HIGHLIGHTS FROM THE WORK OF TECHNICAL COMMITTEES OF RILEM

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Centro de Seguridad y Durabilidad de Estructuras y Materiales

CISDEM (UPM-CSIC)

CREATION AND MEMBERS OF TECHNICAL COMMITTEES

- The duration is for 5 years
- They are created under the initiative of a member who will be the Chairman
- Clear idea and objectives on an unexplored subject
- Initial membership proposed by chairman
- All RILEM members can propose TC members
- The TC meets at least once per year

APPLYING FOR A RILEM TC

Proposal for a new RILEM Technical Committee (TAC-N10 REV5 2007-01-08)
(formerly CC-N5)
This proposal is presented by: O a National Delegate O a Titular or Industrial Member O a RILEM Cluster
Name _____De Belie______ First name ______Nele_______RILEM Code Member: ___7503____

1. Proposed title (in English): Hydration and microstructure of concrete with supplementary cementitious materials
French Title: ....
Proposed Chairman:
Name: ______De Belie______First name: _____Nele__________RILEM Code Member: __7503_______
Proposed Secretary:
Name: ___Lothenbach_______First name: ___Barbara___RILEM Code Member: ___8116___

2. Subject matter

Supplementary cementitious materials (SCM) are commonly used in concrete practice nowadays, either in blended cements or as separate additions into the concrete mixture. The use of cementitious and pozzolanic by-products (fly ash and other artificial pozzolans, natural pozzolans, slag, limestone, …) is one way to obtain a more sustainable binder for the construction industry and there are also benefits related to costs and some durability aspects. In general the effects of these supplementary cementitious materials on microstructure and durability have been widely studied. Nevertheless there are aspects that merit further attention (durability aspects will not be considered within this TC):
- The interaction between Portland clinker hydration and fly ash or slag reaction is not yet fully understood; determination of reaction degrees of SCM is difficult; this is even more so if ternary mixes are concerned
- The interaction between SCM and commonly used admixtures is often not well documented
- The quality of by-products such as fly ash is changing due to for instance co-combustion in the electrical power plants; the effect of changing composition on the cement and SCM reactions, and on the resulting microstructure, should be elucidated
- The ongoing change from Portland to blended cements, and the replacement of Portland cement by SCM in the mix design, will affect construction practices. The exact composition of blended cements may be unknown, and this will affect early age strength development. For the construction industry it is important to know how the variability of SCM affects the properties of their concrete and curing requirements, especially for in-situ cast concrete during cold weather.

3. Proposed terms of reference

The TC is supposed to run for 4 to 5 years
Members will be recruited from academia and industry, based on their experience with blended cements
The work will include literature research, exchange of good practices information, journal publications and/or state-of-the-art report, if appropriate a small test program or round robin test, a short doctoral course on hydration and microstructure of concrete with SCM

4. Detailed working programme

- start-up meeting: introduction of members, suggestion of new members, overview of members' competences and experience, plan of activities, organisation of initial workshop
- small workshop for the members, in order to get an overview of experience, problems and points of attention related to concrete with SCM; decision on most important points for further TC work
- meetings and exchange of information between TC members; compilation of sheets with best practices; round robin test if appropriate
- international conference
- organisation of a short doctoral course
- summary of TC findings in one or more journal publications and/or state-of-the-art report

5. Technical environment

The study of SCM in blended cements or in concrete in general fits into the scope of RILEM as an organisation dealing with a range of construction materials and structural performance. The idea for this committee was initiated by members of TC-PAE "Performance of cement-based materials in aggressive aqueous environment". In relation to durability aspects, there is often discussion if models, test methods, standards, etc are appropriate also for blended cements or for concrete with SCM additions. Common interests may exist with 224-AAM (2007) (chair: Van Deventer, Secretary: Provis) Alkali Activated Materials. A related previous TC was TC FAB-67 Use of fly ash in building. Contacts will also be made with a new fib committee 8.12 "Supplementary Cementitious Materials" (will be established in May 2011).

6. Expected achievements (deliverables) from the TC

Expected benefits are
- improve the knowledge related to reactions and microstructure of concrete made with SCM
- elucidate the effect of composition and crystallinity of SCM on former aspects
- connect researchers working in the field of SCM in concrete and agree on good practices for testing
- best practices sheets for researchers and/or practitioners
- summary of TC findings in one or more journal publications and/or state-of-the-art report
- an international conference and conference proceedings for further dissemination of information
- possibly organisation or participation in a (short) doctoral course on hydration and microstructure of concrete with SCM (e.g. one-day course connected to the final conference of the TC)

7. (*) What group of users will be targeted by these products ?
Academics, testing laboratories, industrialists, practitioners

8. (*) *Define precisely any specific use of the results, and evaluate the economic impact where applicable.*

With the increasing use of blended cement worldwide, the use of SCM coming from abroad, the change in quality of SCM, a better insight in the effect of SCM composition and crystallinity on reactions and microstructure of concrete is needed. Best practices related to the study of concrete with SCM should be available for research and testing laboratories. Optimal use of SCM may contribute to reduction of environmental impacts by the cement and concrete industry.

(*) Items 7 and 8 are not optional and should be filled in for each new TC proposal

9. Suggested members of committee

Nele De Belie, Ghent University, Belgium (chair),
Barbara Lothenbach, EMPA Switzerland (secretary)
Josée Duchesne, Université Laval, Québec, Canada
Marios Soutsos, University of Liverpool, UK
Kosta Kovler, Technion, Haifa
Alexandra Bertron, LMDC, Toulouse, France
Ye Guang, TUDelft, The Netherlands
John Provis, the University of Melbourne, Australia
Carmen Andrade, Institute Eduardo Torroja of Construction Science, Madrid, Spain
Karen Scrivener, EPFL, Lausanne, Switzerland
Mette Geiker, DTU, Denmark
Wolfgang Brameshuber, RWTH Aachen, Germany
Anya Vollpracht, RWTH Aachen, Germany
Maria C. Juenger, Texas Materials Institute, USA
Luc Courard (and Frédéric Michel), Université de Liège, Belgium
Ian Richardson, University of Leeds, UK
Jay Sanjayan, Swinburne University of Technology, Australia
Duncan Herfort, Aalborg Portland, Denmark
Ioanna Papayianni, Aristotle University of Thessaloniki, Greece (corresponding member)

I, as **RILEM Senior Member** and as the Chairman of the proposed TC, will support the general policy of RILEM, as defined by the General Council for implementation by the Bureau, Standing Committees and Secretariat General. I officially accept to implement, with the direct assistance of the Secretariat General, statutory and operational rules of RILEM Technical Committees detailed in the attached annexes, in order to ensure a top quality level of the work and appropriate dissemination of the results of RILEM TCs. I have noted that the **TC duration is limited to 5 years** (see Annex 3).
Name: _______De Belie__________ First name: ____Nele_________ Date: _____07/02/2011
Signature (hand-written by the proposed Chairman, who should be a RILEM Senior Member - **only one chairman, no co-chairman allowed**)

PRODUCTS OF TECHNICAL COMMITTEES

- STATE OF THE ART
- RECOMMENDATIONS AND PRESTANDARDS
- TESTING METHODS
- WORKSHOPS
- CONGRESSES, CONFERENCES

Examples of RILEM Technical Committees

145-WSM (BARTOS): Workability of special concrete mixes

149-HTS (UZIELLI): Diagnosis and repair of historic load-bearing timber structures

151-APC (OHAMA, PUTERMAN): Adhesion technology in concrete engineering - Physical and chemical aspects

157-PRC (FRANCKEN): Systems to prevent reflective cracking on pavement

162-TDF (VANDEWALLE): Test and design methods for steel fibre reinforced concrete

165-SRM (HENDRIKS): Sustainable application of mineral raw materials in construction

166-RMS(ROSSITER): Roofing membranes and systems

167-COM (GROOT): Characterisation of old mortars with respect to their repair

Examples of RILEM Technical Committees

168-MMM (PANDE): Computer modelling of mechanical behaviour of masonry structures 169-MTE (EHLBECK): Test methods for load transferring metalwork used in timber engineering

170-CSH (RICHARDSON): The structure of C-S-H

172-EDM (SARJA): Environmental design methods in materials and structural engineering

174-SCC (SKARENDAHL): Self-compacting concrete

175-SLM(LACASSE): Computer bases on service life methodology

176-IDC (SETZER): Internal damage of concrete due to frost action

177-MDT (BINDA): Masonry durability and on-site testing

Examples of RILEM Technical Committees

178-TMC (ANDRADE): Testing and modelling chloride penetration in concrete

179-CSD (MÜLLER): Data bank of concrete creep and shrinkage

180-QIC (TAMAS): Qualitative identification of clinker and cement

181-EAS (BENTUR): Early shrinkage induced stresses and craking in cementitious systems

182-PEB (PARTL): Performance testing and evaluation of bituminous materials

ATC (REINHARDT): Advanced testing of cement based materials during setting and hardening

CRC (NIXON): Chemical reactions in concrete - Assessment, specification and diagnosis of alkali-reactivity

CSC (SKARENDAHL): Casting of self-compacting concrete

FHP (MARCHAND): Predicting the frost resistance of high-performance concrete structures exposed to numerous freezing and thawing cycles

Work developed by the RILEM Technical Committees

- TC 116. *H. Hilsdorf and J. Kropp-*
  - Permeability to assess Durability
- TC 154- *C. Andrade and C. Alons*o-
  - Electrochemical measurements in concrete
- TC 178- *C. Andrade and J. Kropp-*
  - Testing and modelling chloride penetration into concrete
- TC 213- *C. Andrade and J- Gulikers*
  - Model assisted integral service life prediction of steel reinforced concrete structures with respect to corrosion induced damage

TC 116

Permeability to assess Durability

Materials and Structures/Matériaux et Constructions, Vol. **32**, April 1999, pp 174-179

RILEM TC 116-PCD: Permeability of Concrete as a Criterion of its Durability

Recommendations

Former and present full and corresponding members of the TC as well as members of the research consortium: C. Andrade, Spain; A. Bettencourt-Ribeiro, Portugal; N. R. Buenfeld, UK; M. Carcasses, France; N. J. Carino, USA; F. Ehrenberg, Germany; C. Ewertson, Sweden; E. Garbocczi, USA; M. Geiker, Denmark; O. E. Gjorv, Norway; A. F. Goncalves, Portugal; H. Gräf, Germany; H. Grube, Germany; H. K. Hilsdorf, (chairman 1989-1992), Germany; R. D. Hooton, Canada; J. Kropp, (secretary 1989-1992, chairman since 1992 and project coordinator), Germany; S. Modry, Czech Republic; Ch. Molin, Sweden; L. O. Nilsson, Sweden; J. P. Ollivier, France; C. L. Page, UK; L. J. Parrott, UK; P. E. Petersson, Sweden; F. R. Rodriguez, Spain; M. Rodhe, Sweden; M. Salta, Portugal; N. Skalny, USA; A.M.G. Seneviratne, UK; L. Tang, Sweden; F. Tauscher, Germany; R. Torrent, Argentina; D. Whiting, USA.

TC 116
Permeability to assess Durability

TESTS FOR GAS PERMEABILITY OF CONCRETE

A. PRECONDITIONING OF CONCRETE TEST SPECIMENS FOR THE MEASUREMENT OF GAS PERMEABILITY AND CAPILLARY ABSORPTION OF WATER

4. DETERMINATION OF THE NECESSARY WEIGHT LOSS DURING PRE-DRYING

The necessary weight loss during pre-drying Δm is calculated from the original mass of the test specimen at the end of the curing, its initial evaporable moisture concentration w_e and the equilibrium moisture concentration $w_{e,75}$:

$$\Delta m = \left(\frac{w_e - w_{e,75}}{1 + w_e} \right) m_o \qquad (5)$$

Δm = weight loss [g].

5. PRE-DRYING

TC 116
Permeability to assess Durability

B. MEASUREMENT OF THE GAS PERMEABILITY OF CONCRETE BY THE RILEM - CEMBUREAU METHOD

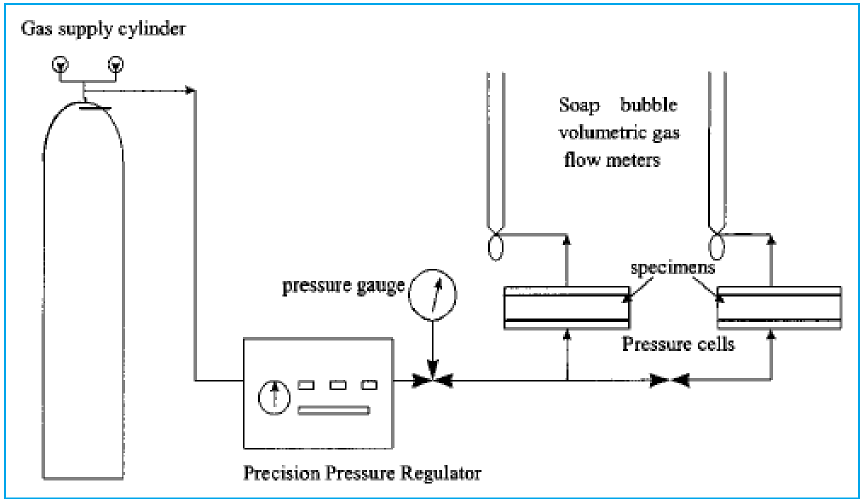


Fig. 1 – Layout of the experimental set-up.

$$K_l = \frac{2 P_a Q_l L \mu}{A\left(P_l^2 - P_a^2\right)}$$

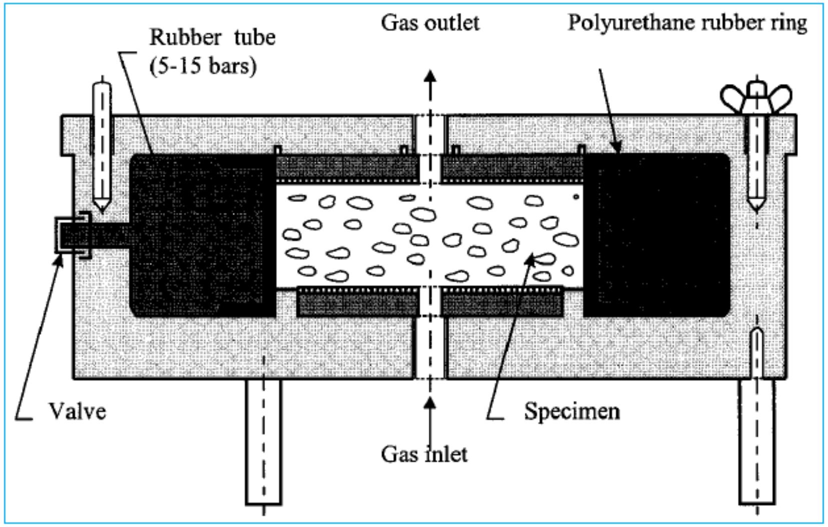


Fig. 2 – Permeameter cell [1].

TC 116
Permeability to assess Durability

C. DETERMINATION OF THE CAPILLARY ABSORPTION OF WATER OF HARDENED CONCRETE

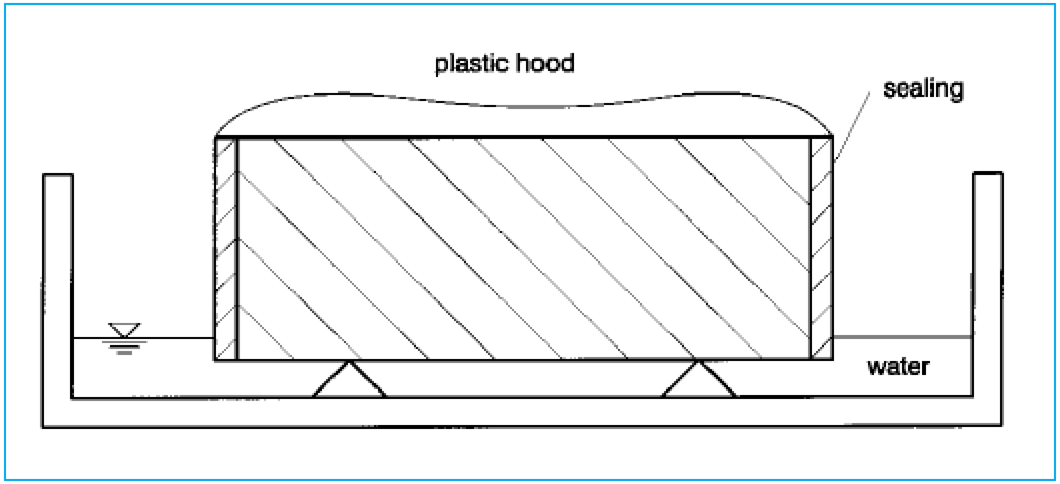


Fig. 1 – Experimental set-up for the capillary absorption test.

TC 154

Electrochemical measurements in concrete

Materials and Structures / Matériaux et Constructions, Vol. **36**, August-September 2003, pp 461-471

RILEM TC 154-EMC: 'Electrochemical Techniques for Measuring Metallic Corrosion'

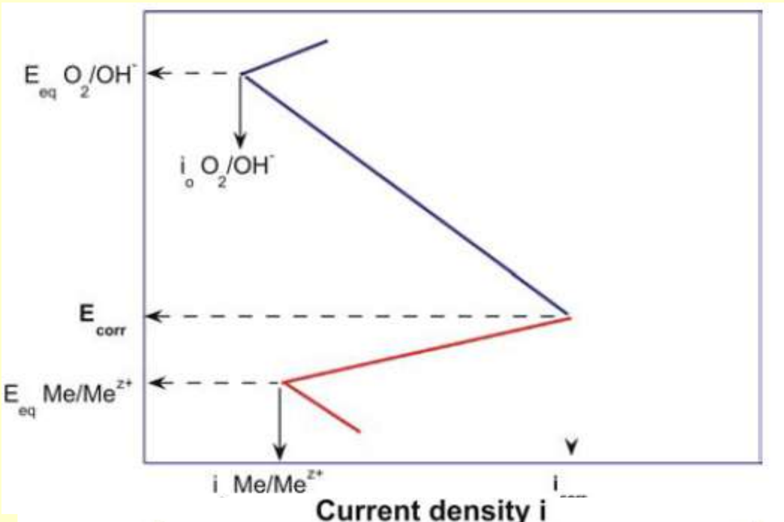
Recommendations

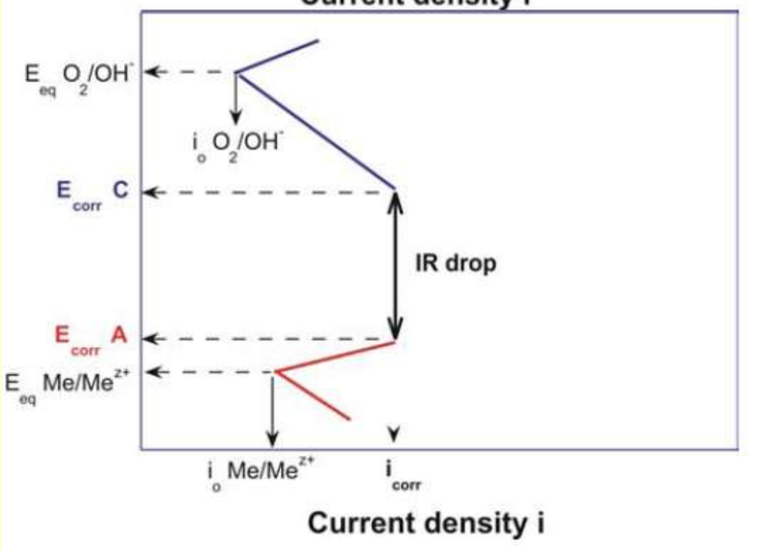
Half-cell potential measurements – Potential mapping on reinforced concrete structures

TC Membership – **Chairlady**: C. Andrade, Spain; **Secretary**: B. Elsener, Switzerland/Italy; **Members**: C. Alonso, Spain; R. Cigna, Italy; J. Galland, France; J. Gulikers, The Netherlands; U. Nürnberger, Germany; R. Polder, The Netherlands; V. Pollet, Belgium; M. Salta, Portugal; Ø. Vennesland, Norway; R. Weydert, Germany/Luxemburg; **Corresponding members**: C. Page, UK; C. Stevenson, South Africa.

TC 154

Electrochemical measurements in concrete





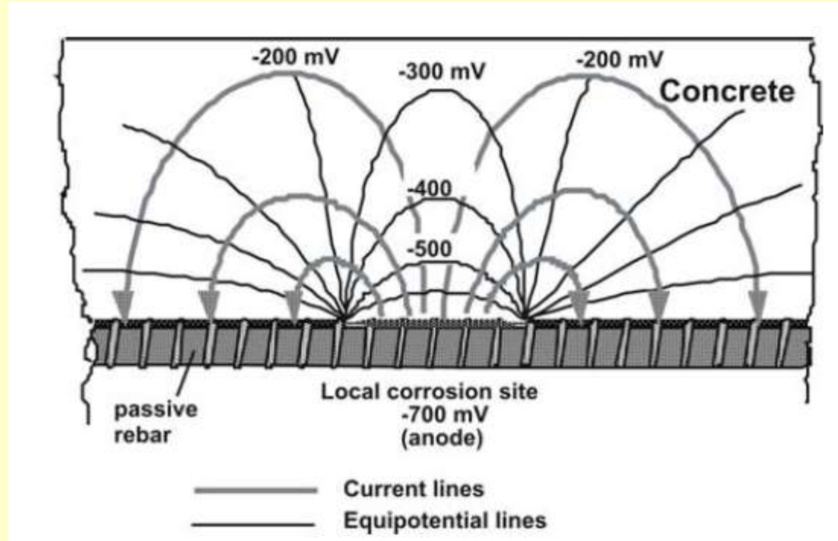


Table 1 - Typical ranges of potentials of normal steel in concrete (Volts CSE)	
water saturated concrete without oxygen	-0.9 .... -1.0 V
wet, chloride contaminated concrete	-0.4 .... -0.6 V
humid, chloride free concrete	+0.1 .... -0.2 V
humid, carbonated concrete	+0.1 .... -0.4 V
dry, carbonated concrete	+0.2 .... 0 V
dry concrete	+0.2 .... 0 V

TC 154

Electrochemical measurements in concrete

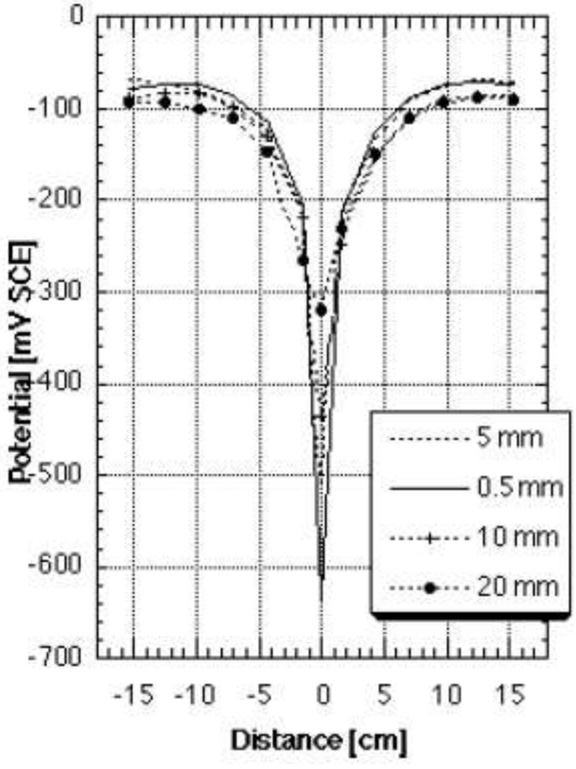


Fig. 3 - Influence of cover depth (distance from the steel surface) on half cell potentials over an active / passive macrocell [15]. Resistivity 1300 Ωm, total length 30 cm, anode 0.5 cm.

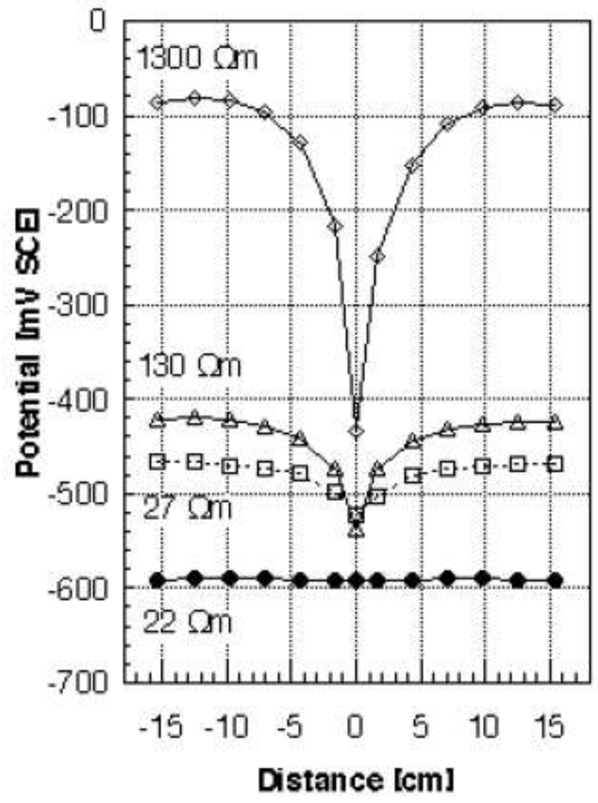


Fig. 4 - Influence of electrolyte resistivity on half cell potential distribution measured on an active / passive model macrocell [15]. Cover depth 20 mm, total length 30 cm, anode 0.5 cm. Open symbols in aqueous electrolyte, closed symbols in very wet, chloride containing mortar.

TC 154

Electrochemical measurements in concrete

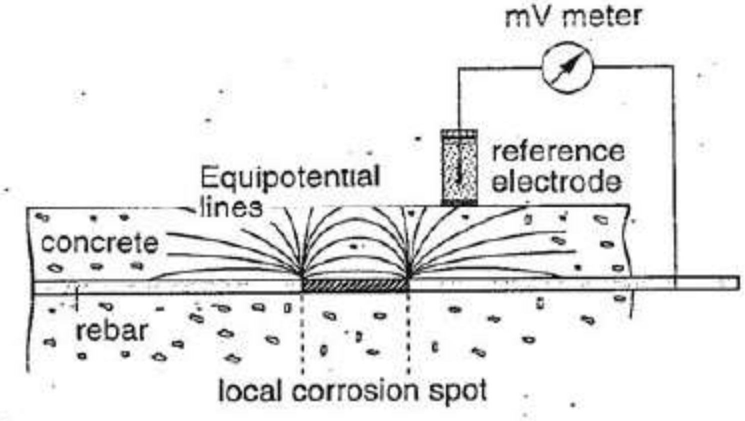


Fig. 5 - Principle and main components of half-cell potential measurements: Reference electrode, high impedance voltmeter, connection to the rebar.

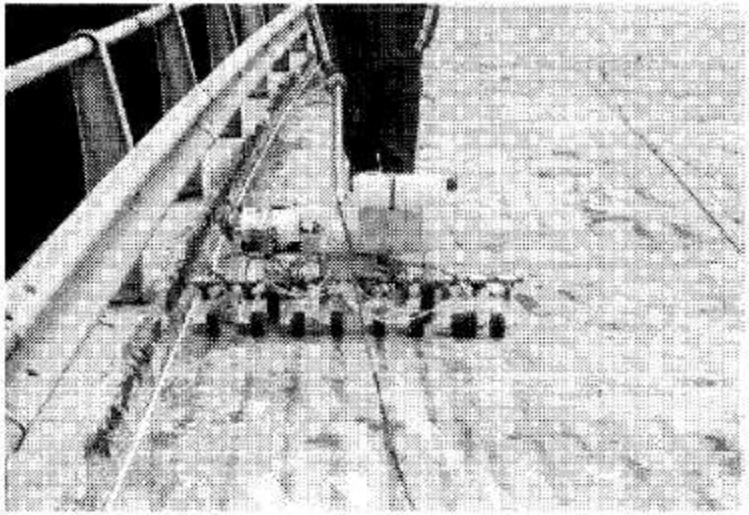


Fig. 6 - Multiple wheel electrode half-cell potential measuring instrument with computer assisted data acquisition [5, 10]. Note the slight wetting of the concrete surface at the wheels in order to achieve a good electrolytic contact between reference electrode and concrete.

TC 154

Electrochemical measurements in concrete

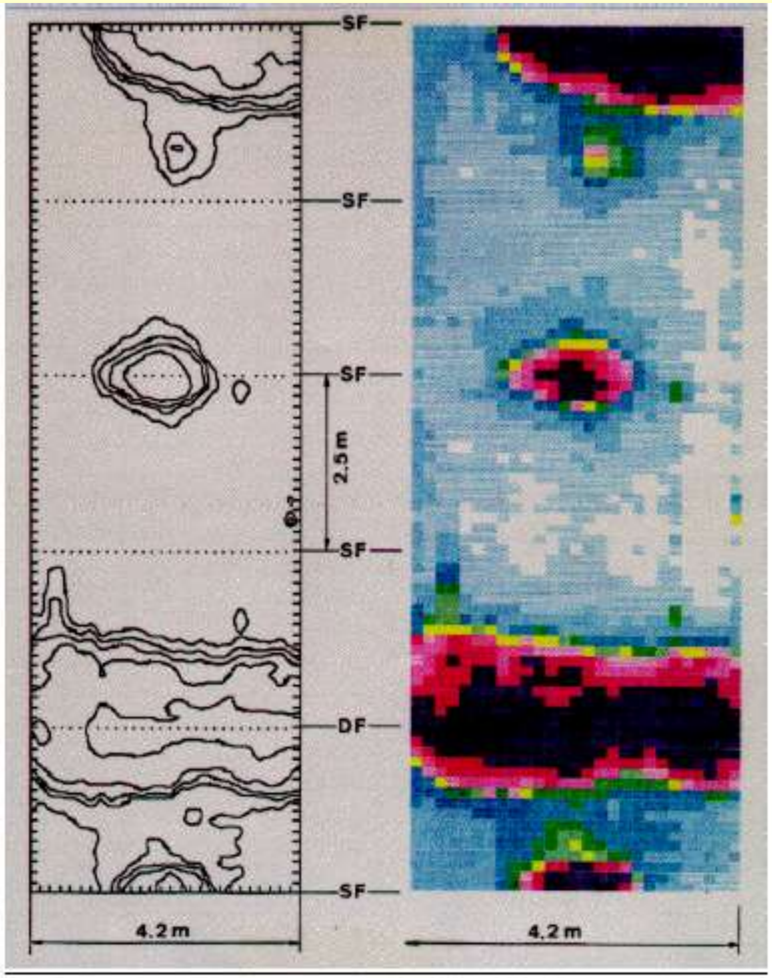


Fig. 7 - Examples of half-cell potential maps (Riding deck in the Tunnel San Bernardino) [5, 6]. Data representation: colour plot (right) and equicontour line plot (left). DF: dilatation joint (every 25 m).

