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Evrokod 3: Projektiranje jeklenih konstrukcij - 4-1.del: Silosi

Eurocode 3 - Design of steel structures - Part 4-1: Silos

Eurocode 3 - Bemessung und Konstruktion von Stahlbauten - Teil 4-1: Silos

Eurocode 3 - Calcul des structures en acier - Partie 4-1: Silos

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Eurocode 3 - Design of steel structures - Part 4-1: Silos

Eurocode 3 - Calcul des structures en acier - Partie 4-1: Silos

Eurocode 3 - Bemessung und Konstruktion von Stahlbauten - Teil 4-1: Silos

This European Standard was approved by CEN on 12 June 2006.

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Contents

Foreword

This European Standard EN 1993-4-1, "Eurocode 3: Design of steel structures – Part 4-1: Silos", has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », the Secretariat of which is held by BSI. CEN/TC250 is responsible for all Structural Eurocodes.

This European Standard shall be given the status of a National Standard, either by publication of an identical text or by endorsement, at the latest by August 2007 and conflicting National Standards shall be withdrawn at latest by March 2010.

This Eurocode supersedes ENV 1993-4-1:1999.

According to the CEN-CENELEC Internal Regulations, the National Standard Organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Background of the Eurocode programme

In 1975, the Commission of the European Community decided on an action programme in the field of construction, based on article 95 of the Treaty. The objective of the programme was the elimination of technical obstacles to trade and the harmonisation of technical specifications.

Within this action programme, the Commission took the initiative to establish a set of harmonised technical rules for the design of construction works which, in a first stage, would serve as an alternative to the national rules in force in the Member States and, ultimately, would replace them.

For fifteen years, the Commission, with the help of a Steering Committee with Representatives of Member States, conducted the development of the Eurocodes programme, which led to the first generation of European codes in the 1980's.

In 1989, the Commission and the Member States of the EU and EFTA decided, on the basis of an agreement[1)] between the Commission and CEN, to transfer the preparation and the publication of the Eurocodes to the CEN through a series of Mandates, in order to provide them with a future status of European Standard (EN). This links de facto the Eurocodes with the provisions of all the Council's Directives and/or Commission's Decisions dealing with European standards (e.g. the Council Directive 89/106/EEC on construction products - CPD - and Council Directives 93/37/EEC, 92/50/EEC and 89/440/EEC on public works and services and equivalent EFTA Directives initiated in pursuit of setting up the internal market).

The Structural Eurocode programme comprises the following standards generally consisting of a number of Parts:

EN1990	Eurocode: Basis of structural design
EN1991	Eurocode 1: Actions on structures
EN1992	Eurocode 2: Design of concrete structures
EN1993	Eurocode 3: Design of steel structures
EN1994	Eurocode 4: Design of composite steel and concrete structures
EN1995	Eurocode 5: Design of timber structures

1) Agreement between the Commission of the European Communities and the European Committee for Standardisation (CEN) concerning the work on EUROCODES for the design of building and civil engineering works (BC/CEN/03/89).

EN1996	Eurocode 6: Design of masonry structures
EN1997	Eurocode 7: Geotechnical design
EN1998	Eurocode 8: Design of structures for earthquake resistance
EN1999	Eurocode 9: Design of aluminium structures

Eurocode standards recognise the responsibility of regulatory authorities in each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level where these continue to vary from State to State.

Status and field of application of Eurocodes

The Member States of the EU and EFTA recognise that EUROCODES serve as reference documents for the following purposes:

– as a means to prove compliance of building and civil engineering works with the essential requirements of Council Directive 89/106/EEC, particularly Essential Requirement N°1 - Mechanical resistance and stability - and Essential Requirement N°2 - Safety in case of fire ;

– as a basis for specifying contracts for construction works and related engineering services ;

– as a framework for drawing up harmonised technical specifications for construction products (ENs and ETAs)

The Eurocodes, as far as they concern the construction works themselves, have a direct relationship with the Interpretative Documents[2] referred to in Article 12 of the CPD, although they are of a different nature from harmonised product standards[3]. Therefore, technical aspects arising from the Eurocodes work need to be adequately considered by CEN Technical Committees and/or EOTA Working Groups working on product standards with a view to achieving full compatibility of these technical specifications with the Eurocodes.

