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Petroleum and natural gas industries — Design and operating limits of drill strings with aluminium alloy components

Industries du pétrole et du gaz naturel — Conception et limites de fonctionnement des garnitures de forage en alliage d'aluminium

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Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 20312 was prepared by Technical Committee ISO/TC 67, *Materials, equipment and offshore structures for petroleum, petrochemical and natural gas industries*.

Introduction

The function of this International Standard is to define operating limits of aluminium drill pipes and recommend design criteria for the drill stem containing such aluminium drill pipes. This International Standard contains formulas and figures to aid in the design and selection of equipment to meet a specific drilling condition.

In this International Standard, data are expressed in the International System of units (SI).

Users of this International Standard need to be aware that further or differing requirements could be needed for individual applications. This International Standard is not intended to inhibit a manufacturer from offering, or the purchaser from accepting, alternative equipment or engineering solutions for the individual application, particularly where there is innovative or developing technology. Where an alternative is offered, the manufacturer will need to identify any variations from this International Standard and provide details.

This International Standard includes provisions of various nature. These are identified by the use of certain verbal forms:

— “shall” is used to indicate that a provision is mandatory;

— “should” is used to indicate that a provision is not mandatory, but recommended as good practice;

— “may” is used to indicate that a provision is optional.

Petroleum and natural gas industries — Design and operating limits of drill strings with aluminium alloy components

1 Scope

This International Standard applies to design and operating limits for drill strings containing aluminium alloy pipes manufactured in accordance with ISO 15546.

2 Normative references

The following referenced documents are indispensable for the application 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.

ISO 9712, *Non-destructive testing — Qualification and certification of personnel*

ISO 15546, *Petroleum and natural gas industries — Aluminium alloy drill pipe*

ASNT Recommended Practice No. SNT-TC-1A, *Personnel Qualification and Certification in Non-destructive Testing*

3 Terms, definitions, symbols and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1.1
aluminium alloy pipe body
aluminium alloy pipe formed by extrusion, including upsets and protector thickening

3.1.2
aluminium alloy drill pipe
aluminium alloy pipe body with threaded steel tool joints

3.1.3
box
tool joint part that has internal tool-joint thread

3.1.4
buckling
unstable lateral deflection of a drill stem component under compressive effective axial force

3.1.5
corrosion
adverse chemical alteration or destruction of a metal by air, moisture or chemicals

3.1.6
critical buckling load
load level associated with initiation of drill stem components buckling

3.1.7
dogleg
sharp change of direction in a well bore

3.1.8
dogleg severity
measure of the amount of change in the inclination and/or direction of a borehole, usually expressed in degrees per 30 m interval

3.1.9
drill string
complete assembly from the swivel or top drive to the drill bit, which can contain the kelly, drill pipes, subs, drill collars and other bottom hole assembly (BHA) members, such as stabilizers, reamers and junk baskets

3.1.10
effective axial force
force created by adverse combinations of axial load and pressure

3.1.11
helical buckling
buckling in which drill stem components form a helix or spiral shape

3.1.12
manufacturer
firm, company or corporation responsible for marking the product

NOTE Marking by the manufacturer warrants that the product conforms to this International Standard, and it is the manufacturer who is responsible for compliance with all of its applicable provisions.

3.1.13
new class pipe
wear-based classification of pipe not having been put in service

3.1.14
pin
tool joint part that has external tool-joint thread

3.1.15
premium class, class 2 pipe
wear-based classification of pipe worn to an extent listed in Tables 12 and 13

3.1.16
sinusoidal buckling
buckling of drill stem components in a sinusoidal shape

3.1.17
slip area
area within a small distance along the pipe body from the box end, clamped by the pipe slips during the pulling and running operations

3.1.18
tool joint
steel tool joint element for drill pipes consisting of two parts (pin and box)

3.1.19
TT type thread
trapezoidal-shaped thread connecting aluminium pipe body and steel joint

NOTE See ISO 15546.

3.2 Symbols

A factor depending on the failure theory selected for calculations and adjusted for anisotropy of drill pipe material

A_b box cross-sectional area at 9,525 mm from the bearing face

A_{dp} drill pipe cross-sectional area

A_{OD} cross-sectional area circumscribed by pipe outside diameter

A_p pin cross-sectional area at 15,875 mm from the bearing face

A_{pb} cross-sectional area of pin A_p or box A_b, whichever is smaller

A_z cross-sectional area of drill pipe in upset part

a_e coefficient of linear expansion of material

a_w cross-sectional area of pipe wall with regard to pipe ovality

B variable

b strain reduction factor

C pitch diameter of thread at gauge point

c area coverage coefficient

D_{dp} pipe body outside diameter

D_h average diameter of the borehole at the regarded interval

D_{max} maximum outside diameter of pipe

D_{min} minimum outside diameter

D_{pt} protector outside diameter

D_{tj} tool joint outside diameter

D_U outside diameter of drill pipe in upset part

$\overline{D}$ conventional outside diameter of drilling pipe with tool joint

d_{dp} pipe body inside diameter

d_p pin inside diameter

E modulus of elasticity or Young's modulus

F variable

f friction factor

g acceleration of gravity, 9,81m/s^2

H thread height not truncated

H_{dm} drilling mud depth

h fluid depth

h_{DS} drilling string setting depth

h_K well depth at the upper limit of drill string section

h_{K-1} well depth at the lower limit of drill string section

I moment of inertia of the pipe body in regard to transverse axis (at bending)

J drill pipe moment of inertia with respect to its diameter

K transverse load factor

k plastic-to-elastic-collapse ratio

L strength-to-weight ratio

$L_{1/2}$ half the distance between tool joints

L_{Al} strength-to-weight ratio of aluminium

L_{dp} pipe length with tool joint (the distance between the tool joint box face and the pin shoulder)

L_{pc} length of the pin that mates with the box

L_s length of slip contact with drill pipe

L_{St} strength-to-weight ratio of steel

l_K length of section "K"

M_B mass per unit length of plain end pipe body

M_{dp} mass per unit length of drill pipe

M_K mass per unit length of drill pipe in drill string section "K"

m_b mass of plain end pipe body

m_p mass gain due to protector thickening

m_{tj} tool joint mass

m_u mass gain due to upsets

n number of the drill string sections

O_i initial ovality

P load applied to the drill string

P_0 collapse pressure

P_c minimum collapse pressure for imperfect pipe

P_e elastic bending pressure

P_{ext} net external pressure

P_{hel} helical buckling force

P_i internal pressure

$P_{i\,y}$ internal yield pressure

P_K tensile stress applied to the bottom cross-section

P_{max} maximum tension yield strength of drill pipe body

P_{sin} sinusoidal buckling force

P_T effective tensile load on tubular

P_y yield pressure with simultaneous tension

P_z axis load when the stress in the body of the pipe chucked in the slips reaches yield strength

p lead of thread

Q_c box counter bore

R dogleg severity radius at the beginning and the end of the build or drop interval

R_s variable

R_t variable

S_a mean axial stress

S_b maximum permissible bending stress

S_{DL} stress produced by the buoyant weight of the drill string below dogleg

S_{rs} root truncation

s bending strain experienced by tubular

s_0 critical bending strain

T torque applied to the drill string

T_j recommended make up torque for the aluminium drill pipes tool joints

T_{max} maximum torsional yield strength of drill pipe body

T_y torsional yield limit in connection

t_{dp} wall thickness

t_0 operational temperature

t_u wall thickness of drill pipe in upset part

W_p polar sectional modulus of torsion of pipe body

w_0 weight per unit length of pipe in air

w_{DL} buoyant weight of drill string section suspended below the dogleg

w_m weight per unit length of pipe in mud

Y_{min} minimum yield strength of material

α zenith angle of the borehole interval

α_0 minimum zenith angle of the borehole

α_H zenith angle at the beginning of the build or drop interval

α_K zenith angle at the end of the build or drop interval

α_{SL} slips taper angle

$\bar{\alpha}$ average zenith angle of the borehole at build or drop interval

Δ taper

ΔL overall elongation of combined drill string

Δl_{BHA} elongation under the weight of the downhole sections and BHA

Δl_t thermal elongation

Δl_w elongation of the relevant drill string section “K” under its own weight load

δ gap between borehole wall and the average outside diameter of drilling pipe

η temperature gradient

Θ dogleg severity

θ half angle of thread

μ Poisson's ratio

μ_{SL} coefficient of friction between slips and master bushing

π constant, π = 3,141 812

ρ_{Al} density of aluminium, 2 800 kg/m^3

ρ_{dm} drilling mud density

ρ_e equivalent density

ρ_{St} density of steel, 7 850 kg/m^3

σ level of normal stresses applied to the design sections of drill string

σ_{-1} fatigue limit of the drill pipe

σ_b pipe material ultimate strength

σ_e equivalent stress

σ_i allowable stress intensity calculated as adjusted to the normative safety factors

σ_r reduced yield stress

τ level of tangential stresses applied to the drill string

τ_{min} shear stress, reaching minimum yield strength

φ out-of-roundness function

ψ imperfection function

ψ_{SL} friction angle

3.3 Abbreviated terms

ADP aluminium alloy drill pipe

BHA bottom hole assembly

EU external upset

HWADP heavy wall aluminium drill pipe

HWSDP heavy weight steel drill pipe

HWDP heavy wall drill pipe

ID inside diameter

IU internal upset

OD outside diameter

ROP rate of penetration

RPM revolutions per minute

SDP steel drill pipe

TJ tool joint

WOB weight on bit

4 Properties of ADP and tool joints

4.1 General

Dimensional and mechanical properties of new ADP and tool joints shall be as specified in ISO 15546. The pipes may be with external or internal upset ends, and with protector thickening. Separate tables of the chapter include the data on the drill pipe torsional strength, tensile strength, and resistance against internal and external pressure.

4.2 New pipes and tool joints data

The new pipes and tool joint data properties are given in Tables 1 and 2.

4.3 Buoyant weight

The ADP buoyant weight of different length groups in the fluids of different density could be calculated by Equation (B.5). The equivalent density of new pipes is given in Tables 1 and 2. For mass calculation purposes, the assumed aluminium alloy density in Tables 1, 2, 5, 6 and 7 is 2 800 kg/m^3, and the steel density is 7 850 kg/m^3. If alloys of other density are used, a correcting factor shall be applied.

EXAMPLE

Objective: Calculate the weight of 1 m of ADP 147 × 11; 11,8 m long; with internal upset ends; with protector thickening in drilling mud with gravity 1 200 kg/m^3.

Solution: According to Table 2, the mass of 1 m of this pipe is 21,45 kg, equivalent density is 3 271 kg/m^3.

The weight in mud will be as follows:

$$w_{\text{m}} = 21{,}45 \times 9{,}81 \times \left(1 - \frac{1\,200}{3\,271}\right) = 133{,}2 \text{ N/m}$$

4.4 Mechanical properties

The mechanical properties of new pipe (tensional yield strength, torsional yield strength, internal yield and collapse pressure values) are given in Table 3. The properties correspond to the temperature of 20 °C. The "weak section" for the calculations was assumed to be the aluminium drill pipe body.

The mechanical properties of the premium class pipe are given in Table 4.

The mechanical properties of class 2 pipe are given in Table 5.

The wear classification of ADP is based on 8.3 and Table 12.

Mechanical properties of aluminium drill pipe bodies can be affected by exposure at elevated temperature (see 5.3).

Table 1 — Dimensional and mass properties of new drill pipe with external upset ends

Outside diameter, mm	Wall thickness, mm	Plain pipe mass per 1 linear metre, kg/m	Mass gain due to upset, kg	Mass gain due to protector thickening, kg		Tool joint			Tool joint mass, kg	Mass per linear metre including all upsets, protector thickening, and tool joint[a], kg/m			Equivalent density of pipe with tool joints[b], kg/m³		
				Range		OD, mm	Minimum ID, mm	Thread		Length range[c]			Length range[c]		
				2	3					1	2	3	1	2	3
90	8	5,77	4,00	—	—	118	68	NC 38	19,5	9,56	8,26	7,76	3 552	3 336	3 244
114	10	9,15	7,77	—	—	155	95	NC 50	38,6	16,63	14,06	13,08	3 688	3 444	3 337
129	9	9,50	21,97	—	—	172	112	5 1/2 FH	46,0	20,46	16,69	15,26	3 652	3 447	3 351
				9,57	13,99					—	17,71	16,45	—	3 402	3 318
131	13	13,49	22,32	—	—	178	105	5 1/2 FH	46,0	24,51	20,72	19,28	3 477	3 298	3 219
				17,29	25,27					—	22,55	21,43	—	3 251	3 185
133	11	11,80	17,10	—	—	172	112	5 1/2 FH	46,0	21,98	18,48	17,15	3 577	3 371	3 279
				13,37	19,53					—	19,90	18,81	—	3 323	3 245
140	13	14,52	9,72	—	—	172	112	5 1/2 FH	46,0	23,51	20,42	19,25	3 513	3 307	3 220
				20,51	29,98					—	22,59	21,79	—	3 251	3 180
147	11	13,16	29,26	—	—	195	124	6 5/8 FH	65,2	28,40	23,16	21,16	3 676	3 464	3 365
				10,37	15,15					—	24,25	22,45	—	3 427	3 338
151	13	15,78	23,69	—	—	195	124	6 5/8 FH	65,2	30,12	25,19	23,31	3 611	3 399	3 304
				28,54	41,72					—	28,21	26,85	—	3 323	3 249
155	15	18,47	18,02	—	—	195	124	6 5/8 FH	65,2	31,90	27,28	25,53	3 554	3 344	3 253
				22,80	33,32					—	29,69	28,35	—	3 292	3 216
164	9	12,27	31,69	—	—	203	124	6 5/8 FH	66,5	28,11	22,66	20,59	3 711	3 499	3 398
				19,39	28,34					—	24,71	22,99	—	3 428	3 345
168	11	15,19	25,51	—	—	203	124	6 5/8 FH	66,5	30,03	24,93	22,99	3 635	3 421	3 324
				15,89	23,23					—	26,61	24,96	—	3 374	3 290

[a] Value is calculated by Equation (B.3).

[b] Value is calculated by Equation (B.4).

[c] ADP length ranges are defined by ISO 15546.

Table 2 — Dimensional and mass properties of new drill pipe with internal upset ends

Outside diameter, mm	**Wall thickness**, mm	**Plain pipe mass per 1 linear metre**, kg/m	**Mass gain due to upset**, kg	**Mass gain due to protector thickening**, kg		**Tool joint**			**Tool joint mass**, kg	**Mass per linear metre including all upsets, protector thickening, and tool joint**[a], kg/m			**Equivalent density of pipe with tool joints**[b], kg/m^3		
				Length range		**OD**, mm	**Minimum ID**, mm	**Thread**		**Length range**[c]			**Length range**[c]		
				2	**3**					**1**	**2**	**3**	**1**	**2**	**3**
64	8	3,94	0,76	—	—	80	34	NC23	9,5	5,60	5,03	4,81	3 399	3 213	3 138
73	9	5,07	1,55	—	—	95	44	NC26	14,5	7,66	6,77	6,43	3 485	3 278	3 193
				6,90	10,09					—	7,50	7,28	—	3 225	3 156
90	9	6,41	2,05	—	—	108	54	NC31	16,5	9,40	8,38	7,98	3 423	3 234	3 155
				8,36	12,22					—	9,26	9,02	—	3 187	3 123
90	9	6,41	2,05	—	—	120,6	56	NC38	16,5	9,40	8,38	7,98	3 423	3 234	3 155
				8,36	12,22					—	9,26	9,02	—	3 187	3 123
103	9	7,44	5,83	—	—	120,6	68	NC38	21,0	11,77	10,28	9,72	3 436	3 252	3 174
				9,48	13,85					—	11,28	10,89	—	3 206	3 142
103	9	7,44	5,83	—	—	127	68	NC38	25,0	12,41	10,70	10,05	3 540	3 329	3 239
				9,48	13,85					—	11,71	11,23	—	3 276	3 202
114	10	9,15	7,34	—	—	145	82	NC44	34,9	15,96	13,62	12,73	3 622	3 392	3 292
				18,88	27,59					—	15,62	15,07	—	3 302	3 229
114	11	9,97	6,92	—	—	152	80	NC46	41,0	17,70	15,04	14,03	3 686	3 438	3 331
				18,88	27,59					—	17,04	16,37	—	3 349	3 267
129	9	9,50	11,58	—	—	162	93	NC50	43,5	18,38	15,33	14,17	3 711	3 470	3 363
				16,75	24,48					—	17,10	16,24	—	3 386	3 302
129	11	11,42	11,07	—	—	162	93	NC50	43,5	20,22	17,19	16,04	3 605	3 383	3 286
				16,75	24,48					—	18,96	18,12	—	3 318	3 240
147	11	13,16	10,17	—	—	178	105	5 1/2 FH	54,3	23,56	19,98	18,62	3 680	3 436	3 329
				22,80	33,32					—	22,39	21,45	—	3 354	3 271
147	13	15,32	11,52	—	—	178	105	5 1/2 FH	54,3	25,94	22,29	20,90	3 577	3 357	3 262
				22,80	33,32					—	24,70	23,73	—	3 293	3 217
147	15	17,42	11,07	—	—	178	105	5 1/2 FH	54,3	27,96	24,33	22,96	3 507	3 302	3 215
168	11	15,19	17,80	—	—	203	127	6 5/8 FH	71,5	29,59	24,64	22,76	3 737	3 489	3 379
				30,26	44,23					—	27,84	26,51	—	3 393	3 309
168	13	17,72	16,26	—	—	203	127	6 5/8 FH	71,5	31,88	27,01	25,16	3 649	3 415	3 313
				30,26	44,23					—	30,21	28,91	—	3 338	3 258

[a] Value is calculated by Equation (B.3).

