



Review

Structural features of cold-formed steel profiles

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ABSTRACT

Using capacity of cold-formed steel sections increases thanks to the opportunities which are offered by the developing technology. Low production cost and variety of profiles that can be produce easy, fast, high quality provide to improve its popularity as a structural material. In production, Sulphur and Phosphorous accumulation region occurs at intersection region of flanges and web of hot rolled steel profile. This causes to decrease strength of profile. Other difference between cold-formed and hot rolled steel sections is that mechanical properties of steel material homogeneously distributes throughout the profile. Both in frame and truss systems, cold-formed steel profiles develop both as main and secondary bearing element. These present variety options to the designers with pure, galvanized, aluminized applications. As with many building materials, mechanical behavior of cold-formed steel profile is quite complex due to the nature of thin walled steel sections. Design and analysis methods of cold-formed steel profile are rapidly shaped day by day. The general theory of beams investigated in past studies make possible analyses of cold-formed steel profile. Moreover, in structural systems, using of cold-formed steel profile provide height strength besides sustainable, environmentalist, green building because it requires less material and cost. Although these profiles have many advantages, use of cold-formed steel profiles in our country structures is rather limited unfortunately. New steel construction regulations in Turkey also do not mention cold-formed thin walled steel structure. Main purpose of this study reviews structural specifications of cold-formed steel profiles which are applied world-wide.

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1. Introduction

Nowadays, reinforced concrete is most commonly structural material in worldwide. Some advantageous properties of reinforced concrete such as to be poured in desired shape, to have enough number of technical personal in market, to be easily accessible provide that this material is popular. Although this material has various properties, strength-weight ratio of reinforced concrete is quietly low when it is compared with other materials. This is so important especially in long span structure. In this type of structures, steel material distinguishes with high strength-weight ratio. That steel structure can be quickly built, which

made it remarkable after WWII (World War II). With the increase in usage of steel as a structural member has expanded since the WWII. When using of this material is increase, their design criteria are developed day by day. Thus, new shaped profiles are emerged (Çiftçioğlu et al., 2017). Steel profiles are commonly produced in the market in two forms; hot rolled sections and cold formed sections. Hot rolled steel sections are generally used as structural member in long span structure and tall compression elements. However, generally, buckling capacity of cold-formed steel profiles is low. Therefore, cold-formed steel profile is assumed as economic for low-rise buildings when span is not enormous.

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Cold-formed steel profiles are used as structural member in many parts of the real-world designs. As an independent building system, structures built with these type elements are implemented at mass production of two story buildings, small commercial buildings, industrial units and single-story sports hall. This structural system can be combined with other structural systems such as reinforced concrete wall and, in this way, it can be applied as a composite bearing system (Azizian, 2015). Cold-formed steel sections are made by bending a thin plate normally having a thickness starting from 1 mm. Generally, it made as structural element which has thickness from 2 mm to 6.4 mm in a certain shape. One of the advantages of cold-formed steel profile is that strength-weight ratio is much higher than hot rolled profiles. Thus, using of this structural member decreases total structural weight. For his reason, cold-formed steel structural elements are assumed as economic for low-rise and low span buildings. However, the calculations and designs of building made of cold-formed steel profiles are difficult due to complicated mechanical behaviors. Nowadays, optimization is used as an effective solution tool to design such complex problems in engineering applications (Akpınar et al., 2017). It is possible to produce cold-formed profiles in designed shape by means of developing technology. Production of cold-formed steel profile can be divided in two main processes as production of plane and bending of this plane. Industrial standard thickness is typically between 0.5 mm to 7 mm for both production methods. Steel used to produce cold-formed steel profiles has yield strength between 250 MPa and 550 MPa (Hancock, 1997).

2. General Material Properties of Cold-Formed Steel Profiles

Nonlinearity of a material can be defined as nonlinear relation between stress and strain. In other words, stress is a nonlinear function of strain. The theory of plasticity patterns mechanical reaction of material because of that material subject to deformation which cannot be repaired. Theory of plasticity presents mathematical relations which characterize elastoplastic reaction of materials. In rate independent plasticity theory, there are three main parts. These are yield criteria, yielding rule, strain hardening rule. Material nonlinearities of cold-formed steel profiles is created by considering a plastic material which has Von Mises yielding criteria and excellent flexibility. Cold forming process reveals cold forming in sections and particularly in corners of sections. As a result, yield stress increase and ductility decrease in corner regions of the sections. Material at corner regions can be anisotropic. Moreover, it can contain permanent stress. By evaluating experimental data, determining of the mechanical properties is so hard. Therefore, same material properties for all the materials are considered to simplify the model (Jegan and Prasath, 2016).

Strength of a structural member which is collapsed by buckling is related not only to yield strength but also to the modulus of elasticity (E) and tangent module (E_t).

