

## **TYPICAL TESTS ON COLD-FORMED STEEL STRUCTURES**

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**ABSTRACT:** Cold-formed steel has been recently brought into Malaysian construction. It is a steelwork technology that has high potential to be developed in Malaysia, that can offer advantages such as fast erection, lightweight, clean and easier construction. This paper reported a series of research studies carried out in UTM for locally produced cold-formed steel sections and roof truss system. The research work included study on the member capacities for lipped C-section and Hat-section, a full-scale test for roof truss system and the cold-formed steel tek-screw connection capacities. All the studies were based on the requirements of British Standard BS 5950 Part 5 1998. The actual capacities of the proposed sections were ratio from 1.09 - 2.21 compared to the design strength. The full-scale experimental test on roof truss also achieved two times of the estimated design capacities. The tek-screw connection capacities in resistance to shear force and pull-out force ranged 76% - 141% higher than the design requirements. The connection also withstand 10000 times of dynamic load that verified its performance in long-term serviceability. The results of the experimental tests on the proposed cold-formed steel section and roof truss system showed good agreement to the requirements of BS5950 Part 5 1998.

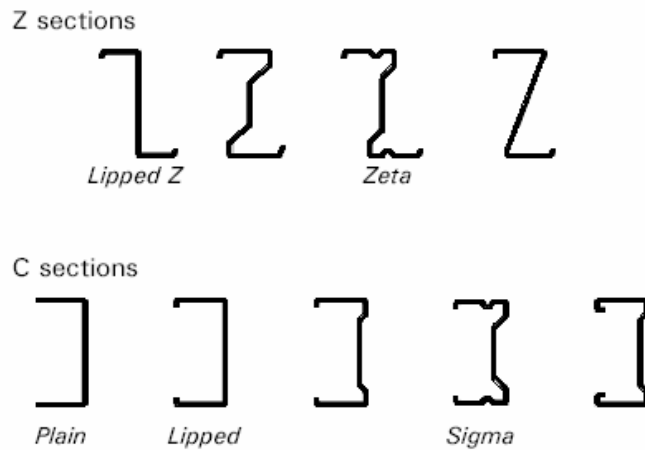
**Keywords** - Cold-formed steel, member capacities, roof truss, connection.

### **1. INTRODUCTION**

Industrialized Building System (IBS) has been promoted diligently by CIDB, Malaysia since Year 2003. Besides reduced dependency on foreign labour, the simplified construction solutions offer better control of quality, increased productivity and faster completion, less wastage and cleaner environment. Through industrialization of construction, huge amount of work has been shifted to the factory and leaving the construction sites tidier and safer (Sumadi, 2001).

In support of the ongoing process of implementation of IBS in the construction industry, the research and development have been identified to focus in the area of open-building, lightweight materials, joints and sealants, services, and IT and robotics (Nuruddin, 2003). The application of light steel framing design using cold-formed steel is one of the developments of lightweight material.

Light steel framing design is generally based on the use of standard C or Z shaped steel sections (see Figure 1) produced by cold rolling from strip steel. Cold formed sections are generically different from hot rolled steel sections (e.g. Universal Beams and Universal Column), which are used in fabricated steelwork. The steel coil used in cold formed sections is relatively thin, typically 0.5 to 3.2 mm, and is galvanized for corrosion protection (Grubb, 2001).



*Fig 1. Common shapes for cold formed steel*

Cold-formed steel sections can be widely used in many sectors of construction, including mezzanine floors, industrial buildings, commercial buildings and hotels and are gaining greater acceptance in the residential sector (see Figure 2). However, the application of light steel framing has not been widely developed in Malaysia, due to the lack of research study on the local practice for such system. This paper gives a series of studies on cold-formed steel section that carried in Universiti Teknologi Malaysia (UTM). It summaries the experimental works on cold-formed steel member capacities, roof truss system and connection capacities. In the end it provides suggestions for future work to enhance the practical use of light steel framing in Malaysia.