[b] Value is calculated by Equation (B.4).

[c] ADP length ranges are defined by ISO 15546.

4.5 ADP with integral tool joint and heavy wall ADP

ISO 15546 does not cover the ADP with integral tool joint and heavy wall ADP, which are manufactured in the assembled condition with steel tool joints (see Figures A.1 and A.2). Their technical properties are given in Annex A. ADP with integral rotary shouldered connections are used as technological sets in the intervals where the danger of drill string sticking exists. Heavy wall ADP are widely used in BHA to ensure smooth stiffness transition from drill collars to ADP or as diamagnetic pipe to perform directional survey inside the drill string when drilling directional or vertical wells.

Table 3 — Mechanical properties of new pipe

Nominal outside diameter, mm	Nominal wall thickness, mm	Upset type	Connection			TJ torsional yield strength[f], kN·m	Tension yield strength[a], kN				Torsional yield strength[b], kN·m				Internal yield pressure[c], MPa				Collapse pressure[d], MPa			
			TJ thread type	TJ OD, mm	TJ pin ID, mm		Material group[e]				Material group[e]				Material group[e]				Material group[e]			
							I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
64	8	**IU**	NC 23	80	34	8,2	457	675	478	492	5,2	7,7	5,5	5,6	81,3	120,0	85,0	87,5	72,9	104,4	76,1	78,2
73	9	**IU**	NC 26	95	44	10,0	588	868	615	633	7,7	11,4	8,1	8,3	80,1	118,4	83,8	86,3	71,7	102,5	74,8	76,9
90	8	EU	NC 38	118	68	21,8	669	989	700	721	11,6	17,1	12,1	12,5	57,8	85,3	60,4	62,2	46,9	63,0	48,7	49,8
90	9	**IU**	NC 31	108	54	16,1	744	1 099	778	801	12,6	18,6	13,2	13,5	65,0	96,0	68,0	70,0	55,2	76,3	57,4	58,9
		IU	NC 38	120,6	58	25,8																
103	9	**IU**	NC 38	120,6	68	24,7	863	1 275	903	930	17,1	25,3	17,9	18,4	56,8	83,9	59,4	61,2	45,7	61,2	47,4	48,5
		IU	NC 38	127	68	25,0																
114	10	**IU**	NC 44	145	82	35,7	1061	1 567	1 110	1 143	23,3	34,4	24,3	25,1	57,0	84,2	59,6	61,4	46,0	61,6	47,7	48,8
		EU	NC 50	155	95	49,9																
114	11	**IU**	NC46	152	80	48,5	1 156	1 708	1 210	1 245	24,9	36,8	26,1	26,8	62,7	92,6	65,6	67,5	52,6	72,1	54,7	56,0
129	9	EU	5 1/2 FH	172	112	55,4	1 102	1 628	1 153	1 187	28,3	41,8	29,6	30,5	45,3	67,0	47,4	48,8	31,8	39,6	32,7	33,3
129	11	**IU**	NC 50	162	95	51,3	1 325	1 956	1 386	1 427	33,0	48,8	34,6	35,6	55,4	81,9	58,0	59,7	44,1	58,6	45,7	46,8
131	13	EU	5 1/2 FH	178	105	69,4	1 565	2 312	1 638	1 686	38,6	57,0	40,3	41,5	64,5	95,3	67,5	69,5	54,6	75,4	56,8	58,3
133	11	EU	5 1/2 FH	172	112	55,4	1 370	2 023	1 433	1 475	35,4	52,3	37,0	38,1	53,8	79,4	56,2	57,9	42,1	55,5	43,6	44,6
140	13	EU	5 1/2 FH	172	112	55,4	1 685	2 488	1 763	1 814	44,9	66,3	47,0	48,4	60,4	89,1	63,1	65,0	49,9	67,8	51,8	53,1
147	11	**IU**	5 1/2 FH	178	105	69,4	1 527	2 255	1 597	1 644	44,3	65,4	46,3	47,7	48,6	71,8	50,9	52,4	35,9	45,8	37,1	37,8
		EU	6 5/8 FH	195	124	84,5																
147	13	**IU**	5 1/2 FH	178	105	69,4	1 778	2 626	1 860	1 914	50,2	74,1	52,5	54,1	57,5	84,9	60,1	61,9	46,5	62,5	48,3	49,4
147	15	**IU**	5 1/2 FH	178	105	69,4	2 021	2 984	2 114	2 176	55,6	82,1	58,1	59,8	66,3	98,0	69,4	71,4	56,7	78,7	59,0	60,5
151	13	EU	6 5/8 FH	195	124	84,5	1 831	2 704	1 915	1 972	53,3	78,8	55,8	57,5	56,0	82,6	58,5	60,3	44,8	59,6	46,4	47,5
155	15	EU	6 5/8 FH	195	124	84,5	2 143	3 165	2 242	2 308	62,8	92,7	65,7	67,6	62,9	92,9	65,8	67,7	52,8	72,5	54,9	56,3
164	9	EU	6 5/8 FH	203	124	107,2	1 424	2 103	1 489	1 533	47,9	70,8	50,1	51,6	35,7	52,7	37,3	38,4	19,7	22,6	20,1	20,3
168	11	EU	6 5/8 FH	203	124	107,2	1 762	2 603	1 844	1 898	59,5	87,9	62,3	64,1	42,6	62,9	44,5	45,8	28,3	34,4	29,1	29,6
		IU	6 5/8 FH	203	127	99,5																
168	13	**IU**	6 5/8 FH	203	127	99,5	2 056	3 037	2 151	2 214	67,8	100,2	70,9	73,0	50,3	74,3	52,6	54,2	37,9	48,9	39,2	40,0

a Value is calculated by Equation (B.6).

b Value is calculated by Equation (B.7).

c Value is calculated by Equation (B.8).

d Value is calculated by Equation (B.9).

e Material groups are as defined in ISO 15546.

f Calculated values are based on Equation (B.15), yield strength of the material and dimensions of tool joint connection as defined in ISO 15546.

Table 4 — Mechanical properties of premium class pipe[a]

Nominal outside diameter, mm	Nominal wall thick-ness, mm	Minimum outside diameter[a], mm	Minimum wall thick-ness[a], mm	Upset type	Connection			TJ torsional yield strength[g],	Tension yield strength[b], kN				Torsional yield strength[c], kN·m				Internal yield pressure[d], MPa				Collapse pressure[e], MPa			
					TJ thread type	TJ OD, mm	TJ pin ID, mm		Material group[f]				Material group[f]				Material group[f]				Material group[f]			
mm	mm	mm	mm					kN·m	I	II	III	IV	I	II	III	IV					I	II	III	IV
64	8	60,8	6,4	IU	NC 23	77,2	34	7,3	355	525	372	383	4,0	5,9	4,2	4,3	68,4	101,1	71,6	73,7	59,0	82,4	61,4	63,0
73	9	69,4	7,2	IU	NC 26	91,0	44	10,0	457	675	478	492	5,9	8,7	6,2	6,4	67,4	99,6	70,5	72,6	57,9	80,6	60,3	61,8
90	8	86,8	6,4	IU	NC 38	115,0	68	17,5	525	776	549	566	9,0	13,3	9,4	9,7	47,9	70,8	50,1	51,6	35,0	44,4	36,1	36,8
90	9	86,4	7,2	EU	NC 31	104,0	54	16,1	582	859	609	627	9,8	14,4	10,2	10,5	54,2	80,0	56,7	58,3	42,6	56,2	44,1	45,1
				IU	NC 38	117,1	58	20,7																
103	9	99,4	7,2	IU	NC 38	117,1	68	20,7	677	1 001	709	730	13,3	19,7	14,0	14,4	47,1	69,5	49,3	50,7	34,0	42,8	35,0	35,7
				IU	NC 38	122,4	68	25,0																
114	10	110,0	8	IU	NC 44	139,9	82	35,7	833	1 230	871	897	18,1	26,8	19,0	19,5	47,3	69,8	49,5	50,9	34,2	43,2	35,3	36,0
				IU	NC 50	150,9	95	39,9																
114	11	109,6	8,8	EU	NC46	146,7	80	47,9	905	1 337	947	975	19,4	28,6	20,3	20,9	52,2	77,1	54,6	56,2	40,2	52,5	41,6	42,5
129	9	125,4	7,2	IU	5 1/2 FH	167,6	112	53,2	868	1 283	909	935	22,2	32,8	23,3	24,0	37,3	55,1	39,0	40,2	21,7	25,3	22,2	22,5
129	11	124,6	8,8	EU	NC 50	156,7	95	51,3	1 040	1 536	1 088	1 120	25,8	38,1	27,0	27,8	45,9	67,8	48,0	49,4	32,5	40,6	33,5	34,1
131	13	125,8	10,4	IU	5 1/2 FH	172,5	105	68,5	1 225	1 809	1 281	1 319	29,9	44,2	31,3	32,2	53,7	79,4	56,2	57,9	42,1	55,4	43,6	44,6
133	11	128,6	8,8	EU	5 1/2 FH	167,6	112	53,2	1 076	1 589	1 126	1 159	27,6	40,8	28,9	29,8	44,5	65,7	46,5	47,9	30,7	38,0	31,6	32,2
140	13	134,8	10,4	EU	5 1/2 FH	167,6	112	53,2	1 320	1 950	1 381	1 422	35,0	51,6	36,6	37,6	50,1	74,1	52,5	54,0	37,8	48,6	39,0	39,8
147	11	142,6	8,8	EU	5 1/2 FH	172,5	105	68,5	1 202	1 775	1 257	1 294	34,7	51,2	36,3	37,4	40,1	59,2	42,0	43,2	25,2	30,1	25,8	26,2
				IU	6 5/8 FH	190,7	124	67,6																
147	13	141,8	10,4	EU	5 1/2 FH	172,5	105	68,5	1 395	2 060	1 459	1 502	39,1	57,8	40,9	42,1	47,7	70,4	49,9	51,3	34,7	43,9	35,8	36,5
147	15	141,0	12	IU	5 1/2 FH	172,5	105	68,5	1 580	2 333	1 653	1 701	43,1	63,6	45,1	46,4	55,3	81,7	57,9	59,6	44,0	58,4	45,6	46,6
151	13	145,8	10,4	IU	6 5/8 FH	190,7	124	67,6	1 437	2 122	1 503	1 548	41,6	61,5	43,5	44,8	46,4	68,5	48,5	49,9	33,1	41,5	34,1	34,7
155	15	149,0	12	EU	6 5/8 FH	190,7	124	67,6	1 678	2 478	1 755	1 807	48,8	72,0	51,0	52,5	52,3	77,3	54,8	56,4	40,4	52,8	41,8	42,7
164	9	160,4	7,2	EU	6 5/8 FH	197,2	124	94,3	1 126	1 663	1 178	1 212	37,8	55,8	39,5	40,7	29,2	43,1	30,5	31,4	12,3	13,3	12,4	12,5
168	11	163,6	8,8	EU	6 5/8 FH	197,2	124	94,3	1 390	2 053	1 454	1 497	46,8	69,1	48,9	50,4	35,0	51,6	36,6	37,7	18,9	21,5	19,2	19,4
				EU	6 5/8 FH	197,2	127	94,3																
168	13	162,8	10,4	IU	6 5/8 FH	197,2	127	94,3	1 617	2 389	1 692	1 742	53,1	78,4	55,5	57,2	41,5	61,3	43,4	44,7	27,0	32,6	27,7	28,1

a Wear criterion based on maximum percentage of uniform wear stated in Table 12.

b Value is calculated by Equation (B.6).

c Value is calculated by Equation (B.7).

d Value is calculated by Equation (B.8).

e Value is calculated by Equation (B.9).

f Material groups are as defined in ISO 15546.

g Calculated values based on Equation (B.15); yield strength of material and dimensions of tool joint connection as defined in ISO 15546.

Table 5 — Mechanical properties of class 2 pipe[a]

Nominal outside diameter, mm	Nominal wall thick-ness, mm	Minimum outside diameter[a], mm	Minimum wall thick-ness[a], mm	Thread type	Upset type	Thread torsional yield kN·m	Tension yield strength[b], kN				Torsional yield strength[c], kN·m				Internal yield pressure[d], MPa				Collapse pressure[e], MPa			
							Material group[f]				Material group[f]				Material group[f]				Material group[f]			
							I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
64	8	59,2	5,6	NC 23	IU	6,2	306	452	320	330	3,4	5,1	3,6	3,7	61,5	90,8	64,3	66,2	51,2	69,9	53,2	54,5
73	9	67,6	6,3	NC 26	IU	10,0	394	582	412	424	5,1	7,5	5,3	5,5	60,6	89,5	63,4	65,2	50,1	68,2	52,1	53,4
90	8	85,2	5,6	NC 38	EU	15,0	455	672	476	490	7,8	11,5	8,1	8,4	42,7	63,1	44,7	46,0	28,5	34,7	29,3	29,8
90	9	84,6	6,3	NC 31	IU	16,9	503	743	527	542	8,4	12,4	8,8	9,1	48,4	71,5	50,6	52,1	35,6	45,3	36,7	37,5
				NC 38	IU	14,6																
103	9	97,6	6,3	NC 38	IU	17,6	587	867	614	632	11,5	17,0	12,1	12,4	42,0	62,0	43,9	45,2	27,5	33,4	28,3	28,7
				NC 38	IU	24,5																
114	10	108,0	7,0	NC 44	IU	35,2	721	1 066	755	777	15,7	23,2	16,4	16,9	42,1	62,2	44,1	45,4	27,8	33,7	28,5	29,0
				NC 50	EU	34,2																
114	11	107,4	7,7	NC46	IU	40,6	783	1 157	820	844	16,7	24,7	17,5	18,0	46,6	68,8	48,8	50,2	33,4	41,9	34,4	35,0
129	9	123,6	6,3	5 1/2 FH	EU	45,5	754	1 114	789	812	19,3	28,5	20,2	20,8	33,1	48,9	34,7	35,7	16,7	18,7	17,0	17,1
129	11	122,4	7,7	NC 50	IU	46,5	901	1 331	943	971	22,3	32,9	23,3	24,0	40,9	60,4	42,8	44,0	26,2	31,4	26,9	27,3
131	13	123,2	9,1	5 1/2 FH	EU	58,3	1 060	1 565	1 108	1 141	25,8	38,1	27,0	27,8	48,0	70,9	50,2	51,7	35,1	44,6	36,2	36,9
133	11	126,4	7,7	5 1/2 FH	EU	45,5	933	1 378	976	1 004	23,9	35,3	25,0	25,8	39,6	58,5	41,4	42,6	24,6	29,2	25,2	25,5
140	13	132,2	9,1	5 1/2 FH	EU	45,5	1 143	1 688	1 196	1 231	30,2	44,6	31,6	32,5	44,7	66,1	46,8	48,2	31,0	38,5	31,9	32,5
147	11	140,4	7,7	5 1/2 FH	IU	58,3	1 043	1 540	1 091	1 123	30,1	44,4	31,4	32,4	35,6	52,6	37,3	38,4	19,7	22,6	20,1	20,3
				6 5/8 FH	EU	58,0																
147	13	139,2	9,1	5 1/2 FH	IU	58,3	1 208	1 784	1 264	1 301	33,8	49,9	35,4	36,4	42,5	62,8	44,5	45,8	28,2	34,3	29,0	29,5
147	15	138,0	10,5	5 1/2 FH	IU	58,3	1 366	2 018	1 429	1 471	37,1	54,8	38,8	40,0	49,5	73,0	51,7	53,3	36,9	47,3	38,1	38,9
151	13	143,2	9,1	6 5/8 FH	EU	58,0	1 245	1 839	1 303	1 341	36,0	53,1	37,6	38,7	41,3	61,0	43,2	44,5	26,7	32,2	27,4	27,8
155	15	146,0	10,5	6 5/8 FH	EU	58,0	1 452	2 144	1 519	1 564	42,1	62,1	44,0	45,3	46,7	69,0	48,9	50,3	33,6	42,2	34,6	35,2
164	9	158,6	6,3	6 5/8 FH	EU	80,5	979	1 446	1 024	1 054	32,9	48,5	34,4	35,4	25,8	38,1	27,0	27,8	8,9	9,5	9,0	9,1
168	11	161,4	7,7	6 5/8 FH	EU	80,5	1 208	1 784	1 263	1 301	40,6	59,9	42,5	43,7	31,0	45,8	32,4	33,4	14,3	15,7	14,5	14,6
				6 5/8 FH	IU	80,5																
168	13	160,2	9,1	6 5/8 FH	IU	80,5	1 403	2 072	1 468	1 511	46,0	67,9	48,1	49,5	36,9	54,5	38,6	39,8	21,3	24,6	21,7	22,0

a Wear criterion based on maximum percentage of uniform wear stated in Table 12.

b Value is calculated by Equation (B.6).

c Value is calculated by Equation (B.7).

d Value is calculated by Equation (B.8).

e Value is calculated by Equation (B.9).

f Material groups are as defined in ISO 15546.

5 Considerations and limitations of drill string design using ADP

5.1 Application aspects of aluminium alloy drill pipe

5.1.1 The main and the decisive characteristic property of aluminium drill pipe is its high "strength-to-weight" ratio, i.e. the ratio of the yield strength to the drill pipe's own weight in the drilling fluid. The drill pipe "strength-to-weight" ratio is expressed in length and is a physical characteristic of the maximum length of the uniform-sized drill-string section suspended in a vertical well, at which the tensile strength in the upper section reaches the yield point. The "strength-to-weight" ratio is calculated by Equation (B.11).

EXAMPLE

Objective: Calculate "strength-to-weight" ratio of ADP 147 × 11 IU with protector thickening; 11,8 m long; II group of alloys and SDP 5 7/8" from S-135 steel in drilling mud with density of 1 000 kg/m^3 and 2 000 kg/m^3.

