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DESIGN OF JOINTS IN STEEL AND COMPOSITE STRUCTURES

Eurocode 3: Design of steel structures
Part 1-8 – Design of Joints
Eurocode 4: Design of composite steel and concrete structures
Part 1-1 – General rules and rules for buildings

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Design of Joints in Steel and Composite Structures

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FOREWORD

With this ECCS book “Joints in Steel and Composite Structures” the authors succeeded in placing the joints on the rightful place they deserve in the structural behaviour of steel and composite steel-concrete structures. The many times used word “details” for the joints in structures by far underestimates the importance of joints in the structural behaviour of buildings and civil engineering structures. In their chapter “Aim of the book” the authors clearly explain how the design and safety verification of structures runs in an integral manner where all structural components, including the joints, play balanced roles leading to economic structures.

This book can be seen as a background document for Eurocode 3 “Design of Steel Structures” and for Eurocode 4 “Design of Composite Steel and Concrete Structures” as far as it concerns structural joints. The central theme in describing the behaviour of joints is using the component method and this is leading all over in this book. The book contain many aspects such as design, fabrication, erection and costs.

In this book attention is paid on joint modelling and idealisation, joint classification for strength and stiffness and deformation capacity. This all for connections with mechanical fasteners and for welded connections, for simple joints and moment resistant joints. Also lattice girder joints are described.

The book provides the designer with design strategies to arrive at economic structures.

The authors based themselves on many bibliographic references covering a time span of about 65 years. Many of these references present research of the authors themselves and of the other members of the ECCS-Technical Committee TC10 “Structural Connections”.

It was really a privilege to have been the chairperson of this committee from 1998 till the end of 2012 and I thank the authors Prof. Dr. Ir. Jean-Pierre Jaspart and Dr.-Ing. Klaus Weynand for their large effort in writing this book.

Prof. ir. Frans Bijlaard

PREFACE

Steel constructions and composite steel-concrete constructions are generally erected on site by the assembly of prefabricated structural parts prepared at workshop. These parts may themselves be the result of an assembly of individual elements. An example is the assembly by bolting on site of built-up sections welded in the workshop.

In these construction types, joints and connections play a key role and recommendations and guidelines are required for engineers and constructors faced to the conception and design, the fabrication and the erection of such structures. In the Structural Eurocodes, all these aspects are mainly covered in the execution standard EN 1090-2 and in the design standards EN 1993-1-8 (Eurocode 3 for steel structures) and EN 1994-1-1 (Eurocode 4 for composite structures).

In the present book which is part of the series of ECCS Eurocode Design Manuals, the main focus is given to design aspects, but references are also made to EN 1090-2 when necessary.

In comparison to some other fields, the design procedures for joints and connections have significantly evolved in the last decades as a result of the progressive awareness by practitioners of the significant contribution of joints and connections to the global cost of structures. Design for low fabrication and erection costs and high resistance is therefore the targeted objective of modern design codes, the achievement of which has justified the development of new calculation approaches presently integrated into the two afore-mentioned Eurocodes. This situation justifies the writing of the present manual with the main goal to demystify the design by explaining the new concepts to design the joints and to integrate their mechanical response into the structural frame analysis and design process, by providing "keys" for a proper application in practice and finally by providing well documented worked examples.

To refer to "modern" or "new" design approaches and philosophies does not mean that traditional ways are old-fashioned or no more valid. It should be understood that the design methods recommended in the Eurocodes are a collection of European practices including the results of intensive research efforts carried out in the last decades and so give many options and alternatives to the engineers to elaborate safe and economic solutions.

Chapter 1 introduces generalities about joint properties, aspects of materials, fabrication, erection and costs, design approach - and especially the so-called component method - and design tools available to practitioners for easier code application. The integration of the response of the joints into the structural analysis and design process is addressed in chapter 2. In chapter 3, the attention is paid to the design of common connections with mechanical fasteners. Preloaded bolts and non-preloaded bolts are mainly considered but the use of some less classical connectors is also briefly described. Welded connections are covered in chapter 5.

The three next chapters relate to three specific types of joints, respectively simple joints, moment resisting joints and lattice girder joints. For these ones, substantial novelties are brought in the Eurocodes in comparison to traditional national codes; and more especially for simple and moment resisting joints. A significant number of pages is therefore devoted to these topics in this manual.

The design of joints under static loading, as it is addressed in the seven first chapters, is essential in all cases but further checks or different conceptual design of the joints are often required in case of load reversal, fire, earthquake or even exceptional events like impact or explosion. Chapter 8 summarises present knowledge in this field.

Traditionally joints were designed as rigid or pinned, what enabled – and still enables – a sort of dichotomy between the design of the frame, on the one hand, and the design of the joints, on the other hand. The clear economical advantage associated in many situations to the use of semi-rigid and/or partial-strength joints leads however to “structure-joints” interactions that have to be mastered by the engineer so as to fully profit from the beneficial generated cost effects. The Eurocodes do not at all cover this aspect which is not falling within the normalisation domain but within the application by engineers and constructors in daily practice. From this point of view, chapter 9 may be considered as “a première” even if the content had already been somewhat described years ago in an ECSC publication.

Before letting the reader discover the contents of this book, we would like to express acknowledgment. We are very grateful to Prof. Frans Bijlaard for all the comments, suggestions and corrections he made through the review process of the present manual. Warm thanks are also addressed to José Fuchs and Sönke Müller who helped us in preparing the drawings. Last but not least we would like to thank our wives for their patience when we worked "on our project" during innumerable evenings and week-ends.