The Eurocode standards provide common structural design rules for everyday use for the design of whole structures and component products of both a traditional and an innovative nature. Unusual forms of construction or design conditions are not specifically covered and additional expert consideration will be required by the designer in such cases.

National Standards implementing Eurocodes

The National Standards implementing Eurocodes will comprise the full text of the Eurocode (including any annexes), as published by CEN, which may be preceded by a National title page and National foreword, and may be followed by a National Annex.

The National Annex may only contain information on those parameters which are left open in the Eurocode for national choice, known as Nationally Determined Parameters, to be used for the design of buildings and civil engineering works to be constructed in the country concerned, i.e. :

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[2] According to Art. 3.3 of the CPD, the essential requirements (ERs) shall be given concrete form in interpretative documents for the creation of the necessary links between the essential requirements and the mandates for harmonised ENs and ETAGs/ETAs.

[3] According to Art. 12 of the CPD the interpretative documents shall :

a) give concrete form to the essential requirements by harmonising the terminology and the technical bases and indicating classes or levels for each requirement where necessary ;

b) indicate methods of correlating these classes or levels of requirement with the technical specifications, e.g. methods of calculation and of proof, technical rules for project design, etc. ;

c) serve as a reference for the establishment of harmonised standards and guidelines for European technical approvals.

The Eurocodes, de facto, play a similar role in the field of the ER 1 and a part of ER 2.

– values and/or classes where alternatives are given in the Eurocode,
– values to be used where a symbol only is given in the Eurocode,
– country specific data (geographical, climatic, etc), e.g. snow map,
– the procedure to be used where alternative procedures are given in the Eurocode.

It may also contain:

– decisions on the application of informative annexes,
– references to non-contradictory complementary information to assist the user to apply the Eurocode.

Links between Eurocodes and harmonised technical specifications (ENs and ETAs) for products

There is a need for consistency between the harmonised technical specifications for construction products and the technical rules for works[4]. Furthermore, all the information accompanying the CE Marking of the construction products which refer to Eurocodes should clearly mention which Nationally Determined Parameters have been taken into account.

Additional information specific to EN1993-4-1

EN 1993-4-1 gives design guidance for the structural design of silos.

EN 1993-4-1 gives design rules that supplement the generic rules in the many parts of EN 1993-1.

EN 1993-4-1 is intended for clients, designers, contractors and relevant authorities.

EN 1993-4-1 is intended to be used in conjunction with EN 1990, with EN 1991-4, with the other Parts of EN 1991, with EN 1993-1-6 and EN 1993-4-2, with the other Parts of EN 1993, with EN 1992 and with the other Parts of EN 1994 to EN 1999 relevant to the design of silos. Matters that are already covered in those documents are not repeated.

Numerical values for partial factors and other reliability parameters are recommended as basic values that provide an acceptable level of reliability. They have been selected assuming that an appropriate level of workmanship and quality management applies.

Safety factors for 'product type' silos (factory production) can be specified by the appropriate authorities. When applied to 'product type' silos, the factors in 2.10 are for guidance purposes only. They are provided to show the likely levels needed to achieve consistent reliability with other designs.

National Annex for EN1993-4-1

This standard gives alternative procedures, values and recommendations for classes with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1993-4-1 should have a National Annex containing all Nationally Determined Parameters to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

National choice is allowed in EN 1993-4-1 through:

– 2.2 (1)
– 2.2 (3)

[4] see Art.3.3 and Art.12 of the CPD, as well as clauses 4.2, 4.3.1, 4.3.2 and 5.2 of ID 1.