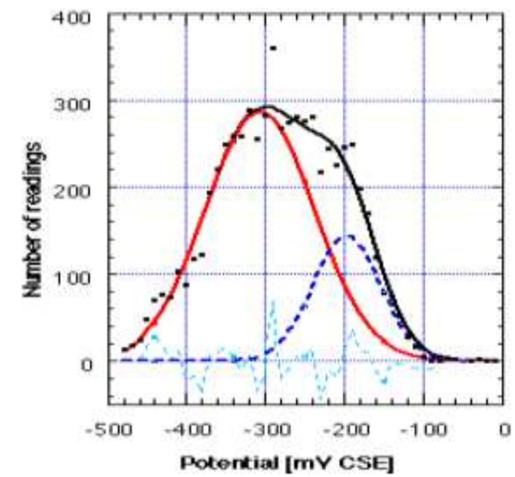


Fig. 8 - Frequency distribution of half cell potential data (retaining wall at Rofla, alpine highway N13 in Switzerland). Original data ▲, curve fitted assuming gaussian distribution for active and passive potentials [22].

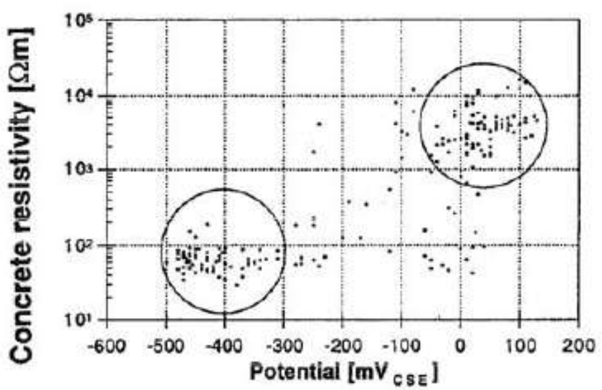
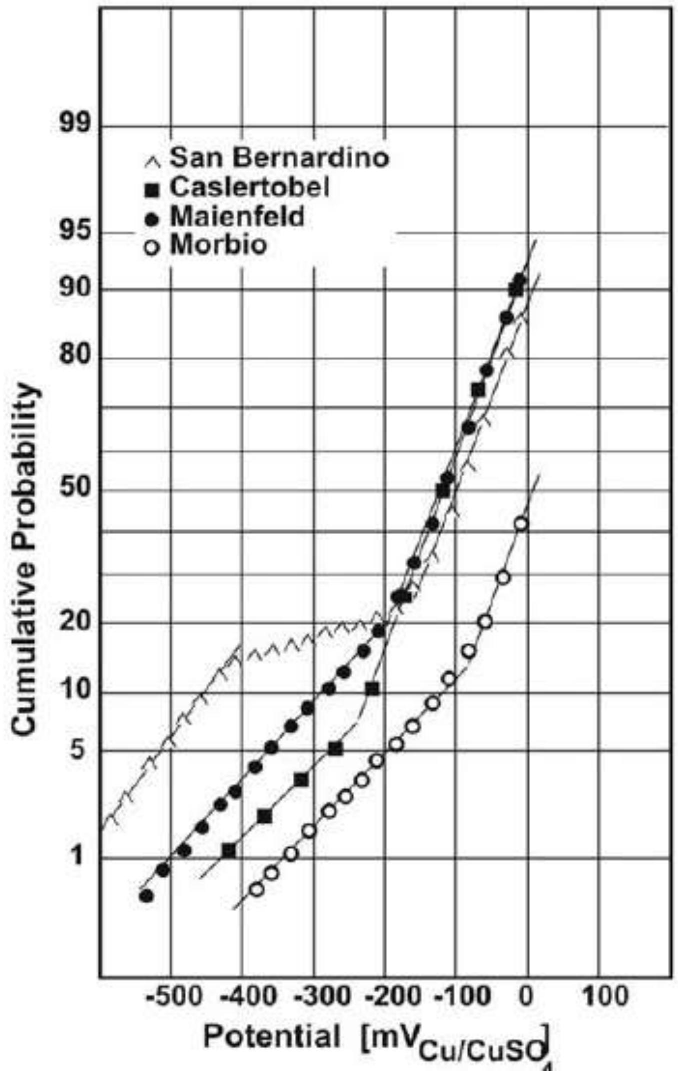


Fig. 11 - Relation between half-cell potential and concrete resistivity measured at the underside of a chloride contaminated bridge deck [14, 15].

TC 154
Electrochemical measurements in concrete



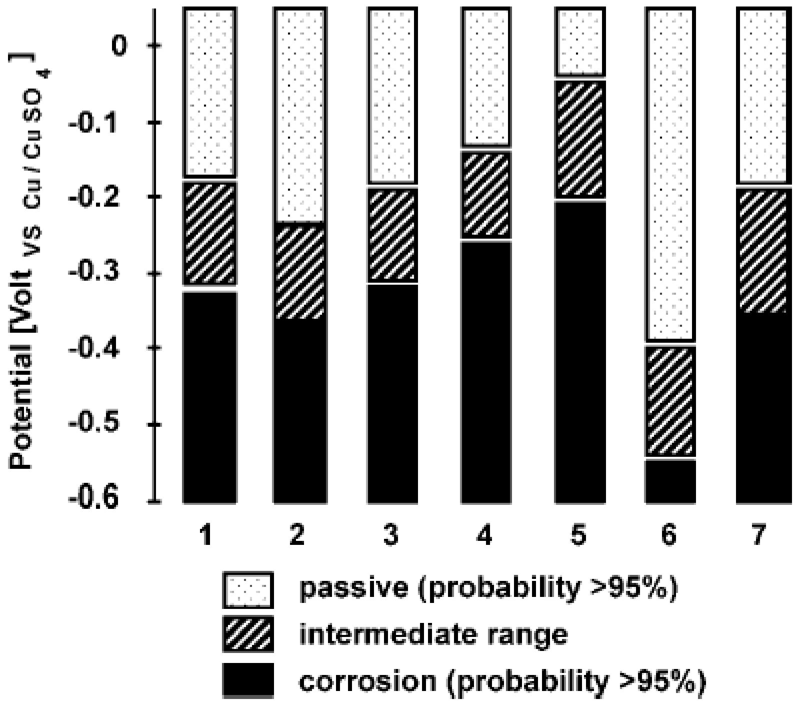


Fig. 10 - Experimentally determined potential range indicating active corrosion on different bridge decks compared to the ASTM C876 standard [6, 10, 15].
1 Cugnertobel, 2 San Bernardino, 3 Rhinebridge Tamins, 4 Caslertobelbrücke, 5 Morbio bridge, 6 Column in seawater, 7 ASTM C876 Standard.

TC 154

Electrochemical measurements in concrete

Materials and Structures/Matériaux et Constructions, Vol. **33**, December 2000, pp 603-611

RILEM TC 154-EMC: ELECTROCHEMICAL TECHNIQUES FOR MEASURING METALLIC CORROSION

Test methods for on site measurement of resistivity of concrete

Prepared by R. Polder, with contributions from C. Andrade, B. Elsener, Ø. Vennesland, J. Gulikers, R. Weidert and M. Raupach

Recommendations

TC MEMBERSHIP: Chairlady: C. Andrade, Spain; **Secretary:** B. Elsener, Switzerland; **Members:** C. Alonso, Spain; R. Cigna, Italy; J. Galland, France; J. Gulikers, The Netherlands; U. Nürnberger, Germany; R. Polder, The Netherlands; V. Pollet, Belgium; M. Salta, Portugal; Ø. Vennesland, Norway; R. Weidert, Germany; **Corresponding members:** C. Page, UK; C. Stevenson, South Africa.

TC 154

Electrochemical measurements in concrete

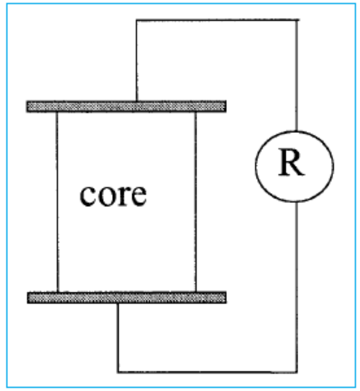


Fig. 3 – Resistivity determination of a concrete core or cube.

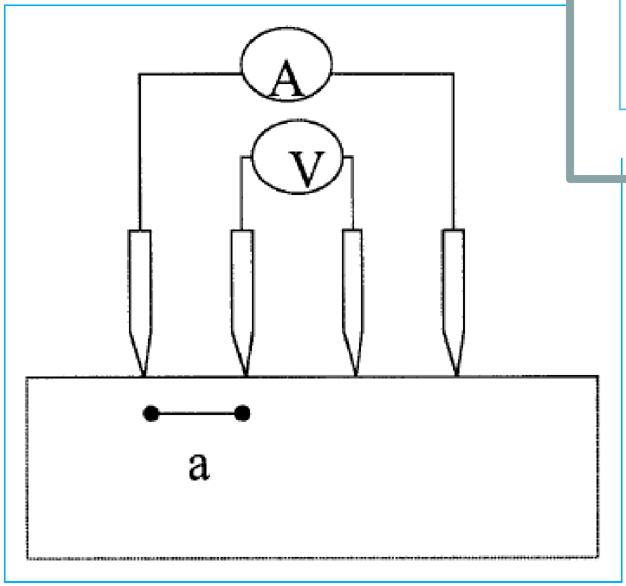


Fig. 1 – Setup of four-electrode measurement of concrete resistivity.

$$\rho = 2 * \pi * a * R$$

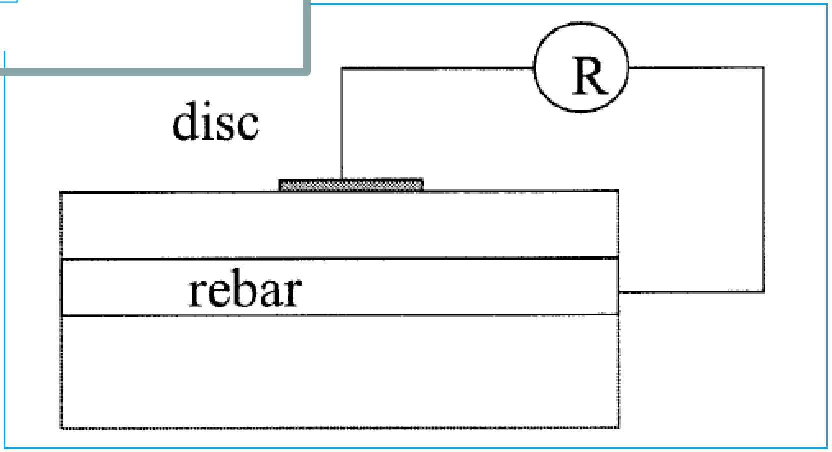


Fig. 2– Setup of one electrode (disc) measurement of concrete resistivity.

$$\rho = 2 * a * R(\text{disc-bar})$$

TC 154

Electrochemical measurements in concrete

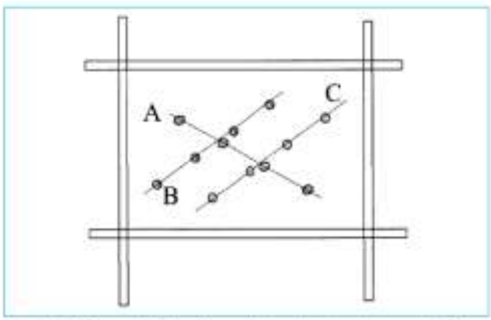


Fig. 4 – Taking resistivity (four electrode) at various spots in the same area to minimise influence of rebars.

Table 2 - Risk of corrosion of reinforcement associated with concrete resistivity [1, 10] for 20°C and OPC concrete

Concrete resistivity $\rho_{concrete}$ (Ω m)	Risk of corrosion
< 100	high
100 - 500	moderate
500 - 1000	low
> 1000	negligible

Table 1 – Global reference values at 20°C for the electrical resistivity of dense-aggregate concrete of existing structures (age > 10 years); conditions between [ ] are the comparable laboratory climates

Environment	Concrete resistivity $\rho_{concrete}$ (Ω m)	
	Ordinary Portland cement concrete (CEM I)	Blast furnace slag (> 65% slag, CEM III/B) or fly ash (> 25%) cement or silica fume (>5%) concrete
Very wet, submerged, splash zone, [fog room]	50 - 200	300 - 1000
Outside, exposed	100 - 400	500 - 2000
Outside, sheltered, coated, hydrophobised [20°C/80%RH], not carbonated	200 - 500	1000 - 4000
ditto, carbonated	1000 and higher	2000 - 6000 and higher
indoor climate (carbonated), [20°C/50%RH]	3000 and higher	4000 - 10.000 and higher

TC 154

Electrochemical measurements in concrete

Materials and Structures / Matériaux et Constructions, Vol. **37**, November 2004, pp 623-643

RILEM TC 154-EMC: 'Electrochemical Techniques for Measuring Metallic Corrosion'

Recommendations

Test methods for on-site corrosion rate measurement of steel reinforcement in concrete by means of the polarization resistance method

Prepared by C. Andrade and C. Alonso with contributions from J. Gulikers, R. Polder, R. Cigna, Ø. Vennesland, M. Salta, A. Raharinaivo and B. Elsener

TC 154

Electrochemical measurements in concrete

$$R_p = \left(\frac{\Delta E}{\Delta i}\right)_{\Delta E \to 0}$$

$$i_{corr} = \frac{B}{R_p}$$

$$V_{corr}\,(mm/y) = 0.0116\, i_{corr}\,(\mu A/cm^2)$$

$$B = \frac{b_a \bullet b_c}{2.303 \cdot (b_a + b_c)}$$

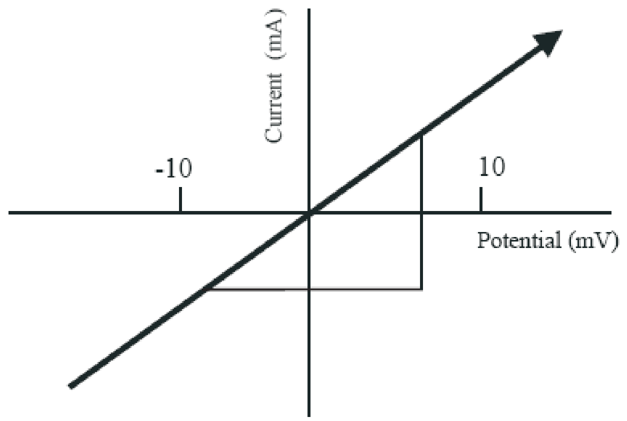


Fig. 1 - Linear plot of the polarization curve around E_{corr} in the anodic direction.

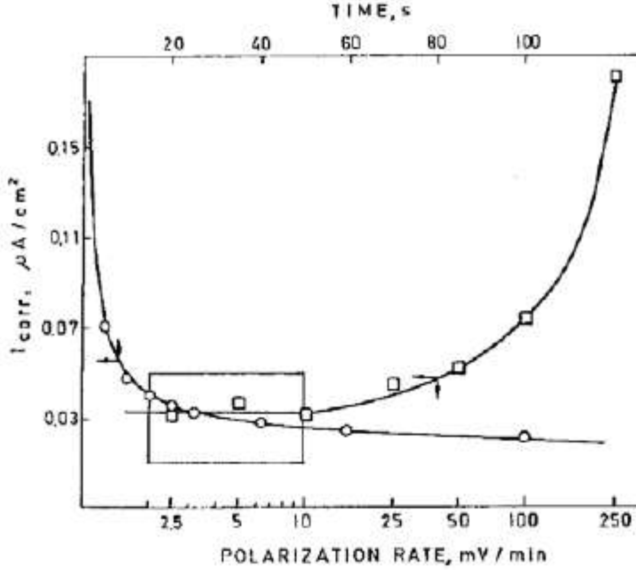


Fig. 2 - Values of I_{corr} obtained at different polarization times (upper scale) or sweep rates (bottom scale). The range indicated in the window refers to the optimum conditions.

TC 154

Electrochemical measurements in concrete

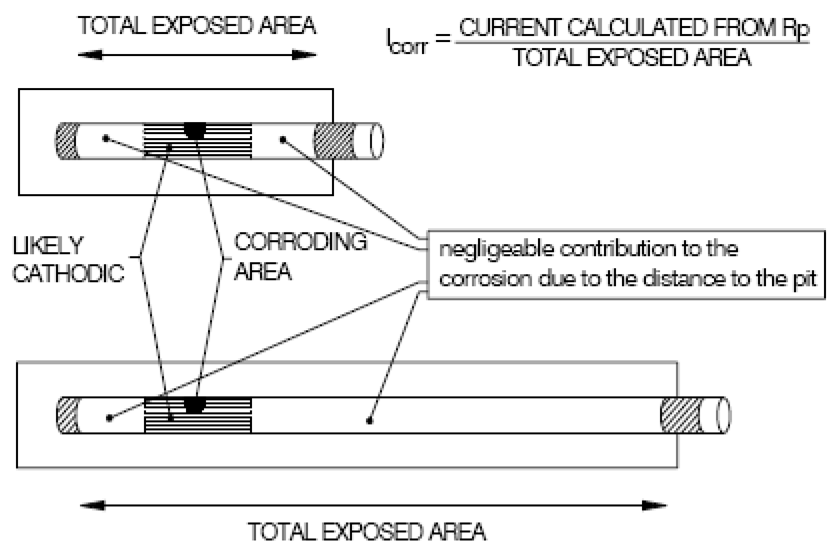


Fig. 3 - Localized attack: Relative error in I_{corr} due to sample area. In the case of localized attack the relative error in determination of I_{corr} is smaller, as smaller is the sample size.

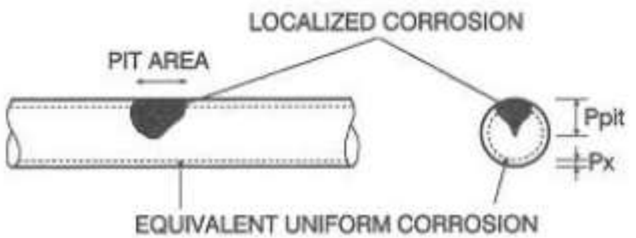


Fig. 4 - Distinction between "corrosion rate" and "local attack penetration". Difference between maximum pit depth (P_{pit}) or maximum attack penetration and the averaged corrosion (P_x): $P_{pit} = \alpha \cdot P_x$

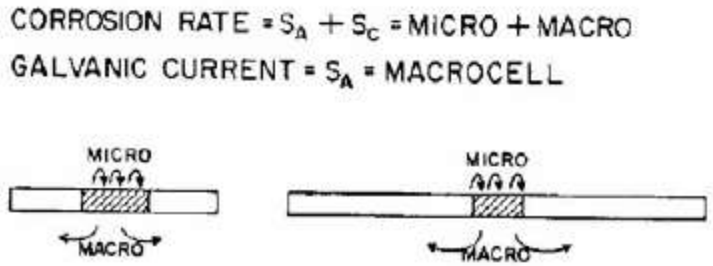


Fig. 5 - Anodic sites S_A present microcell activity in addition to the macrocell formed with the adjacent non-corroding zones, S_C. $S_A + S_C = S$ (total area). Galvanic current may be only a fraction of the total corrosion current.

TC 154

Electrochemical measurements in concrete

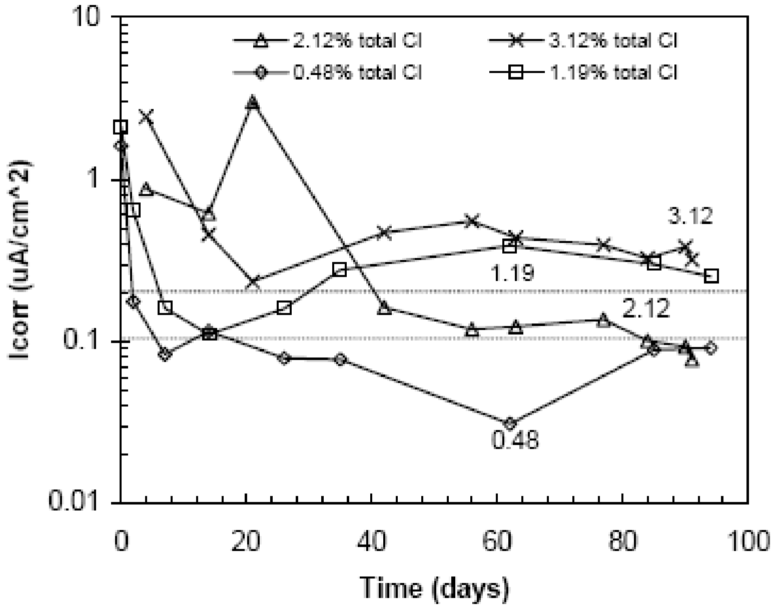


Fig. 6 - Examples of I_{corr}- time plots of rebars embedded in mortar with different proportions of chlorides added in the mix.

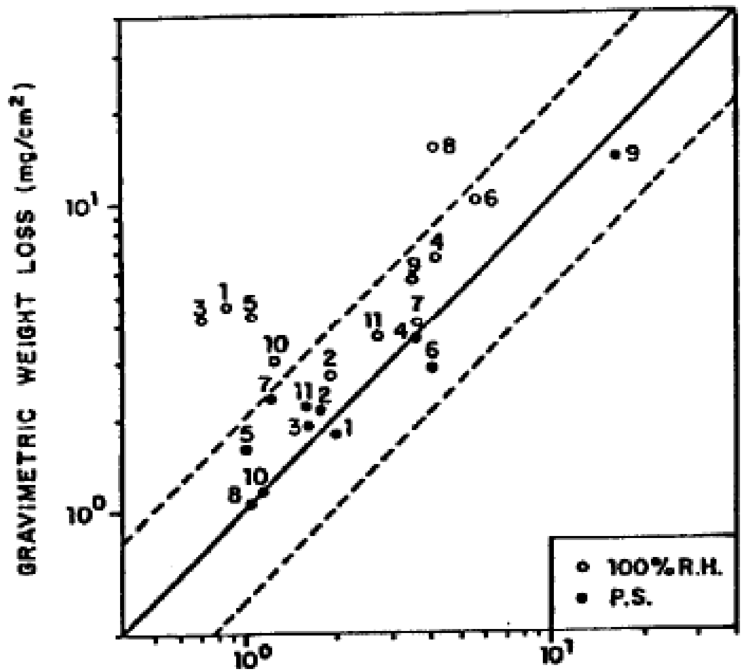


Fig. 7 - Comparison between gravimetrically determined losses and electrochemical ones (obtained from the integration of the I_{corr} – time plots). The dotted parallel lines delimitate the range of accuracy obtainable (a factor of two times the actual value).

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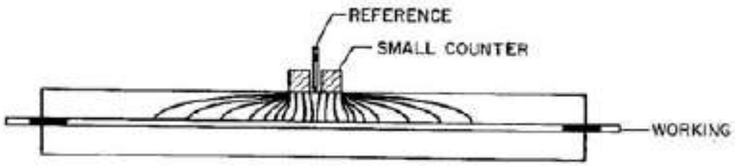

Fig. 8 - Lateral spreading of the current when applied through a small counter electrode.

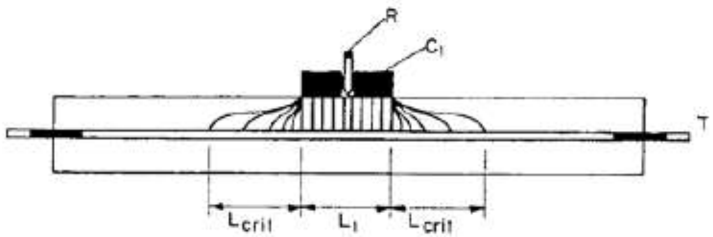

Fig. 9 - The length of the rebar polarized to a significant level by the externally applied current is termed the "critical length", L_{crit}. RE = Reference electrode, CE = counter electrode.

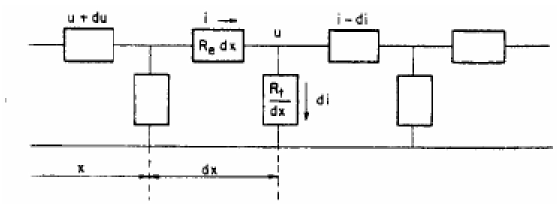

Fig. 10 - Transmission line model (electrical analogue) representing the lateral distribution of the current along the reinforcement bar (see Figs. 8 and 9).

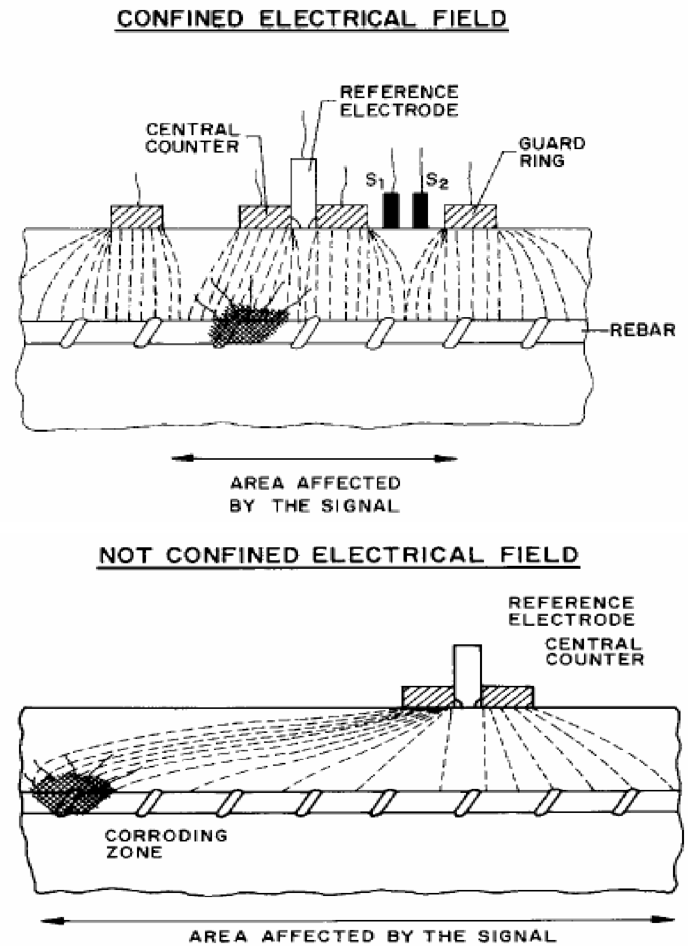

Fig. 14 - Effect of localized corrosion spots on the current lines between the counter electrode and the reinforcement showing localised corrosion attack.

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Electrochemical measurements in concrete

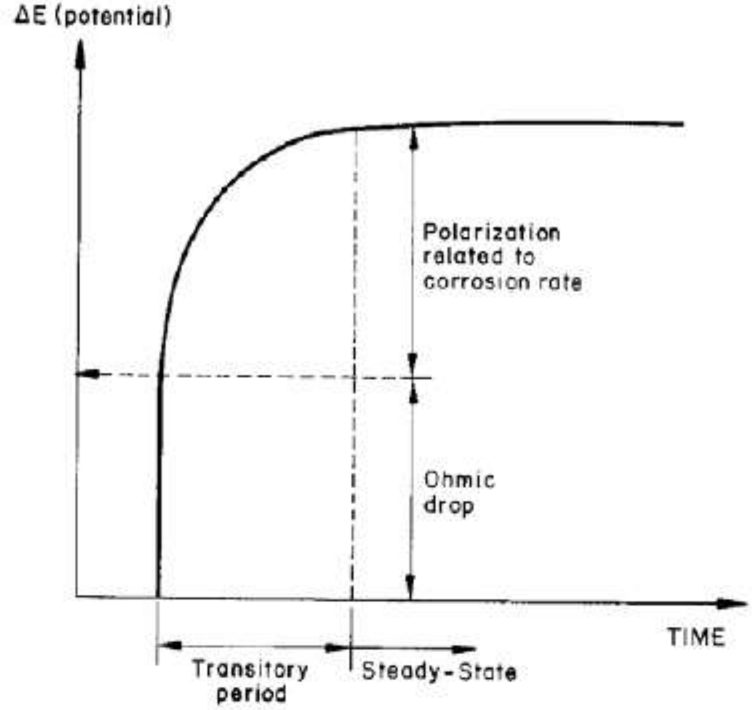

Fig. 17 - Response of potential to a galvanostatic pulse.

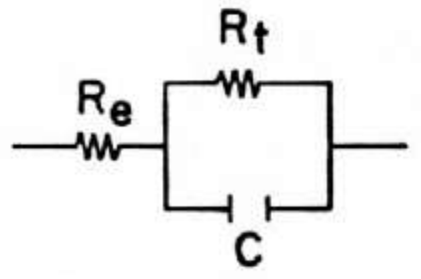

Fig. 18 - Randles circuit or electrical analogue model of metal/electrolyte interference. The circuit is too simple for modelling the dispersion of the applied current in real size structures.

