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European Recommendations for Mechanical Connections in Thin-walled Structural Steel Elements

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EUROPEAN RECOMMENDATIONS FOR MECHANICAL CONNECTIONS IN THIN-WALLED STRUCTURAL STEEL ELEMENTS

by A.W. Tomà*

1. INTRODUCTION

At the Fifth International Specialty Conference on Cold-Formed Steel Structures, held in 1980, Professor E.R. Bryan has reported (see ref. [1]) about the background to the European Convention for Constructional Steelwork (ECCS). However, a brief description of the ECCS will be given again. The ECCS comprises of fifteen national associations representing the structural steelwork industry of each country. The aim of the ECCS is the development of increased and more efficient use of constructional steelwork. Among others this will be pursued by drafting European Recommendations and publishing them. It is intended that these recommendations will have a harmonizing influence in preparation of national or international codes.

The ECCS has a number of committees and each committee covers a different subject area in constructional steelwork. One of the committees is Committee T7 "Cold-Formed Thin-Walled Sheet Steel". At the moment, T7 is under the chairmanship of Professor R. Baehre.

Committee T7 was formed in 1973. Between 1973 and 1978 the references [2], [3] and [4] have been drafted by T7. Since 1977 the preparation of European Recommendations has been delegated to working groups under the supervision of the main committee.

working group T 7.1 "Design of cold formed sheeting and sections"
Chairman: dr. P.O. Thomasson, Sweden
Started: 1977

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working group T 7.2	"Design of connections in thin-walled structural elements" Chairman: A.W. Tomà, the Netherlands Started: 1977 Dissolved: 1983
working group T 7.3	"Good practice in the field of steel cladding and roofing" Chairman: D. Stemmann, Germany Started: 1978 Dissolved: 1983
working group T 7.4	"Design and application of sandwich panels" Chairman: D. Stemmann, Germany Started: 1983.

The working group T 7.1 has drafted design rules for profiled sheeting (ref. [5]). At the moment a preliminary draft concerning design rules for light gauge steel members is available.
The working group T 7.2 has drafted documents on connections and fasteners (ref. [6] and [7]). After completion of their task the working group has been dissolved.
The working group T 7.3 has given a review for good practice in steel cladding and roofing (ref. [8]) and has been also dissolved after finishing their task.
The working group T 7.4 is preparing design specifications and application rules for sandwich panels.

The remaining part of the paper will discuss the documents on connections and fasteners (ref. [6] and [7]) in more detail.

2. RECOMMENDATIONS FOR MECHANICAL FASTENERS AND CONNECTIONS

The field of fasteners and connections consists of a lot of important items. For the sake of clarity and manageability the committee has opted for two documents. One treats the design and testing of connections (ref. [6]). Reference [4] is also included herein. The other one treats the fasteners themselves (ref. [7]).

The recommendations are limited to mechanical fasteners because these have been applied most frequently in Europe in building practice. The fasteners treated are:

- blind rivets
- bolts with nuts
- powder-actuated fasteners
- screws.

The following two chapters give a survey of the contents of both documents and background information on some clauses.

3. EUROPEAN RECOMMENDATIONS FOR THE DESIGN AND TESTING OF CONNECTIONS IN STEEL SHEETING AND SECTIONS (ref. [6])

The recommendations concerning connections have been divided into four main parts:

A. General.

B. Basic principles.

C. Design values determined by testing.

D. Formulae for the design values for fastenings for profiled sheeting and sections.

A. The part "General" consists of a description of the scope, criteria to choose a fastening system, recommendations concerning load factors and limit states to be treated.
Scheme 1 shows the requirements for connections in thin-walled structures (chapter 5 of ref. [9]). These requirements lead to selection criteria for a fastening system. In principle, this means that the type of fastener will be chosen on the basis of the non-structural requirements and then the number of fasteners will be determined based on the structural requirements.

