ANALYSIS AND DESIGN OF COLD-FORMED
C-SECTION MEMBERS AND STRUCTURES

Theses of the PhD Dissertation

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1. Introduction

Cold-formed thin-walled members are used in building industry in many fields. The probably largest area of use is in conventional – mainly industrial – structures as secondary and tertiary load-bearing elements – purlins, sheeting – on a steel or reinforced concrete primary structure. As primary load-bearing structures cold-formed members are extensively used in North-America and Australia/New Zealand in residential housing; in these countries light-gauge building systems are gaining on popularity and compete with the traditional building materials. Another large area of use is composite floors, where trapezoidal sheeting and cold-formed sections are used as tension, and a thin concrete slab is used as compression part resulting in light floor systems applicable in cold-formed buildings or in refurbishment.

In the recent decade the field of cold-formed thin-walled steel structures have been among the busiest research areas at the Department of Structural Engineering, Budapest University of Technology and Economics. Research projects have been carried out on almost all types of structures mentioned previously. Although the research projects dealt with various types of structures, they had the very common purpose to develop a design method that is based on the principles of Eurocode 3 (EC3) and ensures the safety of the structure. In every case an aim was to optimize the structural arrangement and detailing and to provide structural engineers with tools for design.

The presented theses summarize the author’s research activities and main results on cold-formed C-section structural members and structures made of these.

The first part of the work is fundamental research, where compression C-section members with different cross-sections, end- and lateral supporting conditions are investigated by laboratory tests. The studied arrangements are either single C-section members in arrangements widely used in frames, roof systems, wall panels, or potential structural solutions for cases where enhanced load-bearing is necessary, but section size is limited. The speciality of the research, besides investigating members with complex cross-sections is that the supporting conditions used in the tests are similar to those applied in reality: load introduction through the web, the flanges or both, using self-drilling screws or bolts.

The second part of the dissertation deals with a research and development work carried out in confines of a development project of a truss system made of cold-formed C-section members. The aim of the project was to develop the structural arrangement and standard-based design method of the girders, and validate these with laboratory tests. The truss development is strongly bonded to the first research topic, as the majority of the members investigated in the fundamental research programme have supporting and loading conditions similar to that of the members of the truss system. However, the arrangement of these members is not fully covered by the standard.

The basis of the research is in both cases the experimental study. The behaviour and failure modes are classified based on observations and measurements, and Eurocode-based methods are developed to provide safe, yet non-conservative design of the studied structures.

The third part of the research work deals with numerical modelling of the members and structures tested in the laboratory. The aim of the work is to develop models capable of carrying out virtual experiments to complement the laboratory test results and provide a wider basis for design method development. As for cold-formed structures no standardized modelling techniques are present, different approaches are utilized in the case of the member and the truss tests. The models developed can be considered as first steps towards developing standardized modelling methods.
2. Cold-formed C-section members

The design of single C-section members in compression is well covered by the application rules of Eurocode 3. Design formulae for the possible local, distortional, global and interacting stability failure modes are provided by two versions of the standard: by the EC3-1-3:1996 pre-standard and the operational EC3-1-3:2006 standard. In the application rules it is assumed that in the members the stress distribution caused by axial force and bending moment internal actions is uniform. However, the consequences of the applied load introduction at the element ends on the behaviour of the member are not discussed although these local effects may negatively influence the load-bearing capacity. Also, members with complex arrangements are not covered by the standard.

The global purpose of the research on compression C-section members was to provide design methods for these problems for structural arrangements coming up in the building systems, especially frame and truss structures. To achieve this, two sets of laboratory tests – 98 tests on 10 different types of specimens – were carried out with the aim to study the stability behaviour, failure modes and load-bearing capacities of the members.

A selection of the studied cross-section arrangements and notation of the specimens is presented in Figure 1. Members of complex cross-sections are connected to each other at their flanges or webs at discrete points using self-drilling screws.

