Appendix to report:

SBJ-33-C5-OON-22-RE-019
DESIGN OF STAY CABLE BRIDGE

Appendix title:

APPENDIX B STAY CABLES

Contract no:	18/91094
Project number:	5187772/12777
Document number:	SBJ-33-C5-OON-22-RE-019 App. B
Date:	15.08.2019
Revision:	0
Number of pages:	12
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CONCEPT DEVELOPMENT FLOATING BRIDGE E39 BJØRNAFJORDEN

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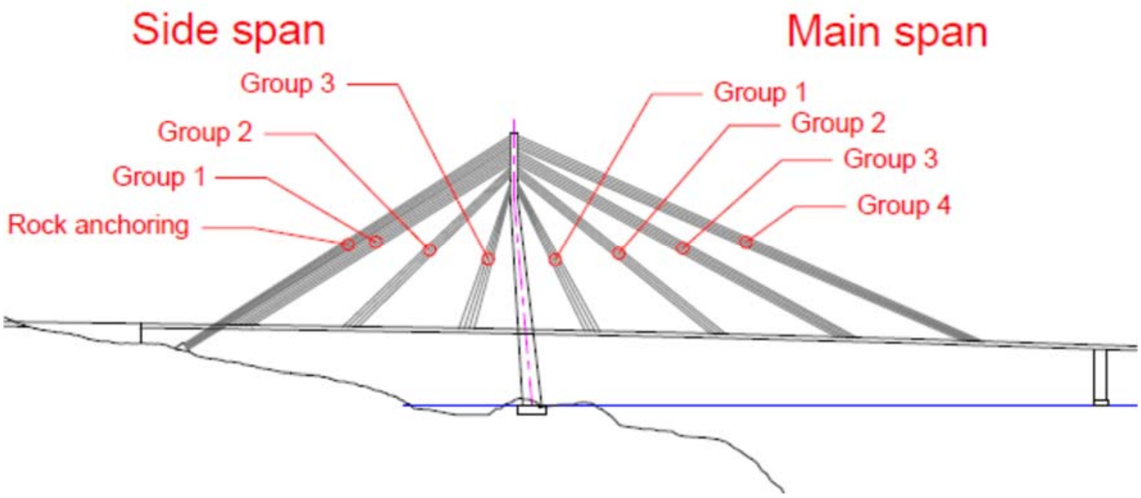
1 INTRODUCTION

This technical note includes the dimensioning of the stay cables, their attachment to the pylon and the box girder and the rock anchoring.

2 DIMENSIONING OF CABLES

The cables are gathered in groups as shown in the figure below. To minimize the number of different cable sizes, we have tried to organize the cables so the maximum tension in each cable within a group should be approximate the same.



> *Figure 1 Cable groups*

The cables are dimensioned for the ultimate limit state (ULS), according to the Håndbok 400, paragraph 13.3.3. In this phase, we have chosen locked coil cables with ultimate tensile strength of 1570 MPa and an estimated spinning loss of 8%. The result is shown in the table below:

Cable identification Numbering from shore Cable group	 Cable no	Max tension ULS (N)	Minimum breaking load (kN)	Metallic cross section (mm2)	Circa diameter (mm)
Rock anchoring	1	13 797 395	24 835	17 084	156
	2	13 799 883	24 840	17 087	156
	3	12 758 823	22 966	15 798	150
	4	12 761 004	22 970	15 801	150
	5	12 359 458	22 247	15 304	148
	6	12 361 544	22 251	15 306	148
	7	12 183 205	21 930	15 085	147
	8	12 184 040	21 931	15 086	147
	9	12 233 755	22 021	15 148	147
	10	12 233 781	22 021	15 148	147

