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THERE IS POSSIBLE TO BUILD LOW RISE MULTI STOREY COLD-FORMED STEEL FRAMED STRUCTURES IN ROMANIA?

BY

Zsolt Nagy[1*] and Dan Dubina[2]

[1]Technical University of Cluj-Napoca,
Faculty of Civil Engineering,
[2]„Politehnica” University of Timişoara,
Faculty of Civil Engineering

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Abstract. Previous studies (Dubina *et al*., 2010; Nagy, 2006) reported the results of experimental and numerical simulation programs carried out in research centre of "Politehnica" University of Timişoara on joints and full-scale pitched roof cold-formed steel portal frames of back-to-back lipped channel sections with bolted joints, in order to evaluate the joint performance and the structural stability performance of these structures. Further research have been started to study the possibility to extend the obtained results for low rise multi storey cold-formed steel framed structures. The study will focus on particular structural solutions and joint typologies, suitable for such a type of structures. The paper summarizes the state of the art on application of cold-formed steel structural solutions for low and medium rise buildings and the preliminary study performed by one of the authors, in order to find adequate structural solutions for different Romanian seismic regions, using cold-formed steel sections. Based on these results, the proposed research program will use finite element modeling to calibrate virtual models, to evaluate the structural performance of proposed bolted joints, suitable for multi storey cold formed steel framed structures.

[*] Corresponding author: *e*-mail: zsolt.nagy@bmt.utcluj.ro

Key words: low rise multi-storey structures; cold-formed sections; bolted joints; numerical simulations; joint typologies.

1. Introduction

Several multi storey application using cold-formed sections (CFS) were identified in North-America (USA, Canada), in different western and northern European countries (UK, Scandinavian countries, Spain). Interesting examples have been found in Japan, but no spread of the solution has been found in Australia – New Zealand, only in the steel housing industry. Examples have been found using mainly shear wall panels, constructed with vertically spaced and aligned C-shape cold formed steel (CFS) studs. Recently, cold-formed steel special bolted moment frames were reported in USA.

In Romania, welded or rolled structural steel elements are still highly preferred, due to the complex analysis and design procedures associated with CFS members. Recent major changes in design codes generated also the need for "best known practice". Also, the seismic performance of CFS structures is limited and, in general, the seismic design codes (including the Romanian one) give few references about CFS structures which are low dissipative. In these conditions the development of low rise CFS framed system was the motivation for this study. Positive results should contribute to increase the number of sustainable buildings in the near future.

2. State of The Art in the World

Several multistory structural applications of CFS have been found in the world. Some of these examples will be presented in this chapter.

2.1. European Situation

a) *Applications*

In Western Europe the most frequent applications of CFS multistory residential buildings in UK and Scandinavian countries have been found. The applied structural solution uses shear wall panels strengthened with oriented strand boards (OSB). The intermediate floors are CFS sections combined with dry materials or lightweight concrete.

Several CFS producers from EU countries conduct strong research and development activity, contributing to the increasing number of multistory applications in which CFS sections are used as structural system solutions. A new trend in residential applications has been the use of standardized houses with light steel structure.

There are also multistory structural applications of CFS sections. The Spanish company Teccon Evolution obtained a European Technical Approval

(Europ. Techn. Approv.) with a registered trademark TECCON® for a multistory structural system using CFS sections.

In UK the most important developers in residential single story or multistory applications (Davies, 2003) steel solutions have the key role. The reduced labor cost and high quality requirements – all this in a very short time – increased the number of steel applications and imposed an optimized design process. The company Faithful & Gould was commissioned by Metsec Plc to produce a report analysing the main construction cost differences between the Metsec steel framing system (SFS) and walling system (http://www.metsec.com) *versus* traditional block work to the internal skin of an external wall (Faithful & Gold Techn. Rep., 2009). This study has demonstrated, in actual direct construction cost terms, that Metsec SFS insted of block work is more competitive (cost difference around 39%). It has also highlighted several advantageous factors for using steel solution particularly relating to reduced time on site and in respect to direct environmental issues.

Building users and clients should seriously consider the consequence of earlier building delivery and the resultant earlier rental and return income.

b) *Design codes*

For the design of CFS structures the Eurocode package is available. EN1993-1-3, EN1993-1-5 should be applicable for CFS member design and EN1993-1-8 for joint design. The actual development level of the code for the design of joints leads the designer to comply with hot rolled sections. For those situations, which are not detailed in the code, the design assisted by testing should be the safest, but not the cheapest way.

c) *Design guides*

It should be mentioned the important role of different educational and research institutes, private companies, which with the support of European Commission realized the Access Steel portal (www.access-steel.org). Different resources, application examples are available for designers and teaching institutes to support the use of Eurocodes. There is also a place for forum discussions in order to find solutions for those which have difficulties in the application process of the new codes.