![Figure 1: Studied arrangements. Red lines indicate connector elements used to introduce load.](image)

From the structural arrangement point-of-view the specimens either:
- are single C-sections (SimpleC, C, Brace, CompressionC) or members with a complex arrangement (IC Brace, IC Column, CU, CC, DoubleC);
- have load introduction only in the flanges (Brace, IC Brace), only in the web of the cross-sections (SimpleC, IC Column), or both (C, CU, CC); CompressionC members are loaded through an endplate;
- are loaded using metric bolts (Brace, IC Brace, IC Column) or self-drilling screws (SimpleC, C, CU, CC, DoubleC) in the load introduction zone;
- have one flange laterally supported by hat sections at discrete points (HatC, end support same as SimpleC, not shown in Figure 1).

Based on the observations during testing, the failure modes have been characterised and classified, the test-based resistances of the specimens have been calculated based on measurement results. The members, grouped by observed failure modes are listed in Table 1, behaviour and failure modes typical for the groups are presented in Figure 2 and Figure 3.

The measured load-bearing capacities of the single C-section members have been compared to the results of design resistances calculated according to the application rules of the standard. The ratio of design and test resistances is between 0.7 and 1.12, with a mean of close to 1.0. The worst match of test and design resistance is found in case of members with a C arrangement due to the uneven force distribution among the self-drilling screws used to introduce load.
A comparative analysis has been carried out based on the similarities in the arrangement and behaviour of the test specimens; the results of the analysis have been used to develop design methods for the members with a complex cross-section.

Table 1: Behaviour modes and grouping.

<table>
<thead>
<tr>
<th>Group</th>
<th>Specimen types</th>
<th>Typical behaviour mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Simple C, Compression C, C</td>
<td>Interaction of local and flexural buckling, bending</td>
</tr>
<tr>
<td>B</td>
<td>CC, Double C, CU</td>
<td>Interaction of local, distortional and flexural buckling, bending</td>
</tr>
<tr>
<td>C</td>
<td>Brace</td>
<td>Interaction of distortional and flexural buckling</td>
</tr>
<tr>
<td>D</td>
<td>IC Brace</td>
<td>Distortional buckling</td>
</tr>
<tr>
<td>E</td>
<td>IC Column</td>
<td>Interaction of local and flexural buckling of chord member</td>
</tr>
<tr>
<td>F</td>
<td>Hat C</td>
<td>Interaction of distortional buckling and strength failure</td>
</tr>
<tr>
<td>G</td>
<td>Local failure modes</td>
<td>Local failure at load introduction; joint failure and/or web crippling, plate buckling</td>
</tr>
</tbody>
</table>

Figure 2: Behaviour of the members of group A, B, C (left to right).

Figure 3: Behaviour the members of group D, E, F, G (left to right).

In case of the single C-section members the interaction formulae of the application rules have been calibrated by modifying the value of eccentricity to be taken into account to yield results only on the safe side. In the following the design formulae are presented with the standard’s notations. According to the modified interaction formulae of EC3-1-3:1996 the design resistance is to be calculated as follows:

\[
\frac{N_{Ed}}{\chi_{Min} \cdot f_{yb} \cdot A_{eff} / \gamma_{M0}} + \kappa_{z} \cdot (N_{Ed} \cdot e_{mod} + \Delta M_{z,Ed}) \leq 1.0 
\]

where:

\[
e_{mod} = 1.4 \cdot e_{nom} \quad \text{but} \quad e_{mod} \geq 0.4 \cdot y_{S} \quad (2)
\]
\[ \Delta M_{z,Ed} = \epsilon_{Nz} \cdot N_{Ed} \]  

the bending due to the shift of the centroid  

\[ e_{nom} \]  

the nominal eccentricity,  

\[ y_{s} \]  

distance of the centroid and the web of the cross-section,  

\[ e_{Nz} \]  

distance of the centroid of the gross and effective cross-section.  

