

# DIN EN 1999-1-1:2014-03 (E)

## Eurocode 9: Design of aluminium structures - Part 1-1: General structural rules

<b>Contents</b>	<b>Page</b>
Foreword to EN 1999-1-1:2007.....	7
<b>A1</b> Foreword to EN 1999-1-1:2007/A1:2009 .....	7
<b>A2</b> Foreword to EN 1991-1-1:2007/A2:2013 .....	7
<b>1 General .....</b>	<b>11</b>
1.1 Scope .....	11
1.1.1 Scope of EN 1999 .....	11
1.1.2 Scope of EN 1999-1-1 .....	11
1.2 Normative references.....	12
1.2.1 General references .....	12
1.2.2 References on structural design .....	13
1.2.3 References on aluminium alloys.....	13
1.2.4 References on welding.....	15
1.2.5 Other references.....	15
1.3 Assumptions .....	15
1.4 Distinction between principles and application rules .....	16
1.5 Terms and definitions .....	16
1.6 Symbols .....	16
1.7 Conventions for member axes .....	27
1.8 Specification for execution of the work.....	27
<b>2 Basis of design .....</b>	<b>29</b>
2.1 Requirements .....	29
2.1.1 Basic requirements.....	29
2.1.2 Reliability management.....	29
2.1.3 Design working life, durability and robustness .....	29
2.2 Principles of limit state design.....	29
2.3 Basic variables.....	30
2.3.1 Actions and environmental influences.....	30
2.3.2 Material and product properties .....	30
2.4 Verification by the partial factor method.....	30
2.4.1 Design value of material properties.....	30
2.4.2 Design value of geometrical data.....	30
2.4.3 Design resistances.....	30
2.4.4 Verification of static equilibrium (EQU).....	31
2.5 Design assisted by testing.....	31
<b>3 Materials.....</b>	<b>32</b>

<b>3</b>	<b>Materials</b>	<b>32</b>
3.1	General	32
3.2	Structural aluminium	32
3.2.1	Range of materials	32
3.2.2	Material properties for wrought aluminium alloys	33
3.2.3	Material properties for cast aluminium alloys	37
3.2.4	Dimensions, mass and tolerances	38
3.2.5	Design values of material constants	38
3.3	Connecting devices	38
3.3.1	General	38
3.3.2	Bolts, nuts and washers	39
3.3.3	Rivets	41
3.3.4	Welding consumables	41
3.3.5	Adhesives	43
<b>4</b>	<b>Durability</b>	<b>43</b>
<b>5</b>	<b>Structural analysis</b>	<b>44</b>
5.1	Structural modelling for analysis	44
5.1.1	Structural modelling and basic assumptions	44
5.1.2	Joint modelling	44
5.1.3	Ground-structure interaction	44
5.2	Global analysis	44
5.2.1	Effects of deformed geometry of the structure	44
5.2.2	Structural stability of frames	45
5.3	Imperfections	46
5.3.1	Basis	46
5.3.2	Imperfections for global analysis of frames	46
5.3.3	Imperfection for analysis of bracing systems	51
5.3.4	Member imperfections	53
5.4	Methods of analysis	53
5.4.1	General	53
5.4.2	Elastic global analysis	53
5.4.3	Plastic global analysis	53
<b>6</b>	<b>Ultimate limit states for members</b>	<b>54</b>
6.1	Basis	54
6.1.1	General	54
6.1.2	Characteristic value of strength	54
6.1.3	Partial safety factors	54
6.1.4	Classification of cross-sections	54
6.1.5	Local buckling resistance	60
6.1.6	HAZ softening adjacent to welds	61
6.2	Resistance of cross-sections	64
6.2.1	General	64
6.2.2	Section properties	64
6.2.3	Tension	66
6.2.4	Compression	66
6.2.5	Bending moment	67
6.2.6	Shear	69
6.2.7	Torsion	70
6.2.8	Bending and shear	72
6.2.9	Bending and axial force	72
6.2.10	Bending, shear and axial force	74
6.2.11	Web bearing	74
6.3	Buckling resistance of members	74
6.3.1	Members in compression	74
6.3.2	Members in bending	79
6.3.3	Members in bending and axial compression	81

