Anchorage of tower foundations in rock

Classification of rock ground and design rules

Jessica Ka Yi Chiu, jessica.ka.yi.chiu@ngi.no

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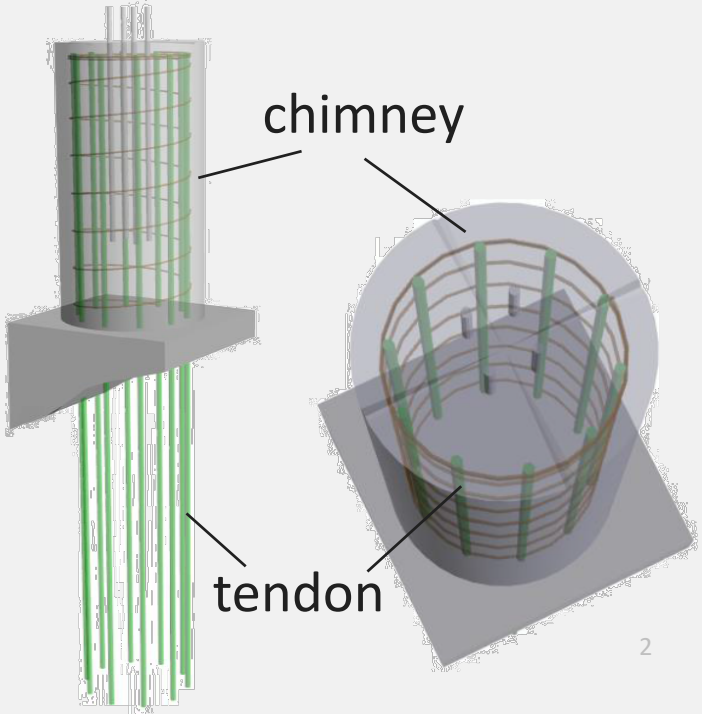
Agenda

1. Background
2. Classification of rock ground
3. Design rules



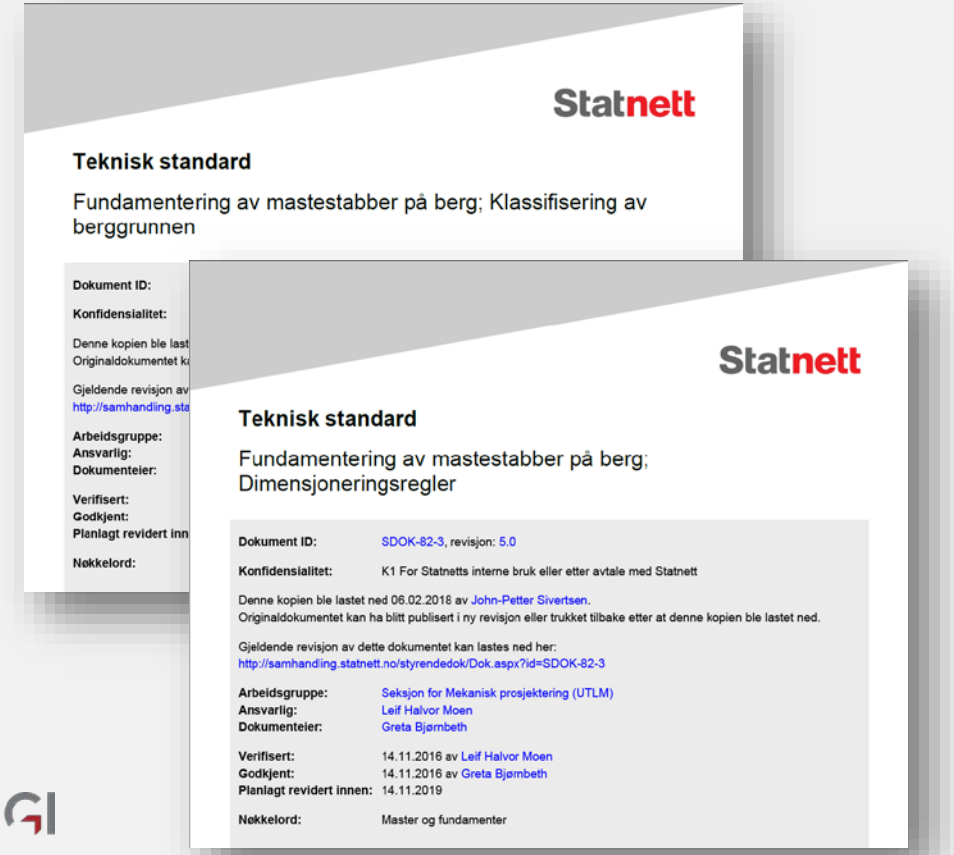
NGI Statnett

Anchorage of power line tower foundation on rock; Classification of rock and design rules

Tore Valstad[1], Einar John Lande[1,2] and Elin Katrine Morgan[1]
[1] *Norwegian Geotechnical Institute (NGI), NO-0806 Oslo, Norway*
[2] *Department of Civil and Transport Engineering – Norwegian University of Science and Technology, NO-7491 Trondheim, Norway*
John-Petter Sivertsen[3]
[3] *Statnett SF, NO-0484 Oslo, Norway*

GEOVANCOUVER 2016

Foundation of tower chimneys on rock



Statnett

Teknisk standard

Fundamentering av mastestabber på berg; Klassifisering av berggrunnen

Dokument ID:

Konfidensialitet:

Denne kopien ble last
Originaldokumentet k

Gjeldende revisjon av
http://samhandling.st

Arbeidsgruppe:
Ansvarlig:
Dokumenteier:

Verifisert:
Godkjent:
Planlagt revidert inn

Nøkkelord:

Statnett

Teknisk standard

Fundamentering av mastestabber på berg; Dimensjoneringsregler

Dokument ID:	SDOK-82-3, revisjon: 5.0
Konfidensialitet:	K1 For Statnetts interne bruk eller etter avtale med Statnett

Denne kopien ble lastet ned 06.02.2018 av John-Petter Sivertsen.
Originaldokumentet kan ha blitt publisert i ny revisjon eller trukket tilbake etter at denne kopien ble lastet ned.