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Electrochemical measurements in concrete

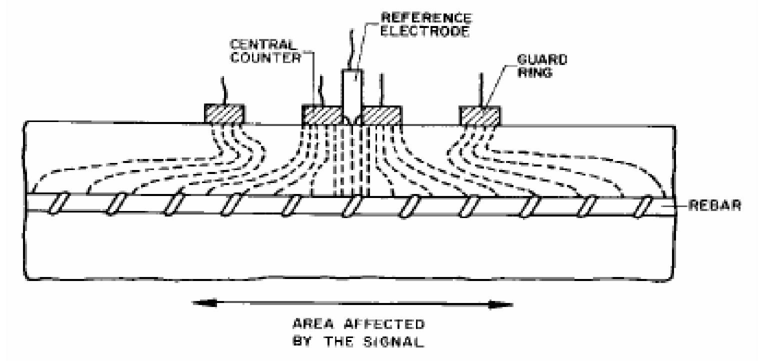
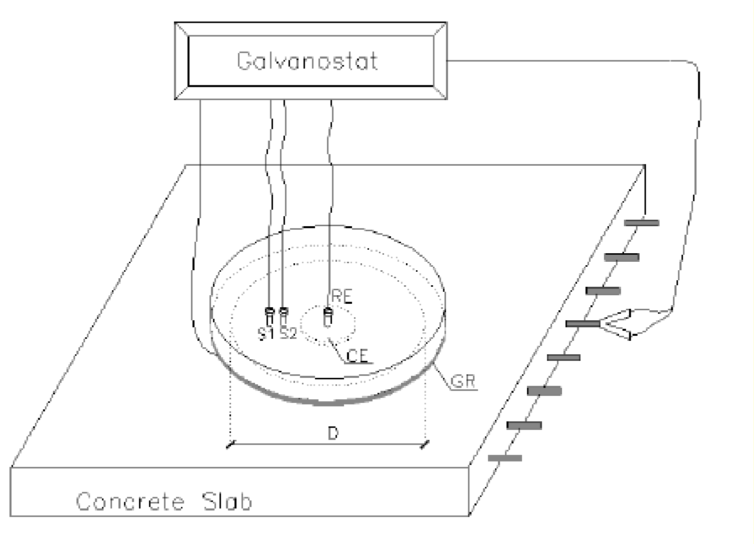


Fig. 13 - Incorrect confinement of the current when the guard ring does not have an independent control or modulation.



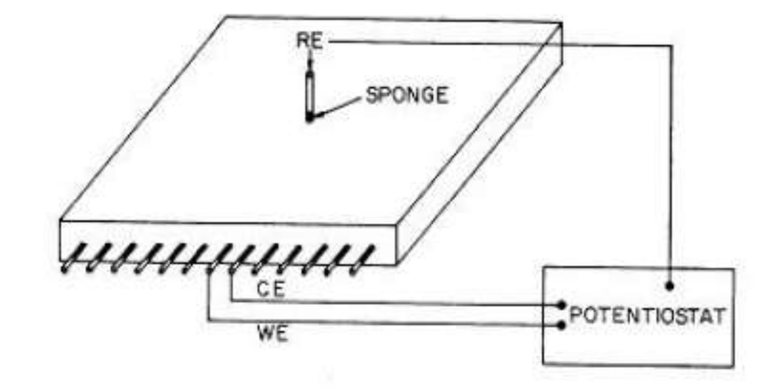


Fig. 19 - Slab type for making reference measurements for calibration of portable corrosion-rate-meters.

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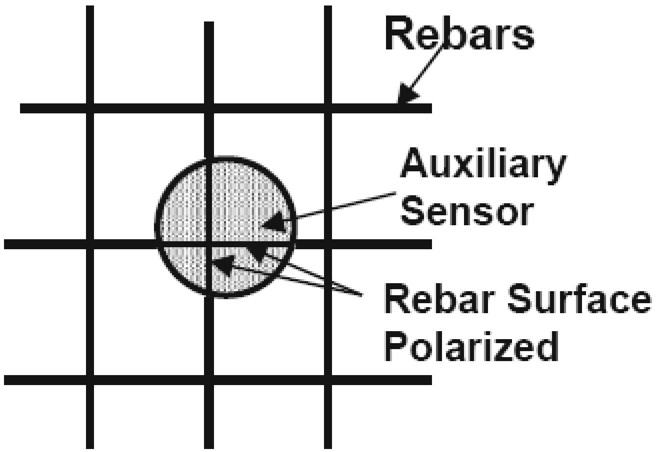

Fig. 21 - The metallic area to be taken into account is that facing the auxiliary sensor.

Table 1 - Ranges of corrosion current values related to the significance in terms of service life of the reinforcement		
I_{corr} (µA/cm²)	V_{corr} (mm/y)	Corrosion level
≤ 0.1	≤ 0.001	Negligible
0.1 – 0.5	0.001-0.005	Low
0.5 – 1	0.005-0.010	Moderate
> 1	> 0.010	High

$$P_{pit} = P_x \cdot \alpha = V_{corr}^{REP} \cdot t_p \cdot \alpha = V_{pit} \cdot t_p$$

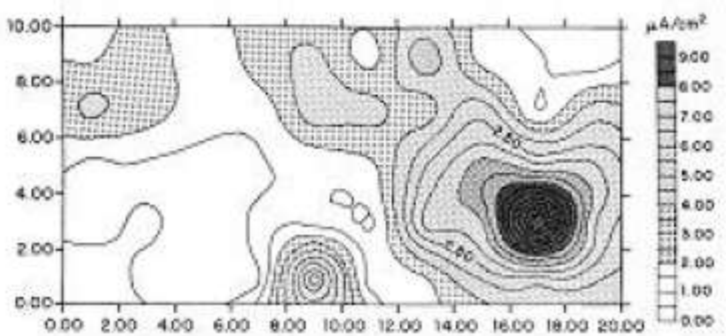

Fig. 20 - Map of corrosion rate values in a slab.

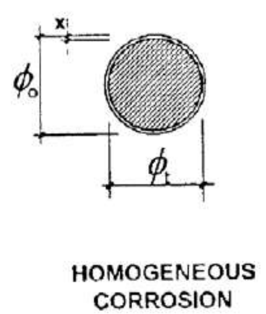

Fig. 22 - Attack penetration: case of uniform corrosion.

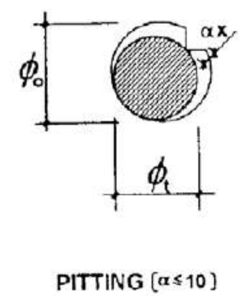

Fig. 23 - Residual cross section in the case of pitting (localized attack). $[\alpha \cong 10]$.

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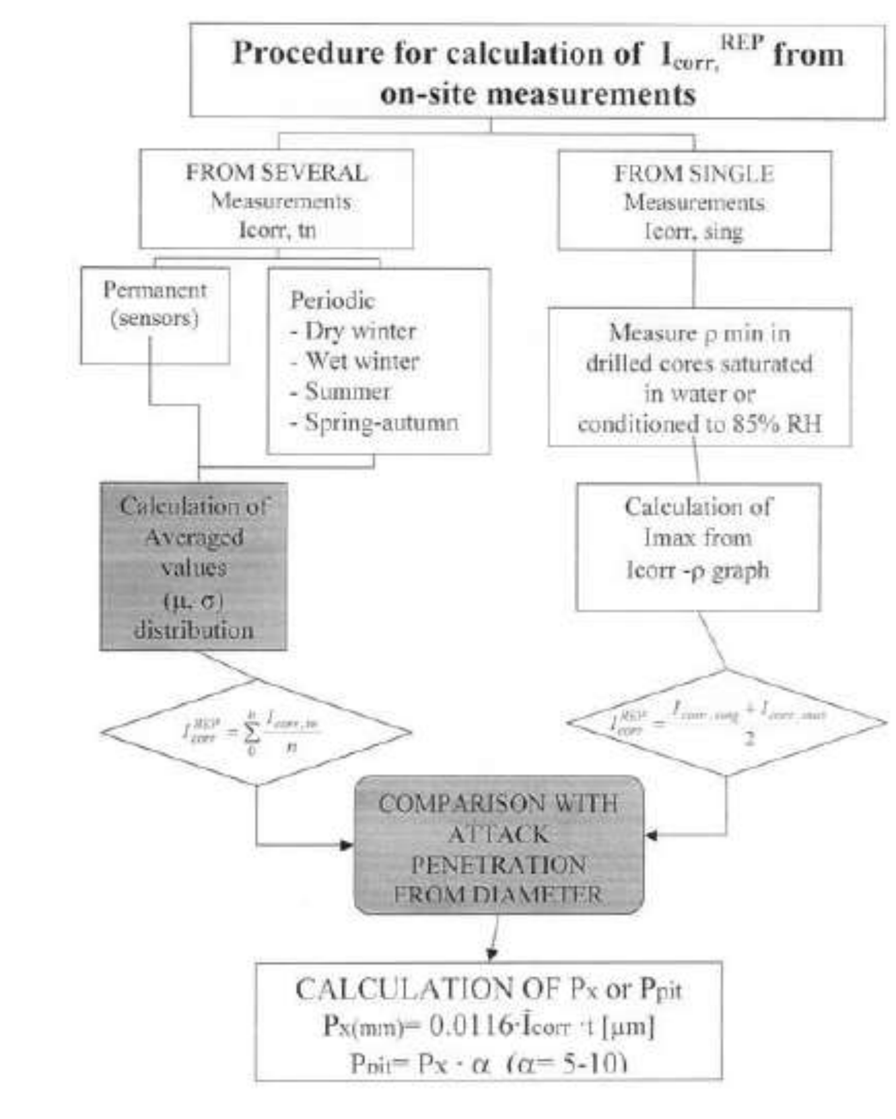

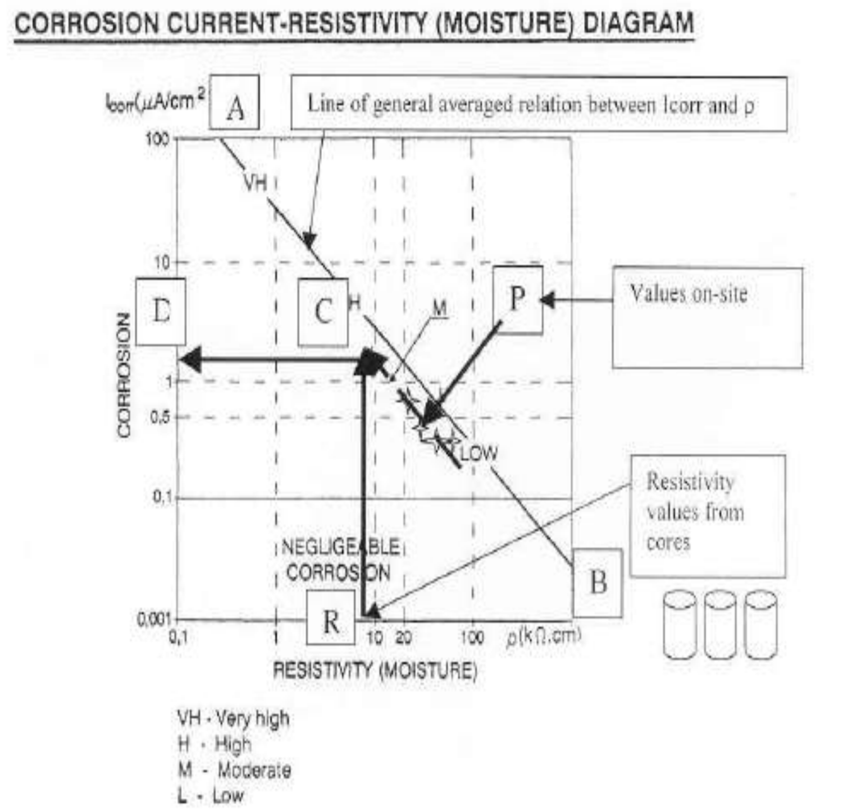

Fig. 27 - Procedure suggested for averaging results measured in a single visit on site with values deduced from resistivity measured in drilled cores conditioned in the laboratory.

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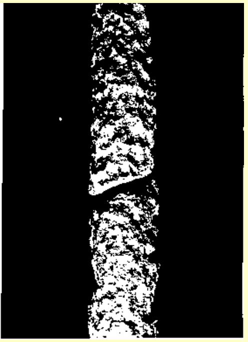
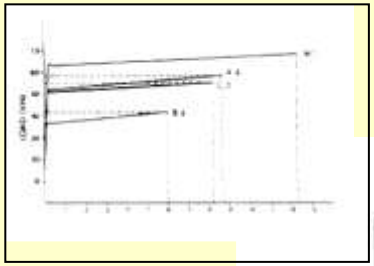
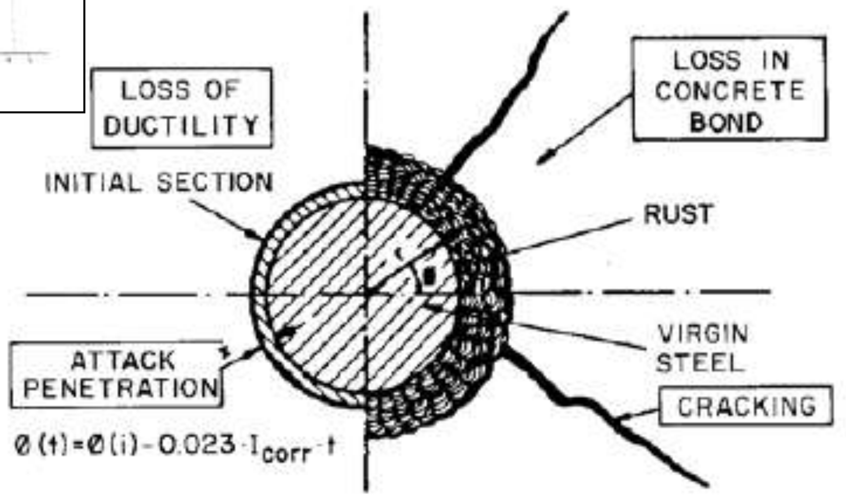
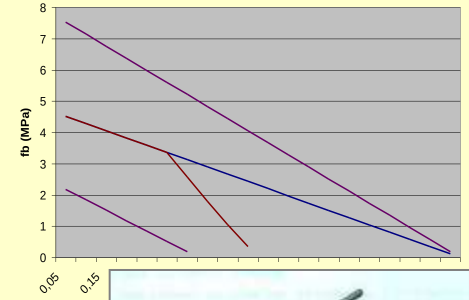
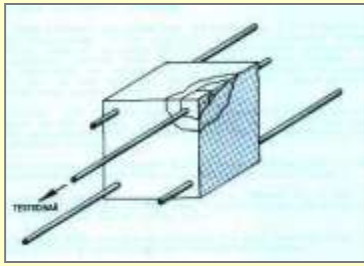


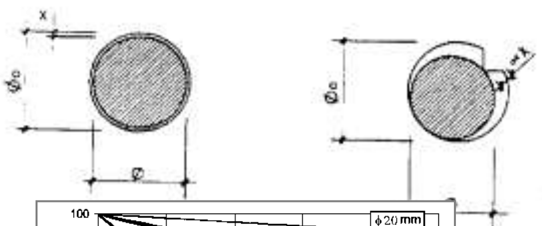


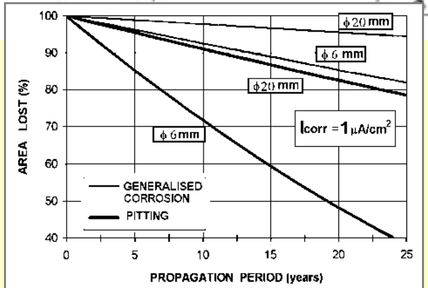


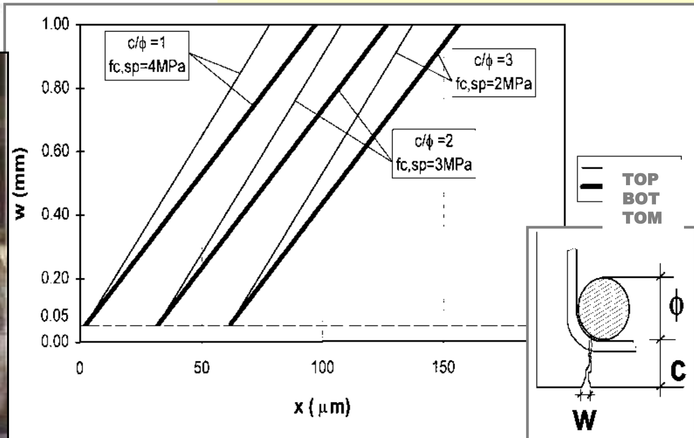
Consequences of rebar corrosion which lead into the in load-bearing capacity of the structure.











TC 178

Testing and modelling chloride penetration into concrete

Materials and Structures/Matériaux et Constructions, Vol. **34**, November 2001, pp 532-556

TC 178-TMC: TESTING AND MODELLING CHLORIDE PENETRATION IN CONCRETE

Round-Robin test on chloride analysis in concrete - Part I: Analysis of total chloride content

M. Castellote and C. Andrade

Institute of Construction Sciences "Eduardo Torroja" (CSIC), Serrano Galvache s/n, 28033, Madrid, Spain

The work described in this paper was developed in co-operation with the members of RILEM TC 178-TMC: 'Testing and Modelling Chloride Penetration in Concrete': **Chairlady:** C. Andrade; **Secretary:** J. Kropp.
Regular members: C. Alonso, C. Andrade, R. Antonsen, V. Baroghel-Bouny, M. P. A. Basheer, M. Carcassès, M. Castellote, K. Cavlek, Th. Chaussadent, M. A. Climent, S. Helland, F. Fluge, J. M Frederiksen, M. Geiker, J. Gulikers, D. Hooton, J. Kropp, A. Legat, T. Luping, M. Maultzsch, S. Meijers, L. O. Nilsson, C. Page, K. H. Pettersson, R. Polder, M. Salta, M. Thomas, J. Tritthart, Ø. Vennesland.
Corresponding members: S. Ahmad, N. S. Berke, J. J. Carpio, G. Gudmundsson, O. Troconis de Rincon, R. François, P. Pedeferri, N. Buenfeld, T. Cao, I. Diaz Tang, P. R. L. Helene, J. R. Mackechnie, D. Naus, A. Raharinaivo, M. Ribas-Silva, A. Sagues, M. Setzer, C. E. Stevenson, W. Trusty.

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Table 2 – Summary of the laboratories participating and tests performed

	Number of laboratories	Number of determinations
Total chloride	30	64
Free chloride	20	37
Colourimetric front	7	10

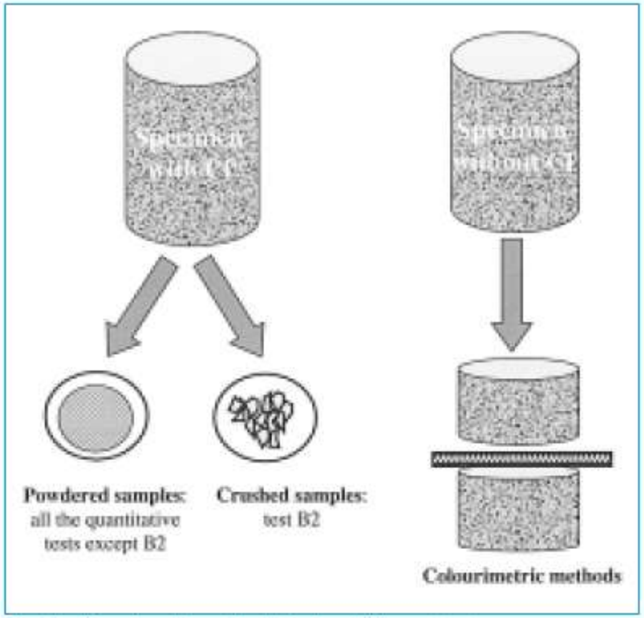

Fig. 1 – Samples dispatched for the different tests.

Table 3 – Test methods selected for the RRT

Reference	Method
A	Extraction of total chlorides from the solid sample
A.1*	Maultzsch's procedure
A.2	Salta's procedure
A.3*	Other methods
B	Extraction of free chlorides from the solid sample
B.1*	AFREM procedure [4]
B.2	Alkaline method (Castellote's *et al.* procedure) [5]
B.3*	Other methods
C	Analysis of the liquid obtained
C.1	Volhard method (Climent's *et al.* procedure) [6, 7]
C.2	Direct potentiometry (Salta's procedure)
C.3*	Direct potentiometry (Maultzsch's procedure)
C.4*	Potentiometric titration (Maultzsch's procedure)
C.5*	Gran's method (Climent's *et al.* procedure) [8]
C.6	Modified AASTHO (Tang's procedure)
C.7*	Other methods
D	Colourimetric methods
D.1	Maultzsch's procedure
D.2*	Collepardi's method [9]
D.3	Other methods

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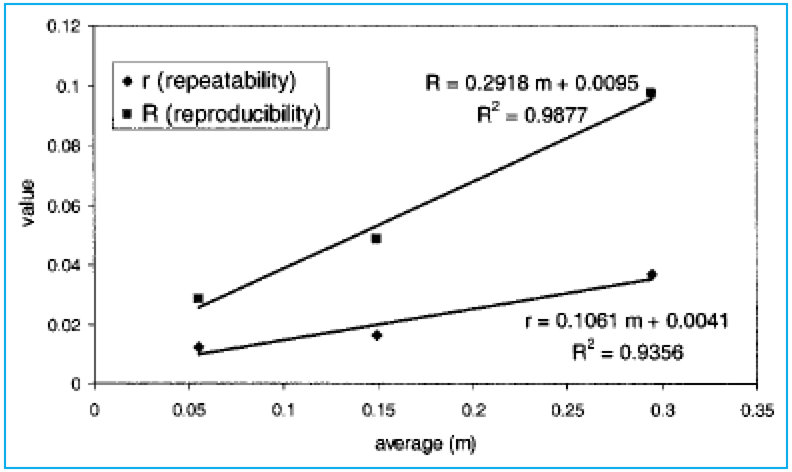

Fig. 3 – Repeatability and reproducibility of the analysis of total chlorides for all the test treated globally in function of the average value found.

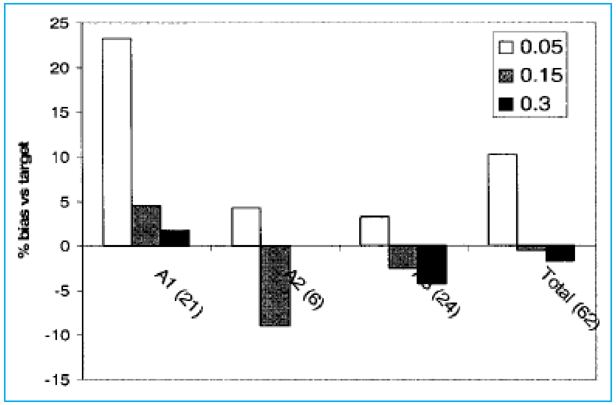

Fig. 7 – Percentage of deviation from the averaged value for each type of extraction independently of the method of analysis, for the three samples tested.

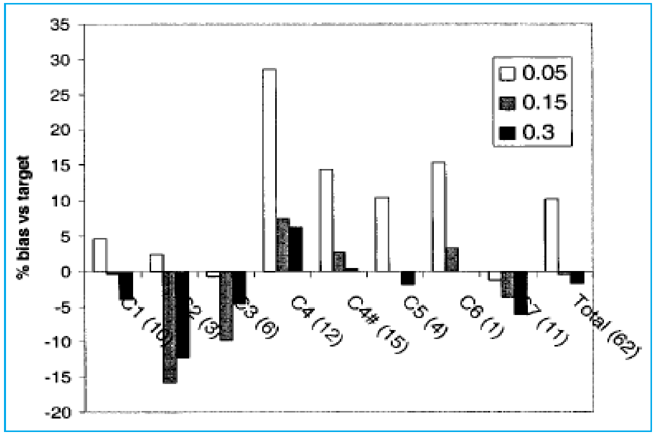

Fig. 9 – Percentage of deviation from the averaged value for each type of analysis independently of the method of extraction, for the three samples tested.

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Testing and modelling chloride penetration into concrete

TC 178-TMC: TESTING AND MODELLING CHLORIDE PENETRATION IN CONCRETE

Round-Robin test on chloride analysis in concrete - Part II: Analysis of water soluble chloride content

M. Castellote and C. Andrade

Institute of Construction Sciences "Eduardo Torroja" (CSIC), Serrano Galvache s/n, 28033, Madrid, Spain

The work described in this paper was developed in co-operation with the members of RILEM TC 178-TMC: 'Testing and Modelling Chloride Penetration in Concrete': **Chairlady:** C. Andrade; **Secretary:** J. Kropp.
Regular members: C. Alonso, C. Andrade, R. Antonsen, V. Baroghel-Bouny, M. P. A. Basheer, M. Carcassès, M. Castellote, K. Cavlek, Th. Chaussadent, M. A. Climent, S. Helland, F. Fluge, J. M. Frederiksen, M. Geiker, J. Gulikers, D. Hooton, J. Kropp, A. Legat, T. Luping, M. Maultzsch, S. Meijers, L. O. Nilsson, C. Page, K. H. Pettersson, R. Polder, M. Salta, M. Thomas, J. Tritthart, Ø. Vennesland.
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Testing and modelling chloride penetration into concrete

Table 1 – Methods selected for the determination of water soluble chlorides in the RRT	
Reference	Method
B	*Extraction of water soluble chlorides from the solid sample*
B.1*	AFREM procedure [8]
B.2	Alkaline method (Castellote's *et al.* procedure) [9]
B.3*	Other methods
C	*Analysis of the liquid obtained*
C.4*	Potentiometric titration (Maultzsch's procedure)

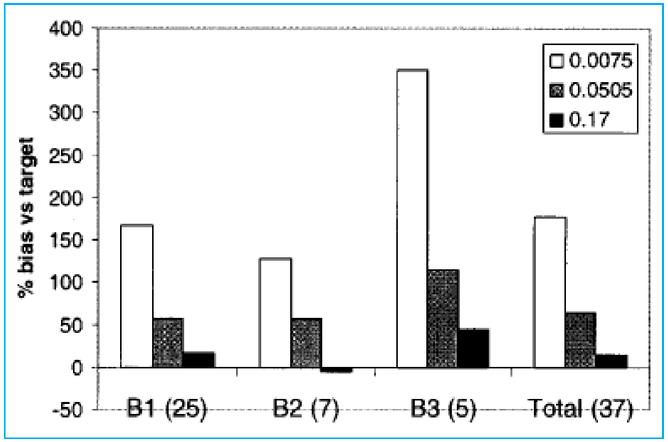

Fig. 2 – Percentage of deviation from the averaged value for each type of extraction, for the three samples tested.

Table 2 – Concentration of total and free chlorides in the samples dispatched for the RRT			
Sample	Total Cl^- (%)	Free Cl^- (%) Individual values	Free Cl^- (%) Averaged values
1	0.05	0.007/0.008	0.0075
2	0.15	0.054/0.047	0.0505
3	0.30	0.177/0.163	0.170

Table 6 – Comparison in deviations between total and free chloride extractions. Samples 1 and 2 for total chloride content have to be compared with Samples 2 and 3 for free chloride content, respectively.

	% Bias vs target			% Maximum deviation (repeatability conditions)			% Maximum deviation (reproducibility conditions)		
	Total Cl^-	Free Cl^-		Total Cl^-	Free Cl^-		Total Cl^-	Free Cl^-	
Sample	C4	B1-C4	B2-C4	C4	B1-C4	B2-C4	C4	B1-C4	B2-C4
1	29			13			31		
2	8	57	57	5	9	48	14	66	80
3	6	16	5	7	10	26	21	30	47

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Testing and modelling chloride penetration into concrete

COMPARISON OF CHLORIDE TEST METHODS

Round-Robin Test on methods for determining chloride transport parameters in concrete

M. Castellote · C. Andrade

Abstract This paper presents the results of a Round-Robin Test on methods for determining chloride transport parameters in concrete, carried out by the Technical Committee TC 178-TMC: "Testing and Modelling Chloride Penetration in Concrete" in which 27 different laboratories around the world have participated, using 13 different methods, in triplicate specimens, for 4 different mixes of concrete cast with different binders. Four different groups of methods have been tested: Natural diffusion methods (D), Migration methods (M), Resistivity methods (R) and Colourimetric methods (C). The statistical treatment of the data has been carried out according to the International Standard ISO 5725-2:1994 for the determination of the accuracy (trueness and precision) of measurement methods and results. Part 2: Basic method for the determination of the repeatability and reproducibility of a standard measurement method. In order to make an evaluation of these methods, four indicators have been identified and within each of them, several sub-indicators have been assigned. According to this system of classification, the methods have been classified following each indicator (trueness, precision, relevance and convenience), and also globally, by assigning different factors of importance, F.I., to the different indicators.

Résumé *Cet article comprend les résultats des essais inter-laboratoires sur les méthodes de mesure de la pénétration des chlorures dans le béton, effectués par la Commission technique RILEM 178-TMC: "Testing and Modelling Chloride Penetration in Concrete". Les participants étaient issus de 27 laboratoires répartis sur différents continents. On a utilisé 4 mélanges de béton différents fabriqués avec différents types de ciment, ainsi que 13 méthodes d'essais utilisant des échantillons*

TC 178-TMC Composition: Chairlady: C. Andrade. Secretary: J. Kropp

Members: C. Andrade, R. Antonsen, V. Baroghel-Bouny, M. P. A. Basheer, L. Bertolini, M, Carcasses, M. Castellote, C. Cavlek, TH. Chaussadent, M. A. Climent, S. Helland, F. Fluge, J. M. Frederiksen, M. Geiker, J. Gulikers, D. Hooton, J. Kropp, A. Legat, T. Luping, M. Maultzsch, S. Meijers, L. O. Nilsson, C. Page, K. H. Pettersson, R. Polder, M. Salta, M. Thomas, J. Tritthart, Ø. Vennesland.