- 2.9.2.2 (3)
- 3.4 (1)
- 4.1.4 (2) and (4)
- 4.2.2.3 (6)
- 4.3.1 (6) and (8)
- 5.3.2.3 (3)
- 5.3.2.4 (10), (12) and (15)
- 5.3.2.5 (10) and (14)
- 5.3.2.6 (3) and (6)
- 5.3.2.8 (2)
- 5.3.3.5 (1) and (2)
- 5.3.4.3.2 (2)
- 5.3.4.3.3 (2) and (5)
- 5.3.4.3.4 (5)
- 5.3.4.5 (3)
- 5.4.4 (2), (3) and (4)
- 5.4.7 (3)
- 5.5.2 (3)
- 5.6.2 (1) and (2)
- 6.1.2 (4)
- 6.3.2.3 (2) and (4)
- 6.3.2.7 (3)
- 7.3.1 (4)
- 8.3.3 (4)
- 8.4.1 (6)
- 8.4.2 (5)
- 8.5.3 (3)
- 9.5.1 (3) and (4)
- 9.5.2 (5)
- 9.8.2 (1) and (2)
- A.2 (1) and (2)
- A.3.2.1 (6)
- A.3.2.2 (6)
- A.3.2.3 (2)
- A.3.3 (1), (2) and (3)
- A.3.4 (4)

1 General

1.1 Scope

(1) Part 4.1 of Eurocode 3 provides principles and application rules for the structural design of steel silos of circular or rectangular plan-form, being free standing or supported.

(2) The provisions given in this Part supplement modify or supersede the equivalent provisions given in EN 1993-1.

(3) This part is concerned only with the requirements for resistance and stability of steel silos. For other requirements (such as operational safety, functional performance, fabrication and erection, quality control, details like man-holes, flanges, filling devices, outlet gates and feeders etc.), see the relevant standards.

(4) Provisions relating to special requirements of seismic design are provided in EN 1998-4, which complements or adapts the provisions of Eurocode 3 specifically for this purpose.

(5) The design of supporting structures for the silo are dealt with in EN 1993-1-1. The supporting structure is deemed to consist of all structural elements beneath the bottom flange of the lowest ring of the silo, see figure 1.1.

(6) Foundations in reinforced concrete for steel silos are dealt with in EN 1992 and EN 1997.

(7) Numerical values of the specific actions on steel silos to be taken into account in the design are given in EN 1991-4 Actions in Silos and Tanks.

(8) This Part 4.1 does not cover:

- resistance to fire;
- silos with internal subdivisions and internal structures;
- silos with capacity less than 10 tonnes;
- cases where special measures are necessary to limit the consequences of accidents.

(9) Where this standard applies to circular planform silos, the geometric form is restricted to axisymmetric structures, but the actions on them may be unsymmetrical, and their supports may induce forces in the silo that are not axisymmetrical.

1.2 Normative references

This European Standard incorporates, by dated and undated reference, provisions from other standards. These normative references are cited at the appropriate places in the text and the publications are listed hereafter. For dated references, subsequent amendments to, or revisions of, any of these publications apply to the European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies.

EN 1090 *Execution of steel structures;*

EN 1990 *Eurocode: Basis of design;*

EN 1991 *Eurocode 1: Actions on structures;*

Part 1.1 *Actions on structures – Densities, self-weight and imposed loads for buildings;*

Part 1.2: *Actions on structures – Actions on structures exposed to fire;*

Part 1.3: *Actions on structures – Snow loads;*

Part 1.4: *Actions on structures – Wind loads;*

Part 1.5: *Actions on structures – Thermal loads;*

Part 1.6: *Actions on structures – Construction loads;*

Part 1.5: *Actions on structures – Accidental actions;*

Part 4: *Actions on silos and tanks;*

EN 1993 *Eurocode 3: Design of steel structures;*

Part 1.1: *General rules and rules for buildings;*

Part 1.3: *Cold formed thin gauge members and sheeting;*

Part 1.4: *Stainless steels;*

Part 1.6: *Strength and stability of shell structures;*

Part 1.7: *Planar plated structures loaded transversely;*

Part 1.8: *Design of joints;*

Part 1.9: *Fatigue strength of steel structures;*

Part 1.10: *Selection of steel for fracture toughness and through-thickness properties;*

Part 4.2: *Tanks;*

EN 1997 *Eurocode 7: Geotechnical design;*

EN 1998 *Eurocode 8: Design provisions for earthquake resistance of structures;*

Part 4: *Silos, tanks and pipelines;*

EN 10025 *Hot rolled products of non-alloy structural steels - technical delivery conditions;*