Gjeldende revisjon av dette dokumentet kan lastes ned her:
http://samhandling.statnett.no/styrendedok/Dok.aspx?id=SDOK-82-3

Arbeidsgruppe:	Seksjon for Mekanisk prosjektering (UTLM)
Ansvarlig:	Leif Halvor Moen
Dokumenteier:	Greta Bjørnbeth
Verifisert:	14.11.2016 av Leif Halvor Moen
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Nøkkelord:	Master og fundamenter

- After a power line foundation failure in Sauda – Liastøl, NGI was employed by Statnett to develop a better procedure for rock ground investigation and designing of anchorage of power line tower foundation on rock.
- This resulted in two contract documents: «Classification of rock ground», which presents a procedure for classification of rock ground.
- «Design rules», which presents a procedure for determining bearing capacity of rock ground and required embedment depth of tendons in the tower chimneys based on rock class.

Load scenarios and loads on tower foundations

- Stretching of line
- Wind (50-year return period)
- Icing (150-year return period)

- Vertical compressional and tensile loads
- Horizontal forces
- (Moments)

«Record» in icing on power line (22 kV), ca. 1.5 m ice that constituted ca. 300 kg/m line
Picture from Lønahorgi, 1961 (Olav Wist)

What is the purpose of these specification?

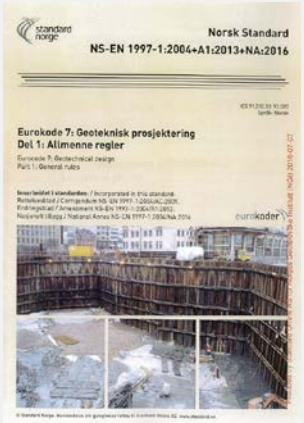
- To establish a safe practise for design of the tower foundations on rock ground, with focus on:

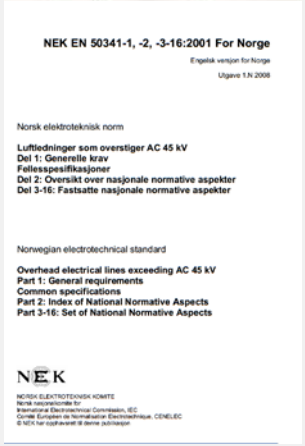
A. Bearing capacity on rock ground

B. Pull-out resistance of the rock ground

Tower 42 Sauda - Liastøl

General information about the specifications





- General rules for design of overhead electric lines are given in NEK-EN 50341-1, and -3-16:2001 «Overhead electric lines exceeding AC 45 kV», however, this does not cover tower foundations in rock.
- Therefore the rules are based on Eurocode 7, NS-EN 1997-1:2004+A1:2013+NA:2016
- The main focus is on anchorage of the chimney foundations against pull-out forces, which is usually controlling the design.
- To be applied by consultants and contractors responsible for design and construction of power lines for Statnett.
- Based on a classification of the rock ground at the site.

Classification of rock ground

Table 1 Classification of rock ground

Rock class	*Designation*	*Description*
0	Massive rock	Intact rock or massive rock with a few widely spaced joints. The joint surfaces are unweathered and rough
1	Slightly jointed rock	Rock mass intersected by one or two sets of joints. The joints are well interlocked and unweathered. Joint surfaces are rough to planar.
2	Blocky rock	Rock mass intersected by two or three, sets of joint forming cubical blocks. Joints are well interlocked and unweathered. Joint surfaces are rough to planar.
3	Very blocky rock	Rock mass intersected by four or more joint sets. Joints are slightly interlocked or slightly weathered. Joints are planar or slightly filled with gauge material.
4	Disturbed or disintegrated rock	Rock mass with several joint sets. Joints are poorly interlocked, persistent or schistose. Joints may be planar or filled with gauge material.
Remark	The term “joint” is used herein as a common description of discontinuities in rock such as crack, fissure, shear, fault, bedding, etc.	

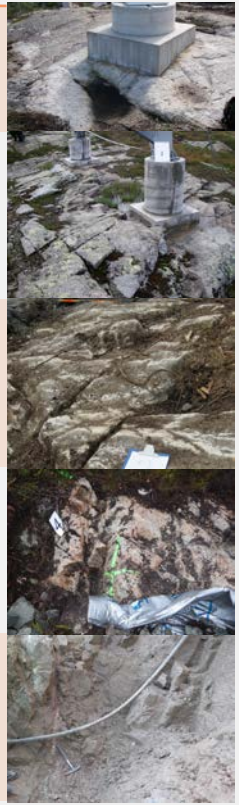
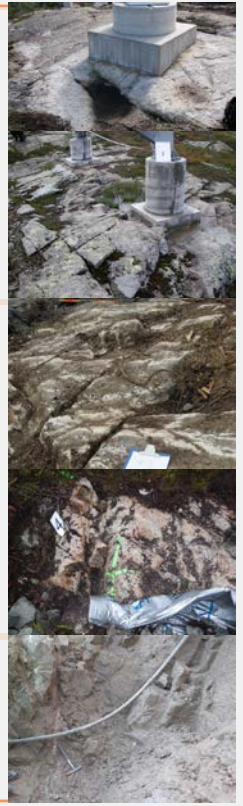


Table 1 Classification of rock ground

Rock class	*Designation*	*Description*
0	Massive rock	**Class 0 & Class 1** **Sufficient tensile strength** to withstand uplifting forces.
1	Slightly jointed rock	
2	Blocky rock	**Class 2 & Class 3** So low tensile strength that the uplifting forces can only be countered by **shear resistance of joints** and the **weight of the rock lump** between the embedded tendons.
3	Very blocky rock	
4	Disturbed or disintegrated rock	**Class 4** A concrete foundation in a blasted or excavated pit is **cheaper** than to reinforce the rock mass with tendons.