Jean-Pierre Jaspart
Klaus Weynand

LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

b_{eff}	effective width
d_n	nominal diameter of the bolt shank
e_o	magnitude of initial out-of-straightness
g	gap (in a lattice girder gap joint)
f_u	material ultimate tensile strength
f_y	material yield strength
h_b	depth of beam cross section
h_c	depth of column cross section
h_r	the distance from bolt-row r to the centre of compression
h_t	distance between the centroids of the beam flanges
k_{eq}	equivalent stiffness coefficient
k_i	stiffness coefficient of component i
l_{eff}	effective length (of a T stub flange)
$m_{pl,Rd}$	design plastic moment of a plate per unit length
r_c	fillet radius of the structural shape used as column
$t_{f,b}$	thickness of the beam flange
$t_{f,c}$	thickness of the column flange
t_p	thickness of the end-plate
$t_{w,c}$	thickness of the column web
t_0	thickness of the chord
t_i	thickness of the braces $i = 1.2$
z	lever arm of the resultant tensile and compressive forces in the connection
z_{eq}	equivalent lever arm
xx	longitudinal axis of a member
yy	major axis of a cross section
zz	minor axis of a cross section
A_o	original cross sectional area
A_s	shear area of the bolt shank
$A_{v,c}$	shear area of the column web

E	Young modulus for steel material
F_b	tensile and compressive forces in the connection, statically equivalent to the beam end moment
$F_{b,Ed}$	design bearing force (bolt hole)
$F_{c,Ed}$	design compressive force
$F_{c,fb,Rd}$	design compression resistance of a beam flange and the adjacent compression zone of the beam web
$F_{c,wc,Rd}$	design resistance of a column web subject to transverse compression
$F_{t,Rd}$	design tension resistance per bolt
$F_{t,r,Rd}$	design tension resistance per bolt r
$F_{T,Rd}$	design tension resistance of a T-stub flange
$F_{t,wc,Rd}$	design resistance of a column web subject to transverse tension
$F_{t,wb,Rd}$	design tension resistance of the beam web
$F_{t,Ed}$	design tensile force
$F_{v,Ed}$	design shear force (bolts)
$F_{v,Rd}$	the design shear resistance per bolt
$F_{wp,Rd}$	plastic shear resistance of a column web panel
H	horizontal load
I	second moment of area
I_b	second moment of area of the beam section (major axis bending)
I_c	second moment of area in the column section (major axis bending)
L	member length
L_b	beam span (system length)
L_c	column height (system length measured between two consecutive storeys)
M	bending moment
M_b	bending moment at the beam end (at the location of the joint)
M_c	bending moment in the column (at the location of the joint)
$M_{j,Rd}$	design moment resistance of a joint
$M_{j,Ed}$	design bending moment experienced by the joint
$M_{j,u}$	ultimate bending moment resistance of the joint
$M_{pl,Rd}$	design plastic moment resistant of a cross section
M_u	ultimate bending moment
M_{Ed}	design bending moment

N	axial force
N_b	axial force in the beam (at the location of the joint)
N_c	axial force in the column (at the location of the joint)
$N_{j,Rd}$	axial design resistance of the joint
Q	prying force
P	axial compressive load
R_k	characteristic value of resistance
S	rotational joint stiffness
S_j	nominal rotational joint stiffness
$S_{j,app}$	approximate rotational joint stiffness (estimate of the initial one)
$S_{j,ini}$	initial rotational joint stiffness
$S_{j,post-limit}$	post-limit rotational joint stiffness
V	shear force or gravity load
V_b	shear force at the beam end
V_c	shear force in the column
V_{cr}	critical value of the resultant gravity load
V_{Ed}	design shear force in the connection
V_n	shear force experienced by the column web panel
$V_{wp,Rd}$	design plastic shear resistance of a web panel
W	gravity load
β	transformation parameter
ε_y	material yield strain
ε_u	material ultimate strain
δ	magnitude of the member deflection or local second-order effect
ϕ	the rotation of a joint (relative rotation between the axis of the connected members or sum of the rotations at the beam ends)
ϕ_{cd}	design rotation capacity of a joint
ϕ_b	rotation of the beam end
ϕ_t	rotation of the (beam + joint) end
γ	shear deformation
γ_F	partial safety factor for the loads (actions)
γ_M	partial safety factor for the resistance (strength function)
η	stiffness reduction factor $\left(S_j / S_{j,ini}\right)$
λ	slenderness
λ_L	load parameter
λ_{cr}	elastic critical load parameter (gravity loads)

λ_p	plastic load parameter
$\bar{\lambda}$	reduced slenderness
θ_b	absolute rotation of the beam end
θ_c	absolute rotation of the column axis
σ_u	average ultimate stress
$\sigma_{com,Ed}$	maximum longitudinal compressive stress in a column due to axial force and bending
ψ	load combination factor
γ_{M0}	partial safety factor for plastic resistance of members or sections
γ_{M1}	partial safety factor for resistance to instability
γ_{M2}	partial safety factor for resistance of cross sections in tension to fracture or bolts or welds
Δ	sway displacement or global second-order effect

ABBREVIATIONS

SLS	Service limit state(s)
ULS	Ultimate limit state(s)
RHS	rectangular hollow section
CHS	circular hollow section