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## Cold-Formed Steel Frame with Bolted Moment Connections

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### ABSTRACT

This paper presents an experimental investigation on cold formed steel frames. The beam and column members were formed by single lipped channel sections connected back-to-back at the joints. A total of 10 frame tests were carried out under lateral load with different stiffness of bolted moment connection between cold formed steel sections. It was found that the stiffness and performance of the column base connections had significant effect on structural behavior of the frames. Furthermore, moment connections among cold formed steel members are structurally feasible and effective and engineers are encouraged to built light weight low to medium rise moment frames with cold formed steel sections.

**Keywords:** Cold-formed steel; bolted moment connections; stiffness; frame; column base.

### 1. Introduction

Over the past two decades, cold formed steel has seen increased usage as the structural frame for residential and multi-story commercial buildings due to inherent features that overcome the downsides of conventional products. Their strength, light weight, versatility, non-combustibility, and ease of production have encouraged architects, engineers, and contractors to use cold-formed steel products which can improve structural function and building performance, and provide aesthetic appeal at lower cost. At the same time, cold formed steel members have a unique structural stability issues primarily due to the large width-to-thickness comparison element ratios, which is not commonly the use with in sections of hot-rolled steel.

Limited researchers investigated the performance of the cold-formed steel frames. Kwon, Chung and Kim (2006) presented Connection and system tests of portal frame composed of closed cold formed steel sections. Findings showed that the semi rigid connection developed had high strength performance and could successfully be applied to portal frame. Dawe and Wood (2006) Tested 23 roof truss to ultimate capacity with point load applied at the ridge with different connection configuration at the connection. Methods of reinforcing the top chord to prevent local buckling were investigated. Raftoyiannis I.G (2005) established linear stability analysis for establishing the effect of joint flexibility and an elastic bracing system on the buckling load of steel plane frame. Numerical results successfully presented in tabular and graphical form the effect of the two parameters on buckling load. Tan S.H (2001) presented non linear analysis by using of mathematical model and tests of cold formed thin walled channel frames with different connection

configuration. Agreement between the theoretical and experimental results was acceptable. Finding showed that effect of connection thickness on the strength of cold formed steel frame was less significant compared to member thickness and lip size.

In order to enhance the practical use of light steel framing studies are still required to investigate the structural behavior and performance of such frames. The structural response of a steel frame is closely related to the behavior of its connections (Hancock et al., 2001, Yu, 2000). Therefore, system tests will be carried out on cold-formed steel plane frames with different connection configurations to study Structural performance of cold-formed steel frame with different stiffness of bolted moment connections. The beam and column members are formed from single channel sections which are bolted back-to-back at the joint. It is expected that the proposed structure will offer efficient and economic frame system and further insight on behavior of single channel sections. There are a number of codes of practice on the design of cold-formed steel structures together with complementary design guides and worked examples to assist practicing engineers. This study will base on the requirements of British Standard BS 5950: Part 5:1998 with assistance from complementary design guides and worked examples (Chung, 1987).

## 2. Section Geometrical Properties

The beam and column members are formed from single cold-formed lipped channel sections. The flange width, web and lip depth of the cold-formed section are 50,100 and 14 mm, respectively, and the thickness of each section is either 1.6 or 2 mm. The section properties are given in Table 1. The member capacity was calculated according to the British Standard BS 5950: Part 5: 1998.

**Table1:** Section Properties

Specimen	Depth (mm)	Thickness (mm)	Area (mm <sup>2</sup> )	I <sub>x</sub> (cm <sup>4</sup> )	Z <sub>x</sub> (cm <sup>3</sup> )	Z <sub>xr</sub> (cm <sup>3</sup> )	M <sub>cx</sub> (kNm)
C10016	100	1.6	335	55.8	11.2	9.65	4.24
C10020	100	2	414	67.9	13.6	12.6	5.5