Classification criteria

Property	ROCK CLASS				
	0	1	2	3	4
	Massive	Slightly jointed	Blocky	Very blocky	Disturbed or disintegrated
Weathering	Grade 0 - 1 Fresh or slightly	Grade 0 - 1 Fresh or slightly	Grade 0 - 1 Fresh or slightly	Grade 0 - 1 Fresh or slightly	Grade 2, 3, 4 Moderate or higher
Unconfined compressive strength	Grade 0 - 2 q_u>100 MPa	Grade 0 - 3 q_u>50 MPa	Grade 0 - 4 q_u>25 MPa	Grade 0 - 4 q_u>25 MPa	Grade 0 - 6 q_u<25 MPa
Number of joint sets	≤ 1 + random	≤ 2	≤ 3	≤ 3 + random	≥4
Joint spacing	Very wide ≥ 2000 mm	Wide or greater ≥ 600 mm	Medium or greater ≥ 200 mm	Close or greater ≥ 60 mm	Very close or less < 60 mm
Joint roughness	Rough, stepped or undulating	Rough, stepped or undulating	Rough, stepped, undulating or planar	Rough, smooth, stepped, undulating or, planar	Any roughness
Joint aperture	Tight or less ≤ 0.25 mm	Partly open or less ≤ 0.5 mm	Open or less ≤ 2.5 mm	Moderately wide or less ≤ 10 mm	Very wide or greater ≥ 10 mm
Joint filling	None	None	Granular material	Granular material	Clayey material

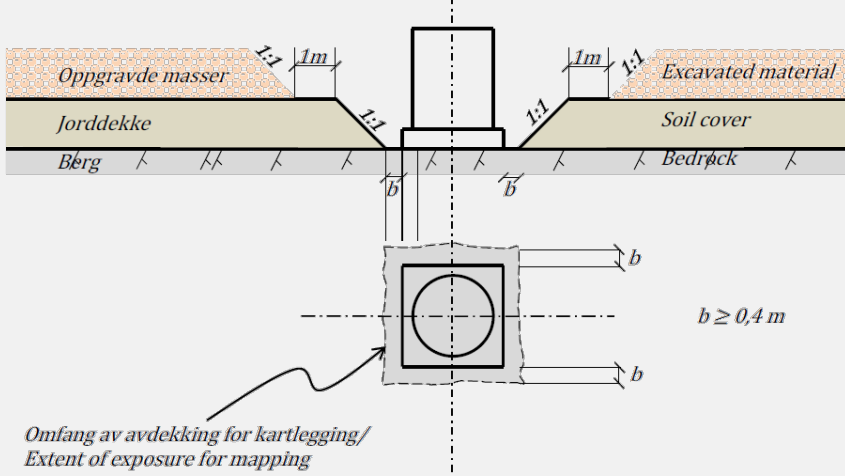
Example from Inner Oslofjord – reporting

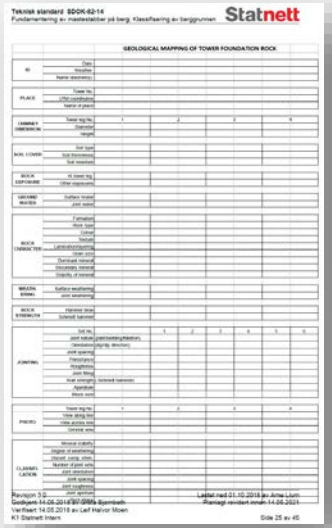
- Results of classification (for each tower leg)

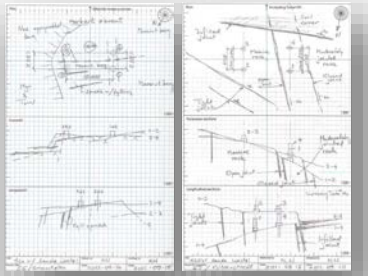
Property	ROCK CLASS				
	0	1	2	3	4
	Massive	Slight jointed	Blocky	Very blocky	Disturbed or disintegrated
Weathering	Grade 0 - 1 Fresh or slightly	Grade 0 - 1 Fresh or slightly	Grade 0 - 1 Fresh or slightly	Grade 0 - 1 Fresh or slightly	Grade 2, 3, 4 Moderate or higher
Unconfined compressive strength	Grade 0 - 2 q_u>100 MPa	Grade 0 - 3 q_u>50 MPa	Grade 0 - 4 q_u>25 MPa	Grade 0 - 4 q_u>25 MPa	Grade 0 - 6 q_u<25 MPa
Number of joint sets	≤ 1 + random	≤ 2	≤ 3	≤ 3 + random	≥4
Joint spacing	Very wide ≥ 2000 mm	Wide or greater ≥ 600 mm	Medium or greater ≥ 200 mm	Close or greater ≥ 60 mm	Very close or less < 60 mm
Joint roughness	Rough, stepped or undulating	Rough, stepped or undulating	Rough, stepped, undulating or planar	Rough, smooth, stepped, undulating or, planar	Any roughnss
Joint aperture	Tight or less ≤ 0.25 mm	Partly open or less ≤ 0.5 mm	Open or less ≤ 2.5 mm	Moderat wide or less ≤ 10 mm	Very wide or greater ≥ 10 mm
Joint filling	None	None	Granular material	Granular material	clayey material

Design investigations (1)

- The design of anchorage of the tower foundations is performed either by the owner, as a part of the detailed design, or by the contractor as part of the construction contract.
- The mapping at the site shall be performed, **documented** and approved in due time ahead of the construction works.
- Where the rock is covered by soil, the bedrock within a minimum of 0.4 m from the chimney base shall be uncovered prior to mapping. All classification shall be carried out after moss, turf and thin soil layers have been removed.
- The classification for each tower leg shall be independent.







