BS EN 13001-3-6:2018+A1:2021

BSI Standards Publication

Cranes — General design

Part 3-6: Limit states and proof of competence of machinery — Hydraulic cylinders

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Full document details: BS EN 13001-3-6:2018+A1:2021

National foreword

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The UK participation in its preparation was entrusted to Technical Committee MHE/3/1, Crane design.

A list of organizations represented on this committee can be obtained on request to its committee manager.

Users' attention is drawn to the fact that neither BS 2573-1:1983, *Rules for the design of cranes — Part 1: Specification for classification, stress calculations and design criteria for structures*, nor BS 2573-2:1980, *Rules for the design of cranes — Part 2: Specification for classification, stress calculations and design of mechanisms*, should be used in conjunction with the EN 13001 series as they are not complementary. The BS 2573 series will remain current until the UK committee has reviewed all published parts of the BS EN 13001 series and determined whether they provide a coherent package of standards in the UK.

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Appareils de levage à charge suspendue - Conception générale - Partie 3-6 : États limites et vérification d'aptitude des éléments de mécanismes - Vérins hydrauliques

Krane - Konstruktion allgemein - Teil 3-6: Grenzzustände und Sicherheitsnachweis von Maschinenbauteilen - Hydraulikzylinder

This European Standard was approved by CEN on 13 November 2017 and includes Amendment 1 approved by CEN on 9 May 2021.

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European foreword

This document (EN 13001-3-6:2018+2021) has been prepared by Technical Committee CEN/TC 147 “Cranes — Safety”, the secretariat of which is held by DIN.

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of an identical text or by endorsement, at the latest by December 2021, and conflicting national standards shall be withdrawn at the latest by December 2021.

This document includes Amendment 1 approved by CEN on 21 May 2021.

This document supersedes EN 13001-3-6:2018.

The start and finish of text introduced or altered by amendment is indicated in the text by tags A1 A1.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

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For relationship with EU Directive(s), see informative Annex ZA, which is an integral part of this document.

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

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Introduction

This European Standard has been prepared to be a harmonized standard to provide one means for the mechanical design and theoretical verification of cranes to conform with the essential health and safety requirements of the Machinery Directive, as amended. This standard also establishes interfaces between the user (purchaser) and the designer, as well as between the designer and the component manufacturer, in order to form a basis for selecting cranes and components.

This European Standard is a type C standard as stated in EN ISO 12100:2010.

The machinery concerned and the extent to which hazards, hazardous situations and events are covered are indicated in the scope of this standard.

When provisions of this type C standard are different from those which are stated in type A or B standards, the provisions of this type C standard take precedence over the provisions of the other standards, for machines that have been designed and built according to the provisions of this type C standard.

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1 Scope

〈A1〉 This document is to be used together with the other generic parts of EN 13001 series of standards, see Annex E, as well as pertinent crane type product EN standards, and as such they specify general conditions, requirements and methods to, by design and theoretical verification, prevent mechanical hazards of hydraulic cylinders that are part of the load carrying structures of cranes. Hydraulic piping, hoses and connectors used with the cylinders are not within the scope of this document, as well as cylinders made from other material than carbon steel.

NOTE 1 Specific requirements for particular crane types are given in the appropriate European product standards, see Annex E.

The significant hazardous situations and hazardous events that could result in risks to persons during intended use are identified in Annex F. Clauses 4 to 7 of this document provide requirements and methods to reduce or eliminate these risks: 〈A1〉

a) exceeding the limits of strength (yield, ultimate, fatigue);

b) elastic instability (column buckling).

〈A1〉 NOTE 2 〈A1〉 EN 13001–3–6 deals only with the limit state method in accordance with EN 13001–1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

〈A1〉 *deleted text* 〈A1〉

EN 10277-2:2008, *Bright steel products — Technical delivery conditions — Part 2: Steels for general engineering purposes*

〈A1〉 EN 10297-1:2003, *Seamless circular steel tubes for mechanical and general engineering purposes — Technical delivery conditions — Part 1: Non-alloy and alloy steel tubes* 〈A1〉

EN 10305-1:2016, *Steel tubes for precision applications — Technical delivery conditions — Part 1: Seamless cold drawn tubes*

EN 10305-2:2016, *Steel tubes for precision applications — Technical delivery conditions — Part 2: Welded cold drawn tubes*

〈A1〉 EN 13001-1:2015, *Cranes — General design — Part 1: General principles and requirements*

