Transport of chlorides through clay layer into concrete



Ingemar Löfgren [1 & 2], Luping Tang [2], Jonas Magnusson [3]

1) Thomas Concrete Group, Gothenburg, Sweden
2) Chalmers University of Technology, Gothenburg, Sweden
3) NCC Construction, Gothenburg, Sweden

ABSTRACT

To assure durability, standards attempt to provide specifications for long-term performance by simple deemed-to-satisfy rules for approximate environmental classification. This paper presents results from a study of chloride ingress in concrete diaphragm walls where the transport of chlorides in both clay and concrete was considered. For the concrete, a physical model, ClinConc, was employed to calculate the chloride ingress profiles. The results show that a clay layer of limited depth structured outside the concrete had no any effect to reduce chloride ingress in concrete, whilst the addition of slag is more effective way to resist chloride ingress in concrete.

Key words: Chloride, clay, concrete, durability, modelling

1. Introduction

At the present, the specification of durability is mainly based on the establishment of various constraints to the mixture proportions of the concrete, such as cement type and water/binder (*w*/*b*) ratio, together with requirements on the cover thickness as function of the severity of the exposure, [1]. This approach does not consider the actual performance of concrete materials nor the actual exposure conditions. With the help of more sophisticated durability models safer structures can be designed with expected service life and with reduced environmental impact. For concrete in aggressive ground conditions both chemical attack as well as chloride induced corrosion make occur. However, the mobility of the groundwater and the soil's ability to transport harmful chemical agents plays a significant role and in EN 206 [1] it is stated that the for clays with a permeability less than 10^{-5} m/s the exposure class for sulfates may be moved into a lower class. Hence, for a clay with low permeability the transport of aggressive chemicals will be reduced but no guidance is given in EN 206 on how to consider this. In [2] guidance for concrete in aggressive ground is provided but in this it only considers the two cases of mobile and static ground water, the latter being the case of low permeability, but the focus of the guideline is chemical attack of concrete and not chloride induced corrosion.

2. Chloride ingress modelling

Based on recent validation results from concrete specimens after over 20 years' exposure in the Träslövsläge harbour [3] and 10 years field exposure in road environment [4] in Sweden, the ClinConc model [5] revealed the best agreement with the field data. Therefore, this model was used for modelling of chloride ingress in this study. The ClinConc model consists of two main procedures, see [5]: 1) Simulation of free chloride penetration through the pore solution in concrete using a genuine flux equation based on the principle of Fick's law with the free chloride concentration as the driving potential, and 2) Calculation of the distribution of the total chloride content in concrete using the mass balance equation combined with non-linear chloride binding. Because the ClinConc model uses free chloride as the driving force and takes non-linear chloride binding into account, it describes chloride transport in concrete in a more scientific way than the empirical or semi-empiric models. The detailed descriptions of this model can be found in [5]. The key input parameter in this model is the chloride diffusion coefficient measured by the rapid chloride migration (RCM) test, e.g. NT BUILD 492 [6], at the age of 6 months, noted as D_{6m}. The environmental parameters include chloride concentration and temperature in the exposure water. To simulate the chloride transport through the clay layer into concrete, the following boundary condition between the clay and the concrete was used:

$$\varepsilon_{clay} \cdot D_{clay} \frac{\partial c_{clay}}{\partial x} = \varepsilon_c \cdot D_c \frac{\partial c_c}{\partial x} \text{ with } c_{clay} = c_c \text{ at the boundary} \quad (1)$$

where: ε_{clay} is the porosity of the clay, D_{clay} is the effective diffusion coefficient of the clay and c_{clay} is the free chloride concentration in the clay. For the clay, an effective diffusion coefficient of D_{clay} = 5 x 10^{-10} m^2/s and a porosity was ε_{clay} = 65% was used. The clay was assumed to be initially saturated with chlorides having a chloride ionic concentration of 18 g/l with an annual mean water temperature of +10°C. To fulfil the boundary condition in equation (1), FDM (Finite Difference Method) with FTCS (Forward-Time Central-Space) was employed. To assure converge in the calculation, a small increment of time must be used due to the sharp interface between clay and concrete.

