JCSS

Joint Committee
on Structural Safety

Workshop on Assessment of Existing Structures

28th and 29th January 2021

Capacity Upgrade of Existing Bridges by Probabilistic Methods

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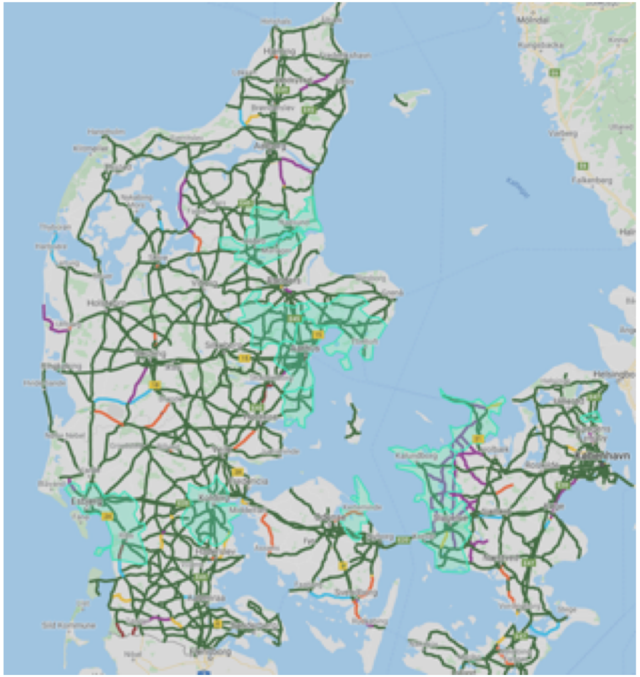
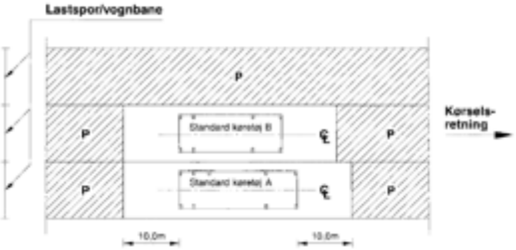
RAMBØLL

EXAMPLES


Reliability-Based Classification
of the Load Carrying Capacity of Existing Bridges
Guideline Document
Report 291
2004
Road Directorate
DANMARK
Bred last
E20
facade