EN 10147 *Hot-rolled flat products made of high yield strength steels for cold forming;*

ISO 1000 *SI Units;*

ISO 3898 *Bases for design of structures - Notation - General symbols;*

ISO 4997 *Cold reduced steel sheet of structural quality;*

ISO 8930 *General principles on reliability for structures - List of equivalent terms.*

1.3 Assumptions

(1) In addition to the general assumptions of EN 1990 the following assumptions apply:

– fabrication and erection complies with EN 1090-2

1.4 Distinction between principles and application rules

(1) See 1.4 in EN 1990.

1.5 Terms and definitions

(1) The terms that are defined in 1.5 in EN 1990 for common use in the Structural Eurocodes and the definitions given in ISO 8930 apply to this Part 4.1 of EN 1993, unless otherwise stated, but for the purposes of this Part 4.1 the following supplementary definitions are given:

1.5.1 shell. A structure formed from a curved thin plate.

1.5.2 axisymmetric shell. A shell structure whose geometry is defined by rotation of a meridional line about a central axis.

1.5.3 box. A structure formed from an assembly of flat plates into a three-dimensional enclosed form. For the purposes of this Standard, the box has dimensions that are generally comparable in all directions.

1.5.4 meridional direction. The tangent to the silo wall in a vertical plane at any point. It varies according to the structural element being considered. Alternatively, it is the vertical or inclined direction on the surface of the structure that a rain drop would take in sliding down the surface.

1.5.5 circumferential direction. The horizontal tangent to the silo wall at any point. It varies around the silo, lies in the horizontal plane and is tangential to the silo wall irrespective of whether the silo is circular or rectangular in plan.

1.5.6 middle surface. This term is used to refer to both the stress-free middle surface when a shell is in pure bending and the middle plane of a flat plate that forms part of a box.

1.5.7 separation of stiffeners. The centre to centre distance between the longitudinal axes of two adjacent parallel stiffeners.

Supplementary to Part 1 of EN 1993 (and Part 4 of EN 1991), for the purposes of this Part 4.1, the following terminology applies, see figure 1.1:

1.5.8 silo: A silo is a vessel for storing particulate granular solids. In this Standard, it is assumed to have a vertical form with solids being added by gravity at the top. The term silo includes all forms of particulate solids storage structure, that might otherwise be referred to as a bin, hopper, grain tank or bunker.

1.5.9 barrel: The barrel is the vertical walled section of a silo.

1.5.10 hopper: A hopper is a converging section towards the bottom of a silo. It is used to channel solids towards a gravity discharge outlet.

1.5.11 junction: A junction is the point at which any two or more shell segments, or two or more flat plate elements of a box meet. It can include a stiffener or not: the point of attachment of a ring stiffener to the shell or box may be treated as a junction.

1.5.12 transition junction: The transition junction is the junction between the barrel and hopper. The junction can be at the base of the barrel or part way down it.

1.5.13 skirt: The skirt is that part of the barrel which lies below the transition junction: it differs from the higher part in that it has no contact with the stored bulk solids.

