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ANALYSIS OF COLD-FORMED STEEL CONNECTIONS

MUHAMAD KHAIRI BIN ABD KHALIL

A project report submitted in partial fulfillment of
the requirement for the award of the degree of
Master of Engineering (Civil – Structure)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

DECEMBER, 2010

I declare that this project report entitled "Analysis of Cold-Formed Steel Connections" is the result of my own research except as cited in the references. The report has been not accepted for any degree and is not concurrently submitted in candidature of any other degree.

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DEDICATION

Dedicated to

my beloved family,

friends

and

lecturers

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ABSTRACT

Finite element models with three-dimensional solid elements were generated to investigate the moment-rotation behavior of cold-formed steel connections. The finite element results were compared with the results of the experimental data from the laboratory tests carried out by a previous researcher. The three dimensional materially static non-linear finite element analysis using LUSAS software was perform on cold-formed steel connections which consisted of column-base connection and beam-column sub-frame. For column-base connection thick hot rolled connection element was used as the base plate which is already designed according to the sized wanted in the laboratory test, while for beam-column connection, channel section were connected back to back as simple and effective means to connect beam to column in steel construction. The moment-rotation curves were plotted to determine the moment resistance values of the connection. Then, the finite element curves were compared with the experimental curves to check the accuracy of the analysis results. The finite element curves for both connections resembled closely with the experimental curves. Comparison between the moment resistance values of both test and LUSAS gave good agreement.

ABSTRAK

Model unsur terhingga dengan elemen isipadu dalam bentuk tiga dimensi digunakan untuk mengkaji sifat momen-putaran sambungan keluli terbentuk sejuk. Keputusan kaedah unsur terhingga dibandingkan dengan keputusan daripada ujikaji yang dijalankan oleh penyelidik sebelum ini. Analisis statik unsur terhingga dengan bahan tak lelurus dalam bentuk tiga dimensi statik menggunakan perisian LUSAS telah dilaksanakan terhadap sambungan keluli terbentuk sejuk yang terdiri daripada sambungan asas tiang dan juga terhadap sambungan rasuk tiang sub rangka. Untuk sambugan asas tiang, unsur sambugan keluli tergolek panas telah digunakan sebagai plat asas yang mana telah direka bentuk mengikut saiz yang diperlukan di dalam ujikaji yang dijalankan di makmal. Sementara untuk sambungan rasuk tiang, bahagian saluran telah disambungkan secara membelakangi di antara satu sama lain sebagai satu cara yang mudah dan berkesan untuk penyambungan rasuk ke tiang di dalam pembinaan struktur keluli. Setelah analisis dijalankan, lengkung momen-putaran telah diplot untuk menentukan nilai momen rintangan bagi sambungan keluli terbentuk-sejuk. Kemudian, lengkung unsur terhingga dibandingkan dengan lengkung momen-putaran daripada ujikaji makmal untuk menentukan ketepatan kaedah analisis unsur terhingga. Lengkung yang diperolehi menggunakan kaedah unsur terhingga adalah hampir menyamai lengkung-lengkung ujikaji. Bandingan nilai-nilai momen rintangan yang diperolehi melalui ujikaji dan LUSAS menunjukkan bandingan yang bersesuaian.

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M	-	Moment
ϕ	-	Rotation
S_e	-	End distance
S_c	-	Strip width
f_{yz}	-	von Mises Stress
d	-	Bolt diameter
k_b	-	Elongation stiffness
S	-	Bolt pitch
e	-	Edge distance
2D	-	Two dimensional
3D	-	Three dimensional
f_y	-	Initial yield stress
E	-	Young's Modulus
v	-	Poisson's ratio
f_u	-	Ultimate yield stress
M_R	-	Resistance Moment
ϕ_b	-	Beam Rotation
ϕ_c	-	Column Rotation
ϕ_j	-	Joint Rotation
M	-	Distance in x-direction
N	-	Distance in y-direction
d_y	-	Vertical Displacement
d_x	-	Horizontal Displacement

CHAPTER I

INTRODUCTION

1.1 Background of Problem

Cold-formed steel are used in construction besides using hot-rolled steel members. Cold-formed steel sections are made of lightweight materials and can be shaped easily to their desired shapes. It is very suitable for building construction owing to their high structural performance and durability. They are widely used as secondary members, such as purlins in roofs, joists of medium span in floors, studs in wall panels, storage racking in warehouse, and hoarding structures in construction sites. Since 1990, there has been a growing trend to used cold-formed steel sections as primary structural members in building construction, such as low to medium rise residential houses and portal frames of modest span.

