CHAPTER 1

INTRODUCTION

1.1 GENERAL

Hot rolled and cold formed members are the two main families of structural members in steel construction. Even though cold formed structural members are less familiar of the two, they have a growing importance relative to the traditional heavier hot-rolled structural members. Cold-formed steel members are made at room temperature using rolling or pressing thin flat steel sheet to get a desired shape that will support more load than the flat sheet itself.

Cold-formed steel is widely used in buildings, automobiles, equipment, home and office furniture, utility poles, storage racks, grain bins, highway products, drainage facilities and bridges. Its popularity can be attributed to ease of mass production and prefabrication, uniform quality, lightweight designs, economy in transportation and handling, and quick and simple erection or installation. Their unique features of having large strength to weight ratio, versatility, very small thickness, non-combustibility with appropriate measures and ease of production make the CFS useful in many situations where higher strength is required with low member weight. Unlike hot rolled steel, a variety of cross sections can be produced in CFS. Some cross sections are shown below in Figure 1.1.
The use of cold-formed steel members in building construction began in about 1850’s in both the United States and U.K. However, such steel members were not widely used in buildings until 1940. In the recent years, it has been recognized that cold-formed steel sections can be used effectively as primary framing components. Light steel systems are widely used to support curtain wall panels. Cold-formed steel in the form of profiled decking has gained widespread acceptance over the past fifteen years as a basic component, along with concrete, in composite slabs. These are now prevalent in the multi-storey steel framed building market.

Their thickness is normally less than 3 mm. The steel used for these sections may have a yield stress ranging from 250 MPa to 550 MPa. The higher yield stress steels are also becoming more common as steel manufacturers produce high strength steel more efficiently.

The use of thinner sections and high strength steels leads to design problems for structural engineers which may not normally be encountered in routine structural steel design. Structural instability of the sections is more likely to occur as a result of the reduced buckling capacity, and the use of
higher strength steel which may make the buckling stress and yield stress of the thin-walled sections approximately equal.

In USA, the specification for the design of cold-formed steel structural members was first laid down in 1946 by the American Iron and Steel Institute and has been regularly updated based on research to the most recent 1996 edition (AISI, 1996, 1999). The first edition of the unified *North American Specification* (AISI, 2001) was prepared and issued in 2001 and recently updated in 2008 USA. It is applicable to the United States, Canada and Mexico for the design of cold-formed steel structural members.

In Europe, the ECCS Committee TC7 originally produced the European Recommendations for the design of light gauge steel members in 1987 (ECCS, 1987). This European document was further developed and published in 1996 as the European Pre standard Euro code 3, Part 1.3 supplementary for cold-formed thin gauge members and sheeting (CEN, 1996).

1.2 TYPES OF COLD-FORMED STEEL SECTIONS

Cold-formed members and profiled sheets are steel products made from coated or uncoated hot rolled or cold-rolled flat strips or coils. Within the permitted range of tolerances, they have constant or variable cross-section. Cold-formed structural members can be classified into two major types:

i) Individual structural framing members.

ii) Panels and decks.
1.2.1 Individual Structural Framing Members

Individual framing members can be used as primary framing members in buildings up to six stories high. In taller multi storey buildings the main framing is typically of heavy hot-rolled sections and the secondary elements may be of cold-formed steel members such as steel joists, decks or panels.

The usual shapes are channels (C-sections), Z-sections, angles, hat sections, I-sections, T-sections and tubular members. The sigma section possesses several advantages such as high load-carrying capacity, smaller flange size, less weight and larger torsional rigidity as compared to standard channels.

1.2.2 Panels and Decks

These sections are generally used for roof decks, wall panels, siding material and bridge forms. Some deeper panels and decks are cold-formed with web stiffeners.

Steel panels and decks not only provide structural strength to carry loads, but they also provide the surface on which flooring, roofing or concrete fill can be applied. They can also provide space for electrical conduits, or they can be perforated and combined with sound absorption material to form an acoustically conditioned ceiling. The cells of cellular panels are also used as ducts for heating and air conditioning. Steel roof decks are successfully used in folded-plate and hyperbolic paraboloid roof construction; roof decks are curved to fit the shape of an arched roof without difficulty.

