Proceedings of International Conference : Issues, Management And Engineering In The Sustainable Development On Delta Areas
Semarang, Indonesia – February 20th, 2015
Paper No. XXX (The number assigned by the OpenConf System)

Cold-Formed Steel Technology in Building Structure and its Problems as an Alternative Solution of Corrosion Resistant Structures at Coastal Areas

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Abstract-This paper aims to determine the technological development of cold-formed steel is happening today and the problems of its application especially on the building structures. The cold-formed steel structures have become alternative could be used in coastal areas due to its corrosion resistant properties. The development of the cold-formed steel use on structures is reviewed. In addition, the advantages and lacks of the cold-formed steel structural members are presented based on the research conducted previously. It is concluded that cold-formed steel technology has great potential to be developed and be applied to building structure even some problems arised have to be overcome especially regarding to local buckling and low capacity of the connection.

Key Words: cold-formed steel, slender section, structural members, local buckling, corrosive area

1. Introduction

Cold-formed steel is the common term for products made by rolling or pressing thin gauges of steel sheet into goods. Recently, the material to be mostly material used on building structure replacing timber or hot-rolled steel (structural steel). The use of cold-formed steel on building constructions has started since a long time ago. However, the use was not widely employed until the 1940's. Starting in 1946, the use and development of cold-formed steel sections began to increase since the code of design of cold-formed steel structure was published (Yu, 1991).

Some general properties of cold-formed steel is similar to hot-rolled steel. The main difference is that of the cold-formed steel composed of slender elements i.e. web and flanges causing it is generally classified as slender section. For the elastic properties the following value can be used (BSI, 1998) :

- Modulus of elasticity E = 205 kN/mm^2
- Shear modulus G = 79 kN/mm^2
- Poisson's ratio υ = 0.3
- Coefficient of linear thermal expansion α = 12 x 10-6 per °C

Meanwhile, for calculating of the section properties of materials up to 3.2 mm thickness, usually it is enough to assume the material is concentrated at the mid-line of the section and the round corners are replaced by the flat element intersections (BSI, 1998).

The most frequently used sections are steel are channel, zee, special and compound sections as shown in Figure 1.