N. S. Berke, J. J. Carpio, G. Gudmundsson, O. Troconis de Rincon, R. François, P. Pedeferri, N. Buenfeld, T. Cao, I. Diaz Tang, P. R. L. Helene, J. R. Mackechnie, D. Naus, A. Raharinaivo, M. Ribas-Silva, A. Sagues, M. Setzer, C. E. Stevenson

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C. Andrade
e-mail: andrade@ietcc.csic.es

PARTICIPATING LABORATORIES

	Laboratory	Responsible	Country
1	BAM, Berlin,	Kühne, H.C. Maultzsch, M.	Germany
2	Laboratoire Béton BOUYGUES TP - 1 Saint-Quentin-en-Yvelines	Taibi, Yan	France
3	BRANZ Ltd	Neil Lee	New Zealand
4	CEFET, Federal Center of Technological Education of Paraíba	Rocha, G.	Brasil
5	Chalmers University of Technology	Tang, L.	Sweden
6	EPUSP/ITA	Geimba de Lima, M.A Helene, Pl	Brasil
7	Fac. Ingeniería, Universidad de la República, Montevideo	Derrégibus, M.T.	Uruguay
8	HBRE-IBM, Germany Institut für Baustofftechnologie, Hochschule, Bremen,	Kropp, J. Luckies, V.	Germany
9	IBRI, The Icelandic Building Research Institute	Gudmundsson, G.	Iceland
10	IETcc, Institute of Construction Science "Eduardo Torroja" (CSIC). Madrid	Castellote, M. Andrade, C. García de Viedma, P.	Spain
11	INSA-UPS. L.M.D.C. Génie Civil. Toulouse	Carcasses, M. Juliens, S. Francois, R.	France
12	IPT - Instituto de Pesquisas Tecnológicas do Estado de S. Paulo S/A - Laboratório de Química de Materiais, Sao Paulo,	Quarcioni, V.	Brasil
13	Italcementi S.p.A. - Italcementi Group, Laboratory of Brindisi	Borsa, M. Vendetta , S.	Italy
14	ITC, Instituto Técnico de la Construcción, S.A., Alicante,	López, M.	Spain
15	L.C.P.C, Laboratoire Central des Points et Chausses, Paris	Baroghel-Bouny, V. Chaussadent, T	France
16	LNEC - Laboratório Nacional de Engenharia Civil, Lisboa	Salta, M. Vaz Pereira, E. Menezes, A.P. Garcia, N.	Portugal
17	LTH, Lund Institute of Technology	Nilsson, L.O.	Sweden
18	Politecnico di Milano - Dipartimento di Chimica, Materiali e Ingegneria Chimica "G. Natta".	Bertolini, L. Redaelli, E.	Italy
19	Queen's University Belfast, Northern Ireland,	Basheer P.A.M. , Nanukuttan, S. V.	United Kingdom
20	SP Swedish National Testing and Research Institute, BORÅS	Tang, L.	Sweden
21	TNO Built Environment and Geosciences	Polder, R. Hans Beijersbergen van Henegouwen	The Netherlands
22	University of Zulia, Centro de Estudios de Corrosión., Maracaibo	Troconis, O. Millano, V. Linares, D. Tarantino, V.	Venezuela
23	University of Alicante, Department of Construction Engineering, Alicante,	Climent, M.A. De Vera, G.	Spain.
24	University of Graz, Technische Versuchs- und Forschungsanstalt (TVFA), Graz	Tritthart, J.	Austria
25	University of Leeds	Page, C	United Kingdom
26	University of Toronto. Concrete Materials Laboratory, Dept. of Civil Engineering, Toronto	Hooton, D. Perabetova, O Nytko, U	Canada
27	ZAG, Slovenian National Building and Civil Engineering Institute, Lubjana	Caulek, K.	Slovenia

QUESTIONNAIRE

In order to prepare the specimens for the IT in the appropriate number, size and shape, it is very important that you fill in this questionnaire and send it to us as your convenience.

a) **Would you prefer to perform the tests either in duplicate or in triplicate specimens?**

Duplicate ☐ Triplicate ☒

b) **Please, confirm the methods (see attached tables) that you are going to perform:**

D1	☒	R1	☒	M1	☒
D1-P/M	☐	R2	☐	M1-R	☐
D2	☒			M3	☐
D3	☒			M4	☒
D4	☐			M5	☒
				M6	☒
				M7	☐

c) **How many, and which dosages are you going to test?**

Hoy many dosages? 4

OPC-1	☒	SLG (slag concrete)	☒
FA (fly ash concrete)	☒	SF (silica flume) or OPC-2	☒

d) **Providing that you are going to test in a device type "cell", which is the diameter of the specimen that you need?**

100 mm (preferable for diffusion/migration cells)

e) **Do you prefer to receive specimens or blocks to take cores from them?**

Specimens ☒ Blocks for cores ☐
(however, we can also core from blocks)

f) **Taking into account the number of devices that you have, your availability of time, etc … , How long do you think it will take to perform the tests (for each dosage) that you are planning to make?**

3 months (indicative)

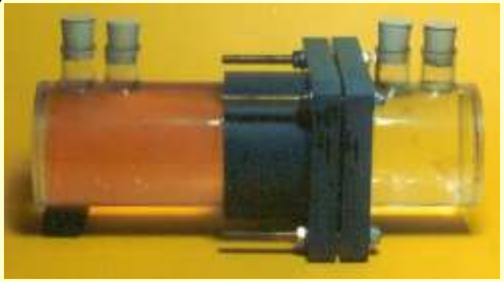
Mixture proportions of concrete

Kg/m^3	SF	OPC	FA	SL
Cast by	CHALMERS	IETcc	LNEC	TNO
Cement	399 I-42.5 N V/SR/LA	400 I-42.5 R/SR	340“ IV/B 32.5 R	350 III/B 42.5 LH HS
Silica fume	21 (slurry)	-----		-----
Fly ash	-----	-----		-----
Slag	-----	-----		-----
Water	168	180	153	157.5
Sand	842.5 (0-8 mm)	742 (0-6 mm)	62 (0-2 mm) 603 (0-4 mm)	70 (0-1 mm) 790 (0-4 mm)
Coarse aggregate	842.5 (8-16 mm)	1030 (6-16 mm)	619 (4-12 mm) 555 (12-25 mm)	1040 (4-16 mm)
Total aggregate	1685	1772	1823	1830
Super-plasticisers	3.4 Cementa 92M	4.8 Melcret 222	4.1 Rheobuild 1000	3.9 Cretoplast
Air content	6%	-----		1.5
W/C	0.42	0.45		
W/B	0.40	0.45	0.45	0.45
Strength (MPa)	63	45	52.6	
Slump (mm)		> 150		
Porosity (% vol)	9.87	7.68	12.7	
Casting date	November 2002	May 2003	June 2003	October 2003
Delivered	May 2003	August 2003	October 2003	April 2004

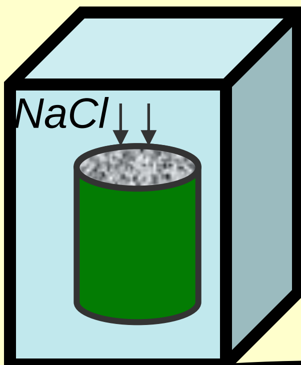
TEST METHODS SELECTED

Label	Name of the Method/Standard	D_s/D_{ns}	Device	Reference
D1	Natural Diffusion Cell	Ds	Diffusion Cell	[3]*
*D1-P	Natural Diffusion Cell *For paste specimens	Ds	Diffusion Cell	[3]*
D2	NT Build 443	Dns	Immersion test	[14]
D3	Natural Diffusion Ponding	Dns	Ponding	[1]*
D4	Natural Diffusion Cell.	Dns	Diffusion Cell	[15]
R1 R1/M	Resistivity	Ds	Resistivimeter, potenciostat,…	[16]*
R2	Monfore Cyclic Resistivity	-------		[17]???
M1	ASTM C-1202-97	-----	Migration cell	[1] [18]
M3	Mesure du coefficient de diffusion effectif des ions chlore par un essai de migration en milieu sature	Ds	Migration cell	[11]
M4	NT Build 492	Dns	Migration device	[19]
M5	Migration colourimetric method	Dns	Ponding	[20]*
M6	Multi-Regime method	Ds and Dns	Migration cell	[21]*
C1	Colourimetric methods	$[Cl^-]$ at the front	Ponding	[22-24]*

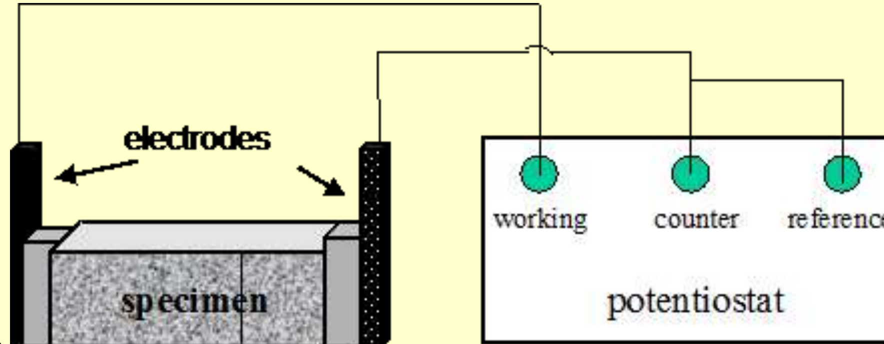
Natural diffusion

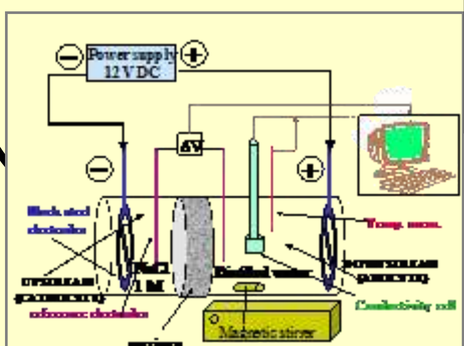


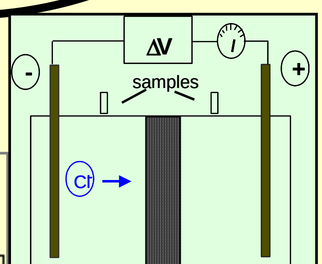
NaCl

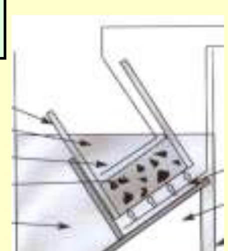


Resistivity



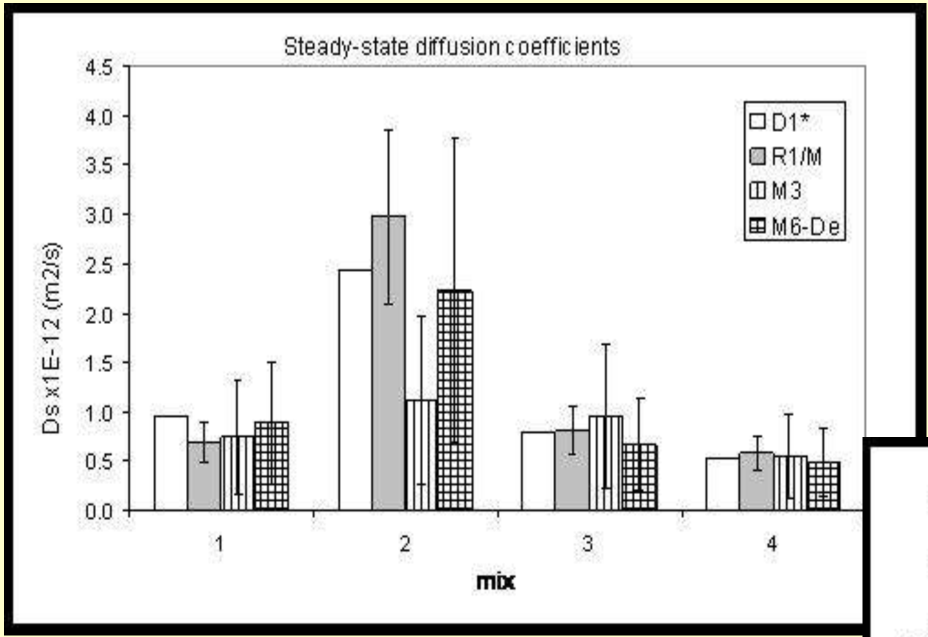


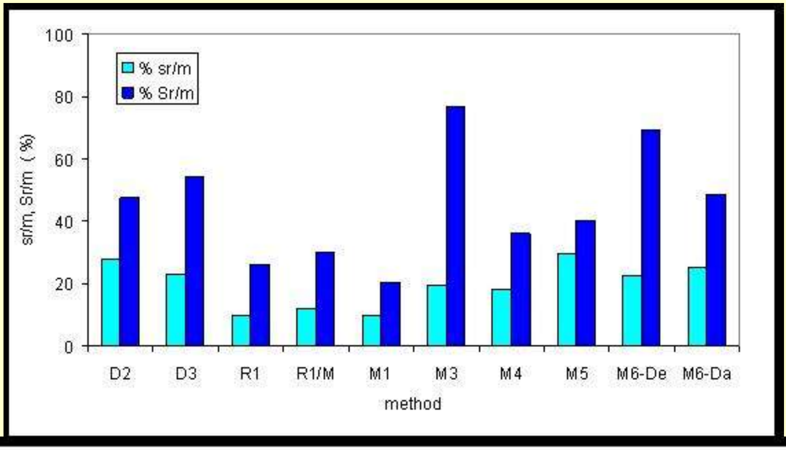


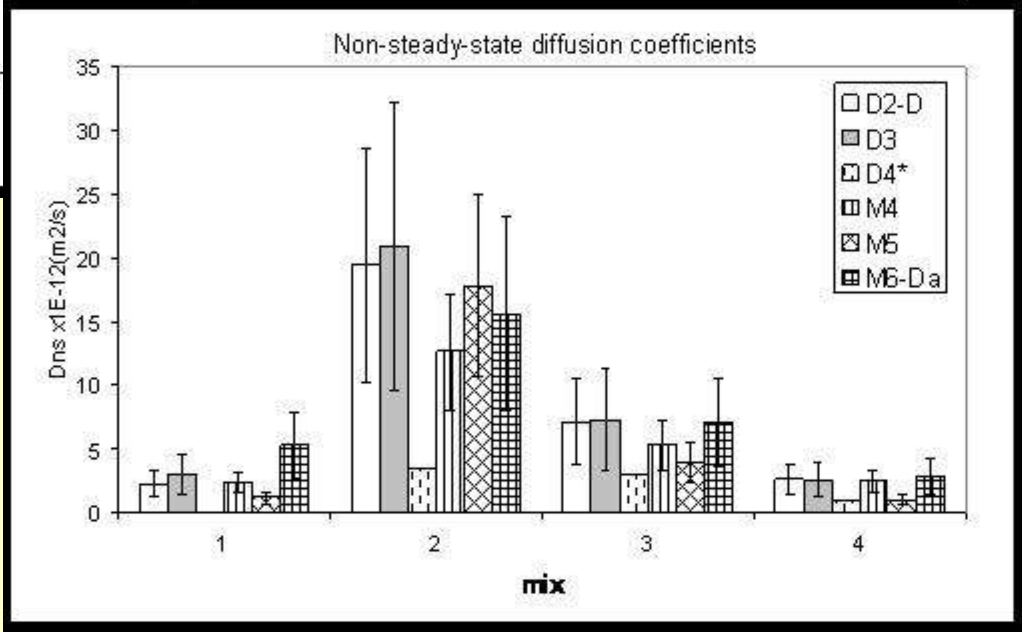


Colorimetric

REPETABILITY/REPRODUCIBILITY

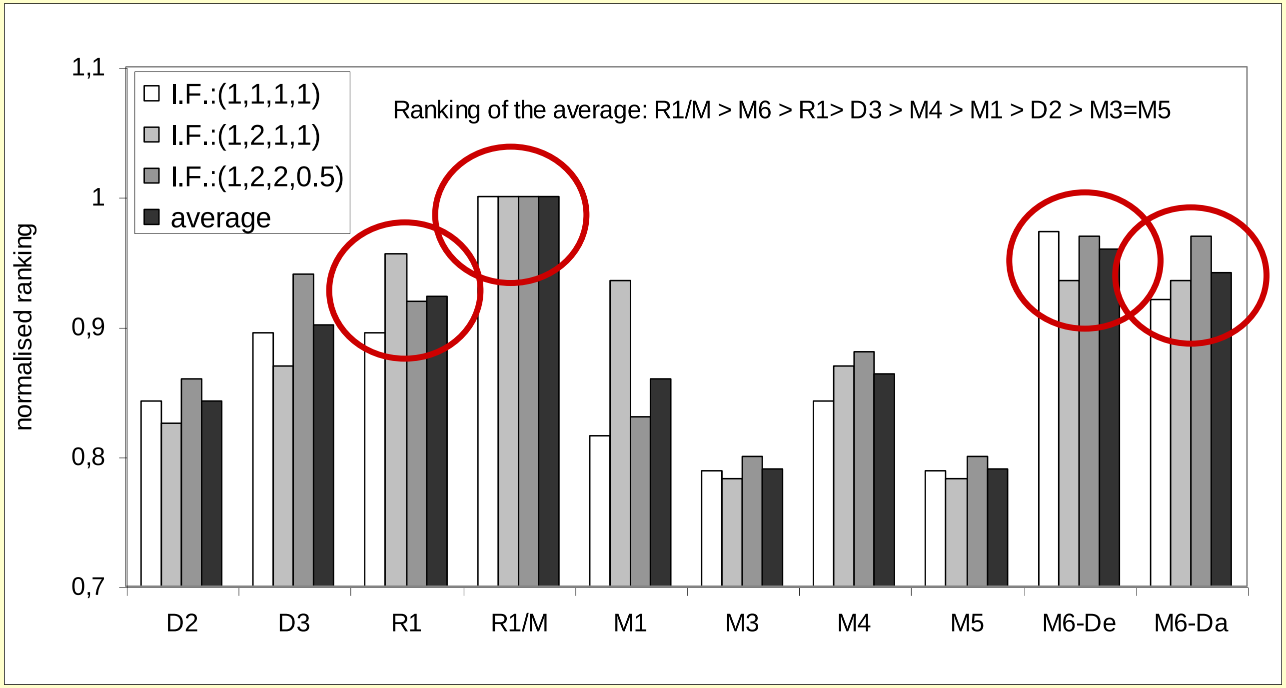






Summary of methods

Label	Method	1.1.1.1 Voltage	D_s/D_{ns}	Pre-treatment	Device	Specimen	Analysis
D1	Natural Diffusion Cell	---------	Ds	Vacuum saturation with water	Cell Ups:1 M NaCl Down: distilled water	1-2 cm	Liquid samples
D1-P/M	Natural Diffusion Cell (Paste and Mortar)	-----------	Ds		Diffusion Cell Ups: 1M NaCl, NaOH Down: NaOH	0.3 cm	Liquid Samples
D2	NT Build 443	---------	Dns	$Ca(OH)_2$ saturation	Immersion 3M, 35 d	5 cm	Profile
D3	Natural Diffusion Ponding	---------	Dns	Vacuum saturation with water	Ponding 1 M NaCl, 90 d	Any depth	Profile
D4	Measuring chloride diffusion coefficients from non-steady state diffusion tests.	---------	Dns	Vacuum saturation with water	Cell Ups:NaCl, KOH and NaOH Down: KOH and NaOH	2 cm	Profile
R1	Resistivity			Vacuum saturation with water	Two electrodes on the surface 5-60 V AC or DC	Any standardized specimen	Resistivity
R2	Monfore Cyclic Resistivity						
M1	C-1202-91	60V	-----	Vacuum saturation with water	Migration cell Catholyte: 3% NaCl Anolyte: 0.3 M NaOH	5.1 cm	Charge
M-R	Ds from Resistivity	5-60 V	Ds	Vacuum saturation with water	Two electrodes on the surface AC or DC	Any standardized specimen	Resistivity
M3	Mesure du coefficient de diffusion effectif des ions chlore par un essai de migration en milieu sature	12 V	Ds	Vacuum saturation with water	Migration cell Catholyte: NaCl, KOH and NaOH Anolyte: NaOH, KOH	3 cm	Liquid samples
M4	NT Build 492	V variable	Dns	Vacuum saturation with $(CaOH)_2$	Migration cell Catholyte: 10% NaCl Anolyte: 0.3 M NaOH	5 cm	Colorimetric
M5	Dns from Colourimetric, Method	Any V	Dns	Vacuum saturation with water	Ponding or cell Ups:1 M NaCl	Any	Colorimetric
M6	Multi-Regime Method	12 V	Ds and Dns	Vacuum saturation with water	Migration cell Catholyte: 1M NaCl Anolyte: Distilled water	2 cm	Conductivity
C1	Natural Diffusion Ponding	---------	Dns	Vacuum saturation with water	Ponding 1 M NaCl, 90 d	Any depth	Colorimetric



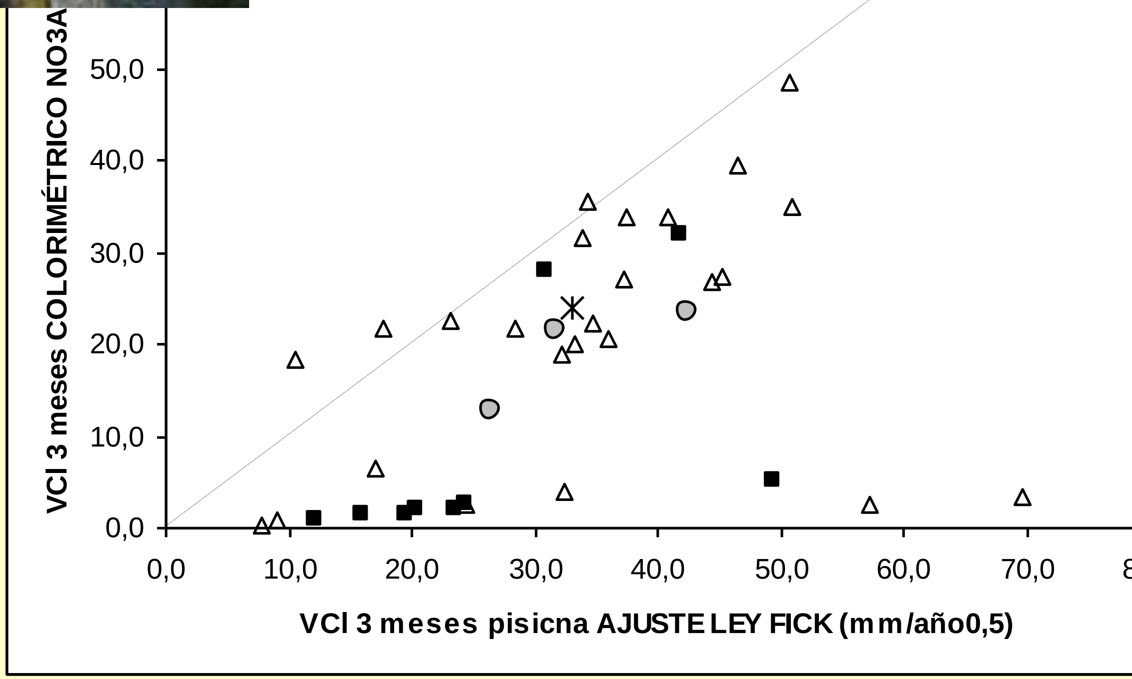
Global ranking of the methods

according to the scoring, normalized to unity, using different importance factors, I.F., for the four indicators. The last series is an average of the values given in the first series.
In the legend: I.F.:(trueness,precision,relevance,convenience).

The method globally classified as the best one for the three I.F. used is the R1/M method that gives the steady state diffusion coefficient by measuring the resistivity of a water saturated specimen. As a global classification including all the methods, the average of the three different I.F. can be used, ranking them as follows: R1/M > M6 > R1> D3 > M4 > M1 > D2 > M3=M5
Concerning the natural diffusion methods, the method D3 gives a better global behaviour in the three cases studied.
As long as the methods for calculation the steady state diffusion coefficient, the ranking is also the same for the three I.F.; the best classified is R1-M, then M6-De and finally M3.
For the calculation of the non steady state diffusion coefficient by migration methods the trend is again, for the three I.F. used: M6-Da as the best one, then M4 and finally M5.

The relative position of the methods R1 and M1, is different depending on the I.F. given to the different indicators. They are very well classified giving higher importance to the precision and they exhibit not so good position in the ranking in the case of using higher I.F. for relevance and lower for convenience. It is worth remarking that the method R1 shows very good mark even in this case.

SCATTER OF COLORIMETRIC TEST



Relation between chloride penetration rate (mm/año0.5) obtained by fit Fick’s law to the profile and by colourmetric method

TC 178

Testing and modelling chloride penetration into concrete

- BENCHMARKING OF CHLORIDE MODELS

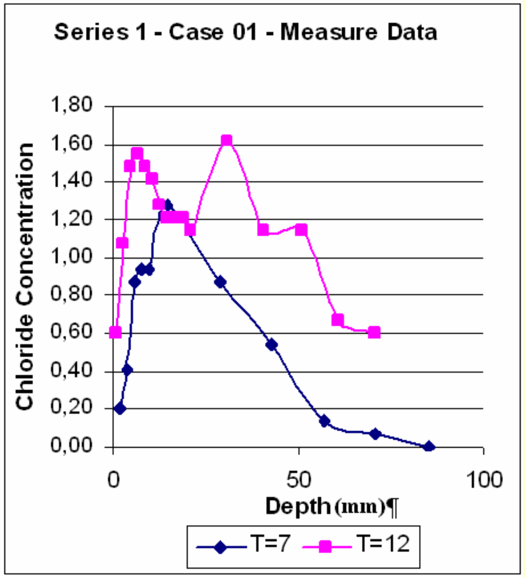
AIM OF BENCHMARKING

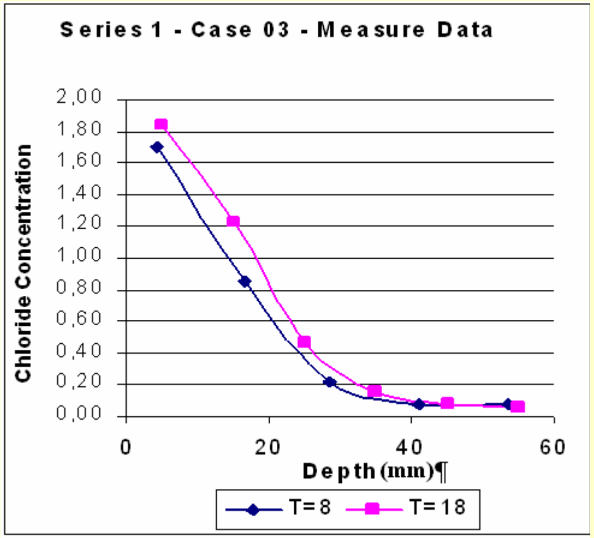
- To compare several models of chloride penetration in order to understand their suitability and limitations
- A method for the comparison exercise has been developed based in using two chloride profiles taken at two different ages in the same specimen type or structures.
- The profile at longer age has to be predicted from thean another at shorter age.
- Deviations from the real profile are used to assess the reliability of the models.

