fib Symposium2025

Antibes - France

Concrete Structures : extend lifespan, limit impacts

16-18 June, 2025

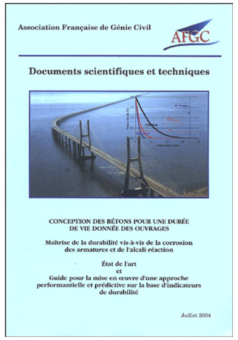
Performance-based approach, durability of low carbon concrete and corrosion: contributions of the French National project PerfDuB and the DECADES and DECISION scientific groups

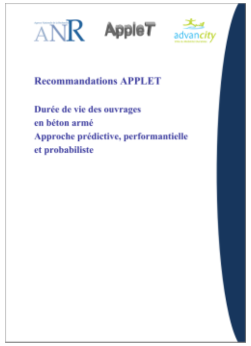
Véronique Bouteiller (Université Gustave Eiffel, France)

and

Patrick Rougeau (CERIB, France)

Background





- **National work on durability performance tests**
  - AFPC / AFREM (publication in 1997)
  - GRANDUBÉ (publication in 2007)
  - APPLET (2007-2010)

- **National project on the durability assessment of different grades of concrete**
  - BHP 2000 (lab test, natural weathering on exposure sites)

- **First Performance Based Approaches**
  - AFGC Guide: introduction of durability index, modeling (2004)
  - FNTP/FFB/CERIB/FiB: provisional recommendations on the concept of equivalent concrete performance by comparison with reference concrete (2009)
  - LCPC provisional guide (2010): contractual part.

- **Application for the construction of major engineering structures with a service life design > 100 years**
  - Rion-Antirion Bridge in Greece,
  - New road of Littoral in La Reunion Island, France

French National Projet PerfDuB (2015-2022)

IREX
Institut pour la recherche appliquée et l'expérimentation en génie civil

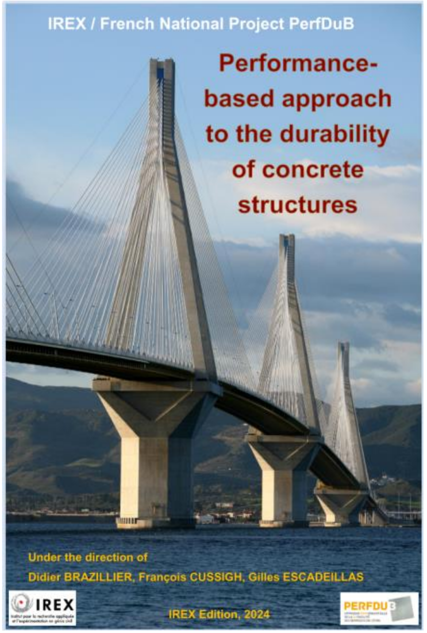
PERFDUB
APPROCHE PERFORMANTIELLE DE LA DURABILITÉ DES OUVRAGES EN BÉTON

- **Around 50 partners: project owners, designers, contractors, cementitious materials manufacturers, concrete producers, precasters, professional associations, universities, laboratories, etc.**
- **Funding: 3,5 M€**

French National Projet PerfDuB (2015-2022)

PERFDUB
APPROCHE PERFORMANTIELLE
DE LA DURABILITÉ
DES OUVRAGES EN BÉTON

- **Theme 1: Test methods**
  - Assessment and development of suitable and practical test methods to measure durability properties
- **Theme 2: Determination of performance threshold values for the PBA**
  - Laboratory measurements with reference concrete complying to EN 206
  - Performance measured on site / drilled samples from existing structures
  - Durability modeling (for carbonation and chloride ingress)
- **Theme 3: Concrete mixes evaluation**
  - Test of 42 concretes (complying or not with EN 206) with methods of Theme 1
- **Theme 4: Recommendations for the contractual application**
  - Set up responsibilities of each concerned parties,
  - Propose appropriate contractual framework(s) and
  - Define terms and conditions for both routine control and non-conformities with trials associated tolerances ➔ FD P 18 480
- **Theme 5: Dissemination**
  - Publications → Collective book https://perfdub.fr/wp-content/uploads/2024/07/PERFDUB_ouvrage-scientifique_english-version.pdf
  - Discussions with international experts during the project (scientific council)



Theme 2: Determination of performance threshold values for the PBA (XS and XD)

On the basis of:
- Lab. measurements with reference concrete complying to EN 206
- Performance measured on site / drilled samples from existing structures
- Modelling (for carbonation and chloride ingress)

The 90d-threshold values for acceptance depends on the **ageing factor**, function of binder concrete composition:

Ageing factor = 0,3 + min (0,2 S ; 0,15) + min (1,1 V ; 0,30) + min (1,1 D ; 0,10) + min (1,1 MK ; 0,10)