Structural Requirements

1. Strength
2. Stiffness
3. Deformation capacity

Non-structural Requirements

1. Economic aspects, such as:
   - (a) total number of fastenings which have to be made:
   - (b) skill required;
   - (c) ability to be dismantled;
   - (d) desing file;
   - (e) installed costs of the fastening. The cost factors are:
     - (i) fastener piece part cost;
     - (ii) direct labour cost;
     - (iii) indirect labour cost;
     - (iv) application tools cost;
     - (v) maintenance cost;
     - (vi) inventory cost;
2. Durability, which depends on:
   - (a) chemical aggressiveness of the environment;
   - (b) possible galvanic corrosion;
   - (c) stress corrosion (can be important with elevated temperatures and aggressive chemical environments).
3. Watertightness
4. Aesthetics

Scheme 1 Requirements for connections in thin-walled structures.

B. The part "Basic principles" is divided into:

- Design principles for fastenings under static load.
- Design principles for fastenings under repeated load.
- Design values of fastenings.
- Forces in fastenings.
- Strength requirements for fastenings.

In the design principles, fastenings loaded in shear or in tension are distinguished. A definition of failure of a fastening is described depending on a strength criterion and a deformation criterion. The clause "design values of fastenings" define these values, taking account of static load and repeated load. For the repeated load it is stated that this effect on fastenings loaded in shear can be neglected. For the fastenings loaded in tension caused by the wind-spectrum, the static design strength has te be reduced by a factor 2.

With regard to "forces in fastenings", distinction is made between primary and secondary forces.

- Primary forces: forces in fasteners which are directly caused by the load.
- Secondary forces: forces in fasteners which are indirectly caused by the load and may be neglected in the presence of sufficient deformation capacity of the fastening.

A number of sources are mentioned which causes shear or tension forces. For the determination of the value of the forces, an appendix is added to the recommendations. Among others, this appendix is based on the references [9], [10] and [11].

The part "strength requirements for fastenings" is in general based on the principle that the design strength of a fastening shall be larger than the forces in a fastening. But it is also stated that in some cases the serviceability state can be governing.

C. The part "Design values determined by testing" gives standard testing procedures to determine strength and flexibility of fastenings. This chapter is mainly based on a recommendation drafted by the main committee at an earlier date (ref. [4]). Standard testing procedures are described for fastenings loaded in tension or loaded in shear. Further on, a statistical evaluation method is given for the tests. Also, a method is described of deriving emperical formulae for characteristic strength.

D. In the section D formulae are given for the design (shear or tension) strength of fastenings. In the beginning of the section it is stated that formulae for fastenings are in generally conservative and therefore design values determined by tests will give more realistic values.

The formulae for the design strength of fastenings are given for the four mechanical fasteners (blind rivets, bolts and nuts, powder-actuated fasteners and screws). For the different failure modes per fastener, different formulae are given to calculate the strength. One of the principles for the whole document, and also for the section with formulae, is that brittle failure modes will have a strength which is 1.3 times higher than ductile failure modes. The reason for this principle is to ensure redistribution and equalisation of forces in connections and to avoid consideration of secondary forces.

For every fastener type, the limits of application for the design formulae are defined.

Finally, two examples of calculation are shown, one for a composite steel wall and one for a roof decking.

The appendix to this paper gives a review of most of the formulae and application limits given in section D.

4. EUROPEAN RECOMMENDATIONS FOR MECHANICAL FASTENERS FOR USE IN STEEL SHEETING AND SECTIONS: INFORMATION AND TESTING (ref. [7])

The recommendations concerning fasteners have been divided into two main parts:

A. Information on mechanical fasteners.

B. Standard testing procedures for mechanical fasteners.

For every fastener type (blind rivets, bolts with nuts, powder-acuated fasteners and screws) the items A and B are determined.

A. The main object of the section "Information about mechnical fasteners" is:

- To give information concerning mechanical fasteners.

- To provide titles and the number of relevant norms (a.o. ISO, DIN).
- To bring about harmonization of terms and definitions in the field of mechanical fasteners.
- To give guidance for the judgement of fastenings made on site.

With regard to these aims for every fastener type, the following clauses are provided.

Field of application for the specific fastener

In this clause, the material thicknesses which can be applied to the fasteners are mentioned.

Definition

In this clause the definition of the specific fastener is given.