EN 13001-2:2014, *Crane safety — General design — Part 2: Load actions*

EN 13001-3-1:2012+A2:2018, *Cranes — General design — Part 3-1: Limit States and proof competence of steel structure* 〈A1〉

EN ISO 148-1:2016, *Metallic materials — Charpy pendulum impact test — Part 1: Test method (ISO 148-1:2016)*

〈A1〉 EN ISO 683-1:2018, *Heat-treatable steels, alloy steels and free-cutting steels — Part 1: Non-alloy steels for quenching and tempering (ISO 683-1:2016)*

EN ISO 683-2:2018, *Heat-treatable steels, alloy steels and free-cutting steels — Part 2: Alloy steels for quenching and tempering (ISO 683-2:2016)* 〈A1〉

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EN ISO 5817:2014, *Welding — Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) — Quality levels for imperfections (ISO 5817:2014)*

EN ISO 8492:2013, *Metallic materials — Tube — Flattening test (ISO 8492:2013)*

EN ISO 12100:2010, *Safety of machinery — General principles for design — Risk assessment and risk reduction (ISO 12100:2010)*

ISO 724:1993, *ISO general-purpose metric screw threads — Basic dimensions*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 12100:2010 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.2 Symbols an abbreviations

The essential symbols and abbreviations are given in Table 1.

Table 1 — Symbols and abbreviations

Symbols	Description
$A\%$	Percentage elongation at fracture
a	Weld throat thickness
A_i, B_i, C_i, D_i	Constants
A_S	Stress area
D	Piston diameter
d	Rod diameter
$D_{a,i}$	Diameter of axles
D_p	Pressure affected diameter
D_W	Weld diameter
E	Modulus of elasticity
F	Compressive force
F_A	Compressive force
FE	Finite Elements
f_{Rd}	Limit design stress
$f_{Rd\sigma}$	Limit design stress, normal

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Symbols	Description
$f_{Rd\tau}$	Limit design stress, shear
F_S	Lateral force
F_{Sd}	External design force
f_u	Ultimate strength
$f_{w,Rd}$	Limit design weld stress
f_y	Yield strength
h	thickness of the cylinder bottom
I	Moment of inertia, generic
I_1	Moment of inertia of the tube
I_2	Moment of inertia of the rod
L	Overall length of the cylinder
L_1	Length of the cylinder tube
L_2	Length of the cylinder rod
m	Slope of the log $\Delta\sigma$ – log N curve
M_0	Shell section bending moment, acting at the intersection between tube and bottom
MB	Bending moment
N	Compressive force
N_k	Critical buckling load
N_{Rd}	Limit compressive design force
[A1⟩	*deleted text* ⟨A1]
p_{i1}	Maximum pressure in piston side chamber
p_{i2}	Maximum pressure in rod side chamber
p_o	Outer pressure
p_{Sd}	Design pressure
R	Middle radius of the tube ($R = R_i + t/2$)
r_i	Inner radius of the tube
R_i	Inner radius of the tube
r_o	Outer radius of the tube
r_r	Outer radius of the piston rod

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Symbols	Description
s_3	Stress history parameter (see EN 13001–3-1)
t	Wall thickness of the tube
T_0	Shell section transverse force, acting at the intersection between tube and bottom
x, y	Longitudinal and lateral coordinates
α	Angular misalignment, radians
γ_m	General resistance factor (γ_m = 1,1, see EN 13001–2)
γ_{mf}	Fatigue strength specific resistance factor (see EN 13001–3-1)
γ_R	Total resistance factor ($\gamma_R = \gamma_m \cdot \gamma_s$)
γ_s	Specific resistance factor
$\Delta\sigma$	Stress range
$\Delta\sigma_b$	Bending stress range in the tube
$\Delta\sigma_c$	Characteristic fatigue strength
$\Delta\sigma_m$	Membrane stress range in the tube (axial)
$\Delta\sigma_{Rd}$	Limit design stress range
$\Delta\sigma_{Sd}$	Design stress range
Δp_{Sd}	Design pressure range on piston side
δ_{max}	Maximum displacement
κ	Reduction factor for buckling
λ	Slenderness
λ_i	Friction parameters
μ_i	Friction factors
ν	Poisson's ratio (ν = 0,3 for steel)
σ_a	Axial stress in the tube
σ_b	Lower extreme value of a stress range
σ_r	Radial stress in the tube
σ_{Sd}	Design stress, normal
σ_t	Tangential stress in the tube (hoop stress)
σ_u	Upper extreme value of a stress range
$\sigma_{w,Sd}$	Weld design stress, normal

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Symbols	Description
τ_{Sd}	Design stress, shear
$\tau_{w,Sd}$	Weld design stress, shear

3.3 Terminology

Terms which are used in this European Standard for the main parts of hydraulic cylinder are indicated in Figure 1 to Figure 3.

