

# Buckling of Steel Shells European Design Recommendations

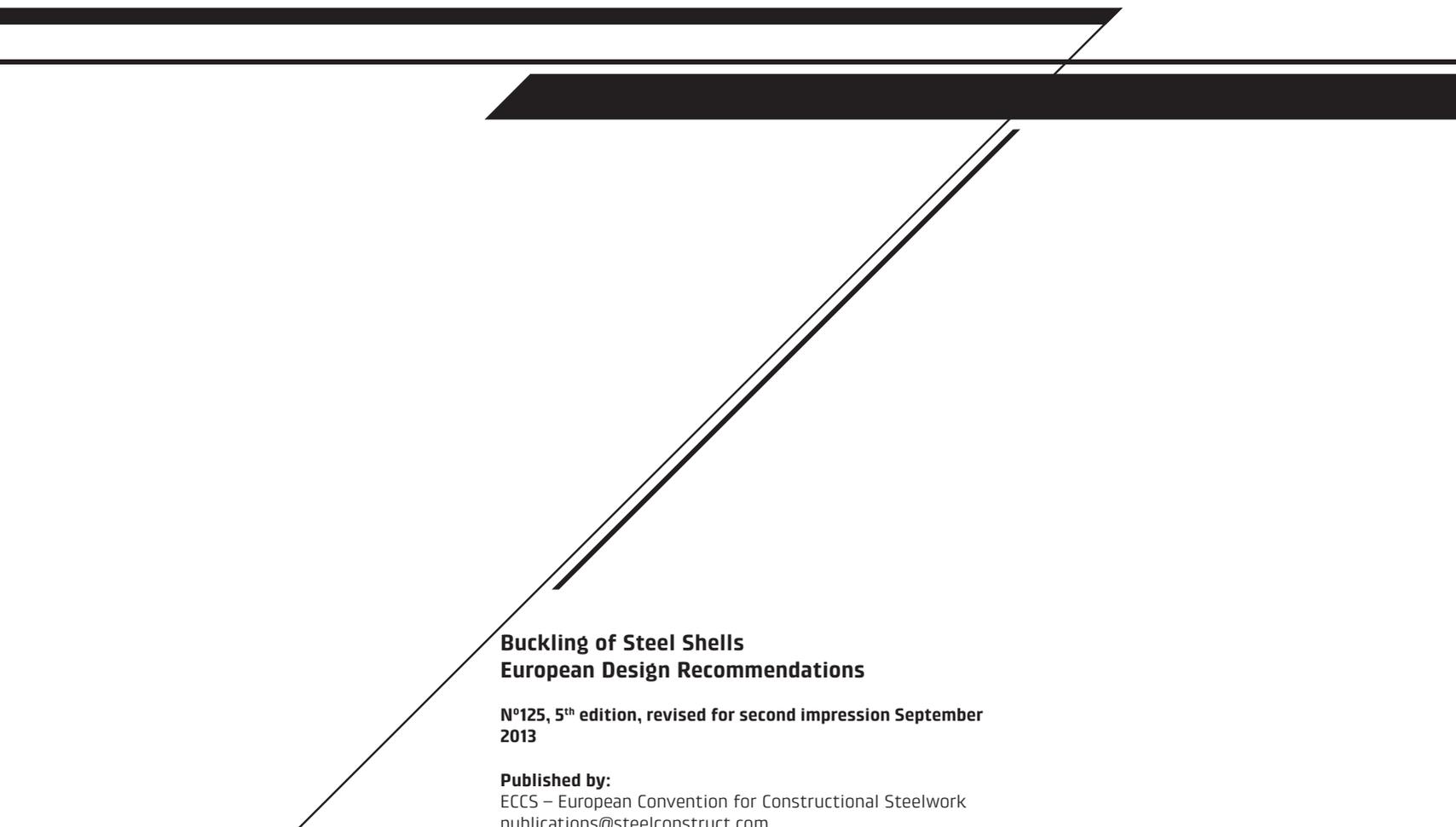
5<sup>th</sup> Edition

REVISED SECOND IMPRESSION

Edited by J. Michael Rotter and Herbert Schmidt

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All sections that are repeated word-for-word from EN 1993-1-6 are marked with a thick vertical line on the left hand side.



