FEM analysis of a floor structural system made of thin-walled cold-formed steel profiles

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Abstract. The paper presents the results of a nonlinear FEM analysis of a floor system made of plane truss beams. The steel profiles are made of U-shaped thin walled cold-formed steel. Experimental data were used to model the stiffness of the joints. To observe the structural behaviour of the floor system, nonlinear constraints were defined as a parabolic function considering previous experimental data.

1. Introduction
Cold-formed steel (CFS) profiles as structural elements and systems are widely used in the building construction industry. Truss-made floors, stud walls, modular building panels, purlins and even as a load-bearing structure in low- to mid-rise buildings use CFS profiles. An example of a house with a structure made of cold formed steel profiles is presented in figure 1. Compared to their hot-rolled counterparts, CFS members are often found to be more economical and efficient, due to inherent advantages such as light weight, ease and speed of erection and a greater flexibility in manufacturing cross-sectional profiles and sizes. Many cold-rolling companies can customise different roll sections on demand. With the versatility of the production, the problem of finding the optimum cross-sectional shape is an important objective for the engineers [1], [2].

The behaviour of this type of elements must be correctly understood and future projects well-designed because of the joints, which in general, are hinges. Some experiments on joints and structural elements reveal that the weakest part of the system is the connection between elements [3], [4]. Furthermore, a large number of experimental studies found that the damage of cold-formed thin-walled steel members is mainly caused by the tilting, shearing and pull-out of screws [5], [6]. The connection between cold-formed thin-walled steel members needs to be tested, verified and improved [7].

An alternative for screws is the self-piercing rivet (SPR) connection process also called semi hollow rivet self-piercing riveting, which is commonly used in the fields of automobile and mechanical engineering [7], [8], [9]. In the case of self-piercing rivet (SPR) connection there are some disadvantages regarding the precision of the hole position of the mounted parts and the amount of time. The connections between parts in floor truss systems based on 2 or 4 screws positioned in an imprint alveolus. The experimental results obtained on a few types of joints were used to calibrate the finite element model. This paper presents the results of an incremental non-linear analysis of a truss floor structural system considering non-linear joints using experimental data results on 90⁰ joint connection tests. The model was analysed with Robot Structural Analysis [10] in order to provide a simple approach for the current design process.
2. Materials

The structure of the floors is made of cold formed steel profiles type C12/41/89/41/12x1, as is presented in figure 2, produced from DX51D + Z sheet with a thickness of 1mm. The specific elongation of steel is 35.4%. The mechanical characteristics of the profile and the material properties are presented in table 1 and 2. The cold formed steel profiles are thin-walled profiles with a C-shaped section and are provided with holes and imprinted alveola for screw assembly.

The joints between the profiles for making the subassemblies are made with self-tapping screws Ø4.8x16 (DIN 7981) or GRABBERTARD screws type GFS 4.8x19 R as presented in figure 3. The clamps of the subassemblies are made with screws type Ø5.5x25 (DIN 7504N) or DRIVALL® FP102275LYZ # 10 19 mm. At the top of the beams there is mounted an 18 mm thick OSB board with mechanical fastening at 200 mm distance.

| Table 1. Section properties |
|-----------------------------|
| Section | Section mechanical properties |
| | $A_s$ (mm$^2$) | $I_y$ (mm$^4$) | $I_z$ (mm$^4$) |
| C 89x41x1 | 189 | 243100 | 45600 |

| Table 2. Material properties |
|-----------------------------|
| Material | Elastic modulus – $E$ (N/mm$^2$) | Shear modulus – $G$ (N/mm$^2$) | Tensile strength (N/mm$^2$) |
| steel DX51D+Z | 150000 | 45000 | 140 |
In order to calibrate the numerical model for joints with a relation of the stiffness of a bolted joint between cold-formed elements, experimental studies were performed [11].