Some roof decks are shipped to the field in straight sections and curved to the radius of an arched roof at the job site. In the past four decades,
cold-formed steel deck has been successfully used not only as formwork, but also as reinforcement of composite concrete floor and roof slabs. Corrugated sheets are often effectively used as roof or wall panels, exterior curtain wall panels, arched roofs of underground shelters and drainage structures.

1.3 APPLICATIONS OF COLD FORMED STEEL

CFS can be grouped into the major areas of use such as:

- Compression members.
- Corrugated and curved panels.
- Flexural members and purling.
- Composite and plasterboard construction.
- Storage racks.

1.4 ADVANTAGES OF COLD FORMED STEEL

- Quality assured material with guaranteed properties and strength.
- Low fabrication and execution cost due to efficiency and speed.
- Equally effective in tension and compression, with no defects internally.
- Readily available sections in standard ranges in a wide range of thicknesses and size.
- High strength to weight ratio at least 1.5 times compared with hot rolled section.
- Pre-galvanized or pre-coated metals can be formed, so that high resistance to corrosion, besides an attractive surface finish, can be achieved.

1.5 BEHAVIOUR OF COLD FORMED STEEL FLEXURAL MEMBERS

Compared with conventional structural beams, the pronounced role of instabilities complicates the behavior and design of thin-walled beams. Past research has revealed that cold-formed steel members subjected to various buckling modes including local, distortional and global modes and their ultimate strength behavior is governed by these buckling modes. Although researchers have studied cold-formed steel members for long, the stability problem has not been fully understood. Generally, the following buckling patterns can occur in flexural members:

- Local buckling.
- Flexural buckling.
- Torsional buckling.
- Distortional buckling.
- Lateral buckling.

1.5.1 Local Buckling

Local buckling is a mode having plate-like deformations or it is a state of instability of its geometry before the yielding of the material takes place. The plate elements of cold-formed sections are normally thin with higher plate slenderness ratio and hence they buckle locally before yield stress is reached. Typical local buckling of an I-section is shown in Figure 1.2. Local buckling mode of a thin walled member depends on its cross section geometry.
(shape & dimensions) and support conditions. The elastic local buckling of thin elements does not immediately lead to failure. The elements can carry additional load in the post-buckling strength before failure occurs. The post-buckling strength of elements having relatively large flat width to thickness ratio may be several times the load that causes local buckling. Consequently, all the cold-formed design specifications take into account the post-buckling strength also.

![Figure 1.2 Local Buckling Mode](image)

**Figure 1.2 Local Buckling Mode**

### 1.5.2 Flexural Buckling

In this mode compression flange buckles about the weaker principle axis and collapse occurs at a rate following excessive buckling deformation (no twisting in which members can bend without change of cross sectional shape). Figure 1.3 shows flexural buckling of the cold-formed steel member.

![Figure 1.3 Flexural Buckling Mode(Yu 2000)](image)
1.5.3 Torsional Buckling (Twisting about Shear Center)

In the torsional buckling mode, the members fail by twisting about the longitudinal axis through the shear center (No bending). Figure 1.4 shows the torsional buckling of the cold-formed steel sections.

![Figure 1.4 Torsional Buckling Mode (Yu 2000)](image)

1.5.4 Distortional Buckling

Distortional buckling, also known as stiffener buckling or local torsional buckling, is a mode characterized by a rotation of the flange at the flange-web junction. In members with intermediate stiffened elements distortional buckling is characterized by displacement of the intermediate stiffener normal to the plane of the element. Distortional buckling is a mode with distortion in the cross-section. Figure 1.5 shows the distortional buckling of the cold-formed steel sections.
1.5.5 Lateral Buckling

Due to slenderness, the section has low torsional stiffness and also if the shear center is located away from the centroid. This causes lateral buckling. In this mode, members can twist and bend simultaneously without change of cross sectional shape.