Design investigations (2)

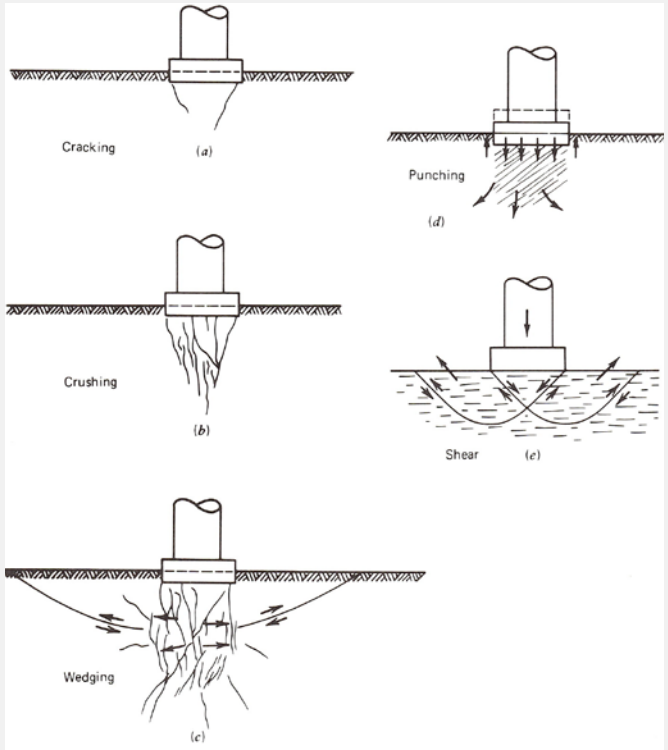
- For Class 2 & Class 3:
- Fractured and weathered surface rock may be removed, then undertake **new classification**.
- Hydraulic hammer are well suited in removal of surface rock.
- Blasting of surface rock will seldom be appropriate. The base charge often tears up the rock and create new joints.

Design rules

Chimney foundation design - general requirements

- Design of chimney foundations comprise two main tasks:

1. Check that bearing capacity of the rock ground are adequate against **design compressional loads** from the chimney.



Possible modes of failure at ultimate bearing capacity of foundation rock (Goodman 1989)

Chimney foundation design - general requirements

- Design of chimney foundations comprise two main tasks:

2. Check that the anchorage in rock has adequate resistance (capacity) against **design tensile forces from chimney**.

Principal modes of failure of grouted rock anchors under applied axial tension (Pease & Kulhawy, 1984)

Strength parameters of rock mass

Tabell 1 *Karakteristiske og dimensjonerende fasthetsparametere for berggrunnen*
Table 1 *Characteristic and design strength parameters of rock mass*

Fasthetsparameter Strength Parameter		Bergklasse / Rock Class			
		0	1	2	3
Enaksial trykkfasthet i intakt berg, $q_{u,k}$ Unconfined compressive strength of intact rock, $q_{u,k}$	MPa	100	50	25	25
Strekkfasthet av bergmassen, $T_{0,k}$ Tensile strength of the rock mass, $T_{0,k}$	MPa	4.0	0.81	0.17	0.06
Bæreevne av berggrunnen, q_{ad} Bearing capacity of rock mass, q_{ad}	MPa	71.4	16.4	5.0	3.1
Dimensjonerende strekkfasthet av bergmassen, T_{0d} Design tensile strength of rock mass, T_{0d}		2.0	0.40	0.085	0.03
Dimensjonerende heftfasthet i berggrunnen og i forankring berg / mørtel, f_{brd} Design bond strength in rock mass and in anchorage rock/mortar, f_{brd}	MPa	1.97	1.4	1.0	0.7
Dimensjonerende heftfasthet mørtel/stag; B35, f_{bcd} [1] Design bond strength mortar/tendon; B35, f_{bcd}	MPa	1.97	1.97	1.97	1.97

[1] Bestemt iht. NS-EN 1992-1 for terningfasthet, f_{cck} = 45 MPa /
According to NS-EN 1992-1 for cube strength, f_{cck} = 45 MPa

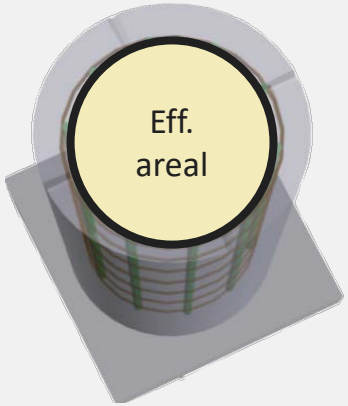
How to determine bearing capacity of the rock ground?

- Characteristic values for bearing capacity of rock class (0-3)
- Bearing capacity based on the UCCS of intact rock, joint spacing, joint aperture.
- Characteristic strength values of rock ground estimated based on classification criteria, using the Hoek & Brown failure criterion.
- Boundary limits between the rock classes and engineering judgements

Bearing capacity of foundation rock

Presumptions:

I. Only effective area of the chimney can transfer compressive force to bedrock (= inner diameter of hoop reinforcement)
II. Design commpression capacity of tendons, f_{yd} = 400 Mpa.
III. Design compressive strength of concrete, f_{cd} = 19,8 Mpa
IV. Concrete cover = 50 mm.
V. Diameter hoop reinforcement 10 mm.



