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# Cold Formed Steel and Buckling Criteria of Cold Formed Steel Purlins

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ABSTRACT

*Cold formed steel member made up at room temperatures which cause the material may become harder and stronger. Generally there are two method of producing cold formed steel either by press breaking or cold forming depending on type and capacity of section required. Cold formed steel can be used either in general application or building application due to several advantages such as high strength, lightweight and cost-effective way of covering a wide variety of building structures. Cold forms steel purlin has are inherently sensitive to local, distorsional, and lateral–torsional buckling. This problem leads due to the thinner of the thickness of purlin in which cause the section undergoes both bending and twists from the beginning of loading. 7 m C35030 simply supported cold formed steel purlin subjected to uplift uniformly distributed load results that the purlin was experiencing lateral and torsion failure which the cross-section rotates and translates, however it did not distorted in shape at the early stage of loading. Immediately before reaching the peak load at 11.53 kN/m, the section is experiencing a lateral torsional buckling where the web of the purlin buckles at the web-bottom flange junction.*

**Keywords:** *buckling criteria, cold formed steel, purlin*

## Introduction

Steel had become a very important construction material by the end of the $19^{th}$ century. In buildings construction, it was consist of three primarily types of structural steel which are build-up section, hot rolled section, and cold formed section. Build-up section is produce by connecting steel plate through welding process to made up a section, hot-rolled steel shape are formed at high temperature while cold formed section is formed at room temperature. Due cold formed steel member are made up room temperature, the material become harder and stronger. Cold-formed steel sections are modern building products that are widely used in building construction, from residential houses to industrial buildings. The manufacturing of cold formed steel member is from steel plate, sheet or strip that are formed into shape either through press breaking or cold forming to archive the desire shape. This process did not involve heat and can be done at room temperature. Press breaking process may be required in producing of small quantity of simple shape while cold rolled forming process required in producing part such as roof, floor, wall panel, and structural section such as Cee, Zee, and hat section. The manufacturing process of the cold form steel is beginning with rolling very large hot coil of steel as shown in Figure 1 to the desire thickness. The thickness can be formed ranges between 0.1 mm up to 7.7 mm and for heavy duty cold formed can be up to 19 mm thick. After the coil been cold, the robbon of steel passes through a series of roller as shown in Figure 2 to form the desire shape as shown in Figure 3.