3. FEM analyses
Numerical modelling and, in particular, the non-linear analysis of cold-formed steel profiles using finite elements as bars or shells has been well studied. [12], [13]. The non-linear analysis (including the effects of residual stresses and imperfections) capturing the local, distortional and overall buckling behaviours (and their interactions), as well as the modelling of the local distortions at the anchorages and connections of the CFS members under axial and lateral loading are well established [3], [14].
Robot Structural Analysis finite element software was used to analyse the structural model. Finite element bars are 236 and 312 nodes. The material is considered linear elastic based on the modulus of elasticity value presented in table 2. Figure 6 presents the model geometry and the load distribution in figure 7. The load was uniformly distributed on claddings on top of the trusses.


![Figure 6. Model geometry.](image)

In order to obtain a behaviour close to the real one in the FEM software, the nonlinear constraints were defined considering the previous experimental data. A parabolic function was defined considering the force – displacement curve presented in figure 5 and 8.
4. Results and discussion
The results consist of maximum tensile stresses, maximum compressive stresses and maximum vertical displacements are also presented in table 3. Deformed shape and stress distribution on the structural model are presented in figure 6.

Comparing the results obtained from the analyses that are presented in table 6 and expressing them graphically in the figure 10, it is observed that at a maximum value of the vertical displacement of 9.6 mm, the maximum stress that appears is 152.84 N / mm². At the same time, the diagonal of the truss next to the support is out of the strength capacity range.
Table 3. Load distribution and static analysis results

| Load step | Load Value (N/m²) | Maximum tensile stress (N/mm²) | Maximum compressive stress (N/mm²) | Maximum vertical displacement (mm) |
|-----------|------------------|-------------------------------|-----------------------------------|-----------------------------------|
| 1         | 480              | 31.04                         | 15.4                              | 1.6                               |
| 2         | 950              | 61.09                         | 29.95                             | 3.3                               |
| 3         | 1430             | 91.55                         | 45.09                             | 5.2                               |
| 4         | 1910             | 122.48                        | 60.22                             | 7.3                               |
| 5         | 2390             | 152.84                        | 75.39                             | 9.6                               |
| 6         | 2860             | 180.4                         | 90.18                             | 12                                |
| 7         | 3340             | 208.3                         | 105.29                            | 16                                |
| 8         | 3820             | 237.82                        | 120.46                            | 20.3                              |
| 9         | 4300             | 266.9                         | 135.57                            | 25.1                              |
| 10        | 4770             | 294.85                        | 150.35                            | 30.4                              |
| 11        | 5250             | 323.35                        | 165.44                            | 36.1                              |
| 12        | 5730             | 347.56                        | 180.61                            | 42.6                              |
| 13        | 6210             | 368.54                        | 195.72                            | 52.6                              |

As it can be seen in the graphical presentation of the results in figure 10, the linear elastic behaviour is marked. After the breaking point of the joint connection caused by the shear stresses, the displacements increase more compared to the rate of increase of force.

Figure 10. Load - displacement curve obtained from the numerical model

5. Conclusions

Structural systems made of U-shaped thin walled cold-formed profiles are used a lot lately due to their advantages such as low cost, low own weight, fast assembly through a system of prefabricated elements and accessible technological conditions. The structural floor systems are made of trusses. The profiles are obtained in workshops by bending and cold rolling sheet metal strips. In the forming process, the component elements of the beams are cut, stamped and drilled. Self-tapping screws are used in the holes with the stamped socket for mounting. Although the tensile strength of the material is usually up to 275 N/mm², failure occurs most often by shearing into the screw holes.

The analysis presented in this article aims to identify a nonlinear calculation approximation model for truss structural floor systems. Modelling a nonlinear behaviour of joints between finite elements is a reasonable approximation to be used in the current process of designing these types of structures. The definition of an axial stiffness with a parabolic function type proved to obtain good results. These results
must be validated by more experimental analysis of truss-made floors. The analysis shows the
deformations of the model and the maximum tensile stresses that can appear near to the ends of the
trusses, close to the supports. However, there is a disadvantage in this approach, that is the phenomenon
of loss of stability of the compressed bars being unavailable. A superior calculation model in terms of
quality must be achieved by considering a curve of material curve behaviour and its calibration with
experimental results at scale.

6. References

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