Types

In this clause, a survey is given of the different types of specific fastener (e.g. open or closed blind rivets, self tapping or self drilling screws).

Terms used in the field of the specific fastener

Here, definitions are given of important terms for the specific fastener. For instance, fastener length, thickness to be fastened, sealing capacity etc.

Mechanical properties of the specific fastener

In this clause, strength values are given for the fastener itself, in priciple independent of the materials to be fastened. Shear strength and tension strength can be mentioned as properties.

Workmanship and erection

This section gives, for every fastener type, the recommended form of marking the boxes in which they are packed. Also in this section, the manner of installing a fastener, such as hole preparation, tools to be used and how to be used are described. Further on, this section describes, for every specific fastener, the method or check-list to control, if a fastener is installed in the right way.

B. The part "Standard testing procedures for mechanical fasteners" has the following objectives:

- To standardize the determination of characteristic strength values of specific fasteners.
- To define possible installation failures and guidance for rejection.

The following items are treated in this part to fulfil the aims mentioned.

Test specimens

A number of testspecimens is recommended, depending upon the object of the test. The object can be the determination of characteristic strength values of a certain batch, or a check if the purchased batch is in accordance with what is ordered.

Standard testing procedures

For every fastener type testing procedures are described which give a judgement on the fastener with regard to its structural properties. The different procedures are linked up as far as possible to existing standards from ISO or IFI (Industrial Fasteners Institute, USA). Depending upon fastener type, the following tests are described:

- shear test
- tensile test
- hardness test
- driving test
- hydrogen embrittlement test
- ductility test.

Evaluation of testresults

A chapter is added which describes the determination of characteristic strength values of fasteners out of test restults. Further on, a method is described for the decision of acceptance or rejection of a purchased batch as far as structural properties are concerned.

5. SUMMARY AND CONCLUSIONS

A survey of the work of committee T 7 (Cold-Formed Thin-Walled Sheet Steel) of the ECCS (European Convention for Constructional Steelwork) is given. The European Recommendations concerning connections and fasteners (ref. [6] and [7]) which are drafted by working group T 7.2 are discussed in more detail. The document on connections gives a design philosophy and rules for design (testing and formulae). The document on fasteners provide a lot of practical information on mechanical fasteners themselves.

It can be concluded that in Europe, the work of committe T 7 has a remarkable influence on national standards concerning thin-walled elements. Examples of relevant countries are France, Germany, Great-Britian, Sweden and the Netherlands. It is hoped that this paper will contribute towards a better harmonization between the USA and Europe in the field of fastenings.

REFERENCES

[1] E.R. Bryan "European Recommendations for cold-formed sheet steel in building". Fifth International Specialty Conference on Cold-Formed Steel Structures, St. Louis, Missouri, U.S.A., November 18-19, 1980.

[2] "European Recommendations for the stressed skin design of steel structures". Constrado, 12 Addiscombe Road, Croydon, CR9 3JH, England, March 1977.

[3] "European Recommendations for the testing of profiled metal sheets". Constrado, 12 Addiscombe Road, Croydon, CR9 3JH, England, April 1977.

[4] "European Recommendations for the testing of connections in profiled sheeting and other light gauge steel components". Constrado, 12 Addiscombe Road, Croydon, CR9 3JH, England, May 1978 (now included in [6]).

[5] "European Recommendations for the design of profiled sheeting". Constrado, 12 Addiscombe Road, Croydon, CR9 3JH, England, April 1983.

[6] "European Recommendations for the design and testing of connections in steel sheeting and sections". Constrado, 12 Addiscombe Road, Croydon, CR9 3JH, England, May 1983.

[7] "European Recommendations for mechanical fasteners for use in steel sheeting and sections: information and testing". Constrado, 12 Addiscombe Road, Croydon, CR9 3JH, England, June 1983.

[8] "European Recommendations for good practice in steel cladding and roofing". Constrado, 12 Addiscombe Road, Croydon, CR9 3JH, England, May 1983.

[9] "Developments in thin-walled structures-1" Edited by J. Rhodes and A.C. Walker.
Published by Applied Science Publishers Ltd., Ripple Road, Barking, Essex, England, 1982.