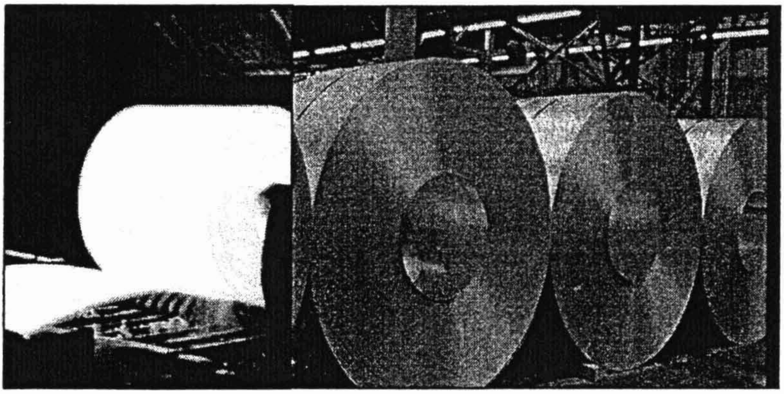


Figure 1: Hot and cold steel coil

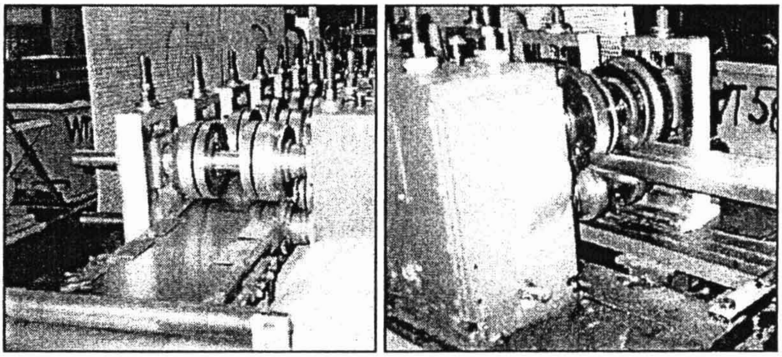


Figure 2: Cold rolled forming process

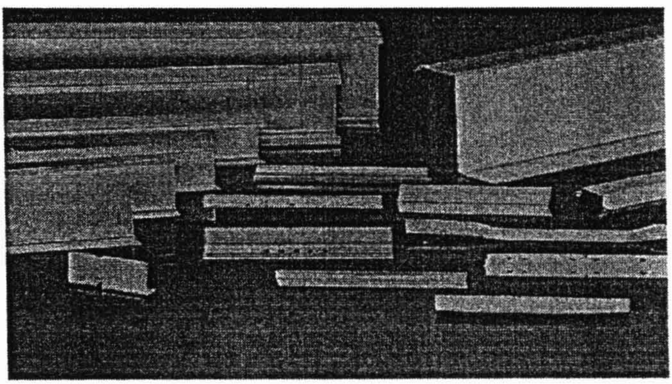


Figure 3: Wide range of cold formed steel product

Cold-formed steel members widely used in buildings, bridges, storage racks, grain bins, car bodies, railway coaches, highway products, transmission towers, transmission poles, drainage facilities, various types of equipment and others (Yu, 2003). In building component it was applied at roof, floor and wall system. Besides that, cold formed member can be used as individuals framing member such as stud, joists, purlin and truss members. Structurally, the cold formed steel section can serve as both primary and secondary structural member.

Figure 4 demonstrate the verities of cold formed steel sections for various purposes. Cold formed steel are regarded as lightweight building components with high strength to self-weight ratios, ease of prefabrication and mass production, uniformity of quality, economy of transportation and handling, quick and simple errection and installation besides the used of metal roofing has become a popular and cost-effective way of covering a wide variety of building structures.

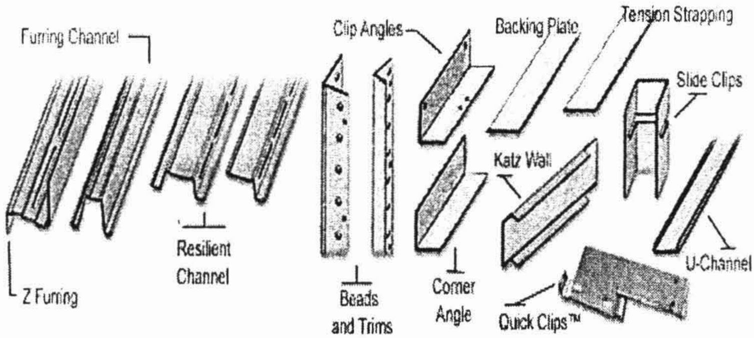



Figure 4: Multi application of cold formed steel

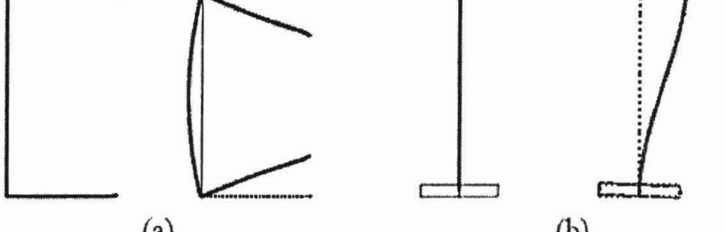
## Cold Formed Steel Cee Section as Purlin

As explaining in previous section, the cold formed steel products can divide into two major types known as panels and structural shape. Structural shape includes open section and closed section, such as Cee section which also called lipped channels, zee section, double channel I beam with stiffened flange, hat section with and without intermediate stiffener, box section, U section and others. All these shapes function as structural component in building such as eave struts, purlins in roof system, and girts in wall system as well as joist and studs. Purlin is horizontal structural member in a roof which supports the loads from the roof deck or sheathing and is primarily subjected to bending under vertical loads such as dead, snow or wind loads. In other word purlin is a type of beam that spans between chords of adjacent trusses used to carry the roofing material load and it is usually subjected to unsymmetrical bending. Depth of the purlins should be limited to 1/30 of their span. The required sag rod or bridge is because the purlin section is weaker in bending about y-axes. Purlins are supported by the principal rafters and/or the building walls used as opposed to closely spaced rafters. Steel purlin in roof system are frequently constructed by cold formed Zee section where the section can be lapped and nested at the support which creates a continues beam configuration between the bays.