*Fig 2 Cold formed steel framing (light steel framing) for residential house in UK (Adopted from Grubb, 2001)*

## 2. THE BENEFITS OF COLD-FORMED STEEL AND THE LIGHT STEEL FRAMING

Generally, cold-formed steel sections have several advantages over hot rolled steel sections, timber sections and concrete. The main aspects are listed as follows (Rogan, 1998; Thong, 2003):

1. **No insect and fungal infection:** The problems such as rotten or discomposed due to insect and fungal infection are eliminated; therefore the material curing and maintenance costs, which are necessary for the timber and concrete construction, could be eliminated as well.
2. **Consistency and accuracy of profile:** The nature of the manufacturing process: cold rolling - enables the desired profile maintained and repeated for as long as it is required, in a very close tolerance. Moreover, the very little tool wears and the cold rolling process is ideally suited to computerized operation which assists to the maintenance of accuracy.
3. **Versatility of profile shape:** Almost any desired cross-sectional shape can be produced by cold rolling, such as T-section, Z-section, Sigma-section etc.
4. **It could be pre-galvanized or pre-coated:** The steel material may be galvanized or coated by plastic materials either to enhance its resistance to corrosion or as an attractive surface finish.
5. **Variety of connection and jointing methods:** All conventional methods of connecting components, e.g. riveting, bolting, welding, and adhesives are suitable for cold-formed section. The tek-screw is concerned in this study since it is fastest and easiest way which is available in local.
6. **Speedy in construction, and suit for site erection:** Generally the steel construction has eliminated the curing time which is inevitable in concrete construction; therefore it is far faster than concrete construction. The cold formed steel may more advantageous than the hot rolled steel since it can be cut and erected with very light machine and even only man power.
7. **Increase in yield strength due to cold forming:** The cold forming process introduces local work hardening in the strip being formed in the vicinity of the formed corners. This local work hardening may results an increment of ultimate yield strength about 25% from its virgin strength.
8. **Minimization of material:** Since the material used can be very thin in comparison to the lower thickness limits of hot rolled steel sections, it allows the material usage for a given strength or stiffness requirement to be much less than that of the smallest hot rolled sections. The material thickness, or even the cross-sectional geometries, could be controlled to achieve the structural features with minimum material weight.
9. **High profitably:** In cold rolled process, the manufacturing costs of cold rolled steel section, mainly involve the initial modal of purchasing the rolling machine and the costs of steel strip material later. The machinery cost only expensed once then it could be covered back in the continuous production. The cold formed steel roof truss system, which is mainly interested by local industries, is normally short in

construction, and involve only some light erection tools. Therefore, the investment required is not high and the return back is sooner than most of the constructional part.

### 3. EXPERIMENTAL TESTS ON COLD-FORMED STEEL IN UTM

The Steel Technology Centre (STC), Universiti Teknologi Malaysia has carried a series of analytical and experimental research on cold-formed steel structures. The studies include:

- Member capacities of cold-formed lipped C-section and Hat-section
- Full-scale cold-formed roof truss system
- Tek-screw connection capacities for UNI-Interlocked roof truss system.

The research works is discussed separately in the following sub titles.

#### 3.1 Study on the Member Capacities of Cold-formed Lipped C-section and Hat-section

A research was carried by Steel Technology Centre on cold-formed steel Lipped C-section and Hat-section (Thong, 2003; Tahir, 2005). It aimed to provide a complete design of the proposed Lipped C-section and hat-section (see Figure 3), which is anticipated to be applied as members of conventional school roof truss for JKR.

These sections have been tested for their material yield strength, tension strength, compression strength for both short and slender member and bending capacity. The connection capacity tests included pull-out test and shear test. The capacities estimation and tests are done in accordance to BS5950 Part 5: 1987 (BSI, 1987; Chung, 1993). The experimental layout was shown in Figure 4, and the summary of the results was given in Table 1.

