2G EUROCODES – CONCRETE DAMS

Mikael Hallgren

Structural Engineer, Tyréns
Guest Researcher/Docent, KTH Concrete Structures

Member and former chair of SIS/TK556 Betongkonstruktioner
Convenor of CEN/TC250/SC2/WG1 for 2G Eurocode 2 – Concrete Structures

GAP-Analysis of
2nd Generation Eurocode for Concrete Dams

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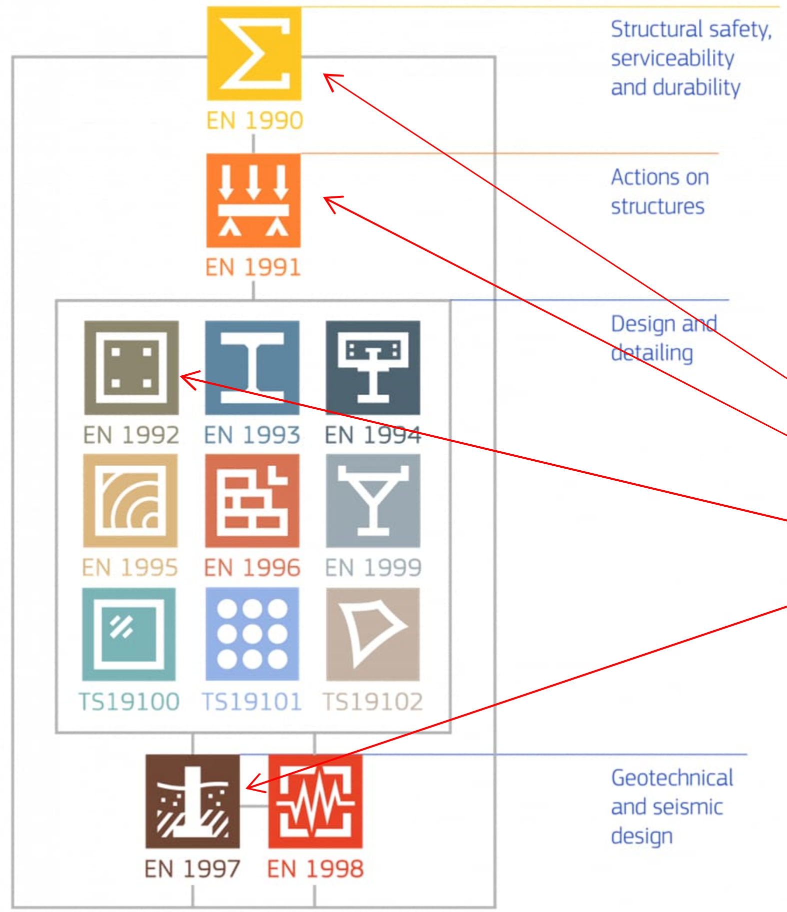
Mikael Hallgren and Fredrik Stenesand, Tyréns

2nd generation Eurocodes (EC) at a glance

All new 2G ECs will be published in September 2027 at the latest. Publication is ongoing since 2023.

They will replace the current 1G ECs in March 2028 at the latest.



Of interest for concrete dams:

EN 1990 Basis of design

EN 1991 Actions

EN 1992 Concrete Structures

EN 1997 Geotechnical design

2G EC – CONCRETE DAMS
SS-EN 1990:2023 BASIS OF DESIGN

EN 1990 now includes dams!

Table A.1.1 (NDP) — Examples of buildings in different consequence classes

Consequence class	Description of consequence	Examples
CC4[a]	Highest	Nuclear power plant, dams
CC3	High	Buildings or parts of buildings where a very large number of people could be affected by failure, e.g. grandstands, concert halls, high-rise buildings
CC2	Normal	Buildings or parts of buildings not covered by CC1 or CC3
CC1	Low	Buildings or part of buildings where very few people could be affected by failure, e.g. agricultural buildings, storage buildings
CC0[a]	Lowest	Elements other than structural, see 3.1.1.7.

[a] For provisions concerning CC0 and CC4, see 4.3.

Table A.1.9 (NDP) — Consequence factors for buildings and geotechnical structures

Consequence class (CC)[a]	Description of consequences	Consequence factor k_F
CC3	High	1,1
CC2	Normal	1,0
CC1	Low	0,9

[a] The provisions in Eurocodes cover design rules for structures classified as CC1 to CC3, see 4.3.