In case of EC3-1-3:2006 the formula to be used is either (4) or (5):  

\[
\left( \frac{N_{Ed}}{N_{b,Rd}} \right)^{1.0} + \left( \frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{z,Rd}} \right)^{0.47} \leq 1.0
\]  

(4)  

\[
\left( \frac{N_{Ed}}{N_{b,Rd}} \right)^{0.65} + \left( \frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{z,Rd}} \right)^{0.65} \leq 1.0
\]  

(5)  

The load-bearing capacity of members with a HatC arrangement is to be calculated as follows:  

\[
\frac{N_{Ed}}{f_{yb} \cdot 0.5 \cdot A_{eff} / \gamma_{M1}} \leq 1.0
\]  

(6)  

The design resistances of members with a complex cross-section have been derived from the design resistance of single members depending on the arrangement:  

\[
\frac{N_{Ed}}{N_{b,Rd}} + \frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{c,Rd}} \leq \alpha
\]  

(7)  

<table>
<thead>
<tr>
<th>Arrangement</th>
<th>( \alpha )</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC Column</td>
<td>0.8-L+1.0, with L being the member length in [m]</td>
</tr>
<tr>
<td>CC</td>
<td>1.8</td>
</tr>
<tr>
<td>CU</td>
<td>1.3, if C-section is loaded</td>
</tr>
<tr>
<td></td>
<td>1.8 if U-section is loaded</td>
</tr>
<tr>
<td>IC Brace</td>
<td>2.5</td>
</tr>
<tr>
<td>DoubleC</td>
<td>2.0</td>
</tr>
</tbody>
</table>

In the strength checking of DoubleC  

\[ \Delta M_{z,Ed} = (\epsilon_{Nz}+2y_{s}) \cdot N_{Ed} \]  

bending moment about the weak axis.  

3. **Truss system made of cold-formed C-section members**  

The aim of the R&D project with industrial background was to develop a truss system made of cold-formed members spanning 12–24 meters. The industrial partner specified only the outlines of the truss system: span, roof slope and the type of section to be used.  

The developed structural arrangement of the truss is shown in Figure 4. The chords members consist of two C-sections aligned back-to-back; their distance equals to the web height of the brace members. This arrangement results eccentric structural joints (both in-plane and out-of-plane eccentricity is present). A consequence of this alignment is that all brace members must have the same web height – thicknesses may be different –, but they can be doubled if higher load-bearing capacity is necessary (e.g.: at supports).  

Five laboratory tests were carried out on the prototypes of the truss system designed with the preliminary version of the design method. The test results were used to define the failure modes relevant from the design point-of-view, enhance the structural performance of the members by means of modifications in the detailing and refine and validate the design formulae based on the obtained failure modes and measured load-bearing capacities. Relevant failure modes are presented in Figure 5 to Figure 7.
The design method of the truss system follows the conventional design methodology of Eurocode 3: design internal actions are obtained from a global analysis, formulae are evaluated for different failure modes of the members, bolted connections and structural N-joints. The global analysis of the truss is to be carried out using a 2D beam model; in the model the cross-sectional properties are to be taken into account as the properties of the gross cross-section of the members; in case of doubled members (chord members, double brace members) no composite action is to be taken into account.
The design method of the compression chord members was derived from the application rules of EC3-1-3:1996 for members in compression and bending by reducing the value of eccentricity to be taken into account to calculate bending about the weak axis by 50%. In the following the design formulae are presented with the standard’s notations.

\[
\frac{N_{Ed}}{\gamma_{M1}} + \frac{\kappa_{LT} \cdot (M_{y,Ed} + \Delta M_{y,Ed})}{f_{yb} \cdot A_{eff}} + \frac{\kappa_{z} \cdot (0.5 \cdot M_{z,Ed} + \Delta M_{z,Ed})}{f_{yb} \cdot W_{eff,com}} \leq 1
\]  

(9)

To account for accidental misplacing the brace members during the assembly of the truss – the reason of the failure as shown in Figure 5 – the design formulae of these members have been modified to take into account an additional eccentricity, thus an increased bending about the weak axis.