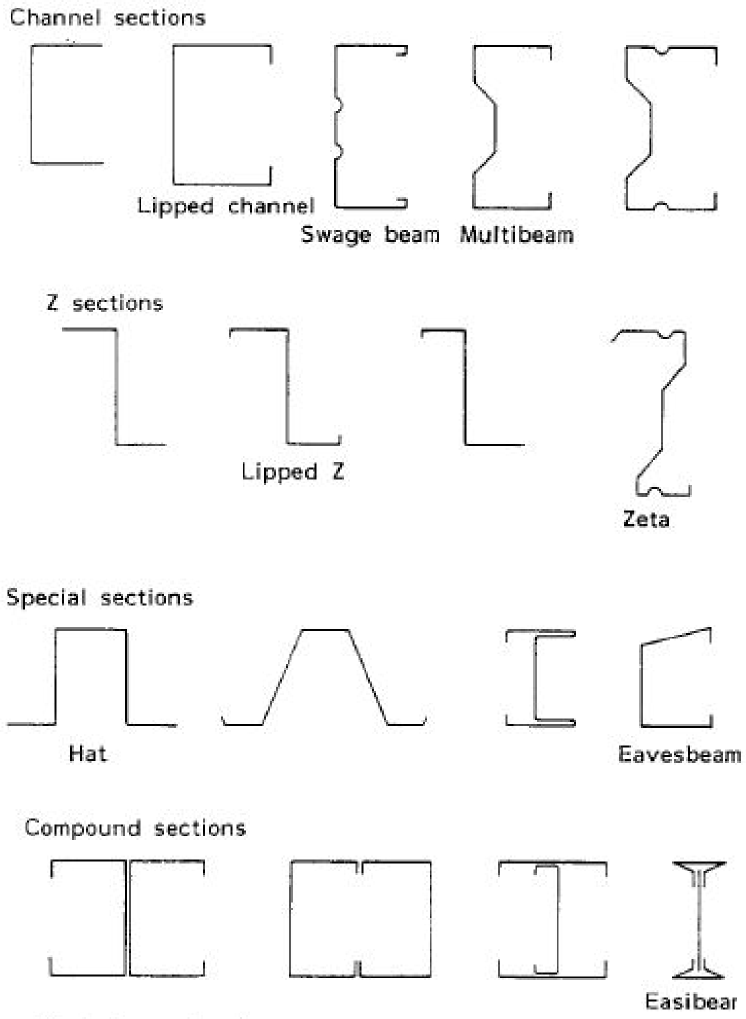

Fig. 1. Types of cold-formed section

Usually, cold-formed steel sections is galvanized by 0,04 mm thickness of zinc which giving adequate corrosion protection this materials suitable applied for the delta area structures where the corrosion need to take account in the design. However, understanding the lacks of the application for such structure need to be considered.

Development of Cold-Formed Steel in Building

Cold-formed steel members have been used in building, bridges, storage, racks, grain bins, car bodies railway coaches, highway products, transmission towers, transmission poles, drainage facilities, various types of equipment and others (AISI 2007 b).

The main developments in the use of cold-formed steel in buildings are in secondary elements such as purlins and side rails, in the primary framing of housing and light industrial buildings, and in new cladding system such as composite panels. Other developments have been in methods of connection such as the swage beam system and in storage racking.

The Use of Cold-Formed Steel in Building

Cold-formed steel has been used extensively as secondary elements in building frames such as purlins, cladding, lintels, etc, but it was now becoming more popular in the primary structural elements such as columns and beams. There have also been developments in particular structural systems using cold-formed steel members and sheeting entirely. This trend is likely to continue.

In UK, the use of cold-formed steel in building is shown in Table 1 (Lawson, 1992).

Table 1 Use of cold-formed steels in building (1989)

	Tonnes
Roof and wall sheeting	150.000
Rof decking	15.000
Composite decking	40.000
Purlins	50.000
Partitions	20.000
Lintels and other elements	40.000
H and V ducting	100.000
Other components	80.000
Total (aprox.)	500.000

2. Advantages and Lacks of Cold-formed Steel Use

Cold-formed steel sections provide the following main advantages in building construction (Yu, 1991):

- Unusual sectional configurations can be produced economically by cold-forming operations and consequently favourable strength-to-weight ratios can be obtained;
- Nestable sections can be produced, allowing for economic and compact packaging and shipping;
- Very good strength to weight ratio;
- Load carrying panels and decks can provide useful surfaces for floor, roof, and wall construction, and in other cases they can also provide enclosed cells for electrical and other conduits;
- Load carrying panels and decks not only withstand load normal to their surfaces, but they can also act as shear diaphragms to resist force in their own planes if they are adequately interconnected to each other and to supporting members;
- Buildings made using this material are lights, thus they are recommended to be used in seismic zones;
- Fast and easy erection and installation;
- Cold-formed steel structures are very recyclable;
- Cold-formed steel structures can have an adaptable architecture.

However, there are two kind of structural problems which have to be solved for this type of sections i.e.:

- Stability problems, mainly due to their slenderness;
- Specific connection technology which leads to specific design detailing.

3. Discussion

Previous researches on the use of cold-formed steel sections on building structure and the results are presented including truss, portal frame and the connections.

Wood and Dawe (2006) had investigated the behaviour of cold-formed steel section of roof truss structure. This experimental study evaluated the strength and behaviour of cold-formed roof truss subjected to point load panel. The whole truss members were made of channel section. The truss had span of 6.1 m length. From the result of this study, it was concluded that local buckling on the top member adjacent to the heel plate was the main failure mechanism. Meanwhile, crippling of the connector plate appeared on the side away from that point.

Experimental test on cold-formed roof structure also had been carried-out by Tahir *et al.* (2006). The objective of this study was to derive the capacity of the sections, roof truss, shear bearing capacity and pull-out resistance of the tack-screws connections. The conclusions were that the proposed sections capacity has ratios 1.09 to 2.21 in comparison to the design strength. In addition, the test of the full scale roof truss reached two times of the estimated design capacity. In addition, the tack-screw connection had shear bearing capacity and pull out resistance in the range of 76% - 141% higher than the design requirements.