Bearing capacity of foundation rock

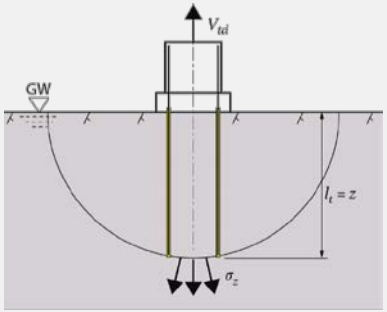
- For rock class 0 and 1, the bearing capacity is limited by the reinforced chimney, i.e steel and concrete.
- For rock class 2 and 3 the bearing capacity is limited by capacity of rock mass and steel tendons.

Tabell 2 *Dimensjonerende bæreevne av berggrunnen; stabbe type I, II og III*
Table 2 *Design bearing capacity of bedrock; chimney type I, II and III*

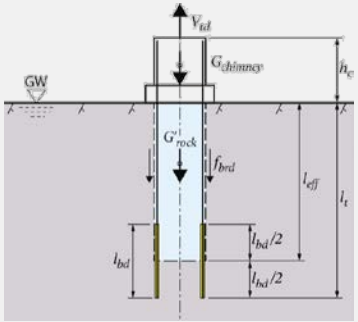
Stabbe / Chimney						Dim. bæreevne / Design bearing capacity			
		Lengdearmering / reinforcement				Bergklasse /rock class			
Type	Diameter	Ø stag / bar	Antall stag / number of tendons	Kapasitet/ capacity, R_{rd} [1]	Eff. areal betong/ Net area concrete	0	1	2	3
	mm	mm	-	kN	mm²	kN	kN	kN	kN
I	600	25	6	1178	180 956	4 761	4 761	1 794	1 377
			8	1571		5 154	5 154	2 186	1 770
			10	1964		5 547	5 547	2 579	2 163
			12	2357		5 940	5 940	2 972	2 556
			14	2750		6 333	6 333	3 365	2 949
I	600	32	6	1930	180 956	5 513	5 513	2 545	2 129
			8	2573		6 156	6 156	3 188	2 772
			10	3216		6 799	6 799	3 831	3 415
			12	3859		7 442	7 442	4 474	4 058
			14	4502		8 085	8 085	5 118	4 701
II	750	25	6	1178	311 725	7 351	7 351	2 238	1 521
			8	1571		7 743	7 743	2 631	1 914
			10	1964		8 136	8 136	3 024	2 307
			12	2357		8 529	8 529	3 417	2 700
			14	2750		8 922	8 922	3 809	3 092
			16	3142		9 315	9 315	4 202	3 485
			18	3535		9 707	9 707	4 595	3 878
II	750	32	6	1930	311 725	8 102	8 102	2 989	2 272
			8	2573		8 745	8 745	3 633	2 916
			10	3216		9 388	9 388	4 276	3 559
			12	3859		10 031	10 031	4 919	4 202
			14	4502		10 675	10 675	5 562	4 845
			16	5146		11 318	11 318	6 205	5 488
			18	5789		11 961	11 961	6 849	6 132
III	1000	25	6	1178	608 212	13 221	13 221	3 246	1 847
			8	1571		13 614	13 614	3 639	2 240
			10	1964		14 007	14 007	4 032	2 633
			12	2357		14 399	14 399	4 425	3 026
			14	2750		14 792	14 792	4 818	3 419
			16	3142		15 185	15 185	5 210	3 811
			18	3535		15 578	15 578	5 603	4 204
			20	3928		15 971	15 971	5 996	4 597
			22	4321		16 363	16 363	6 389	4 990
			24	4714		16 756	16 756	6 782	5 383
			26	5106		17 149	17 149	7 174	5 775
			28	5499		17 542	17 542	7 567	6 168
III	1000	32	6	1930	608 212	13 972	13 972	3 998	2 599
			8	2573		14 615	14 615	4 641	3 242
			10	3216		15 259	15 259	5 284	3 885
			12	3859		15 902	15 902	5 927	4 528
			14	4502		16 545	16 545	6 570	5 171
			16	5146		17 188	17 188	7 214	5 815
			18	5789		17 831	17 831	7 857	6 458
			20	6432		18 475	18 475	8 500	7 101
			22	7075		19 118	19 118	9 143	7 744
			24	7718		19 761	19 761	9 786	8 387
			26	8362		20 404	20 404	10 430	9 031
			28	9005		21 047	21 047	11 073	9 674

[1] R_{rd} = Dimensjonerende motstand i ståltverrsnitt stag med dim. flytekapasitet f_{yd} = 400 N/mm² / Design resistance of tendon cross section for design yield strength f_{yd} = 400 N/mm².

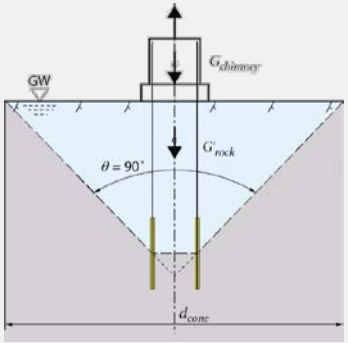
Computational models for pull-out resistance in rock



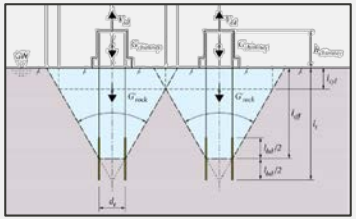
1. Tensile strength model (rock class 0-1)