\[
\frac{N_{Ed}}{\gamma_{M0}} + \frac{N_{Ed} \cdot e_{add} + M_{z,Ed} + \Delta M_{z,Ed}}{W_{eff} \cdot f_{y}} \leq 1
\]  

(10)

where:

\[e_{add} = \max(8 \, \text{mm}, 0.2 \cdot b_{1})\]  

(11)

\[b_{1}\]  

(12)

A new design formula for N-type structural joints made using cold-formed C-section members has been derived from the existing application rule provided by EC3-1-8 for N-type joints of RHS or H-sections. The developed design method accounts for the shear buckling utilisation of the web of the chord members considering it an infinitely long plate and reduces the axial resistance of them (13). This checking is augmented by a shear checking of the webs of the chord sections (14). The two design formulae not only provide additional checking of these structural elements, but take into account the interaction between the truss members and structural joints as well.

\[
N_{0,Rd} = \left( (A_{0,eff} - A_{v,eff}) \cdot f_{y} + A_{v,eff} \cdot f_{y} \cdot \sqrt{1 - \left( \frac{V_{Ed}}{V_{b,Rd}} \right)^{2}} \right) / \gamma_{M5}
\]  

(13)

In (13) \(A_{0,eff}\) stands for the gross cross-sectional area of the chord member if the joint is in the tension chord, the effective area of the cross-section of the chord member for axial compression if the joint is in the compression chord. The design shear resistance is calculated as follows:

\[
V_{b,Rd} = \frac{\kappa_{w} \cdot f_{y} \cdot A_{v,eff}}{\sqrt{3} \cdot \gamma_{M5}} \geq V_{Ed}
\]  

(14)

In (14) \(A_{v,eff}\) stands for the gross area of the web if the joint is in the tension chord, the effective area of the web for uniform compression stress if the joint is in the compression chord.

The design method summarized can be used to design trusses made of cold-formed C-section members if the detailing corresponds the prescribed constructional rules.
4. Finite element modelling of cold-formed structures

Parallel with the laboratory tests shell finite element models of the C-section and truss tests were developed with the primary aim to accurately reproduce the behaviour of the test specimen: rigidity, load-bearing capacity and failure mode. A model satisfying these requirements can be considered verified against real tests and can be used to carry out virtual experiments either to check the design method derived from the real tests or to widen the parameter space available to derive the design method from. To reach this aim a model capable of geometrically and materially nonlinear imperfect analysis is to be applied with material properties determined from coupon tests and geometry (screw positions, gusset plates, contact surfaces, plate thicknesses, etc.) as accurate as possible. Great attention was given to the stiffness of the model, as that is – according to the results of the single C-section tests – greatly influenced by the stiffness of the connector elements (self-drilling screws, bolts) used in the specimen.

In the two models a unified approach was utilized regarding the geometry, modelling of contact areas and element types used. Mechanical and geometrical imperfections were substituted in both models with equivalent geometrical imperfections. The modelling of the connector elements was solved different ways, since the structural behaviour of them is different, but the same basic idea was used to create these models to be compatible with the shell elements. Details of the models are presented in Figure 8 and Figure 9.

Figure 8: End support of the model of a SimpleC test specimen.

Figure 9: Structural joint from the truss model.

In the case of the SimpleC models imperfections were chosen from buckling shapes generated using the constrained finite strip method (cFSM); it was used to classify the obtained shapes and choose the pure local, distortional and global shapes to be applied in the model. Figure 10 shows the result of the analysis completed with cFSM; in Figure 11 the local, distortional and global shapes are presented. The imperfect shape of the C-section member was generated by dragging the selected shapes along the member length using sinusoidal lines. The advantage of this approach against using eigenshape-based imperfections is that this way imperfections can be applied to the model in a controlled way – eigenshapes of the finite element model cannot be accurately classified –, ultimately, this approach enables studying the imperfection sensitivity of the members.