Solution: Use Equation (B.11).

$$L = \frac{Y_{\mathrm{min}} \times 10^6}{9{,}81 \times \left(\rho_{\mathrm{e}} - \rho_{\mathrm{dm}}\right)}$$

where

Y_{min} is the minimum yield stress of group II aluminium alloy (ISO 15546) = 480 MPa;

ρ_{e} is the equivalent density of ADP with tool joints (Table 2) = 3 271 kg/m^3;

ρ_{dm} is the drilling mud density:

— for ρ_{dm} = 1 000 kg/m^3:

$$L_{\mathrm{Al}} = \frac{480 \times 10^6}{9{,}81 \times (3\,271 - 1\,000)} = 21\,545 \text{ m};$$

— for ρ_{dm} = 2 000 kg/m^3:

$$L_{\mathrm{Al}} = \frac{480 \times 10^6}{9{,}81 \times (3\,271 - 2\,000)} = 38\,497 \text{ m}.$$

For steel S-135 (ISO 11961):

σ_{min} is the yield stress of S-135 steel = 931 MPa;

ρ_{e} is the equivalent density of steel pipe = 7 850 kg/m^3;

ρ_{dm} is the drilling mud density:

— for ρ_{dm} = 1 000 kg/m^3:

$$L_{\mathrm{St}} = \frac{931 \times 10^6}{9{,}81 \times (7\,850 - 1\,000)} = 13\,854 \text{ m};$$

— for ρ_{dm} = 2 000 kg/m^3:

$$L_{\mathrm{St}} = \frac{931 \times 10^6}{9{,}81 \times (7\,850 - 2\,000)} = 16\,223 \text{ m}.$$

5.1.2 Low modulus of elasticity, E, of aluminium alloys in aluminium alloy drill pipe gives possibility to considerably increase their operating life when drilling intervals with high dogleg severity. Dogleg severity shall be derived from Equation (B.20).

5.1.3 As aluminium is non-magnetic material, ADP can be used for directional survey inside drill string.

5.1.4 ADP are normally corrosion resistant in most of drilling muds with a pH range from 4 to 11. Aluminium alloy pipe body is not affected by corrosion in hydrogen sulphide or carbon dioxide environment of any concentration. Aluminium alloy serves as an electrochemical corrosion protector for steel tool joints thus increasing the operational life of ADP in these environments (see Reference [6]).

5.1.5 In order to ensure the best mud circulation hydraulic characteristics it is recommended to follow the combination of the drill pipe and bit sizes specified in Table 6.

Table 6 — Recommended combinations of bit and pipe sizes

Dimensions in millimetres (inches)

Bit size	Pipe outside diameter	Bit size	Pipe outside diameter
120 (4 3/4)	73	190,5 (7 1/2)	114; 129; 133
132 (5 3/16)		215,9 (8 1/2)	
139,7 (5 1/2)	90	228,6 (9)	
158,0 (6 1/4)		215,9 (8 1/2)	129; 133; 140; 147
165,1 (6 1/2)	103, 114	228,6 (9)	
187,3 (7 3/8)		over 228,6 (over 9)	147; 151; 155; 164; 168; 170

5.2 General principles of aluminium drill string assembly design

5.2.1 To provide smooth transition of rigidity and to lower bending stress level, the downhole assembly in the transition zone from drill collars to aluminium alloy drill pipe shall be fitted with HW ADP or SDP (200 m to 250 m long).

5.2.2 To ensure safe working conditions of drill crew when eliminating the drill string sticking by forced methods, reaching the limit tensile loads, the top part of the drill string shall be equipped with 300 m to 400 m of steel drill pipe with strength characteristics higher than those of the aluminium drill pipe used.

5.2.3 The material group and standard sizes of the aluminium drill pipe for assembly of separate sections of the drill string should be selected in dependence with expected loads and operation temperature.

5.2.4 Values for various performance properties of drill pipe given in this International Standard do not include factors of safety. In the design of drill pipe strings, factors of safety should be used as are considered necessary for a particular application.

5.2.5 When drilling vertical and directional wells (with the angle of deviation less than 45°) the drill string assembly remains in the well bore in a stretched condition. The BHA weight parameters are defined by the design axial WOB, which shall be from 0,75 to 0,8 of the assembly buoyant weight in the drilling mud and the loss of weight in inclined sections. It is not recommended to create axial WOB by partially transferring the weight of aluminium drill pipe.

EXAMPLE The standard design of the drill string with ADP for drilling vertical and directional wells includes the following elements:

— BHA, whose composition and length are defined by the drilling method;

— aluminium heavy wall pipe: 200 m to 250 m for smooth rigidity transition;

— aluminium drill pipe, whose design parameters, dimension-type and material group are defined by the length of the drill string;

— steel drill pipe: 300 m to 400 m, to ensure safe emergency work.

5.2.6 While drilling horizontal wells and, especially, wells with a long horizontal section, most of the drill string resists compressing load, overcoming drag in the horizontal section while creating axial WOB. The main drilling method when drilling such boreholes is the combined method when the drill bit is rotated by the downhole motor and the drill string rotates for angle stabilization and lessening the drag.

5.2.7 For horizontal wells, besides the traditional tensile, torsional and fatigue strength calculations, it is necessary to perform the drill string buckling calculations estimating the possibility of sinusoidal and helical buckling.

5.2.8 In the horizontal well sections and, especially, in long sections it is advisable to use ADP with protector thickening or with a specially designed centralizer which protects the pipe from wear and increases the critical buckling load.

EXAMPLE The standard design of the drill string with ADP for drilling horizontal wells includes the following elements:

— BHA, whose composition and length are defined by the drilling conditions and the necessity of using downhole MWD telemetric systems;

— HWADP: 200 m to 250 m, for smooth rigidity transition, from BHA to ADP (it is possible to replace plain HWDP by pipe with outside spiral riffling, which would improve the cleaning of the bottom-hole zone);

— ADP, whose design parameters, dimension-type, material group and section length are defined by the length, profile and the design of the well;

— HWADP or SDP: 200 m to 250 m, for smooth rigidity transition from aluminium drill pipe to HWDP;

— HWDP or drill collars: for producing and applying axial load to the drill string;

— SDP: for drill string build-up.

5.3 Influence of temperature on choice of material for drill pipe

5.3.1 Mechanical and operational characteristics of aluminium alloys depend on the temperature of operation. This dependence becomes especially apparent at the temperatures of operation corresponding to the ones in a temperature zone of structural transformations of pipe material. Therefore, for each group of alloys, the limiting critical values of operation temperature, as given in ISO 15546, are as follows:

— for material group I: 160 °C;

— for material group II: 120 °C;

— for material group III: 220 °C;

— for material group IV: 160 °C.

5.3.2 The design of drill string assembly and material assignment for the ADP working in a zone of high temperatures should be done in accordance with requirement of operation temperature interval being below critical temperatures for the given group of alloys.

5.3.3 On the basis of experimental data, the approximate empirical dependences of aluminium alloy yield stress limit versus operation temperature of drill string section were developed (see Figure 1). The given dependencies give values more conservative than the actual properties of the material at elevated temperatures. This conservative approach made it possible to exclude the time of exposure at certain temperatures from the list of factors influencing the strength of material. The listed dependencies can be applied when the total time of exposure to the elevated temperature does not exceed 500 h. If more detailed graphs are applied, they can be taken from special publications covering aluminium alloy properties and behaviour (see References [6], [17] and [18]).

The minimum yield strength of alloy, Y_{min}, expressed in megapascals, is calculated according to Equations (1) to (8), where t_0 is the operational temperature, expressed in degrees Celsius:

— for Group I:

 — at 20 °C ≤ t_0 ≤ 140 °C:

$$Y_{min} = 325 - 0{,}125\ (t_0 - 20) \tag{1}$$

 — at 140 °C ≤ t_0 ≤ 160 °C:

$$Y_{min} = 310 - 0{,}875\ (t_0 - 140) \tag{2}$$

— for Group II:

 — at 20 °C ≤ t_0 ≤ 80 °C:

$$Y_{min} = 480 - 0{,}25\ (t_0 - 20) \tag{3}$$

 — at 80 °C ≤ t_0 ≤ 120 °C:

$$Y_{min} = 465 - 0{,}92\ (t_0 - 80) \tag{4}$$

— for Group III:

 — at 20 °C ≤ t_0 ≤ 190 °C:

$$Y_{min} = 340 - 0{,}118\ (t_0 - 20) \tag{5}$$

 — at 190 °C ≤ t_0 ≤ 220 °C:

$$Y_{min} = 320 - (t_0 - 190) \tag{6}$$

— for Group IV:

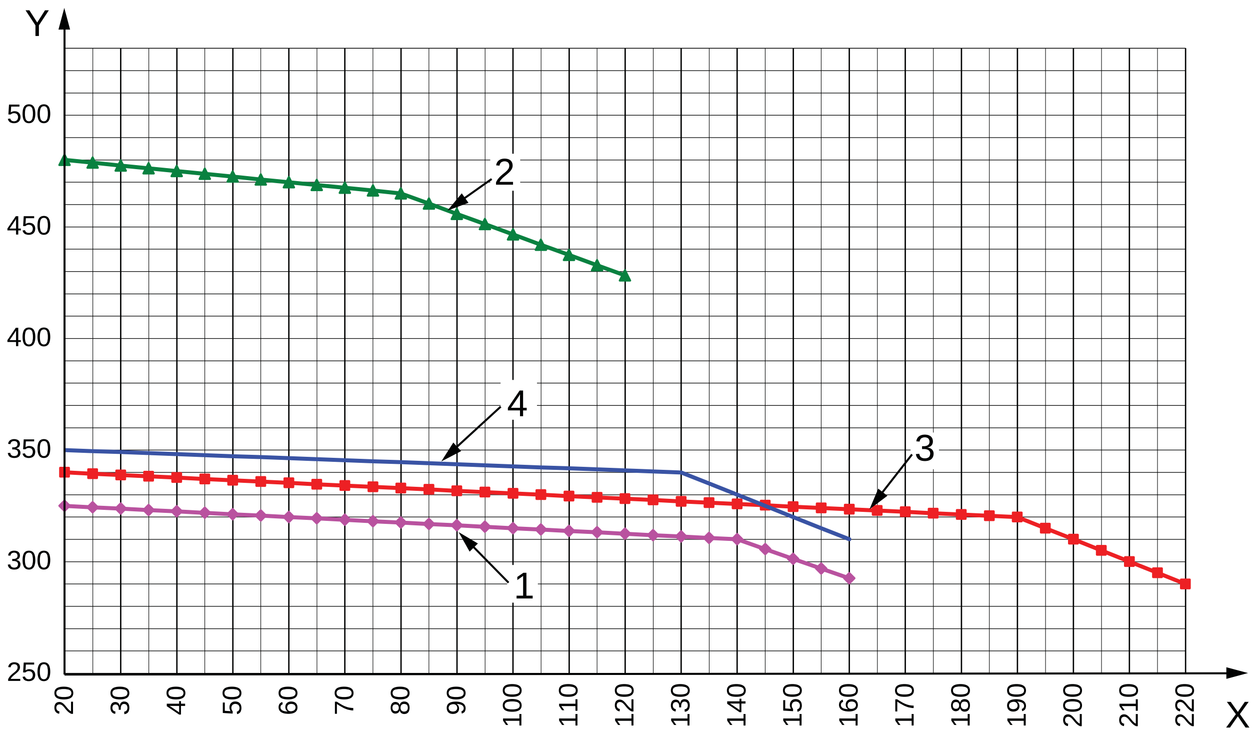
 — at 20 °C ≤ t_0 ≤ 130 °C:

$$Y_{min} = 350 - 0{,}091\ (t_0 - 20) \tag{7}$$

 — at 130 °C ≤ t_0 ≤ 160 °C:

$$Y_{min} = 340 - (t_0 - 130) \tag{8}$$

It should be taken into account that strength characteristics of pipe material while reduced at elevated temperature do not restore after temperature reduction.



Key

X temperature, °C

Y yield stress, MPa

1 Group I

2 Group II

3 Group III

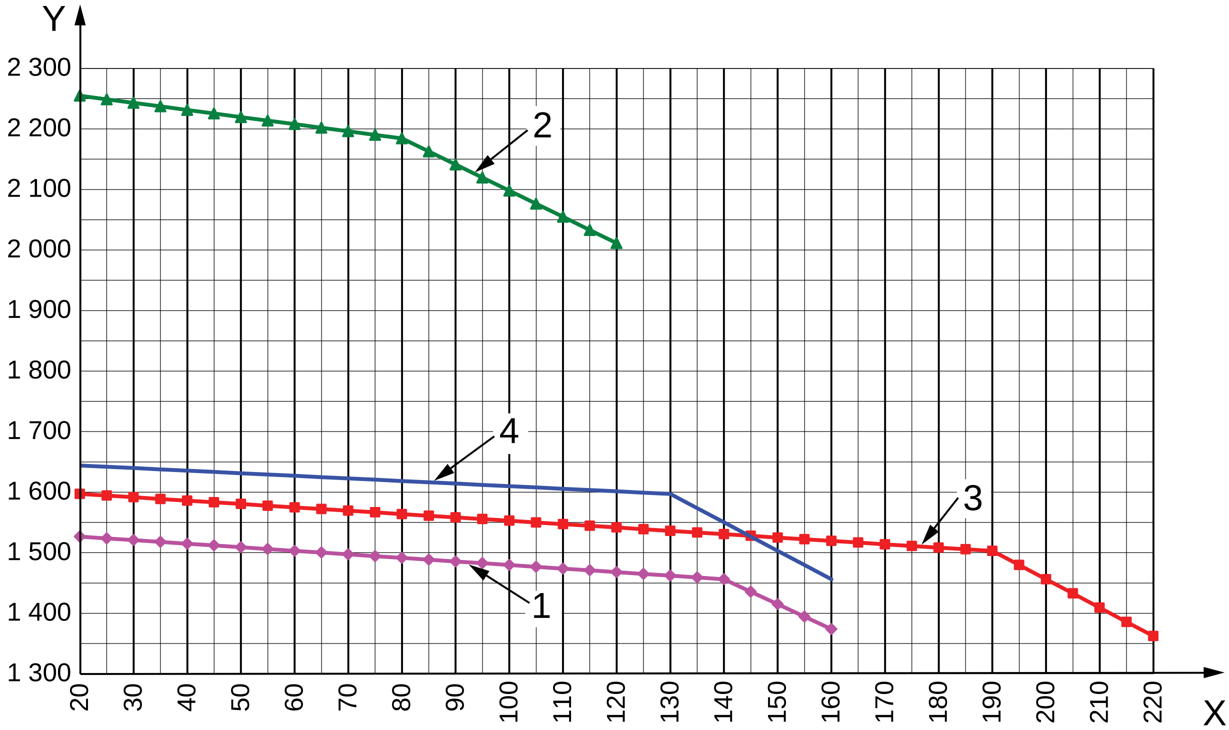
4 Group IV

NOTE The curves are plotted based on Equations (1) to (8).

Figure 1 — Minimum yield strength versus temperature correlation of aluminium alloys

5.3.4 The temperature impact on the aluminium drill pipe affects strength performance. Since the aluminium drill pipe minimum yield point depends largely on the material temperature, the main strength parameters of the aluminium drill pipe will also be subject to the temperature effects.

Figures 2, 3, 4 and 5 show the example curve indicating the approximate basic strength performance changes of aluminium drill pipe 147 × 11 as affected by the operating temperature.



Key

X temperature, °C

Y tension yield strength, kN

1 Group I

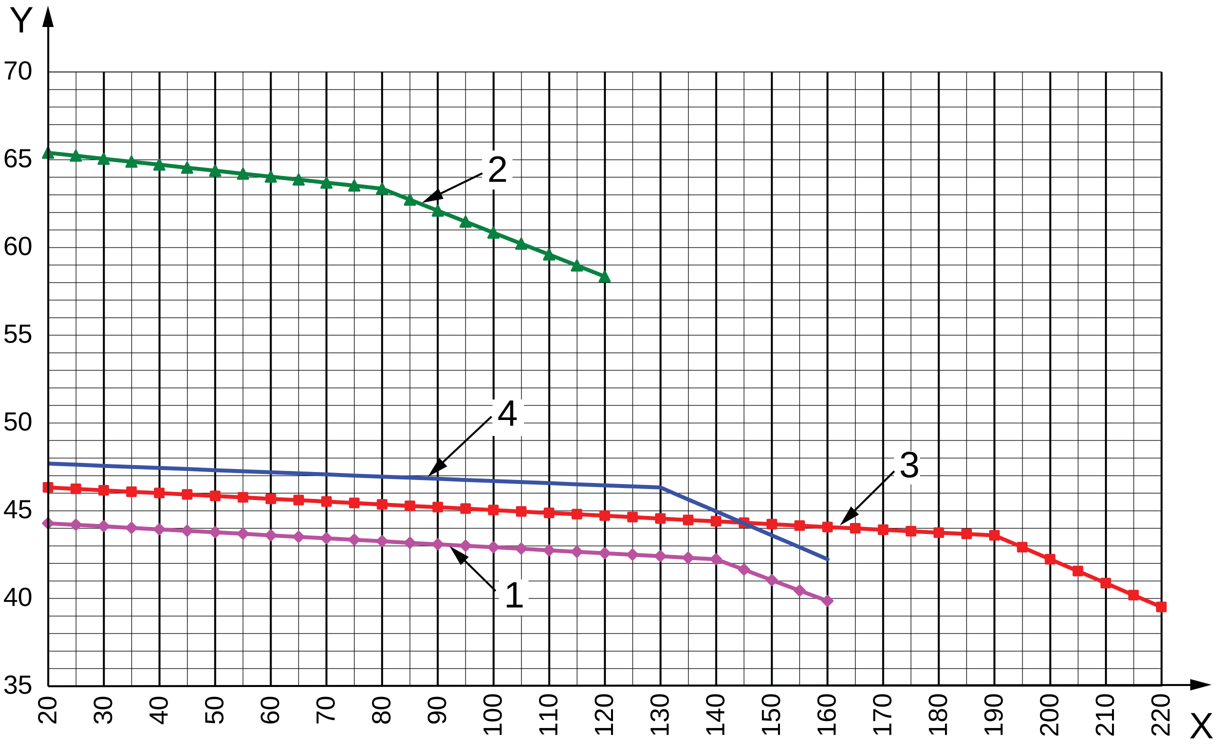
2 Group II

3 Group III

4 Group IV

NOTE The curve is plotted based on Equations (1) to (8) and Equation (B.6).