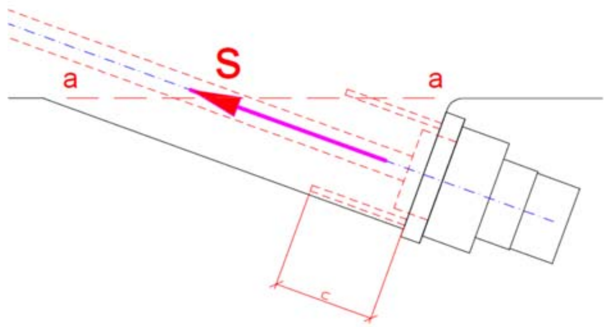
Cable identification Numbering from shore Cable group	 Cable no	Max tension ULS (N)	Minimum breaking load (kN)	Metallic cross section (mm2)	Circa diameter (mm)
Side span group 1	11	6 765 521	12 178	8 377	109
	12	6 820 181	12 276	8 445	110
	13	5 433 842	9 781	6 728	98
	14	5 482 410	9 868	6 788	99
	15	5 522 686	9 941	6 838	99
	16	5 580 087	10 044	6 909	99
	17	6 556 433	11 802	8 118	108
	18	6 635 947	11 945	8 217	108
	19	6 561 681	11 811	8 125	108
	20	6 648 979	11 968	8 233	109
Side span group 2	21	7 639 133	13 750	9 459	116
	22	7 818 117	14 073	9 681	118
	23	5 905 142	10 629	7 312	102
	24	6 051 203	10 892	7 493	104
	25	5 771 001	10 388	7 146	101
	26	5 930 989	10 676	7 344	102
	27	6 592 832	11 867	8 163	108
	28	6 794 748	12 231	8 413	110
Side span group 3	29	6 013 419	10 824	7 446	103
	30	6 258 746	11 266	7 750	105
	31	4 793 933	8 629	5 936	92
	32	5 009 727	9 018	6 203	94
	33	4 958 039	8 924	6 139	94
	34	5 193 778	9 349	6 431	96
	35	6 475 293	11 656	8 018	107
	36	6 778 078	12 201	8 393	110
Main span group 1	37	7 195 219	12 951	8 909	113
	38	7 510 394	13 519	9 299	115
	39	5 708 394	10 275	7 068	101
	40	6 002 901	10 805	7 433	103
	41	5 474 039	9 853	6 778	98
	42	5 783 843	10 411	7 162	101
	43	6 467 675	11 642	8 008	107
	44	6 830 509	12 295	8 458	110
Main span group 2	45	9 027 101	16 249	11 178	126
	46	9 381 464	16 887	11 616	129
	47	7 690 890	13 844	9 523	117
	48	8 033 497	14 460	9 947	119
	49	7 632 467	13 738	9 451	116
	50	7 999 400	14 399	9 905	119
	51	9 312 892	16 763	11 531	128
	52	9 770 893	17 588	12 098	132
Main span group 3	53	11 134 539	20 042	13 787	140
	54	11 548 219	20 787	14 299	143
	55	9 007 630	16 214	11 153	126
	56	9 363 033	16 853	11 593	129
	57	7 948 140	14 307	9 842	119

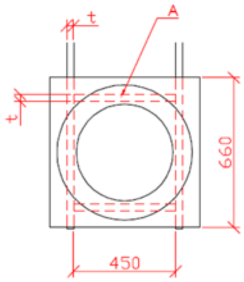
Cable identification Numbering from shore Cable group	 Cable no	Max tension ULS (N)	Minimum breaking load (kN)	Metallic cross section (mm2)	Circa diameter (mm)
	58	8 273 507	14 892	10 244	121
	59	8 023 112	14 442	9 934	119
	60	8 349 603	15 029	10 339	122
	61	9 656 449	17 382	11 957	131
	62	10 044 969	18 081	12 438	133
Main span group 4	63	12 219 662	21 995	15 131	147
	64	12 575 706	22 636	15 571	149
	65	10 363 215	18 654	12 832	135
	66	10 682 622	19 229	13 227	138
	67	9 241 157	16 634	11 443	128
	68	9 538 691	17 170	11 811	130
	69	8 777 910	15 800	10 869	125
	70	9 071 757	16 329	11 233	127
	71	9 238 851	16 630	11 440	128
	72	9 621 484	17 319	11 913	131

The table shows that the minimum cable diameter varies from 92 to 156 mm. If we use the same size within a group, we can reduce the number to six different diameters; 110, 120, 130, 140, 150 and 155 mm, which can be sensible and probably give the most economical solution.