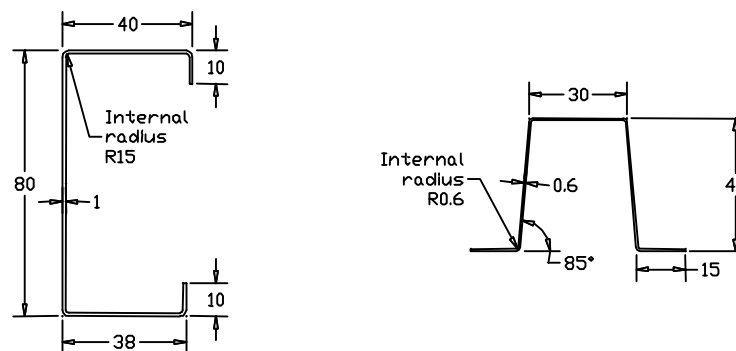
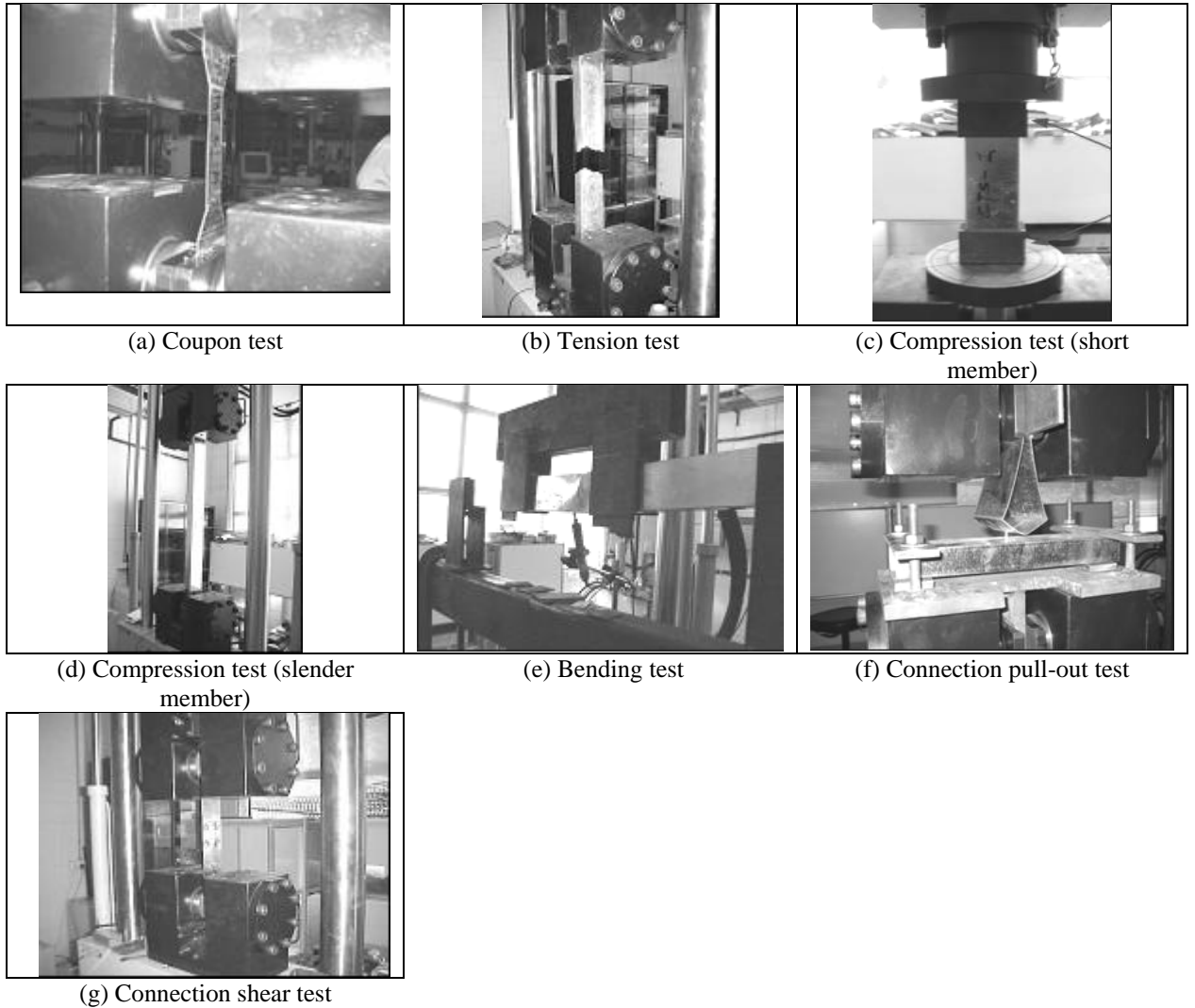