The most common cold-formed steel sections are lipped C-sections and lipped Z-sections, and the thickness typically ranges from 1.2 to 3.2 mm. Common yield strengths are 280 and 350 N/mm^2. Moreover, there are a whole range of variants of these basic shapes, including sections with single and double lips, and sections with internal stiffeners. Due to the thinness of cold-formed steel sections, local buckling is a predominant consideration in assessing their section capacities. Futhermore, as they are very weak in torsion, torsional flexural buckling in columns and lateral torsional buckling in beams may be critical.

In building construction, cold-formed steel sections are usually bolted to hot-rolled steel plates or sections to form simple and moment connections. However, despite their simplicity, simple connections between cold-formed steel sections have received relatively little attention. So it is important to study and understand the structural behavior of connection between cold-formed members.

The aim of this study is to investigate the moment-rotation behavior of bolted moment connections between cold-formed steel sections. The analyses work were conducted by using the LUSAS Version 13.57 software [1] utilising three-dimensional solid elements which included material non-linearity.

1.2 Problem Statement

It is very important to understand the structural behavior of cold-formed steel connection especially for design and analysis. In design, a connection will be considered as pin or rigid where a pin connection only take the axial force while the rigid connection resists the moment without any rotation. So, in the design of connection, they will be assumed as perfectly pinned or fully rigid but in real situation the connection usually behaves between these two extreme cases which is semi-rigid.

For cold-formed steel sections, the types of connection usually used is simple connection which is only bolted to hot rolled steel plates or sections to form moment connections but it should be noted that most of the design recommendations on connections among cold-formed steel sections concern the load carrying capacities of individual fasteners such as bolts, screws, rivets and spot welds.

It is important to carry out physical tests to establish the use of moment connections between cold-formed steel sections so that efficient moment framing may be designed and built in building construction [2]. But with the introduction and availability of the computer software nowadays, it will be easier and cheaper to study the behavior of moment connections between cold-formed members than using the lab-test which is time consuming and involve a high cost. So, finite element modeling will be used to model the connection of cold-formed steel section having similar dimensions to the specimens tested in the laboratory.

1.3 Objectives of Study

The objective of this research is to model cold-formed steel connections using the finite element method. The connections modelled consisted of column-base and beam-column sub-frame by using four bolts connection configurations with 2 mm thickness of cold-formed steel. From the results of the analysis, the moment-rotation (M-ϕ) curves of the connection were plotted in order to determine the moment resistance of the connection. Then, the results obtained from the analysis were compared with the results obtained from full scale laboratory tests in order to determine their accuracy.

1.4 Scope of Study

In this research, the connections for column-base and beam-column sub-frame were modelled and analyzed using the finite element analysis software, LUSAS 13.57 [1]. This research was focused on column-base and beam-column sub-frame connections made of cold-formed steel where for the beam-column connection, channel sections were connected back to back as simple and effective means to connect beam to column in steel construction. The dimensions and material properties for the model followed the dimensions of the full scale laboratory test specimens, conducted by Ali [3] whose results were compared with those obtained in the present work.

1.5 Importance of Study

The present study concerns about the analysis and the behavior of column-base and beam-column sub-frame of cold-formed steel connection. Good comparison between the moment-rotation curve, results from the finite element analysis and the results from laboratory test would prove that the finite element method was good and could be used to predict the strength and the moment-rotation curves of the above connections.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

In building construction, cold-formed steel sections are always used as secondary structural members such as purlins to support roof cladding. But since the 1990's, there is a trend where cold-formed steel members are used as primary structural members such as beams and columns. They are used to build low rise domestic houses (see Figure 2.1). The most common sections are the C and Zed sections where the thickness of this section usually varied in the range from 1.2 to 3.0 mm (see Figure 2.2). Moreover, there are a whole range of variants of these basic shapes, including sections with single and double lips, and sections with internal stiffeners and longitudinal ribs in web.