Two different concrete mixes were initially evaluted (water/binder ratio of 0.50 and 0.45), both had a binder consisting of 53% CEM I 42.5N SR3 (moderate heat and low alkali) and 47% ground granulated blastfurnace slag (GGBS). The concrete mixes were compared with a reference mix with 100% CEM I 42.5N SR3 (moderate heat and low alkali) and a w/b-ratio of 0.45. The chloride migration coefficient measured by NT BUILD 492 at different ages are presented in table 1. Since the chloride migration coefficient were so low for the mixes containing GGBS and small differences between 0.50 and 0.45 it was decided to use the mix with w/b 0.50 for the simulation.

Table 1. Chloride migration coefficients for the concrete mixes.

Age [days]	*w/b* 0.50 (47% GGBS) $D_{NTB\ 492}$ 10^{-12} [m^2/s]	*w/b* 0.45 (47% GGBS) $D_{NTB\ 492}$ 10^{-12} [m^2/s]	w/b 0.45 (0% GGBS) $D_{NTB\ 492}$ 10^{-12} [m^2/s]
28	5.3	4.9	20
56	2.9	2.6	14.9
120	2.4	2.1	
180	1.9*	1.7*	14.6

* Extrapolated from the data tested at 28, 56 and 120 days.

3. Results and discussion

The results from the modelling of chloride ingress through a 300 mm and a 500 mm clay layer into concrete are shown in figure 1. The calculated results clearly show that the concrete containing slag dramatically reduced chloride ingress due to its significantly lower chloride migration coefficient, as shown in table 1. The chloride content in the clay layer close to the concrete surface decreased with time. This decrease is more markedly in the reference concrete than in the concrete with slag, owing to the lager transport flux in the former case.

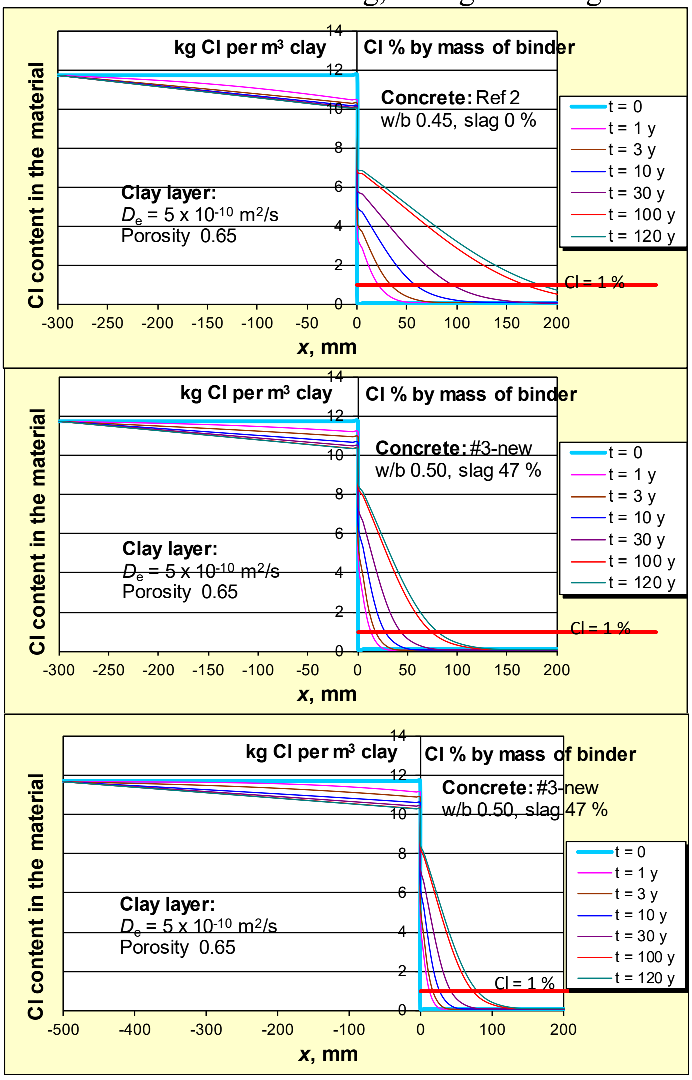

Figure 1. Chloride ingress through the clay into two types of concrete.