Fig 3 Cold-formed Lipped C-section (Left) and Hat-section (Right)



*Fig 4 Experimental Test Layout for the Member Capacities of the Proposed Cold-formed Section*

Table 1 Comparison of the experimental test results to the design calculation for member capacities

Type of Test	Type of Specimen	Design Strength	Experimental Result	Ratio of Exp/Des*
Coupon test	0.6mm plate	300 N/mm <sup>2</sup>	344 N/mm <sup>2</sup>	1.15
	1.0mm plate	250 N/mm <sup>2</sup>	300 N/mm <sup>2</sup>	1.20
Tension test	Lipped C 80×40×38	20.66 kN	26.0 kN	1.26
Compression test for short member	Lipped C 80×40×38	33.70 kN	38.0 kN	1.13
Compression test for slender member	Lipped C 80×40×38	22.84 kN	25.0 kN	1.09
Bending test	Hat section	0.26 kNm	0.38 kNm	1.46
	Lipped C 80×40×38	0.97 kNm	1.50 kNm	1.55
Connection pull-out test	1 screw - Lipped C	0.73 kN	1.50 kN	2.05
	2 screws - Lipped C	1.46 kN	3.20 kN	2.19
	1 screw - Hat	0.53 kN	1.00 kN	1.89
	2 screws - Hat	1.06 kN	2.20 kN	2.08
Connection shear test	2 screws - 0.6mm plate	1.90 kN	3.00 kN	1.58
	4 screws - 0.6mm plate	3.80 kN	7.00 kN	1.84
	2 screws - 1.0mm plate	3.40 kN	7.50 kN	2.21
	4 screws - 1.0mm plate	6.80 kN	12.50 kN	1.84

\* Exp/Des = Experimental Result / Design Strength

The test results showed that actual resistance of the cold-formed steel were higher than the design strength, ranged 1.09 - 1.55 for section capacities, and 1.58 - 2.21 for connection capacities. The study concluded that the proposed cold-formed steel section give good agreement compared to the design strength. It is suggested that a full-scale test on the proposed roof truss to be carried out, in order to gain further understanding on the global truss behaviour and to build confidence in utilisation of the system.

### 3.2 Full-scale Test on the Cold-formed Roof Truss System

Lotez Engineering has proposed the *Mega Truss System* which is intended to be laid out, fabricated and handled like wood trusses, except that they are built using screw guns rather than plated methods. A full scale testing for the plane truss system was carried out at Laboratory of Structure and Material, UTM, Malaysia under the supervision of Steel Technology Centre (Tahir, 2004). The objectives of the test are:

1. To conform the adequacy of intended use of the proposed system.
2. To define the actual behaviour of the truss system in comparison of theoretical estimation.
3. To fit the requirements claimed by Public Works Department of Malaysia, for the application in conventional school buildings.

The proposed truss is spanned over 7.8m over two supports; and cantilevered at a span of 2.3m from each end. The truss height from the support is 2.078m. The cold-formed steel section in used was lipped C-channel. More specification of the truss system and the section properties is given in Table 2 and Table 3.