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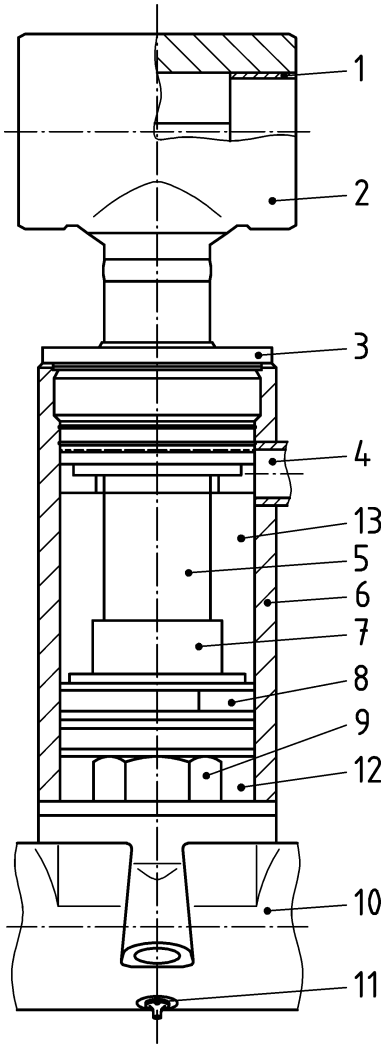

Key

1 bushing
2 rod head
3 cylinder head
4 oil connector
5 piston rod
6 cylinder tube
7 spacer
8 piston
9 nut
10 cylinder bottom
11 grease nipple
12 piston side chamber
13 rod side chamber

Figure 1 — Complete cylinder

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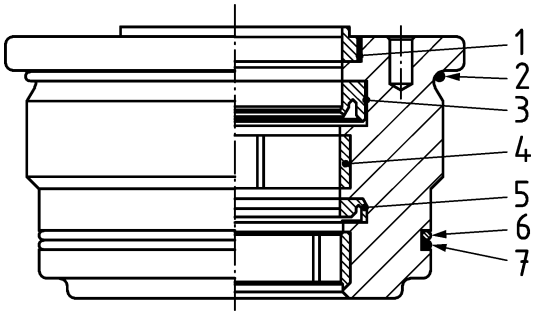
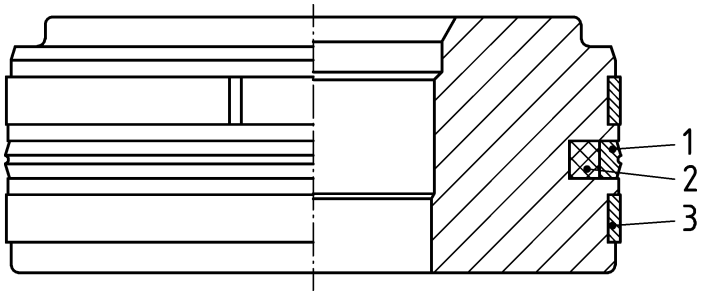


Key

1 wiper
2 O-ring
3 secondary seal
4 guide ring (2 ×)
5 primary seal
6 backup ring
7 O-ring

Figure 2 — Cylinder head



Key

1 seal
2 pressure element
3 guide ring (2 ×)

Figure 3 — Piston

The figures above show some specific design features in order to exemplify the terminology. Other designs may be used.

4 General

4.1 Documentation

The documentation of the proof of competence shall include:

— design assumptions including calculation models;

— applicable loads and load combinations;

— material grades and qualities;

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〈A1〉 — weld quality levels, in accordance with EN ISO 5817:2014 and EN 13001-3-1:2012+A2:2018; 〈A1〉

— relevant limit states;