3 ATTACHMENT TO THE BOX GIRDER

The principle of the attachment to the box girder is described in main document, paragraph 7.3. In this paragraph, we perform the dimensioning of the attachment for cable 63 with an ultimate tension of 12576 kN.





> *Figure 2 Attachment to the box girder*

The cable force is transmitted to the steel box through the stiffeners area A:

$A = 2 * (660 + 450) * t$

and

$A \geq \frac{S}{f_d} = \frac{12576 * 10^3}{355/1{,}05} = 37200\ mm^2$

Which gives

$$t \geq \frac{37200}{2 * (660 + 450)} = 16{,}8\ mm$$

The side panel of the box girder has a thickness of 40 mm and we chose the thickness 30 mm for the other, which give a stress of:

$\sigma = \frac{12576 * 10^3}{40 * 660 + 30 * (660 + 450 * 2)} = 172\ MPa$ OK

The load bearing plate with length **c** has a span of 0,45 m and a distributed load of:

$q = 172 * 30 = 5160\ N/mm = 5160\ kN/m$

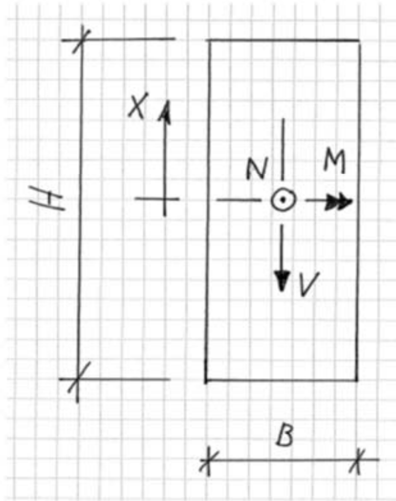
$M = \frac{5160 * 0{,}45^2}{8} = 131\ kNm$

$V = \frac{5160 * 0{,}45}{2} = 1161\ kN$

The spreadsheet below calculates the stress in a rectangular cross section:

Regneark for rektangulært tverrsnitt

Dim. moment:	131	kNm			
Dim. skjærkraft:	1161,0	kN			
Dim. normalkraft:	0	kN	(Negativ = trykk)		
B=	30	mm			
H=	500	mm	MT=	0	kNm
A=	15000	mm2	It=	4329900	mm4
Iy=	3,1E+08	mm4	Iw=	2,3E+10	mm6
Wy=	1250000	mm3			
Wpy=	1875000		fu=	470	MPa
Ix=	1125000	mm4	fy=	355	MPa
Wx=	75000	mm3	f_y/γ_{M0}=	322,7	MPa
Wpx=	112500		γ_{M0}=	1,1	



x	σ	τ	σ_j	τ_{MT}	σ_{j2}
250	105	0	105		
200	84	42	111		
150	63	74	143		
100	42	98	174		
50	21	111	194		
0	0	116	201	0	**201**
-50	-21	111	194		
-100	-42	98	174		
-150	-63	74	143		
-200	-84	42	111		
-250	-105	0	105		

Max:: **201** < **322,7** MPa **OK**

Kontroll plastisk tverrsnitt:

Medgår til normal- og skjærkraft:	H1=	208	mm
Kapasitet moment:	Md=	**500,7**	**kNm**
Utnyttelse:	n=	**0,42**	**OK**

