Exercise 3: Risk of corrosion initiation (chlorides)

Retaining wall on a motorway

Background and objective

The following image shows a retaining wall built in 1985 along a motorway in Switzerland. The dosage of cement in the concrete is 300 kg/m^3. This wall is subjected to heavy salt spraying conditions on the road in wintertime.

Table 1 gives concentration values $C^0_{Cl^-}$ (in kg per m^3 of concrete) in chloride ions on the concrete surface for the 3 zones A, B, C of the wall, depending on their exposure:

Table 1

Exposure	Concentration $C^0_{Cl^-}$ [kg/m^3]
Splash (zone A)	3.5
Splash/Mist (zone B)	2.8
Mist (zone C)	2.1

The aims of the exercise are to determine the risk of corrosion initiation induced by chloride ions for different zones of the wall, different depth, and for different types of concretes.

Answer the following questions using the data from Table 1, the diffusion model given in Appendix I and material properties given in Appendix II:

Question 1

Determine the free chloride profiles (concentration as a function of depth) for average - quality concrete according to Table 2 in Appendix II, after 30 years of exposure, for the 3 exposure zones in Table 1.

Question 2

Determine, for the 3 different concrete qualities according to Table 2 in Appendix II, the evolution of the free chloride content as a function of time (from 0 to 100 years), for a depth of 30 mm, with splash exposure according to Table 1.

Question 3

The average concrete cover for the full wall is 30 mm. Determine the age at which the probability of depassivation of reinforcement bars at 30 mm will exceed 50 %, for B500B for the 3 concrete qualities with properties shown on Table 2, Appendix 2, for Splash exposure according to Table 1.

Question 4

Discuss the calculation assumptions and the obtained results, what would be the benefit of using other types of steel ?.

Note: this exercise is adapted from the lecture notes of Prof. Eugen Brühwiler "Structures existantes : Examen et interventions - Bases", edition 2022, exercise 5, course CIVIL-436, courtesy of Prof. Brühwiler.

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Appendix I: Chloride ions transport in concrete

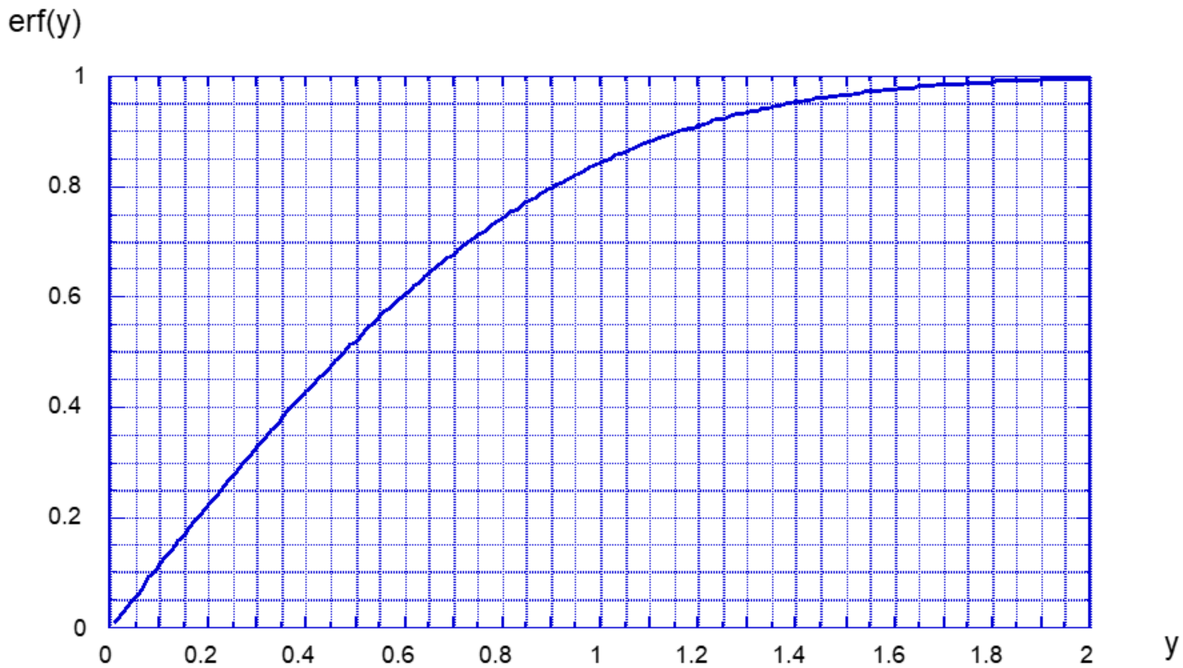
Chloride ion transport in concrete is a complex phenomenon associated with water transport, capillary absorption and diffusion of ions. As they penetrate, some chloride ions become chemically bound in the hardened cement paste. Only the local concentration of free (unbound) chloride ions is of interest in assessing the risk of corrosion. As a first approximation, free chlorides transport can be represented by the following equation, based on ion diffusion in water-saturated concrete under steady-state conditions, where *x* is the depth of penetration into the concrete, *t* is the time, D_c is the diffusion coefficient of the concrete, $C^{0}_{Cl^-}$ is the chloride ion content at the surface of the concrete, and $C^{libres}_{Cl^-}(x,t)$ is the free chloride ion content at depth *x* at time *t* (60 % of the total chloride content).

$$C^{libres}_{Cl^-}(x,t) = 0.6 C^{0}_{Cl^-}\left(1 - erf\left(\frac{x}{2\sqrt{D_c t}}\right)\right) \tag{1}$$

The "erf" or Euler error function is defined by:

$$erf(y) = \frac{2}{\sqrt{\pi}} \int_0^y e^{-z^2} dz \tag{2}$$

The figure below shows a graphical representation of this function.



Appendix II: Material properties

Concretes

Table 2 shows the values of the diffusion coefficient for different concretes as a function of their quality and water/cement ratio:

Table 2

Water/Cement ratio	Cover concrete quality	Diffusion coefficient D_c [m^2 /s]
0.4	Good	0.73×10^{-12}
0.5	Average	2.14×10^{-12}
0.6	Low	6.25×10^{-12}

Steel reinforcement bars

The following figure shows the probability of corrosion initiation for different types of steels as a function of the free chlorides content.