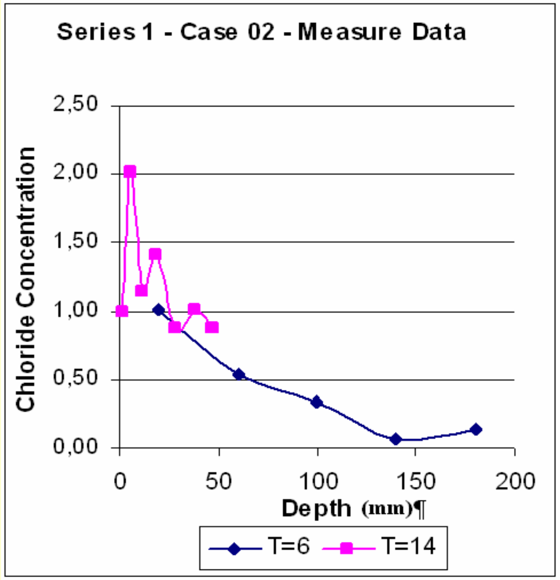
MODELS USED IN THE COMPARISON

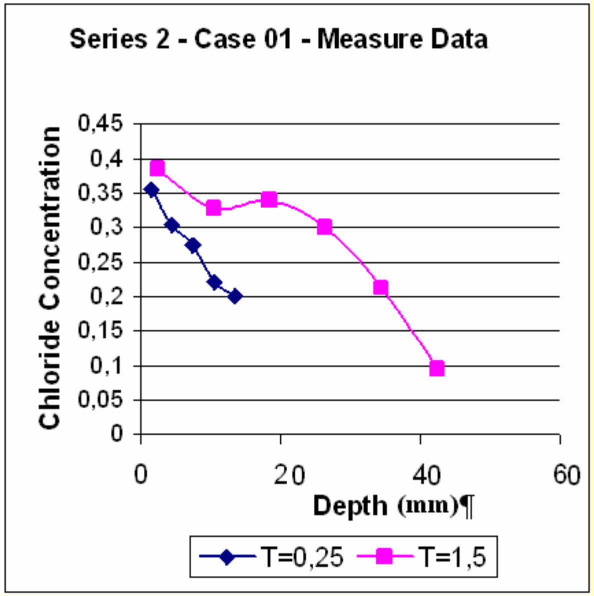
Model characteristic	*Basis of the Model*	*Time dependence of D or equivalent*	*Time dependence of C_s*	*Chloride binding*
Model 1	Square root, does not need a Diffusion coeff.	Yes	Yes	Yes
Model 2	Classical error function	Yes	Yes	Apparent D
Model 3	Fick'second Law, theoretical	No	No	Apparent D
Model 4	Fick'second Law, empirical	Yes	Yes	No
Model 5	Fick'second Law, numerical	Yes	Yes	Yes
Model 6	Fick'second Law, numerical	No	Yes	Yes
Model 7	Fick'second Law, numerical	Yes	Yes	No
Model 8	Fick'second Law, analytical	Yes	No	Yes

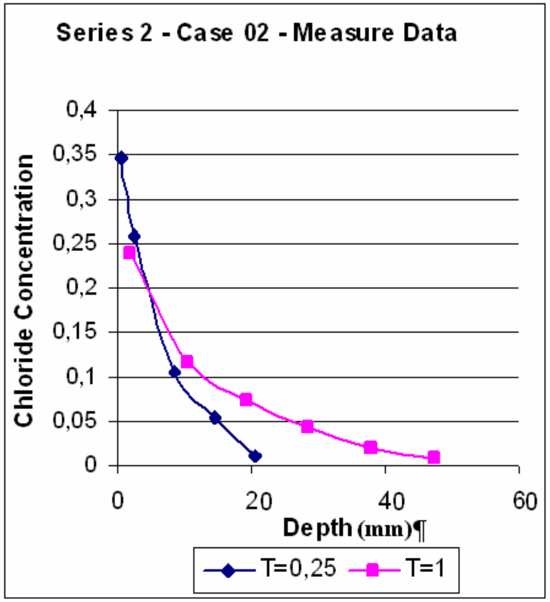
PROFILES SELECTED









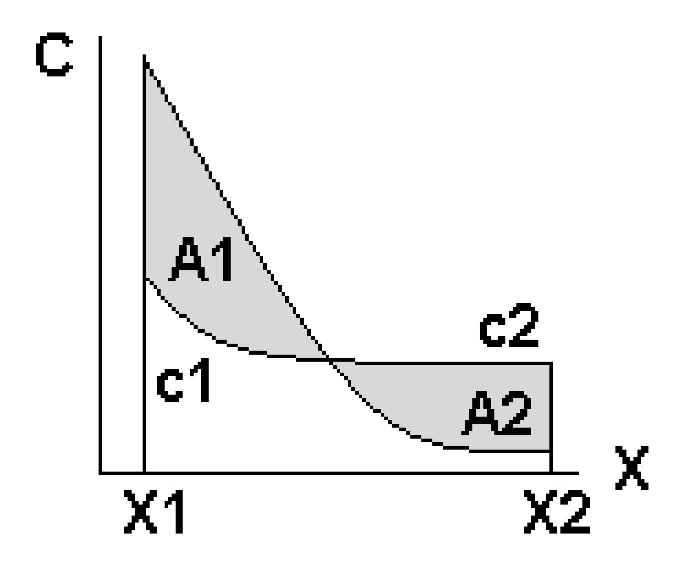


CRITERIA FOR THE COMPARISON

The Values used to compare are the Areas with and without sign:

$S1 = |A1| + |A2|$

$S2 = A1 + A2$



c1 : measured curve (total chlorides)

c2 : model curve (total chlorides)

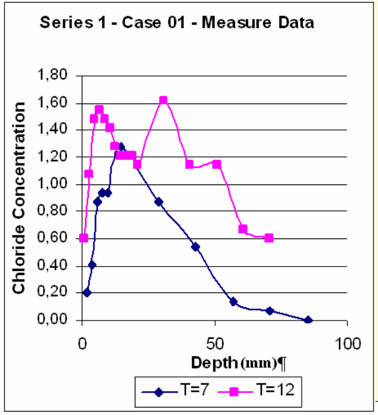
X1, X2 : validation range 10mm to 50 mm

A1 : area between the measured curve and model curve (negative part)

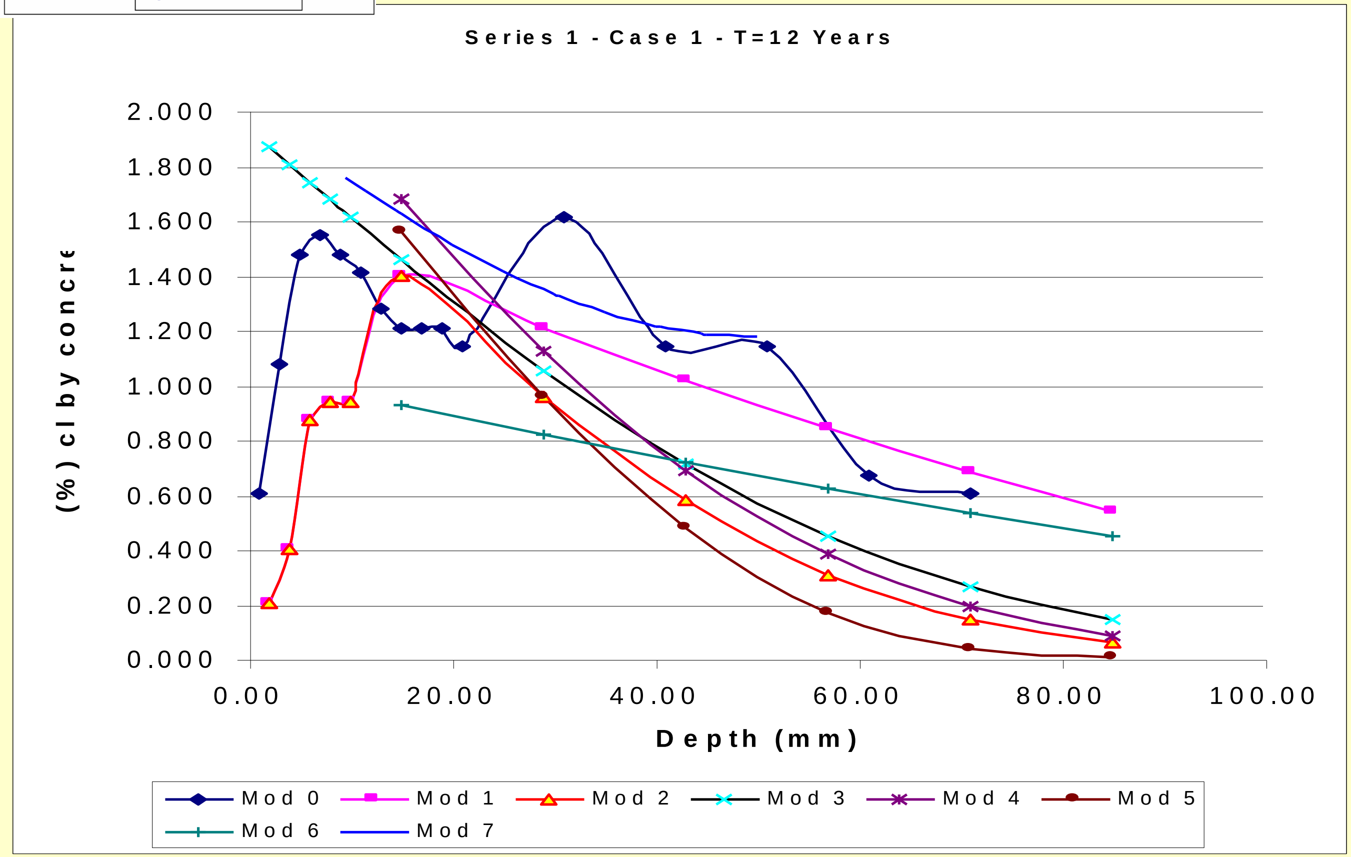
A2 : area between the measured curve and model curve (positive part)

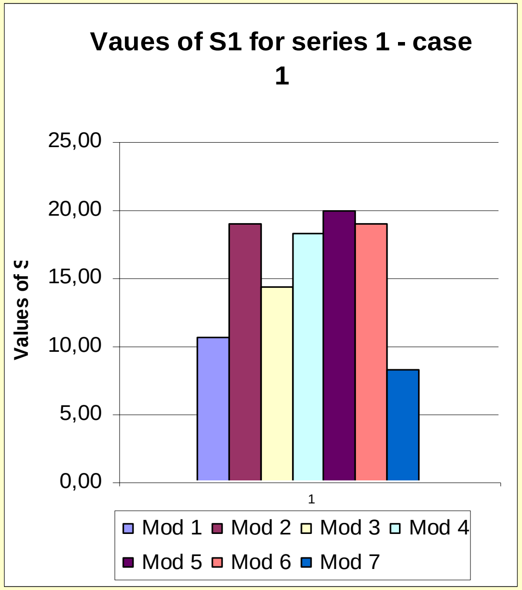
S1 give the information about how near the model is from the measured data.

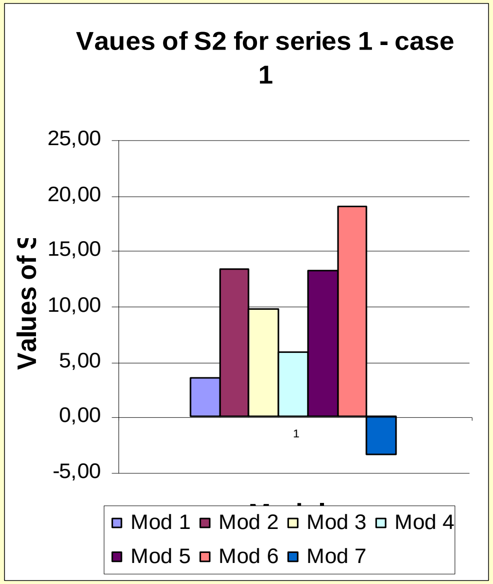
S2 gives the information about how higher or lower the model is, compared with the measured data.


Series 1 - Case 01 - Measure Data
Chloride Concentration
1,80
1,60
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
0
50
100
Depth (mm)¶
T=7
T=12

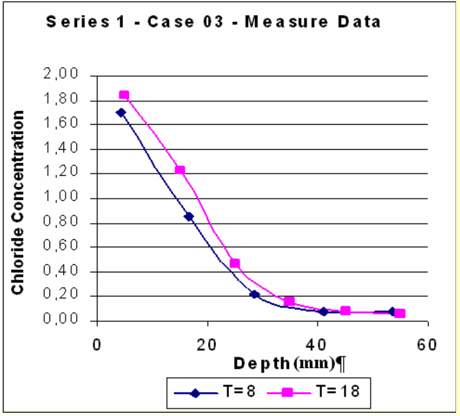
RESULTS

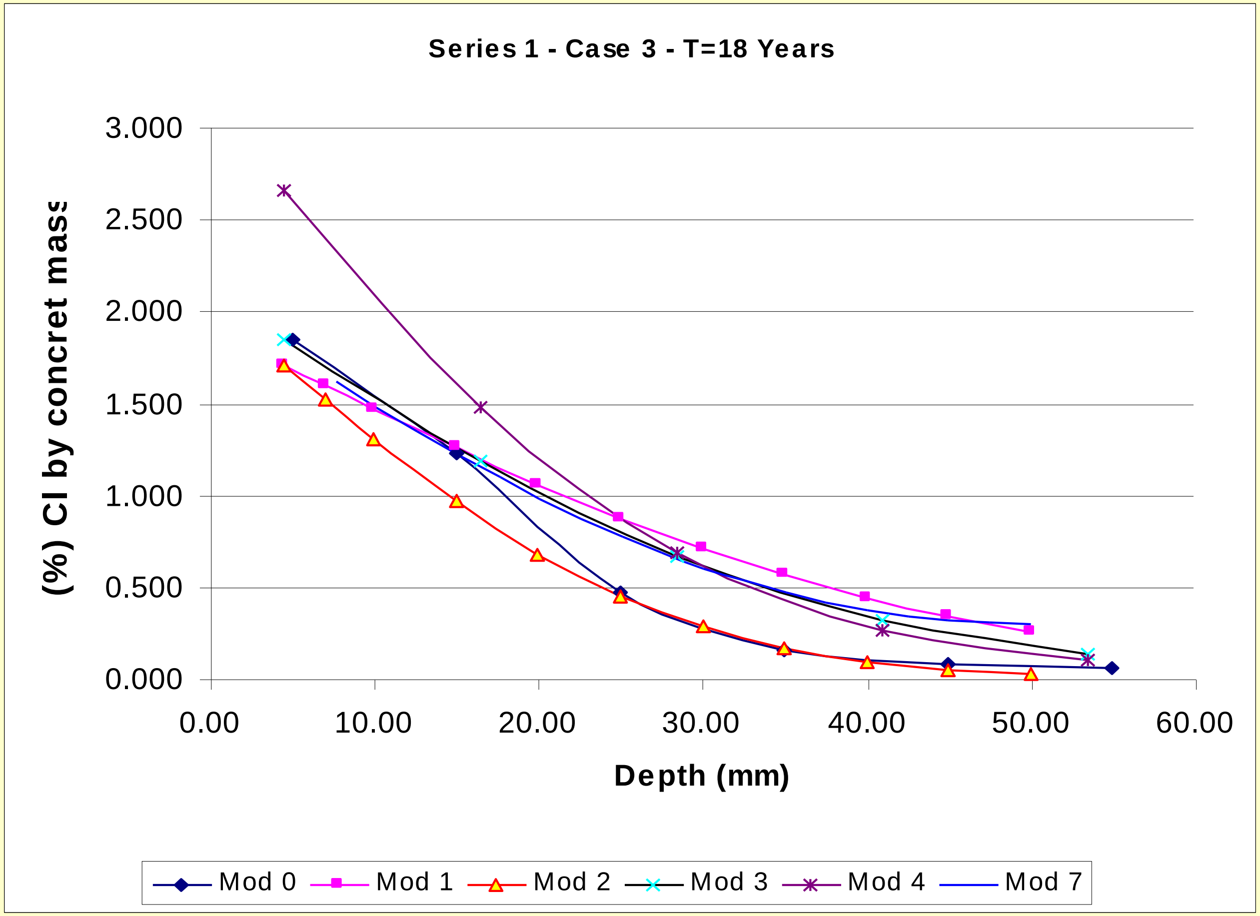

Series 1 - Case 1 - T=12 Years
(%) cl by concre
2.000
1.800
1.600
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0.00
20.00
40.00
60.00
80.00
100.00
Depth (mm)
Mod 0
Mod 1
Mod 2
Mod 3
Mod 4
Mod 5
Mod 6
Mod 7

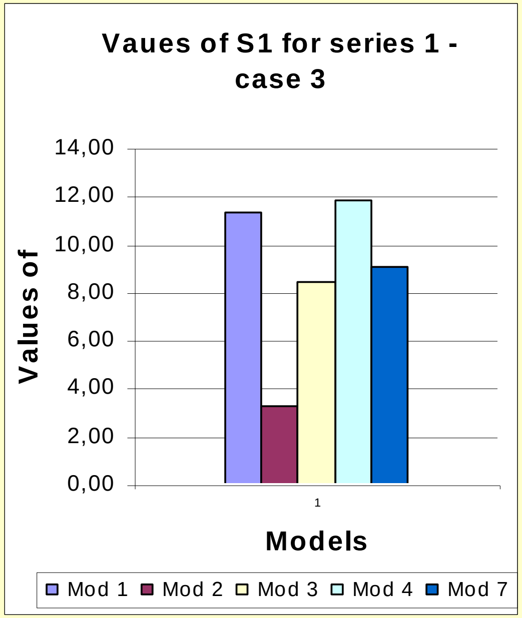

Vaues of S1 for series 1 - case 1
Values of S
25,00
20,00
15,00
10,00
5,00
0,00
1
Mod 1
Mod 2
Mod 3
Mod 4
Mod 5
Mod 6
Mod 7

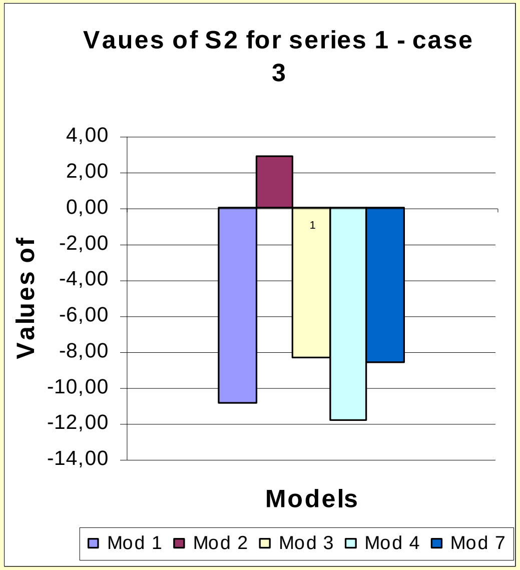

Vaues of S2 for series 1 - case 1
Values of S
25,00
20,00
15,00
10,00
5,00
0,00
-5,00
1
Mod 1
Mod 2
Mod 3
Mod 4
Mod 5
Mod 6
Mod 7

RESULTS


Series 1 - Case 03 - Measure Data
Chloride Concentration
2,00
1,80
1,60
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
0
20
40
60
Depth (mm)¶
T=8
T=18


Series 1 - Case 3 - T=18 Years
(%) Cl by concret mass
3.000
2.500
2.000
1.500
1.000
0.500
0.000
0.00
10.00
20.00
30.00
40.00
50.00
60.00
Depth (mm)
Mod 0
Mod 1
Mod 2
Mod 3
Mod 4
Mod 7


Vaues of S1 for series 1 - case 3
Values of
14,00
12,00
10,00
8,00
6,00
4,00
2,00
0,00
1
Models
Mod 1
Mod 2
Mod 3
Mod 4
Mod 7


Vaues of S2 for series 1 - case 3
Values of
4,00
2,00
0,00
-2,00
-4,00
-6,00
-8,00
-10,00
-12,00
-14,00
1
Models
Mod 1
Mod 2
Mod 3
Mod 4
Mod 7

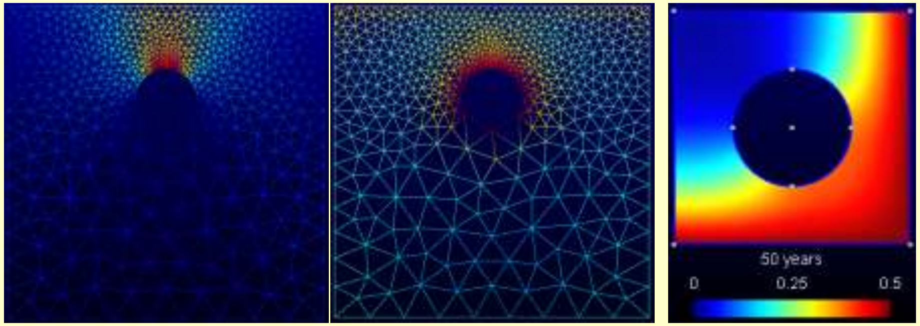
CONCLUSIONS

- Regarding the sensitivity of the models to the variation of the constitutive parameters, the most influencing one is the Cs value
- Models to predict Cs are needed
- The value of D is meaningless if the Cs is not simultaneously specified or given
- Example $D = 5 \times 10^{-8}$ cm^2/s for $Cs = 0.5$

TC 213
Model assisted integral service life prediction

- **REVIEW ON ACCURACY OF EXISTING MODELS**

MODELS
THE COMPUTER DO NOT THINK ALONE

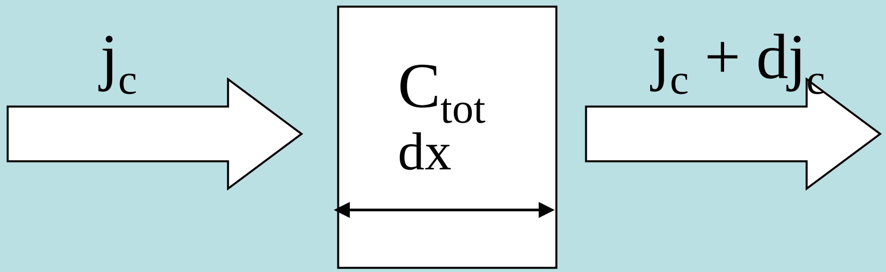


- There are not models calibrated at long term
- All data available are at short term

TRANSPORT MODELS BASED IN FICK’ s SECOND LAW

Non stationary conditions

$$\frac{\partial}{\partial t}c = \frac{\partial}{\partial x}\left[-\left(j_c\right)\right] = \frac{\partial}{\partial x}\left[-\left(-D\frac{\partial}{\partial x}C(x,t)\right)\right] = D\frac{\partial^2}{\partial x^2}C(x,t)$$



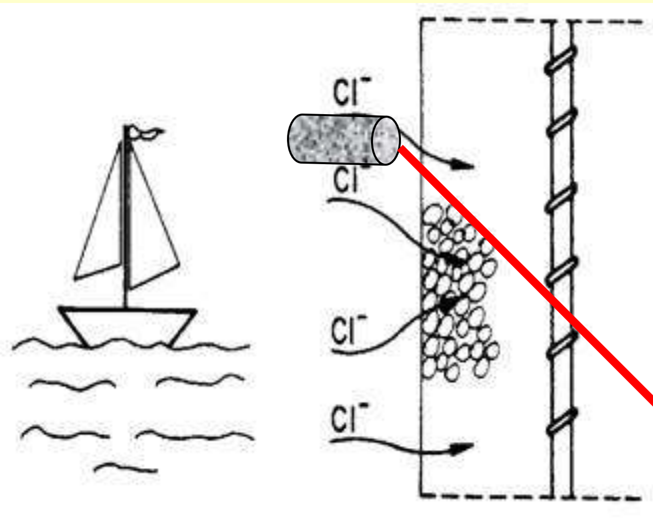
Initial conditions

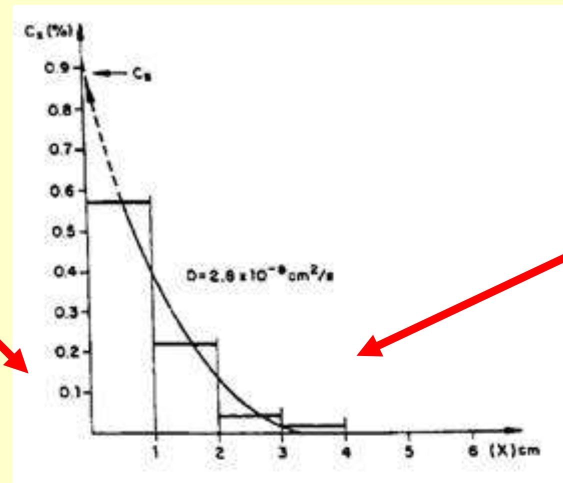
Boundary conditions

Chloride transport

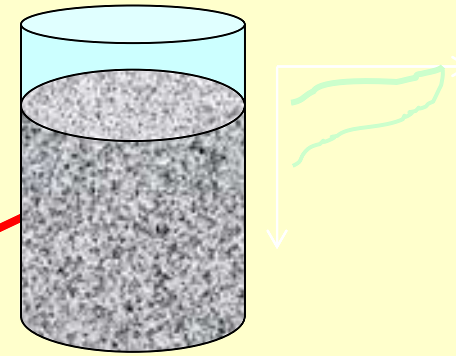
$$C(x,t) = C_s\left(1 - erf\left(\frac{x}{2\sqrt{D\cdot t}}\right)\right)$$

MODEL FOR CHLORIDE INGRESS
Cs is a boundary condition

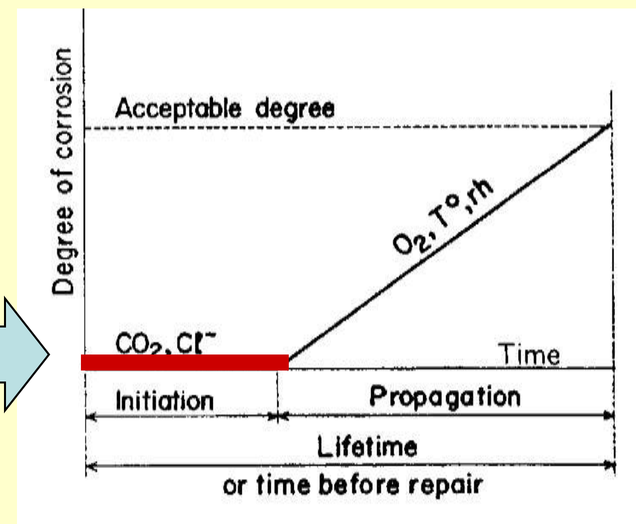




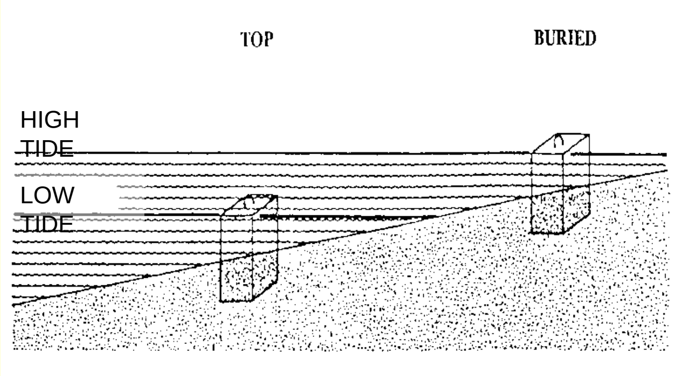
TEST

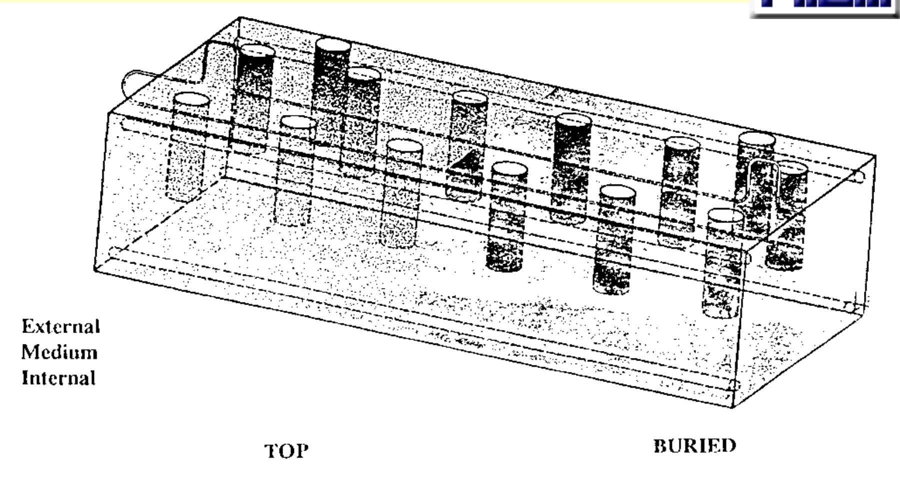


$$\frac{C_X - C_0}{C_S - C_0} = \left(1 - erf\left[\frac{x}{2\sqrt{D_{ns} t}}\right]\right)$$



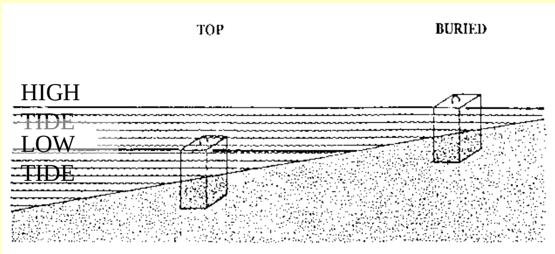
Concrete bloks exposed to Atlantic sea water

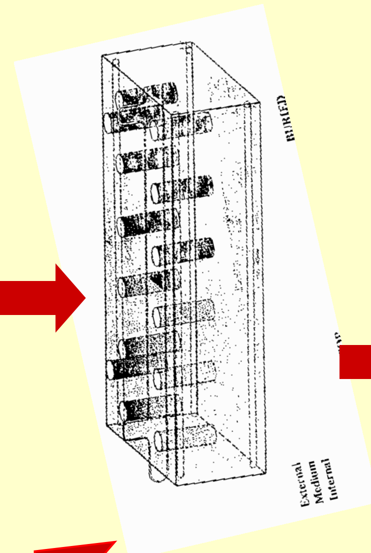


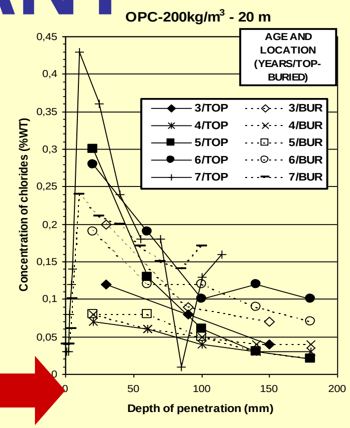


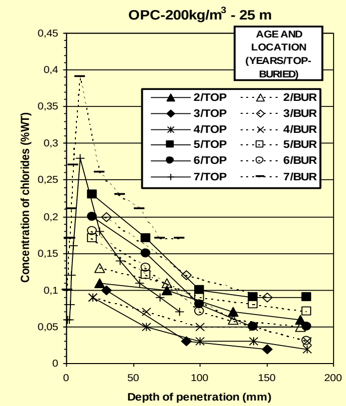
TEST STATION IN A BEACH

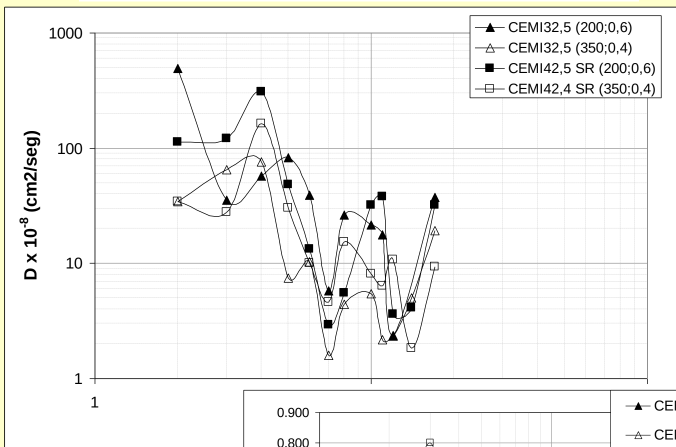
IN REAL STRUCTURES D and Cs ARE NOT CONSTANT