Figure 2 — Tension yield strength dependence on temperature for new ADP 147 × 11 of different material groups



Key

X temperature, °C

Y torsional yield strength, kN·m

1 Group I

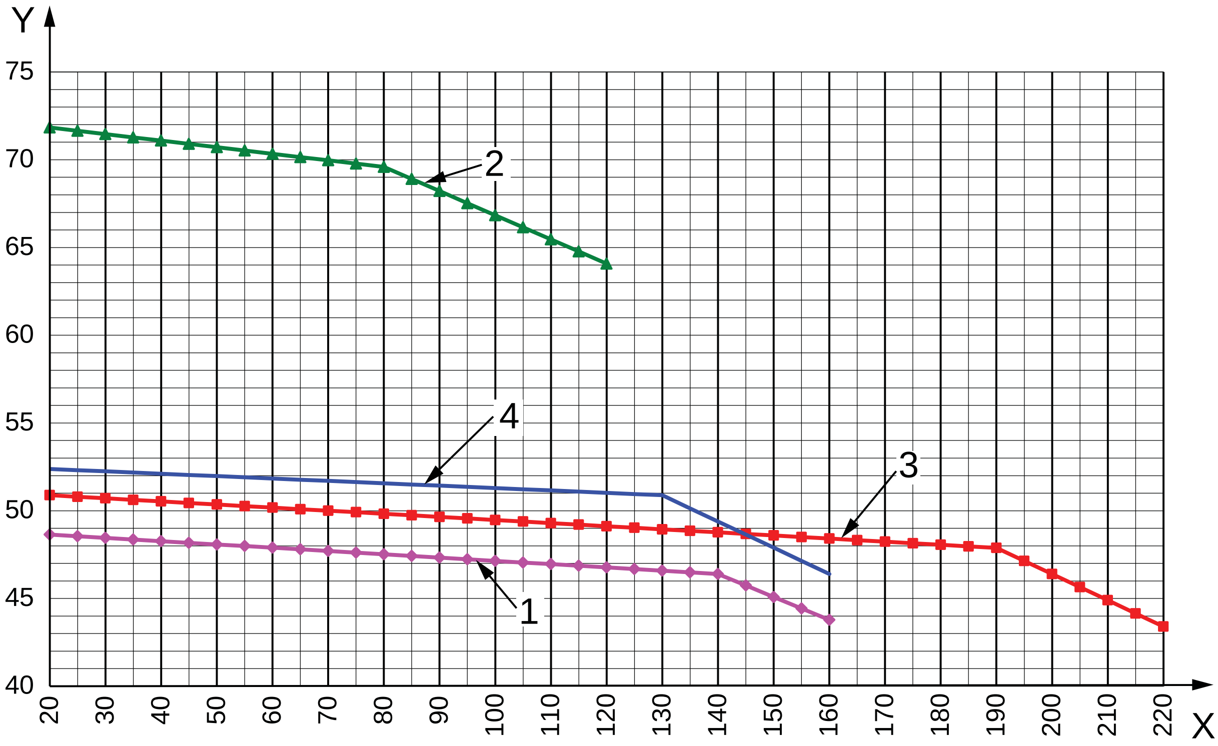
2 Group II

3 Group III

4 Group IV

NOTE The curve is plotted based on Equations (1) to (8) and Equation (B.6).

Figure 3 — Torsional yield strength dependence on temperature for new ADP 147 × 11 of different material groups



Key

X temperature, °C

Y internal yield pressure, MPa

1 Group I

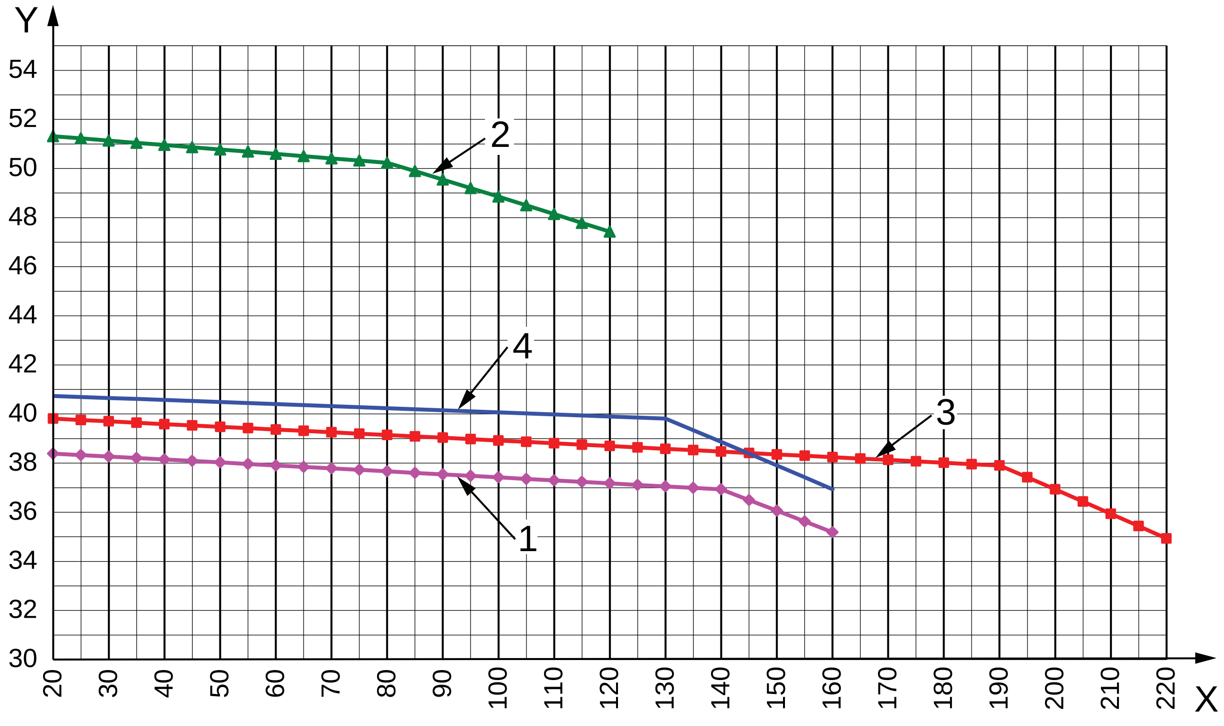
2 Group II

3 Group III

4 Group IV

NOTE The curve is plotted based on Equations (1) to (8) and Equation (B.6).

Figure 4 — Internal yield pressure dependence on temperature for new ADP 147 × 11 of different material groups



Key

X temperature, °C

Y external yield pressure, MPa

1 Group I

2 Group II

3 Group III

4 Group IV

NOTE The curve is plotted based on Equations (1) to (8) and Equation (B.6).

Figure 5 — External yield pressure dependence on temperature for new ADP 147 × 11 of different material groups

5.4 Resistance to hydroabrasive and corrosive damage

5.4.1 ADP possesses lower abrasive wear resistance of the external and internal surface of the pipe due to lower hardness of the aluminium drill pipe material. Surface hardness of aluminium alloys used in aluminium drill pipe production is 120 HB to 140 HB, which is 1,5 to 2,0 times less than the same value for steel drill pipe. External surface wear is rather noticeable during rotary drilling and intensifies with greater rotary speed of the drill string. Abrasive wear is distributed unevenly along the length and the perimeter of the pipe. The drill pipe body is subject to a greater wear in the middle part, and this wear is usually eccentric.

Abrasive particles contained in the drilling fluid cause the internal surface wear of the aluminium drill pipe. This process is most intensive in the areas adjacent to the tool joint and to the internal upsets of the pipe, which is explained by turbulization of the drilling fluid. The hydroabrasive wear is most dangerous if drilling fluids loaded with solid weighting material are used. Hydroabrasive wear by normal density muds containing approximately 1 % to 1,5 % of solid phase does not normally exceed 1 mm for 1 000 pumping hours.

5.4.2 Aluminium drill pipe suffers increased corrosive damage in the drilling fluids with the pH factor outside of the recommended range of values of ($4 \leq pH \leq 11$).

For this reason, and in order to reduce the pipe corrosion, the pH factor shall be maintained within the specified limits by adding appropriate inhibitors to the drilling mud.

5.5 Buckling

Buckling of the drill string can lead to substantial fatigue damage, potential washout or twist off. When designing a drill string assembly for certain applications, it is required to predict and locate the first order of buckling, i.e. sinusoidal buckling.

The method and equations for evaluation of critical buckling load are given in B.11.

The values of sinusoidal buckling critical loads largely depend on the relevant well section (inclination angle, angle build rate), pipe stiffness and submerged weight, and on the annular clearance between the drill string and the well bore wall. The compression load applied to the different string sections should not exceed the critical load of sinusoidal buckling.

Figures 6 and 7 show the sample calculations of sinusoidal buckling critical loads for the well slant portions and borehole curved sections. The calculations were made by Equations (B.12) to (B.14), as applied to aluminium drill pipe 147 × 11 of the first group.

EXAMPLE 1

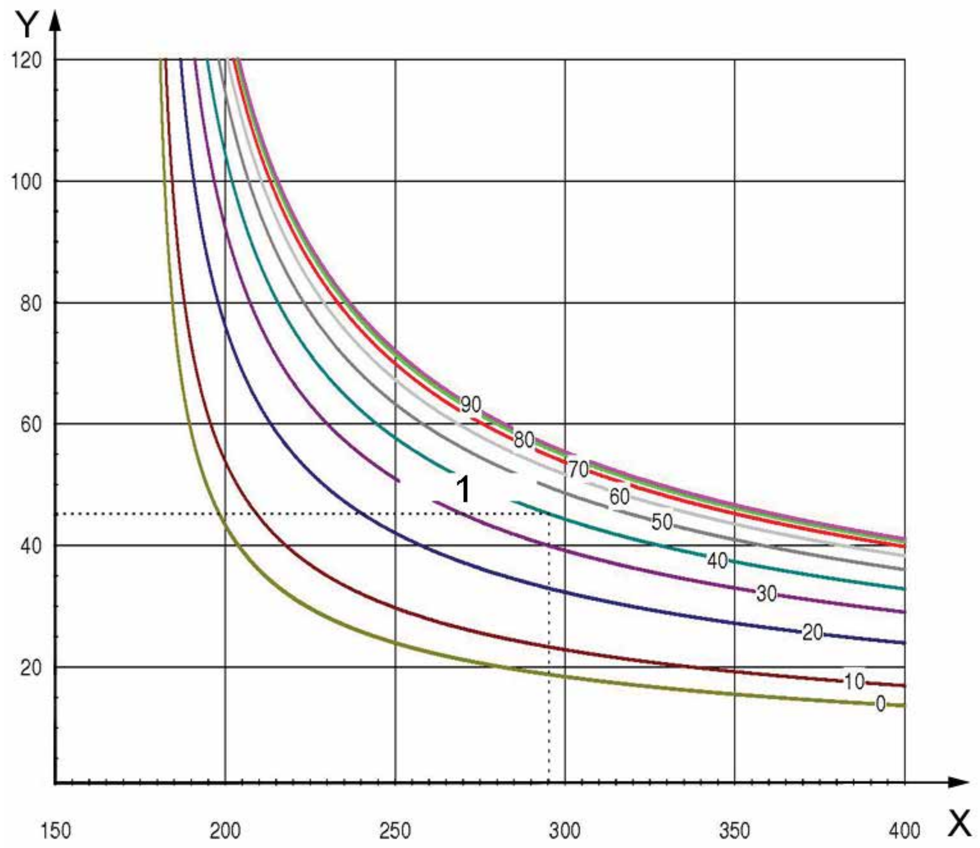
Objective: Find the critical load of sinusoidal buckling at the slant borehole interval with the borehole inclination of 40°, 295,3 mm diameter well bore, when drilled with aluminium drill pipe 147 × 11 of the 3-d range, in 1 200 kg/m^3 drilling mud.

Solution: Based on Figure 6, the critical load of sinusoidal buckling is found to be 45,2 kN.

EXAMPLE 2

Objective: Find the critical load of sinusoidal buckling at a 295,3 mm curved borehole interval with the angle build rate of 0,95°/30,48 m, and mean inclination angle of 90°, drilled with aluminium drill pipe 147 × 11 in 1 200 kg/m^3 drilling mud at the inclination angle build section.

Solution: Based on Figure 7, the critical load of sinusoidal buckling is found to be 88,0 kN.



Key

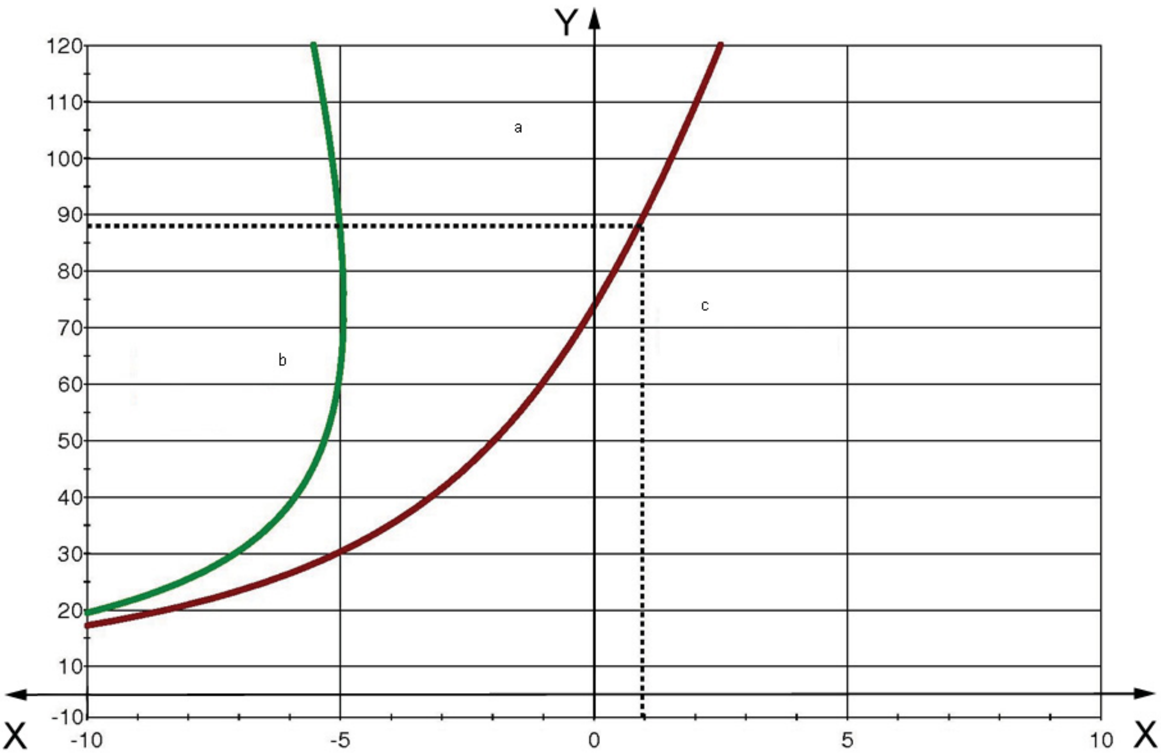
X wellbore diameter, mm

Y axial load, kN

1 inclination angle

NOTE The curve is plotted based on Equation (B.12).

Figure 6 — Critical buckling load versus borehole diameter and inclination angle for aluminium drill pipe 147 × 11, Group I at the slant borehole portions



Key

X dogleg severity, degrees per 30 m

Y compressive axial load, kN

[a] Pipe is buckled.

[b] Not buckled; high side of hole.

[c] Not buckled; low side of hole.

NOTE The curve is plotted based on Equations (B.13) and (B.14).

Figure 7 — Critical buckling load versus dogleg severity at borehole angle build or drop interval for aluminium drill pipe 147 × 11,3 length range in 90°, 295,3 mm borehole with 1 200 kg/m^3 drilling mud

6 Basic requirements for calculation of drill strings containing ADP

This clause specifies the general provisions of the static strength calculation for the stress-deformed state of the drill string containing ADP.

The loads applied to the drill pipe, including the aluminium drill pipe, should be identified based on the results of the static strength and buckling force calculation of the stressed-deformed state of the drilling string elements for the weakest sections of the pipe body.

The mathematical model that describes the drilling string stressed-deformed state shall account for the major dimensional and strength factors, including the following:

— three-dimensional borehole configuration;

— the drill pipe weight in the drilling fluids of specified density, as distributed along the drill string length;

— the open and cased hole walls resistance (friction) against the longitudinal and rotational drill string movement;

— the effects of the temperature changes along the well depth on the drill pipe material mechanical properties based on the geothermal gradient depth distribution for the drilling area in question;

— buckling of the compressed drill string section resulting in the increased contact force between the drill string and borehole wells;

— performance specifications of all drill pipe in the configuration to be calculated;

— BHA components, dimensions and weight;

— the data on the drilling process technical parameters, including the well portions drilled with different boring methods, characteristics of rock-cutting tools and bottomhole motors, drill string rpm;

— rig technical description, i.e. maximum permissible hook load and driving mechanism rotation torque, etc.