LaBoube and Yu (1998) had investigated the structural behaviour and failure mode of compression web truss members and of top chord members under concentrated load as well as the effect of openings in the section web. The truss was made of C-sections and connected with self-drilling screws. It was concluded that neither the rotational restraint conditions of the top chord nor its flexural stiffness had a significant effect on the capacity of the compression web. Web crippling failures occurred at the intermediate panel point of the top chord, while failures also occurred between the ridge connection and the intermediate panel point at which a bearing stiffener was attached. The web opening might have influence on the bending, shear and web crippling strengths of the member.

Nuttayasakul and Easterling (2006) had performed an investigation on cold-formed steel roof truss system with hat complex sections for chord member. The test results were compared with the analytical results using finite element analysis. It was concluded that distortional buckling is the first mode of the specimen's failure. Meanwhile, the second mode of the failure depended on the thickness and length of the specimens.

Dawe *et al.* (2010) had investigated the slope effect and some strengthening methods effectiveness of cold-formed steel sections used in a full-scale truss. It was concluded that local buckling of the top chord adjacent to the heel was the main failure mechanism while distortion or crippling of the heel plate only occurred in specimens with unstiffened heel plate. The strengthening of the top chord and the stiffened heel plate connection could significantly increase the capacity compared to the standard configuration truss of 24%.

Vos and Rensburg (1997) had proposed the concept of the use of cold-formed steel portal frame for industrial building, community building and housing. It was concluded that the proposed concept met the demand in terms of economics because it was more economical for small to medium scale of industrial buildings. In addition, this concept was more efficient in terms of material because it produced a lightweight structure constructed of lightweight materials from the roof to the foundation.

Lim and Nethercot (2004) had investigated numerically the behaviour of cold-formed steel portal frame with idealizing the column and the rafter members as simple linear beams and rotational springs were used to represent rotational flexibility of the joints. A full-scale test of two portal frame types was also conducted. The portal frames were in 12 m span and 3 m of column height, but having different bracket size and bolt numbers. It was concluded that the simple linear beam and rotational spring idealization performed could be used and appropriate for analyzing the cold-formed steel portal frame.

The experimental study of cold-formed steel portal frame had also been conducted by Kwon and Chung (2006). The objective was to investigate the flexural strength and structural behaviour of the proposed section as well as connection which were applied on portal frame. The experimental result was compared to the result of the numerical analysis. It was concluded that the cold-formed steel section and the connection proposed have sufficient capability to be used on a pitched roof portal frame structure.

Plastic behaviour of cold-formed rectangular hollow sections used in portal frame had been experimentally studied by Wilkinson (2006). A number of finite element analysis were conducted to model the beams. It was concluded that the cold-formed rectangular hollow sections can be used in the plastic design of portal frame but strictly limits of the element slenderness (b/t) and the connection method were required.

All connection methods commonly used in hot-rolled steel construction can be used for the connections of cold-formed steel structure. However, due to the different behaviour between both the materials there were only few method had been investigated by previous researchers as will be described. In addition, some new connection methods are also presented.

Pedreschi *et al*. (1997) had examined structural behaviour and application of press joining method for connecting the cold-formed steel structure members. The objectives were to examine the behaviour of shear connection, moment-rotation of the connection model and connection in a full-scale roof truss. In general, it was concluded that based on the investigation results the press joining method could effectively be used in cold-formed steel structure.

Shear test of steel sheets connected using bolts had been conducted by Rogers and Hancock (1998). The steel sheets consisted of grade G 550 and G 300 with a thickness between 0.42 mm to 0.6 mm. Variations were made to the size and shape of the specimens, type and bolts number, in order to obtain three failure modes such as end pull-out, bearing and net section failure. It was concluded that the current design standard (AS / NZS 4600, AISI and Eurocode) could not accurately be used for predicting the failure mode of bolted connections fabricated from the thin G 550 and G 300 steel sheets.