Purlins will usually carry a combination of dead, snow, and wind loadings, Chu, Rickard and Li (2005), reported that most purlins will subject to uniform vertical distributed load and because of the asymmetry of its cross section, it may generate vertical and horizontal deflection. If the loading is not acting on the shear centre, twisting will take place about its original axis. The steel component known as the structural Cee section is the principal shape for framing floors, walls, and roofs. The primary difference from one use to another is the thickness of the steel and the depth of the member. Due to ease of production and comparative strength to other shape, the used of Cee section as purlin is study to investigate the buckling criteria of section. The major problem of cold formed steel is the thinner of the thickness in which cause the section undergoes both bending and twists from the beginning of loading. This describes that the individual flats, or plates, elements of the section often have width to thickness ratios that will permit buckling at stresses well below the yield point. Therefore, these types of cross-sections are inherently sensitive to local, distorsional, and lateral–torsional buckling.

## Local, Distorsional and Lateral Torsional Buckling

Thin walled section may undergoes a mode of buckling called distortional in which a lip stiffened flange of the section rotates about the flange web junction. Buckling is a condition where the limit state of sudden change in the geometry of a structure or any of its elements under a critical loading condition. Local buckling for a structural section is identify as the state where the section begin to deflect out of its original straight, or plane shape while reaching the initial buckling stress without failure and capable to resist increasing compressive stress. Schafer (2005) for instant the definition of local buckling for thin walled buckling mode is define as the mode which involve plate-like deformation alone, without the translation of the intersection line of adjacent plate element. The distorsional for thin walled buckling mode is considered as a mode with cross-sectional distorsion that involves the transilation of some of the fold lines (intersection lines of adjacent plate element) (Schafer, 2005). While lateral torsioanl buckling of thin walled plate is define as buckling mode where the member deformed with no deformation in its cross-sectional shape (Schafer, 2005). The definition can be demonstrated as in Figure 5. Figure 5(a) is steel channel section that classified as local buckling mode and Figure 5(b) show a symmetrical I-section loaded as a beam and presented as buckling shape of distorsional buckling.



(a) (b)

Figure 5: Example for uncertainty in buckling mode definitions (Schafer, 2005)

The cross-section deformations associated with each of the three buckling modes are demonstrated in Figure 6. For cold-formed steel joists, purlins, or girts, if the compression flange is not restrained by attachment of sheathing or paneling, distortional buckling may be the predominant failure mode.

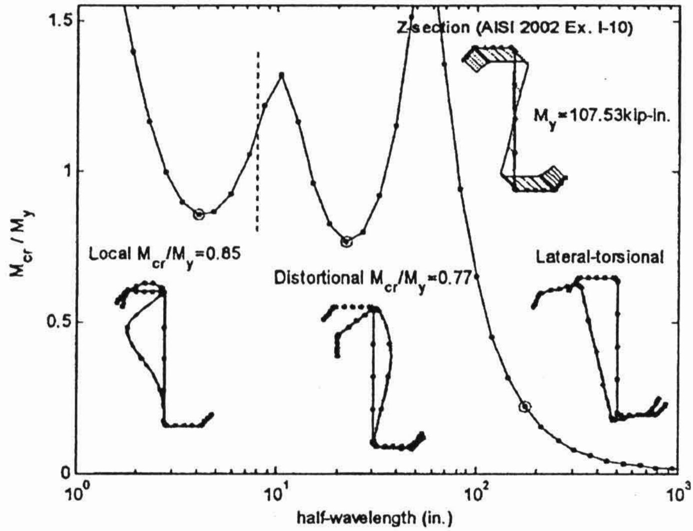



Figure 6: Cross-section deformations of cold-form section

Long beams will demonstrate low lateral stiffness and low torsional stiffness usually are very prone to buckle laterally where because of the geometry of the cross-section that gives great flexural rigidity about one axis and low torsional rigidity and low flexural rigidity about a perpendicular axis.