### 2.1 Material Properties

The structural steel grade of the cold-formed steel section is G450. In order to obtain the actual yield strength, tensile tests were carried out in accordance to the British Standard BS EN 10002-Part 1 2000, tensile test of metallic materials with the nominal width of 25 mm. The average measured yield strengths were found to be 490 and 500 N/mm<sup>2</sup> for 1.6 and 2 mm thick sections respectively. The test results showed that actual resistance of cold-formed steel was higher than the design strength as in accordance with the code (BSI, 1987). The tests concluded that the proposed steel sections gave good yield strength value compared to the design strength. The fasteners used in the study were bolt grade 8.8 of 12 mm diameter with two washers. The bolt holes were standardized to 12.5 mm

so as to prevent abrupt deformation due to wide hole-spaces between the steel members (Tahir & Tan, 2008).

### **3. System Tests**

#### **3.1 Scope of Investigation**

The system test specimens consisted of 10 frame tests formed by single cold-formed channels C10016 or C10020 with a member thickness of 1.6 and 2 mm respectively. For all specimens, bolts grade 8.8 of 12 mm diameter were used.

A total of eight frames were investigated to examine the effect of different stiffness of column base connections on structural performance of the frame for two different member thicknesses. Another two system tests were carried out under lateral load for double bay frame to assess the stiffness of the frame with different stiffness of column base connections and to study the effect of increasing number of bays on stiffness of the frame. Channel sections were connected back to back as simple and effective means to connect beam to columns in steel constructions. The applied loads at the loaded points, rotations and deflections of the test specimens were recorded during the tests. The column base of the test specimens referred as CB02, CB03, CB04, where a column member is connected to a typical fabricated steel base plate with two, three and four bolts respectively. A typical frame and connection detailing is given in Figure 1 and Figure 2.

#### **3.2 Testing Set-Up and Boundary Conditions**

All the tests were carried out in the Magnus Frame. In all tests, out of plane deflection is prevented by using a lateral restrained bar. The load was applied using hydraulic jack and recorded by a 100 kN load cell. An inclinometer was placed near the column base connections at the centre of web depth to record columns rotations. Also, rotation of beam-column joint was recorded by using two inclinometers placed at the centre of beam and column webs near to the connection. Displacement transducers (LVDT) were placed through line of load application to measure lateral deflection of the frame. Details of the set up are shown in Figure 2 and 3.

#### **3.3 System Test Procedures**

Due to the presence of the clearance in the bolt holes of the tested specimens, tightening the bolts was essential prior to any testing. The load application was applied with the increments controlled by the load. This loading application was continued until the specimen had reached its failure condition. The applied loads of the loaded point, joint rotations and lateral deflections of the test frames were recorded during the tests.