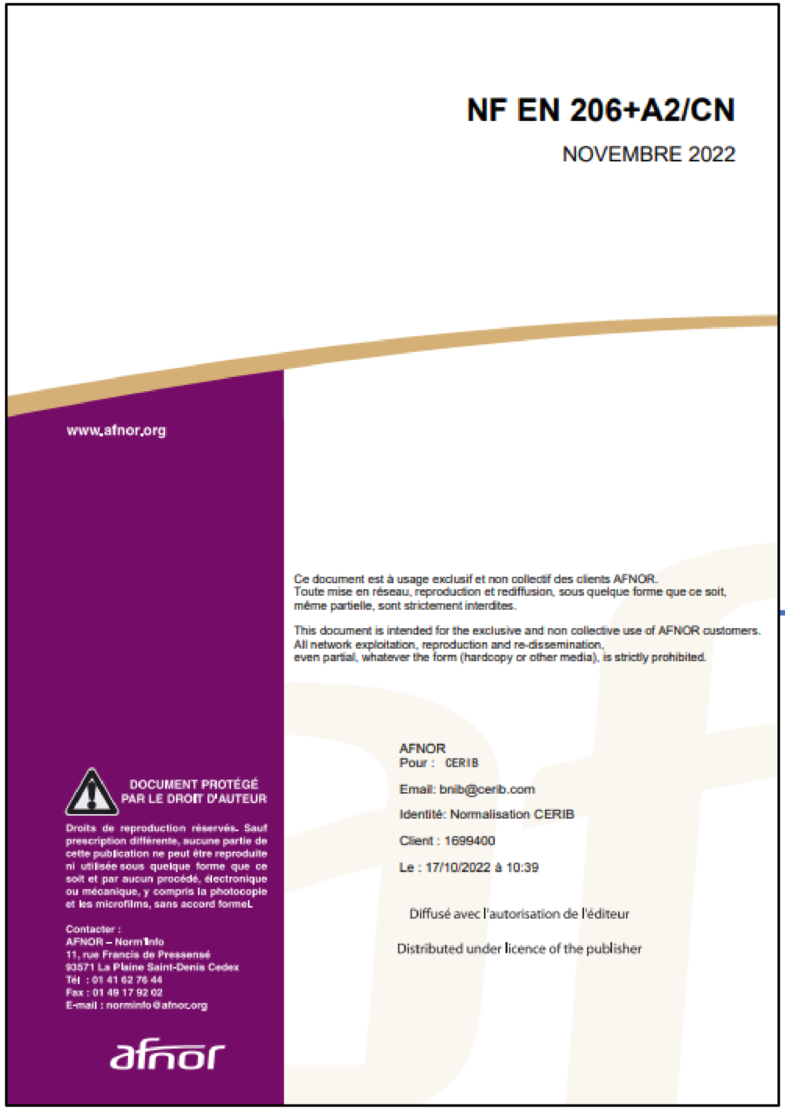
with: S, the mass fraction of GGBS of the total binder;
V, the mass fraction of the Fly Ash of the total binder;
D, the mass fraction of the Silica Fume of the total binder;
Mk, the mass fraction of the metakaolin of the total binder.

Similar approach with XD exposure classes.

Exposure class	**Characteristic value (90% fractile) for 90d-chloride migration coefficient (m^2/s)** *Testing method: XP P 18-462: 2022*		
	Ageing factor class	**Service life design**	
		50 years	**100 years**
XS1	0,30 - 0,39	16 (28*)	9 (16)
	0,40 - 0,49	28	22
	0,50 - 0,59		
	≥ 0,60		
XS2	0,30 - 0,39	5 (9*)	3 (5*)
	0,40 - 0,49	9	5
	0,50 - 0,59	16	9
	≥ 0,60		
XS3e (spray conditions)	0,30 - 0,39	5	5
	0,40 - 0,49	9	9
	0,50 - 0,59	16	16
	≥ 0,60	22	22
XS3m (wet/dry conditions)	0,30 - 0,39	2	2
	0,40 - 0,49	3	3
	0,50 - 0,59	5	5
	≥ 0,60	9	9

*: applicable for concretes whose water porosity measured at 90 days is less than or equal to 13.5%.