The local, distortional, and lateral-torsional buckling modes also differ greatly in their longitudinal variation along the beam. The local buckling mode occurs with repeated waves at a short length, while lateral-torsional buckling occurs in one half-wave over the unbraced length of the beam. Distortional buckling repeats at a wavelength intermediate to the two other modes. (Yu and Schafer, 2006).

Definition of local buckling review by Yu and Schafer (2006) involves distortion of the cross section with only rotation occurring at interior fold lines of the section while distorsion buckling involves distortion of the cross section with rotation and translation occurring at interior fold lines. Local buckling according to Li (2004) on the lateral–torsional buckling is by a mode in which individual cross-sections rotate and translate but do not distort in shape and is characterised by rigid body movements of the whole member. Despite Yu and Schafer (2006) definition excluded the distortion of the cross section; however, translation and rotation of the entire cross section may occur.

## Failure in Cold-formed Steel Beams

Chu et al (2005) review that many investigators did not give any consideration to the lateral-torsional buckling because of the belief that cold-formed steel member usually laterally restrained by attachment of metal sheeting or by the used of less-costing anti-sag bars which can reduce the occurrence of lateral-torsional buckling.

Cold-form sections usually undergo out-of-plane banding of the web under uplift loading where the section rotates about the point of attachment to the roofing materials latter influence to the postbuckling capacity of the section. Current specification assumed that the cross-sectional properties of cold-formed member remain constant until failure occurs. Investigation by Dimos Polyzois (1991) indicates that the degree of out-of-plane bending of the web of cold-formed steel purlins depends on shear rigidity and rotational stiffness of roofing material, as well as the absence/presence of sag rods.

Channel generally undergoes vertical deflection and twisting including section distortion under some degree of torsion restrain. The deformation of channel occurs in two stage; vertical bending stage, and torsion stage as shown in Figure 7 (Rousch and Hancock, 1997).

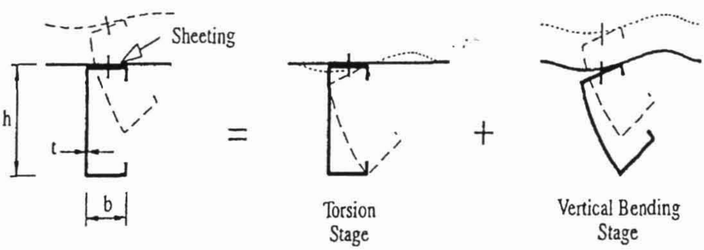



Figure 7: Deformation of a channel (Rousch and Hancock, 1997)

Distortional buckling of flexural members such as C- sections usually involves rotation of only the compression flange and lip about the flange-web junction as shown in Figure 8. The web undergoes flexure at the same half-wavelength as the flange buckle, and the compression flange may translate in a direction normal to the web, also at the same halfwavelength as the flange and web buckling deformations. The web buckle involves double curvature transverse bending of the web. (Hancock, 1997).

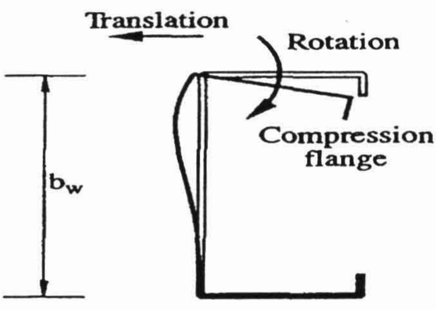
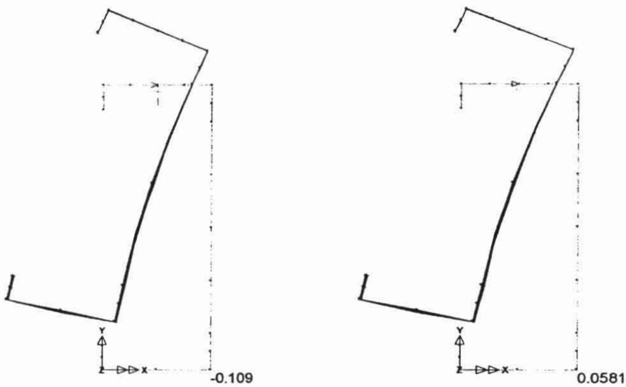



Figure 8: Distortional buckling modes of flexural member
(Hancock, 1997)

## Load-deflection Response under Uplift Loading

Under uplift loading, channel section experience out-of-plane bending of the web where the section is rotated about the point of attachment to the roofing materials as shown in Figure 9 (a) and (b). The cross-sectional properties of the channel remain constant until failure. Under this loading, the whole section of the channel is moved upward resulting in vertical bending failure while the lower portion of the web and bottom flane is moved laterally and torsional failure occurs.