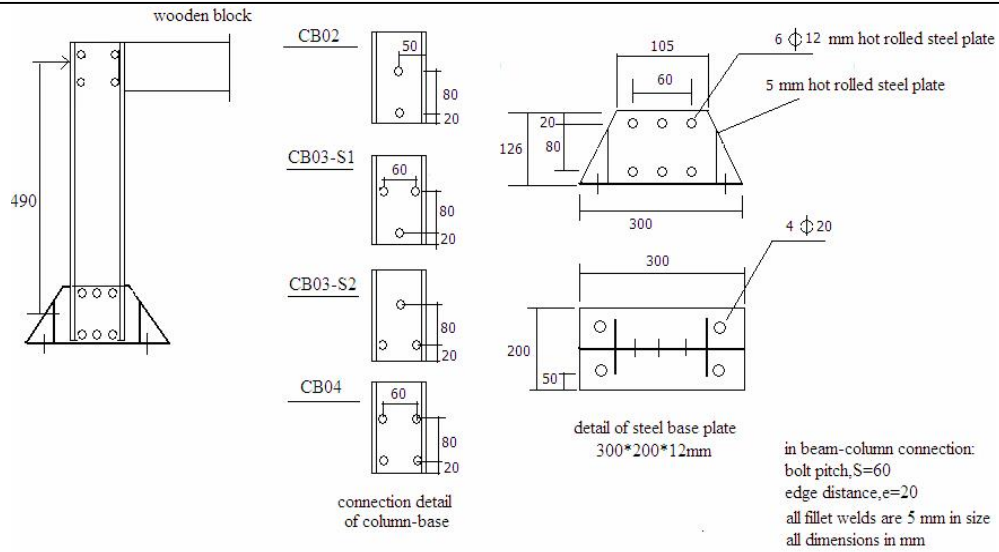


Figure 1: Connections detail of system specimen tests

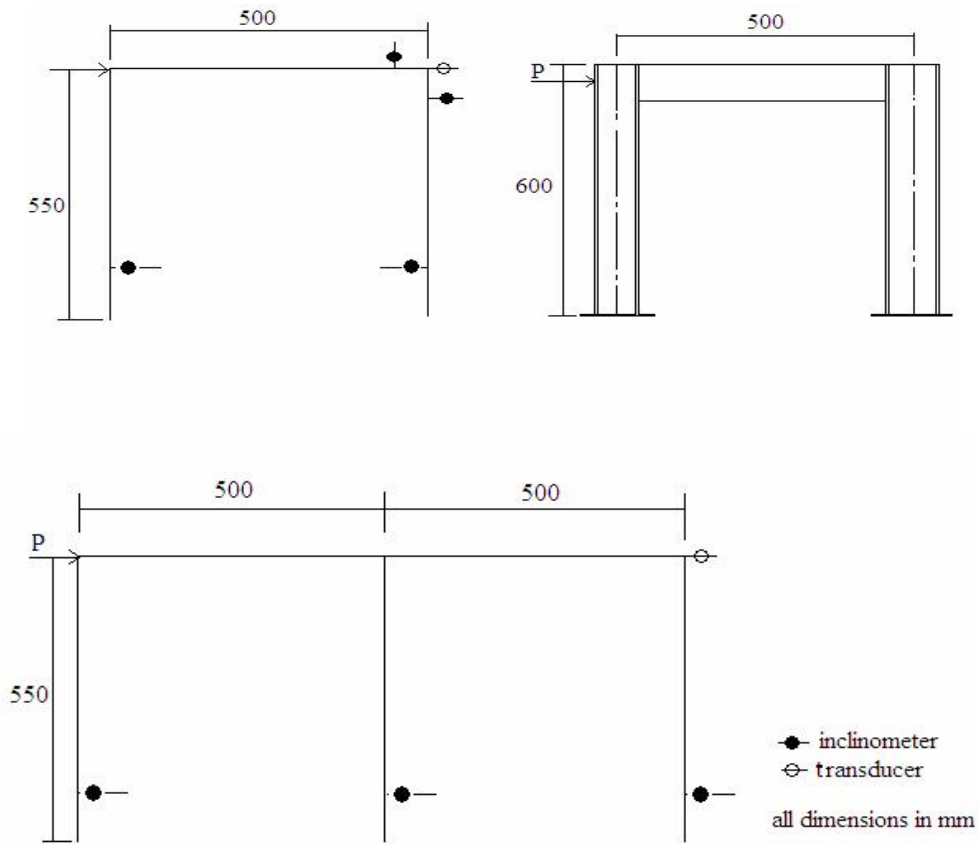
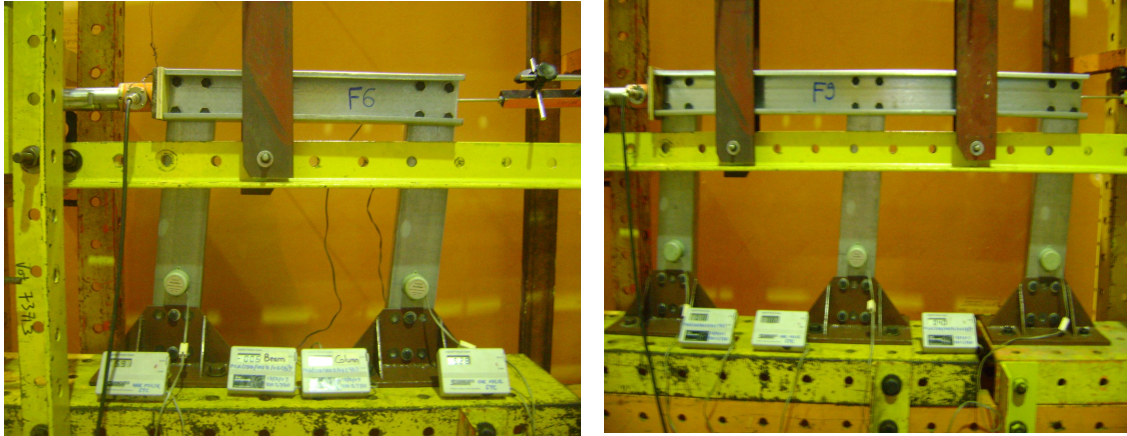