**Buckling of Steel Shells  
European Design Recommendations**

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# Contents

## **PART I:**

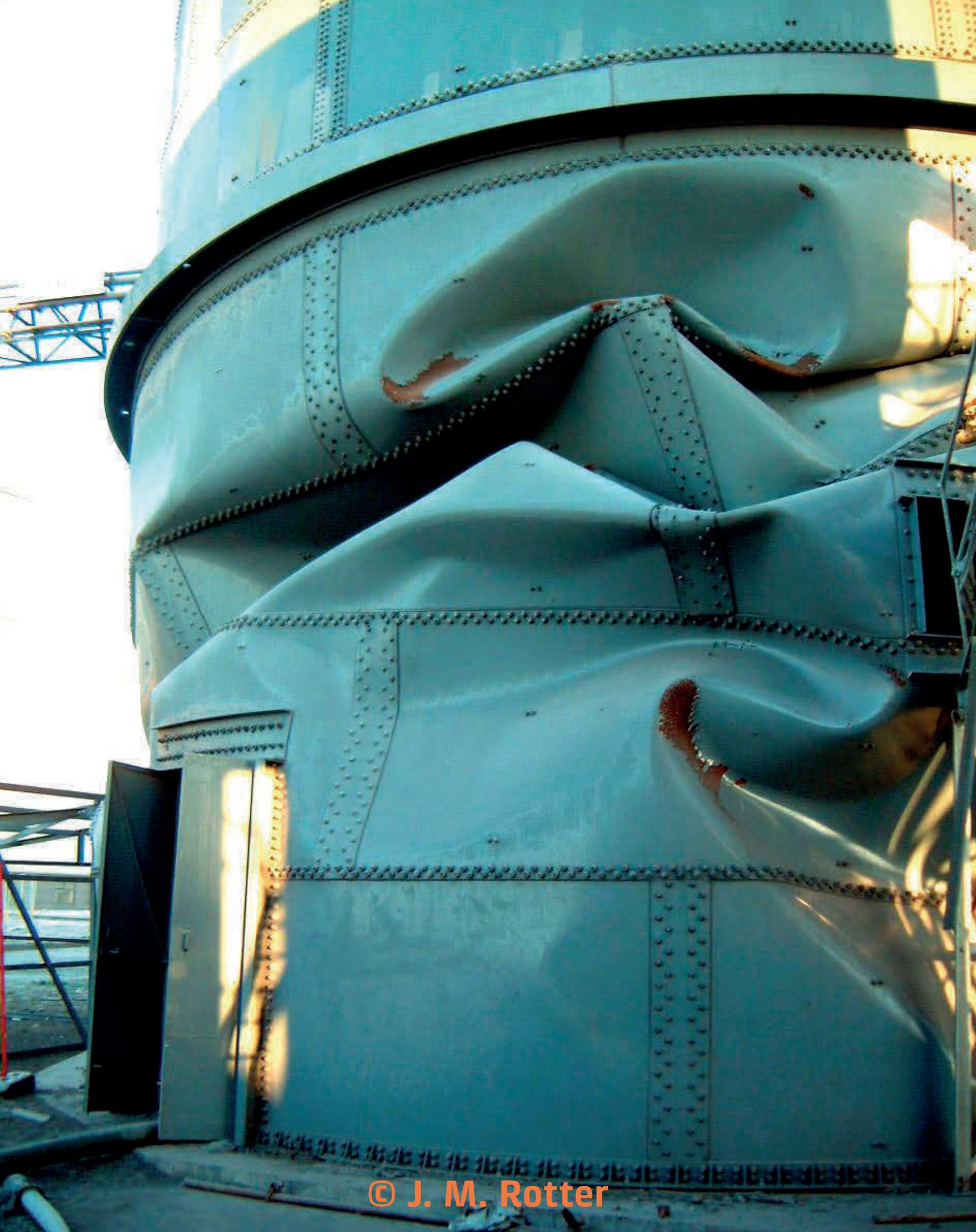
### **General recommendations for design against buckling**

1. Introduction	03
2. Shell buckling behaviour and design concepts	13
3. Scope, conventions, definitions, units, symbols and sign conventions	25
4. Modelling of the shell	39
5. Material assumptions	49
6. Geometrical tolerances and imperfections	61
7. Rules for the plastic limit state and plastic reference load assessment	77
8. Rules for the buckling limit state assessment using global numerical analysis	89
9. Rules for the buckling limit state assessment using stress design	145

## **PART II:**

### **Recommendations for particular shells**

10. Cylindrical shells of constant wall thickness under general loading	169
11. Cylindrical shells of stepwise variable wall thickness	221
12. Cylindrical shells under wind loading	241
13. Conical shells and truncated conical shells under general loading	265
14. Liquid-filled conical shells supported from below	287
15. Spherical shells under uniform external pressure	319
16. Toriconical and torispherical shells under uniform external or internal pressure	329
17. Cylindrical shells with ring stiffeners under uniform external pressure	341
18. Cylindrical shells with longitudinal stiffeners under meridional compression	365
19. Conical shells with longitudinal stiffeners under meridional compression	379
20. Saddle or ring supported cylindrical shells	385



# Preface

This document is described as the 5<sup>th</sup> Edition of the ECCS European Recommendations for the Buckling of Steel Shells. It is the successor to the 4<sup>th</sup> Edition, published in 1988, which was very different in style, format and content, though some of the regulatory requirements of the 4<sup>th</sup> Edition are here retained in the 5<sup>th</sup> Edition.