But, recommended factor for CC4 is missing…

In RIDAS TV9 (2020), correction factor γ_k = 1,2.

Proposal k_F^{CC4} = 1,2 ?

2G EC – CONCRETE DAMS
SS-EN 1990:2023 BASIS OF DESIGN

Action or effect				Partial factors γ_F and γ_E for verification cases				
Type	Group	Symbol	Resulting effect	Structural resistance[a]	Static equilibrium and uplift[b]		Geotechnical design	
Verification case				VC1[a]	VC2(a)[b]	VC2(b)[b]	VC3[c]	VC4[d]
Permanent action (G_k)	All[f]	γ_G	unfavourable /destabilizing	$1{,}35k_F$	$1{,}35k_F$	1,0	1,0	G_k is not factored
	Water[l]	γ_{Gw}		$1{,}2k_F$	$1{,}2k_F$	1,0	1,0	
	All[f]	$\gamma_{G,stb}$	stabilizing[g]	not used	1,15[e]	1,0	not used	
	Water[l]	$\gamma_{Gw,stb}$			1,0[e]	1,0		
	All	$\gamma_{G,fav}$	favourable[h]	1,0	1,0	1,0	1,0	
Prestressing (P_k)		γ_P[k]						
Variable action (Q_k)	All[f]	γ_Q	unfavourable	$1{,}5k_F$	$1{,}5k_F$	$1{,}5k_F$	1,3	$\gamma_{Q,red}$[j]
	Water[l]	γ_{Qw}		$1{,}35k_F$	$1{,}35k_F$	$1{,}35k_F$	1,15	1,0
	All	$\gamma_{Q,fav}$	favourable	0				
Effects of actions (E)		γ_E	unfavourable	γ_E is not applied				$1{,}35k_F$
		$\gamma_{E,fav}$	favourable					1,0

New partial load factors for water pressure!

In current SS-EN 1990:2002 general load factors for permanent action (1,35) and variable action (1,5) are used for water pressure.

2G EC2 – CONCRETE DAMS
SS-EN 1992-1-1:2023 CONCRETE STRUCTURES

➢ **Some new design provisions promoting climate-improved concrete structures:**

- Allows reference age for concrete strength up to 91 days to utilise the increased (but slow) strength development in concrete with new SCMs (FA, GGBS, etc.)
- Exposure Resistance Classes (ERC) for improved assessment of durability of both normal OPC concrete and new SCM concrete;
- Design provision for Recycled Aggregate Concrete Structures;
- New appendix for assessment of existing concrete structures – Re-use!

2G EC2 – CONCRETE DAMS
EXPOSURE RESISTANCE CLASSES (ERC)

- Durability of concrete is classified based on the performance => opens up for new SCM concrete

Concrete cover for Carbonation (XRC)

Table 6.3 (NDP) — Minimum concrete cover $c_{min,dur}$ for carbon reinforcing steel — Carbonation

ERC	Exposure class (carbonation)							
	XC1		XC2		XC3		XC4	
	Design service life (years)							
	50	100	50	100	50	100	50	100
XRC 0,5	10	10	10	10	10	10	10	10
XRC 1	10	10	10	10	10	15	10	15
XRC 2	10	15	10	15	15	25	15	25
XRC 3	10	15	15	20	20	30	20	30
XRC 4	10	20	15	25	25	35	25	40
XRC 5	15	25	20	30	25	45	30	45
XRC 6	15	25	25	35	35	55	40	55
XRC 7	15	30	25	40	40	60	45	60

NOTE 1 XRC classes for resistance against corrosion induced by carbonation are derived from the carbonation depth [mm] (characteristic value 90 % fractile) assumed to be obtained after 50 years under reference conditions (400 ppm CO_2 in a constant 65 %-*RH* environment and at 20 °C). The designation value of XRC has the dimension of a carbonation rate [mm/√ (years)].

NOTE 2 The recommended minimum concrete cover values $c_{min,dur}$ assume execution and curing according to EN 13670 with at least execution class 2 and curing class 2.

NOTE 3 The minimum covers can be increased by an additional safety element $\Delta c_{dur,\gamma}$ considering special requirements (e.g. more extreme environmental conditions).