Figure 2: General set-up and instrumentation of system tests



**Figure 3:** Actual specimen layout for system tests single bay frame (left) and double bay frame (right)

### 3.4 System Test Results

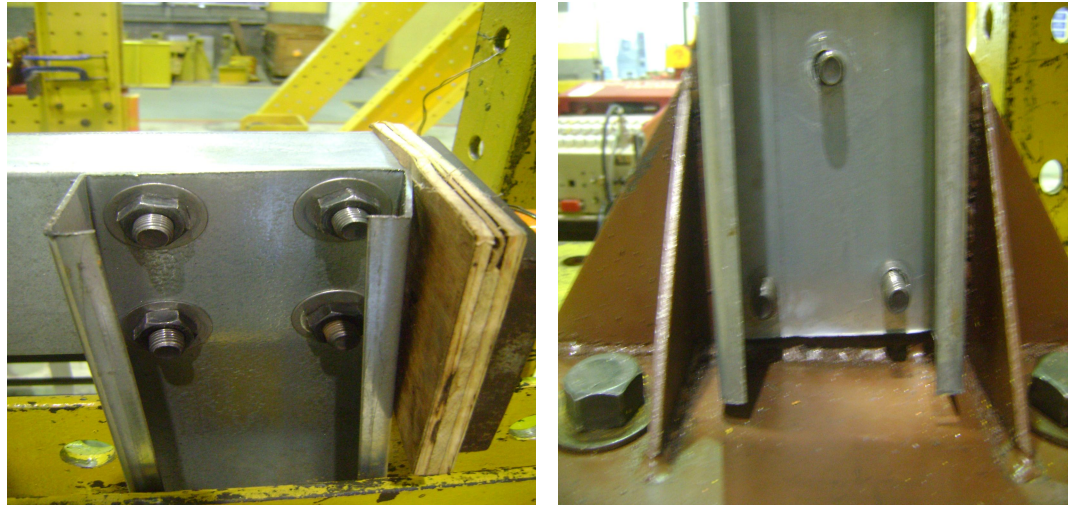
The recorded experimental data from the system tests are given and explained in this section. The test results are discussed under the headings of strength and stiffness. For each test, joint rotations and lateral deflections of the frame were recorded. Member rotation were taken from inclinometer readings and converted from the unit of degree to unit of radian. Lateral deflections of the frames were measured by using the displacement transducer. The moments at the joints were calculated assuming rigid joint boundary of plane frame. Conservatively, the moment-rotation curve with lower stiffness is chosen to get the moment resistance of connection. The moment resistances of the connections and applied loads for the frames are restricted to be the applied moment and load at a connection rotation of 0.05 rad. (Chung and Lau, 1999, Wong and Chung, 2002).

In order to assess the effectiveness of the bolted moment connections, a moment resistance ratio is calculated as the ratio of the measured moment resistance of a connection to the calculated moment capacity of connected section. For connections with moment resistance ratios approaching unity, the connections are regarded to be effective in transmitting moment across. The rotational stiffness of the connections is measured from the slope of the moment rotation curves on elastic range. Comparisons were made among all the proposed connections and the findings are presented in Table 2.