Figure 2 shows the comparison of the results with and without clay layer. The chloride content close to the concrete surface becomes a little lower when a clay layer is structured outside the concrete, but the deeper ingress profiles are identical, implying that the clay layer has very limited “braking” effect, even when the thickness of clay layer was increased to 500 mm. The reason could be that the concrete has a diffusion coefficient which is lower than the clay by two orders of magnitude and thus the transport of chloride through the clay is mainly dependent on the flux in concrete.

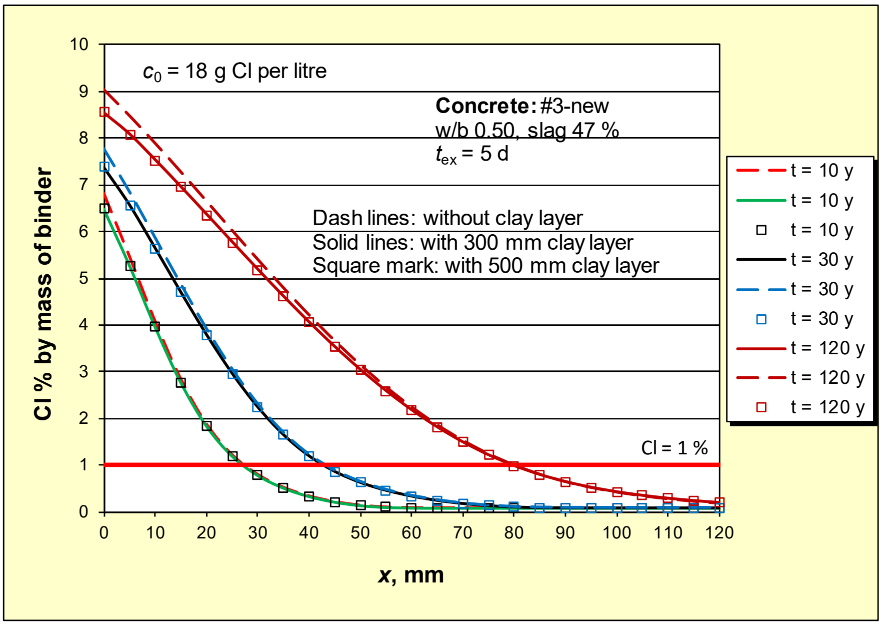

Figure 2. Effect of clay layer on chloride ingress into concrete.

4. Conclusions

Based on the result of this study, the following conclusions can be drawn:

- The clay layer (limited depth considerd) has very limited braking effect on chloride ingress into concrete, although it can slightly reduce the chloride concentration on the concrete surface.
- The more effective way to reduce chloride ingress is the addition of GGBS in concrete.

References

[1] EN 206: Concrete - Specification, performance, production and conformity. Brussels, European Committee for Standardization, 2013.

[2] BRE Special Digest, Concrete in aggressive ground, BRE, 2005.

[3] Boubitsas D., Tang L. and Utgenannt P., Chloride Ingress in Concrete Exposed to Marine Environment - Field data up to 20 years’ exposure. CBI Report to SBUF Project 12684, Swedish Cement and Concrete Research Institute, Stockholm, Sweden, 2012.

[4] Tang L. and Lindvall A. Validation of models for prediction of chloride ingress in concrete exposed in de-icing salt road environment, International Journal of Structural Engineering, 4(1/2) (2013) 86-99.

[5] Tang L., Engineering expression of the ClinConc model for prediction of free and total chloride ingress in submerged marine concrete. Cem. & Conc. Research, 38, 1092-1097.

[6] NT Build 492: Concrete, mortar and cement-based repair materials: Chloride migration coefficient from non-steady-state migration experiments. Espoo, Nordtest, 1999.