Since Nov. 2022



NF EN 206+A2/CN

NOVEMBRE 2022

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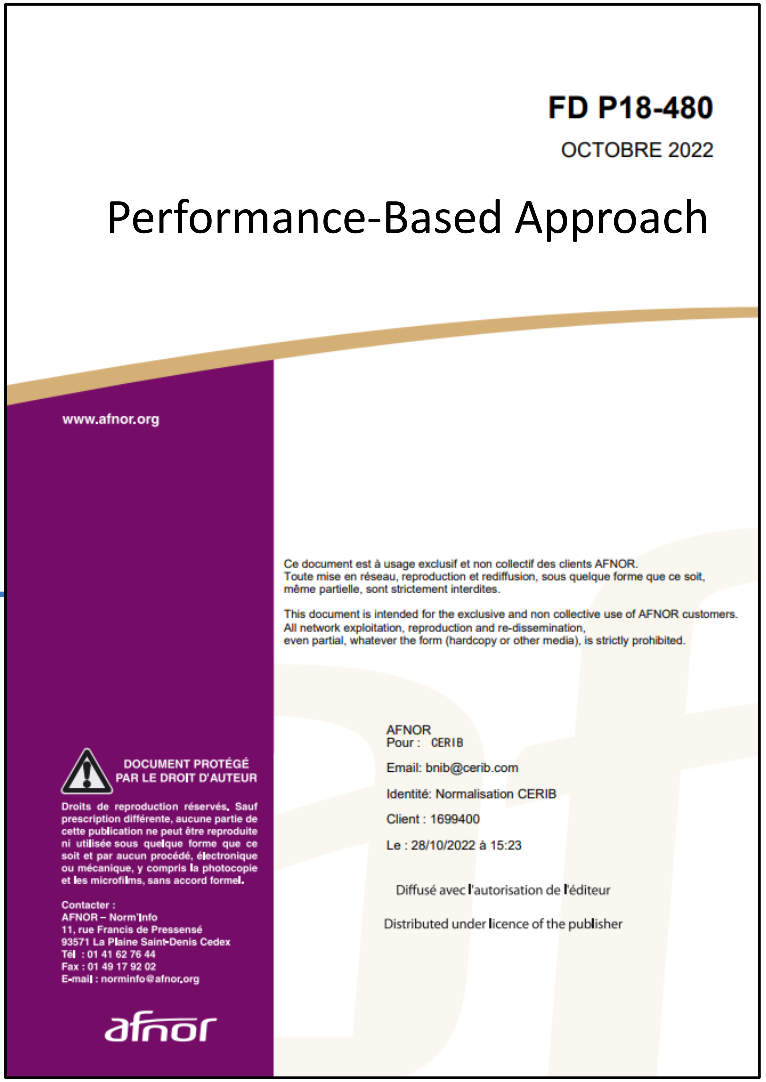

FD P18-480

OCTOBRE 2022

Performance-Based Approach

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Prescriptive vs performance-based approach in the EN 206 French annex

Since Nov. 2022

Prescriptive-Based Approach

or

Performance-Based Approach

Compliance with <u>prescriptive specifications</u> for the assigned exposure class(es):

- Limit values
  - minimum content of equivalent binder,
  - maximum water to eq. binder ratio,
  - maximum addition rate,
  - …
- Aggregate quality requirements
- Minimum concrete cover
- Minimum strength class

Compliance with <u>performance specifications</u> for the assigned exposure class(es):

- Threshold values for durability testing
  - Maximum carbonation rate for XC exposure class
  - Maximum chloride migration coefficient for XS and XD exposure class
  - Maximum expansion value or degradation rate for XA exposure class
- Reduced cover if higher durability
- Minimum strength class *(unchanged)*

2021 - Concrete Standardization Commission (P18B)

- ❑ **Have we really done our best to decarbonize concrete infrastructures?**
- ❑ **What could be the other areas for progress?**
- ❑ **What can be our road-map for the early future?**

Main deliverables from the "Low Carbon Solutions" Expert Group – Concrete Standardization Commission (P18B)

- New — **FD P 18-483-2 (2025)** « Ecodesign of concrete structures – Part 2: Specification of concrete for structures with reduced carbon impact » — Published – March 2025
- New — **FD P 18-483-1** « Ecodesign of concrete structures – Part 1 : Optimization of concrete structures for designs with reduced carbon impact » — In progress
- Reviewed — **Norme NF EN 206/CN + A2** « Concrete - Specification, performance, production and conformity » — In progress
- Reviewed — **FD P 18-480 (2025)** « Performance-based approach for justifying the durability of concrete structures» — Published – June 2025
- New — **FD P 18-484 (2025)** « Methodology for qualifying new binders and new additions » — In progress

FD P 18-483-2 (2025) « Ecodesign of concrete structures – Part 2: Specification of concrete for structures with reduced carbon impact »

- GWR (Global Warming potential Reduction) classes

$$\text{« GWR »} = 100 \times \left(1 - \frac{\text{Global Warming Potential of the concrete}}{\text{Global Warming Potential of Reference concrete}}\right)$$

The total GWP value of 1 m3 of concrete takes into account:
- the components (excluding reinforcement/reinforcement)
- the transportation of the components to the production site the concrete production up to the mixer outlet

The total GWP value must be derived from either:
- a verified FDES configurator (see INIES program)
- a verified FDES (see INIES program)
- a calculation tool compliant with NF EN 15804+A2/CN with periodic critical review by an independent third party

Value sof Global Warming potential of Reference concrete (in kgCO_2/m^3) depending to the exposure classes, compressive strength classes and design service life

R_c	DUP	XC1	XC2	XC3	XC4	XS1	XS2	XS3	XD1	XD2	XD3	XF1	XF2	XF3	XF4	XA1	XA2	XA3
C20/25	50	219	219															
C25/30	50	219	219	235	235				235			235	252					
	100	235	235															
C30/37	50	235	235	235 a)	235 a)	276	276		235 a)	276		235 a)	274	274	285	276		
	100	235	235	252	276	276	276		276	276		276	292	318	318	276		
C35/45	50	276	276	276	276	276	276	292	276	276	292	276	300	301	301	276	292	
	100	276	276	276	276	276	276	292	276	276	292	276	300	323	323	276	292	
C40/50	50 et 100	318	318	318	318	318	318	318	318	318	318	318	330	330	330	318	318	318
C45/55	50 et 100	336	336	336	336	336	336	336	336	336	336	336	346	346	346	336	336	336
C50/60	50 et 100	354	354	354	354	354	354	354	354	354	354	354	366	366	366	354	354	354
C55/67	50 et 100	356	356	356	356	356	356	356	356	356	356	356	367	367	367	356	356	356
C60/75	50 et 100	357	357	357	357	357	357	357	357	357	357	357	368	368	368	357	357	357

a) Valeur portée à 252 pour les bétons précontraints

GWP value modulations:

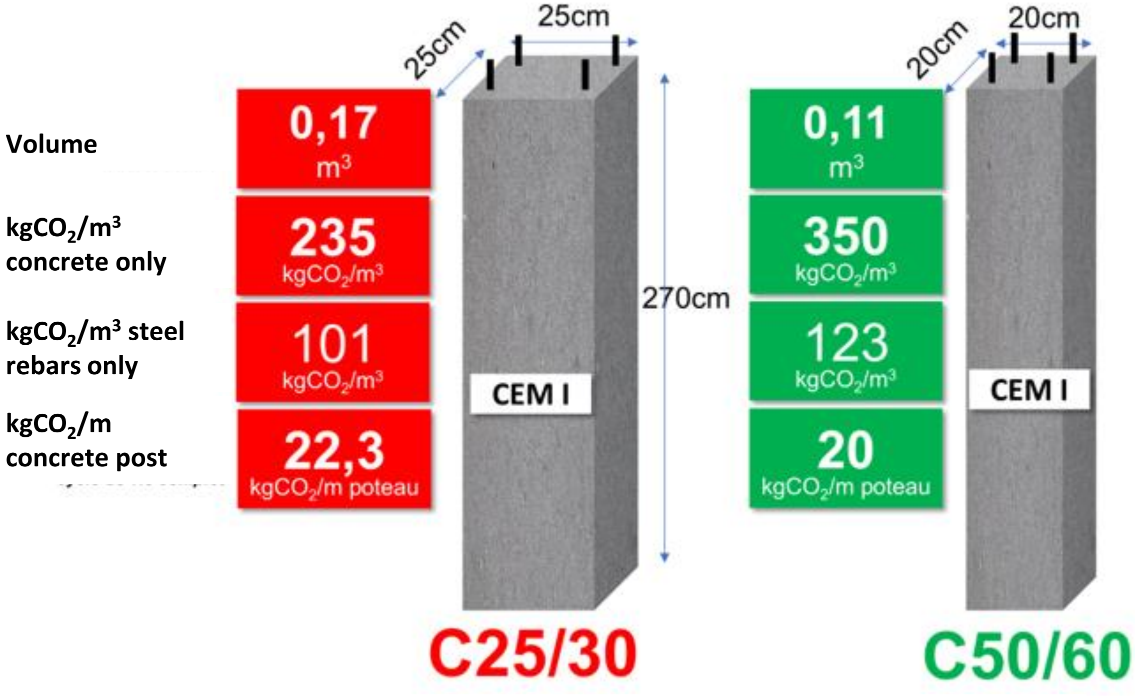
- D_{max} = 16 mm : + 4,5 %
- D_{max} = 14 mm : + 7 %
- D_{max} = 12,5 mm : + 9 %

- + 30 kgCO_2eq/m^3 for SCC

- + 10 kgCO_2eq/m^3 for recycled aggregate (≥ R1)

FD P 18-483-2 (2025) « Ecodesign of concrete structures – Part 2: Specification of concrete for structures with reduced carbon impact »

GWR Classes (Design service life 50 years)	Reduction (%)
GWR0	≤ 9
GWR1	10-19
GWR2	20-29
GWR3	30-39
GWR4	40-49
GWR5	50-59
GWR6	60-69
GWR7	≥ 70