(a) (b)

Figure 9: Displacement at mid span (a) horizontal (b) vertical

Horizontal displacement contour in Figure 10 shows that the part of the web and bottom flange of the mid span of the channel is moved out of plane of the section. The lateral displacement near to the end of the span is reduced due to restraining of the web to stop lateral torsional buckling of the whole purlin.

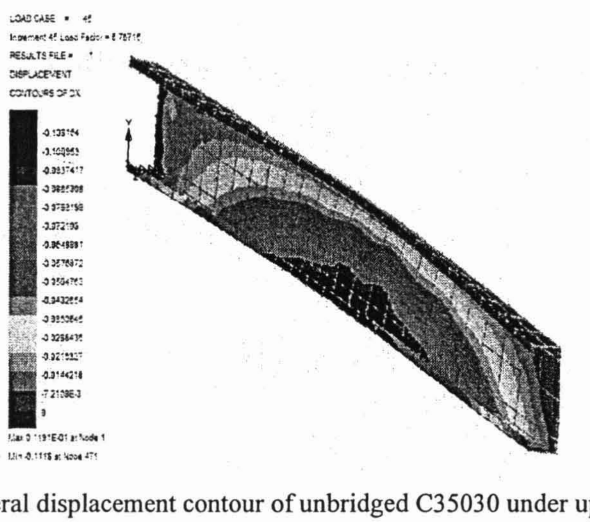


Figure 10: Lateral displacement contour of unbridged C35030 under upward loading

Vertical displacement contour in Figure 11 shows that the purlins experienced a bending deformation at the mid span of the channel. The failure mainly occurred at the top and bottom flange, while the web experienced only small deformation. The vertical displacement near to the end of the span is reducing due to restraining of the web and the bottom of the purlin.

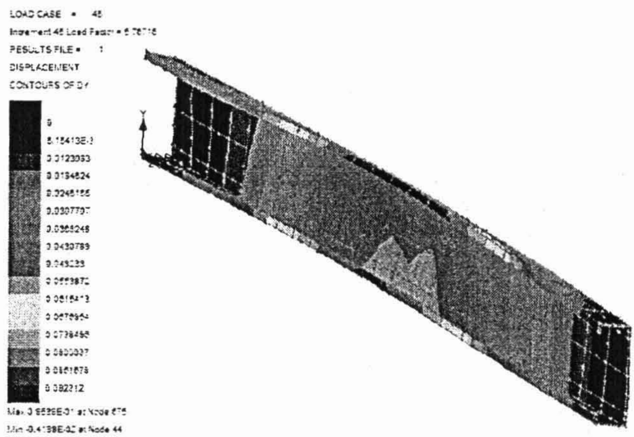
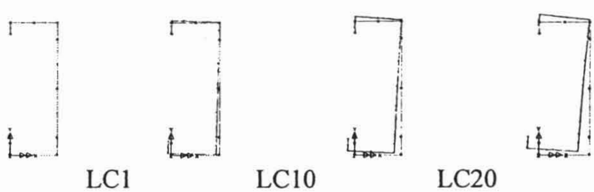


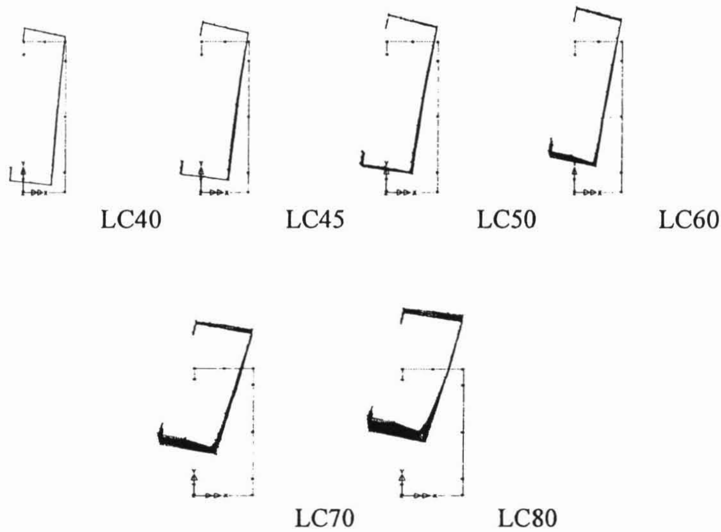
Figure 11: Vertical displacement contour of unbridged C35030 under upward loading