Besides drill string strength calculation, it shall be reasonable to evaluate the pressure loss in the well mud-circulating system.

7 Drill pipe operation

7.1 Operations management

The drill pipe operation shall be managed by the engineering team of the company that prepares the pipe for operations, that develops appropriate preventive actions to extend the pipe service life and that indicates the frequency of those actions.

7.2 General drill pipe operating recommendations

7.2.1 To ensure failure-free operation using the aluminium alloy pipe, the company's technical service shall make up a list of preventive actions indicating their completion dates. Table 7 shows a recommended list of such actions.

Table 7 — Recommended list of operation actions

Works	Frequency	
	Rotary drilling	Downhole motor drilling
Tool joint threads lubrication	At each make-up operation	
Make-up torque control	At each make-up operation	
Retorquing (applying make-up torque on) inactive tool joints in a stand	After 5 round trips	After 8 round trips
Callipering of any single pipe before assembling into drill pipe stands	At each make-up operation	
Exchanging of active and inactive connections in the stands	After 40 round trips	
Drill string run-in deceleration or shutdown and drill string fill-up	If weight indicator shows no drill string weight, increase when drill string is run-in.	
NOTE The check frequencies are approximate, since they depend on the specific drilling condition in the region.		

7.2.2 When the pipe is operated at the drilling rig, it shall be prohibited to:

— “drop” the pin into the box when making up the pipe;

— rotate the drill pipe (stand) after the thread is disengaged, and to break loose the pin from the box until breaking out is completed;

— rapidly slowdown the drill string run;

— operate power tongs on the pipe body;

— pick up and eject the drill pipe without thread protective caps being fitted;

— allow pipe ends to hit against the rotary table;

— use the slips with dies that do not match the pipe size;

— set the slips when the pipe is moving;

— place slips on the pipe outside pipe upset area.

7.2.3 The maximum allowable tensile loads should not exceed minimum yield strength of the pipe material accounting for temperature effect. In a contingency situation, the load applied can reach or exceed the minimum yield strength, but that should be followed by unscheduled pipe inspection including non-destructive examination.

7.2.4 When making up the tool joint, a thread compound shall be used.

7.2.5 When putting new pipe into service, in order to extend the service life and prevent thread jamming, it is recommended to break in the threads by three to five make-up/break-out cycles with recommended make-up torque at 2 rpm to 4 rpm, if this was not completed during manufacturing time.

7.2.6 Upon subsequent make-up operations, the drill mud remainder shall be removed from the threaded surface and the new lubricant shall be applied.

7.2.7 The drill pipe tool joints should be connected by applying the torque values specified in Table 8.

7.2.8 To prevent the thread damage and wear the maximum break-out speed shall be 25 rpm. Rotation shall be stopped as soon as the pin thread is disengaged.

7.2.9 To ensure uniform wear of tool joint thread the position of drill pipe in the stand shall be changed as shown above in Table 7 (changing active connection with inactive one).

7.2.10 To prevent tool joint pins damage (if the stands are vertically positioned at the setback), it is recommended to line the metal setback with cushioning material (rubber, wood boards, etc.).

7.2.11 When running and connecting the pipe sharp stabbing of drill pipe pin into the box, abrupt slowdown of drill string and sharp drill string stabbing into the slips or to the elevator shall not be allowed.

Table 8 — Recommended make-up torque for tool joints

Outside diameter	Wall thickness	Tool joint		Thread	Make-up torque for new TJ	Make-up torque for premium TJ	Make-up torque for 2 class TJ
		OD	ID (pin)				
mm	mm	mm	mm		kN·m[a]	kN·m[ab]	kN·m[ab]
External upset ends							
90	8	118	68	NC 38	**13,1**	**10,5**	**9,2**
114	10	155	95	NC 50	**30,0**	**24,0**	**21,0**
129	9	172	112	5 1/2 FH	**33,2**	**31,9**	**27,9**
131	13	178	105	5 1/2 FH	**41,6**	**41,1**	**36,0**
133	11	172	112	5 1/2 FH	**33,2**	**31,9**	**27,9**
140	13	172	112	5 1/2 FH	**33,2**	**31,9**	**27,9**
147	11	195	124	6 5/8 FH	**50,7**	**40,6**	**35,5**
151	13	195	124	6 5/8 FH	**50,7**	**40,6**	**35,5**
155	15	195	124	6 5/8 FH	**50,7**	**40,6**	**35,5**
164	9	203	124	6 5/8 FH	**64,3**	**56,6**	**49,5**
168	11	203	124	6 5/8 FH	**64,3**	**56,6**	**49,5**
Internal upset ends							
64	8	80	34	NC 23	**4,9**	**4,4**	**3,8**
73	9	95	44	NC 26	**6,0**	**6,0**	**6,0**
90	9	108	54	NC 31	**9,7**	**9,7**	**9,7**
90	9	120,6	58	NC 38	**15,5**	**12,4**	**10,8**
103	9	120,6	68	NC 38	**14,8**	**12,4**	**10,8**
103	9	127	68	NC 38	**15,0**	**15,0**	**15,0**
114	10	145	82	NC 44	**21,4**	**21,4**	**21,1**
114	11	145	80	NC 46	**29,1**	**28,7**	**25,1**
129	11	162	95	NC 50	**30,8**	**30,8**	**28,7**
147	11	178	105	5 1/2 FH	**41,6**	**41,1**	**36,0**
147	13	178	105	5 1/2 FH	**41,6**	**41,1**	**36,0**
147	15	178	105	5 1/2 FH	**41,6**	**41,1**	**36,0**
168	11	203	127	6 5/8 FH	**59,7**	**56,6**	**49,5**
168	13	203	127	6 5/8 FH	**59,7**	**56,6**	**49,5**

[a] The recommended values are based on Equations (B.15) and (B.16) and yield strength of tool joint material as specified in ISO 15546 and ISO 11961.

[b] Wear criterion of tool joint based on values stated in Table 13.

7.2.12 When slips are used, the maximum axial loads on the pipe (the weight of drill string) should not exceed the values specified in Table 9.

It is important to note that the values given in Table 9 are only a guideline, as Equation (B.17), which was used for their calculation, gives dependence of the slip crushing constant from the size of the drill pipe, the length of the slips, and the coefficient of friction between the backs of the slips and the master bushing. Other variable that could result in crushing the pipe wall as well as catastrophic fracture of the toe section of the slip segments are not accounted for in this equation.

Table 9 — Tension yield strength in the slips at pipe body yield stress limit

Tension yield strength in kN

Tubular sizes	Slips length 300 mm				Slips length 350 mm				Slips length 400 mm			
	Material group				Material group				Material group			
	I	II	III	IV	I	II	III	IV	I	II	III	IV
External upset ends												
90 × 8	730	1 078	764	786	766	1 132	802	825	795	1 174	832	856
114 × 10	1 205	1 780	1 261	1 298	1 279	1 889	1 338	1 377	1 339	1 977	1 401	1 442
129 × 9	1 265	1 869	1 324	1 362	1 351	1 995	1 413	1 455	1 421	2 099	1 486	1 530
131 × 13	**1 480**	**2 186**	**1 549**	**1 594**	1 582	2 336	1 655	1 703	1 665	2 459	1 742	1 793
133 × 11	**1 293**	**1 909**	**1 352**	**1 392**	1 382	2 041	1 446	1 489	1 456	2 150	1 523	1 568
140 × 13	**1 242**	**1 835**	**1 300**	**1 338**	**1 332**	**1 967**	**1 393**	**1 434**	**1 406**	**2 076**	**1 471**	**1 514**
147 × 11	1 606	2 373	1 681	1 730	1 727	2 550	1 806	1 859	1 826	2 697	1 911	1 967
151 × 13	**1 636**	**2 416**	**1 711**	**1 761**	**1 760**	**2 600**	**1 842**	**1 896**	**1 864**	**2 753**	**1 950**	**2 008**
155 × 15	**1 664**	**2 458**	**1 741**	**1 792**	**1 793**	**2 649**	**1 876**	**1 931**	**1 901**	**2 808**	**1 989**	**2 047**
164 × 9	1 586	2 343	1 660	1 708	1 714	2 532	1 794	1 846	1 822	2 691	1 906	1 962
168 × 11	**1 609**	**2 377**	**1 684**	**1 733**	**1 742**	**2 572**	**1 822**	**1 876**	**1 853**	**2 737**	**1 938**	**1 995**
Internal upset ends												
64 × 8	534	788	558	575	553	816	578	595	568	838	594	611
73 × 9	709	1 048	742	764	738	1 090	772	795	761	1 124	796	819
90 × 9	863	1 275	903	930	906	1 339	948	976	940	1 389	984	1 013
103 × 9	967	1 429	1 012	1 042	1 022	1 509	1 069	1 100	1 065	1 573	1 114	1 147
114 × 10	**1 047**	**1 546**	**1 095**	**1 128**	1 111	1 641	1 162	1 197	1 163	1 718	1 217	1 252
114 × 11	**1 047**	**1 546**	**1 095**	**1 128**	**1 111**	**1 641**	**1 162**	**1 197**	1 163	1 718	1 217	1 252
129 × 9	1 206	1 781	1 261	1 298	1 287	1 901	1 347	1 386	1 354	2 000	1 417	1 458
129 × 11	**1 323**	**1 955**	**1 384**	**1 425**	1 413	2 087	1 478	1 522	1 486	2 195	1 555	1 601
147 × 11	**1 316**	**1 943**	**1 377**	**1 417**	**1 414**	**2 089**	**1 479**	**1 523**	**1 496**	**2 209**	**1 565**	**1 611**
147 × 13	**1 512**	**2 233**	**1 582**	**1 629**	**1 625**	**2 400**	**1 700**	**1 750**	**1 719**	**2 539**	**1 799**	**1 851**
147 × 15	**1 637**	**2 418**	**1 713**	**1 763**	**1 760**	**2 599**	**1 841**	**1 895**	**1 861**	**2 749**	**1 947**	**2 005**
168 × 11	**1 573**	**2 324**	**1 646**	**1 694**	**1 703**	**2 515**	**1 781**	**1 834**	1 812	2 675	1 895	1 951
168 × 13	**1 681**	**2 482**	**1 758**	**1 810**	**1 819**	**2 686**	**1 902**	**1 958**	**1 935**	**2 858**	**2 024**	**2 084**

NOTE Tension yield strength in slips is calculated based on Equation (B.17) and coefficient of friction between slips and master bushing 0,08. Bold type figures indicate the values which are less than tension yield strength of a new ADP.

7.2.13 If aluminium alloy drill pipe is broken, it is recommended to drill it out to the tool joint at the maximum pump capacity to carry up the broken pipe fragments and chips and then attempt to connect to the failed string tool joint.

7.2.14 When tripping the bottom section of the drill string, and if the weight of the pipe in the well is not sufficient to prevent the string from turning in the spider, the tool joints shall be made up and broken out with the tool joint box fixed in the rotary tongs or in the lower dies of hydraulic (or mechanical) tongs.

7.2.15 The alignment control of derrick or mast and the well head shall be done periodically, since misalignment results in additional bending moment that increases the contact loads on the threaded connection during make-up and break-out operations.

7.2.16 Before each string running, careful consideration shall be given to monitoring the condition of the pin and box bearing faces. If there are dents, scratches, etc., they shall be removed using special devices. If this is not possible on site, such connections shall be repaired at a special facility.

7.2.17 To prevent collapsing of a drill string running into a deep hole when the string has no time to be filled with mud through a downhole motor (the weight indicator does not mark the drilling string weight increment, the string is “floating”), or when loaded (weighted) drilling fluid is used, the fluid shall be added to the string. The minimum height, h, of drilling fluid to be added into string for prevention of its collapse shall be derived from Equation (B.18).

7.2.18 If there is a risk of drill string clamping during cementing job, it is recommended to use integral joint pipe in the interval of possible sticking. This pipe is without steel joints, its thread is cut straight on the upset. The length of the drill string portion composed of integral joint pipe should be longer than the dangerous interval (usually 50 m to 100 m). In case of sticking, integral joint pipe is easy to drill-out (preferably with downhole motor), after disconnection of the stuck section from the main string.

Information on integral joint pipe is given in Annex A.

7.2.19 For greater accuracy when determining the length of the drill string, the additional elongation due to thermal expansion should be considered. The total elongation of drill string in the well is calculated by Equation (B.19).

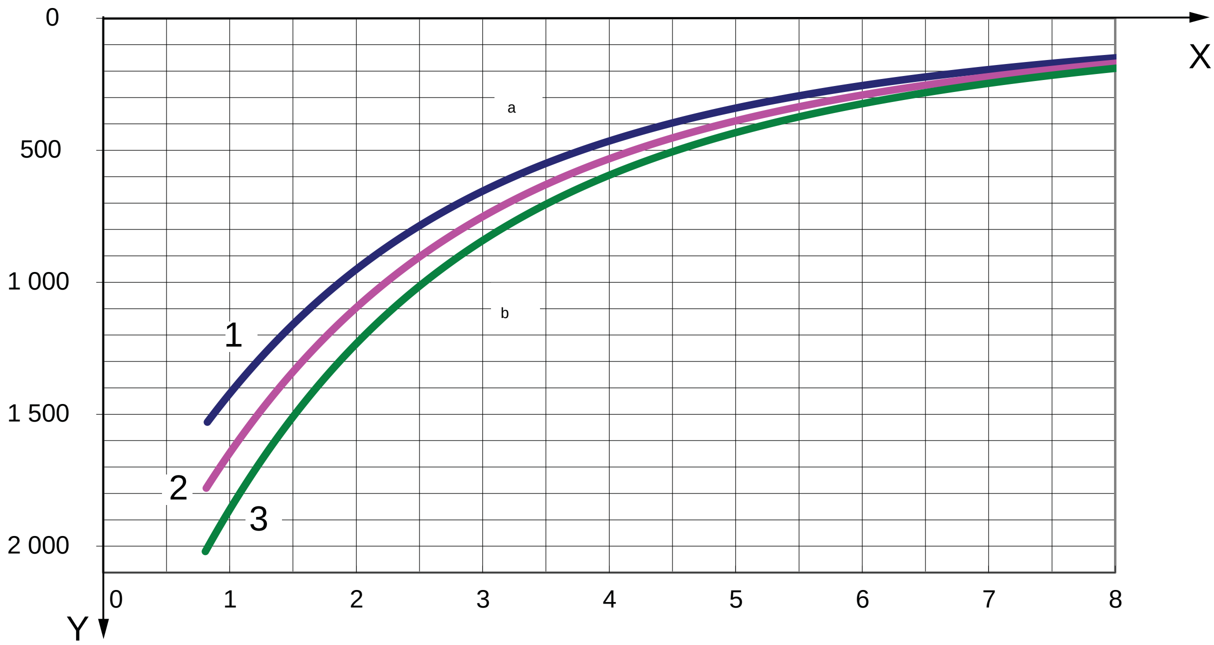
7.3 Fatigue strength limitations

7.3.1 The fatigue limit determines the resistance of the drill string elements to cyclic bending stress. ISO 15546 specifies that the minimum acceptable fatigue limit for aluminium drill pipe is 50 MPa. The value was defined based on the fatigue testing of 2×10^7 bending stress cycles at 20 °C.

Drill pipe fatigue stress appears during pipe rotation and movement in the well bore curvature. The permissible borehole profile change depends on the well bore and drill pipe geometrical dimensions, pipe submerged weight, mechanical properties and fatigue resistance of different drill string elements.

Taking into account lower aluminium drill pipe stiffness, its permissible curving rate is higher than that of steel pipe of similar size. Permissible dogleg severity is calculated according to Equation (B.20) when aluminium drill pipe is used.

7.3.2 Figure 8 illustrates the example calculations, based on Equation (B.20), of maximum dogleg severity (in degrees per 30 m) and drill string weight positioned below the dogleg (taking into account its weight loss in drilling mud) when the pipe can be operated. Figure 8 applies to totally non-aggressive environments. If the pipe works in the area above the curve of the corresponding size of pipe, fatigue failures do not take place, and vice versa.



Key

X dogleg severity, degrees per 30 m

Y buoyant weight suspended below the dogleg, kN

1 ADP 147 × 11

2 ADP 147 × 13

3 ADP 147 × 15

[a] Region of no fatigue damage.