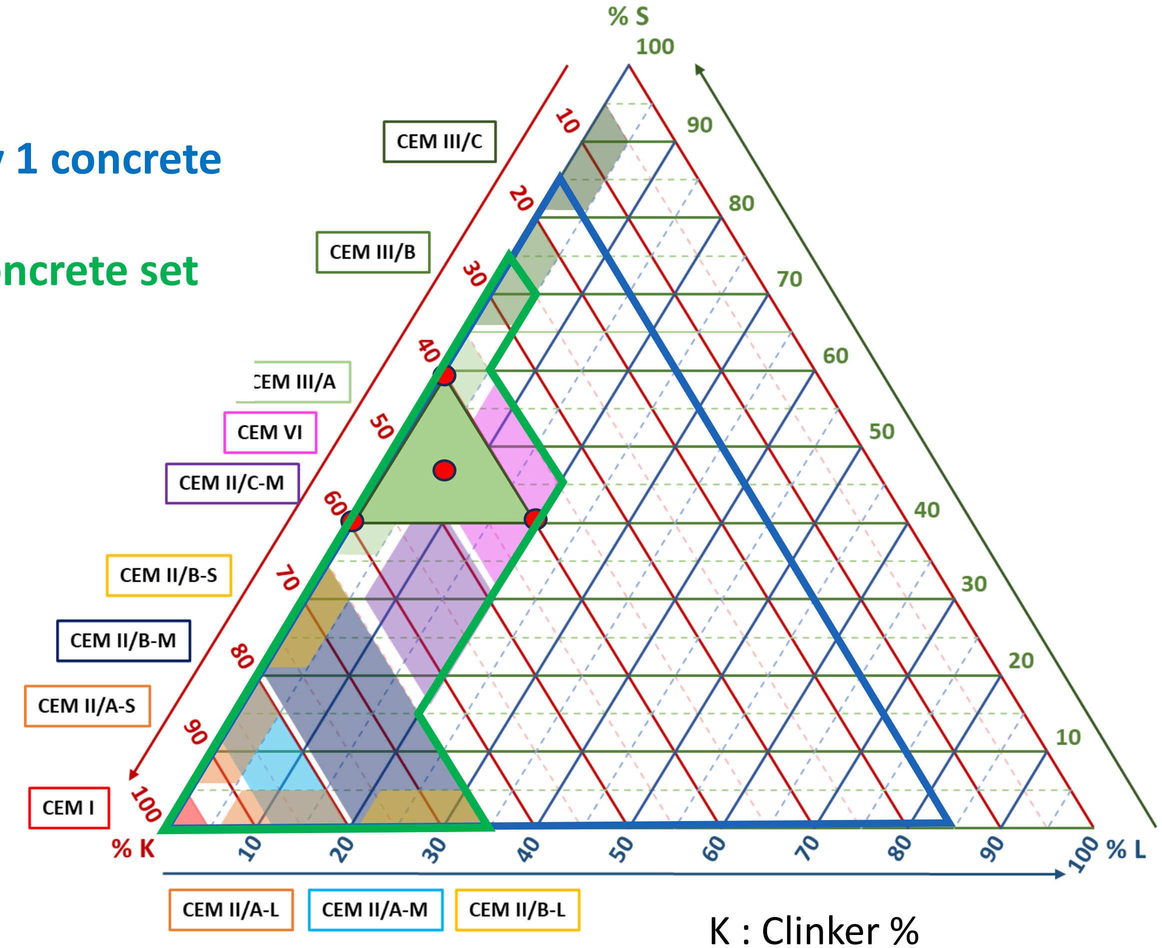
FD P 18-480 (2025) « Performance-based approach for justifying the durability of concrete structures »

Performance-based approach (2022) → validation of only 1 concrete

Performance-based approach (2025) → Validation of a concrete set

Realization of a Generic Study:

- 4 concretes
- Binder: maximum area for the constituent proportions (clinker, slag, limestone, metakaolin, métakaolin…) = ± 10 %.
- Same total binder content, W_{eff}/B_{tot} ratio, granular skeleton, constituent nature
- Durability properties comply with threshold values defined in FD P 18-480



K : Clinker %
S : Slag %
L : Limestone %

DECADES scientific interest group*

Durabilité Et Corrosion des Armatures Dans les ouvragEs en béton intégrant ou non des Solutions bas carbone

- **Establish a national, inter-institutional and interdisciplinary network of scientific expertise in the field of reinforced concrete durability, incorporating a performance-based approach to durability and reinforcement corrosion**

- **Establish a scientific group to contribute to the main French and European standardisation bodies dealing with issues related to the durability of structures particularly in the context of low environmental impact concrete and, more specifically, concrete with lower CO_2 emissions**

- **Exchange knowledge in the field of reinforced concrete sustainability (annual workshop)**

- **Follow-up of test specimens “history” cast during the national PerfDuB (2015-2022) and BHP2000 (1995-2003) projects and the ANR Modevie (2015-2019) and Applet (2007-2010) projects**

(* No funding in a scientific community group)

fib Symposium2025
Antibes - France
Concrete Structures : extend lifespan, limit impacts

DECADES scientific interest group

Workshop#2, 13 May 2025 à La Rochelle, France

Programme du workshop

08h30 - 9h00 Accueil
09h00 – 9h15 - Introduction et organisation de la journée (Ph. Turcry/J. Mai-Nhu)

i. Méthode d'essais en laboratoire et sur site (chairwoman : Stéphanie Bonnet)

09h15 - 09h30 : Méthodes de mesure de la résistivité électrique (Géraldine Villain)
09h30 - 09h45 : Méthodes et limites de détection des fissures sur ouvrages par CND (Olivier Anterrieu)
09h45 - 10h00 : Évaluation de la corrosion (cinétique, localisation et dimension des zones corrodées) par "tomographie électrochimique" (Lucas Hesse)
10h00 - 10h30 : Échanges
10h30 – 10h40 : Nouvelle méthode d'évaluation de la résistance à la carbonatation, thèse de Oujdane Qacami, Holcim/Université La Rochelle/KIT (Philippe Turcry)
10h40 – 10h50 : Retour sur les essais croisés de durabilité au niveau européen : carbonatation accélérée, migration des chlorures, résistivité (Jonathan Mai-Nhu)
10h50 - 11h05 : Échanges

ii. Corps d'épreuve PN Perfdub & VISITE DE LA PLATEFORME

11h05 – 11h15 Présentation du programme d'essais 2025 sur les corps d'épreuve (Véronique Bouteiller)
11h15 – 12h15 Plateforme au pied de la Tour Saint-Nicolas et présentation des techniques de mesure
12h15 – 13h30 Déjeuner (Technoforum)

iii. Fissuration des bétons (chairman : Thierry Vidal)