2G EC2 – CONCRETE DAMS
MINIMUM REINFORCEMENT FOR CRACK CONTROL

- Minimum reinforcement area to avoid yielding of reinforcement
  - Balance between concrete force when cracking and steel force when yielding (f_{yk}) applied on the full tensile concrete area A_c

(i) For pure bending:

$$A_{s,min,w1} \geq \frac{0{,}2 k_h f_{ct,eff} A_c}{f_{yk}}$$

(ii) For pure tension:

$$A_{s,min,w1} = A_{s,min,w2} \geq \frac{0{,}5 k_h f_{ct,eff} A_c}{f_{yk}}$$

$$k_h = 0{,}8 - 0{,}6(\min\{b; h\} - 0{,}3) \begin{cases} \leq 0{,}8 \\ \geq 0{,}5 \end{cases}$$

- Minimum reinforcement area for crack width control
  - Applied only on the effective concrete tensile area $A_{c,eff}$ and $\sigma_{s,lim}$ = f[$w_{lim,calc}$]

a) For pure bending:

$$A_{s,min,w1} = \frac{0{,}8 \frac{h - h_{c,eff}}{h} f_{ct,eff} A_{c,eff}}{\sigma_{s,lim}}$$

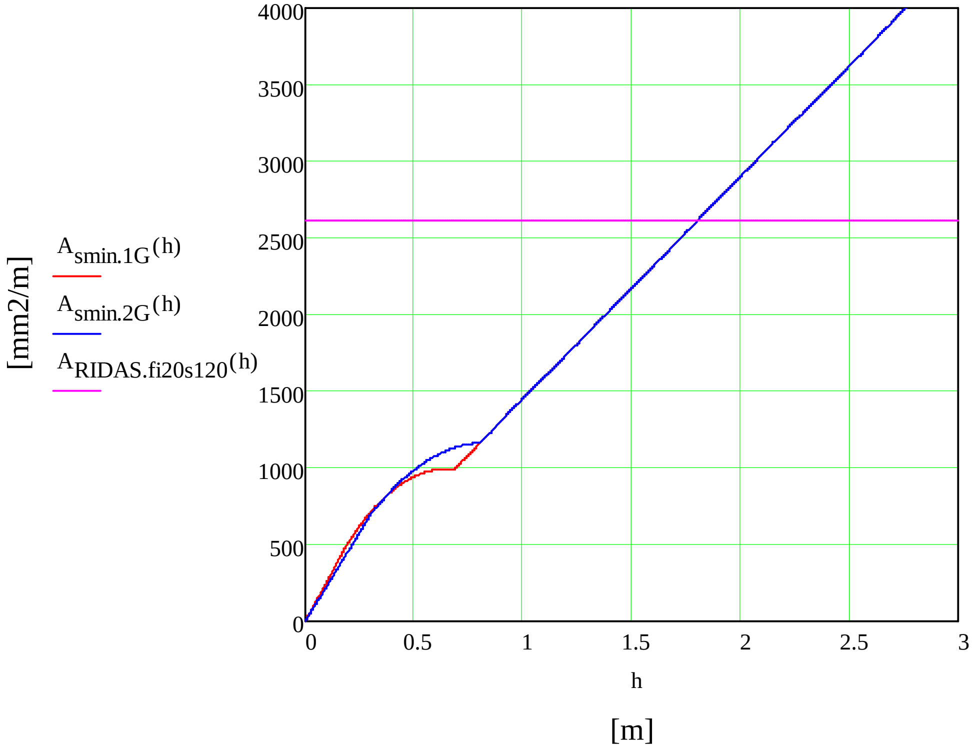
b) For pure tension:

$$A_{s,min,w1} = A_{s,min,w2} = \frac{f_{ct,eff} A_{c,eff}}{\sigma_{s,lim}}$$

$$\sigma_{s,lim} \leq k_{\sigma 1} f_{ct,eff} \cdot \left(\frac{1}{\phi}\right)\left(-c + \sqrt{c^2 + k_{\sigma 2} \frac{E_s \cdot w_{lim,cal} \cdot \phi}{k_w \cdot k_{\frac{1}{r},simpl} \cdot f_{ct,eff}}}\right)$$