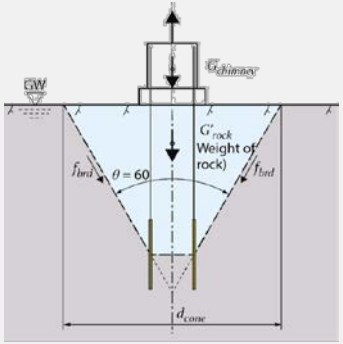
2. Pull-out cylinder shaft (rock class 1-2)



3. Weight of cone (rock class 2-3)



For long embedded tendons



4. Combined weight of cone and bond strength (rock class 2-3)

Required embedment depth of tendons

CHIMNEY							FORANKRINGSDYBDE I BERG / EMBEDMENT DEPTH OF TENDONS IN BEDROCK																				
Type	Outer diameter	Reinforcement					Bond resistance					Tensile Strength Criterion				Shaft Friction Criterion				Gravity & Bond Criterion			Gravity criterion	Summary			
		Cover	Ø-bar	Ø-hoop	Number of bars	R_{id}	R_{bcd}	R_{grd}				Rock Class				Rock Class				Rock class				Rock Class			
								0	1	2	3	0	1	2	3	0	1	2	3	1	2	3		0	1	2	3
	mm	mm	mm	mm		kN	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm
I	600	50	25	10	6	1 178	1 270	910	1 280	1 790	2 550	530	1 190	2 570	4 330	460	650	920	920	1350	1 450	1 600	4 500	1 270	1 350	1 790	2 550
					8	1 571	1 270	910	1 280	1 790	2 550	610	1 370	2 970	5 000	610	870	1230	1230	1450	1 600	1 750	4 850	1 270	1 450	1 790	2 550
					10	1 964	1 270	910	1 280	1 790	2 550	680	1 530	3 320	5 590	770	1090	1540	1540	1550	1 700	1 900	5 200	1 270	1 550	1 790	2 550
					12	2 357	1 270	910	1 280	1 790	2 550	750	1 680	3 640	6 120	920	1300	1840	1840	1650	1 800	2 000	5 500	1 270	1 680	1 840	2 550
					14	2 750	1 270	910	1 280	1 790	2 550	810	1 810	3 930	6 620	1 080	1520	2150	2150	1750	1 900	2 100	5 750	1 270	1 810	2 150	2 550
I	600	50	32	10	6	1 930	1 620	1 300	1 830	2 560	3 660	680	1 520	3 290	5 540	750	1070	1510	1510	1700	1 900	2 100	5 350	1 620	1 830	2 560	3 660
					8	2 573	1 620	1 300	1 830	2 560	3 660	780	1 750	3 800	6 400	1 010	1420	2010	2010	1850	2 000	2 250	5 850	1 620	1 850	2 560	3 660
					10	3 216	1 620	1 300	1 830	2 560	3 660	880	1 960	4 250	7 150	1 260	1780	2520	2520	1950	2 150	2 400	6 250	1 620	1 960	2 560	3 660
					12	3 859	1 620	1 300	1 830	2 560	3 660	960	2 150	4 660	7 840	1 510	2140	3020	3020	2050	2 300	2 550	6 600	1 620	2 150	3 020	3 660
					14	4 502	1 620	1 300	1 830	2 560	3 660	1 040	2 320	5 030	8 470	1 760	2490	3520	3520	2150	2 400	2 700	6 900	1 620	2 490	3 520	3 660
II	750	50	25	10	6	1 178	1 270	910	1 280	1 790	2 550	530	1 190	2 570	4 330	350	500	700	700	1350	1 450	1 600	4 400	1 270	1 350	1 790	2 550
					8	1 571	1 270	910	1 280	1 790	2 550	610	1 370	2 970	5 000	470	660	940	940	1450	1 600	1 750	4 800	1 270	1 450	1 790	2 550
					10	1 964	1 270	910	1 280	1 790	2 550	680	1 530	3 320	5 590	590	830	1 170	1 170	1550	1 700	1 900	5 100	1 270	1 550	1 790	2 550
					12	2 357	1 270	910	1 280	1 790	2 550	750	1 680	3 640	6 120	700	990	1 410	1 410	1650	1 800	2 000	5 450	1 270	1 680	1 800	2 550
					14	2 750	1 270	910	1 280	1 790	2 550	810	1 810	3 930	6 620	820	1 160	1 640	1 640	1750	1 900	2 100	5 700	1 270	1 810	1 900	2 550
					16	3 142	1 270	910	1 280	1 790	2 550	870	1 940	4 200	7 070	940	1 320	1 870	1 870	1850	2 000	2 200	5 950	1 270	1 940	2 000	2 550
					18	3 535	1 270	910	1 280	1 790	2 550	920	2 050	4 460	7 500	1 050	1 490	2 110	2 110	1900	2 100	2 300	6 150	1 270	2 050	2 110	2 550
II	750	50	32	10	6	1 930	1 620	1 300	1 830	2 560	3 660	680	1 520	3 290	5 540	580	810	1 150	1 150	1700	1 900	2 100	5 300	1 620	1 830	2 560	3 660
					8	2 573	1 620	1 300	1 830	2 560	3 660	780	1 750	3 800	6 400	770	1 080	1 530	1 530	1850	2 000	2 250	5 750	1 620	1 850	2 560	3 660
					10	3 216	1 620	1 300	1 830	2 560	3 660	880	1 960	4 250	7 150	960	1 360	1 920	1 920	1950	2 150	2 400	6 150	1 620	1 960	2 560	3 660