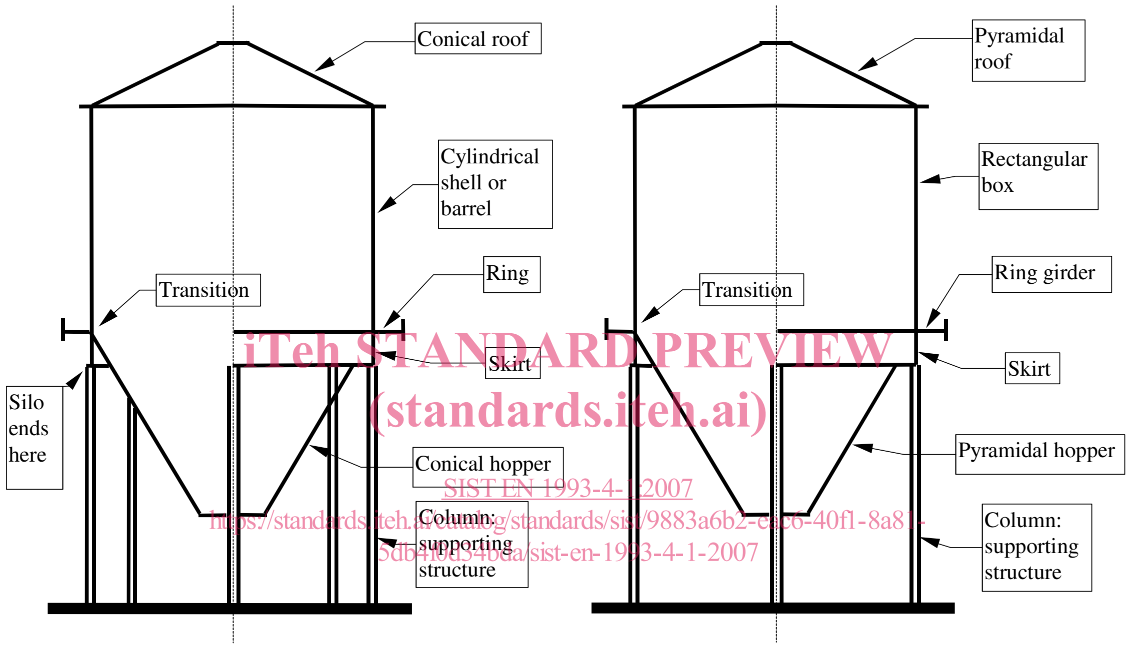
1.5.14 strake: A strake or course is a single layer of steel plates used to form one level of the cylindrical barrel of a silo.

1.5.15 stringer stiffener: A stringer stiffener is a local stiffening member that follows the meridian of a shell, representing a generator of the shell of revolution. It is provided to increase the stability, or to assist with the introduction of local loads or to carry axial loads. It is not intended to provide a primary load carrying capacity for bending due to transverse loads.

1.5.16 rib: A rib is a local member that provides a primary load carrying path for loads causing bending down the meridian of a shell or flat plate, representing a generator of the shell of revolution or a vertical stiffener on a box. It is used to distribute transverse loads on the structure by bending action.

1.5.17 ring stiffener: A ring stiffener is a local stiffening member that passes around the circumference of the structure at a given point on the meridian. It is assumed to have no stiffness in the meridional plane of the structure. It is provided to increase the stability or to introduce local loads, not as a primary load-carrying element. In a shell of revolution it is circular, but in rectangular structures is takes the rectangular form of the plan section.

1.5.18 smeared stiffeners: Stiffeners are said to be smeared when the properties of the shell wall and the individual stiffeners are treated as a composite section using a width equal to an integer multiple of the separation of the stiffeners. The stiffness properties of a shell wall with smeared stiffeners are orthotropic with eccentric terms leading to coupling between bending and stretching behaviour.



a) Circular planform silo **b) Rectangular planform silo**

Figure 1.1: Terminology used in silo structures

1.5.19 base ring: A base ring is a structural member that passes around the circumference of the structure at the base and provides means of attachment of the structure to a foundation or other element. It is required to ensure that the assumed boundary conditions are achieved in practice.

1.5.20 ring girder or ring beam: A ring girder or ring beam is a circumferential stiffener which has bending stiffness and strength both in the plane of the circular section of a shell or the plan section of a rectangular structure and also normal to that plane. It is a primary load-carrying element, used to distribute local loads into the shell or box structure.

1.5.21 continuous support: A continuously supported silo is one in which all positions around the circumference are supported in an identical manner. Minor departures from this condition (e.g. a small opening) need not affect the applicability of the definition.

1.5.22 discrete support: A discrete support is a position in which a silo is supported using a local bracket or column, giving a limited number of narrow supports around the silo circumference. Four or six discrete supports are commonly used, but three or more than six are also found.

1.5.23 pyramidal hopper: A pyramidal hopper is used for the hopper section of a rectangular silo, in the form of an inverted pyramid. In this Standard, it is assumed that the geometry is simple, consisting of only four planar elements of trapezoidal shape.