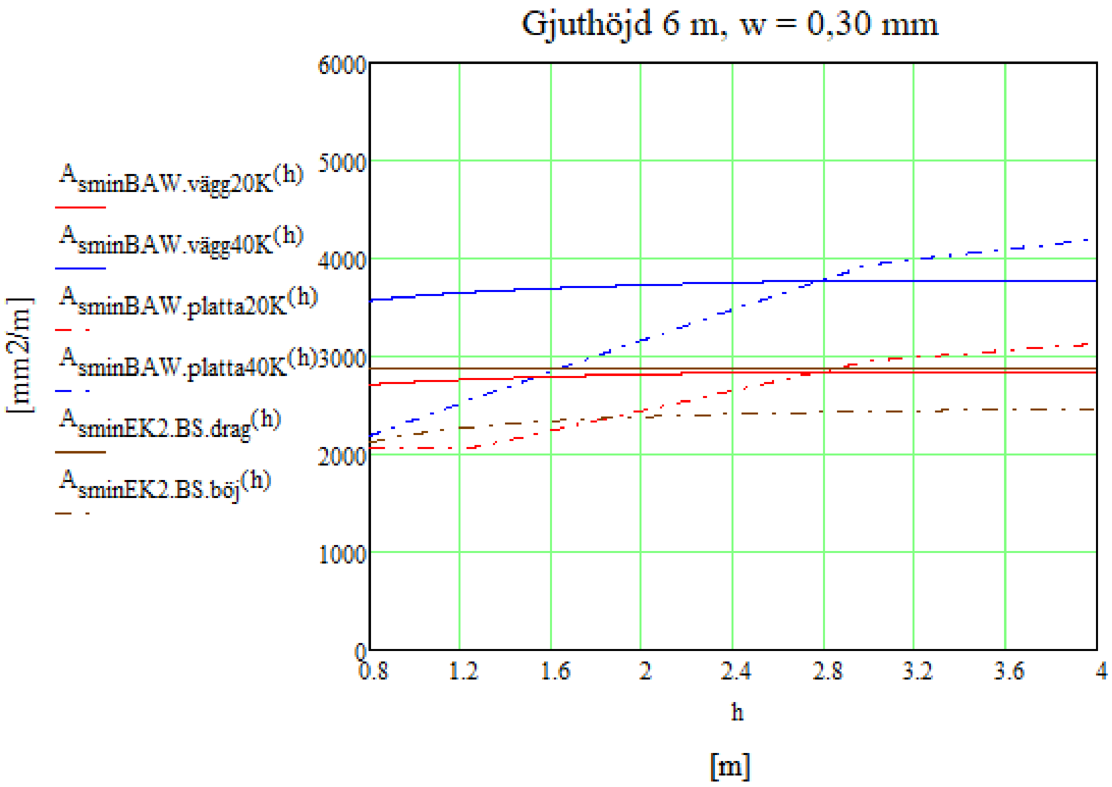
2G EC2 – CONCRETE DAMS
MINIMUM REINFORCEMENT TO AVOID YIELDING

Comparison with
1G EC2 (EKS)
and with RIDAS



2G EC2 – CONCRETE DAMS
MINIMUM REINFORCEMENT FOR CRACK WIDTH

Comparison with RIDAS (BAW)



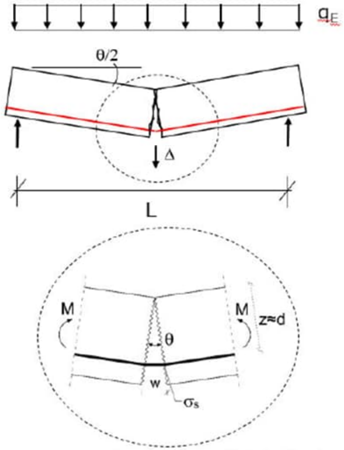
2G EC2 – CONCRETE DAMS
MINIMUM REINFORCEMENT FOR ROBUSTNESS

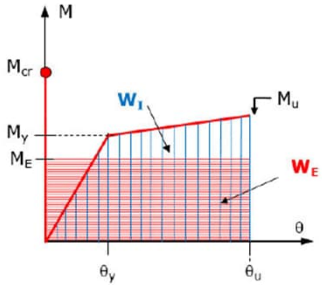
- Requirement written in a general form
  - Bending with or without axial force (ULS):

$$M_{\mathrm{R,min}}\left(N_{\mathrm{Ed,min}}\right) \geq M_{\mathrm{cr}}\left(N_{\mathrm{Ed,min}}\right)$$

  - Pure tension:

$$A_{\mathrm{s,min}} = A_{\mathrm{c}} \cdot f_{\mathrm{ctm}}/f_{\mathrm{yk}}$$





  - Members statically determinate without requirement for crack control:

$$M_{\mathrm{Rd,min}}\left(N_{\mathrm{Ed}}\right) = k_{\mathrm{dc}} \cdot M_{\mathrm{Ed}}$$

$k_{\mathrm{dc}} = 1{,}3$ for ductility class A;

$k_{\mathrm{dc}} = 1{,}1$ for ductility class B;

$k_{\mathrm{dc}} = 1{,}0$ for ductility class C.