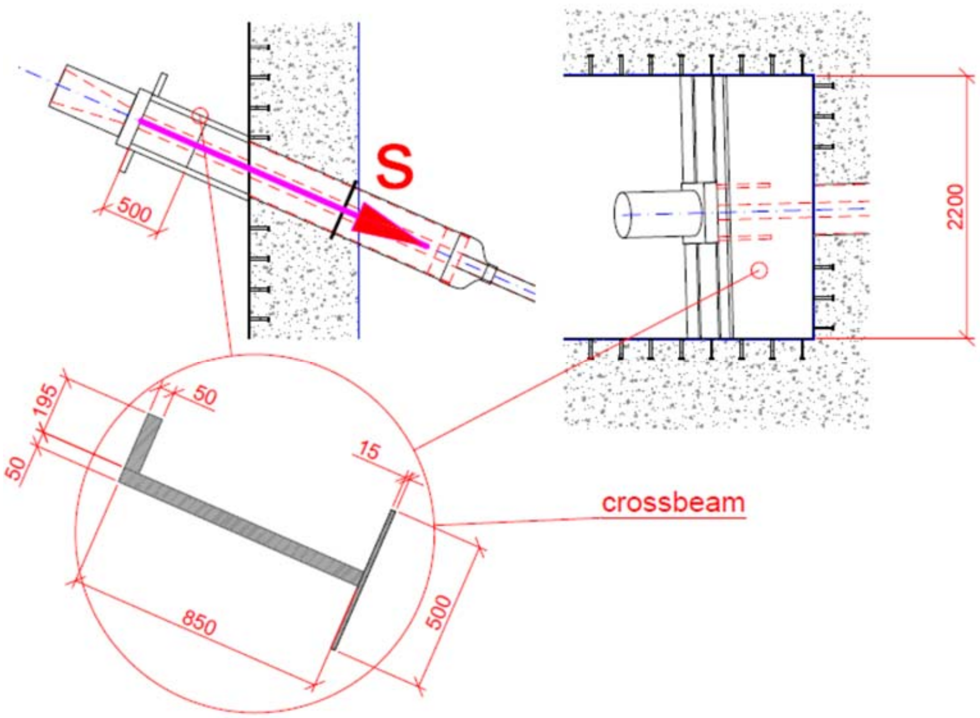
The length c = 500 mm gives a maximum von-mise stress from shear of 201 MPa which is OK.
If the fatigue calculation gives a force range in the cable of 1000 kN, we get a stress range in the steel plate connection of:

$$\Delta\sigma = \frac{201*1000}{12576} = 16\ MPa$$

The section marked a-a in the figure has a length of about 2 meters which will give a very low stress. It should be unnecessary to carry out a control here.

4 ATTACHMENT TO THE PYLON

The principle of the attachment to the pylon is described in main document, paragraph 7.4. In this paragraph, we perform the dimensioning of the attachment for cable no 2 with an ultimate tension of 13800 kN.



> *Figure 3 Attachment to the pylon*

The point load **S** is carried by two crossbeams transferring the load to the sidewalls of the steelbox. The dimensions and the presumed geometry of the crossbeam are given in the lower figure. Each crossbeam carries S/2 = 6900 kN which gives:

$M = \frac{P*L}{4} = \frac{6900*2,2}{4} = 3795\ kNm$

$V = \frac{P}{2} = \frac{6900}{2} = 3450\ kNm$

The spreadsheet, next page, calculates the stress in a cross section built up of rectangular plates and gives for this beam a maximum stress 309 MPa which is ok.

If the fatigue calculation gives a force range in the cable of 1000 kN, we get:

Von mise stress range between web and upper flange: $\Delta\sigma = \frac{269*1000}{13800} = 19,5\ MPa$

Von mise stress range between web and lower flange: $\Delta\sigma = \frac{307*1000}{13800} = 22,2\ MPa$

Von mise stress range between web and the side wall: $\Delta\sigma = \frac{175*1000}{13800} = 12,7\ MPa$

For the supporting plates, (length 500 mm), the calculation for the box girder attachment is valid.