2.2 Cold-formed steel

Cold-formed steel structures is the product made by bending flat sheets of steel at ambient temperature into shapes which it can support more than the flat sheets themselves. The use of the cold-formed steel in structures started about more than a century ago since the first flat sheets of steel were produced by steel mills. The use of cold-formed steel members in building construction began in the 1850's in both the United States and Great Britain. In the 1920's and 1930's, there was still a limited acceptance of cold formed steel for use as a construction material because the design standard was not adequate and information was limited.

In recent years, there was a significant growth in cold-formed steel because of the wider range of structural applications relative to the traditional heavier hot-rolled steel structural members. There are basically two types of structural steel in building construction which are the hot rolled steel and the cold-formed steel. The hot rolled steel is manufactured and formed at elevated temperature, while the cold-formed steel is formed at room temperature. The process of manufacturing cold-formed steel members is by forming the material either using press-braking technique or cold roll forming technique to achieve the desired shape. The shape of cold-formed steel structural members are commonly manufactured from steel plates, sheet metal or strip material.

Figure 2.1 Cold-formed steel framing for residential houses [4]

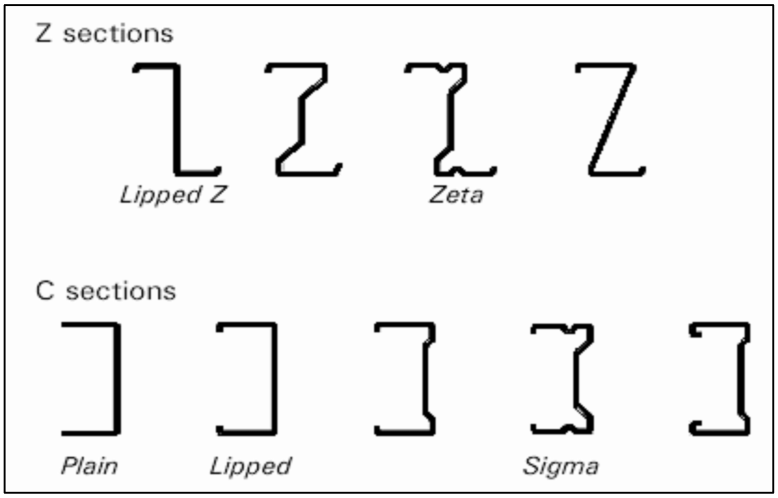

Figure 2.2 Common shapes for cold-formed steel [4]

2.3 Connection

2.3.1 Type of Connection

The stability and performance of cold-formed steel structures will be influenced by the connection between beam and column. A connection is a medium through which forces and moments are transferred from beam to column. The connection is subject to axial forces, shear force, bending moment and torsion. The effect of torsion can be excluded, shear and axial forces also very small compared to the bending moment. The connections are used to transfer forces and moments due to applied loading. The capability of the connection in resisting moments will be used to classify the types of connections in steelwork especially for cold-formed steel. Based on this criterion, connections are divided into three groups: simple connection, semi-rigid connection and rigid connection. Figure 2.3 shows the moment-rotation characteristic of these three groups of connections.