13h30 – 13h45 Présentation de l'étude d'opportunité du Projet National CRACODUB sur l'influence des ouvertures de fissures et autres facteurs sur la durabilité du béton armé (L. Boutillon)
13h45 – 14h00 Auto-cicatrisation des matériaux avec liants bas-carbone : application au génie civil de l'eau, présentation d'un nouveau sujet de thèse FNTP/Ecole Centrale de Nantes (E. Rozière)
14h00 – 14h15 Modélisation de la fissuration du béton armé induite par la corrosion (Lucas Adelaide)
14h15 – 15h00 Échanges

iv. Durabilité du béton d'enrobage (chairman : Abdelkarim Aït-Mokhtar)

15h00 – 15h15 Lien entre microstructure et hydratation des liants bas carbone de type LC3, thèse Mines Alès, IMT Nord-Europe, CERIB, (Ranim El-Dah)
15h15 – 15h30 Durabilité des bétons bas-carbone non structurels (Gilles Escadeillas)
15h30 – 16h00 Échanges
16h00 – 16h15 Pause

v. Principales évolutions du contexte normatif, lien avec le GE SBC (chairman : Abdelkarim Aït-Mokhtar).

16h15 – 16h30 Diminution de l'impact carbone des ouvrages en béton - Principales évolutions du contexte normatif en 2025 (Patrick Rougeau)
16h15 – 16h45 Echanges

17h00 Fin du workshop

GIS DECADES | Page d'accueil (gisdurabilite-betoncorrosion.com)

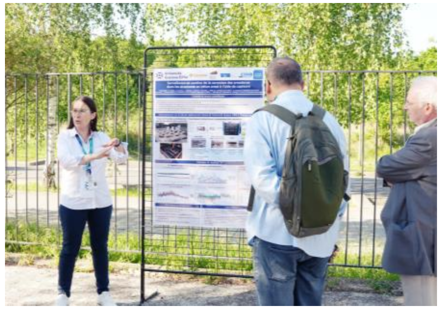
Durabilité et corrosion des armatures dans les ouvrages en béton intégrant ou non des solutions bas carbone

Le Groupement d'Intérêt Scientifique "Durabilité Et Corrosion des Armatures Dans les ouvragEs en béton intégrant ou non des Solutions bas carbone" (GIS DECADES) a pour objectifs de développer, structurer et promouvoir la recherche dans le domaine de la durabilité du béton et la corrosion des armatures dans les ouvrages en béton armé, intégrant ou non des solutions bas carbone.

DÉCISION scientific chair
➔ performing collaborative work

« Durabilité du bÉton et CorrosIon des armatureS en envIronnements chlOrure ou carboNatation »

Launched on 29 April 2025 at the Gustave Eiffel University in Champs-sur-Marne, France



17 June 2025

CHAIRE
DÉCISION

Fondation Université Gustave Eiffel

DURABILITÉ DES BÉTONS ARMÉS SOUMIS À LA CORROSION

I- Durabilité du béton armé

- Déterminer les cinétiques de la dégradation en fonction des conditions climatiques
- Quantifier la dégradation par expérimentation sur sites naturels

II- Corrosion du béton armé

- Diagnostiquer l'évolution de la corrosion en fonction du temps
- Proposer des solutions de réparations pour les constructions dégradées

© Crédit Photo : Fondation Le Corbusier

The partners of the DÉCISION scientific chair

Funding partners (patrons):

VINCI CONSTRUCTION

EIFFAGE

France Ciment

Heidelberg Materials

Bâtir le vivre ensemble VICAT

EQIOM A CRH COMPANY

LAFARGE

FEREC

Fondation Université Gustave Eiffel

Scientific and funding partners:

Université Gustave Eiffel

La Rochelle Université

LRMH Laboratoire de Recherche des Monuments Historiques

CERIB Expertise concrète

The context of the DÉCISION scientific chair

CHAIRE DÉCISION

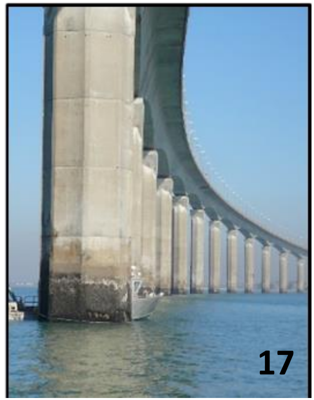
- **The world's population is set to grow to almost 10bn people by 2050, 68% of which will live in urban areas.**
  - **These increases will drive a critical demand for infrastructure over the coming decades – from clean water, effective sanitation, safe dwellings and vital transport networks.**
  - **At the same time there is a growing need for resilient construction to protect our cities and natural environment from a changing climate.**
  - **As the world's most used man-made product, concrete is vital to meeting those challenges**