Modulus of elasticity is defined as the slope of linear region of strain-stress curve of material. Measured value of modulus of elasticity according to standard method is between 200 GPa and 207 GPa. This value has been used as 203 GPa for cold-formed steel elements by American Iron and Steel Institute (AISI, 2007) for design purpose since 1946. There is it currently in North American Specifications. Tangent modulus is defined by slope of any point on the strain-stress curve. Tangent modulus value increase until it is equal to modulus of elasticity for absolute yielding. Tangent modulus is equal to modulus of elasticity in gradual yielding. Yet in this case, it increases until it will receive proportional limit value. When the stress proportional limit is exceeded, tangent modulus is gradually smaller than initial modulus of elasticity. Thus, steels with sharp yield stress for average slenderness have greater buckling strength than steels which has graded tensile strength. Various buckling conditions in North America Specifications are written for situation that steels maximum yielding stress is not approximately %70 less than the ones having graded yielding (AISI Standard, 2016).

Definition of shear modulus (G) is a ratio between shear stress and shear strain. Shear modulus is linear part of the slope of shear strength-strain curve. It is calculated by a traditional equation which is depended on poisson ratio and modulus of elasticity ($G=E/[2*(1+\mu)]$). In this equation, if modulus of elasticity is 203 GPa and poisson ratio is 0.3, shear modulus will be calculated as 78 GPa. Therefore, value of shear modulus in North America Specification is obtained (AISI, 2007; AISI Standard, 2016). This value is used in order to calculate torsional buckling stress in design of wall stud.

3. Advantages of Cold-Formed Steel Profiles

Cold-forming process has effect of increasing the yielding stress of steels. This increasing is result of that the cold forming process is well incorporated into the strain hardening range. Therefore, effect of cold forming process enhances average yielding stress between %15 and %30. It can be assumed that yielding stress increases minimum %15 for design purposes (Yu and La Boube, 2010).

There are some different properties of cold-formed profile from hot rolled profile.

- i) Cross sections of cold-formed steel profiles are designed to eliminate tolerance. These can be repeated continuously if necessary.
- ii) Cold forming can be used to produce any desired shape in any desired length.
- iii) Pre-galvanized or pre-coated metals can be produced. Thus, an attractive surface coating and high corrosion resistance can be obtained.
- iv) All traditional connections method can be used (riveting, screwing, welding and using adhesive).
- v) High strength ratio is obtained from cold-formed product.
- vi) These are generally light. Therefore, transportation and montage of cold-formed steel profiles are easy. Otherwise, this present environmentalist and

sustainable structuring because of them can be completely recycled.

vii) To send away material is possible in order to increase maximum load carrying capacity especially in beams (Narayanan et al., 2011).

Cold-formed steel profiles have not only above main advantages, but also other advantages. Decreasing weight of steel in general applications provides profit in both cost of steel and cost of transportation and montage. This is one of the main causes that provide a huge advantageous to steel profiles becoming popular nowadays. Consequently, the use of cold-formed steel is increasing day by day. Additionally, cold-formed steel can

be protected against corrosion by using suitable galvanizing or powder paint. A desired thickness limitation can also be applied for components such as lipped channel profiles.

Typical cross section properties of hot rolled and cold-formed channel sections are shown in Fig. 1. When Fig. 1 is considered, by decreasing wall thickness, corresponding values of the moment of inertia (I_{xx} and I_{yy}) can be larger. Therefore, it is able to resist larger bending moments (Narayanan et al., 2011). Yet, that special care should be taken to discharge the appropriate design conditions into account for the expected buckling problems has not been ignored.

<i>A</i>	1193 mm ²	1193 mm ²	1193 mm ²	1193 mm ²
<i>I_{xx}</i>	1.9 × 10 ⁶ mm ⁴	2.55 × 10 ⁶ mm ⁴	6.99 × 10 ⁶ mm ⁴	15.53 × 10 ⁶ mm ⁴
<i>Z_{xx}</i>	38 × 10 ³ mm ³	43.4 × 10 ³ mm ³	74.3 × 10 ³ mm ³	112 × 10 ³ mm ³
<i>I_{yy}</i>	0.299 × 10 ⁶ mm ⁴	0.47 × 10 ⁶ mm ⁴	1.39 × 10 ⁶ mm ⁴	3.16 × 10 ⁶ mm ⁴
<i>Z_{yy}</i>	9.1 × 10 ³ mm ³	11.9 × 10 ³ mm ³	22 × 10 ³ mm ³	33.4 × 10 ³ mm ³

Fig. 1. The geometrical properties of some channel profiles.

4. Types and Application Areas of Cold-Formed Steel Profile

Cold-formed steel elements are commonly used as *C* sections, *Z* sections and various hat channels in North America. These standard sections have traditionally been used for years. Cold-formed special section profiles are used in storage space, existing rack structural systems. Especially in the past decade, with the advantages of developing production technology and lowering the costs in mass production, new generation sections have begun to emerge. Many steel building companies start developing new generation cold-formed steel profile sections. These have larger flange, thinner web and intermediate stiffeners. Steel building companies introduce also several variations of *C* section profiles. Among these, the most popular sections are stiffened and web opening profiles. Thanks to these openings, both beauties are attended to the design element architecturally and the electricity, water and sewerage systems used in the structure is passed through the web openings and the assemblies are provided without damaging the structure. These cold-formed steel structures, which are designed using closed tube sections, have a higher load carrying capacity than hot rolled steel construction elements. In addition, constructions which are designed using cold-formed steel profiles generally enter the green

building categories. They have great advantages in terms of material savings and therefore cost savings. Thanks to developing production technologies and analysis methods, these profiles are becoming more and more advantageous day by day (Hancock et al., 2001).