6.4	Uniform built-up members .....	85
6.4.1	General .....	85
6.4.2	Laced compression members .....	87
6.4.3	Battened compression members .....	89
6.4.4	Closely spaced built-up members .....	90
6.5	Un-stiffened plates under in-plane loading .....	91
6.5.1	General .....	91
6.5.2	Resistance under uniform compression .....	91
6.5.3	Resistance under in-plane moment .....	92
6.5.4	Resistance under transverse or longitudinal stress gradient .....	93
6.5.5	Resistance under shear .....	93
6.5.6	Resistance under combined action .....	94
6.6	Stiffened plates under in-plane loading .....	95
6.6.1	General .....	95
6.6.2	Stiffened plates under uniform compression .....	96
6.6.3	Stiffened plates under in-plane moment .....	98
6.6.4	Longitudinal stress gradient on multi-stiffened plates .....	99
6.6.5	Multi-stiffened plating in shear .....	99
6.6.6	Buckling load for orthotropic plates .....	99
6.7	Plate girders .....	102
6.7.1	General .....	102
6.7.2	Resistance of girders under in-plane bending .....	102
6.7.3	Resistance of girders with longitudinal web stiffeners .....	103
6.7.4	Resistance to shear .....	105
6.7.5	Resistance to transverse loads .....	109
6.7.6	Interaction .....	112
6.7.7	Flange induced buckling .....	113
6.7.8	Web stiffeners .....	114
6.8	Members with corrugated webs .....	115
6.8.1	Bending moment resistance .....	115
6.8.2	Shear force resistance .....	116
<b>7</b>	<b>Serviceability Limit States .....</b>	<b>118</b>
7.1	General .....	118
7.2	Serviceability limit states for buildings .....	118
7.2.1	Vertical deflections .....	118
7.2.2	Horizontal deflections .....	118
7.2.3	Dynamic effects .....	118
7.2.4	Calculation of elastic deflection .....	118
<b>8</b>	<b>Design of joints .....</b>	<b>120</b>
8.1	Basis of design .....	120
8.1.1	Introduction .....	120
8.1.2	Applied forces and moments .....	120
8.1.3	Resistance of joints .....	120
8.1.4	Design assumptions .....	121
8.1.5	Fabrication and execution .....	121
8.2	Intersections for bolted, riveted and welded joints .....	121
8.3	Joints loaded in shear subject to impact, vibration and/or load reversal .....	122
8.4	Classification of joints .....	122

8.5	Connections made with bolts, rivets and pins.....	122
8.5.1	Positioning of holes for bolts and rivets .....	122
8.5.2	Deductions for fastener holes .....	125
8.5.3	Categories of bolted connections.....	127
8.5.4	Distribution of forces between fasteners .....	129
8.5.5	Design resistances of bolts.....	130
8.5.6	Design resistance of rivets .....	132
8.5.7	Countersunk bolts and rivets .....	133
8.5.8	Hollow rivets and rivets with mandrel.....	133
8.5.9	High strength bolts in slip-resistant connections .....	133
8.5.10	Prying forces.....	135
8.5.11	Long joints.....	136
8.5.12	<b>A<sub>2</sub></b> Single lap joints <b>A<sub>2</sub></b> .....	136
8.5.13	Fasteners through packings.....	136
8.5.14	Pin connections.....	137
8.6	Welded connections.....	140
8.6.1	General.....	140
8.6.2	Heat-affected zone (HAZ) .....	140
8.6.3	Design of welded connections .....	140
8.7	Hybrid connections.....	148
8.8	Adhesive bonded connections .....	148
8.9	Other joining methods .....	148
<b>A<sub>1</sub></b>	<b>Annex A [informative] – Reliability differentiation .....</b>	<b>149</b>
A.1	Introduction .....	149
A.2	Design provisions for reliability differentiation - Design supervision levels.....	149
A.3	Execution provisions for reliability differentiation – Execution classes .....	149
A.4	Governing factors for choice of execution class .....	149
A.5	Determination of execution class .....	150
A.6	Utilization grades .....	150
	<b>Annex B [normative] - Equivalent T-stub in tension .....</b>	<b>152</b>
B.1	General rules for evaluation of resistance.....	152
B.2	Individual bolt-row, bolt-groups and groups of bolt-rows.....	156
	<b>Annex C [informative] - Materials selection .....</b>	<b>158</b>
C.1	General .....	158
C.2	Wrought products .....	158
C.2.1	Wrought heat treatable alloys.....	158
C.2.2	Wrought non-heat treatable alloys.....	161
C.3	Cast products .....	162
C.3.1	General .....	162
C.3.2	Heat treatable casting alloys EN AC-42100, EN AC-42200, EN AC-43000 and EN AC-43300.....	162
C.3.3	Non-heat treatable casting alloys EN AC-44200 and EN AC-51300.....	162
C.3.4	Special design rules for castings.....	162
C.4	Connecting devices.....	164
C.4.1	Aluminium bolts.....	164
C.4.2	Aluminium rivets.....	164
	<b>Annex D [informative] – Corrosion and surface protection.....</b>	<b>165</b>
D.1	Corrosion of aluminium under various exposure conditions.....	165
D.2	Durability ratings of aluminium alloys.....	165
D.3	Corrosion protection.....	166
D.3.1	General .....	166
D.3.2	Overall corrosion protection of structural aluminium .....	166
D.3.3	Aluminium in contact with aluminium and other metals .....	167
D.3.4	Aluminium surfaces in contact with non-metallic materials .....	167