DANISH CLASSIFICATION

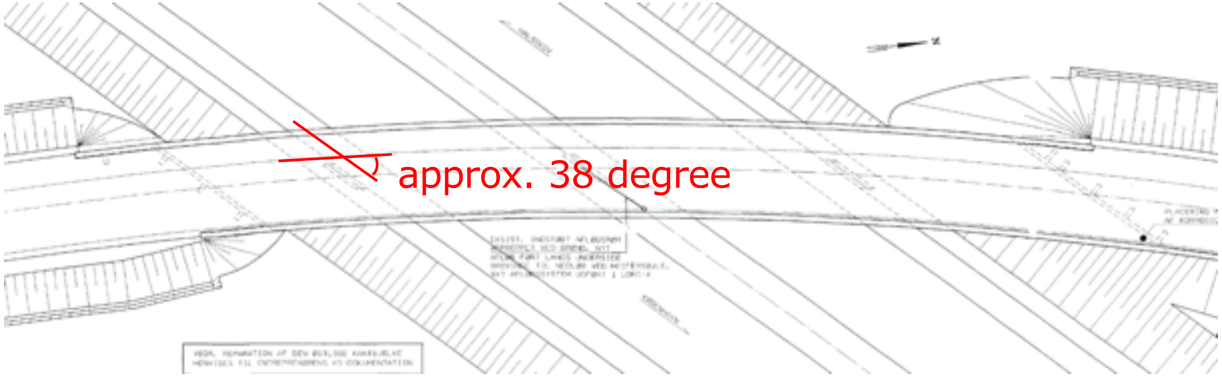


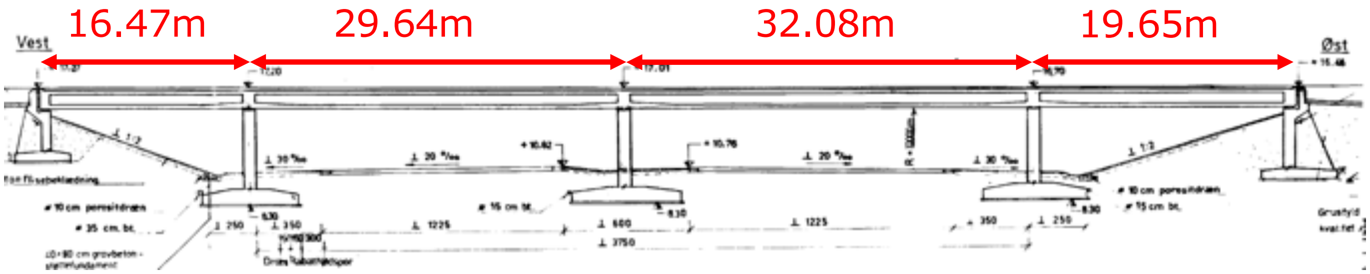


Klasse	Akselkonfiguration Akseltryk i tons og akselafstande i m	Sporvidde m
10	2,0 4,4 4,4 / 3,0 1,4	2,6
20	3,0 5,0 6,5 6,5 / 3,2 3,2 1,4	2,6
30	5,0 8,0 9,5 9,5 / 3,2 3,5 1,4	2,6
40	5,5 5,0 5,0 4,2 10,8 10,8 / 3,2 1,4 3,5 1,4 1,4	2,6
50	6,5 6,5 6,5 10,9 11,8 10,9 / 3,2 1,4 4,5 1,4 1,4	2,6
60	6,5 7,0 7,0 9,3 12,8 11,5 9,3 / 3,2 1,4 6,0 1,4 1,4 1,4	2,6
70	6,5 9,0 9,0 11,8 11,0 10,5 11,8 / 3,2 1,4 6,0 1,4 1,4 1,4	2,6
80	6,0 9,0 9,0 9,0 9,0 14,0 14,0 10,5 / 3,2 1,4 6,0 1,4 1,4 1,4 1,4	2,6
90	7,0 7,0 9,5 9,5 11,0 11,0 14,7 14,7 11,0 / 1,4 3,2 1,4 6,0 1,4 1,4 1,4 1,4	2,6
100	7,0 7,0 9,5 9,5 11,8 11,8 11,8 15,1 15,1 11,8 / 1,4 3,2 1,4 6,0 1,4 1,4 1,4 1,4 1,4	2,6
125	7,0 7,0 9,5 9,5 6 × 15,4 / 1,4 3,2 1,4 6,0 1,4 1,4 1,4 1,4 1,4	2,8
150	7,0 7,0 9,5 9,5 7 × 17,8 / 1,4 3,2 1,4 6,0 1,4 1,4 1,4 1,4 1,4 1,4	2,8
175	7,0 7,0 9,5 9,5 7 × 19,5 / 1,4 3,2 1,4 6,0 1,4 1,4 1,4 1,4 1,4 1,4	2,8
200	7,0 7,0 9,5 9,5 8 × 21 / 1,4 3,2 1,4 6,0 1,4 1,4 1,4 1,4 1,4 1,4 1,4	2,8

