

**ECCS TC8 TWG 8.4
Shells**

**Buckling of Steel Shells
European Design Recommendations**

5th Edition, 2008



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

Stability of Steel Shells: European Design Recommendations: Fifth Edition 2008

PART I: General recommendations for design against buckling

Chapter	Title	
1	Introduction	11
2	Shell buckling behaviour and design concepts	21
3	Scope, conventions, definitions, units, symbols and sign conventions	33
4	Modelling of the shell	47
5	Material assumptions	57
6	Geometric tolerances and imperfections	69
7	Rules for the plastic limit state assessment	83
8	Rules for the buckling limit state assessment using design by global numerical analysis	95
9	Rules for the buckling limit state assessment using stress design	147

PART II: Recommendations for particular shells

Chapter	Title	
10	Cylindrical shells of constant wall thickness under general loading	167
11	Cylindrical shells of stepwise variable wall thickness	217
12	Cylindrical shells under wind loading	237
13	Conical shells and truncated conical shells under general loading	259
14	Liquid-filled conical shells supported from below	281
15	Spherical shells under uniform external pressure	309
16	Toriconical and torispherical shells under uniform external and internal pressure	319
17	Cylindrical shells with ring stiffeners under external pressure	331
18	Cylindrical shells with longitudinal stiffeners under meridional compression	353
19	Conical shells with longitudinal stiffeners under meridional compression	365
20	Saddle or ring supported cylindrical shells	371

Preface

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

In the 20 years since the publication of the 4th 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 5th 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 4th 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 5th 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 5th 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 4th Edition, taking over the role of formal regulation of design of metal shells against buckling. Its scope was far greater than that of the 4th 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 the 5th Edition of the Recommendations.

The 5th 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 5th 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 5th 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 4th Edition of the ECCS Recommendations.

The Drafting Committee ECCS TWG 8.4

In the extended period since the 4th 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.

Past members of the committee who contributed greatly during the period 1989-2008 were:

Dr Lars A. Samuelsen	Sweden
Prof. Patrick J. Dowling	UK
Prof. Maria Esslinger	Germany
Prof. Gerry D. Galletly	UK
Dr Jonas Odland	Norway
Prof. J. Rathé	Belgium

Current members of the committee (2008) who are responsible for its full content, and who have all participated and contributed to all chapters are:

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Dr Wesley Vanlaere	Belgium	Corresponding
Prof. Walter Wunderlich	Germany	Full

Key contributions of members to chapters

All members of the committee effectively 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 “principal authors” of each chapter. However, the very significant contributions of others to particular chapters are here also noted.

Chapter	Title	Principal authors and further substantial contributors (...)
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	Chryssanthoupolos, Spagnoli
20	Saddle or ring supported cylindrical shells	Krupka (Schmidt, Rotter, Karamanos)

Proposed 6th Edition

The members of the committee are very aware that simple advice on many critically important practical problems has not been given in the 5th 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 6th 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

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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.

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Closure

The committee hopes that the reader will find much useful information in this 5th 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 July 2008