Recently, the companies Arcelor Mittal, Peiner Träger, Corus in co-operation with Centre Technique Industriel de la Construction Métallique (CTICM) and Steel Construction Institute (SCI) as a consortium „Steel Alliance", issued two design guides, called *Steel Buildings in Europe*. First is dedicated to Single Storey Steel Buildings and second to Multi Storey Steel Buildings (MSSB) (Steel Buil. in Eur., 2008). The MSSB guide with ten parts, provide information for architect's, includes concept design considerations, gives support for design engineers to evaluate actions, for detailed and joint design, but mainly for hot rolled steel products.

European Lightweight Steel-framed Construction (2005) edited by European Light Steel Construction Association and published by Arcelor Mittal, furnishes guidance for the use of CFS for housing industry in a similar way as in US (Prescriptive Method…, 2000), without any break trough till this moment.

2.2. North American Examples

According to the latest market reports, 20% of the new single story residential buildings are realized with CFS structures and tends to replace the old wooden structures. There are also several multi story applications using CFS: the primary structural elements are Shear Wall Panels (SWP), load-bearing wall panels, and floor and roof panels: the Canadian company Bayley Metal Products built six story buildings (Kingsway Arms Retirement Home, six story, 9,890 m^2). The company Steelform (http://www.steelform.ca) developed the mega joist (Fig. 1) for wall girts and intermediate floor supports.

Low rise multi story buildings in US are in use even in seismic area. Eight story building structural examples was presented by prof. R. Schuster from Waterloo University, Canada, in a seminar, in 2005 (Fig. 2).

Fig. 1 – MSSB example: the mega joist and his application (source www.cssbi.ca).

a *b* *c*

Fig. 2 – Hotel Marriot (*a*, *b*) and eight story residential building (*c*).

Due to the lack of analytical design methods for SWP structural system, mid rise steel buildings using CFS have some restrictions. The lateral strength of SWP imposes experimental tests in some cases (Martinez, 2007). For this reason, research works undergoes to implement design methodologies aiming to eliminate the restrictions and to extend the applicability of SWP system for mid rise buildings.

National Building Code of Canada (NBCC) issued in 2005, had no particular design rules for SWP structural systems in seismic applications. For such kind of structures, the prescriptions of FEMA 273 (1997) have been used. The provided limit drift ratios as acceptance criteria for different performance levels and types of structural systems has been used, even for SWP structural systems FEMA does not provide such limits.

2007 is the year when American Iron and Steel Institute (AISI) in USA issued the first code for seismic design of CFS structural system (1997). This is under revision; the new version will include the latest research results (Sato & Uang, 2010, 2009).

2.3. Japanese Experience

In Japan, steel houses became a usual application since 1950. The destroying effects of Second World War imposed the construction of 4 million houses. The use of wood was problematic: several wooden houses burn, the reconstruction process using wood needed the Japanese production over 150 years. In order to protect the Japanese forests, the usage of wood was restricted. These restrictions are on the base of nowadays statistics: 70% of the Japanese houses had steel structure in 2000, 19% wood and only 11% concrete (Sumiyoshi *et al*., 2001), during the time steel keeping a constant market share.

Fig. 3 – Nittetsu Super Frame, Kitakyushu Science and Research Park during erection and finished.

As a consequence, a series of steel structural solutions has been developed. A recent application, called Nittetsu-Super-Frame, has been developed by Nippon Steel (2008). With academic and government joining effort and the involvement of steel industry, a student hostel with 200 rooms was built in 2005 (Fig. 3). This was marked as one of the most important structural application of CFS in Japan.

In 15-th of November, year 2000, structural systems made by CFS sections were classified in the Japanese building code as particular type of structures.

2.4. Romanian Experience

Structural systems based on CFS sections are one of the most dynamic industrial sectors of the building industry in Romania. If we look on the application range of CFS sections, at the beginning they were used mainly for secondary structures. Last fifteen years CFS elements took the place of main structural elements in single story steel buildings and houses with two story heights. Steel residential and industrial buildings with small and medium span (8…20 m) have been realized successfully by several companies. First pilot project, using CFS structures, developed by the authors, was „Bulzesc House" built in Timişoara (2001) and „Constantin House" in Ploieşti, finished in 2004. Nowadays the concept of steel houses using CFS sections penetrated the housing market, and keep growing in market share. The concept of multi storey building with CFS structure isn't familiar, even such kind of buildings has been built (two level offices building for Timas car service in year 2002).