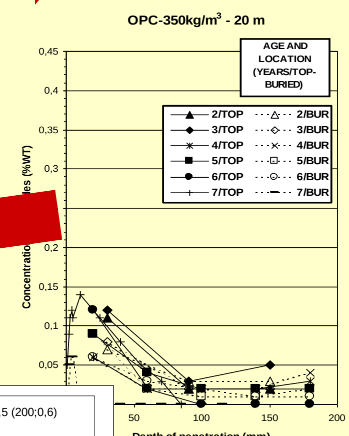


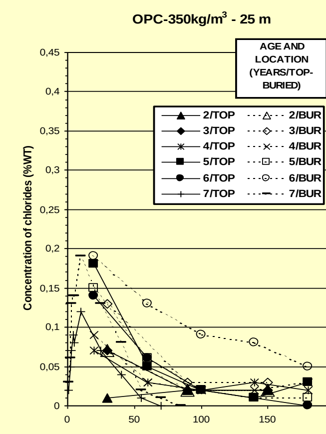


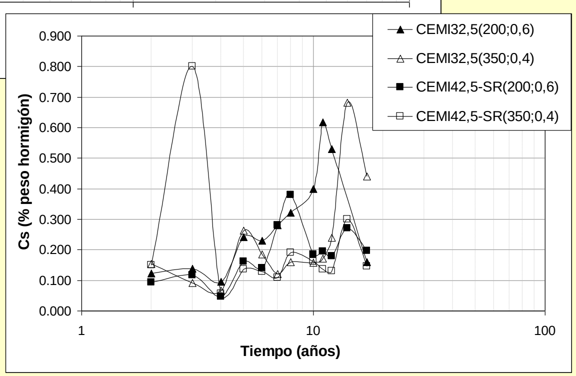


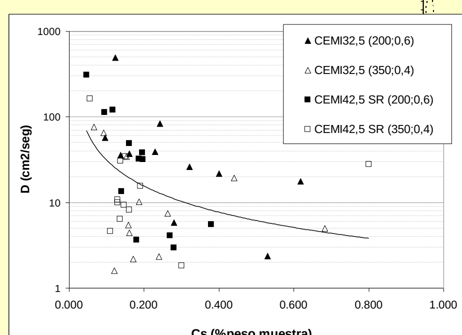












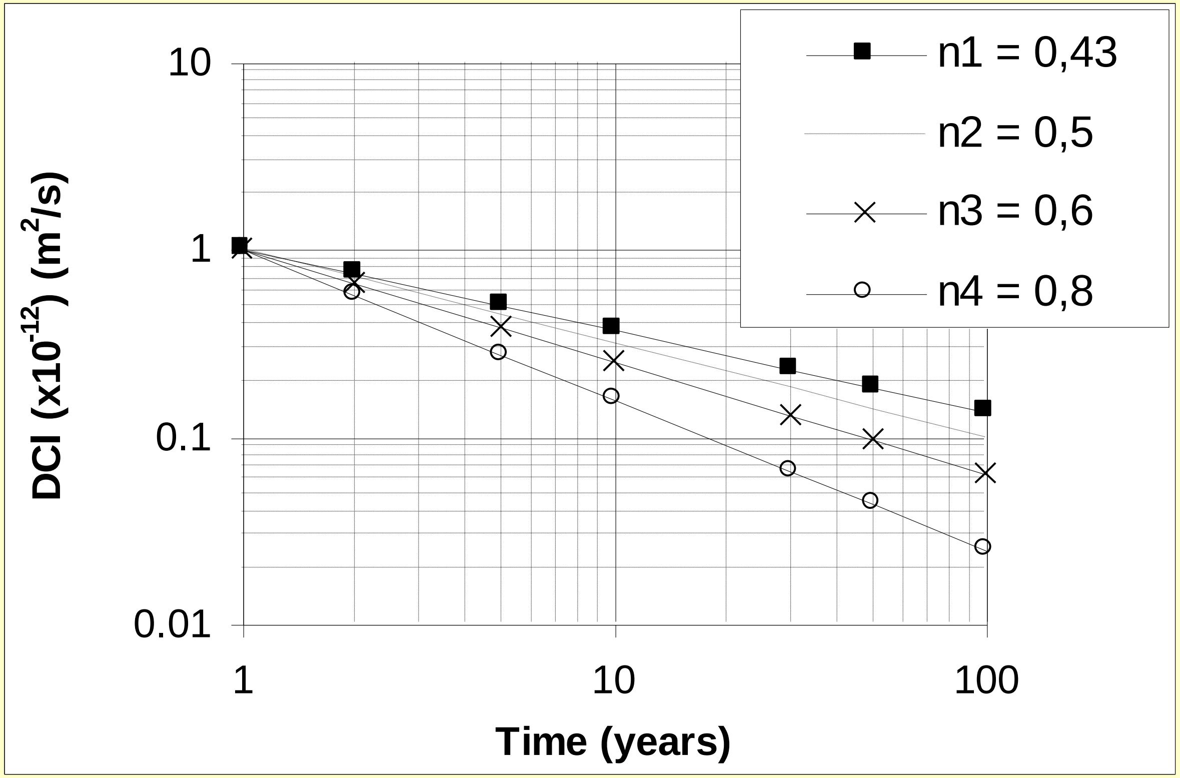
AGING FACTOR

The parameters evolve with hydration

The aging has a very high impact in the prediction

how to calculate it?

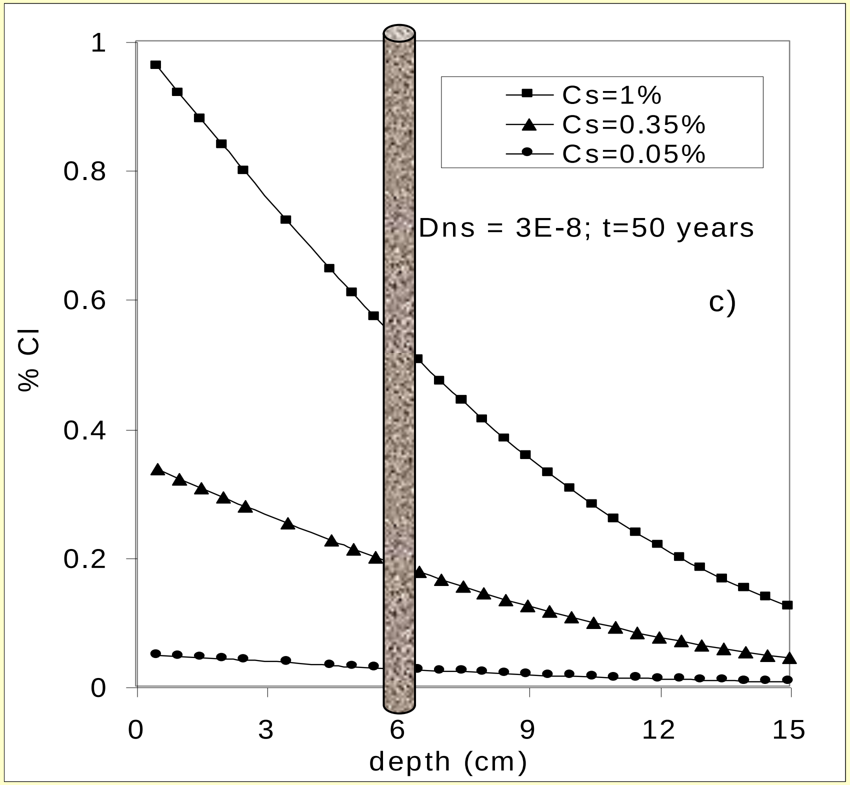
$$D_t = D_0 \left(\frac{t}{t_0}\right)^{-n}$$



THE MODELS FAIL BECAUSE THE BOUNDARY CONDITINS ARE NOT RESPECTED

- Cs is not constant
- D is not constant

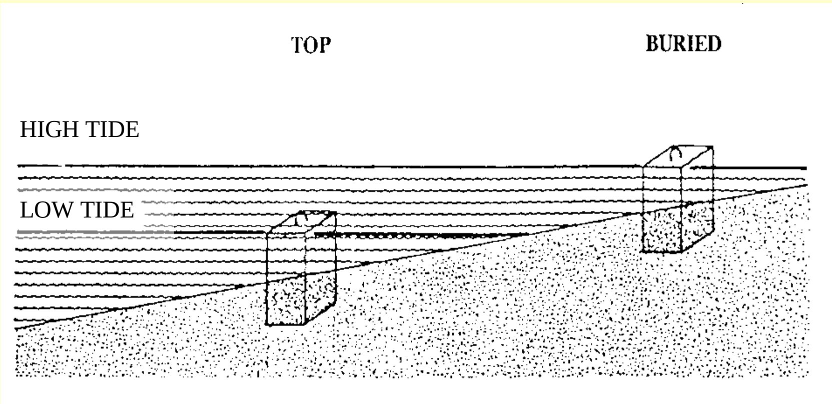
$$\frac{C_X - C_0}{C_S - C_0} = \left(1 - erf\left[\frac{x}{2\sqrt{D_{ns} t}}\right]\right)$$

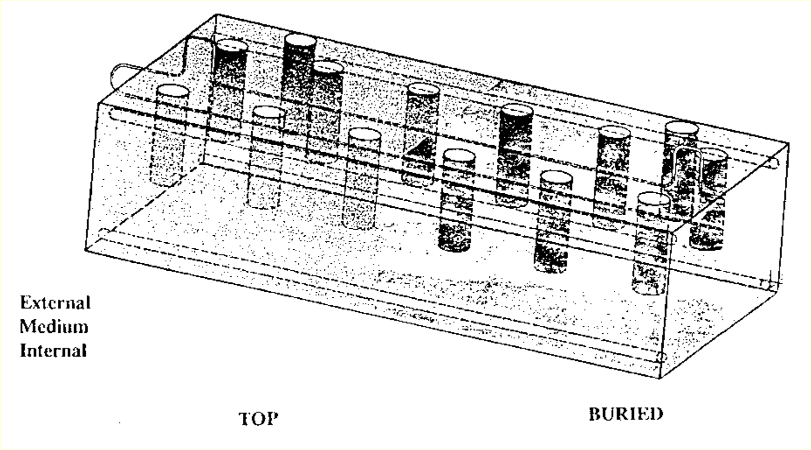


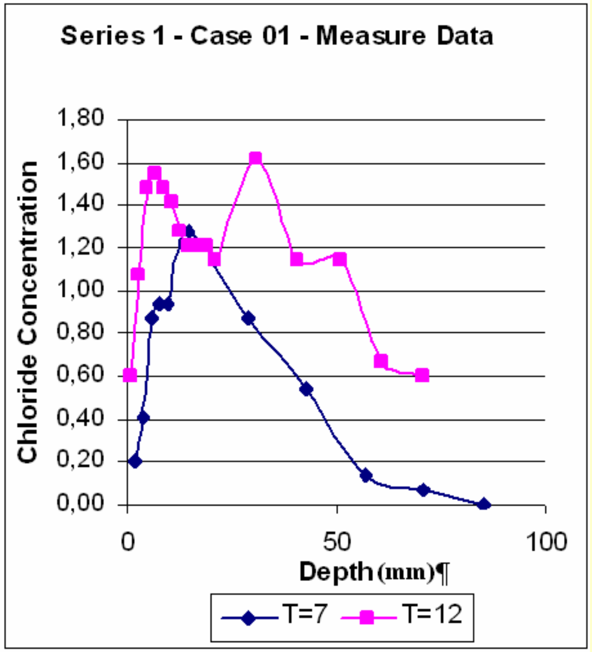
OTHER LIMITATIONS

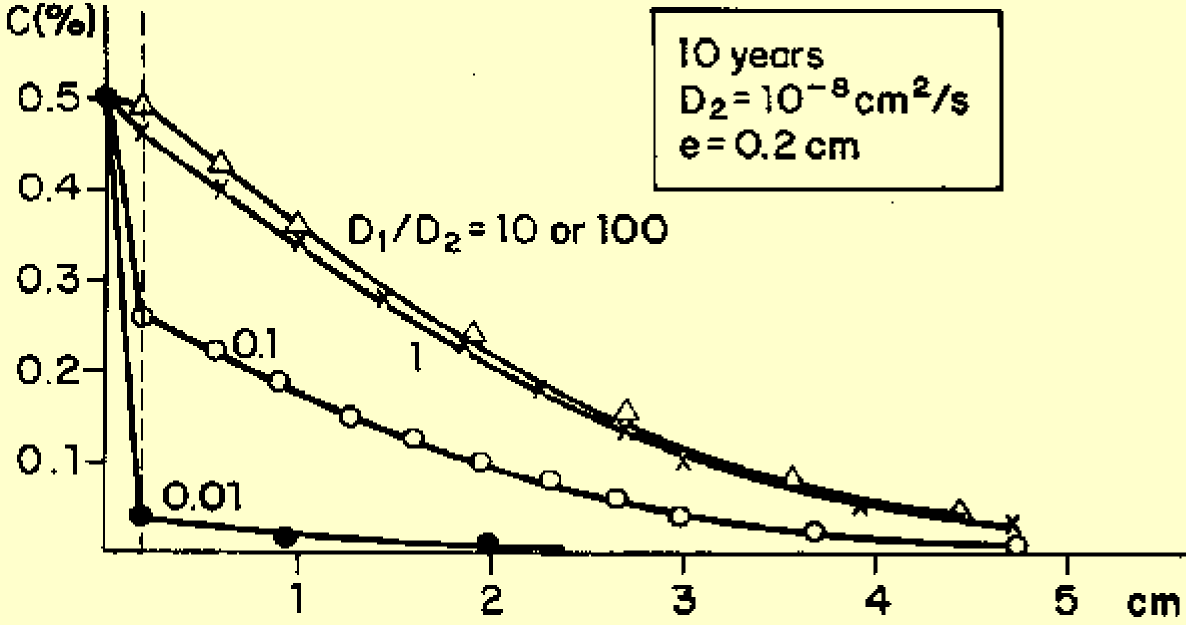
- The climate is not constant

Formation of a “SKIN”

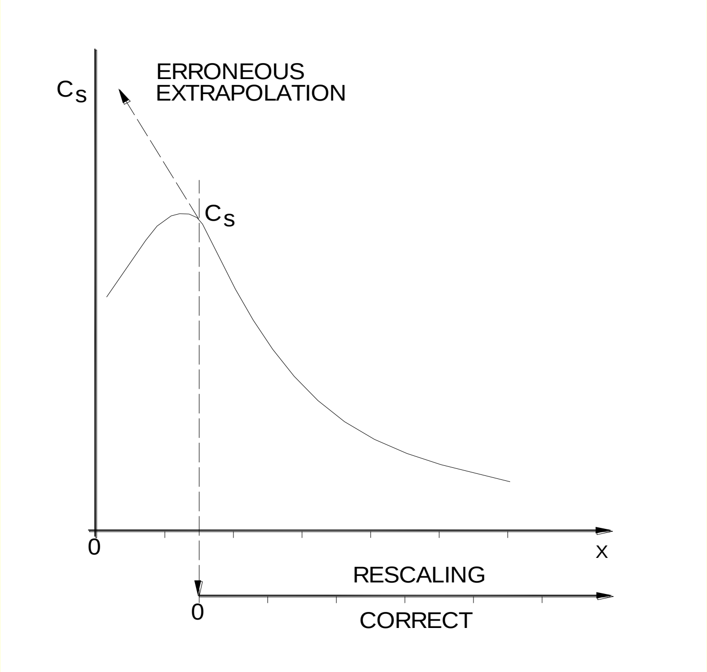


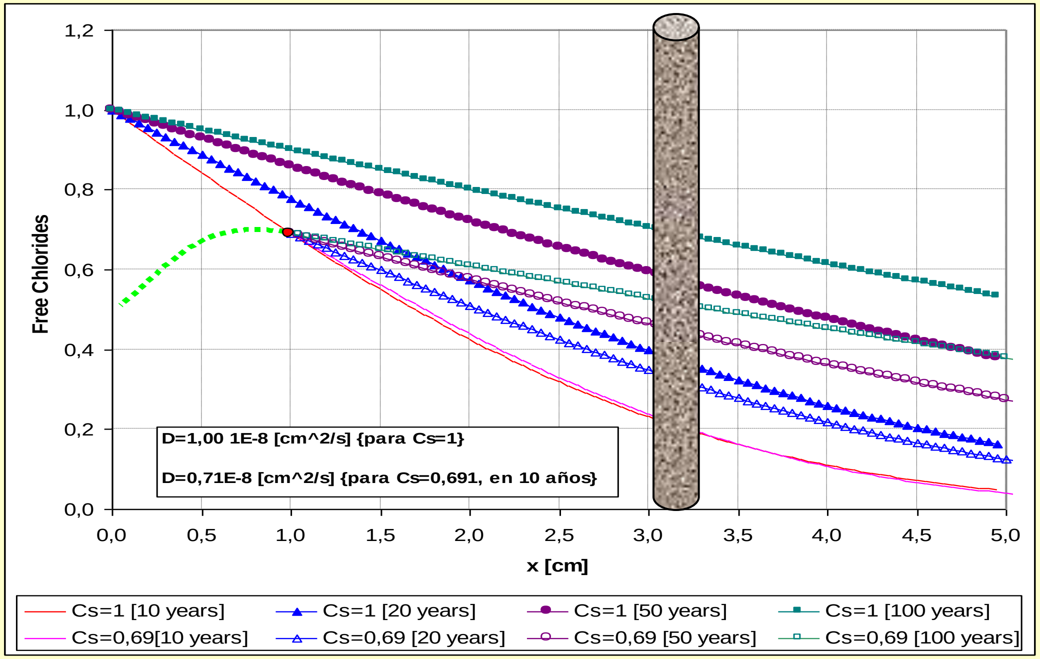






Skin effect
extrapolation for Cs value





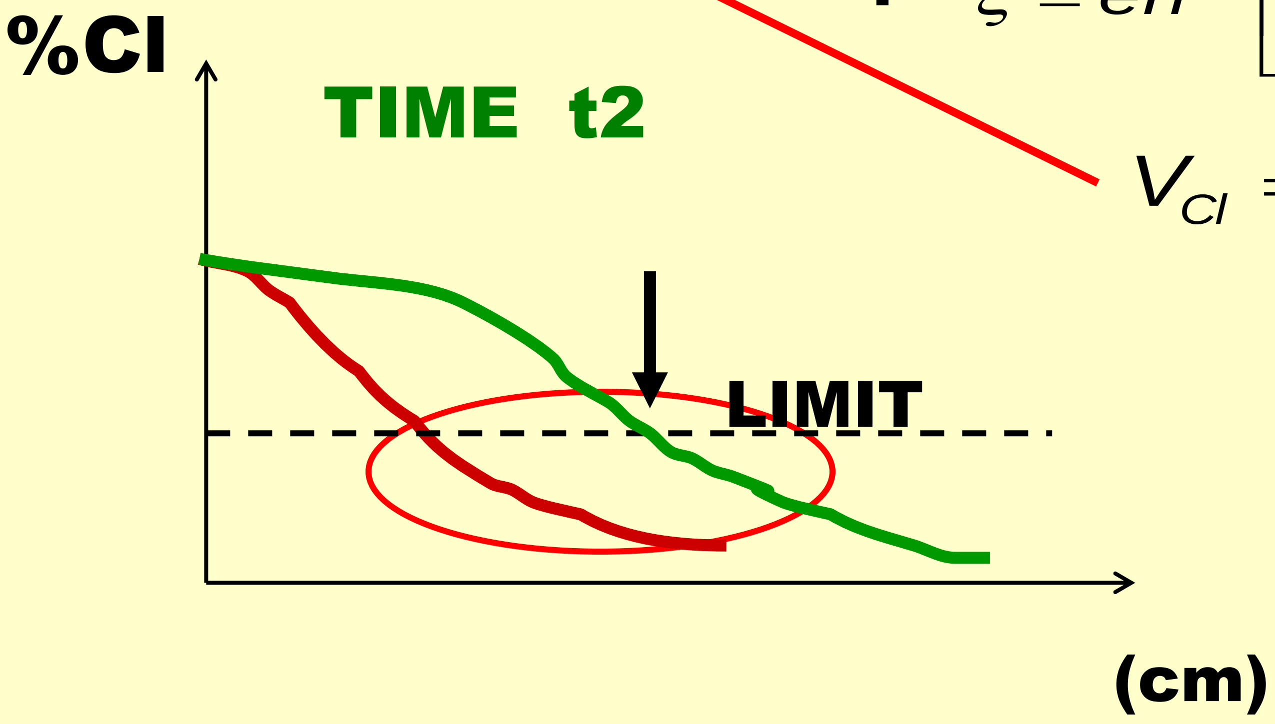
SQUARE ROOT MODEL

$$x = V_{Cl}\sqrt{t}$$

$$\frac{C_X - C_0}{C_S - C_0} = \left(1 - erf\left[\frac{x}{2\sqrt{D_{ns}t}}\right]\right)$$

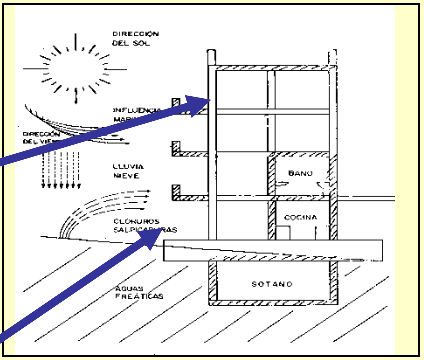
$$\xi = erf^{-1}\left[1 - \frac{C_x C_0}{C_S - C_0}\right]$$

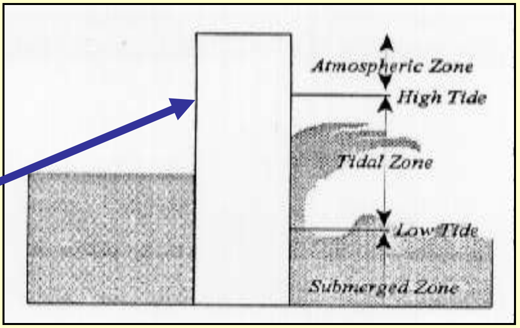
$$V_{Cl} = 2\,\xi\,\sqrt{D_{ns}}$$

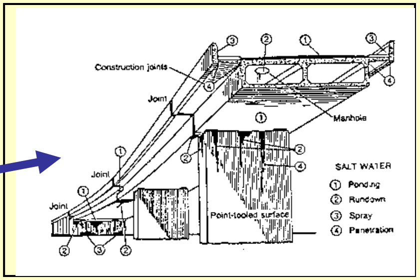


NEED TO MODEL THE ENVIRONMENT
Classification of environmental classes is not enough

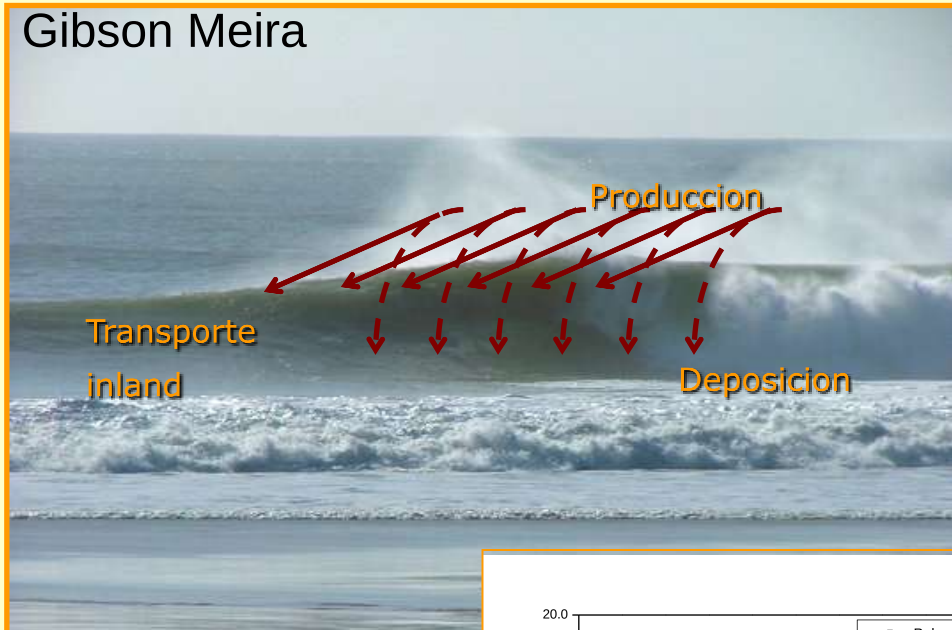
Exposure class	type
dry	•interiors
carbonation	• a low humidity • High humidity • cycles
Marine chlorides	• **Atmospheric** • **Submerged** • **Tidal**
Non marine chlorides	•Deicing salts •Swiming pools

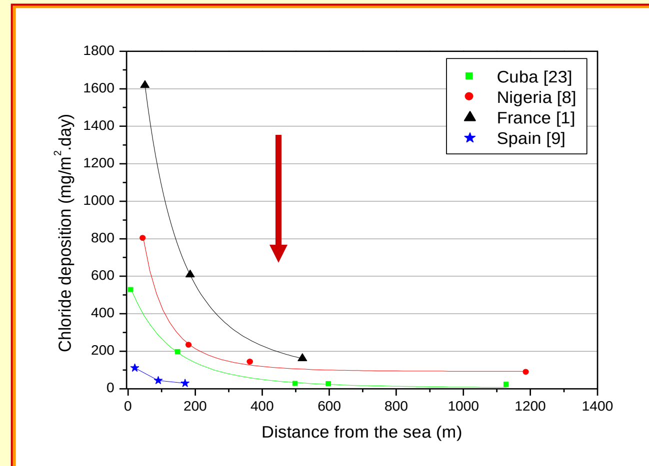


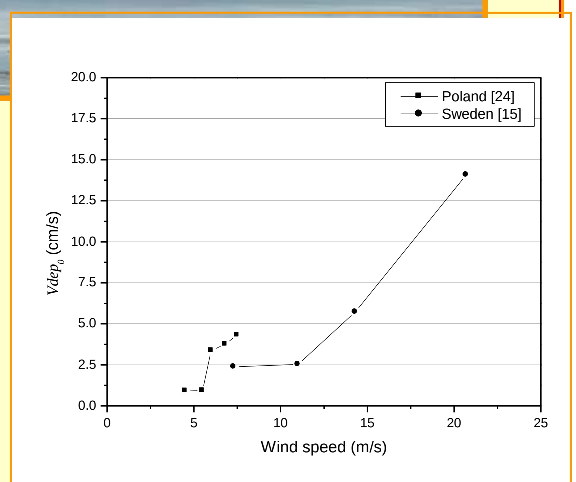


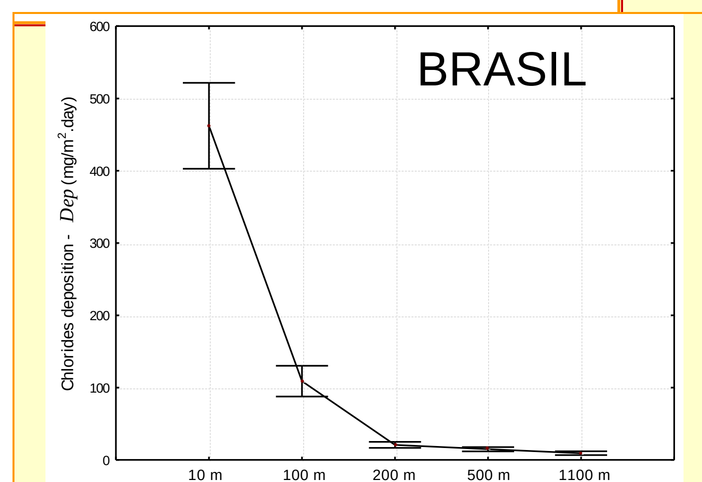


Marine aerosol

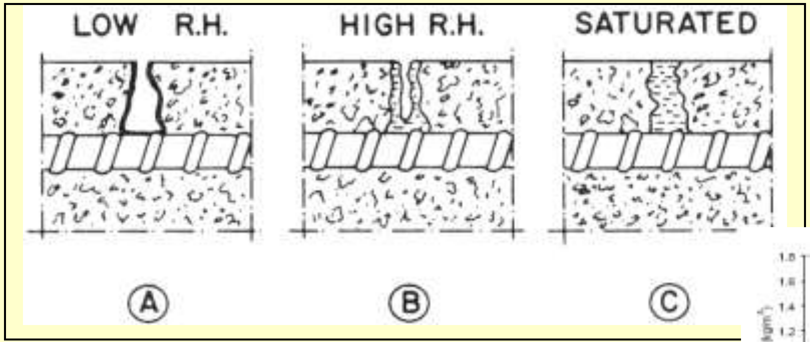


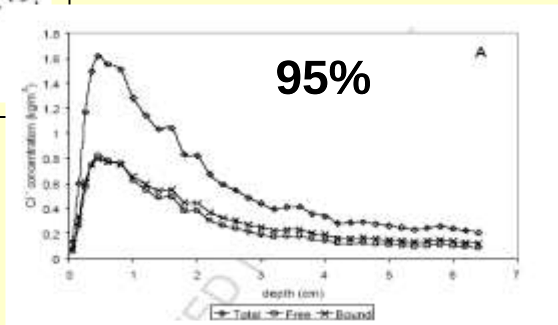


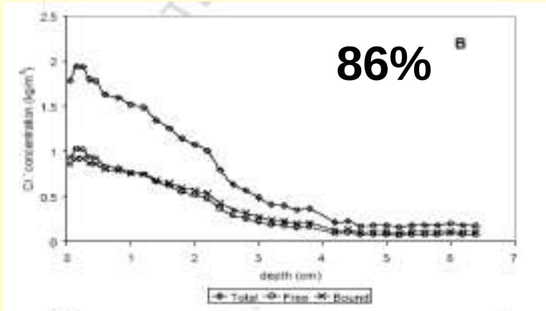


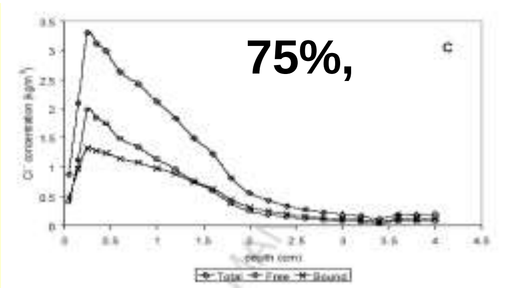


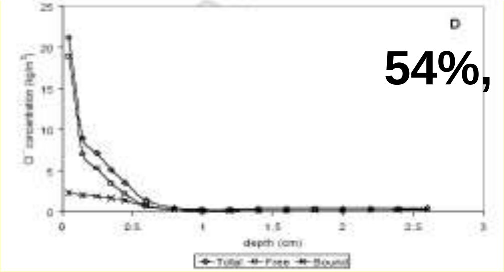
NON SATURATED CONDITIONS
CHLORIDES PROFILES WITH CONSTANT Cs











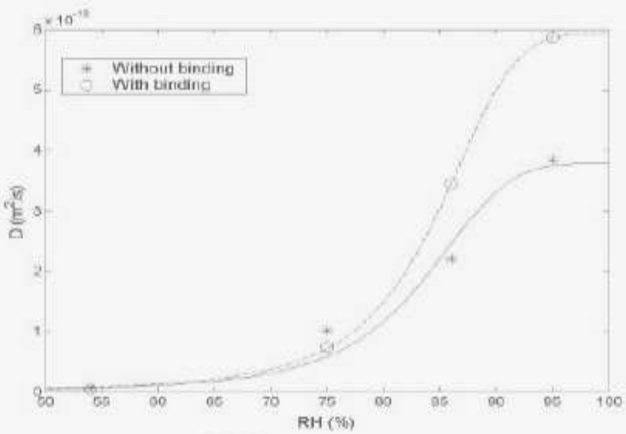
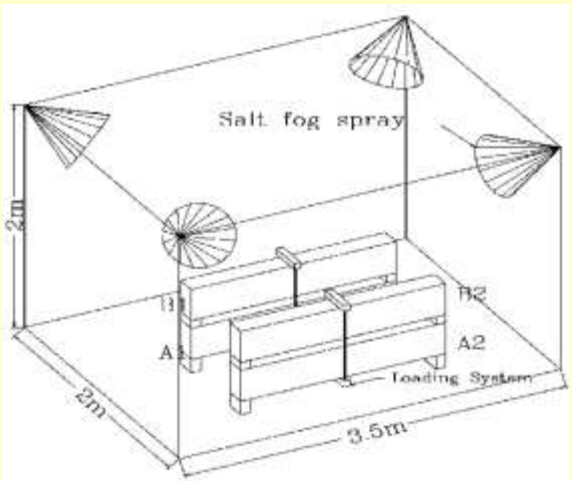