					12	3 859	1 620	1 300	1 830	2 560	3 660	960	2 150	4 660	7 840	1 150	1 630	2 300	2 300	2050	2 300	2 550	6 500	1 620	2 150	2 560	3 660
					14	4 502	1 620	1 300	1 830	2 560	3 660	1 040	2 320	5 030	8 470	1 340	1 900	2 680	2 680	2150	2 400	2 700	6 800	1 620	2 320	2 680	3 660
					16	5 146	1 620	1 300	1 830	2 560	3 660	1 110	2 480	5 380	9 050	1 530	2 170	3 070	3 070	2250	2 500	2 850	7 100	1 620	2 480	3 070	3 660
					18	5 789	1 620	1 300	1 830	2 560	3 660	1 180	2 630	5 700	9 600	1 730	2 440	3 450	3 450	2350	2 600	3 000	7 350	1 620	2 630	3 450	3 660
III	1 000	50	25	10	6	1 178	1 270	910	1 280	1 790	2 550	530	1 190	2 570	4 330	250	360	500	500	1350	1 450	1 600	4 250	1 270	1 350	1 790	2 550
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					12	2 357	1 270	910	1 280	1 790	2 550	750	1 680	3 640	6 120	500	710	1 010	1 010	1650	1 800	2 000	5 300	1 270	1 680	1 800	2 550
					14	2 750	1 270	910	1 280	1 790	2 550	810	1 810	3 930	6 620	590	830	1 170	1 170	1750	1 900	2 100	5 550	1 270	1 810	1 900	2 550
					16	3 142	1 270	910	1 280	1 790	2 550	870	1 940	4 200	7 070	670	950	1 340	1 340	1850	2 000	2 200	5 800	1 270	1 940	2 000	2 550
					18	3 535	1 270	910	1 280	1 790	2 550	920	2 050	4 460	7 500	750	1 070	1 510	1 510	1900	2 100	2 300	6 050	1 270	2 050	2 100	2 550
					20	3 928	1 270	910	1 280	1 790	2 550	970	2 170	4 700	7 910	840	1 190	1 680	1 680	1950	2 200	2 400	6 250	1 270	2 170	2 200	2 550
					22	4 321	1 270	910	1 280	1 790	2 550	1 020	2 270	4 930	8 290	920	1 300	1 840	1 840	2000	2 300	2 500	6 450	1 270	2 270	2 300	2 550
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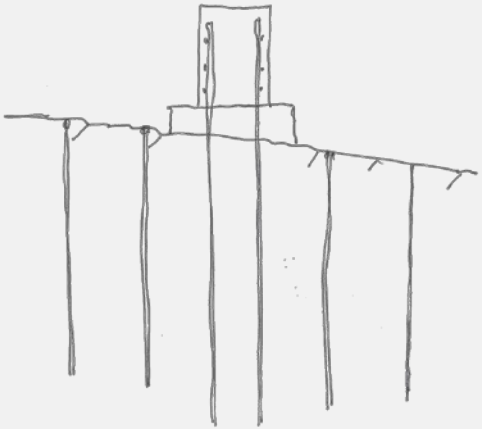
					26	5 106	1 270	910	1 280	1 790	2 550	1 100	2 470	5 360	9 020	1 090	1 540	2 180	2 180	2100	2 500	2 700	6 800	1 270	2 470	2 500	2 700
					28	5 499	1 270	910	1 280	1 790	2 550	1 150	2 560	5 560	9 360	1 170	1 660	2 350	2 350	2150	2 600	2 800	6 950	1 270	2 560	2 600	2 800
III	1 000	50	32	10	6	1 930	1 620	1 300	1 830	2 560	3 660	680	1 520	3 290	5 540	410	580	820	820	1700	1 900	2 100	5 150	1 620	1 830	2 560	3 660
					8	2 573	1 620	1 300	1 830	2 560	3 660	780	1 750	3 800	6 400	550	780	1 100	1 100	1850	2 000	2 250	5 650	1 620	1 850	2 560	3 660
					10	3 216	1 620	1 300	1 830	2 560	3 660	880	1 960	4 250	7 150	690	970	1 370	1 370	1950	2 150	2 400	6 050	1 620	1 960	2 560	3 660
					12	3 859	1 620	1 300	1 830	2 560	3 660	960	2 150	4 660	7 840	820	1 160	1 650	1 650	2050	2 300	2 550	6 400	1 620	2 150	2 560	3 660
					14	4 502	1 620	1 300	1 830	2 560	3 660	1 040	2 320	5 030	8 470	960	1 360	1 920	1 920	2150	2 400	2 700	6 700	1 620	2 320	2 560	3 660
					16	5 146	1 620	1 300	1 830	2 560	3 660	1 110	2 480	5 380	9 050	1 100	1 550	2 200	2 200	2250	2 500	2 850	7 000	1 620	2 480	2 560	3 660
					18	5 789	1 620	1 300	1 830	2 560	3 660	1 180	2 630	5 700	9 600	1 240	1 750	2 470	2 470	2350	2 650	3 000	7 250	1 620	2 630	2 650	3 660
					20	6 432	1 620	1 300	1 830	2 560	3 660	1 240	2 770	6 010	10 120	1 370	1 940	2 750	2 750	2450	2 800	3 100	7 500	1 620	2 770	2 800	3 660
					22	7 075	1 620	1 300	1 830	2 560	3 660	1 300	2 910	6 300	10 610	1 510	2 140	3 020	3 020	2550	2 950	3 200	7 700	1 620	2 910	3 020	3 660
					24	7 718	1 620	1 300	1 830	2 560	3 660	1 360	3 040	6 580	11 080	1 650	2 330	3 290	3 290	2650	3 050	3 300	7 950	1 620	3 040	3 290	3 660
					26	8 362	1 620	1 300	1 830	2 560	3 660	1 410	3 160	6 850	11 540	1 780	2 520	3 570	3 570	2750	3 200	3 400	8 150	1 620	3 160	3 570	3 660
					28	9 005	1 620	1 300	1 830	2 560	3 660	1 470	3 280	7 110	11 970	1 920	2 720	3 840	3 840	2850	3 300	3 500	8 350	1 620	3 280	3 840	3 840