The technical and economical advantages and the economic growth between 2006…2008 attracted a series of integrated systems from abroad. Hardell system using Protektor profiles , Horizont® housing system, Richter system are only few which were promoted as integrated systems. Shortly, local suppliers started to apply particular structural solutions, copying or simply applying the principle of residential steel framing (Prescriptive Method…, 2000) creating numerous particular applications, according to the user's requirement.

There are technical and economical arguments which confirm the performance of these structures also in multistory applications, but the market development is slow due to the lack of design information and misconceptions concerning the use of such structural solutions. Since the "science" of CFS design is very young, the developed design codes are not covering totally the intended applications. Also the best known practice is limited, making the designers job much more difficult. Due to this reason, solutions with CFS sections are simply skipped from the beginning. But analysing the collected examples, multi story structural applications using CFS sections are also possible in Romania.

In terms of design codes, this structures can be designed according to Eurocode: SR-EN1993-1-3 together with SR-EN1993-1-5 and are available for design of cold formed steel members, respectively SR-EN1993-1-8 for the design of joints, with the previous mentioned restrictions (s. section **2.1**).

Analysing the short review of the state of the art in this field, it is easy to understand why this applications haven't penetrated the Romanian market.

For this reason the main objective of this research is to find applicable structural solutions using CFS sections for multi storey structures for Romanian loading conditions. A reference building, suitable for residential application, has been set up, using CFS section.

3. Reference Structure for Romanian Loading Conditions

3.1. Structural Configuration

To be able to define a realistic frame configuration and study the applicability of CFS sections for a multi story framed structure, a two storey reference building was firstly designed (s. Fig. 4). The building geometric dimensions consist of three spans of 5.6 m, three bays of 4.5 m and a storey height of 3.3 m. This structure was subjected to loads common in the Romanian design practice: structure and floor self weight 0.75 kN/m^2 (with a partial safety factor γ_{ULS} = 1.35 for the ultimate limit state), technological load 0.15 kN/m^2 (γ_{ULS} = 1.35), variable loads 2.0 kN/m^2 (with a partial safety factor γ_{ULS}=1.5 for the ultimate limit state) and snow load 2.0 kN/m^2 (γ_{ULS} = 1.5). The frame was analysed and designed according to EN 1993-1-3.

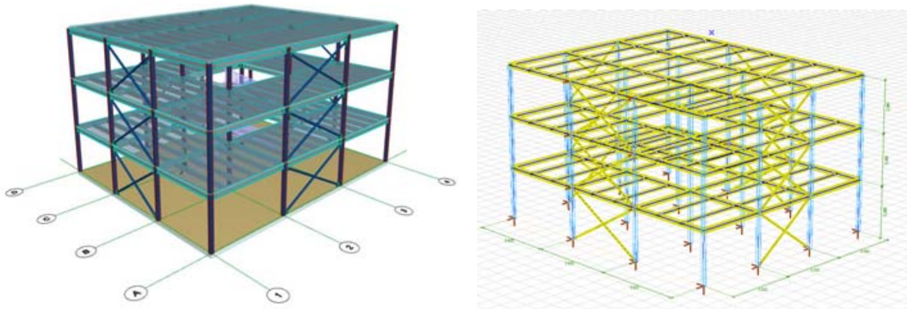


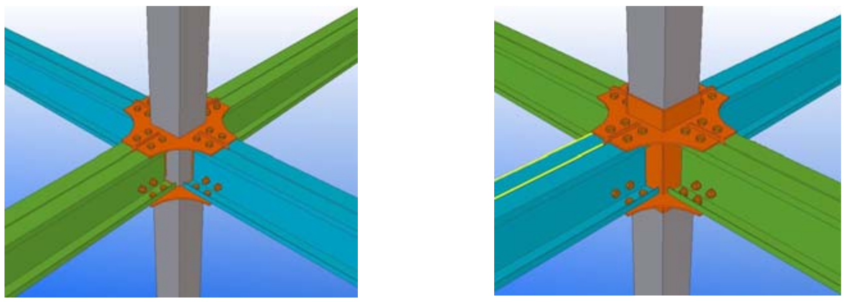
Fig. 4 – The reference structure.