Regneark for generelt tverrsnitt - rev 2/00

Horisontal akse

del	bredde B (mm)	høyde H (mm)	Antall stk	flate Fn (mm2)	multfakt. fakt	ekv. flate Fnekv	arm zn (mm)	stat. mom Sn (mm3)	egenvekt g (kN/m3)	vekt pr. m kN/m
1	50	850	1	42500	1	42500	425	18062500	77	3,2725
2	200	50	1	10000	1	10000	25	250000	77	0,77
3	500	15	1	7500	1	7500	857,5	6431250	77	0,5775
4				0		0		0	77	0
5				0		0		0	77	0
6				0		0		0	77	0
7				0		0		0	77	0
8				0		0		0	77	0
9				0		0		0		0
10				0		0		0		0
11				0		0		0		0
12				0		0		0		0
				60000		60000		24743750		4,62

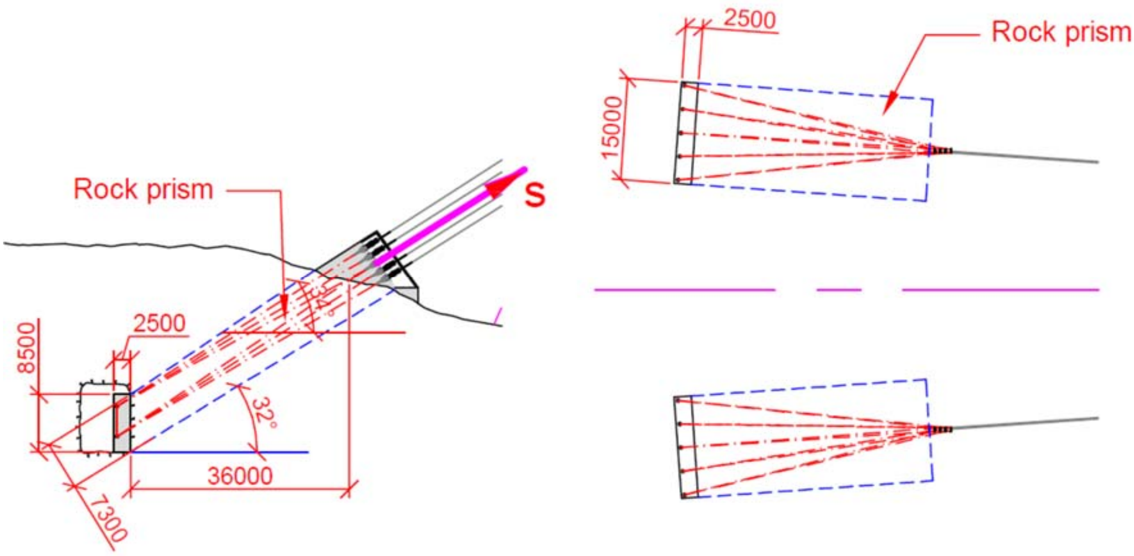
Moment=	3795	kNm
Skjærkraft=	3450	kN
Normalkraft=		kN

z (mm)	t (mm)	S (m3)	q (kN/m)	τ (MPa)	σ (MPa)	σj (MPa)
0,0		0	0	0	282	**282**
50,0	50	0,004842	3008	60	248	**269**
395	50	0,008118	5042	101	12	**175**
850	50	0,003338	2073	41	-299	**307**
865		0	0	0	-309	**309**
		0	0	0	0	**0**
		0	0	0	0	**0**
		0	0	0	0	**0**
		0	0	0	0	**0**
		0	0	0	0	**0**
					Max:	**309**

Tyngdepunkt, z_T=	4,124E+02 mm		
Flate, F=	6,000E-02	m2	6,000E+04 mm2
Treghetsmoment, Iy=	5,554E-03	m4	5,554E+09 mm4
Wo=	1,347E-02	m3	1,347E+07 mm3
Wu=	1,227E-02	m3	1,227E+07 mm4
Tyngdepunkt, zT=	1,035E+03 mm		
Vertikal akse, Iz=	1,670E-01	m4	1,670E+11 mm4
W=		m3	0,000E+00 mm3