The roof truss was designed based on BS 5950-1990-Part 5 (BSI, 1998). The design loading were referred to BS 6399 (BSI, 1988). The loadings were to be transferred from the

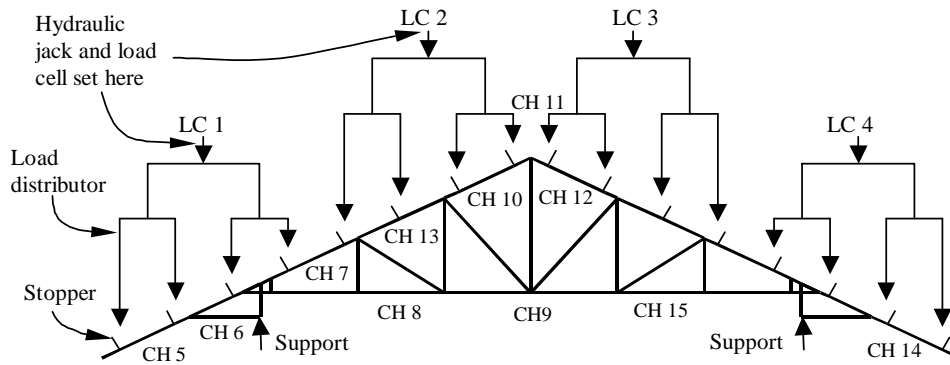
purlin to the truss' span at 600mm spacing, as shown in Figure 5. From the design analysis, it was estimated that each point load transferred from the purlin should not less than 8.4kN.

*Table 2 Specification of the Roof Truss System*

Section	C - Lipped Channel (MC 10016), 102mm × 51mm × 1.6mm thick
Material	High Tensile Galvanized Steel Yield Stress 450 N/mm <sup>2</sup> Zinc Coating of Z 275
Connection	Class 2 - Self Tapping Screws
Truss Spacing	1.5m
Roof Pitch	25°

*Table 3 Section properties of the lipped C-channel and purlin*

Section	Design strength, $p_y$ (N/mm <sup>2</sup> )	Effective aea, $A_{eff}$ (mm <sup>2</sup> )	Second moment of area, $I$ (cm <sup>4</sup> )	Elastic modulus, $Z$ (cm <sup>3</sup> )	Moment capacity, $M_c$ (kNm)	Tension capacities, $P_T$ (kN)	Compression capacity, $P_c$ (kN)
Lipped C	450	297.2	146.35	11.2	4.92	148.05	133.74
Purlin	550	77.63	1.16	0.6	3.22	45.1	42.7