Several types of sections and joint typologies accordingly were analysed for the reference framed structure. Due to the technological advantages and obtained structural performances, square hollow section (SHS) profiles for columns and back-to-back lipped C channels (2 × C) for beams were chosen. Elements of the frame resulted back-to-back built up sections made of Lindab C300/3.0 profiles (yield strength f_y = 350 N/mm^2) for beam sections and SHS 200 × 8 (yield strength f_y = 235 N/mm^2) for column sections.

This structural setup was found for low intensity seismic regions (ground acceleration a_g < 0.12 g). The joints were initially considered continuous in the structural analysis. Due to the supposed semi-rigid behavior of these joints it is necessary to find out how to model the stiffness of these joints in the structural analysis, in order to obtain more realistic results. The goal of a further study is to develop a simplified method to define the joint stiffness for the structural analysis and to create engineering tools to help the designer in the design process.

3.2. Preliminary Analysis Results

The structural analysis results on a bar structure model shows that for low and medium intensity of seismic action (a_g < 0.12 g) the structural elements design are not affected by the seismic action. More detailed analysis started to define the stiffness of these joints.



a *b*

Fig. 5 – Selected joint typologies for beam to column connection: *a* – simple joint; *b* – strengthened joint.

Calibrated FE model was used based on previous experimental tests on portal frame joints (Nagy, 2006). Based on this, a finite element model has been developed to study the structural behaviour of the joint presented in Fig. 5 *a*. ABAQUS/CAE v.6.10 was used for numerical simulations. Some features about the FE model: (i) finite element type: 8-noded standard quadratic, reduced integration, homogeneous shell element (S4R) to model the cold-formed mem-

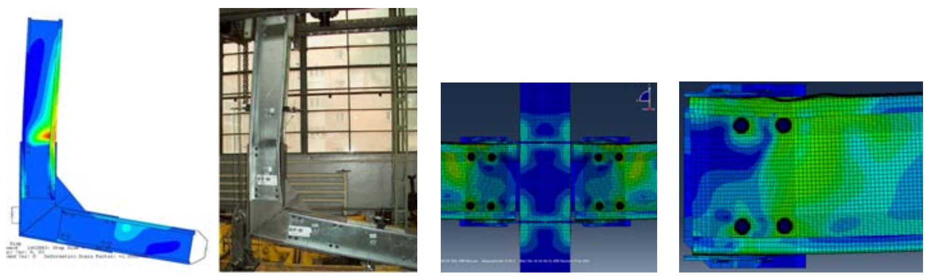
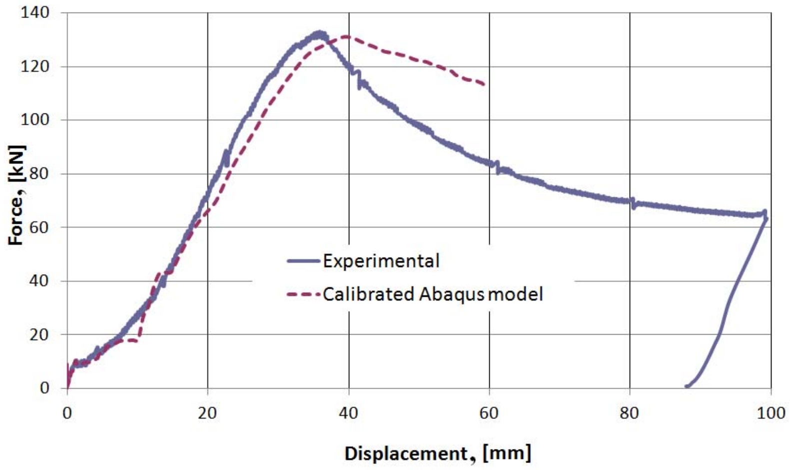
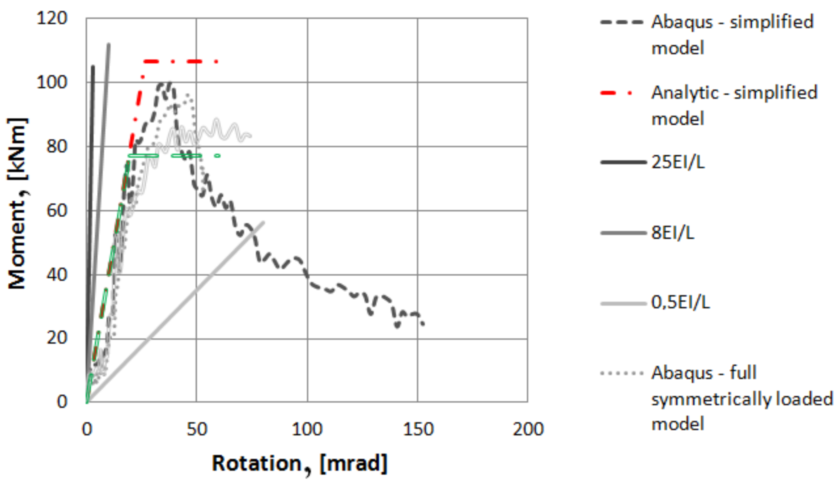