In the 20 years since the publication of the 4<sup>th</sup> Edition in 1988, much has changed in the field of metal shell buckling. Extensive research has been undertaken, much new knowledge has been developed, and powerful computational modelling has transformed the field, though much design is still conducted by hand calculation. These changes are reflected in this 5<sup>th</sup> Edition.

## Previous editions

These European Recommendations have quite a long history: the First Edition was published in 1980, the 2nd in 1983, the 3rd in 1984 and the 4<sup>th</sup> Edition in 1988. The energetic chairmanship of Professor Vandepitte over this period made progress very rapid. But after these 4 editions in the space of only 9 years, a gap of 20 years ensued until the present 5th Edition. This 5<sup>th</sup> Edition has been some 10 years in gestation, partly because the development of the Eurocode on the Design of Shells (EN 1993-1-6, 2007) took up the energies of the same committee, and the 5<sup>th</sup> Edition could not be completed until that standard was also complete.

The Eurocode EN 1993-1-6 was, in many respects, the successor to the 4<sup>th</sup> Edition, taking over the role of formal regulation of design of metal shells against buckling. Its scope was far greater than that of the 4<sup>th</sup> Edition, covering other failure modes apart from buckling, extended to include computational treatments for shells, and having a very strong and clear structure to permit application to shells under all loading and stress conditions. It also borrowed greatly from DIN 18800 Part 4 (1990), which had been developed for German-speaking countries in the late 1980s.

The Eurocode was required to have a format, style, notation and terminology that is compatible with the remainder of the Eurocode standards (EN 1990 to EN 1999). This led to a number of changes in format and terminology relative to traditional shell design formulations, and these are all adopted into this 5th Edition of the Recommendations.

The 5<sup>th</sup> Edition quotes extensively from the Eurocode EN 1993-1-6 (2007) and is completely compatible with that standard. However, the Eurocode has no commentary, so the meaning, limitations and origins of many rules are not always clear. This 5<sup>th</sup> Edition provides an extensive commentary on the existing rules relating to buckling in the Eurocode, but extends far beyond it in giving recommendations, expansions, advice and warnings, explanations and examples, all of which should give the user considerably more insight and confidence in applying the rules of EN 1993-1-6.

## Structure of the document

This 5<sup>th</sup> Edition is divided into two parts. Part I sets out the basic information and general procedures required to undertake all shell buckling calculations according to EN 1993-1-6. It describes the methodology and conceptual principles for numerical analysis, either to derive the basic data that can be used in a straightforward buckling design by hand calculation, or to replace parts of this calculation with numerical assessments, or to carry out a buckling design that is completely based on numerical assessment.

Part II sets out the detailed information for hand calculation procedures when a shell of a particular geometry is being designed for a particular loading condition. Many well-proven engineering formulas, empirical data and simplified rules extracted from numerical parametric studies have been included in this part. In particular, Part II contains radically updated versions of the rules set out in the 4<sup>th</sup> Edition of the ECCS Recommendations.

## The Drafting Committee ECCS TWG 8.4

In the extended period since the 4<sup>th</sup> Edition was published in 1988, the membership of the drafting committee has seen several changes.

Chairmanship of the committee was first with Dr Lars Samuelsen, was then taken over by Prof. Herbert Schmidt, and finally passed to Prof. J. Michael Rotter. The efforts of each of these chairmen to progress the work towards its final form are here acknowledged. The good work of the secretaries to the committee during this period, Prof. Marios Chryssanthopoulos, Prof. Carlo Poggi, Prof. Werner Guggenberger and Prof. Spyros Karamanos is also gratefully acknowledged.

Members of the committee (2011) who were responsible for its full content are:

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Prof. Cem Topkaya	Turkey	Corresponding
Prof. Thomas Ummenhofer	Germany	Corresponding
Prof. Walter Wunderlich	Germany	Full

**A LARGE DIAMETER TANK  
WITH A SPHERICAL DOME  
ROOF**

Past members of the committee who contributed greatly during the period 1989-2010 were:

Dr Lars A. Samuelson	Sweden
Prof. Patrick J. Dowling	UK
Prof. Maria Esslinger	Germany
Prof. Gerry D. Galletly	UK
Dr Jonas Odland	Norway
Prof. J. Rathé	Belgium
Prof. Marios Chryssanthopoulos	UK
Prof. Guy Lagae	Belgium
Prof. Carlo Poggi	Italy
Dr Wesley Vanlaere	Belgium

## Key contributions of members to chapters

All members of the committee contributed in some way to all of the chapters in these Recommendations. But because each chapter was essentially written by one or a few individuals, they are named in the text as the authors of each chapter. However, the significant contributions of others to particular chapters are here also noted.

