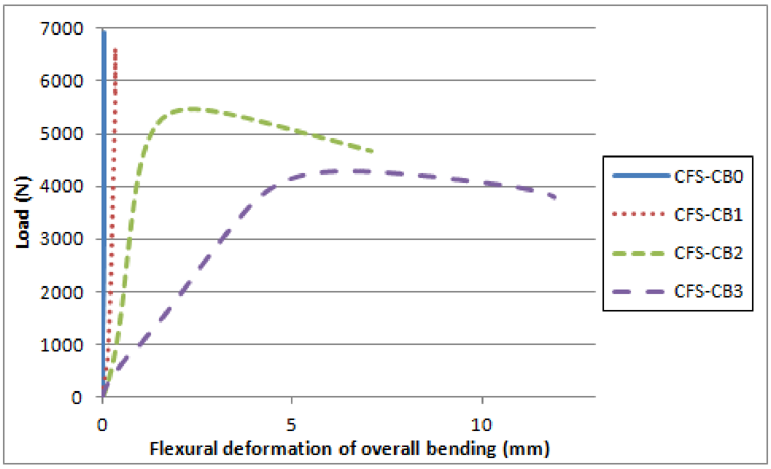
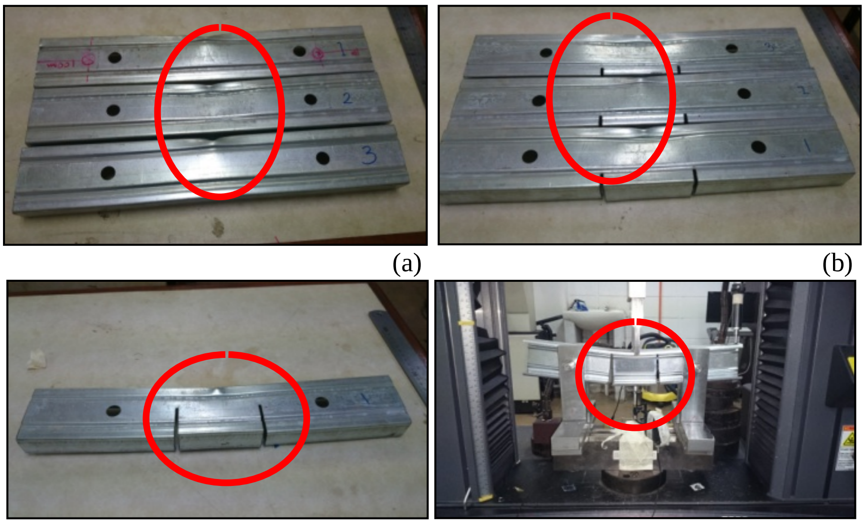


Fig. 8 Applied load versus flexural deformation of overall mid-span beam graph.

When the load is applied, the beam with higher notch depth is able to open in widespread, adding more stress at the end of the notch and eventually cause the part to be torn. CFS-CB2 and CFS-CB3 are illustrated to have the additional gap of the notch width to 40-60%. From observation, the CFS-CB channel section with the notch is so flexible and elastic when the load is applied, and form into large deformation. But, after the applied load is released, the beam is capable to form back to original shape with less deformation. The flange element at top side is more critical compared with bottom side. Whilst as the web element for CFS-CB0 and CFS-CB1 are not critical when distinguished with CFS-CB2 and CFS-CB3 channel section. The failure of local and distortional buckling of the CFS-CB is less deformation compared with the CFS-CC specimen this is due to slenderness. Fig. 9 is shown the failure shape of CFS-CB0, CFS-CB1, CFS-CB2, and CFS-CB3.



(a) (b) (c) (d)

Fig. 9 The failure shape of (a) CFS-CB0, (b) CFS-CB1, (c) CFS-CB2 and (d) CFS-CB3

4. CONCLUSION AND RECOMMENDATION

CFS-CC1 channel section which notch location below the web stiffener is a specimen that has a higher value of the ultimate load and lower value of axial shortening at ultimate load when compared with another specimen with the notch. Besides that, 56.85% and 17.44% of ultimate load and axial shortening at the ultimate load percentage difference between CFS-CC0 with CFS-CC1 is achieved. Consequently, the notch depth is increased and the ultimate load of the specimen decreased.

CFS-CB1 channel section is a specimen with the highest value of ultimate load among the specimen with notch and percentage difference when compared with specimen without a notch is 4.80%. The failure mode shape of the specimen is recorded having local and distortional buckling. Initial stiffness of the CFS-CB1 is a good result when compared with CFS-CB2 and CFS-CB3.

For further study, some experiment for several of cross-section and section dimension must be done to get the good relationship between the ultimate load and cross-section.

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