To accurately predict the stiffness of the SingleC members a model of the self-drilling screws was developed. The model consists of beam elements only, hence it is compatible with shell elements, and can be calibrated by changing two of its stiffness parameters. The calibration of the model was carried out taking into account both screw rigidity and imperfections to result a good match of load-bearing capacity, stiffness and failure mode. Force-axial shortening diagrams of test and model are presented in Figure 12.
The imperfections of the truss model have been derived from its eigenshapes, as these were clearly distinguishable, the applied amplitudes have been derived from recommended values of EC3-1-5. To model the structural behaviour of the bolts used in the trusses as connector elements a model consisting of linear and nonlinear line elements was developed. This model can be calibrated by one parameter representing the bearing stiffness of the bolted connection. The model was used to reproduce the results of the last test carried out in the laboratory (Figure 7), and it was shown, how such models can be used to investigate parts of the structure not included in the measurement program of the test. The force-deflection diagram of the test and model is shown in Figure 13; the failed shape of the model of the truss is presented in Figure 14.

The results provided by the developed models can be considered as proof-of-the-concept: using a consistent approach in terms of modelling detail and modelling techniques all major characteristics of the investigated structures can be accurately predicted using numerical modelling.
5. New scientific results

5.1. The theses of the PhD dissertation in English

The presented research and its scientific results can be summarized as follows:

Thesis 1

I worked out and completed an experimental test program on compression members made of cold-formed C-sections with cross-sectional configurations and supporting conditions, which were not analysed previously.

I determined and classified the stability behaviour of
   a) single C-section members with load introduction in the web or in the web and the flanges using self-drilling screws, and load introduction in the flanges using bolts,
   b) single C-section members with load introduction in the web using self-drilling screws, laterally supported by hat sections in discrete points at one flange,
   c) members made of two C-sections in a back-to-back arrangement connected to each-other at the webs by self-drilling screws, with load introduction in the web or in the flanges using bolts,
   d) members made by sticking two C-sections in each-other, connected at the flanges by self-drilling screws, with load introduction in the webs or in the web and the flanges using self-drilling screws,
   e) members made by sticking a C- and a U-section in each-other, connected at the flanges by self-drilling screws, with load introduction in web of the C-section and the flanges using self-drilling screws.

Publications connected to the thesis: 3, 7, 8, 9, 10, 11.

Thesis 2

I developed Eurocode-based design methods for the members studied in the laboratory tests based on the comparative analysis of the test-based design resistances and behaviour modes.

   a) I defined the eccentricity to be taken into account in the design of single C-section members without lateral support,
   b) I defined the interaction formula of single C-section members without lateral support in compression and bending about the weak axis,
   c) I developed a design method for single C-section members laterally supported at one flange,
   d) I derived the design resistances of members with complex cross-sectional arrangement on the basis of the design resistance of single members.

Publications connected to the thesis: 1, 4, 11.

Thesis 3

I completed an experimental test program on prototypes of a truss system made of cold-formed C-sections. The specialities of the structural arrangement are: i) the chord members consist of two C-sections in a back-to-back arrangement, with a distance equal to the web height of the brace members, ii) brace members are stuck between the chord members, iii) structural joints are made using fitted bolts, iv) brace members may be of single sections or doubled in a back-to-back arrangement, v) in the ridge joint both webs and flanges of the chord members are connected to each-other.
I determined and characterized the behaviour of the truss based on the following observed failure modes:

a) interaction of out-of-plane global and local buckling of compression chord members,

b) interaction out-of-plane global and local buckling of built-up compression chord members,

c) strength failure of compression brace members at the element end,

d) strength failure of brace-to-chord and chord-to-chord structural joints.

Based on the observed behaviour I defined constructional rules regarding the detailing of the joints ensuring favourable structural behaviour.

Publications connected to the thesis: 5, 6.

Thesis 4

I developed Eurocode-based design methods for the structural members of the trusses studied in the laboratory tests based on the observed behaviour and failure modes and validated them based on the measured load-bearing capacities.

a) I defined the modelling level to be applied in global analysis and verified the model based on the results of strain and deflection measurements,

b) I defined the magnitude of eccentricity to be taken into account in the design of compression chord and brace members,

c) I developed a design method to calculate the design resistance of structural joints, taking into account the interaction of structural members and joints.