2G EC2 - CONCRETE DAMS
SHEAR DESIGN

➢ Shear strength

- New design provision based a mechanical model – Critical Shear Crack Theory (CSCT),
- Considers the infuence of the shear span with respect to the control section (a_{cs}),
- Considers the influence of the aggregate size and aggregate interlock (d_{dg}),
- Considers the size effect in the cross section (d).

$$\tau_{Rd,c} = \frac{0,66}{\gamma_V} \cdot \left(100\rho_l \cdot f_{ck} \cdot \frac{d_{dg}}{a_v}\right)^{\frac{1}{3}}$$

$$a_v = \sqrt{\frac{a_{cs}}{4} \cdot d} \qquad a_{cs} = \left|\frac{M_{Ed}}{V_{Ed}}\right| \geq d$$

2G EC2 - CONCRETE DAMS
ANCHORAGE AND LAPS

- Bond strength method is replaced by a simple factor method

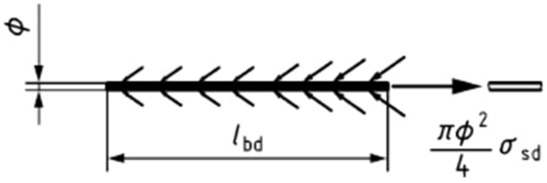
Table 11.1 (NDP) — Anchorage length of straight bars divided by diameter l_{bd}/ϕ

ϕ [mm]	Anchorage length l_{bd}/ϕ							
	f_{ck}							
	20	25	30	35	40	45	50	60
≤ 12	47	42	38	36	33	31	30	27
14	50	44	41	38	35	33	31	29
16	52	46	42	39	37	35	33	30
20	56	50	46	42	40	37	35	32
25	60	54	49	46	43	40	38	35
28	63	56	51	47	44	42	40	36
32	65	58	53	49	46	44	41	38

NOTE The values of Table 11.1 (NDP) are derived from Formula (11.3).

$$l_{bd} = k_{lb} \cdot k_{cp} \cdot \phi \cdot \left(\frac{\sigma_{sd}}{435}\right)^{n_\sigma} \cdot \left(\frac{25}{f_{ck}}\right)^{\frac{1}{2}} \cdot \left(\frac{\phi}{20}\right)^{\frac{1}{3}} \cdot \left(\frac{1{,}5\phi}{c_d}\right)^{\frac{1}{2}} \geq 10\phi$$

Table valid for:
$c_d \geq 1{,}5\phi$, σ_{sd} = 435 MPa
and good bond condition



NDPs: k_{lb} = 50; n_σ =1,5
Good bond: k_{cp} = 1,0
Poor bond: k_{cp} = 1,2

Lap length: $l_{sd} = k_{ls} \cdot l_{bd}$
NDP: k_{ls} = 1,2

2G EC2 – CONCRETE DAMS
WATER TIGHTNESS

- For TC1, $w_{k,lim1}$ is the width of any cracks expected to pass through the full thickness

- Based on the ratio h_D/h of the hydrostatic head h_D to the thickness of the member h, as follows:

  — for $h_D/h \leq 5$: $w_{k,lim,1} = 0{,}20$ mm;
  — for $h_D/h \geq 35$: $w_{k,lim,1} = 0{,}05$ mm.

- For structures of classes TC 2 or TC 3 so that cracks do not pass through the full width of a section, the design value of the depth of the compression zone should be at least x_{min} under the quasi-permanent combination of actions.