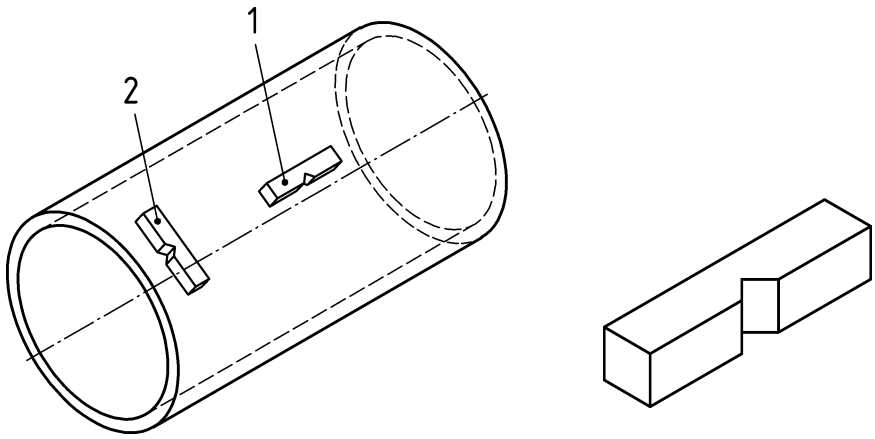
— results of the proof of competence calculation, and tests when applicable.

4.2 Materials for hydraulic cylinders

4.2.1 General requirements

〈A1〉 The materials for cylinder tubes and piston rods shall fulfil the following requirements: 〈A1〉

〈A1〉 — The impact toughness shall be tested in accordance with EN ISO 148-1:2016 and shall meet the requirements stated in EN 13001-3-1:2012+A2:2018. Samples shall be cut out in the longitudinal direction. For cylinder tubes and tubes for pressurized piston rods, samples shall also be cut out in the transversal direction. The samples shall be prepared such that the axis of the notch is perpendicular to the surface of the tube. 〈A1〉



Key

1 sample cut out in longitudinal direction

2 sample cut out in transversal direction

Figure 4 — Sample for impact toughness testing

〈A1〉 — If the material thickness does not allow samples to be cut out in the transversal direction, the tube material shall instead pass a flattening test in accordance with EN ISO 8492:2013. Two flattening tests are required for welded tubes, one with the weld aligned with the press direction and one where the weld is placed 90 degrees from the press direction. The tube section shall be flattened down to a height H given by: 〈A1〉

〈A1〉

$$H = \frac{\left(1 + C\right) \cdot t}{C + \frac{t}{D_o}}$$

〈A1〉

where

〈A1〉 C is a factor that depends on the yield strength of the tube,

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C is 0,07 for $f_y \leq 400$ MPa and C is 0,05 for $f_y > 400$ MPa; A1

D_o is the outer diameter of the tube;

t is the wall thickness of the tube.

A1 Material used in other parts shall meet the requirements stated in EN 13001-3-1:2012+A2:2018. A1

4.2.2 Grades and qualities

A1 European Standards specify materials and specific values. This standard gives a preferred selection. Steels in accordance with the following European Standards shall be used as material for cylinder tubes and piston rods: A1

A1 — EN ISO 683-1:2018;

— EN ISO 683-2:2018;

— EN 10277-2:2008;

— EN 10297-1:2003;

— EN 10305-1:2016;

— EN 10305-2:2016. A1

A1 Alternatively, other steel grades and qualities than those listed in this clause may be used as material for cylinder tubes and piston rods, provided that the following conditions apply: A1

— the design value of f_y is limited to $f_u/1{,}1$ for materials with $f_u/f_y < 1{,}1$;

— the percentage elongation at fracture A % ≥ 14 % on a gauge length $L_0 = 5{,}65 \times \sqrt{S_0}$ (where S_0 is the original cross-sectional area);

A1 Grades and qualities of materials used in other parts of cylinders or mounting interfaces of cylinders shall be selected in accordance with EN 13001-3-1:2012+A2:2018. A1

5 Proof of static strength

5.1 General

A1 A proof of static strength by calculation is intended to prevent excessive deformations due to yielding of the material, elastic instability and fracture of structural members or connections. Dynamic factors given in EN 13001-2:2014 or relevant product standards are used to produce equivalent static loads to simulate dynamic effects. Also, load increasing effects due to deformation shall be considered. The use of the theory of plasticity for calculation of ultimate load bearing capacity is not considered acceptable within the terms of this standard. The proof shall be carried out for structural members and connections while taking into account the most unfavourable load effects from the load combinations A, B or C in accordance with EN 13001-2:2014 or relevant product standards.