HIGHWAY BRIDGE

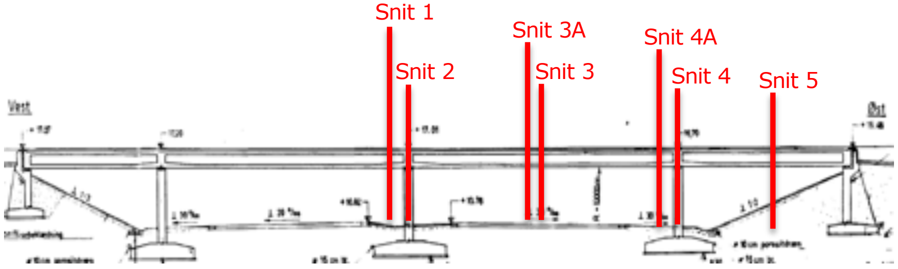
GEOMETRI

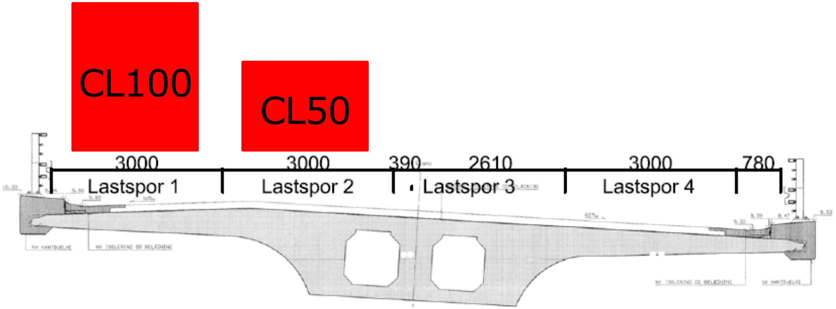


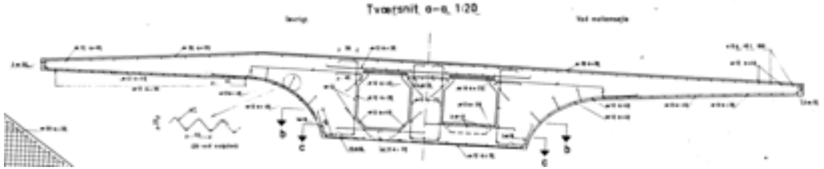


- < Class 100 after re-isolation
- Skew supports
- Prestressed bridge

DETERMINISTIC

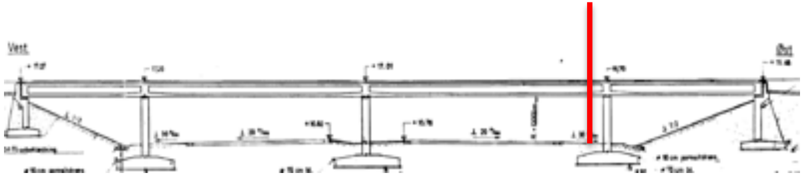






- Moment capacity ok
- Shear reduction due to the inclination of the prestressing cables
- Shear in the middle web
- Torsion in the horizontal flanges critical

DETERMINISTIC



$$V_{reinforcement} = V_{concrete}$$

$$f_y \cdot \cot\theta \cdot z \cdot A_{sw\_V} = \frac{t_{ef} \cdot z \cdot \nu_t \cdot f_c}{\left(\cot\theta + \frac{1}{\cot\theta}\right)}$$

$$\cot\theta = \sqrt{\left(\frac{t_{ef} \cdot \nu_t \cdot f_c}{f_y \cdot A_{sw\_V}}\right) - 1}$$

Class 100

	Vertical wall			Horizontal wall		
	cot(θ)	$\mu_{reinforcement}$	$\mu_{concrete}$	cot(θ)	$\mu_{reinforcement}$	$\mu_{concrete}$
3 m	4	0.98	0.90	1.65	1.31	1.32
4 m	4	0.94	0.86	1.65	1.25	1.26
5 m	3.9	0.91	0.79	1.65	1.18	1.18

Class 70

	Vertical wall			Horizontal wall		
	cot(θ)	$\mu_{reinforcement}$	$\mu_{concrete}$	cot(θ)	$\mu_{reinforcement}$	$\mu_{concrete}$
3 m	4	0.81	0.68	1.65	0.99	0.99
4 m	4	0.78	0.65	1.7	0.92	0.97
5 m	4	0.74	0.62	1.8	0.83	0.95