[10] J.W.B. Stark and A.W. Tomà "Connections in cold-formed sections and steel sheets". Fourth International Specialty Conference on Cold-Formed Steel Structures, St. Louis, Missouri, USA, June 1-2, 1978.

[11] J.W.B. Stark and A.W. Tomà "Fastening of steel sheets for walls and roofs on steel structures". International Conference at the University of Strathclyde, Glasgow, 3-6 April 1979.

APPENDIX

FORMULAE FOR THE DESIGN STRENGTH OF FASTENINGS

In part D of "European Recommendations for the design and testing of connections in steel sheeting and sections" (ref. [6]) formulae are given to determine the design strength of fastenings. It has to be mentioned that the formulae are in generally conservative and therefore design values determined by tests will give more realistic values. Tables 1 and 2 gives a survey of design formulae for the various failure modes of fastenings loaded respectively in shear and tension. The design strength of a fastening is the smallest value resulting from the formulae for a given type of fastener.
In the tables 1 and 2 the following symbols are used:

d_n	=	nominal diameter of the fastener
d	=	nominal diameter of the hole
e_1	=	edge distance in load direction
e_2	=	centre-to-centre distance in load direction
f_n	=	design value for the net section stress
f_u	=	the specified ultimate tensile strength of the bolt material
f_y	=	the specified yield strength of the steel sheet with thickness t
f_{yc}	=	the specified yield strength of the base material
r	=	the force transmitted by the bolt or bolts at the section considered, divided by the tension force in the member at that section
t	=	thickness of the thinnest sheet
t_1	=	thickness of the thickest sheet (base material)
u_1	=	distance between edge and centre of fastener perpendicular to the load direction
u_2	=	centre-to-centre spacing of fasteners perpendicular to the load direction
A_{et}	=	tensile stress area of the bolt
A_n	=	net cross sectional area of the plate material
F_b^*	=	the design shear strength of a connection per fastener for the hole bearing mode of failure
F_n^*	=	the design strength of a connection for the yield of net section mode of failure

F_s^* = the design strength of a connection per fastener for the mode of failure involving shear of the material between the edge and the fastener

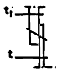
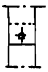
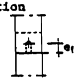
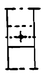
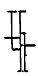
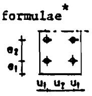
F_{th}^* = the design strength of a connection per fastener for the mode of failure involving tilting followed by hole bearing failure

F_v^* = the design capacity per bolt per shear plane (for thin walled steel the thread is always up to the head)

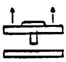
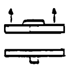
F_p^* = the design strength of a connection per fastener for the mode of failure involving pull through-pull over

F_o^* = the design strength of a connection per fastener for the mode of failure involving pull out of the fastener