Fig. 6 – Calibrated model and the behaviour of cruciform joint: collapse mechanism.

bers; (ii) 3-D solid elements (C3D4) to model the brackets at the beam–column joints; (iii) 3-D elements to model the bolts between the back-to-back cold-formed lipped channels and brackets; (iv) mesh size: 8 mm × 8 mm; (v) pre-tensioning force to model the effect of bolt tightening; (vi) v = 0.33 (Poisson's ratio). Nonlinear inelastic post-buckling analysis using the standard RIKS method were used, which takes into account stiffness loss due to local buckling. The collapse mechanism due to local buckling can be seen in Fig. 6. A simplified component method was tested (Nagy, 2006), which generate reliable results, confirmed by FEM results.



a



b

Fig. 7 – FEM *vs*. analytical model: *a* – FEM calibration to initial test; *b* – results for analysed cruciform joint.

Comparative results of FEM *vs*. analytical method in mechanical characteristics of the analysed joint (stiffness and strength) are presented in Fig. 7 *b*. Generally a fair agreement between FEM and analytical calculated stiffness of the connection can be observed. Stiffness of the connection is considerably lower than the EN1993-1-8 limits for classification of joints as rigid ($25EI_b/L_b$ for non braced frames and $8EI_b/L_b$ for braced frames), which amounts to 35,019 kN.m/rad for non braced frames and 11,206 kN.m/rad for braced frames (considering the beam span, L_b, equal to frame span and using gross moment of inertia, I_b). Therefore, these types of connections are semi-rigid, and their characteristics need to be taken into account in the global design of frame. In case of this particular configuration, as expected, flange bolts contribute to the stiffness of the joint, while web bolts contribute only to the strength of the joint.

The research will be continuated with the experimental set-up, in order to validate the analytically obtained results.

4. Conclusions

This short review about the state of the art in the world of CFS multistory building applications lead to the following conclusions:

1. There is a continuous development in this field with recent advances, applications and research results.

2. In Romania, welded or rolled structural steel elements are still highly preferred, due to the complex analysis and design procedures associated with CFS members.

3. Even in Canada, mid rise steel buildings using CFS have some restrictions, due to the lack of analytical design methods for SWP structural system.

4. The reduced labor cost and high quality requirements – all this in a very short time – tends to increase the number of steel applications and require an optimized design process.

5. Preliminary results obtained on a reference structure, configured for common Romanian design situation, confirm the solution viability.

6. Preliminary results show that these types of connections are semi-rigid, and their characteristics need to be taken into account in the global design of frame.

7. The research process is in progress, to validate the preliminary results.

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SE POT REALIZA ÎN ROMÂNIA STRUCTURI MULTIETAJATE UTILIZÂND PROFILE CU PEREȚI SUBȚIRI FORMATE LA RECE?

(Rezumat)

Studii anterioare întreprinse în cadrul centrului de cercetare al Universității "Politehnica" din Timişoara pe noduri şi cadre portal la scară reală, realizate din profile cu pereți subțiri formate la rece, compuse din două secțiuni C spate-în-spate, utilizînd îmbinări bulonate, au evidențiat performanțele structurale şi de stabilitate ale acestor tipologii de structuri. Cercetările actuale întreprinse au ca scop extinderea rezultatelor anterior obținute pe noduri şi cadre parter şi la aplicații structurale multietajate. Cercetările începute vizează identificarea de soluții particulare şi tipologii specifice de noduri, ce pot fi adecvate şi pentru aplicații multietajate. În lucrare se face o trecere în revistă a soluțiilor existente la ora actuală în lume în acest domeniu, precum şi rezultatele studiilor preliminare întreprinse în vederea identificării de soluții adecvate utilizînd profile cu pereți subțiri formate la rece pentru România, care are regiuni seismice, de diferite intensități. Pe baza rezultatelor identificate în studiul preliminar, programul de cercetare va continua, utilizînd metoda elementelor finite, în vederea realizării unui model, cu ajutorul căruia performanțele structurale ale tipologiilor de noduri propuse devin predictibile.