Publications connected to the thesis: 5, 6.

Thesis 5

I developed shell finite element models of the single C-section members with load introduction in the web using self-drilling screws and of the truss girders, both capable of carrying out virtual experiments by materially and geometrically nonlinear analysis. The specialities of the models are the modelling of equivalent geometrical imperfections and modelling connector elements.

I generated the imperfections of the models as follows:

a) in the case of the single C-section members using the constrained finite strip method enabling the control of the weight of pure – local, distortional, global – buckling modes in the generated imperfect shape,

b) in the case of the truss girders based on selected eigenshapes of the model.

I developed models of connector elements used in the laboratory tests, compatible with shell elements and capable of following the structural behaviour as: tilting and pull-out in the case of self-drilling screws, shear and bearing in the case of bolts.

I used the laboratory test results to determine the stiffness parameters of the models of the connector elements and the shape and amplitude of imperfections to be applied in the model.

Publications connected to the thesis: 2.
5.2. The theses of the PhD dissertation in Hungarian

Az ismertetett kutatás és annak eredményei a következőképpen foglalhatóak össze:

1. Tézis
Megterveztem és végrehajtottam egy kísérleti programot korábban nem vizsgált keresztmetszeti elrendezésű és megtámasztási viszonyokkal rendelkező vékonyfalú, hidegen hajlított C-szelvényű nyomott szerkezeti elemek vizsgálatára.

Meghatároztam és stabilitási viselkedésük alapján osztályoztam a vizsgált szerkezeti elemek viselkedését. A vizsgált kialakítások:

a) egy C-szelvényből álló, gerincén vagy gerincén és övein önfűrócsavaros kapcsolaton keresztül, vagy övein csavarozott kapcsolaton keresztül terhelt elemek,

b) egy C-szelvényből álló, gerincén önfűrócsavaros kapcsolaton keresztül terhelt, egyik öven pontonként kalapszelvényekkel oldalirányban megtámasztott elemek,

c) két egymásnak háttal fordított, gerincüknél önfűró csavarokkal összekapcsolt szelvényből készített, gerincén vagy övein csavarozott kapcsolaton keresztül terhelt elemek,

d) két egymásba illesztett és öveinknél önfűró csavarokkal összekapcsolt C-szelvényből készített, a gerincéken vagy egy gerincen és az öveken önfűrócsavaros kapcsolaton keresztül terhelt elemek,

e) egy C- és egy U-szelvény egymásba illesztésével és öveik önfűró csavarokkal való összekapcsolásával készített, a C-szelvény gerincén és az öveken önfűrócsavaros kapcsolaton keresztül terhelt elemek.

A tézishez kapcsolódó publikációk: 3, 7, 8, 9, 10, 11.

2. Tézis
A laboratóriumi kísérletekben vizsgált szerkezeti elemek stabilitási viselkedése és a kísérletek alapján megállapított tervezési ellenállások összehasonlító elemzése alapján kifejlesztettem a vizsgált kialakítású elemek Eurocode 3 alapú méretezési eljárásait.

a) Meghatároztam az egy C-szelvényből álló, oldalirányú megtámasztással nem rendelkező szerkezeti elemek méretezése során figyelembe veendő különbségeket.

b) Meghatároztam az egy C-szelvényből álló, oldalirányú megtámasztással nem rendelkező szerkezeti elemek normálró-nymatéki interakciós képletét.

c) Méretezési eljárást fejlesztettem az egyik övköhn kalapszelvényekkel oldalirányban megtámasztott C-szelvényű elemek teherbírásának meghatározására.

d) Az egy C-szelvényből álló elemek méretezési eljárása alapján eljárást adtam a több szelvényből összetett szerkezeti elemek méretezésére.

A tézishez kapcsolódó publikációk: 1, 4, 11.