In all the tests, two different modes of failure were identified as follows

- Twisting of the column under the concentrated load, as shown in Figure 4(a).
- Bearing failure in section web around bolt hole, as shown in Figure 4(b).

In some of the specimens there is a combination of both modes of failure.



(a) (b)  
**Figure 4:** Modes of failure of the specimens

**Table 2:** Summary of test specimens and test results of system test specimens

Frame references	Specimen description	Measured lateral load@0.05rad (kN)	Initial Rotational stiffness (kNm/rad)	Measured moment resistance@0.05rad (kNm)	Normalised moment resistance (kNm)	Moment resistance ratio
F1	CB04-T1.6	21.3	90	3.4	3.12	0.73
F2	CB02-T1.6	9.8	37	1.6	1.46	0.34
F3	CB03-T1.6-S1	15	51	2.5	2.29	0.54
F4	CB03-T1.6-S2	15.7	56	2.5	2.29	0.54
F5	CB04-T2	22.5	92	3.7	3.33	0.60
F6	CB02-T2	10	37	1.6	1.31	0.24
F7	CB03-T2-S1	18.2	54	2.9	2.61	0.47
F8	CB03-T2-S2	18.8	60	3.1	2.79	0.50
F9	CB04-T1.6 two bays	31	90	3.5	3.21	0.75
F10	CB04-T2 two bays	32	93	3.6	3.24	0.60

F: denotes a cold-formed steel frame formed from single channel sections connected back-to-back; T1.6 and T2: denote the thickness of cold-formed steel member 1.6 and 2 mm respectively; S1 and S2: denote different bolt arrangement for column base with three bolts.

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### 3.5 Performance of Test Specimens in System Tests

The maximum applied moments at beam column connections were 2.1 and 2.25 kNm with rotational stiffness more than 55kNm/rad Figure 5. In order to allow direct comparison among the performance of the test specimens, the moment rotation curves for the column-base connections and the load deflection curves for the frames presented in Figure 6 and 7. The load versus deflection graph explains the physical behavior of the joint specimens along the test progress and it can be seen that the connection as well as the frame overall stiffness increases when stiffer connections are used.

#### 3.5.1 Test F1 and F5

During load application, the test specimens were very stiff against lateral applied load with rotational stiffness of the column base estimated to be about 90kNm/rad while the moment resistance was 3.4 and 3.7 kNm for F1 and F5 respectively. The tests were terminated after significant twisting of column base near beam column connection under concentrated load. After testing the connections was examined and little evidence of bearing failure was found in the steel around the bolt holes of beam column connections. The measured lateral load resistance of the test specimens was found to be 21.3 and 22.5 kN for F1 and F5 respectively.

#### 3.5.2 Test F2 and F6

During load application, the test specimens deflected significantly and rotational stiffness was estimated to be 37 kNm/rad and moment resistance found to be 1.6 kNm at the column base for both F2 and F6. Large deformation of the test specimens along the direction of load application was observed at collapse. Both the tests were terminated due to excessive deformation as well as little twisting at the column base near load application. After testing the connections was examined and bearing failure was found in the steel around the bolt holes of column base connections and beam column connections. The measured lateral load resistance of the test specimens was found to be 10 kN for both test specimens.

#### 3.5.3 Test F3 and F7

During load application, the test specimen's deflected significantly and rotational stiffness was estimated to be around 50 kNm/rad and moment resistance found to be 2.5 and 2.9 kNm at the column base connections of F3 and F7 respectively. The test was terminated after significant twisting of column base near beam column connection under concentrated load. After testing, the connections were examined and little evidence of bearing failure was found in the steel around bolt holes at the connections. The measured lateral load resistance of the test specimen was found to be 15 and 18.2 kN for F3 and F7 respectively.