Figure 12 demonstrates the cross section distorsion of 7 m C35030 purlin at mid span as determined at various load levels. It shows that the lateral displacement of the top flange was greatly inhibited by the presence of the lateral restrain at the centre flange node of the purlin provided by the sheeting. Large degree of cross-section distorsion experience by the purlin under upward loading which is the bottom flange is rotating clockwise. The top flange was restrained to move laterally by providing lateral restrain that represent sheeting respond to the purlins.

The channel section tends to rotate around the middle of the flange where the screw connection is located. The channel was undergoes vertical bending and torsional stages. The torsional stage is results of lateral torsional of the purlin. At the early stages loading, the purlin is experiencing lateral and torsion failure which the cross-section rotates and translates, however it did not distorted in shape and it is characterized by rigid body movement as reported by Li (2004). Before the purlin reaching the peak load at 11.53 kN/m, the section is experiencing a lateral torsional buckling where the web of the purlin buckles at the web-bottom flange junction.



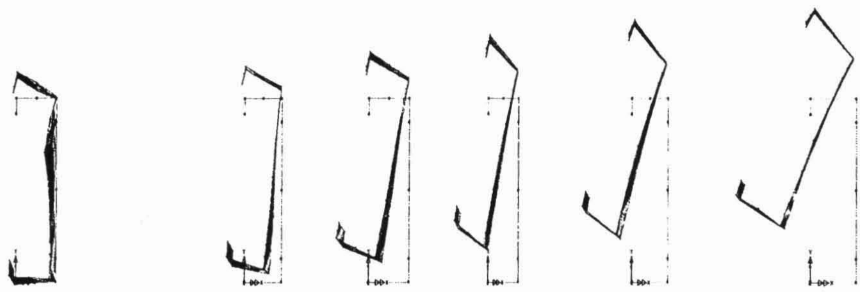
LC1 LC10 LC20 LC30



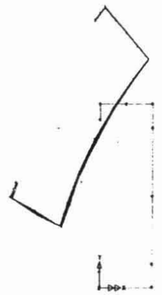

| Loadcase | Load (kN/m) | dx (mm) | dy (mm) |
|---|---|---|---|
| LC1 | 0.02 | -0.18 | 0.04 |
| LC10 | 2.11 | -17.13 | 4.12 |
| LC20 | 5.12 | -37.91 | 10.72 |
| LC30 | 8.09 | -57.06 | 18.61 |
| LC40 | 10.67 | -82.53 | 34.29 |
| LC45(peak) | 11.53 | -108.76 | 58.13 |
| LC50 | 11.13 | -130.89 | 91.64 |
| LC60 | 10.48 | -145.02 | 128.77 |
| LC70 | 10.06 | -169.63 | 244.85 |
| LC80 | 9.86 | -169.10 | 321.08 |

Figure 12: Deformation shape of C35030 under upward loading

Figure 13 represents the cross section deformation through the span from end span to the mid-span of purlin under upward loading. End support provides lateral restrain to the web and has reduced the lateral torsional buckling of the end span of the purlin. However, due to upward loading, buckling occurred at top flange-web junction. Due to longer span, the restrain provided by support is no longer effective to provide a restraint to the purlin, it causes lateral torsional buckling to the purlin which was severe at mid span.



(end span)



(mid span)

Figure 13: Cross section deformation through the span from end span to the mid span of purlin under upward loading

## Conclusion

Based of discussion on failure criteria of cold formed steel purlin, the follwing conclusion can be made.

i. Simply supported deep channel cold formed steel purlin under uplift loading is experiences out-of-plane bending of the web where the section is rotated about the point of attachment to the sheeting.
ii. Vertical bending occurs on the whole section while the bottom flange of the section moves laterally resulting in lateral torsional buckling failure on the section.

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