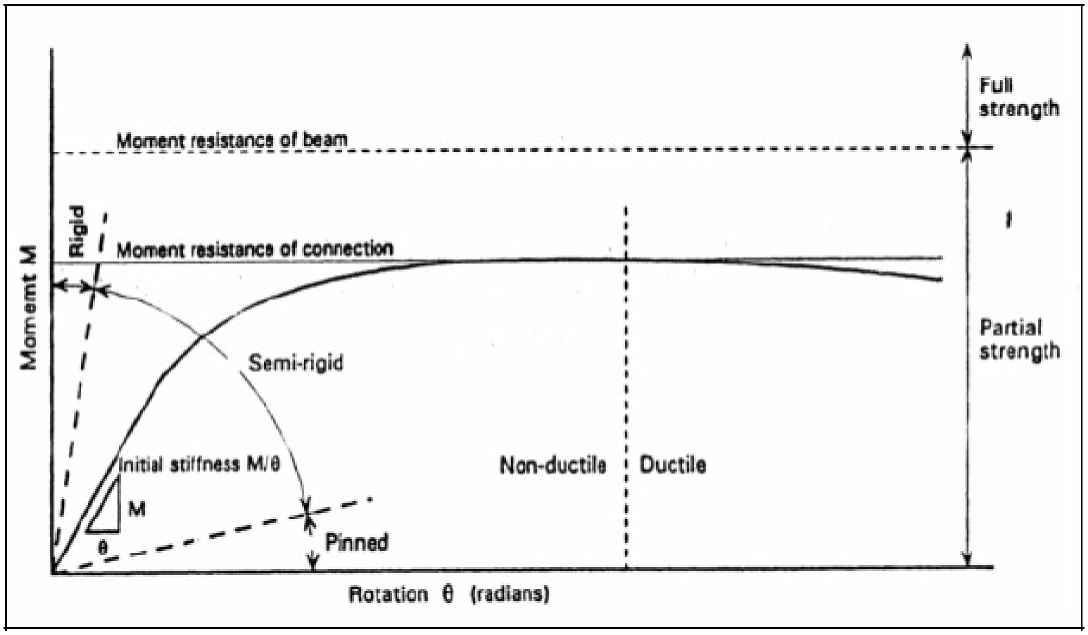

Figure 2.3 Moment-rotation characteristics of typical rigid, semi rigid and simple connections [5]

2.3.1.1 Simple Connection

In steelwork, simple connection is the simplest type of connection. The connection is used to resist shear and normal forces only. It does not provide any moment restraint at the connection. Simple connection is those connections that provide zero rotational restraint at the connections. In design, simple connections are assumed to transfer shear force only, from the beam to the column besides nominal moment and axial load. This means that members with simple connection are free to rotate when load is applied. When designing simple connections, the member is assumed to be simply supported, and care should be taken in construction so as not to provide extra strength to the connection, because the column might fail from buckling due to the extra moment transferred to it.

2.3.1.2 Rigid Connection

Rigid connections are connections with rigidity, sufficient to maintain the original angle between intersecting members that is virtually unchanged under the design load. Rigid connection is also known as fully restraint connection which is able to fully restraint the moment at the connection. At the joint, no rotation of the member will occur. Rigid connections are designed to be fully restraint, in which theoretically no relative rotation should occur between the connected members. In this connection, full continuity of the connection is maintained where the bending moment is transferred fully from the beam to the column, along with shear and axial forces.

2.3.1.3 Semi Rigid Connection

In practice, the connection rarely fall in the categories of the simple and rigid although it is common to design using either simple or rigid connections. Majority of the connection do not fall in these two categories because it is hard to maintain such idealized situation, where either no relative rotation should occur for rigid connections, and no moment is transferred in simple connections. Many connections transfer some bending moments and rotation occurs to a certain degree. This type of connection is called the semi rigid connection, or partial strength connection. The member end joints are permitted to rotate but it is limited. This connection is designed to provide predictable degree of interaction between the members based on the M-ϕ characteristic of the joint.

2.3.2 Benefits of Semi Rigid Connection

a) It is cheaper compared to simple and rigid connection. In comparison with simple connection, the characteristics of semi rigid connection in transferring some moment will reduce the amount of moment to be carried by the beam, hence, smaller beam can be used and this will indirectly save the cost for the construction.

b) Semi rigid connection is easier to design compared to rigid connection. This is because rigid connection has more complicated joint detailing. Meanwhile, it also saves the time and workmanship during fabrication and installation work.

c) It provides better stability and performance compared to simple connection. This is because of its ability in transferring the moment carried by the beam and therefore, moments are partially shared by the beam and the column section.

2.3.3 Moment-Rotation (M-ϕ) Characteristic

Moment-rotation curve usually used to define the behavior of a connection which may be obtained either through theoretical procedures or experimental research. It is often inappropriate to classify the connection as either rigid or pinned because their behavior is often highly non-linear. Several classification schemes based on the total moment-rotation behavior have been developed to aid in the design and analysis of connection. Connection classification schemes which had been proposed included those of Wheeler et.al [6] and Eurocode 3 [7]. Both of these schemes classify connections into the following three basic categories according to the moment-rotation characteristic which is flexible, rigid and semi rigid. Figure 2.4 shows the rotational deformation of a connection.