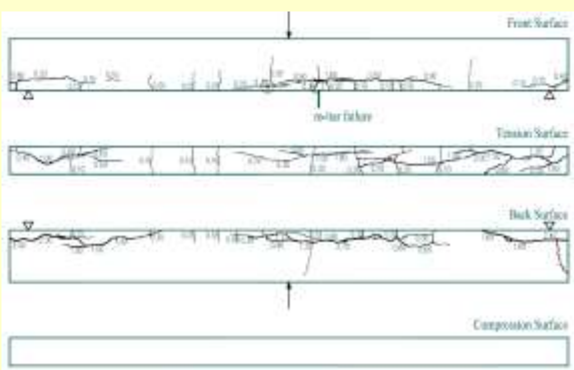
Figure 6. Relationship between the obtained Cl⁻ diffusion coefficients for H-25 concrete with and without binding consideration and the relative humidity of the atmosphere. Lines show non-linear curve fittings to Equation (1).

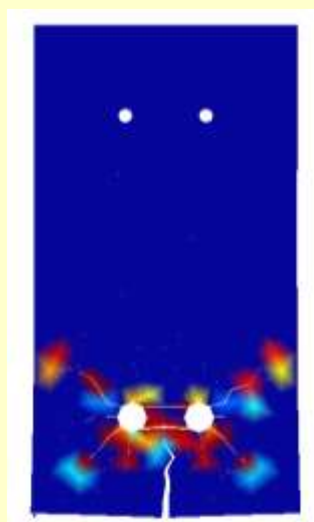
MODELLING DIFFUSION IN CRAKED CONCRETE

Exposed to salt spray

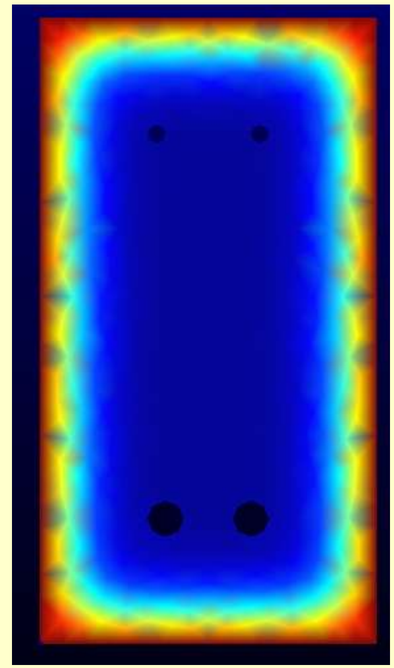


F. Tavares
Results provided by CEA- France

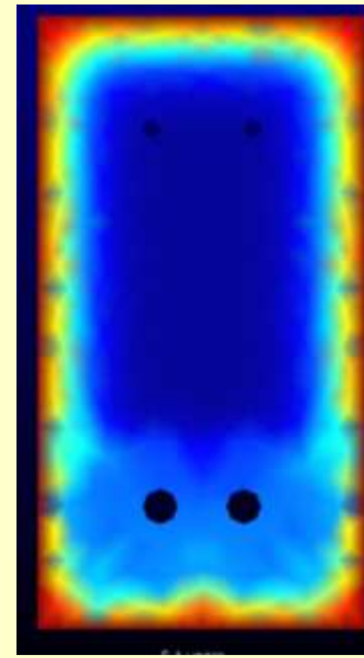




No craked

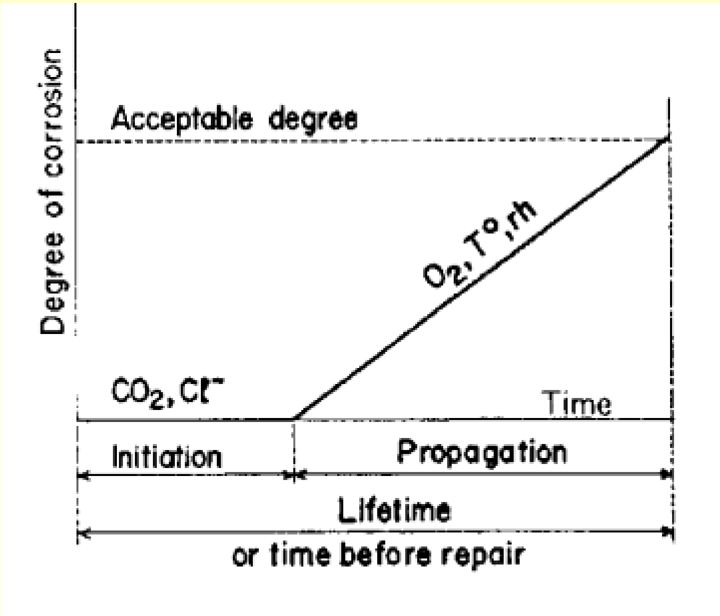


Craked



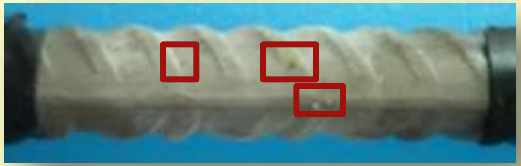
CONTENT

Corrosion onset. Chloride threshold.

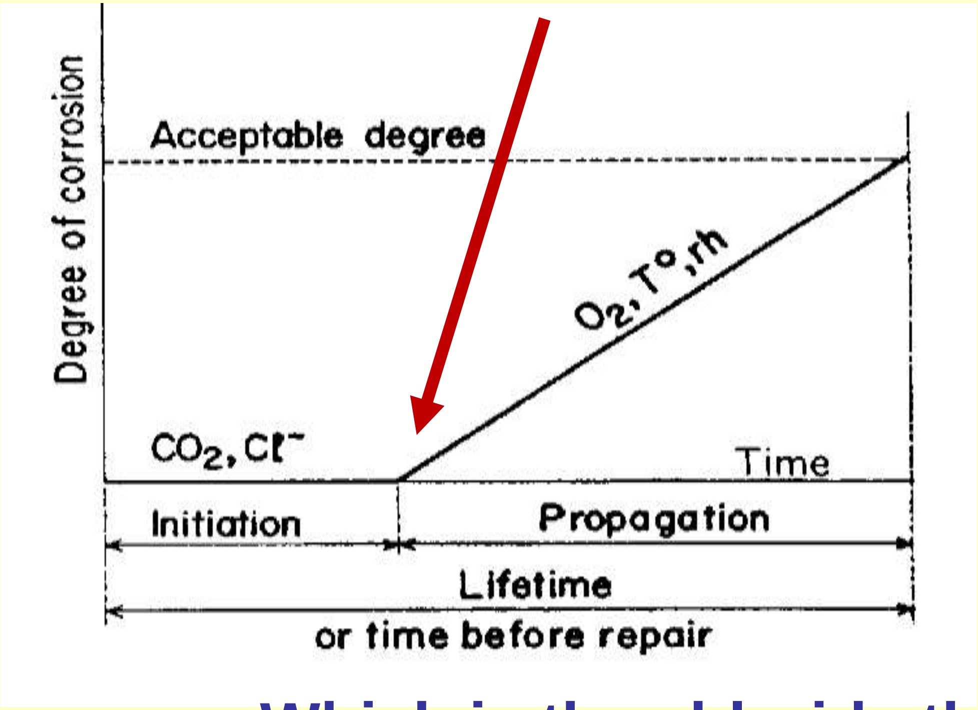


WHICH IS THE ACCEPTABLE LIMIT STATE?

$$t_{life} = t_i + t_p$$



CORROSION THRESHOLD



Which is the chloride threshold ?

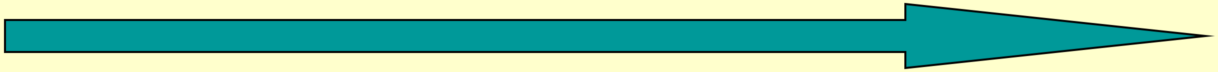
ESTADOS LIMITE

- Definicion de “estados límite" en EN 1992 : **"States beyond which the structure no longer fulfils the relevant design criteria."**

- Tambien:

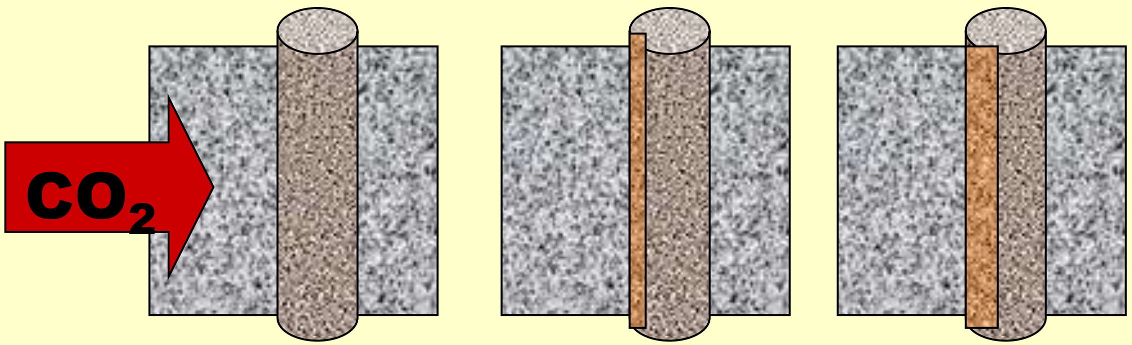
"**State for which a particular requirement regarding structural safety or serviceability is exactly fulfiled."**

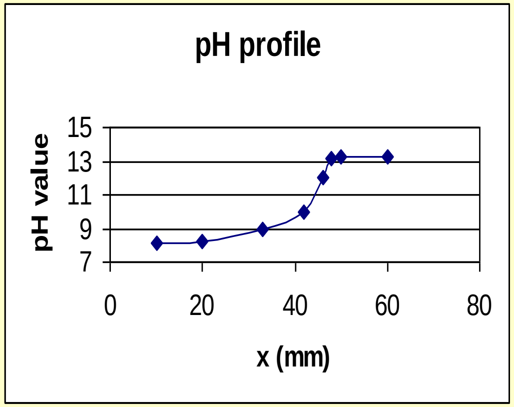
CORROSION ONSET
CARBONATION



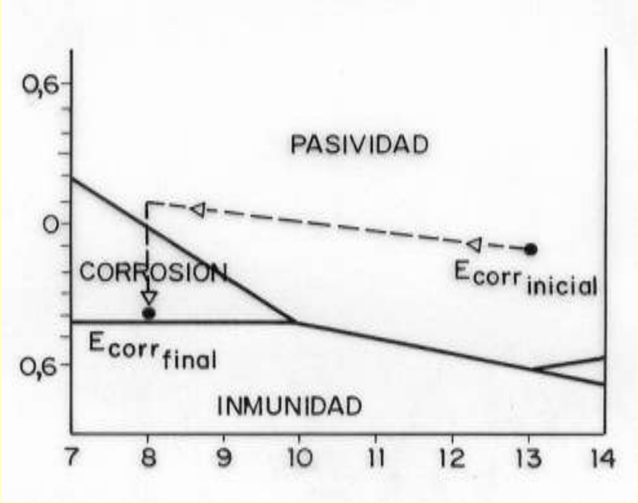
TIME

STEPS DURING DEPASSIVATION





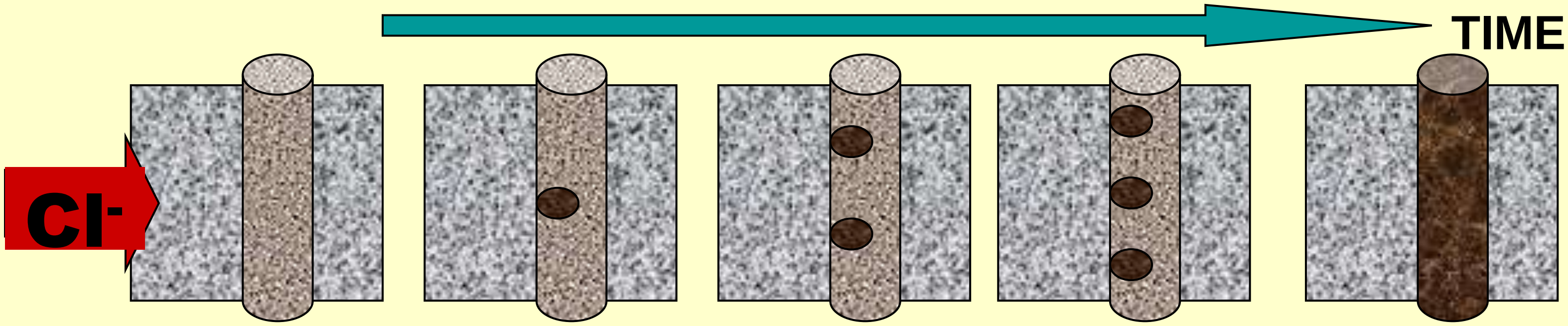
Thiery M., Villain G., Dangla P., Platret G. - -Cement and Concrete Research 37 (2007) 1047–1058.

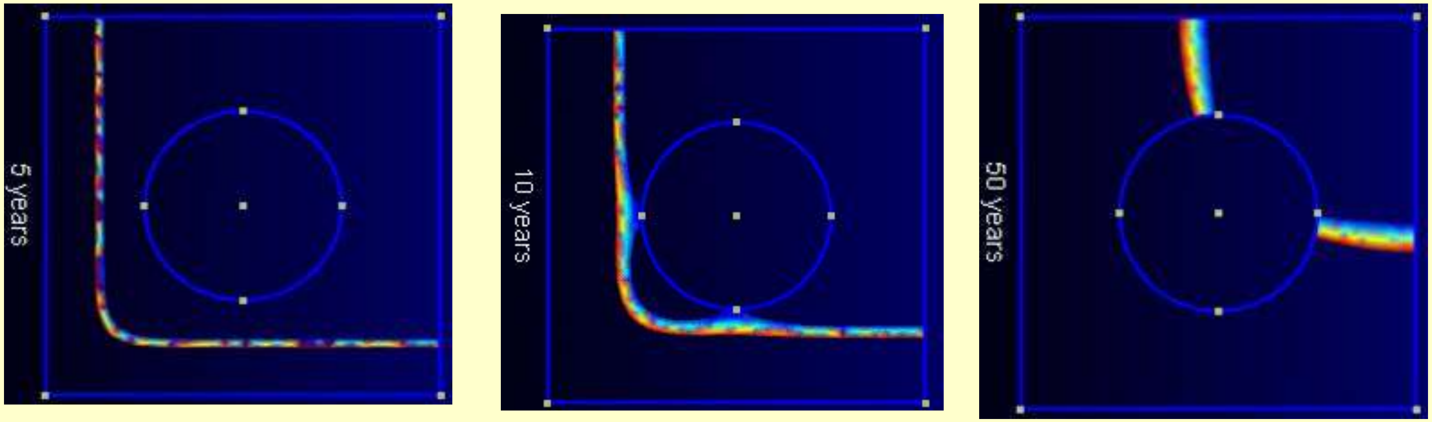


C. Andrade et al. 8th ICCC Brasil 1986

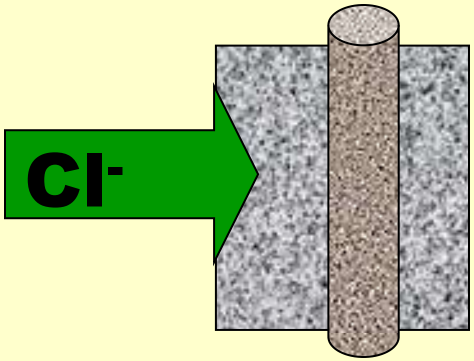
CORROSION ONSET

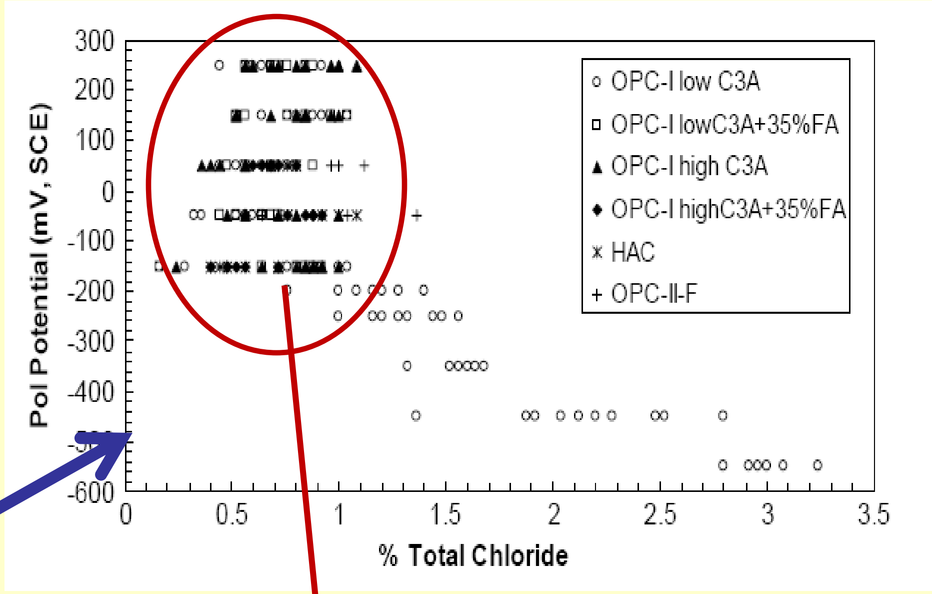
CHLORIDE THRESHOLD



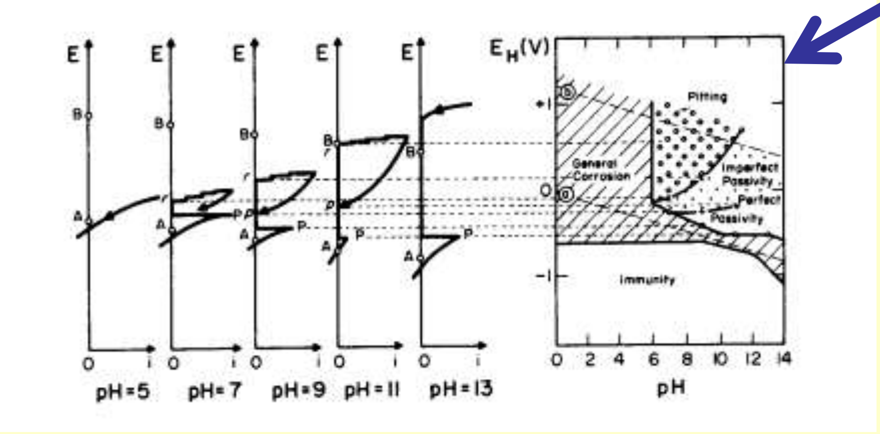


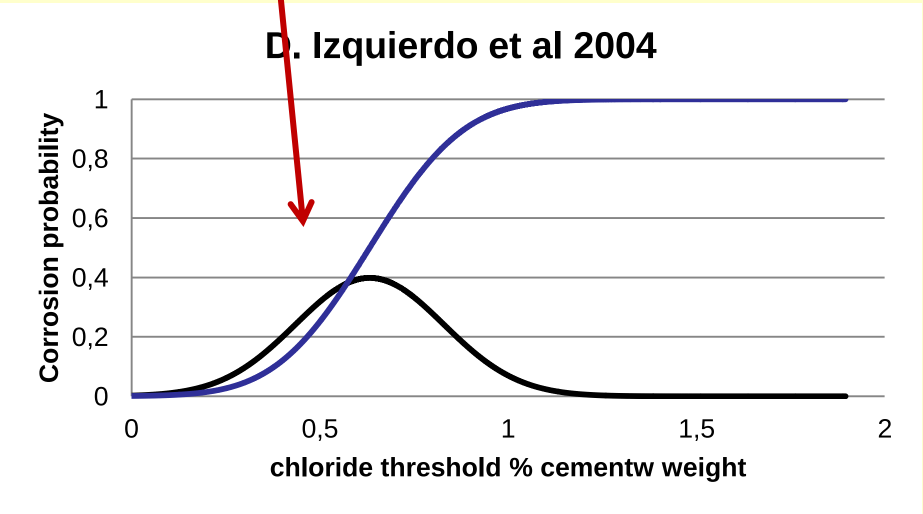
DEPENDENCE OF THE CHLORIDE THRESHOLD FROM THE CORROSION POTENTIAL





POURBAIX DIAGRAM





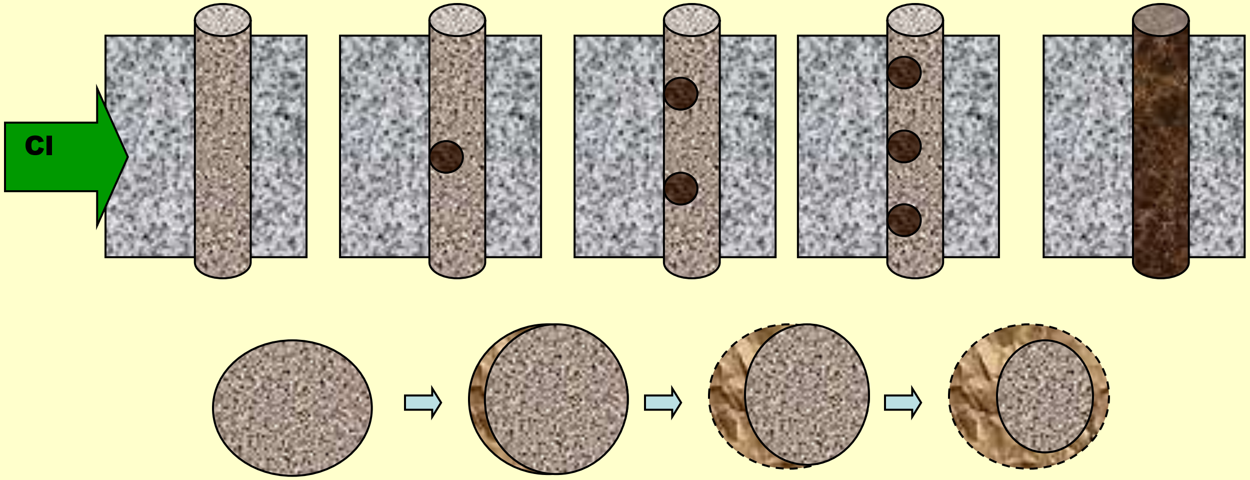
Izquierdo D., et al.-Electrochimica Acta 49 (2004) 2731–2739.

WHICH IS THE ACCEPTABLE DAMAGE LEVEL?

The answer should come from the analysis of the consequences and effects of the corrosion.

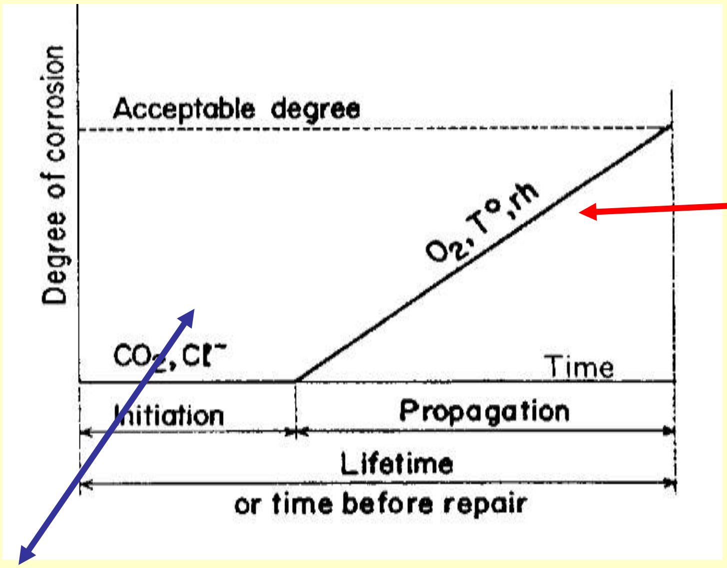
How to calculate it?

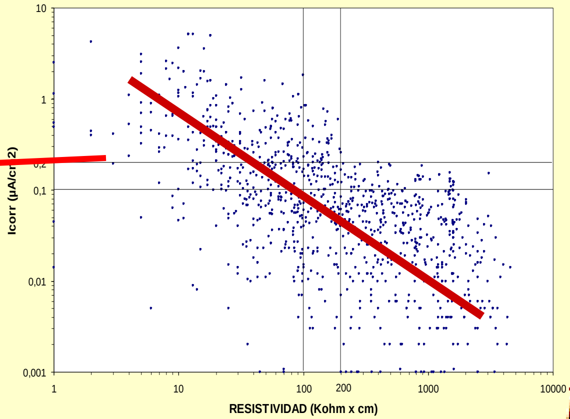
through the loss in cross section from the accumulated corrosion



HOW TO ESTIMATE THE FUTURE CORROSION RATE???