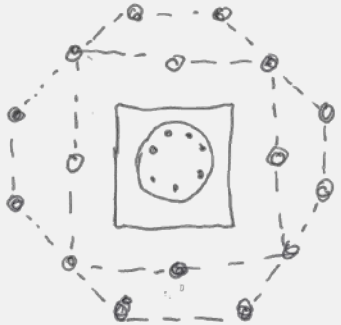
R_{id} - Design resistance of tendon cross section for design yield strength f_{yd} = 400 N/mm^2.
R_{bcd} - Design bond resistance between tendon and mortar
R_{grd} - Design bond resistance between mortar and rock mass
γ_r - Effective weight of rock mass is assumed to be 17 kN/m^3

Color codes:					
1250	Min. bond length, 50 x Ø-bar	530	Tensile strength criterion	4500	Gravity criterion
1270	Bond resistance tendon-mortar	460	Shaft friction criterion		
910	Bond resistance mortar-rock	1600	Gravity + bond strength criterion		

Ground improvement

- For Class 2 & Class 3:
- As an alternative to long tendons, the rock may be reinforced around the chimney to engage lateral rock mass instead of at depth.





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NGI Statnett

Monitoring of permanent post-tensioned rock anchors

Surveillance d'ancrages permanents en post-tension dans la roche

E.J. Lande
Norwegian Geotechnical Institute, Oslo, Norway
Norwegian University of Science and Technology (NTNU), Trondheim, Norway

T. Valstad, E. Stein and J.M. Josefsen
Norwegian Geotechnical Institute, Oslo, Norway

I. Brovold
Statnett SF, Oslo, Norway

Design pylon, Lysefjorden (read more)

- Measurement once a year by Statnett
- Condition control and assess the need for future tensioning
- R&D: to gain more knowledge on the long-term behavior and hopefully improve the current design methodology for anchors in **strong rock types**.
- At least 10 years' monitoring (post-tensioning 13 September, 2017)

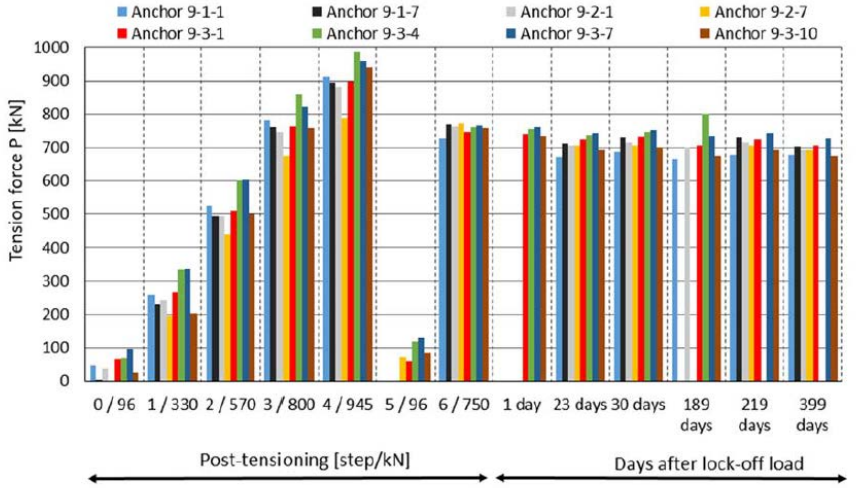
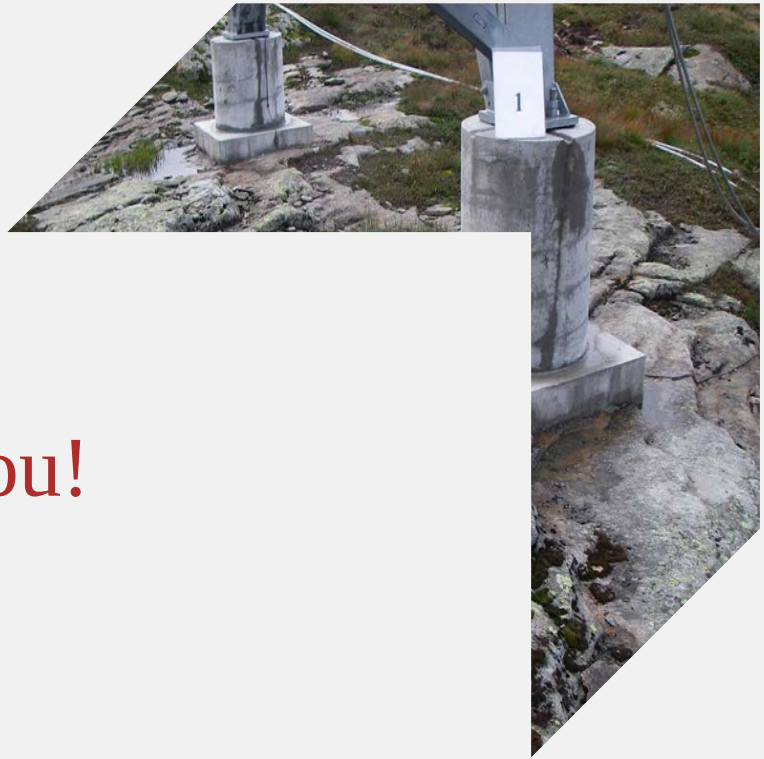


Figure 7. Tension force P in rock anchors measured with load cells on anchor head. Results from post-tensioning steps 0 to 6 (left side), and the first 399 days after lock-off load (right side).



Thank you!

#påsikkergrunn

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NGI.NO