Global Cement and Concrete Association

- **The European Green Deal aims**
  - **To reduce net greenhouse gas emissions by 55% by 2030 compared to 1990 levels**
  - **To achieve a climate-neutral continent by 2050**

European Commission

- **Reinforced concrete structures are mainly affected by corrosion of the steel reinforcement**



The objective and studies of the DÉCISION scientific chair

CHAIRE DÉCISION

- Improve the SUSTAINABILITY of reinforced concrete structures ➔ from material to structure, considering function and safety

- 4 studies:

2025-2030

1) Determining the kinetics of reinforced concrete corrosion under environmental conditions (including climatic changes)
2) Quantifying the durability of reinforced concrete on metric test specimens exposed to natural ageing

(Studies initiated in the PerfDuB project)

3) Diagnosing the state of corrosion of reinforced concrete over time with Non Destructive Testing, Corrosion Health Monitoring and Destructive Testing
4) Proposing appropriate repair solutions for reinforced concrete structures damaged by corrosion

The challenges of the DÉCISION scientific chair

CHAIRE DÉCISION

❶ Studying the sustainability of reinforced concrete using a combined methodology ➔ multidisciplinary

❑ Performance-based approach

- ❖ Concrete cover ➔ **Physico-chemical barrier**
- ❖ Study of **transfer reactions** to delay the arrival of aggressive species (carbon dioxide or chloride ions)

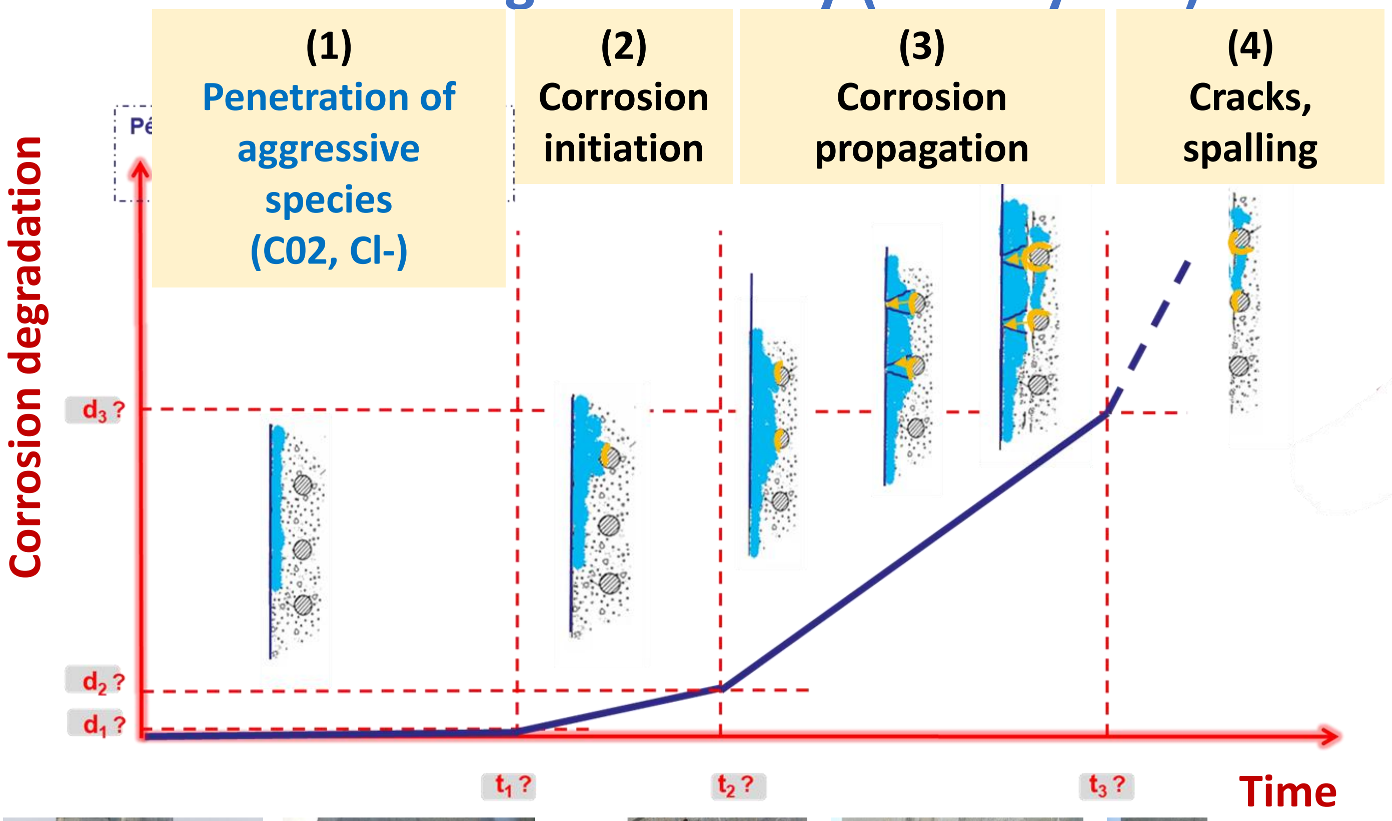
➕

❑ Corrosion approach

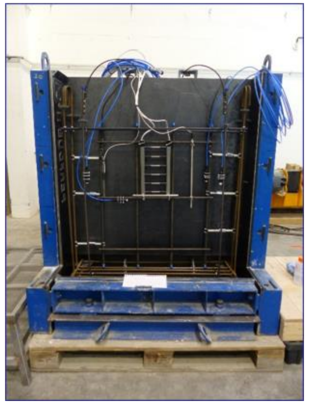
- ❖ Steel reinforcement ➔ **Resistance to corrosion**
- ❖ Study **of the electrochemical characteristics of steel/concrete interface** and **concrete cracking**