A total of 150 single overlap screwed connections with variation of multiple point fasteners had been tested by Rogers and Hancock (1999), to observe the behaviour and to evaluate the provisions provided by the current design standards due to the screwed connections made of grade G 550 and G 300 steel sheets. A thickness of 0.42 mm, 0.6 mm and 1.0 mm was used for grade G 550 and of 0.5 mm and 0.8 mm for grade G 300. The connections were tested in shear with the types, numbers and arrangements of the screws were varied. It was concluded that the current design standards provided accurate load prediction for single overlap screwed connections of a similar thickness and failure more likely depended on tilting of the screws. However, when two different thickness steel sheets were connected with screws the failure will probably resulted from bearing distress in the thinner connected element.

Serrette and Peyton (2009) had reviewed the design provisions for screw-fastened cold-formed steel connections including criteria for testing and evaluating the strength of screw fasteners. In addition, the relationship between the connected members computed strength and the strength of the connector screws were also examined. The conclusion is that the shear strength of screws can be lower than connected members computed strength depending on the thickness and tensile strength of the connected members. It is recommended that manufacturers be required to publish the computed safety factor manufacturer for their fasteners. The requirements in the Specification for computing safety factors for screws be re-evaluated. A plate of sufficient thickness be used to restrain fastener tilt in the shear test.

Experimental investigation on the structural behaviour of cold-formed steel members connected with bolts had been carried-out by Chung and Lau (1999). Two channel section back to back connected to form I section were used as beams and columns. Only web of the channel were connected by gusset plate with bolts. The experimental study involved column-base connections, beam-column and portal tests. In general, it was concluded that the rigid and strong moment connection of cold-formed steel members could be formed. These connections could not develop the full moment capacity due to the load path discontinuity along the section flanges. Maximum moment resistance of all the connections tested were found on the average of 84% of moment capacity of the connected members.

Study on bearing strength of bolted connection for cold-formed steel structural members had been performed by Wallace *et al*. (2001). This study investigated the double and single shear cold-formed steel bolted connections failing in bearing. Connections with and without washers were studied. Two different thicknesses of sheet steel were used. The value of eccentricity e, e_1, and the bolt diameter were varied. It was concluded that the use of washers is significant in bolted connections when bearing is the mode of failure. Outside failure in double shear bolted connections behave in a similar manner as single shear connections.

An experimental study of cold-formed steel bolted connections using oversized holes without washers had been conducted by Yu *et al*. (2011). The test parameters include the sheet thickness, the connection type, the number of bolts, and the bolt diameter. The cold-formed steel nominal thicknesses are 0.762, 0.838, 1.092, 1.448, 1.727, 1.854, 2.388, 2.896, and 2.997 mm. The bolted connection types are single shear and double shear using one and two bolts. The bolt diameters are 6.4, 9.5, 12.7, and 15.8 mm. The tensile tests were conducted to investigate the bearing strength of cold-formed steel bolted connections without washers on oversized holes. It is indicated that the use of oversized holes without washers will cause excessive connection deformation and reduce the connection strength. In addition, a new design method is developed to determine the bearing strength of cold-formed steel bolted connections when oversized hole is used without washers.

Experimental study to check the strength of welded connections had been conducted by Teh and Hancock (2005), providing test data and design guidance for welded connections in G450 sheet steel of various thicknesses. The test results were used to check the relevant design rules in the North American Specification for Cold-Formed Steel Structural Members and the Australian/New Zealand Standard for Cold-Formed Steel Structures *AS/NZS 4600*. It was found that the current design rules were not adequate for certain connection configurations in G450 steel to achieve the target safety index of 3.5. Reduced resistance capacity factors were proposed for some connections. In addition, the current design rule for longitudinal flare-bevel welded connections was unnecessarily conservative.

Tests of stiffened and unstiffened welded knee connections in cold-formed rectangular hollow sections had been performed (Wilkinson and Hancock, 1998) The aim of the tests was to simulate the behaviour of a portal frame joint under positive and negative bending. It was found that in tension, there was often fracture in the heat affected zone at low rotation values. In compression, web buckling occurred at the connection. The unstiffened welded joints could not achieve the plastic moment, and are not suitable for plastic hinge formation.