### 3.5.4 Test F4 and F8

During load application, the test specimens deflected significantly and rotational stiffness was estimated to be around 55 kNm/ rad and moment resistance of 2.5 and 3.1 kNm at the column base connections of F4 and F8 respectively. The tests were terminated after significant twisting of column base near beam column connection under concentrated load. After testing, the connections were examined and little evidence of bearing failure was found in the steel around bolt holes. The maximum lateral load resistance of the test specimen was found to be 15.7 and 18.8 kN for F4 and F8 respectively.

### 3.5.5 Test F9 and F10

During load application, both the test specimens were very stiff against lateral applied load with rotational stiffness of the column base estimated to be about 90kNm/rad while the moment resistance was 3.5 and 3.6 kNm for F9 and F10 respectively. The test was terminated after significant twisting of column base near beam column connection under concentrated load. After testing the connections was examined and little evidence of bearing failure was found in the steel around the bolt holes of beam column connections. The measured lateral load resistance of the test specimen was found to be 31 and 32 kN for F9 and F10 respectively.

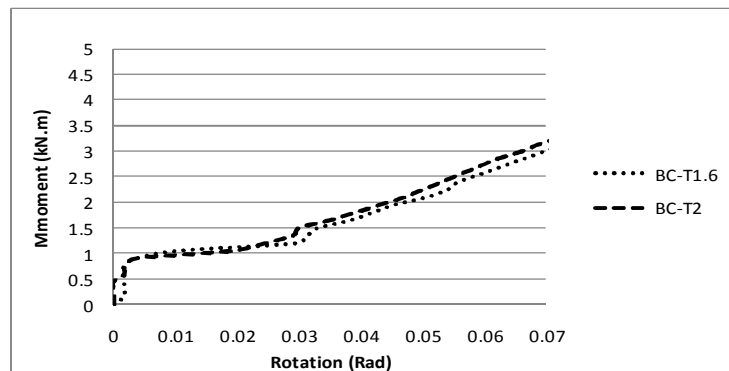


Figure 5: Moment rotation curves of beam-column connection T1.6 and T2

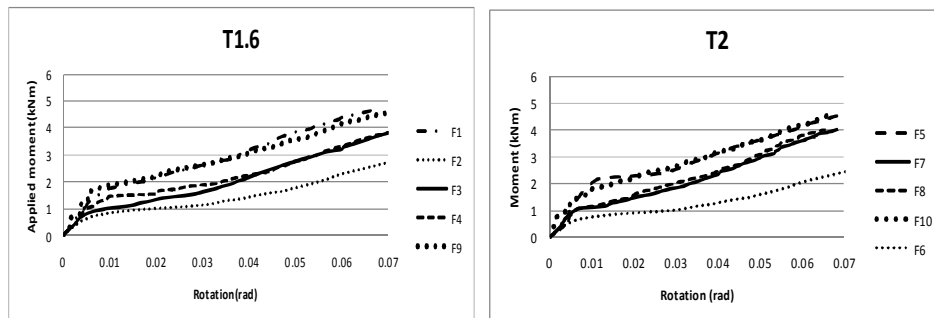


Figure 6: Moment rotation curves of column base connections, T1.6 and T2



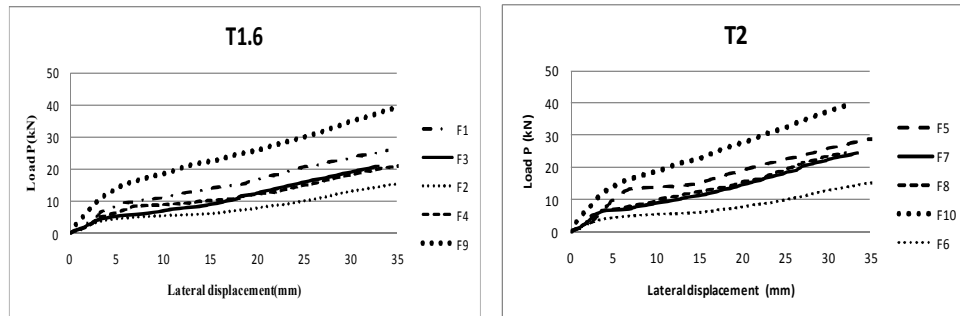


Figure 7: Load-deflection curves of frame specimens, T1.6 and T2

#### 4. Concluding remarks of system tests

- Column base with four bolts is able to form stiff and strong moment connection with a rotational stiffness about 90 kNm/rad and a moment resistance over 60% of the connected members.
- The initial rotational stiffness of the connections in the tests was proportional to the number of bolts used at the connections. The higher number of bolts in the connection can provide higher rotational stiffness in the connection and these show agreement to Professor Chung's findings (1999, 2002).
- All specimens developed high ductility performance, no catastrophe failure happened. The beam developed large deflection and the rotation of joints were more than 30 mRad.
- The load bearing capacity of the frames was proportional to the stiffness and the performance of the column base connections this shows agreement to researchers findings (Kwon et. al, 2006).
- Doubling the number of bay from 1 to 2 causes the load carrying capacity of the frame to increase about 40% for column base connected to steel base plate with four bolts.