<b>Annex E [informative] - Analytical models for stress strain relationship</b> .....	<b>172</b>
E.1 Scope .....	172
E.2 Analytical models.....	172
E.2.1 Piecewise linear models .....	172
E.2.2 Continuous models.....	174
E.3 Approximate evaluation of $\varepsilon_u$ .....	178
<b>Annex F [informative] - Behaviour of cross-sections beyond the elastic limit</b> .....	<b>179</b>
F.1 General .....	179
F.2 Definition of cross-section limit states .....	179
F.3 Classification of cross-sections according to limit states .....	179
F.4 Evaluation of ultimate axial load.....	180
F.5 Evaluation of ultimate bending moment .....	181
<b>Annex G [informative] - Rotation capacity</b> .....	<b>183</b>
<b>Annex H [informative] - Plastic hinge method for continuous beams</b> .....	<b>185</b>
<b>Annex I [informative] - Lateral torsional buckling of beams and torsional or torsional-flexural buckling of compressed members</b> .....	<b>188</b>
I.1 Elastic critical moment and slenderness .....	188
I.1.1 Basis.....	188
I.1.2 General formula for beams with uniform cross-sections symmetrical about the minor or major axis .....	188
I.1.3 Beams with uniform cross-sections symmetrical about major axis, centrally symmetric and doubly symmetric cross-sections.....	193
I.1.4 Cantilevers with uniform cross-sections symmetrical about the minor axis .....	194
I.2 Slenderness for lateral torsional buckling.....	196
I.3 Elastic critical axial force for torsional and torsional-flexural buckling .....	198
I.4 Slenderness for torsional and torsional-flexural buckling .....	199
<b>Annex J [informative] - Properties of cross sections</b> .....	<b>204</b>
J.1 Torsion constant $I_t$ .....	204
J.2 Position of shear centre S .....	204
J.3 Warping constant $I_w$ .....	204
J.4 Cross section constants for open thin-walled cross sections .....	208
J.5 Cross section constants for open cross section with branches.....	210
J.6 Torsion constant <del><math>I_{A2}</math></del> Deleted text <del><math>A_2</math></del> of cross section with closed part .....	210
<b>Annex K [informative] - Shear lag effects in member design</b> .....	<b>212</b>
K.1 General.....	212
K.2 Effective width for elastic shear lag .....	212
K.2.1 Effective width factor for shear lag .....	212
K.2.2 Stress distribution for shear lag .....	213
K.2.3 In-plane load effects .....	214
K.3 Shear lag at ultimate limit states .....	215
<b>Annex L [informative] - Classification of joints</b> .....	<b>216</b>
L.1 General.....	216
L.2 Fully restoring connections.....	217
L.3 Partially restoring connections .....	217
L.4 Classification according to rigidity.....	217
L.5 Classification according to strength.....	218
L.6 Classification according to ductility .....	218
L.7 General design requirements for connections.....	218
L.8 Requirements for framing connections.....	218
L.8.1 General.....	218
L.8.2 Nominally pinned connections .....	219
L.8.3 Built-in connections.....	220

**Annex M [informative] - Adhesive bonded connections ..... 221**

- M.1 General ..... 221
- M.2 Adhesives ..... 221
- M.3 Design of adhesive bonded joints ..... 222
  - M.3.1 General ..... 222
  - M.3.2 Characteristic strength of adhesives ..... 223
  - M.3.3 Design shear stress ..... 223
- M.4 Tests ..... 223

**▣ Bibliography ..... 224**