Behaviour of screwed connection of cold-formed steel members in residential construction had been investigated by LaBoube and Sokol (2002). This research intended to study the behaviour of single-shear connections with self-drilling screws on cold-formed steel structure. In this study, the variation were made for the fastener patterns, screws spacing, stripped screws and screw numbers to determine their effect to the connection strength. The results indicated that fastener pattern of screw did not significantly affect the connection strength. In addition, the connection strength decreased with decreasing spacing of the screws.

Bolted moment connections in cold-formed steel beam-column sub-frame had experimentally been investigated by Yu *et al.* (2005). A total of 16 internal and external beam-column sub-frames were tested under lateral load. The sub frames were varied in the connection configurations. Moreover, a non-linear finite element model of the beam-column sub frame was also analyzed incorporating the effect of semi-rigid joints. It was found that of the 6 specimens with large bolt pitches and thick gusset plates, flexural failure of the connection was always critical. The connection moment resistances reached at least 85% of moment capacities of the connected sections.

Research on investigating the semi rigid and inelastic joint, and lateral-torsional buckling of the eaves of cold-formed steel sections had been carried-out by Dundu and Kemp (2006). These tests observed the moment-rotation behaviour of eaves connection to form a plastic hinge. The cold-formed portal frame members were made of C-sections, which were back-to-back connected using bolts at the eaves and apex joint. In addition, these tests examine the purlin-rafer connections capacity to limit the lateral-torsional buckling. It was concluded that the proposed portal frame could be used as an alternative to the hot-rolled portal frame in terms of structural capacity and of practical construction. However, the eave connection remained the weak spot of the portal frame.

The test of eaves connections on cold-formed steel portal frame structure had been carried-out by Wilkinson (2003). This study intended to test experimentally capabilities of some types of connection to form plastic hinge. The rectangular hollow section was used as the beam and column of the portal frame. Some types of connections were tested including welded joints with reinforcement and without reinforcement, bolted end-plate, as well bolted or welded internal sleeves. Failure mode and moment-rotation diagram of the connections were also determined. The conclusion was that the connection with internal sleeve showed the most suitable behaviour for plastic design and achieved large plastic rotation, larger than the stiffened connection.

Pham *et al*. (2003) had performed finite element analysis for eaves connection on cold-formed steel portal frame to determine the best eaves connection with self-drilling screw.

The finite element analysis was performed using FEA STRAND7 program. The results were compared to the experimental and theoretical calculation results. It was concluded that the finite element model successfully modelled the observed connection configuration behaviour such as in the experimental test conditions.

Experimental test of eaves connection on cold-formed steel portal frame had also been carried-out by Mills (2003), using C-section members but with a large thickness. This study investigated the behaviour of bolted moment connection end-plate. The tested connections were designed using the design guidelines for hot-rolled steel connections to determine whether these guidelines could be applied without modification to the portal frames. It was indicated that the portal frame made of section C DuraGal (cold-formed steel with a large thickness) could be designed using the design standard of hot-rolled steel connection.

Moss and Mahendran (2003) had tested experimentally the structural behaviour of self-piercing riveting (SPR) connection used in the house frame structure. The tests were carried-out on steel G 300 and G 550 with a thickness between 0.75 mm to 1.15 mm. These tests aimed to determine the primary failure mode and find out the application suitability of the standard of single point lap shear test with the existing connections in the house framing. It was concluded that the connection with self-piercing riveting (SPR) has a similar behaviour to the screwed or bolted connections when it was tested with standard lap shear conditions.

4. Conclusion

Some conclusions can be taken from the reviewing results especially on the cold-formed steel application for structural members as follows:

1) It is a big opportunity of applying cold-formed steel as structural members located on delta areas for the material have a good protection against corrosive problems.
2) The main problems have to be solved to apply the material on the structure are the local buckling and the connection method which able to behave as rigid connection for the ridge and eaves of pinned based gable portal frames.
3) Combined closed cold-formed steel section composed of two channel sections have higher capacity and stability compared to the open one.

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