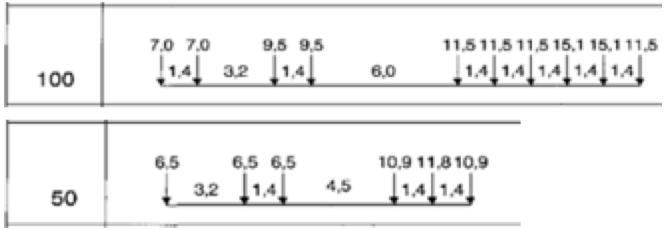
Critical limit state becomes:

$$\frac{\sqrt{\left(V_{reinforcement}\right)^2 + \left(V_{concrete}\right)^2}}{\sqrt{2}} \geq V_{Ed\_T}$$

TARGET SAFETY LEVEL

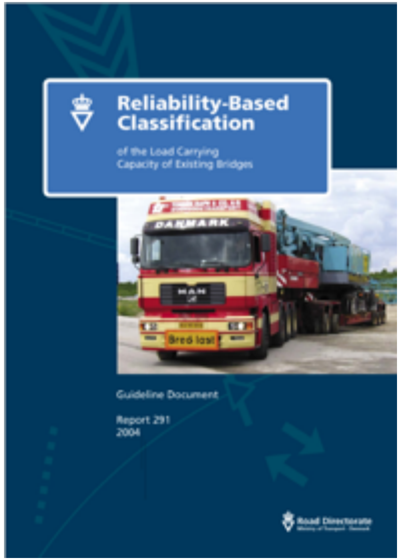
K_{FI} x (1.00 x Permanent load + 1.25 x ϕ x Vehicle A + 1.05 x ϕ x Vehicle B + 0.56 x UDL)

Φ the dynamic factor decreases from 1,25 to 1,13.



Failure type	Failure with warning and bearing capacity reserve	Failure with warning but without capacity reserve	Failure without warning
β_t	4.26	4.75	5.20
P_f	10^{-5}	10^{-6}	10^{-7}

Table 3.1: Required safety index for ultimate limit states.



STOCHASTIC TRAFFIC LOAD

Variable	Name	Type	Expected Value	CoV (std)
Vehicle weight Class 100	μ_1, σ_1	Parameters in Normal distribution	1071kN	4.58% (49.1kN)
Vehicle weight Class 50	μ_2, σ_2	Parameters in Normal distribution	521kN	9.42% (49.1kN)
Vehicle length	L_1	Deterministic	19.0m	
Vehicle length	L_2	Deterministic	11.9m	
Influence length	Il_1, Il_2	Deterministic	32.1m	
Dynamic increment	ε	Normal	0.0	100%
Model Uncertainty	I_{m1}, I_{m2}	Normal (independent)	1.0	10%
Relative importance	ρ_1, ρ_2	Deterministic	0.90/0.10	
Annual truck frequency	N_1, N_2	Deterministic		
Speed	V_1, V_2	Deterministic		
% Trucks in flow	$Load_1, Load_2$	Deterministic	100%/100%	

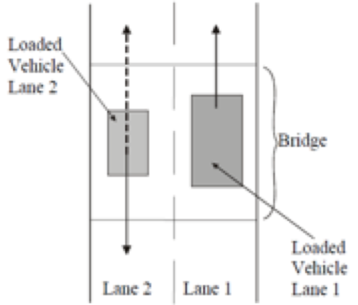


Figure 5.1 - Normal Passage Situation, Heavy transport + Standard vehicle

The total extreme load effect:

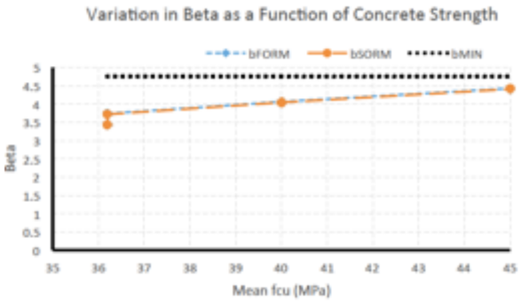
$$F_{max}(q) = \exp\left(-(\nu_1 - \nu_{12})T\left(1 - F_1(q)\right)\right) \cdot \exp\left(-(\nu_2 - \nu_{12})T\left(1 - F_2(q)\right)\right) \cdot \exp\left(-\nu_{12}T\left(1 - F_{12}(q)\right)\right)$$