The challenges of the DÉCISION scientific chair

❷ Characterizing, simulating and predicting the durability of reinforced concrete over time ➔ Long-term study (10-20 years)



11 specimens in La Rochelle, tide zone, XS3m

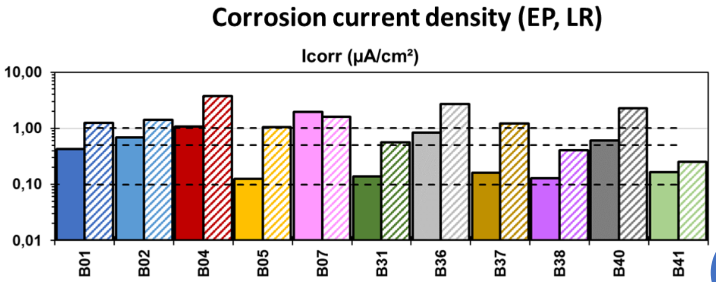


3 specimens with sensors, in Champs-sur-Marne, XC4, at Université Gustave Eiffel

The challenges of the DÉCISION scientific chair

❸ Diagnosing reinforced concrete throughout its life and repairing it

➔ Tools for non-destructive testing, corrosion health monitoring and destructive testing and Interpretations



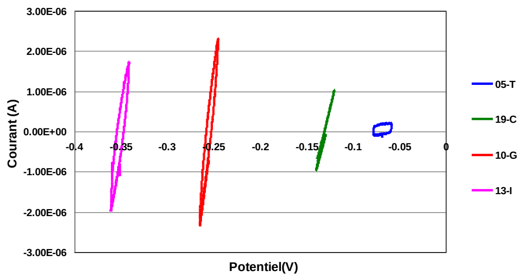
Materials Methods

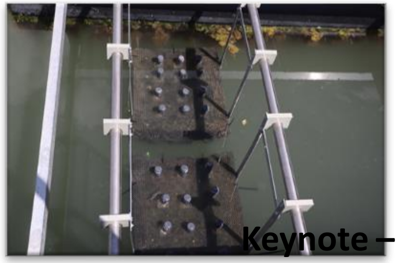
Initiation

Propagation, Cracking

Maintenance, Repair

Realkalisation of Pont Camille de Hogues





Cathodic Protection of Viaduc de Saint-Cloud

History and information

- C. Alonso, et al., **Chloride threshold values to depassivate reinforcing bars embedded in a standardized OPC mortar**, Cement and Concrete Research, **2000,** DOI:10.1016/S0008-8846(00)00265-9
- U. Angst et al., **Critical chloride content in reinforced concrete - A review**, Cement and Concrete Research, **2009,** DOI: 10.1016/j.cemconres.2009.08.006
- V. Bouteiller et al., **Corrosion initiation of reinforced concretes based on Portland or Ground Granulated Blast furnace Slag cements: Chloride contents and electrochemical characterizations versus time**, Cement and Concrete Research, **2012,** DOI: 10.1016/j.cemconres.2012.07.004
- **Gordon Research Conferences**, Italy, **2022**

  Karen Scrivener and Carmen Andrade

- E. Marie-Victoire et al., **Concrete of tomorrow: corrosion performances in marine environment**, Concrete Solutions, Leeds, United-Kingdom, **2022**, DOI:10.1051/matecconf/202236101004
- S. Mundra, et al., **Application of electrochemical methods for studying steel corrosion in alkali-activated materials**, Materials and Corrosion, **2023,** DOI: 10.1002/maco.202313743

Conclusions 1/2

- **The performance-based approach facilitates a global approach which allows the technical aspects specific to each work to be taken into account**

- **The performance-based approach contributes to current issues:**
  - Longer service life
  - Higher use of concrete with lower CO_2 footprint

- **Progress must be made to further integrate lower carbon impact concrete into standards**

Conclusions 2/2

- **Increasing the knowledge of the durability of the concrete compositions with a lower carbon footprint in relation to corrosion resistance of steel reinforcement ➔ database**

- **Enabling the prescription of 'standardised' concrete that incorporates materials with a lower environmental impact**

- **Sharing expertise at the French and international levels**
  - CEFRACOR, AFGC, IMGC, *fib*, RILEM,…

- **Presenting the results at congresses and courses**
  - *13 May 2025 Workshop#2 GIS DECADES in La Rochelle University*
  - *16-18 June 2025 fib Symposium Antibes ➔ Special Sessions 23 and 17*

Thank you for your kind attention!

veronique.bouteiller@univ-eiffel.fr

P.ROUGEAU@cerib.com