4.1. Application areas of cold-formed profiles

Cold-formed steel profiles are used as load-carrying elements in three main sections, in frames, in metal structures, and in rack systems used in industrial structure (Gherzi et al., 2005; Schafer, 2011).

4.1.1. Frames

By taking into account buckling conditions, most of the civil engineers consider that cold-formed steel profiles are suitable for using as low height and low span structural members. Using of low height and/or low span structural elements as bearing member is so much similar to timber structure element which is used for same purpose. Therefore, beams which are made from cold-formed steel profiles in single or two-story structures are likely to compete with wooden structures which is the types of bearing structure traditionally used in the market, and after that this competition will be exist. Most of in floor frame structures designed by using

cold-formed steel profiles at most medium heights is considered as an alternative for the frame platform. Each of these structures is separately mounted with studs

In the medium height structures which are designed by using cold-formed steel profiles, there is a need for an improved specification that can be applied in the technical direction in engineering and design phases. Despite the fact that North America and other some countries are specifically developed and implemented for frame structures, these required specifications are not still worked seriously in our country.

4.1.2. Steel buildings

The distinction between cold-formed steel framing systems and load carrying metal buildings made from cold-formed steel profiles is not perfect. Yet, metal buildings which are made from cold-formed steel profiles generally attempt to create a clear opening area indoors, while cold-formed steel frame structures may not do this. In addition, steel sheet is used to cover in cold-formed metal structures to substitute plywood, gypsum board etc. In addition, metal buildings which are made of cold-formed steel profiles are generally designed as a whole system. The frame structures which are made of paneled cold-formed steel profiles extend to the metal building in some situations. Load-bearing walls made of steel sheets also starts to spread rapidly in countries such as America, Australia, Hungary and Poland.

4.1.3. Rack structures

Rack structure systems which are used in storage areas and designed using cold-formed steel profiles are commonly and long-term used. Although building elements and connections have not changed significantly over the last five years, the understanding of behavior and the transformation of this understanding into improved designs have become very productive. Significant new tests have been experimented on girders, connections of vertical rack and base plates. Particularly, the analysis protocols with the use of second-order analysis and the experimental protocols have been developed and formalized. Current concerns such as the impact forces (Gilbert and Rasmussen, 2011a, 2011b) and gradual collapse (Ng et al., 2009) are seemed to have found their place in recent studies. Standard (specification) organizations that support the industry of rack systems which are made from cold-formed steel profiles are quite effective. In many cases, these are highly developed due to their complex nature of rack structural performance. For example, the Australian-based rack standard (AS 4084, 2012) provides fully coded guidance in the performance of geometric and material nonlinear analyzes on faulty structures.

5. Conclusions

The general material properties of cold-formed steel profiles, advantages over hot-rolled structural elements, partial mechanical properties, type of cross-section

shapes and using areas of these steel profiles are shortly reviewed in this study. Cold-formed steel profiles are used in a wide range as the main load bearing element and / or the secondary element in many important buildings. The using areas of these profiles are expanding day by day. New analysis and design methods accelerate the success and spreading of cold-formed steel profiles. Looking at the development of cold-formed steel profiles from past to present, it is possible to say that the development and application potential of these new generation structural elements continues to increase.

Today, the construction industry has an important negative impact on the environment from the start of raw materials collection, transportation, manufacturing to the completion of the construction of buildings. Buildings of structure do not only produce more waste, but also cause more consumption by requiring transport and electricity (emissions) and generally cause landscaping damage, ecological degradation, destroyed natural habitats and forests. For this reason, a variety of technologies are currently being employed for construction systems that are ungenerous for the consumption of energy resources, as well as easy to build, comfortable, more safety and cost saving construction systems. Herein, using of cold-formed steel profiles in structural systems provides environmental construction because they require less material to bear the same load than other types of materials and reduce the amount of waste material on construction sites. In addition, using of cold-formed steel profiles reduces amount of waste materials which emerged in the construction site due to the fact that structure members and panels can be produced in workshops, factories and then it is transported to the construction site and it is mounted.

Most important advantages of cold-formed steel profiles are that it is necessary to have the possibility of forming sections in different shapes in order to obtain income of maximum resistance in the sections which are made from these profiles, to be light, to have high strength and rigidity, to have high accuracy and fast and easy installation in application detail. It has been found that the weight of a structure which is built by using cold-formed steel profiles is about 573% lighter than a building system made of reinforced concrete elements and about 59% less than a building system made by using steel elements.

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