(a) Load configuration of the experimental test



(b) Experimental Layout

Fig 5 Full-scale test of the roof truss system



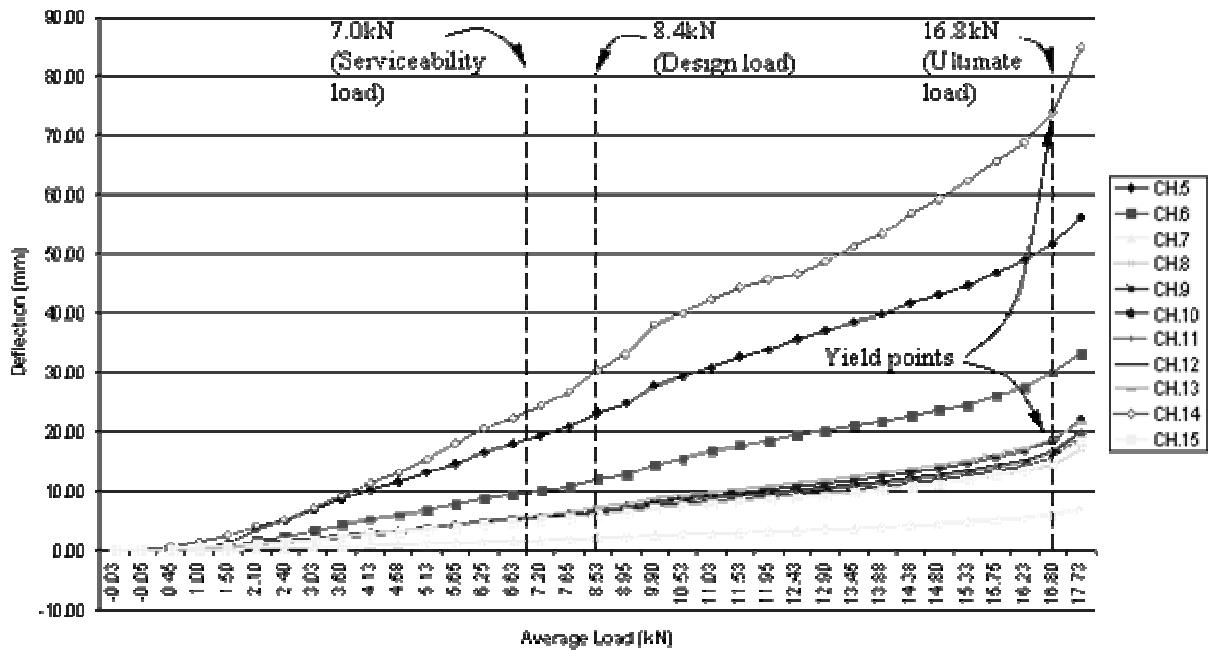


Fig 6 Full-scale test results

The full-scale test on the truss system was carried out successfully and was proven to be valid by computer modelling using *MultiFrame 3D*. From the study, some conclusions can be made:

1. All the analysis models are valid to represent the actual behaviour of the truss.
2. The loading condition in the test is worse than the designed condition. Therefore if the truss able to resist the test condition, it should be more than enough to resist the design condition.
3. The truss is able to resist a loading of 16.8kN at each loaded point (or total load of 67.2kN) in the test condition. It is two times higher than the design load. Therefore it can be concluded that the capacity of truss is very safe to be implemented.
4. There are no visible failure observed during the yielding of the truss, therefore the components are expected have a ductile behaviour. The ductile behaviour is favourable in term of safety since it delays the significant collapse of the structure.

From the facts stated above, it is concluded that the truss is having the adequate strength to resist the design loads, and it is safe to be implemented in the intended uses.

### 3.3 Connection Tests for UNI-Interlocked Roof Truss System

Three sets of connection tests were performed on the product of Tong Yong Sdn. Bhd. - cold formed sections of UNI-Interlocked steel roof truss system at Laboratory of Structural and Material, UTM, on April 2004 (Thong, 2004). The main purpose of the tests was to verify the validity of design method provided by *BS 5950 Part 5: Code of practice for design of cold formed thin gauge sections* (BSI, 1998) in estimating the actual behaviour of the connection in the truss system. One of the tests - the fastener dynamic test was aimed to show the durability of the connections under long term dynamic loads. The other two tests were shear test and pull-out test.

All specimens were 0.55mm thick. The dimension of the specimens were shown in Figure 7. They were tested by using DARTEC MACHINE with maximum capacity of 250kN. The loading sequence used was in accordance with European Recommendations (ECCS, 1983).

The European Recommendations stated that the rate of loading shall not exceed 1kN/min and the rate of straining shall not exceed 1mm/min during the test.

As for fastener dynamic test, the connection of roof truss was inherently subjected to both the dead load and dynamic load especially the vibration of fan. According to Rhodes in *Design of Cold Formed Steel Members* (1991), it was proven that the strength of shear connections were rarely affected by less 10000 cycles of repeated loading. In this test, 10,000 cycles of cyclic loading (varied between 0 to  $\pm 6$ kN, by 0.5Hz frequency) was imposed onto the connection. The test configuration is shown in figure 8.