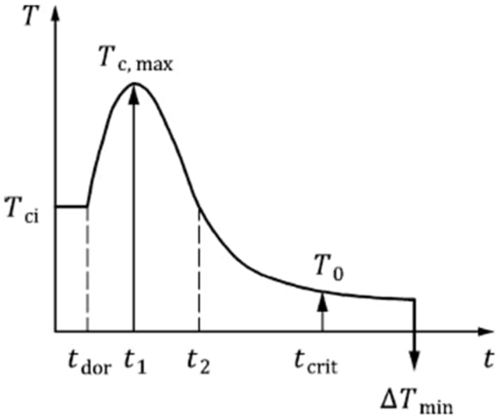
- x_{min} is the lesser of 50 mm or $0{,}2h$

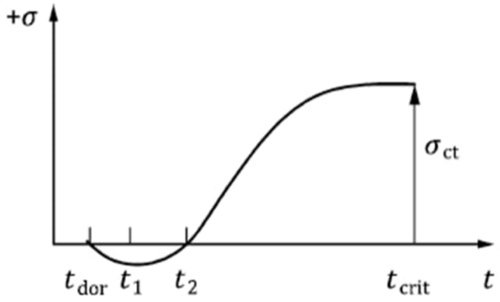
Table H.1 — Classification of tightness

Tightness Class	Requirements for leakage
TC 0	Some degree of leakage acceptable, or leakage of water irrelevant.
TC 1	Leakage to be limited to a small amount. Some surface staining or damp patches acceptable.
TC 2	Leakage to be minimal. Appearance not to be impaired by staining.
TC 3	No leakage is permitted.

2G EC2 – CONCRETE DAMS

EARLY-AGE AND LONG-TERM CRACKING DUE TO RESTRAINT





for early-age cracking:

$$R_{ax}\varepsilon_{free} = R_{ax,1}\left(k_{Temp}\alpha_{cth}\left(T_{c,max}-T_0\right)+[\varepsilon_{cbs}(t_{crit})-\varepsilon_{cbs}(t_2)]\right)$$

for long-term cracking:

$$R_{ax}\varepsilon_{free} = R_{ax,1}\left(k_{Temp}\alpha_{cth}\left(T_{c,max}-T_0\right)+[\varepsilon_{cbs}(t)-\varepsilon_{cbs}(t_2)]\right) + R_{ax,2}\alpha_{cth}\Delta T_{min} + R_{ax,3}\cdot[\varepsilon_{cds}(t)-\varepsilon_{cds}(t_2)]$$

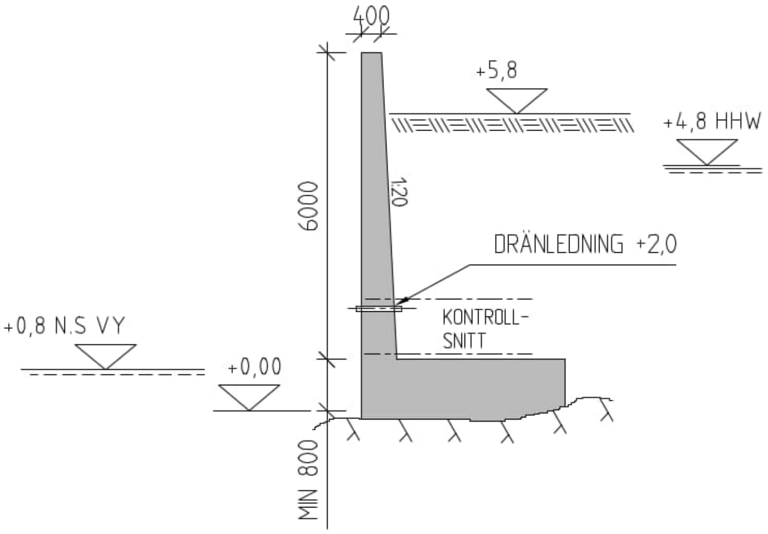
$$\varepsilon_{sm}-\varepsilon_{cm} = R_{ax}\varepsilon_{free} - k_t\frac{f_{ct,eff}}{E_{cm}} \geq 0$$

$$s_{r,m,cal} = 1{,}5\cdot c + \frac{k_{fl}\cdot k_b}{7{,}2}\cdot\frac{\phi}{\rho_{p,eff}} \leq \frac{1{,}3}{k_w}(h-x)$$

$$\boxed{w_{k,cal} = k_w\cdot k_{1/r}\cdot s_{r,m,cal}(\varepsilon_{sm}-\varepsilon_{cm})}$$