5 DIMENSIONING OF ROCK ANCHOR

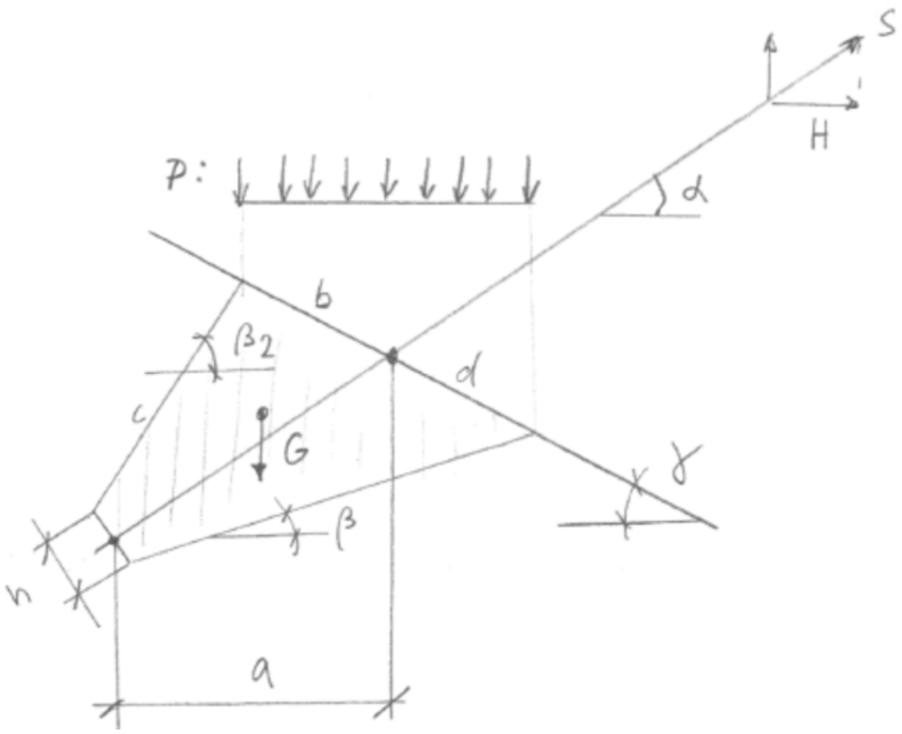
The principle for the rock anchoring is described in the main document, paragraph 8. In this paragraph, we perform the dimensioning of anchoring for the cables no. 1 – 10, see paragraph 2, with the total sum of tension forces of 127000 kN. The half of this force, 63500 kN, is anchored on each side of the bridge in separate structures. The figure below shows the anchoring system.



> *Figure 1 The anchoring, section to the left – plan to the right*

The spreadsheet below calculates the capacity of a rock anchor with given geometry.

Horisontalavstand F-K	a=	36	m
Kammerhøyde:	h=	7,3	m
Terrenghelning:	γ=	10	grad.
Helning øvre plan:	β2=	34	grad
Kabelhelning 1/n:	n=	1,577	
	α=	32,4	grad
Utrivningsvinkel:	β=	32	grad
	b=	1,735	m
	c=	41,362	m
	d=	0,422	m
Egenvekt gravitasjonsmasse:	ρ=	15	kN/m3
Medvirkende bredde:	t=	15	m
Ytre linjelast:	p=	0	kN/m
Totalvekt gravitasjonsprisme:	G=	76733	kN
Dimensjonerende kabelkraft:	S=	63500	kN
Tilhørende H-kraft:	H=	53627	kN
Materialfaktor:	γm=	1,4	
Forankringskapasitet:	Hd=	63365	kN
Utnyttelse:		**0,85**	



With these conservative assumptions regarding the geometry of the rock prism, we get an utilization rate of only 0,85 which should be reassuring.

6 REFERENCES

[1] Håndbok N400 , «Bruprosjektering,» Statens vegvesen Vegdirektoratet, 2015.

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[3] NS-EN 1993-1-1:2005+A1:2014+NA:2015, «Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings,» Standard Norge, 2005.