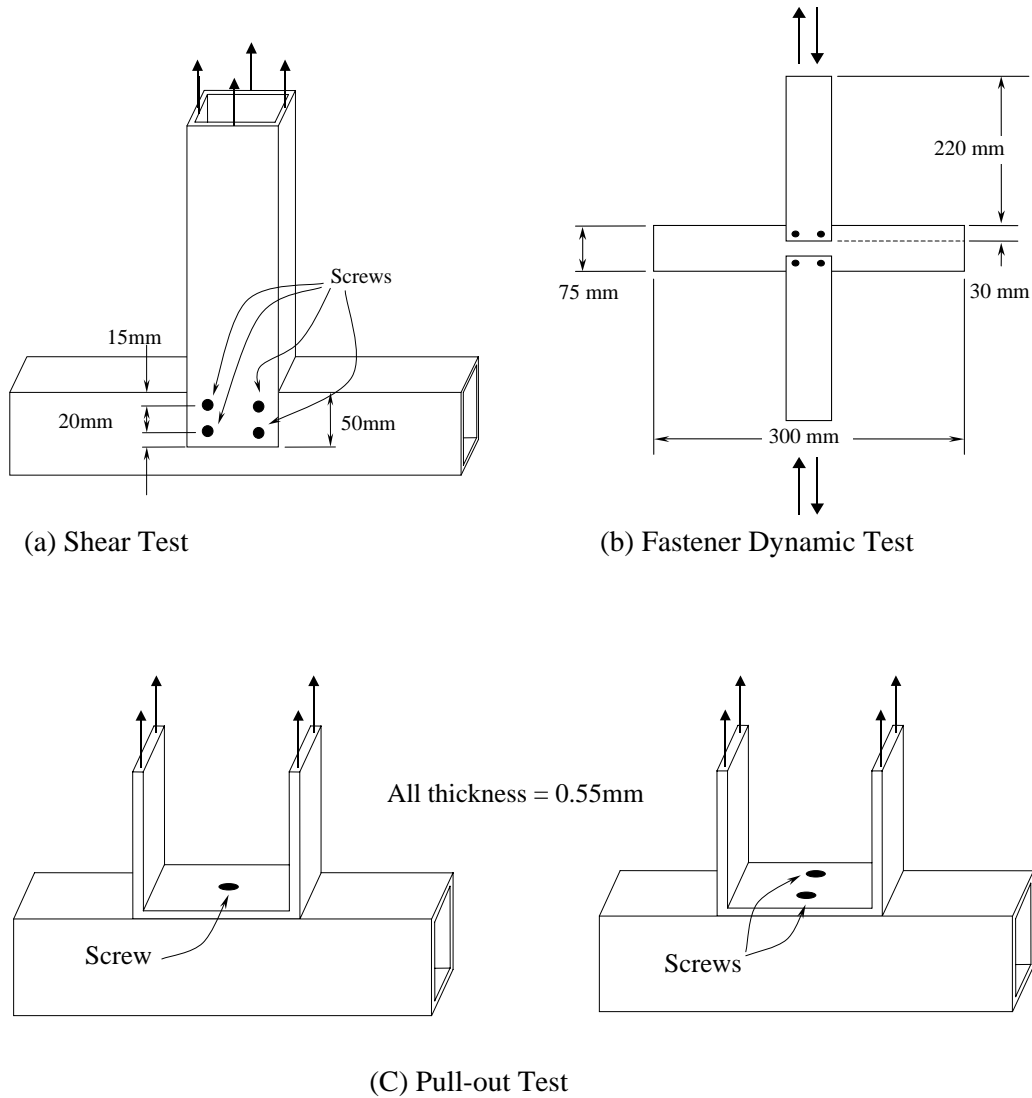


Fig 7 Connection tests on cold-formed steel section with thickness of 0.55mm

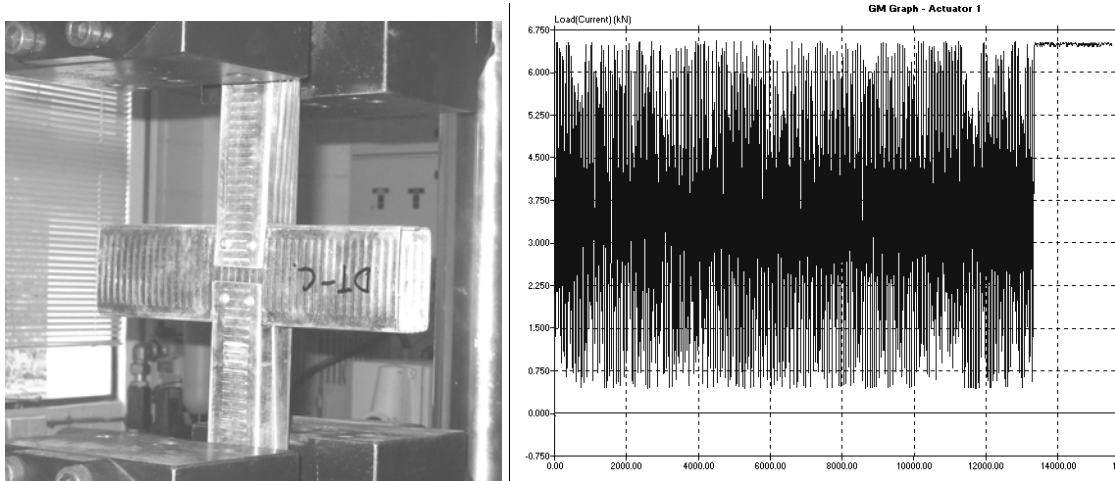


Fig 8 Configuration of fastener dynamic load test and the example of collected data

Table 4 Summary of experimental test results

Type of Test	Type of Specimen	Experimental Result (per Unit Capacity)	Average Value of Exp. Result	Design Strength
Connection shear test	Typical model - 2 screws	3.43 kN	3.22 kN	1.44 kN
	Typical model - 4 screws	3.00 kN		
	On-site model - 4 screws	3.47 kN	3.47 kN	
Connection pull-out test	1 layer 1 screw	1.40 kN	1.55 kN	0.88kN
	1 layer 2 screws	1.33 kN		
	2 layers 1 screw	1.91 kN		
	2 layers 2 screws	1.55 kN		
Fastener dynamic test	-	The connections were able to sustain its strength after 10000 cycles of cyclic loading.		

The shear test average result is 3.22kN for typical model and 3.47kN for on-site model. These values are 124% - 141% greater than the design strength. Connection pull-out test average value is 1.55kN, which is 76% greater than their design strength. As for dynamic test, the connections were able to sustain its strength after 10000 cycles of cyclic loading, thus its performance is proven for long-term service.

#### 4. CONCLUSION

A series of experimental tests on cold-formed steel members and structures has been carried out successfully in UTM. The result of the tests can be concluded as follow:

1. For experiment study on the member capacities of cold-formed lipped C-section and Hat-section, all tests result is higher than the design value. The ratio of difference lay between 1.09 and 2.21. The test proven that the proposed sections are suitable for the design of roof truss system.

2. For the full-scale test of roof truss system, the truss was able to sustain the total load up to 67.2kN (or point loads of 16.8kN) which is two time higher than the predicted capacity (8.4kN).
3. For the connection tests, the actual strength of the connection in resisting shear force and pull-out force is greater than the design strength. The percentage of difference is 76% - 141%. The connection was able to withstand 10000 cycles load, which also proven its performance for long-term serviceability.

Currently most of the laboratory research and construction practice of cold-formed steel in Malaysia were focus to roof truss system. It is suggested that studies on the member capacities of thicker cold-formed sections (range 1.0mm to 3.2mm) can be carried out in order to widen the application area of steel structures, such as wall stub, floor batten, beam and column. The studies on the partial strength connection for beam-column cold-formed steel structure is also proposed, that it may leads to optimization of the structural robustness and steel weight saving. The cold-formed steel sections can be further applied into sub-structures such as staircases, foundation system, retaining walls and scaffolding.

## **5. ACKNOWLEDGEMENT**

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