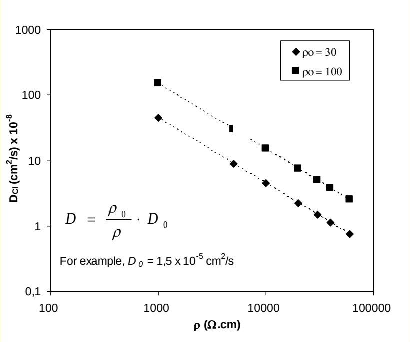
FROM THE CONCRETE RESISTIVITY

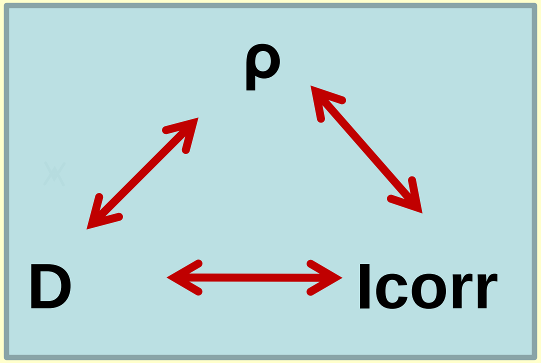




$$I_{corr} = \frac{k_{corr}}{\rho_{ef}}$$

$$D_{app} = \frac{26 \cdot 10^{-5}}{\rho_e \cdot r_b}$$

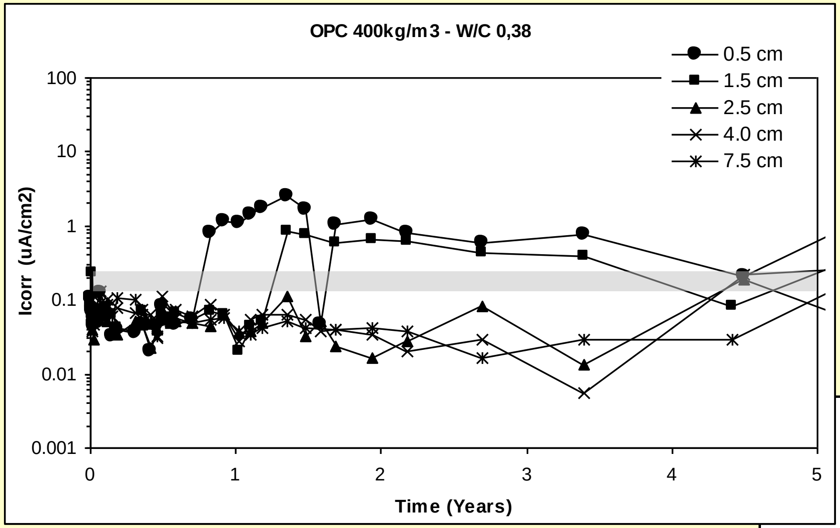


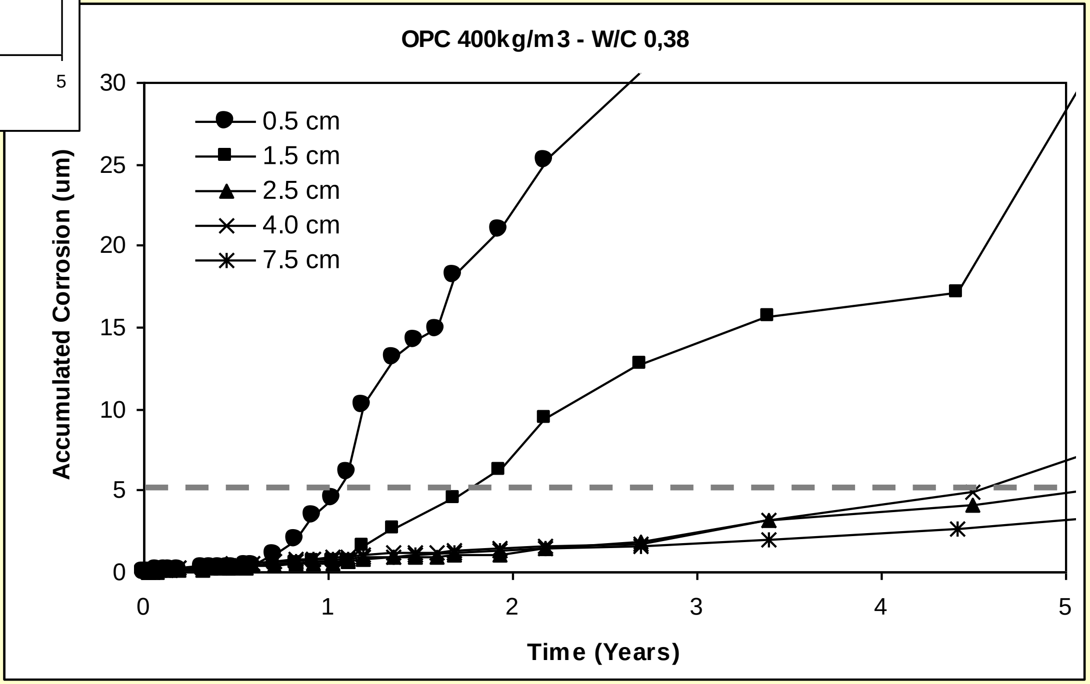


Corrosion rate

BY INTEGRATION

acccumulated corrosion



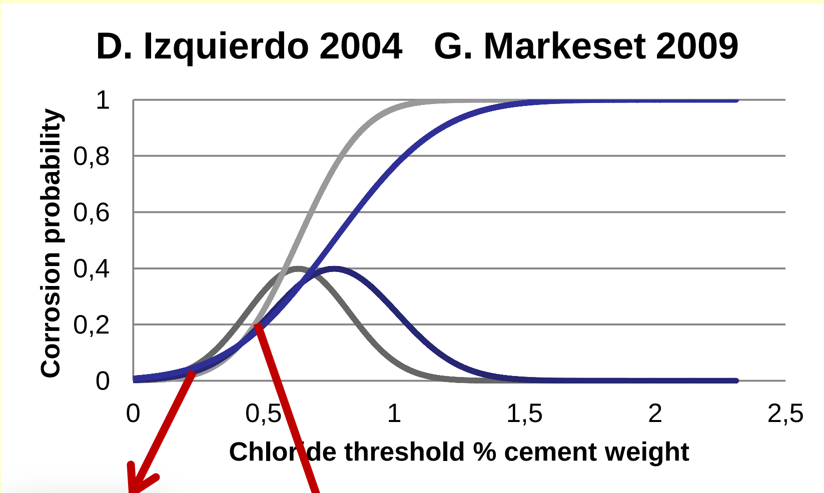


Example of quivalence between diffusivity-corrosion rate through resistivity

$$D_{app} = \frac{26 \cdot 10^{-5}}{\rho_e \cdot r_b} \Longleftrightarrow I_{corr} = \frac{26}{\rho_e}$$

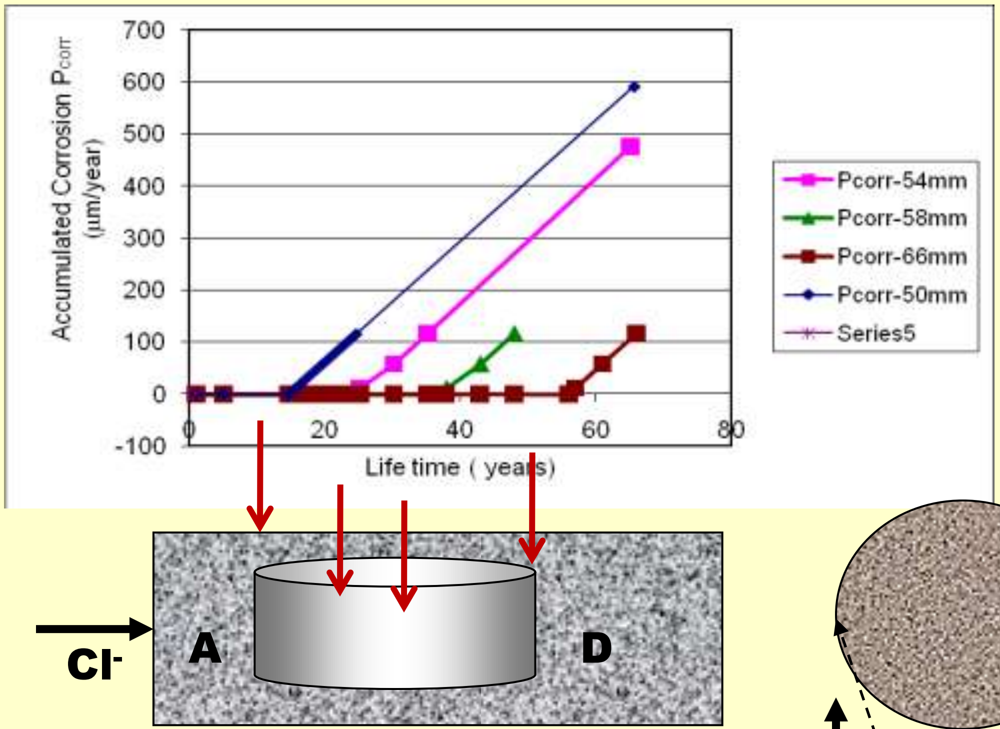
D_{app} (cm^2/s)	0.1E-8	1E-8	10E-8
I_{corr} (μm/year)	1	10	100

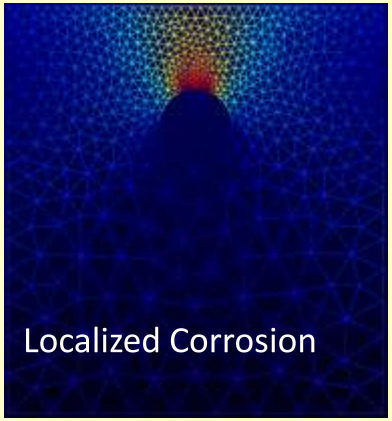
FOR THE PROBABILITY=1
IT IS NECESSARY TO DEFINE THE WHOLE SYSTEM

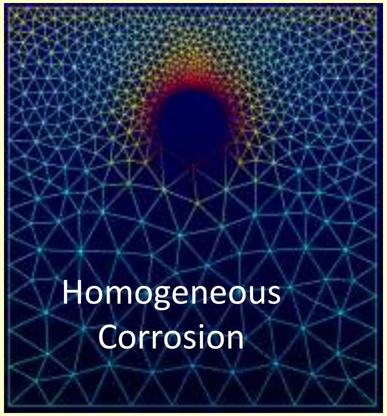


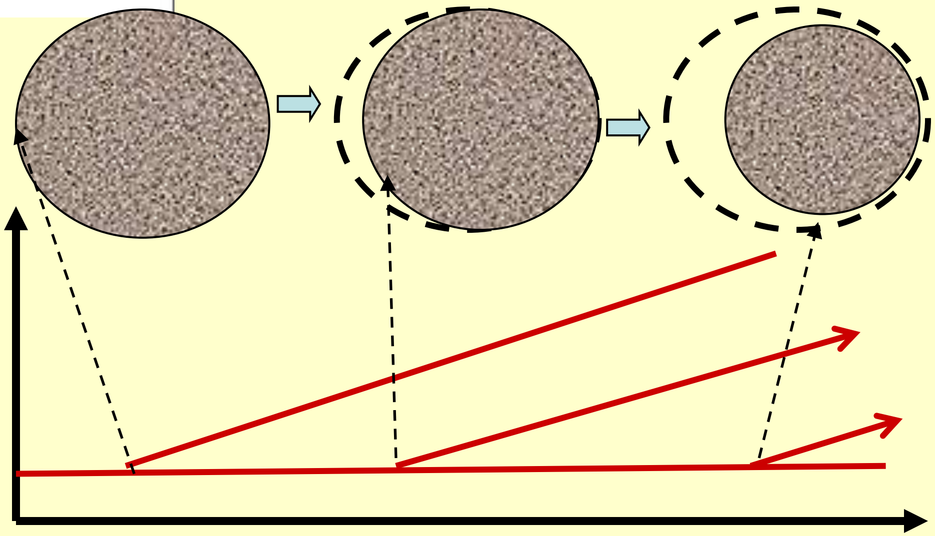
STRUCTURAL ELEMENT
To consider the most solicited section

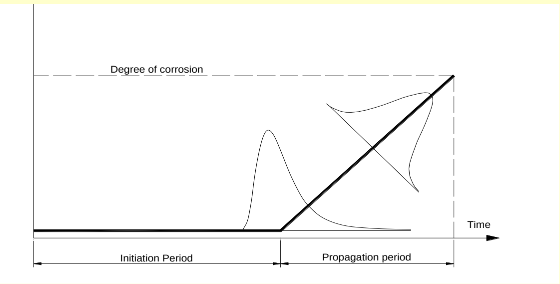
Calculation of the accumulated corrosion in each time



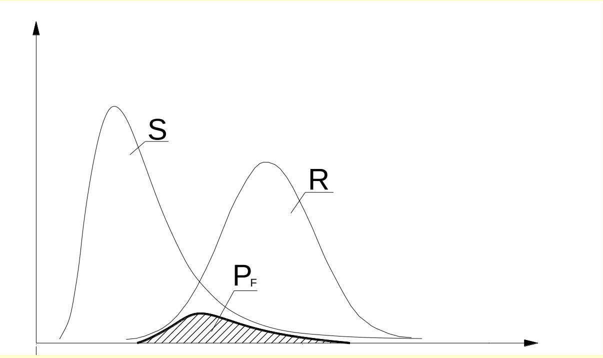


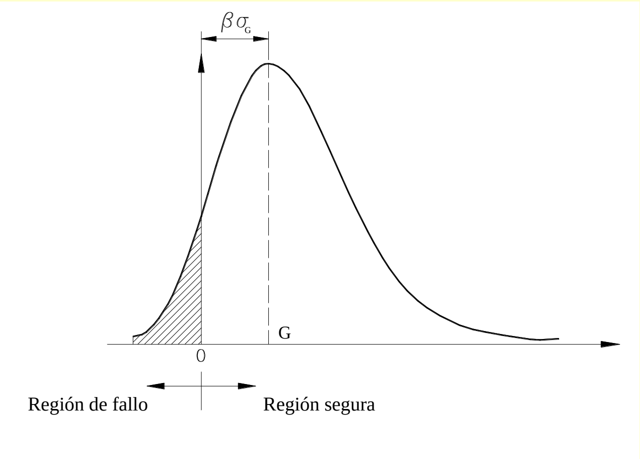






FAILURE PROBABILITY
SAFETY FACTORS





$$Z = R - S$$

$$\mu_Z = \mu_R - \mu_S$$

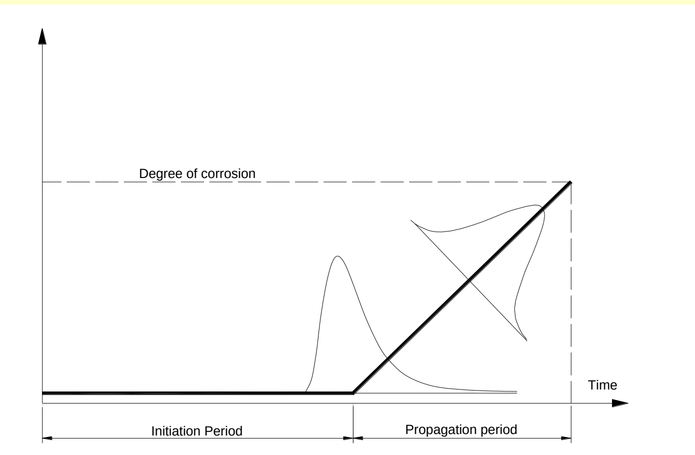
$$\sigma_Z^2 = \sigma_R^2 + \sigma_S^2$$

$$P_F = P(R - S \leq 0) = P(Z \leq 0) =$$

$$\Phi\left(\frac{0 - \mu_Z}{\sigma^2}\right) = \Phi(-\beta)$$

β	**1,5**	**2,3**	**3,8**	**4,26**	**4,8**
P_F	0,067	10^{-2}	$7\ 10^{-5}$	10^{-5}	10^{-6}

To register variation of different durability parameters for future probabilistic treatements

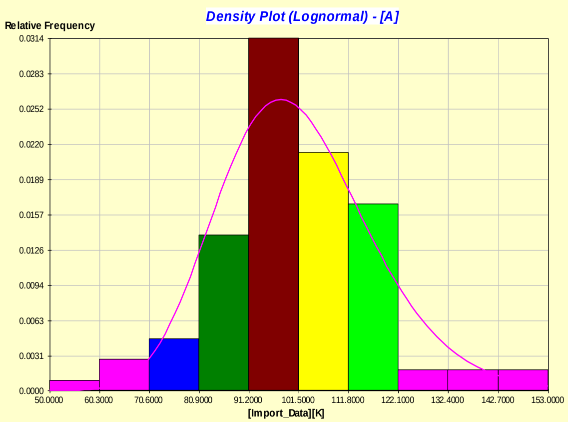


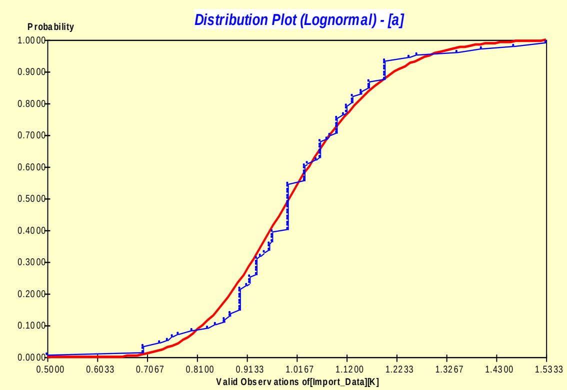
$$R_d \geq S_d \quad \Rightarrow$$

$$R_d - S_d \geq 0 \quad \Rightarrow \quad G(R,S) \geq 0$$

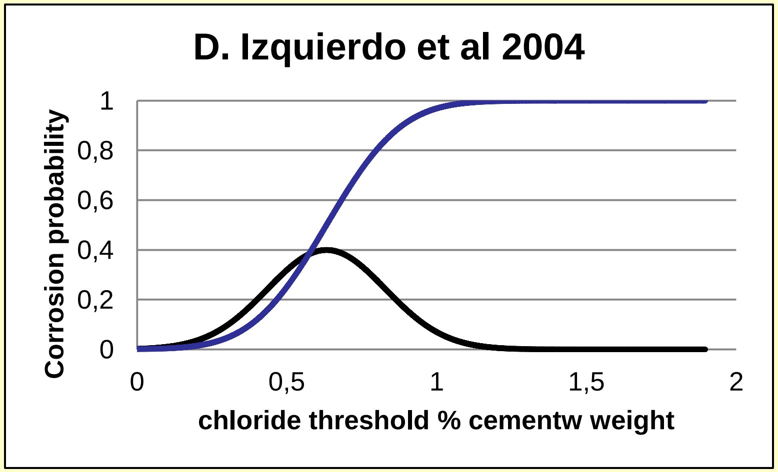
Limit state function **G (R,S):**

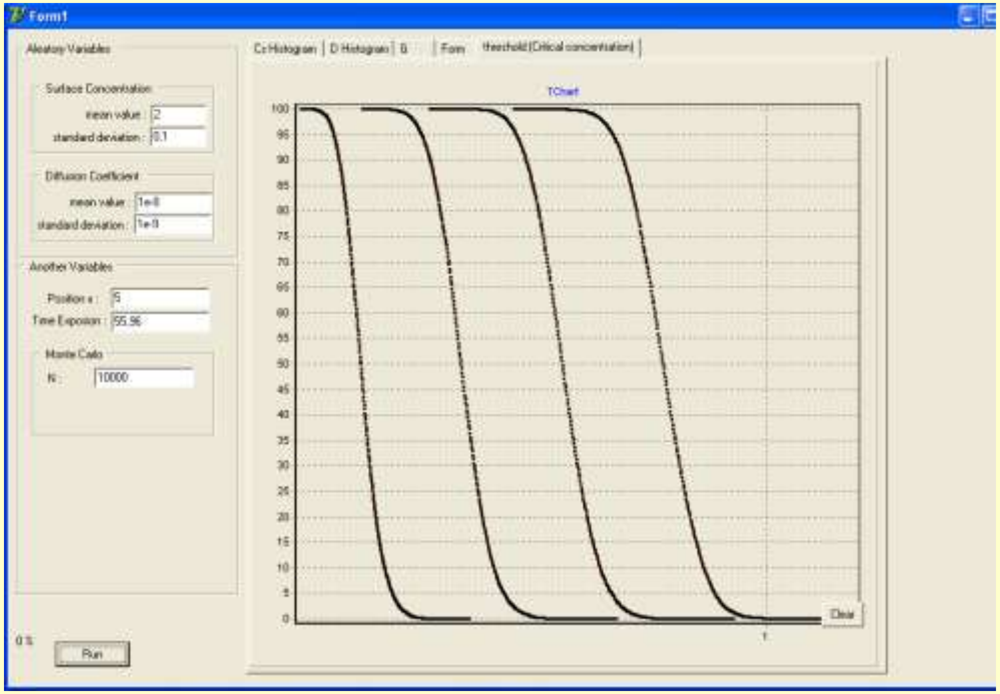
$$\text{C-V}_{\text{Cl}}\ \ t^n > 0$$

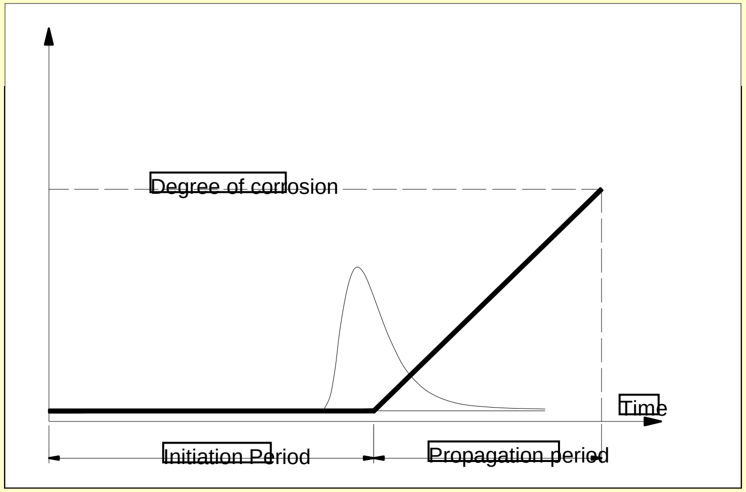




Calculation of probabilities of depassivation

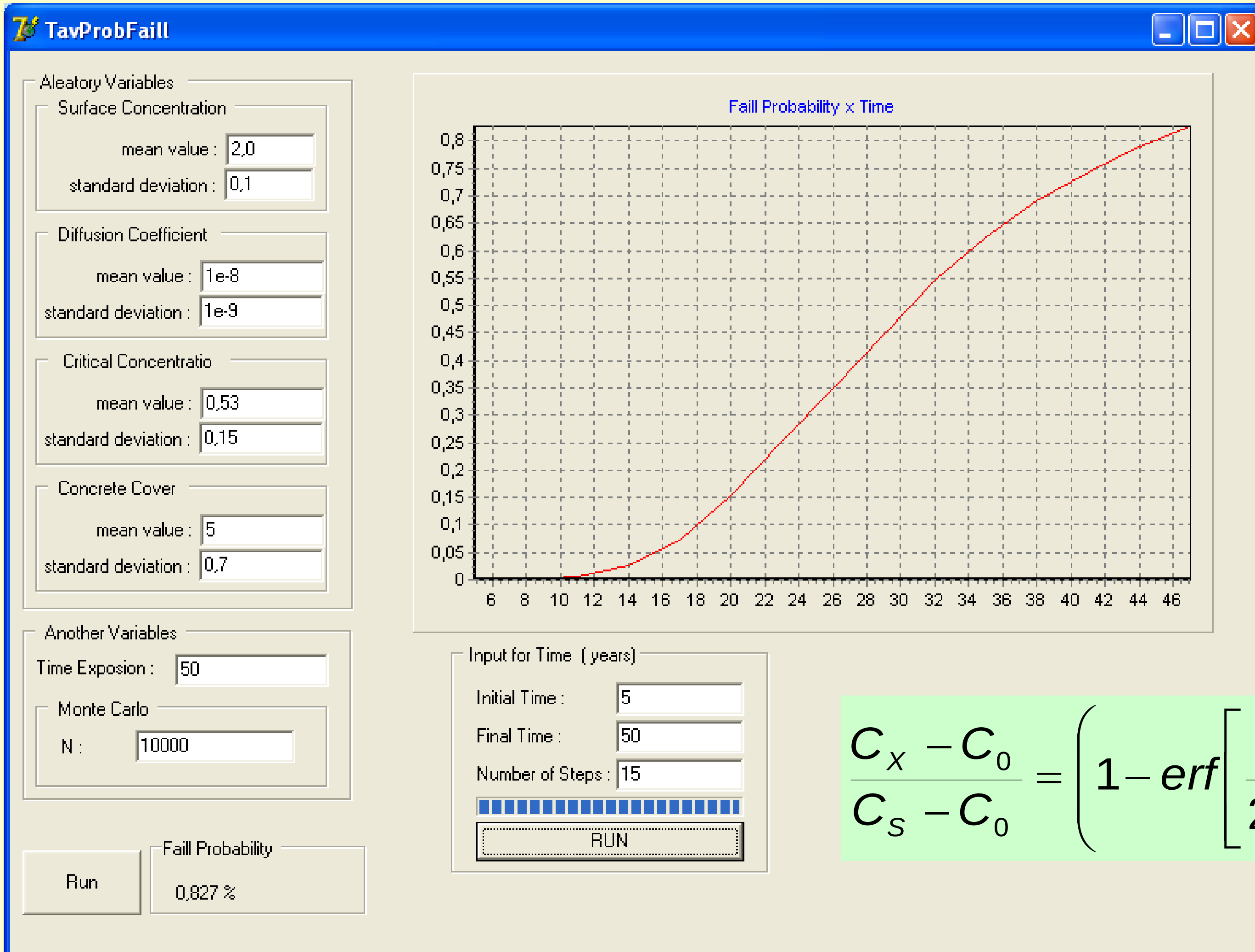






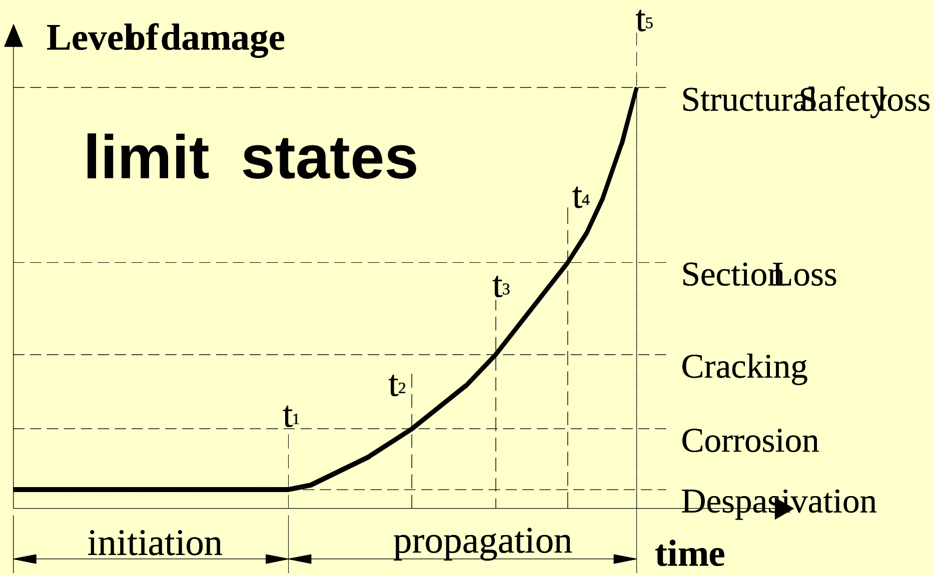
PROBABILITY CALCULATION

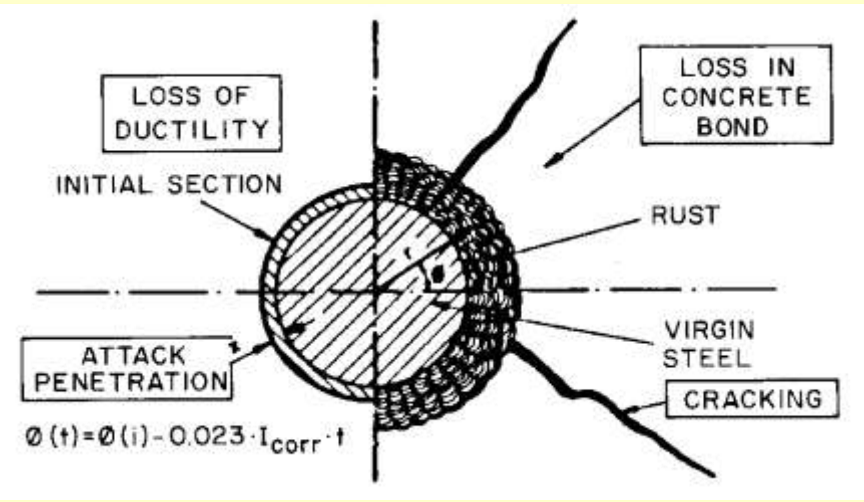
for a chloride concentration to reach a cover depth in a certain time

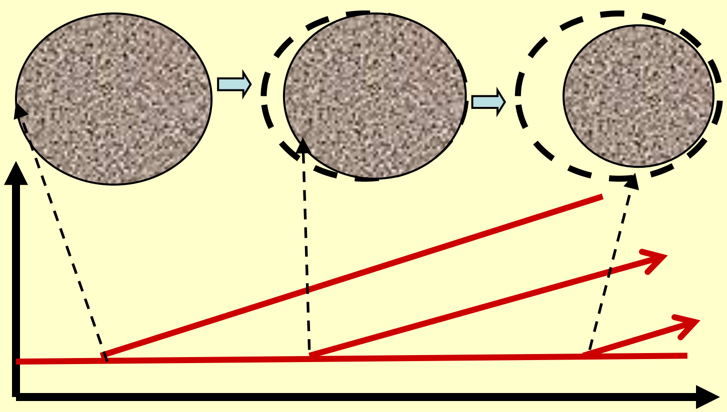


$$\frac{C_x - C_0}{C_s - C_0} = \left(1 - erf\left[\frac{x}{2\sqrt{D_{ns} t}}\right]\right)$$

VERIFICATION OF SLS AND ULS FROM THE LOSS IN CROSS SECTION







PROPOSAL (D. Izquierdo) OF RELIABILITY INDEXES FOR *CORROSION INITIATION LS*

$$\left(\frac{C}{V_{CO_2}}\right)\frac{1}{1.30}+\left(\frac{P\lim}{V_{Corr}}\right)\frac{1}{1.50}\geq t_L$$

CARBONATION

CHLORIDES

$$\left(\frac{C}{V_{Cl}}\right)\frac{1}{1.70}\geq t_L$$

t_L=50 years

$$\left(\frac{C}{V_{Cl}}\right)\frac{1}{1.50}\geq t_L$$

t_L=100 years

β	**1,5**	**2,3**	**3,8**	**4,26**	**4,8**
P_F	0,067	10^{-2}	$7\ 10^{-5}$	10^{-5}	10^{-6}

END