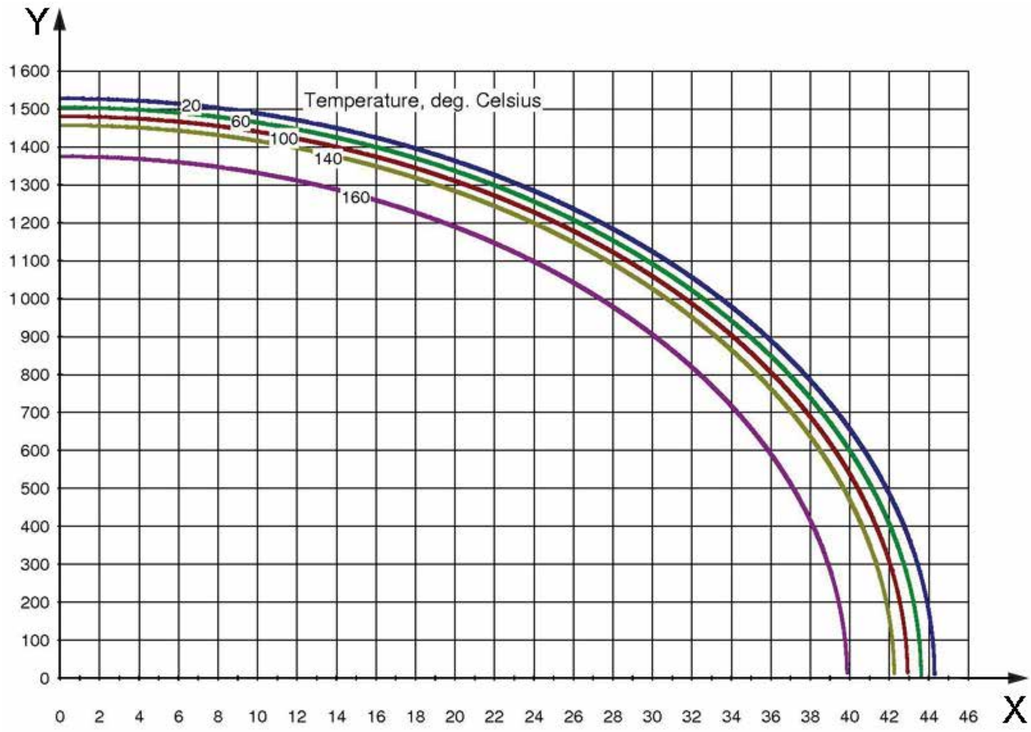
[b] Region of fatigue damage.

Figure 8 — Dogleg severity limits for fatigue of aluminium drill string in non-aggressive environment for new ADP: 147 × 11, 147 × 13 and 147 × 15 (Range 2, material Group 1, without protectors)

7.4 Combined load capacity limitation

If there are drill string breakdowns connected with sticking or blocking, they are eliminated with the help of alternating tensile load with its subsequent removal or with the help of simultaneous application of tensile load and torque. In doing so, it is important to know the value of loads that can be applied simultaneously. The limit values for simultaneous application of tensile load and torque for pipe of different material groups and degrees of wear shall be selected according to Equation (B.21).

Figures 9, 10, 11 and 12 include the sample graphs that show the combination of tensile load and torque for new aluminium drill pipe 147 × 11 of four material groups at different operation temperatures. The graphs were plotted using Equation (B.21), taking into account 5.3.3.

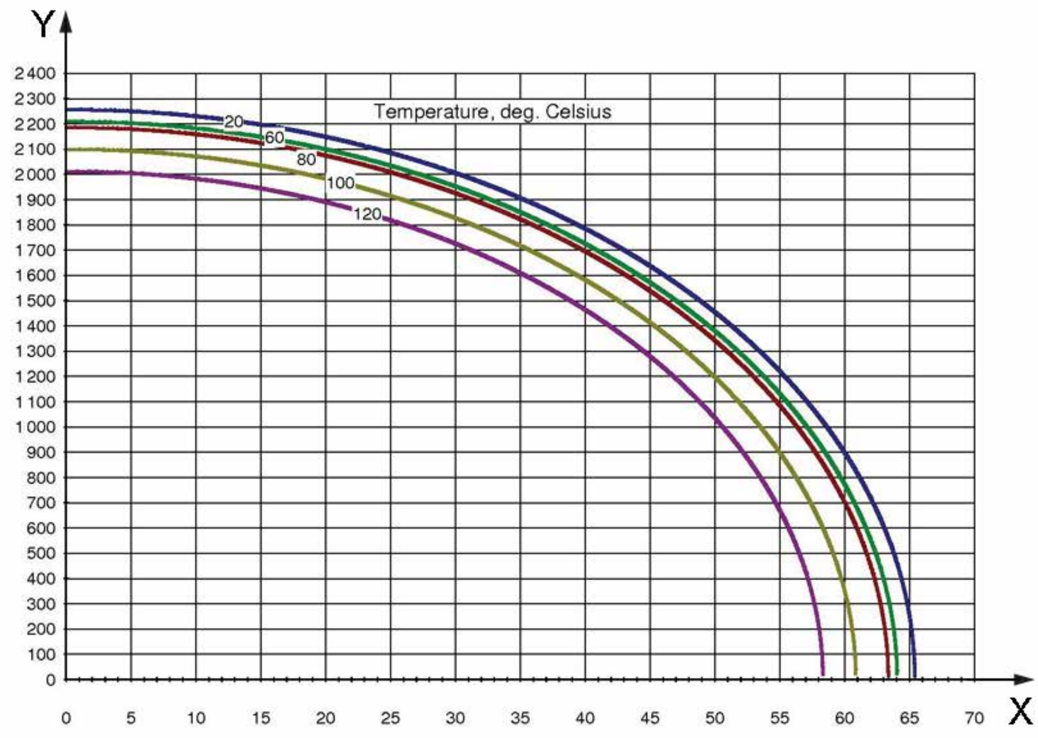


Key

X torque, kN·m

Y axial load, kN

Figure 9 — Permissible tensile loads and torque combination applied to new aluminium drill pipe 147 × 11 of material group I at particular temperatures

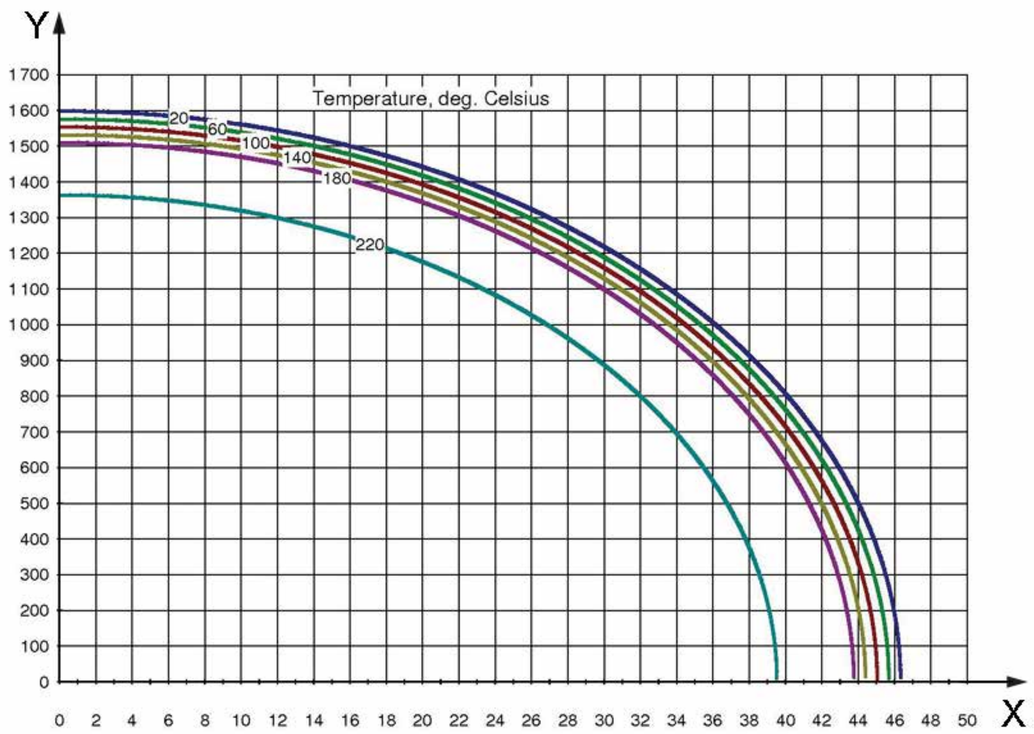


Key

X torque, kN·m

Y axial load, kN

Figure 10 — Permissible tensile loads and torque combination applied to new aluminium drill pipe 147 × 11 of material group II at particular temperatures

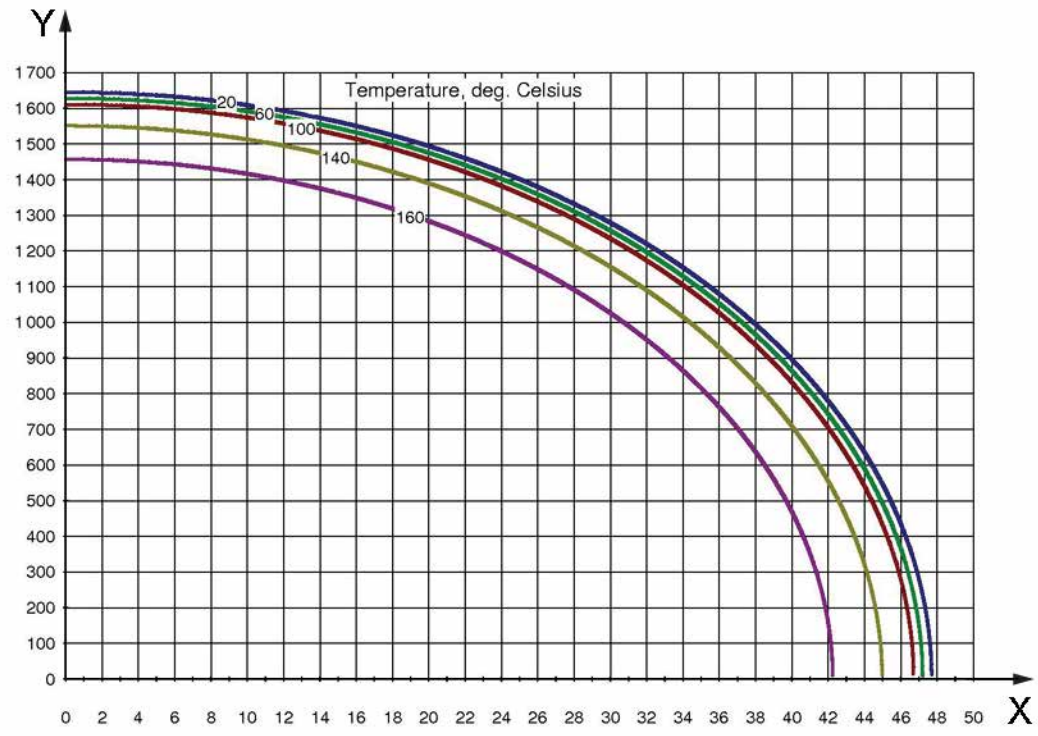


Key

X torque, kN·m

Y axial load, kN

Figure 11 — Permissible tensile loads and torque combination applied to new aluminium drill pipe 147 × 11 of material group III at particular temperatures



Key

X torque, kN·m

Y axial load, kN

Figure 12 — Permissible tensile loads and torque combination applied to new aluminium drill pipe 147 × 11 of material group IV at particular temperatures

8 Wear-based inspection, identification and classification of aluminium drill pipe

8.1 Inspection

8.1.1 The inspection company shall have a detailed written inspection programme and certified personnel to perform non-destructive examination. ISO 9712 or ASNT SNT-TC-1A shall be applied as the basis.

8.1.2 All drill pipe to be inspected shall be marked with permanent serial numbers as assigned by the manufacturer or the owner. Any component found unnumbered or without a clear number shall be assigned with a number as agreed with the owner and/or user. The technical documents attached shall identify where the number is located on the drill pipe.

8.1.3 The owner/operator shall provide the inspector with a work place or deliver each aluminium drill pipe to be inspected to the location suitable for inspection where the pipe can be visually inspected on the appropriately elevated rack. The aluminium drill pipe shall be placed in single layer so that it can be fully turned (rolled) around during inspection. Failure to fulfil this requirement will prevent the proper inspection performance as required by this International Standard. All connection threads and torque shoulders shall be covered with thread protectors.

8.1.4 All of the inspection companies shall comply with all applicable regulatory guidelines and shall have appropriate inspection procedures, test methods and applicable documents at the work place.

8.1.5 Inspections shall not begin without all the equipment being checked and adjusted as required, in order to ensure full compliance with the inspection to be performed. Good housekeeping of the inspection area and equipment shall be maintained.

8.1.6 The pipe user/owner shall establish the inspection frequency of the pipe in use. Recommended field inspection intervals are shown in the Table 10.

Table 10 — Recommended field inspection intervals

Description		Interval	
		Rotary drilling	**Downhole motor drilling**
Measuring pipe and tool joint wear with limit snap gauges		After 200 h	After 400 h
Inspection of tool joint thread wear (end clearance)		After 40 round trips	
Drill pipe thickness gauging		After 200 h	After 400 h
Non-destructive drill pipe inspection to detect fatigue cracks when drilling depth is	up to 3 000 m	After 450 h	After 600 h
	from 3 000 m to 5 000 m	After 300 h	After 450 h
	over 5 000 m	After 200 h	After 250 h
NOTE 1 The inspection intervals are approximate, since they will depend on specific drilling condition variables.			
NOTE 2 Non-destructive drill pipe inspection is performed for TT type thread connection, upset transition zone and stabilizing shoulder, as most probable areas for detection of fatigue cracks.			

8.1.7 Aluminium drill pipe in use is subject to the non-destructive examination types described below.

a) Visual inspection:

— defects on the outside and inside pipe surfaces (dents, deep longitudinal and transverse scratch mark, pitting, lamination, exfoliation corrosion, general corrosion damage);

— tool joint defects inspection (thread wear, thread surface conditions, pin and box torque shoulder surface conditions, eccentric circumferential wear, adequate tong space);

— tool joint circumferential displacement on the pipe: at the time of original tool joint installation or prior to its first use, the pipe and tool joint connection may be marked on the tool joint and the pipe body, one mark applied on the tool joint (on the side facing the pipe) and another on the pipe, these two marks being located in line; a change in circumferential displacement between the two marks will indicate that movement has occurred from the original tool joint/pipe position and the tool joint shall be repaired or rejected as described in g) below.

b) Dimensional inspection:

— determine the minimum outside diameter of the pipe;

— determine the pipe body eccentric wear;

— determine the minimum and maximum pin and box outside diameters;

— determine the tool joint outside diameter eccentric wear;

— determine the minimum width of the pin and box torque shoulder faces;

— determine the pin thread stretch.

c) Magnetic particle testing:

— tool joint pin and box threads may be tested by the wet magnetic-particle-inspection method.

d) Pipe thread and stabilizing shoulder ultrasonic testing:

— examine for fatigue cracking in the TT type thread in the pipe and tool joint connection;

— the zone of stabilizing shoulder shall be examined as well.

e) Ultrasonic testing of the pipe body and upset transition sections:

— examine for longitudinal and transverse flaws;

— examine for pitting.

f) Pipe wall thickness inspection:

— measure the pipe wall thickness with a $450\left(^{0}_{-50}\right)$ mm helical path along the entire pipe length;

— determine the minimum pipe wall thickness.

g) Pipe and tool joint connection quality control, which shall include the following:

— examination for radial clearance between the back side OD taper of the connected tool joint and pipe OD around the entire stabilizing shoulder, using a steel probe approximately 12 mm wide and 0,3 mm thick; should the probe be able to penetrate the gap at 5 mm or deeper, the connection shall be deemed defective and the pipe shall be rejected;

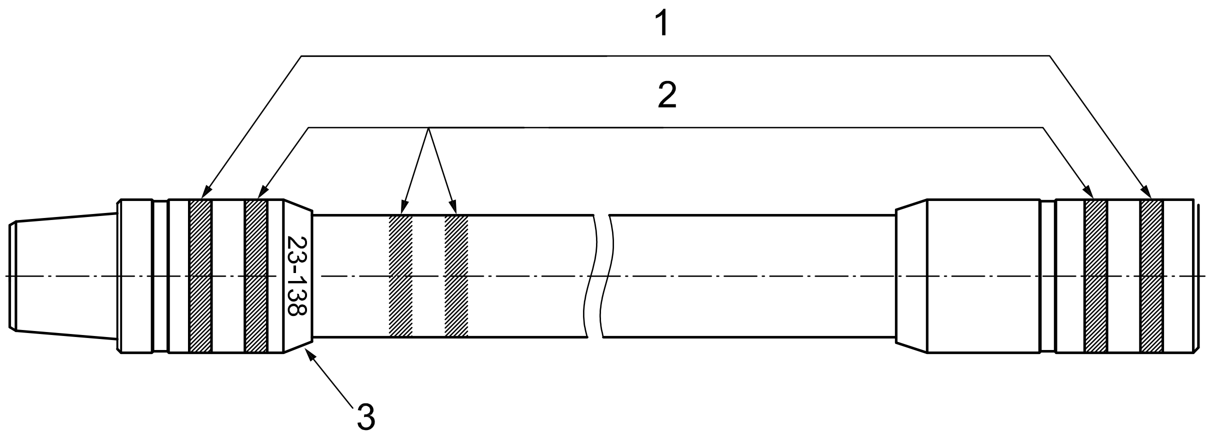
— the clearance between the pipe nose end and the internal tool joint shoulder face shall be identified using the same probe, the clearance being checked across the entire connection circumference; should the probe be able to penetrate the end clearance by more than 5 mm, the pipe/tool joint shall be deemed defective and the pipe shall be rejected.

8.1.8 Inspection of each drill stem element shall require that all the procedures required for this category have been completed before each length is classified. There are cases, however, when such conditions as cracks, pits or unrepairable conditions are identified before the required procedures have been completed. All inspection procedures shall be discussed and agreed upon by the parties involved prior to work start-up.

8.1.9 When the inspection is finished all the magnetic particle fluids, wetting agents, liquid penetrant, wiping material, etc., shall be removed from all connections and aluminium drill pipe surfaces. The clean aluminium drill pipe threads shall be coated with an API thread compound or an alternative specified by the owner or user. After that, the tool joint pins and boxes shall be covered with thread protectors to prevent mechanical impact and damage of the thread.

8.2 Wear-based marking and identification of pipe and tool joints

Wear-based marking and identification of pipe and tool joints is as specified in Figure 13 and Table 11.