#### 5. Conclusion

An experimental study was conducted to investigate the structural performance of cold-formed steel frame with bolted moment connections. Channel section was connected back to back at the joints as simple and effective means to connect beam to columns in steel constructions. Among all the tests on the frames it was demonstrated that practical, strong and stiff moment connections may be formed with bolts through rational design. In all test specimens, tests were terminated due to twisting of the column base near load application. In order to avoid excessive deformation of the test specimens, the moment and load resistance of the frame are restricted to the applied moment and load at a column base connection rotation of 0.05rad. The portal frame tests showed that the semi rigid

connection developed had high structural performance and could successfully be applied to portal frames. Among all the tests, the stiffness of the column base connection had significant effect on the load carrying capacity of the frame. Increasing number of bays from 1 to 2 causes increase in load capacity of the frame about 40%. Consequently, to increase the frame collapse load, the stiffness of the column base connection should be taken into account. Through rational design, effective cold-formed steel framing can be constructed. Engineers are encouraged to build light-weight low to medium rise moment frames with cold-formed steel sections.

## 6. References

1. BS 5950, Structural use of steelwork in buildings, Part 5: Code of practice for the design of cold formed thin gage sections, London: British Standards Institution, 1998.
2. Chung K.F., Building Design using Cold Formed Steel Sections: Worked Examples to BS5950: Part 5:1987.
3. Yu, W. W., Cold Formed Steel Design, 3<sup>rd</sup> Edition, John Wiley and Sons Inc, 2000.
4. Hancock, G.J., Murray, T. M. and Ellifritt, D.S., Design of cold-formed steel structure to the AISI specification, Macel Dekker, New York, 2001.
5. Chung K.F., Lau L. (1999) Experimental investigation on bolted moment connections among cold formed steel members, Engineering Structure Vol. 21, pp 898-911.
6. Chung K.F. Wang M.F., Structural behavior of bolted moment connections in cold-formed steel beam-column sub-frames, Journal of Constructional Steel Research, Vol. 58, (2002) pp 253–274.
7. Tahir, M.M. & Tan, C.S. Experimental Tests on Partial Strength Connection for Cold-formed Steel of Double Lipped Channel Sections. Fifth International Conference on Thin-Walled Structures. Brisbane, Australia. 2008.
8. Kwon Y. B.; Chung H. S.; and Kim G. D. (2006) Experiments of cold-formed steel connections and portal frames, ASCE, Vol. 132, No. 4, pp 600- 607.
9. Dawe J. L. and Wood J. V. (2006) Small-scale test behavior of roof trusses cold-formed steel, ASCE, Vol. 132, No. 4, pp 608-615.
10. Raftoyiannis I.G (2005), The effect of semi-rigid joints and an elastic bracing system on the buckling load of simple rectangular steel frames, Journal of Constructional Steel Research, Vol. 61 , pp1205–1225.

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11. Tan S.H. (2001) Channel frames with semi-rigid joints, Computers and Structures, Vol. 79, pp 715-725.