1.6 Symbols used in Part 4.1 of Eurocode 3

The symbols used are based on ISO 3898: 1987.

1.6.1 Roman upper case letters

A	area of cross-section;
C	membrane stretching stiffness;
C	buckling coefficient;
D	bending flexural rigidity;
E	Young's modulus;
F	force;
G	shear modulus;
H	height of structure;
I	second moment of area of cross-section;
I_t	uniform torsion constant;
K	flexural stiffness of wall panel;
L	height of shell segment or stiffener;
M	bending moment;
N	axial force;
Q	fabrication tolerance quality of construction of a shell susceptible to buckling;
R_ϕ	local radius at the crest or trough of a corrugation.

1.6.2 Roman lower case letters

a	coefficient;
b	width of plate or stiffener;
d	crest to crest dimension of a corrugation;
e	eccentricity of force or stiffener;
f_y	yield strength of steel;
f_u	ultimate strength of steel;
h	separation of flanges of ring girder;
j	joint efficiency factor for welded lap joints assessed using membrane stresses;
j	equivalent harmonic of the design stress variation;
ℓ	effective length of shell in linear stress analysis;
ℓ	wavelength of a corrugation in corrugated sheeting;
ℓ	half wavelength of a potential buckle (height to be considered in calculation);
m	bending moment per unit width;
m_x	meridional bending moment per unit circumference;
m_y	circumferential bending moment per unit height of box;
m_θ	circumferential bending moment per unit height of shell;
m_{xy}	twisting shear moment per unit width of plate;
$m_{x\theta}$	twisting shear moment per unit width of shell;
n	membrane stress resultant;
n	number of discrete supports around silo circumference;
n_x	meridional membrane stress resultant per unit circumference;
n_y	circumferential membrane stress resultant per unit height of box;
n_θ	circumferential membrane stress resultant per unit height of shell;
n_{xy}	membrane shear stress resultant per unit width of plate;
$n_{x\theta}$	membrane shear stress resultant per unit width of shell;

p pressure distributed loading;
p_n pressure normal to shell (outward);
p_x meridional surface loading parallel to shell (downward);
p_θ circumferential surface loading parallel to shell (anticlockwise in plan);
q transverse force per unit length acting on a tie;
r radial coordinate in a circular plan-form silo;
r radius of shell middle surface;
s circumferential separation of stiffeners;
t wall thickness;
t_x, t_y equivalent wall thickness of corrugated sheet for stretching in the x, y directions;
w imperfection amplitude;
w radial deflection;
x local meridional coordinate;
y local circumferential coordinate;
z global axial coordinate;
z coordinate along the vertical axis of an axisymmetric silo (shell of revolution).

1.6.3 Greek letters

α elastic buckling imperfection factor (knock-down factor);
α coefficient of thermal expansion;
β hopper apex half angle;
γ_F partial factor for actions;
γ_M partial factor for resistance;
δ limiting deflection;
Δ increment;
χ reduction factor for flexural column buckling;
χ shell buckling stress reduction factor;
λ shell meridional bending half-wavelength;
$\bar{\lambda}$ relative slenderness of a shell;
μ wall friction coefficient;
ν Poisson's ratio;
θ circumferential coordinate around shell;
σ direct stress;
σ_{bx} meridional bending stress;
σ_{by} circumferential bending stress in box;
$\sigma_{b\theta}$ circumferential bending stress in curved shell;
τ_{bxy} twisting shear stress in box;
$\tau_{bx\theta}$ twisting shear stress in curved shell;
σ_{mx} meridional membrane stress;
σ_{my} circumferential membrane stress in box;
$\sigma_{m\theta}$ circumferential membrane stress in curved shell;
τ_{mxy} membrane shear stress in box;
$\tau_{mx\theta}$ membrane shear stress in curved shell;
σ_{sox} meridional outer surface stress;
σ_{soy} circumferential outer surface stress in box;
$\sigma_{so\theta}$ circumferential outer surface stress in curved shell;
τ_{soxy} outer surface shear stress in box;
$\tau_{sox\theta}$ outer surface shear stress in curved shell;
τ shear stress;
ω dimensionless parameter in buckling calculation;