Key

1 stripes to indicate the tool joint conditions

2 stripes to indicate the pipe and tool joint classification

3 location to mark the pipe classification and pipe serial number if no permanent OEM (original equipment manufacturer)/owner serial number is stamped on the drill pipe

Figure 13 — Drill pipe and tool joint identification colour codes

Table 11 — Drill pipe and tool joint identification colour codes

Tool joint and pipe class	Number and colour of strips	Tool joint condition	Strip colour
New	One white	—	—
Premium Class	Two white	To be field repaired	Green
Class 2	One yellow	Scrap or shop repair is required	Red
Scrap	One red	—	—

8.3 Wear-based pipe classification

Based on the visual, mechanical, non-destructive examination and thickness gauging results, the pipe class is assigned (New to Premium Class, Premium Class to Class 2) or the pipe is completely rejected (see Table 12).

Table 12 — Pipe classification based on the outer diameter wear and wall thickness

Pipe body flaw type	Premium class %	Class 2 %	To be rejected %
Minimum used pipe body wall thickness at uniform wear of outside surface	80	70	< 65
Maximum dents, necking or bearing failure to outside diameter	3	5	> 5
Maximum residual necking or expansion to outside diameter	3	5	> 5
Minimum wall thickness under longitudinal grooves	80	70	< 65
Minimum wall thickness under transverse grooves	90	80	< 80
Maximum groove length to pipe circumference	10	10	> 10
Minimum wall thickness in deepest corrosion pit to nominal thickness value	80	70	< 65

8.4 Wear-based tool joints classification

The pipe class is assigned on the basis of the visual examination of the tool joint and its outside diameter gauging results. Tool joint outside diameters, for different wear classes, are established based on the remaining torsional yield strength of the tool joint after wear of its outside surface and reduction of wall thickness. Remaining torsional yield strength shall be not less than 80 % of the new tool joint torsional yield strength for Premium class ADP and not less than 70 % of the new tool joint torsional yield strength for Class 2 ADP. If the tool joint outside diameter is found to be less than the minimal for Class 2, ADP shall be rejected.

Table 13 — Wear classification of tool joint

Dimensions in millimetres

Tool joint nominal outside diameter	Thread type	Tool joint minimum outside diameter	
		Premium class	Class 2
80	NC 23	77,0	75,5
95	NC 26	90,6	88,4
108	NC 31	103,6	101,4
118	NC 38	114,8	113,2
120,6	NC 38	116,9	115,0
127	NC 38	122,0	119,5
145	NC 44	139,5	136,7
155	NC 50	150,7	148,5
162	NC 50	156,3	153,4
172	5 1/2 FH	167,3	164,9
178	5 1/2 FH	172,1	169,1
195	6 5/8 FH	190,4	188,2
203	6 5/8 FH	196,4	193,8

NOTE Calculated values are based on Equation (B.15), yield strength of the material and dimensions of tool joint rotary shouldered connection as defined in ISO 15546.

8.5 Pipe repairing and discarding

8.5.1 If the aluminium drill pipe end clearance is below the lower limit specified for the Class 2 tool joints, as caused by the thread wear, while the pipe and tool joint outside diameter wear allows for further use, the pipe shall be repaired by rethreading the tool-joint thread.

8.5.2 If the tool joints are to be repaired, the minimum tong space shall be defined before the pipe is repaired/used again. The tong space length shall be large enough to ensure the complete tong dies grip along their entire length; additionally, appropriate free space shall be reserved to allow the driller or worker to visually verify that the coupled shoulders or connections are clear for damage-free connection make-up or break-out operation.

Caution may be necessary to define other minimum tong space length that differs from the length required above. In such cases, the user shall apply the criteria required to ensure compliance with these guidelines. The selected minimum tong space lengths shall be defined upon the parties' agreement.

8.5.3 The pipe shall be discarded only based on its physical deterioration after final rejection in conformity with the data of Tables 12 and 13.

9 Transportation and storage of pipe

9.1 Transportation of pipe

9.1.1 Aluminium drill pipe may be transported in packs. Packs, depending on the size of pipe and their amount, shall contain from six to 25 pipes.

9.1.2 Packs, for increase of rigidity and protection against mechanical damages, shall have wooden pads between horizontal and vertical rows of pipe, and the whole pack shall be tied up together in four or five sections along the length of the pack with cargo polypropylene or steel tape. The tape shall be not less than 15 mm in width.

9.1.3 Between packs of pipe, not less than five wooden linings shall be put for protection from damages and providing convenience during loading operations.

Loading and unloading of packs of pipe from a vehicle shall be made by mechanized load-lifting devices, with strict following of safety rules for handling long length loads.

9.1.4 The pipe bundles shall be loaded and unloaded from the vehicle using power-driven lifting devices, in accordance with the safe practices of long items handling.

9.2 Storage of pipe

9.2.1 Separate pipe or pipe in packs shall be stored on racks. Pipe shall not be stacked directly on the ground, rails or concrete floor.

9.2.2 The surface of racks in contact with pipe (basic surface) shall be horizontal enough to prevent spontaneous rolling of pipe.

9.2.3 The height of basic surface of racks shall be not less than 499 mm from the ground, while the height of stacked pipe shall be no more than 2 500 mm.

9.2.4 Between rows or packs of pipe on a rack, no fewer than three wooden pads shall be placed. Between a basic surface of a rack and the first row of pipe, there shall be dielectric linings which could hold the full weight of all pipe without deformation.

9.2.5 Pipe tool joints shall be covered with preservative greasing, and threads shall be secured with protective caps.

9.2.6 On each rack pipe of only one standard size, material and a class of wear shall be placed. The rack shall be equipped with a sign showing the characteristics of stored pipe.

9.2.7 When preparing pipe that is in operation, for storage, its internal and external surfaces shall be washed out by fresh water, and tool joints shall be covered with preservative greasing.

9.2.8 Acids in open containers, alkali and other chemical materials shall be placed at a sufficient distance from the racks with stored pipe to avoid reaction causing corrosion of pipe and tool joints.

Annex A
(informative)

Drill pipe design, range and technical properties of integral tool joint ADP and heavy wall ADP

A.1 This annex contains a number of figures and tables with sizes, mechanical properties and operating performance of new integral joint drill pipe that are not covered by ISO 15546.

Separate tables present the data on the drill pipe torsional yield strength, tension yield strength, and resistance against internal and external pressures.

A.2 Integral joint ADP designs are shown in Figure A.1.

The distinguishing feature of integral joint ADP is that the tool joint thread is cut directly on the upset ends of the pipe. The absence of steel joints gives them additional specific properties (full diamagneticity, possibility of quick drilling out under emergency conditions).

A.3 Dimensions and weight of integral joint ADP are shown in Table A.1.

A.4 Strength characteristics of ADP with integral tool joints are given in Tables A.1, A.2 and A.3.

A.5 Heavy wall ADP (see Figure A.2) are used as elements of the bottom part of drill string as diamagnetic pipe, as vibration absorbing elements in BHA, and as connecting pipe for gentle rigidity transition from steel drill collars to ADP.

A.6 Dimensions and weight of heavy wall ADP are shown in Table A.4.

A.7 Strength characteristics of heavy wall ADP are given in Tables A.5 and A.6.

A.8 Heavy wall ADP is supplied in a ready-assembled state with tool joints.

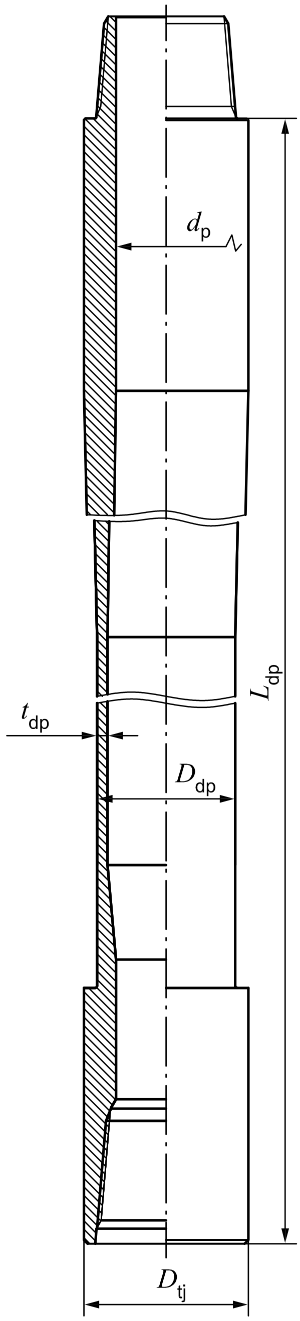


Figure A.1 — ADP with integral tool joints

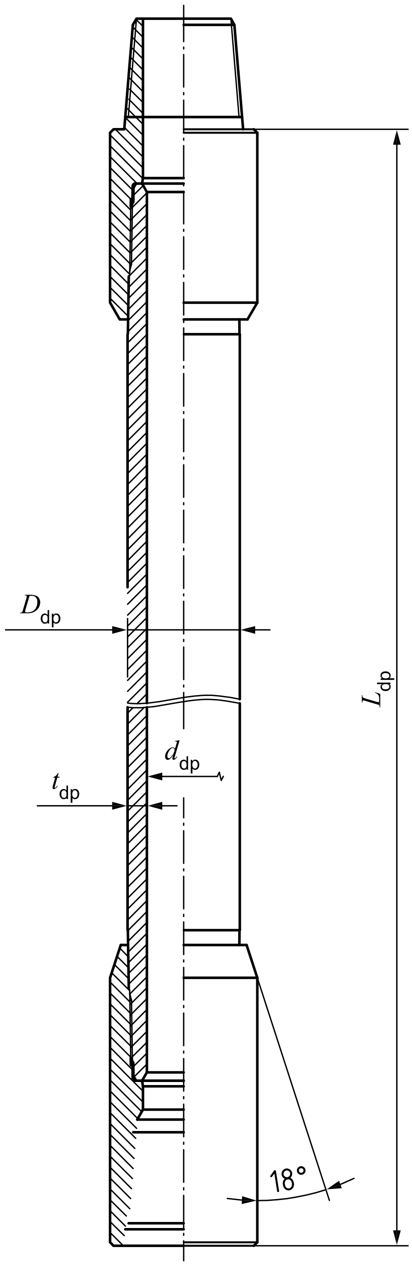


Figure A.2 — Heavy wall ADP

Table A.1 — Characteristics of ADP with integral tool joints

Outside diameter D_{dp}	Wall thickness t_{dp}	Tool joint		Pipe length L_{dp}	Pipe mass	Thread
		OD D_{tj}	ID d_p	$^{+200}_{-250}$		
mm	mm	mm	mm	mm	kg	
128	11	155	95	12 400	163,4	NC 50
146	11	174	106	12 400	189	5 1/2 FH

Table A.2 — ADP with integral tool joint strength characteristics

Outside diameter D_{dp} mm	Wall thickness t_{dp} mm	Tension yield strength[a] kN				Torsional yield strength[b] kN·m				Recommended make-up torque[c] kN·m			
		Material group				Material group				Material group			
		I[d]	II	III	IV	I	II	III	IV	I	II	III	IV
128	11	1 313	1 940	1 374	1 414	19,7	29,0	20,6	21,2	11,8	17,4	12,3	12,7
146	11	1 515	2 238	1 585	1 632	26,4	39,0	27,7	28,5	15,9	23,4	16,6	17,1

NOTE Pipe torsional yield strength is given for the weakest part of drill pipe (tool joint connection).

[a] The recommended value shall be calculated based on Equation (B.6).

[b] Value is calculated by Equation (B.15).

[c] Value is calculated by Equations (B.15) and (B.16).

[d] Material groups are as defined in ISO 15546.

Table A.3 — ADP with integral tool joints strength characteristics

Outside diameter D_{dp} mm	Wall thickness t_{dp} mm	Internal yield pressure[a] MPa				Collapse pressure[b] MPa			
		Material group				Material group			
		I[c]	II	III	IV	I	II	III	IV
128	11	55,9	82,5	58,4	60,2	46,6	64,5	48,5	49,8
146	11	49,0	72,3	51,2	52,7	38,8	51,9	40,2	41,2

[a] Value is calculated by Equation (B.8).

[b] Value is calculated by Equation (B.9).

[c] Material groups are as defined in ISO 15546.

Table A.4 — Heavy wall ADP

Outside diameter D_{dp} mm	Wall thickness t_{dp} mm	Inside diameter d_{dp} mm	Pin inside diameter d_p mm	Tool joint outside diameter D_{tj} mm	Pipe length L_{dp} mm	Pipe mass kg	Thread
91	20	51	54	120,6	9 290	136	NC 38
103	20	63	68	127	9 310	157	NC 38
114	20	76	80	152	9 325	192	NC 46
129	22	84	89	162	9 350	235	NC 50
147	25	97	101	178	9 340	292	5 1/2 FH
168	27	114	127	203	9 330	367	6 5/8 FH

Table A.5 — Strength characteristics of heavy wall ADP

Outside diameter D_{dp} mm	Wall thickness t_{dp} mm	Tension yield strength[a] kN				Torsional yield strength[b] kN·m				Recommended make-up torque[c] kN·m
		Material group				Material group				
		I[d]	II	III	IV	I	II	III	IV	
91	20	1 449	2 140	1 516	1 561	19,8	29,3	20,8	21,4	15,5
103	20	1 694	2 502	1 772	1 824	27,5	40,5	28,7	29,6	15,0
114	20	1 919	2 834	2 007	2 066	35,6	52,6	37,2	38,3	29,1
129	22	2 402	3 548	2 513	2 587	50,9	75,2	53,2	54,8	36,1
147	25	3 113	4 597	3 256	3 352	75,2	111,1	78,7	81,0	46,0
168	27	3 885	5 738	4 064	4 184	109,2	161,2	114,2	117,5	59,7

a Value is calculated by Equation (B.6).

b Value is calculated by Equation (B.15).

c Value is calculated by Equations (B.15) and (B.16); yield strength of the material and dimensions of tool joint connection as defined in ISO 15546 and ISO 11961.

d Material groups are as defined in ISO 15546.

Table A.6 — Strength characteristics of heavy wall ADP

Outside diameter D_{dp} mm	Wall thickness t_{dp} mm	Internal yield pressure[a] MPa				Collapse pressure[b] MPa			
		Material group				Material group			
		I[c]	II	III	IV	I	II	III	IV
91	20	142,9	211,0	149,5	153,8	136,3	200,8	142,5	146,7
103	20	126,2	186,4	132,0	135,9	119,5	175,9	125,0	128,7
114	20	114,0	168,4	119,3	122,8	107,2	157,6	112,1	115,4
129	22	110,9	163,7	116,0	119,4	104,0	152,8	108,8	111,9
147	25	110,5	163,3	115,6	119,0	103,7	152,3	108,5	111,6
168	27	104,5	154,3	109,3	112,5	97,6	143,1	102,0	105,0

a Value is calculated by Equation (B.8).

b Value is calculated by Equation (B.9).

c Material groups are as defined in ISO 15546.

Annex B
(normative)

Calculations

B.1 Equation (B.1) calculates the pipe cross-sectional area, A_{dp}, in square millimetres.

$$A_{dp} = 0{,}785\,4 \times \left(D_{dp}^{\;2} - d_{dp}^{\;2} \right) \tag{B.1}$$

where

D_{dp} is the pipe body outside diameter, expressed in millimetres;

d_{dp} is the pipe body inside diameter, expressed in millimetres.

B.2 Equation (B.2) calculates the polar sectional modulus of torsion of pipe body, W_p, in cubic millimetres.

$$W_p = \frac{3{,}14 \times \left(D_{dp}^{\;4} - d_{dp}^{\;4} \right)}{16 \times D_{dp}} \tag{B.2}$$

where

D_{dp} is the pipe body outside diameter, expressed in millimetres;

d_{dp} is the pipe body inside diameter, expressed in millimetres.

B.3 Equation (B.3) calculates the mass per linear metre of the pipe including the upset, protector and tool joint, M_{dp}, in kilograms per metre.

$$M_{dp} = M_B + \frac{m_u + m_p + m_{tj}}{L_{dp}} \tag{B.3}$$

where

M_B is the plain end pipe body mass per linear metre, expressed in kilograms per metre;

m_u is the mass gain due to upsets, expressed in kilograms;

m_p is the mass gain due to protector thickening, expressed in kilograms;

m_{tj} is the tool joint mass, expressed in kilograms;

L_{dp} is the pipe length with tool joint, expressed in metres.

B.4 Equation (B.4) calculates the equivalent density of ADP with tool joints, ρ_e, in kilograms per cubic metre.

$$\rho_e = \frac{m_b + m_u + m_p + m_{tj}}{\left(\dfrac{m_b + m_u + m_p}{\rho_{Al}}\right) + \left(\dfrac{m_{tj}}{\rho_{St}}\right)} \tag{B.4}$$

where

ρ_{Al} is the density of aluminium alloy (pipe body), expressed in kilograms per cubic metre;

ρ_{St} is the density of steel (tool joints), expressed in kilograms per cubic metre;

m_b is the mass of plain end pipe body, expressed in kilograms;

m_u is the mass gain due to upsets, expressed in kilograms;

m_p is the mass gain due to protector thickening, expressed in kilograms;

m_{tj} is the tool joint mass, expressed in kilograms.

B.5 Equation (B.5) calculates the weight per unit length of the pipe in drilling mud, w_m, in newtons per metre.

$$w_m = w_0\left(1 - \frac{\rho_{dm}}{\rho_e}\right) \tag{B.5}$$

where

ρ_{dm} is the drilling mud density, expressed in kilograms per cubic metre;

ρ_e is the equivalent density of pipe with tool joints, expressed in kilograms per cubic metre;

w_0 is the weight per unit length of pipe in air, expressed in newtons per metre, calculated as follows:

$$w_0 = M_{dp} \times g$$

where

M_{dp} is the pipe mass per linear metre, expressed in kilograms per metre;

g is the acceleration of gravity (9,81 m/s^2).