Table 1: design shear strength for fastenings

mode of failure	fastener type			
	blind rivets	bolts with nuts	srecws	powder-actuated fasteners
tilting + hole bearing 	$F^*_{th}=\alpha f_y \cdot d_n t$ where: $\alpha=3,6\sqrt{\frac{t}{d_n}}$ for $t=t_1$ $\alpha=2.1$ for $t_1>2.5t$;linear interpolation for $1<\frac{t_1}{t}<2.5$	not relevant	$F^*_{th}=\alpha f_y \cdot d_n t$ where: $\alpha=3.2\sqrt{\frac{t}{d_n}}$ for $t=t_1$ $\alpha=2.1$ for $t_1>2.5t$;linear interpolation for $1<\frac{t_1}{t}<2.5$	not relevant
hole bearing 	$F^*_b=2.1td_n f_y$	$F^*_b=\alpha f_y \cdot d_n t$ where: $\alpha=2.1$ for $t<1mm$ $\alpha=2.6-0.5t+0.9(t-1)\ln(\frac{e_1}{d_n})$ for $1mm<t<3mm$ and $\frac{e_1}{d_n}<6$ $\alpha=1.0+1.1t$ for $1mm<t<3mm$ and $\frac{e_1}{d_n}>6$ $\alpha=1.1+1.8\ \ln(\frac{e_1}{d_n})$ for $t>3mm$ and $\frac{e_1}{d_n}<6$ $\alpha=4.3$ for $t>3mm$ and $\frac{e_1}{d_n}>6$	$F^*_b=2.1td_n f_y$	$F^*_b=3.2td_n f_y$
shear of section 	not relevant when $e_1 > 3d_n$	$F^*_s=te_1 f_y$	not relevant when $e_1 > 3d_n$	not relevant when $e_1 > 4.5d_n$
yield of net section 	$F^*_n=A_n f_y$	$F^*_n=A_n f_n$ where: $f_n=(1-0.9r+3r\ \frac{d}{u})f_y$ with a maximum of $f_n=f_y$ u=minimum of $2u_1$ or u_2	$F^*_n=A_n f_y$	not relevant
shear of fasteners 	characteristic shear strength of fasteners should be 1.5 times larger than other failure modes	$F^*_v=\frac{0.8f_u A_{et}}{\sqrt{2}}$ F^*_v should be 1.3 times larger than other failure modes	characteristis shear strength of fasteners should be 1.5 times larger than other failure modes	the pull-out load due to shear should exceed $F_b{}^*$
application limits for formulae* 	$e_1 > 3d_n$ $e_2 > 3d_n$ $u_2 > 3d_n$ $u_1 > 1.5d_n$ $2.6mm < d_n < 6.4mm$	$e_1 > 1.5d_n$ $e_2 > 4d_n$ $u_2 > 4d_n$ $u_1 > 1.5d_n$ M6–M16 8.8 or 10.9	$e_1 > 3d_n$ $e_2 > 3d_n$ $u_2 > 3d_n$ $u_1 > 1.5d_n$ $3.0mm < d_n < 8.0mm$	$e_1 > 4.5d_n$ $e_2 > 4.5d_n$ $u_2 > 4.5d_n$ $u_1 > 4.5d_n$ $3.7mm < d_n < 6mm$ base material $t_1>6mm$

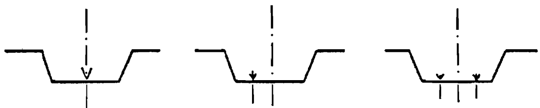
* These limits are only limits for the application of the formulae and not limits for the use of the fasteners. The limits are imposed by the extent of the relevant research.

Table 2: design tension strength for fastenings in sheeting		
mode of failure	fastener type	
	screws	powder-actuated fasteners
pull through-pull over 	$F_p^* = 15tf_y$ or $F_p^* = 7.5tf_y$ (See footnotes a, b, c)	$F_p^* = 15tf_y$ or $F_p^* = 7.5tf_y$ (See footnotes a, b, c)
pull out 	$F_o^* = 0.65t_1f_{yc}$ (See footnote d)	Characteristic pull out strength larger than F_p^* (See footnote e)
tensile failure 	Characteristic tensile strength of fastener larger than F_p^* or F_o^* (See footnote e)	not relevant
Application limit for formulae (see footnote f)	0.5mm $<t<$ 1.5mm $t_1>$0.9mm	0.5mm $<t<$ 1.5 mm $t_1>$6mm

a The formula $F_p^* = 15tf_y$ is valid for static loads. The formula $F_p^* = 7.5tf_y$ is valid for repeated loads with a spectrum similar to wind.

b The failure mode 'gross distortion' is not covered by the given formulae. For fastenings through flanges with a width smaller than 150 mm, the local deformation of the flange under working loads is in most cases in the elastic range.

c It is assumed that load is applied centrally and that the head of the fastener or washer, if any, has a diameter of at least 14 mm and has sufficient rigidity to prevent it being deformed appreciably, When attachment is at a quarter point, the design value is 0.9 F_p^*, and when it is at both quarter points, it is 0.7 F_p^*.



d When $F_o^* < F_p^*$, it has to be proved that the deformation capacity is sufficient.

e For more than one sheet layer the tensile strength of the fastener should be more than one times F_p^* or F_o^*. The factor depends on the number of sheet layers.

f These limits are only limits for the application of the formulae and not limits for the use of the fasteners. These limits are imposed by the extent of the relevant research.