3. Tézis
Kísérlet sorozatot hajtottam végre hidegen hajlított, C-szelvényű elemekből készített rácsos tartók prototípusain. A vizsgált szerkezet különlegessége, hogy i) az övрудak két, egymásnak háttal fordított C-szelvényből állnak, távolságuk egyenlő a rácsrudak gerincmagasságával, ii) a rácsrudak az övűd elemek közé illeskednek, iii) a szerkezeti csomópontok illesztőcsavaros kialakításuk, iv) a rácsrudak egy szelvényből, vagy két, háttal egymásnak fordított C-szelvényű elemből készülnek, v) a tarécsomópontban az övрудak gerincei és övei is csavarozott kapcsolattal csatlakoznak egymáshoz.
A kísérleti viselkedés alapján meghatároztam és osztályoztam a tartók tönkremeneteli módjait.

a) A nyomott övrudak tartósíkra merőleges globális stabilitásvesztsének és lokális horpadásának interakcióját.
b) Az összetett szelvénnyű nyomott övrudak tartósíkra merőleges globális stabilitásvesztsének és lokális horpadásának interakcióját.
c) A nyomott rácsrudak elemvégű szilárdsági tönkremenetelét.

A tartók kísérletek során megfigyelt viselkedése alapján a szerkezeti kialakításra vonatkozó, kedvező szerkezeti viselkedést biztosító szerkesztési szabályokat dolgoztam ki.

A tézishez kapcsolódó publikációk: 5, 6.

4. Tézis

A laboratóriumi kísérletek során megfigyelt szerkezeti viselkedés és tönkremeneteli módok alapján Eurocode 3 alapú eljárást fejlesztettem ki a rácsos tartók szerkezeti elemeinek méretezésére, az eljárások alkalmazhatóságát a mérési eredményekkel igazoltam.

a) Meghatároztam a rácsos tartók erőjátékának vizsgálatához szükséges modellezési szintet, a modell alkalmazhatóságát nyúlás- és lehajlásmérési eredményekkel igazoltam.
b) Meghatároztam a nyomott övrudak, illetve nyomott- vagy húzott rácsrudak méretezési eljárásában alkalmazandó különböző stabilitásvesztségek méretezését.
c) A rácsrud elemeinek és csomópontjainak interakcióját figyelembe vevő méretezési eljárást dolgoztam ki a szerkezeti csomópontok teherbírásának meghatározására.

A tézishez kapcsolódó publikációk: 5, 6.

5. Tézis

Virtuális kísérletek végrehajtására alkalmazásra került a nemlineáris felületszerkezeti végeselemes modellt, amely a C-szelvényből álló, gerincen önfúrócsavaros kapcsolaton keresztül terhelt elemek és a rácsos tartók vizsgálatához. A modell a helyettesítő geometria és a helyettesítő geometria imperfeckciók és a kapcsolóelemek és a felületszerkezeti modell, amely a helyettesítő geometria imperfeckciók

a) a C-szelvényű elemek esetében a kényszermátrixokat alkalmazó végessávos módszerrel határoztam meg, lehetővé téve az alkalmazott imperfeckt alakban a tisza – lokális, torzulásos horpadás és globális – stabilitásvesztségi méretezés alakban a méretek biztosítását.
b) a rácsos tartó modellje esetében a modell sajátalakjaiból állítottam össze.

A felületszerkezeti modelllel kompatibilis modelleket fejlesztettem a kísérletek alapján alkalmazott kapcsolóelemek releváns szerkezeti viselkedésének figyelembe vételére, melyek az önfúró csavarok esetében a ferdülés és kihúzódás, a csavarok esetében pedig nyírás és palástnyomás.

A laboratóriumi kísérletek eredményei alapján megállapítottam a kapcsolóelemek modelljeinek merevégéi paramétereit és a globális modellben alkalmazandó imperfeckciók alakját és nagyságát.

A tézishez kapcsolódó publikációk: 2.
6. Main publications on the subject of the thesis

International journal papers


International conference papers


Paper in edited book


Others (diploma work, TDK, presentation)