Chapter	Title	Authors. Further substantial contributors are marked thus (...)
1.	Introduction	
2.	Shell buckling behaviour and design concepts	Chryssanthopoulos, Rotter
3.	Scope, conventions, definitions, units, symbols and sign conventions	
4.	Modelling of the shell	Rotter, Schmidt (Wunderlich)
5.	Material assumptions	Rotter, Gresnigt (Schmidt)
6.	Geometric tolerances and imperfections	Rotter, Schmidt (Gresnigt)
7.	Rules for the plastic limit state assessment	Rotter (Gresnigt)
8.	Rules for the buckling limit state assessment using design by global numerical analysis	Schmidt, Rotter, (Karamanos, Schneider, Guggenberger, Vanlaere, Doerich, Holst)
9.	Rules for the buckling limit state assessment using stress design	Schmidt, Rotter, Greiner (Karamanos, Holst)
10.	Cylindrical shells of constant wall thickness under general loading	Schmidt, Rotter (Karamanos, Limam) (flow charts by Poggi and Vanlaere)
11.	Cylindrical shells of stepwise variable wall thickness	Greiner, Rotter (Karamanos, Doerich, Schmidt)
12.	Cylindrical shells under wind loading	Greiner, Guggenberger, Schneider (Schmidt, Rotter, Marcinowski)
13.	Conical shells and truncated conical shells under general loading	Greiner, Poggi (Schmidt, Lagae, Vanlaere) (Flow charts by Poggi and Vanlaere)
14.	Liquid-filled conical shells supported from below	Lagae, Guggenberger, Vanlaere
15.	Spherical shells under uniform external pressure	Wunderlich (Karamanos)
16.	Toriconical and torispherical shells under uniform external and internal pressure	Wunderlich
17.	Cylindrical shells with ring stiffeners under external pressure	Schmidt, Greiner
18.	Cylindrical shells with longitudinal stiffeners under meridional compression	Schmidt, Samuelson (Rotter)
19.	Conical shells with longitudinal stiffeners under meridional compression	Chryssanthopoulos, Spagnoli
20.	Saddle or ring supported cylindrical shells	Krupka (Schmidt, Rotter, Karamanos)

## Revisions in the reprint of the 5<sup>th</sup> Edition

All chapters of the 5<sup>th</sup> Edition, as published in October 2008, have been revised and many small corrections and minor additions made in most chapters. The drafting committee hopes that these corrections will have eliminated all previous typing errors, and that the reader will be freed from uncertainties about the intended meaning in other places. Many improvements have also been noted for implementation into the 6<sup>th</sup> Edition.

## Proposed 6<sup>th</sup> Edition

The members of the committee are very aware that simple advice on many critically important practical problems has not been given in the 5<sup>th</sup> Edition. The original plan was to include many more chapters. However, in the interests of completing the publication in a reasonable time, these chapters were omitted. The following subjects are expected to be treated in a focused manner in a forthcoming 6<sup>th</sup> Edition.

- GMNIA analysis and interpretation advice for complex load cases
- Cylinders with cut-outs
- Cylinders on local supports at the base
- Cylinders on local brackets and engaged columns
- Bending and transverse shear in long cylinders
- Bending and transverse shear in short cylinders
- Cylinder-cone junctions in chimneys, towers and masts
- Cone-cylinder junctions in silos and tanks
- Shallow conical roofs and eaves stiffeners
- Corrugated stiffened and unstiffened cylinders for silos

## Disclaimer

The opinions expressed in these Recommendations are those of the authors and members of the drafting committee and are not necessarily those of the ECCS.

Every effort has been made to ensure accuracy in these Recommendations, but the publisher, the ECCS and the authors cannot accept responsibility for any loss, damage or other consequence resulting from the use of this information.

Anyone making use of the information or material contained in these Recommendations, in whole or in part, does so at his or her own risk and assumes any and all liability from such use.

## Closure

The committee hopes that the reader will find much useful information in this 5<sup>th</sup> Edition of the European Recommendations, will forgive any errors in the document, and will provide feedback to the committee on any issues that should be reconsidered.

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Edinburgh March 2011