STOCHASTIC VARIABLES

Variable	Name	Type	Expected Value	CoV (std)
Concrete, Compressive Strength	fc	Log-Normal	36.2MPa	17.43% (6.31MPa)
Steel Strength	fy	Log-Normal	582MPa	11.15% (65.45MPa)
Dead Load	DL	Normal	1.0	7.1%
Superimposed Dead Load	SIDL	Normal	1.0	11.18%
Parasitic Forces	IPAR	Normal	1.0	7.1%
Young's Modulus	Ec, Es	Deterministic		
Area of reinforcement	As	Deterministic		
Reinforcement cover	c	Deterministic		

$$\beta = 3.74$$

$$\beta_{target} = 4.75$$

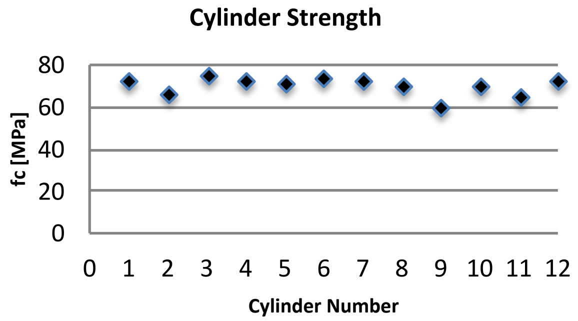


UPDATED CONCRETE STRENGTH

Variable	Name	Type	Expected Value	CoV (std)
Concrete, Compressive Strength	fc	Log-Normal	58.7MPa	15.87% (9.32MPa)
Steel Strength	fy	Log-Normal	582MPa	11.15% (65.45MPa)
Dead Load	DL	Normal	1.0	7.1%
Superimposed Dead Load	SIDL	Normal	1.0	11.18%
Parasitic Forces	IPAR	Normal	1.0	7.1%
Young's Modulus	Ec, Es	Deterministic		
Area of reinforcement	As	Deterministic		
Reinforcement cover	c	Deterministic		

Results of Cylinder Tests on the Structure, f_{ck} = 61.5MPa.

Based upon Eurocode assume f_{ck} = 50MPa.

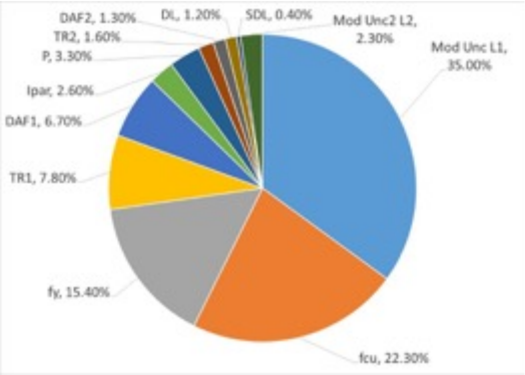


f_{ck} [MPa]	$E[f_c]$ [MPa]	V_{f_c}
5	6.76	0.22
10	12.8	0.18
15	18.9	0.17
20	24.8	0.16
25	30.6	0.15
30	36.2	0.14
35	41.7	0.13
40	47.0	0.12
45	52.8	0.12
50	58.7	0.12

RESULTS

Table 1: Old and new partial safety factors - Vestmotorvejen

	Deterministic	$\boldsymbol{\beta = 5.33}$ with Class 100	$\boldsymbol{\beta = 4.82}$ with Class 115
Class 115 vehicle	1.25	-	1.19
Class 100 vehicle	1.25	1.31	-
Class 50 vehicle	1.05	1.08	1.08
Dynamic Amplification $\phi_{Class115}$	1.13	1.16	1.14
Dynamic Amplification $\phi_{Class50}$	1.13	1.14	1.14
γ_c	1.45	1.30	1.38
γ_s	1.20	1.12	1.1
K_{FI}	1.1	1.0	1.0



CONCLUSIONS

- Capacity upgrade from Class 70 to Class 115
- Avoidance of unnecessary repair
- Cost savings
- CO_2 savings

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