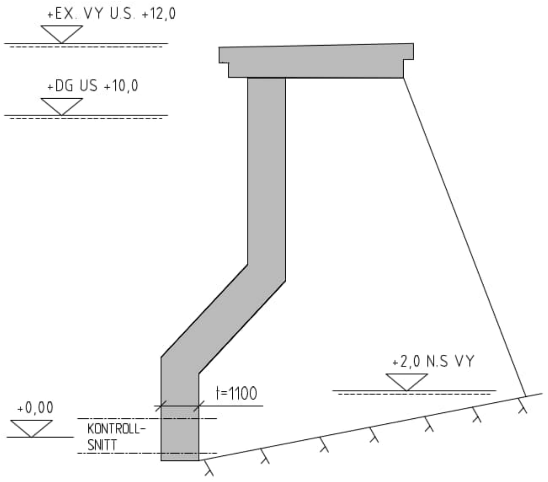
CASE STUDY 1:
RETAINING WATERWAY WALL

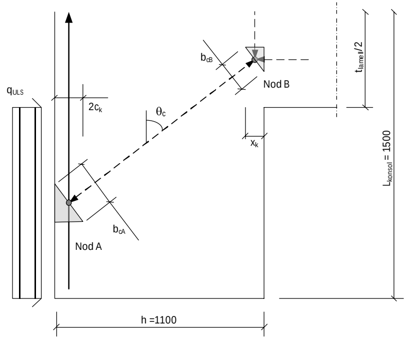
Result	Unit	EC2:2005/ RIDAS/EKS	EC2:2023	incr./decr. %
Vertical reinf.:				
A_s ULS	cm^2/m	9,9	9,9	0 %
A_s SLS (crack width)	cm^2/m	13,0	11,7	-10 %
$A_{s,min}$ (robustness)	cm^2/m	9,7	8,3	-14 %
Horizontal reinf.:				
$A_{s,min}$ ($\sigma_s = f_{yk}$)	cm^2/m	10,2	11,4	12 %
$A_{s,min}$ (limit w_k)	cm^2/m	25,4	30,5	20 %
A_s (limit w_k, restraint)			14,9	-41 %
Shear:				
$V_{Ed}/V_{Rd,c}$ (utilization)	-	0,78	0,66	-15%
Anchorage length, l_{bd}	mm	618	790	28%
Lap length, l_{sd}	mm	927	948	2%



CASE STUDY 2:
FRONT PLATE IN BUTTRESS DAM

Result	Unit	EC2:2005/ RIDAS/EKS	EC2:2023	incr./decr. %
Horizontal reinf.:				
A_s ULS	cm^2/m	29,7	29,7	0%
A_s SLS (crack width)	cm^2/m	55,0	50,6	-8%
$A_{s,min}$ (robustness)	cm^2/m	16,8	14,9	-11%
$A_{s,min}$ ($\sigma_s = f_{yk}$)	cm^2/m	17,6	17,6	0%
$A_{s,min}$ (limit w_k)	cm^2/m	43,8	42,6	-3%
φ (creep coefficient)	-	1,752	1,969	12%
Shear:				
$V_{Ed}/V_{Rd,c}$ (utilization)	-	1,16	1,23	6%
A_{sw} (req. shear reinf.)	cm^2/m	9,47	9,47	0%
Anchorage length, l_{bd}	mm	772	985	28%
Lap length, l_{sd}	mm	1158	1182	2%
Cantilever calc. with S&T:				
$\sigma_c/\sigma_{cmaxCCT}$ (CCT-nod)	-	0,0834	0,0871	4%
$\sigma_c/\sigma_{cmaxCCC}$ (CCC-nod)	-	0,1064	0,0915	-14%
$A_{s,konsol}$ (cantilever reinf.)	cm^2/m	4,91	4,91	0%





CONCLUSIONS

- 2G Eurocode: Basis of design – impact on design of concrete dams
  - Now includes dam structures in the scope
  - New consequence class CC4 which should be used for dams
  - Reduced load coefficients for permanent and variable water pressure
- 2G Eurocode 2: Concrete structures – impact on design of concrete dams
  - Opens up for more use of climate improved concrete (SCM concrete)
  - Small differences in ULS design compared to 1G EC2
  - Reasonable amounts of minimum reinforcement
  - New design provisions for stress and cracks due to early-age and long-term restraints,
  - New design provisions for water tightness
  - Longer anchorage lengths (but may be adjusted with Swedish NDP)

THANK YOU!

mikael.hallgren@tyrens.se

www.tyrens.se