B.6 Equation (B.6) calculates the maximum tension yield strength of aluminium alloy pipe, P_{max}, expressed in kilonewtons.

$$P_{max} = A_{dp} Y_{min} \times 10^{-3} \tag{B.6}$$

where

A_{dp} is the pipe body cross-sectional area, expressed in square millimetres;

Y_{min} is the minimum yield strength, expressed in megapascals.

B.7 Equation (B.7) calculates the maximum torsional yield strength for pipe body, T_{max}, expressed in kilonewton-metres.

$$T_{max} = \tau_{min} W_p \times 10^{-6} \quad \text{(B.7)}$$

where

τ_{min} is the shear stress, reaching minimum yield strength (τ = 0,457 8 × Y_{min} for aluminium alloys), expressed in megapascals;

W_p is the polar sectional modulus of torsion, expressed in cubic millimetres.

B.8 The internal yield pressure at which the pipe body stress reaches the yield limit, P_{iy}, expressed in megapascals, shall be derived from Equation (B.8).

$$P_{iy} = \frac{2 Y_{min} t_{dp}}{D_{dp}} \quad \text{(B.8)}$$

where

Y_{min} is the pipe material yield strength, expressed in megapascals;

t_{dp} is the wall thickness, expressed in millimetres;

D_{dp} is the pipe body outside diameter, expressed in millimetres.

B.9 The collapse pressure at which the pipe body stress reaches the yield limit shall be derived from Equations (B.9) and (B.10) (see API RP 2RD):

— the collapse pressure for round pipe, P_0, expressed in megapascals, is given by Equation (B.9):

$$P_0 = P_e P_y \left(P_e{}^2 + P_y{}^2 \right)^{-1/2} \quad \text{(B.9)}$$

— the collapse pressure for imperfect pipe, P_c, expressed in megapascals, is given by Equation (B.10):

$$P_c = P_0 \left(\psi - \frac{s}{s_0} \right) \quad \text{(B.10)}$$

where

P_y is the yield pressure with simultaneous tension, $P_y = \frac{2 \sigma_r t_{dp}}{D_{dp}}$, expressed in megapascals;

P_e is the elastic bending pressure, $P_e = \left[\frac{2E}{1-\mu^2} \left(\frac{t_{dp}}{D_{dp}} \right)^3 \right]$, expressed in megapascals;

ψ is the imperfection function, $\psi = \frac{\left(1+k^2\right)^{1/2}}{\left(k^2 + \frac{1}{\varphi^2}\right)^{1/2}}$;

s is the bending strain experienced by tubular;

s_0 is the critical bending strain, $s_0 = \frac{t_{dp}}{2bD_{dp}}$;

σ_r is the reduced yield stress $\sigma_r = Y_{min}\left\{\left[1-3\left(\frac{S_a}{2Y_{min}}\right)^2\right]^{1/2} - \left(\frac{S_a}{2Y_{min}}\right)\right\}$, expressed in megapascals;

D_{dp} is the pipe outside diameter, expressed in millimetres;

t_{dp} is the pipe outside wall thickness, expressed in millimetres;

E is the modulus of elasticity;

μ is the Poisson's ratio;

Y_{min} is the specified minimum yield stress, expressed in megapascals;

k is the plastic-to-elastic-collapse ratio, $k = \frac{P_y}{P_e}$;

b is the strain reduction factor (b = 1,5 for API pipe);

S_a is the mean axial stress, expressed in megapascals, calculated as follows:

$$S_a = \frac{P_T - (P_{ext} \times A_{OD})}{a_W}$$

where

P_T is the effective tensile load on tubular, expressed in kilonewtons;

P_{ext} is the net external pressure, expressed in megapascals, calculated as follows:

$$P_{ext} = \rho_{dm} H_{dm} - P_i$$

where

ρ_{dm} is the drilling mud density, expressed in kilograms per cubic metre;

H_{dm} is the drilling mud depth, expressed in metres;

P_i is the internal pressure, expressed in megapascals;

A_{OD} is the cross-sectional area circumscribed by pipe outside diameter, $A_{OD} = \frac{\pi D^2}{4}$, expressed in square millimetres;

a_w is the cross-sectional area of pipe wall with regard to pipe ovality, $a_w = \pi \left[\frac{D^2 - (D - 2t)^2}{\varphi} \right]$, expressed in square millimetres;

φ is the out-of-roundness function, $\varphi = \left[1 + \left(\frac{O_i D}{t} \right)^2 \right]^{1/2} - \frac{O_i D}{t}$;

O_i is the initial ovality, $O_i = \frac{(D_{max} - D_{min})}{(D_{max} + D_{min})}$;

D_{max} is the maximum outside diameter of pipe, expressed in millimetres;

D_{min} is the minimum outside diameter, expressed in millimetres.

B.10 Equation (B.11) calculates the "strength-to-weight" ratio, L, expressed in metres:

$$L = \frac{Y_{min} \times 10^6}{9,81 \times (\rho_e - \rho_{dm})} \tag{B.11}$$

where

Y_{min} is the pipe material minimum yield strength, expressed in megapascals;

ρ_e is the equivalent density of pipe material, expressed in kilograms per cubic metre;

ρ_{dm} is the density of drilling mud, expressed in kilograms per cubic metre.

B.11 Equation (B.12) is the most conservative equation for prediction of drill string sinusoidal buckling in straight boreholes:

$$P_{sin} = 2\sqrt{\frac{E \times I \times w_m \times \sin\alpha}{\delta}} \tag{B.12}$$

whilst, at curved borehole intervals, it is recommended to use Equations (B.13) and (B.14):

$$\Theta_{min} = \frac{-1746,5\left[W_{eq} + \left(w_m \times \sin\alpha\right)\right]}{P_{sin}} \tag{B.13}$$

$$\Theta_{max} = \frac{-1746,5\left[W_{eq} - \left(w_m \times \sin\alpha\right)\right]}{P_{sin}} \tag{B.14}$$

where

W_{eq} is the buoyant weight equivalent for pipe in a borehole, expressed in newtons per metre, $W_{eq} = \frac{\delta \times P_{sin}^2}{4 \times E \times I}$;

Θ_{min} is the minimum dogleg severity causing buckling, expressed in degrees per 30 m (degrees per 100 ft);

Θ_{max} is the maximum dogleg severity causing buckling, expressed in degrees per 30 m (degrees per 100 ft);

P_{sin} is the axial compressing force which causes initiation of sinusoidal buckling, expressed in newtons;

E is the Young's modulus or modulus of elasticity, expressed in pascals;

NOTE For all aluminium alloys, $E = 7\times10^4$ MPa.

I is the moment of inertia of the pipe body in regard to transverse axis (at bending), expressed in metres to the power of 4, $I = \pi\left(\frac{D_{dp}{}^4 - d_{dp}{}^4}{64}\right)$;

D_{dp} is the pipe outside diameter, expressed in metres;

d_{dp} is the pipe inside diameter, expressed in metres;

w_m is the weight of 1 m of pipe in drilling mud, expressed in newtons per metre;

α is the zenith angle of the studied borehole interval, expressed in degrees;

δ is the gap between borehole wall and tool joint OD, expressed in metres, calculated as follows:

$$\delta = 0{,}5\left(D_h - D_{tj}\right);$$

where

D_h is the average diameter of the borehole at the regarded interval, expressed in metres;

D_{tj} is the tool joint OD, expressed in metres.

The given equations meet recommendations given in API RP 7G. Their thorough description and background is given in References [7], [8] and [9].

B.12 Equation (B.15) (see ISO 10407-1 and API RP 7G) calculates the torque to yield tool joint connection, T_y, expressed in kilonewton-metres:

$$T_y = Y_{min} A_{pb}\left(\frac{p}{2\pi} + \frac{R_t f}{\cos\theta} + R_s f\right)\times10^{-6} \quad \text{(B.15)}$$

where

Y_{min} is the specified minimum yield stress, expressed in megapascals;

A_{pb} is the cross-sectional area of pin A_p or box A_b, whichever is smaller;

A_b is the box cross-sectional area at 9,525 mm from the bearing face, expressed in square millimetres, $A_b = \frac{\pi}{4}\left\{D_{tj}{}^2 - \left[Q_c - \left(\Delta\times 9{,}525\right)^2\right]\right\}$;

A_p is the pin cross-sectional area at 15,875 mm from the bearing face, expressed in square millimetres, $A_p = \frac{\pi}{4}\left[\left(C - B\right)^2 - d_p{}^2\right]$;

p is the lead of thread, expressed in millimetres;

f is the thread friction factor, assumed to be 0,08 (see ISO 10407-1);

θ is the half angle of thread, expressed in degrees;

R_t is a variable, $R_t = \frac{C + \left[C - (L_{pc} - 15{,}875) \times \Delta\right]}{4}$

R_s is a variable, $R_s = \frac{\left(D_{tj} + Q_c\right)}{4}$;

C is the pitch diameter of thread at gauge point, expressed in millimetres;

B is a variable, $B = 2 \times \left(\frac{H}{2} - S_{rs}\right) + \Delta \times 3{,}175$;

d_p is the pin inside diameter, expressed in millimetres;

L_{pc} is the length of the pin that mates with the box, expressed in millimetres;

Δ is the taper;

H is the thread height not truncated, expressed in millimetres;

S_{rs} is the root truncation, expressed in millimetres;

D_{tj} is the tool joint outside diameter, expressed in millimetres;

Q_c is the box counter bore, expressed in millimetres.

NOTE All thread dimensions are listed in ISO 10424-2.

B.13 Equation (B.16) calculates the recommended make up torque for aluminium drill pipe tool-joint thread:

$$T_j = 0{,}6 \times T_y \tag{B.16}$$

where

T_j is the recommended make up torque for the aluminium drill pipe tool joints, expressed in kilonewton-metres;

T_y is the torsional yield limit value, which, when applied, shall cause the tool joint body (pin or box) to be under the tensile (for the pin) and compression (for the box) load equal to the minimum yield strength of the tool joint material (see B.12).

B.14 The axis load when the stress in the body of the pipe gripped in the slips reaches yield strength, P_z, expressed in kilonewtons, is calculated according to Equation (B.17) (see References [15] and [16]):

$$P_z = \frac{Y_{min} \times A_z}{\sqrt{1 + \frac{D_U K}{2L_s} + \left(\frac{D_U K}{2L_s}\right)^2}} \quad (B.17)$$

where

Y_{min} is the pipe material minimum yield strength, expressed in megapascals;

A_z is the cross-sectional area of drill pipe in upset part, expressed in square millimetres;

D_U is the outside diameter of drill pipe in upset part, expressed in millimetres;

K is the transverse load factor, $K = \frac{1}{\tan(\alpha_{SL} + \psi_{SL})}$;

α_{SL} is the slips taper angle, α_{SL} = 9°27'45";

ψ_{SL} is the friction angle, $\psi_{SL} = \tan^{-1} \mu_{SL}$;

μ_{SL} is the coefficient of friction between slips and master bushing;

L_s is the length of slip contact with drill pipe, expressed in millimetres;

Equation (B.17) is based on the Reinhold and Spiri formula (see ISO 10407-1) with regard to the increase of the pipe wall thickness in the upset part, where the slips come in contact with pipe body.

B.15 The minimum height of drilling fluid to be added into string for prevention of its collapse due to external pressure, h, expressed in metres, shall be derived from Equation (B.18):

$$h = h_{DS} - \frac{P_0}{\rho_{dm}} \quad (B.18)$$

where

h_{DS} is the drilling string setting depth, expressed in metres;

P_0 is the collapse pressure, expressed in pascals;

ρ_{dm} is the drilling mud density, expressed in kilograms per cubic metre.

B.16 In order to determine the true position of the rock cutting tool (drill bit) in a well, the corrections related to the drilling string elastic and thermal elongation shall be introduced. For aluminium alloy drill pipe these values are essential and shall be derived from Equation (B.19):

$$\Delta L = \sum_{K-1}^{n} \left(\Delta l_{BHA} + \Delta l_w + \Delta l_t\right) \quad (B.19)$$

where

ΔL is the overall elongation of combined drill string, expressed in metres;

Δl_W is the elongation of the relevant drill string section "K" under its own weight, expressed in metres,

$$\Delta l_w = \frac{9{,}81 \times l_K{}^2 M_K \left(1 - \frac{\rho_{dm}}{\rho_e}\right)}{2 \times E \times A_{dp}};$$

Δl_t is the thermal elongation, expressed in metres, $\Delta l_t = \frac{a_e \eta}{3}\left(h_K{}^2 - h_{K\text{-}1}{}^2\right)$;

Δl_{BHA} is the elongation under the weight of the downhole sections and BHA, expressed in metres;

n is the number of the drill string sections;

l_K is the length of section "K", expressed in metres;

M_K is the mass per unit length of drill pipe in drill string section "K", expressed in kilograms per metre;

ρ_{dm} is the drill mud density, expressed in kilograms per cubic metre;

ρ_e is the equivalent density of drill pipe, expressed in kilograms per cubic metre;

E is the Young modulus of drill pipe material, expressed in megapascals;

A_{dp} is the pipe body cross-sectional area, expressed in square millimetres.

a_e is the coefficient of linear expansion of the material of the pipe, expressed in degrees Celsius to the power of –1;

η is the temperature gradient, expressed in degrees Celsius per metre;

h_K is the well depth at the upper limits of this section;

$h_{K\text{-}1}$ is the well depth at the lower limits of this section;

p_K is the tensile stress applied to the bottom cross-section of section "K", expressed in kilonewtons.

B.17 Equation (B.20) calculates the maximum permissible dogleg severity of the drill pipe, Θ, expressed in degrees per 30 m (100 ft):

$$\Theta = 3\,493 \times 10^3 \times \frac{S_b}{E \times D_{dp}} \times \frac{\tanh F \times L_{1/2}}{F \times L_{1/2}} \tag{B.20}$$

where

S_b is the maximum permissible bending stress, expressed in megapascals, $S_b = \sigma_{-1}(1 - \frac{S_{DL}}{\sigma_B})$;

E is the Young's modulus, expressed in megapascals (MPa);

F is a variable, $F = \sqrt{\frac{w_{DL}}{E \times I}}$;

$L_{1/2}$ is half the distance between tool joints, expressed in millimetres;

w_{DL} is the buoyant weight (including tool joints) suspended below the dogleg, expressed in kilonewtons;

I is the drill pipe moment of inertia in regard to transverse axis, expressed in millimetres to the power of 4, $I = \frac{\pi}{64}\left(D_{dp}{}^4 - d_{dp}{}^4\right)$;

D_{dp} is the drill pipe outside diameter, expressed in millimetres;

d_{dp} is the inside diameter of pipe body, expressed in millimetres;

S_{DL} is the stress produced by the buoyant weight of the drill string below dogleg, expressed in megapascals, $S_{DL} = \frac{w_{DL}}{A_{dp}}$;

σ_{-1} is the endurance limit of the drill pipe (minimum endurance limit for ADP is determined by ISO 15546 as 50 MPa at 2×10^6 cycles of alternative loading), expressed in megapascals;

σ_b is the pipe material ultimate strength, expressed in megapascals;

A_{DP} is the cross-sectional area of drill pipe body, expressed in square millimetres.

B.18 Equation (B.21) calculates the correlation between the tensile strength and torque under emergency conditions. The static strength condition for any design section of aluminium alloy drill string is as follows:

$$\left|\sigma_i\right| = \sqrt{\sigma^2 + K\tau^2} = \sqrt{\left(\frac{P}{A_{dp}}\right)^2 + A\left(\frac{T}{W_p}\right)^2} \le Y_{min} \quad \text{(B.21)}$$

where

σ_i is the allowable stress intensity calculated as adjusted to the normative safety factors, expressed in megapascals;

σ is the level of normal stresses applied to the design sections of drill string, $\sigma = \frac{P}{A_{dp}}$,expressed in megapascals;

P is the load applied to the drill string, expressed in kilonewtons;

A_{dp} is the cross-sectional area of the drill pipe, expressed in square millimetres;

τ is the level of tangential stresses applied to the drill string, expressed in megapascals, $\tau = \frac{T}{W}$;

T is the torque applied to the drill string, expressed in kilonewton-metres;

W_p is the polar sectional modulus of torsion, expressed in cubic millimetres;

A is the factor depending on the failure theory selected for calculations and adjusted for anisotropy of aluminium alloy drill pipe material;

NOTE A usually takes the value of 4,77 for aluminium alloy drill pipe for calculation purposes, when the basic parameter is the yield strength at 20° C; A value diminishes and approaches 4,0 as long as the operating temperature grows.

Y_{min} is the pipe material minimum yield strength, expressed in megapascals.

Annex C
(informative)

Conversion of SI units to USC units

Table C.1 — Conversion of SI units to USC units

Derived quantity	SI derived unit		Expressed in terms of SI base units and SI derived units
	name	symbol	
Length	millimetre	mm	1 mm = 0,039 37 in
	metre	m	1 m = 3,280 8 ft
Area	square millimetre	mm^2	1 mm^2 = 0,001 55 in^2
Mass	kilogram	kg	1 kg = 2,202 6 lb
Force (weight)	newton	N	1 = 0,225 lb
	kilonewton	kN	1 kN = 224,809 lb
Linear mass	mass per linear metre	kg/m	1 kg/m = 0,671 1 lb/ft
Torque	kilonewton-metre	kN·m	1 kN·m = 737,561 ft·lb
Density	kilogram per cubic metre	kg/m^3	1 kg/m^3 = 0,062 4 lb/ft^3 1 kg/m^3 = 0,008 35 lb/gal (ppg)
Curvature	dogleg severity	°/30 m	1°/30 m = 1°/100 ft
Stress, pressure	megapascal	MPa	1 MPa = 145,033 psi

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