Cylinder actions are either active or passive. The action is active when the force from the cylinder exerts a positive work on the crane structure, elsewise the action is passive. As the forces applied to the cylinder by the crane structure are computed in accordance with EN 13001-2:2014, they are already increased by the partial safety factors γ_p and relevant dynamic factors. Formulae (1) and (2) give design pressures p_{Sd} caused by forces acting on the cylinder from the crane structure. In addition, additional

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pressures p_{Sde} caused by internal phenomena in the hydraulic circuit shall be considered and added to the design pressures p_{Sd}. Such internally generated pressures can be caused e.g. by regenerative connections, pressure drop in return lines or cushioning. ⟨A1⟩

In case a cylinder is intended to be tested as a component at higher pressure than the design pressure p_{Sd}, this load case shall also be taken into account in the proof of static strength, and in which case the test pressure shall be multiplied by a partial safety factor γ_p equal to 1,05.

The design pressure p_{Sd} in the piston side chamber or in the rod side chamber shall be computed from the design force F_{Sd} taking into account the force direction and the cylinder efficiency η due to friction. An efficiency factor Ψ is used to handle the effect of cylinder friction. For active cylinders Ψ has the value of $1/\eta$ and for passive cylinders Ψ has the value of η.

For the piston side chamber, the design pressure is given by:

$$p_{Sd} = \frac{4 \cdot F_{Sd}}{\pi \cdot D^2} \cdot \Psi \tag{1}$$

where

F_{Sd} is the external design force;

D is the piston diameter.

Ψ is set to η for passive cylinders and to $1/\eta$ for active cylinders.

For the rod side chamber the design pressure is given by:

$$p_{Sd} = \frac{4 \cdot F_{Sd}}{\pi \cdot \left(D^2 - d^2\right)} \cdot \Psi + p_{Sde} \tag{2}$$

where

F_{Sd} is the external design force;

D is the piston diameter;

d is the rod diameter;

Ψ is set to η for passive cylinders and to $1/\eta$ for active cylinders;

p_{Sde} is additional pressure caused by internal phenomena.

⟨A1⟩ Unless justified information (e.g. obtained by test) for the value of η is used, Ψ shall be assigned the value of 1,1 for active cylinders and the value of 1,0 for passive cylinders. ⟨A1⟩

⟨A1⟩

NOTE The cylinder efficiency η due to friction is assumed to be evaluated at the working pressure. ⟨A1⟩

This standard is based on nominal stresses, i.e. stresses calculated using traditional elastic strength of materials theory which in general neglect localized stress non-uniformities. When more accurate alternative methods of stress calculation are used, such as finite element analysis, using those stresses for the proof given in this standard may yield inordinately conservative results.

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5.2 Limit design stresses

5.2.1 General

The limit design stresses shall be calculated from:

$$\text{Limit desing stresses } f_{Rd} = \text{function}\left(f_k, \gamma_R\right) \tag{3}$$

where

f_k is the characteristic values (or nominal value);

γ_R is the total resistance factor $\gamma_R = \gamma_m \cdot \gamma_s$;

〚A1〛 γ_m is the general resistance factor γ_m = 1,1 (see EN 13001-2:2014); 〈A1〉

γ_s is the specific resistance factor applicable to specific structural components as given in the clauses below.

NOTE f_{Rd} is equivalent to R_d / γ_m in EN 13001–1.

5.2.2 Limit design stress in structural members

The limit design stress f_{Rd}, used for the design of structural members, shall be calculated from:

$$f_{Rd\sigma} = \frac{f_y}{\gamma_{Rm}} \text{ for normal stresses} \tag{4}$$

$$f_{Rd\tau} = \frac{f_y}{\gamma_{Rm} \cdot \sqrt{3}} \text{ for shear stresses} \tag{5}$$

with

$$\gamma_{Rm} = \gamma_m \cdot \gamma_{sm}$$

where

f_y is the minimum value of the yield stress of the material;

γ_{sm} is the specific resistance factor for material.

$\gamma_{sm} = 0,95$ for steels according to standards listed in 4.2.2;

$\gamma_{sm} = 1,0$ for other steels.

〚A1〛 For tensile stresses perpendicular to the plane of rolling (see Figure 5), the material shall be suitable for carrying perpendicular loads and be free of lamellar defects. EN 13001-3-1:2012+A2:2018 specifies the values of γ_{sm} for material loaded perpendicular to the rolling plane. 〈A1〉

Example from cylinder tube bottom, where plate steel is used (eye is welded). The figure shows a tensile load perpendicular to plane of rolling where:

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