1.6 NEED FOR THIS STUDY

Research on the behaviour of cold-formed steel beams spans approximately fifty years. Even today, despite numerous investigations of past decades, research in this specialized field has by no means reached finality. Since the beginning of this century, substantial progress has been
made due to technical and economical developments which demand the use of ever stronger and ever lighter structures in an increasingly wider range of applications. Such an expansion of usage is made possible by developments in theory and understanding of behaviour of material under load, construction technologies and computer aided design, economic considerations, construction efficiency etc. These developments continually change the way in which traditional structures are designed and built and hence make possible the economic use of materials. The demands of higher strength and lighter weight inexplorably lead to structures which are slender, in which a consideration of stability must play a crucial role in design. Increased strength and increased slenderness spell problems with stability. These aspects have significant relevance in light weight steel structures. In built-up I section, a thin web may be sufficient to take care of shear stresses developed due to external loads; sometimes, thin web shows instability and hence stiffeners are necessary to account for such type of stability problems. Instead of using stiffeners, corrugation in the web portion is created. This situation leads to corrugation in web. The corrugated web due to its profile shows more lateral stiffness than flat web. Corrugated web beams are built with a thin walled corrugated web and two flanges connected by welding. The corrugated web beams are an added advantage to the construction industry, due to the increase in the lateral stiffness of the beam

1.7 OBJECTIVE OF THE RESEARCH

Though the corrugated web beam results in economical construction, the use of such members is limited at present because of the complexity involved in the analysis and lack of understanding of the behaviour of such sections. In codes of cold-formed steel, no design rules are available for corrugated web beam. The use of corrugated webs allows for the use of thin plates without the need for stiffeners. The use of corrugated webs
is a potential method to achieve adequate out-of-plane stiffness and shear buckling resistance without using stiffeners. There are many types of corrugation like sinusoidal, triangle, trapezoidal, rectangle etc. The primary objective of this investigation is to examine the performance of the I-beam with trapezoidal corrugated web and to formulate design criteria for them.

1.8 SCOPE OF THE INVESTIGATION

The present investigation aims to study the behaviour of built-up cold-formed lipped I-beam with trapezoidal corrugation in web, for which there is a need for detailed investigation to understand their behaviour under flexure. Sixty one specimens have been used in the experiments by varying the aspect ratio, corrugation angle and height of the web.

The details of works done in this investigation, on built-up cold-formed lipped I-beam with trapezoidal corrugation in web, are grouped below.

- Sixty one specimens are studied. Seventeen specimens are investigated by varying the aspect ratio for three series of lengths 1800mm, 3000mm, 3600mm. Eleven specimens are investigated by varying corrugation angle for two series of length 3000mm and 3600mm. Twenty nine specimens are investigated by varying height of the web in four series of lengths 1050, 1800mm, 3000mm, 3600mm and four specimen are investigated by varying the length.

- Numerical analysis using FEM ANSYS 12.0 is performed on the tested models and the results are compared with the experimental results.
• A simplified method to locate shear center and to calculate the warping constant of lipped I-beam with trapezoidal corrugation in web is proposed.

• Experimental results are compared with the resistance by North American Specifications (AISI-S100:2007), Australian/New Zealand standards (AS/NZS-4600:2005) and Indian standard Specification (IS-801:1975).

• For designing the cold-formed lipped I-beam with trapezoidal corrugation in web, limitation of aspect ratio of corrugation, \( h_w/t_w \) ratio, \( b_f/t_f \) ratio and corrugation angle are proposed.

• A design equation to calculate moment capacity is proposed.

1.9 CONTENTS OF THIS THESIS

The contents in this thesis are presented in seven chapters as follows:

Chapter 1 presents an introduction of the topic, research objectives, scope of this research.

Chapter 2 presents the literature review. It describes the design criteria and behaviour of I-girder with trapezoidal corrugated, for hot-rolled sections.

Chapter 3 presents the details of the experimental programme and material properties and also presents the theoretical results predicted by AS/NZS-4600:2005, AISI-S100:2007 and IS-801:1975.

Chapter 4 presents the details of finite element analysis and validation of the finite element model.
Chapter 5 presents the simplified method of calculating warping constant for lipped I-section with trapezoidal corrugated web in order to find the lateral torsional buckling capacity.

Chapter 6 presents the summary of results of parametric study consolidates the results and discussion of the entire work carried out and proposes a design equation for calculating the moment capacity for I-beam with trapezoidal corrugated web.

Chapter 7 presents the summary of the most significant findings of this research and recommendations for further research.