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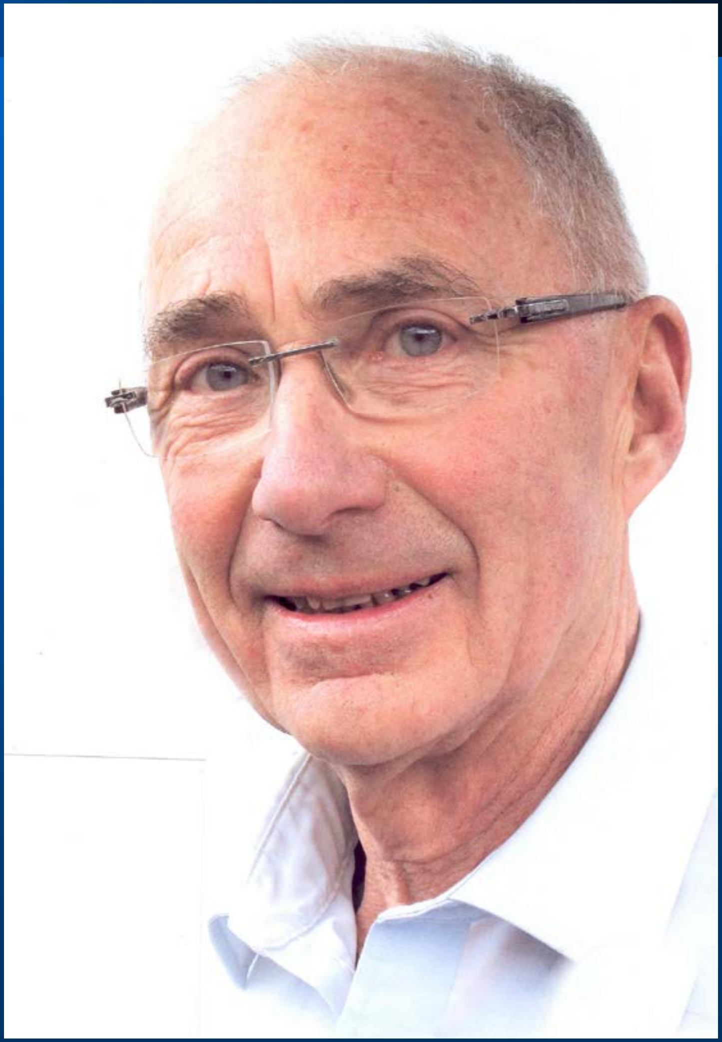


Durability and Service Life of Major Concrete Infrastructure

HISTORICAL BACKGROUND

- **1917: Extensive field investigations of concrete structures in US waters showed that steel corrosion was the big problem to the durability of the structures**

HISTORICAL BACKGROUND (cont.)

- 1924: Atwood and Johnson had assembled a list of approximately 3.000 references on durability of concrete in marine environments

HISTORICAL BACKGROUND (cont.)

- **After 1924: Numerous investi-gations have been carried out in many countries and a large number of durabilty papers and recommen-dations have been produced**

CURRENT FIELD EXPERIENCE

Major concrete infrastructure in Norwegian marine environments

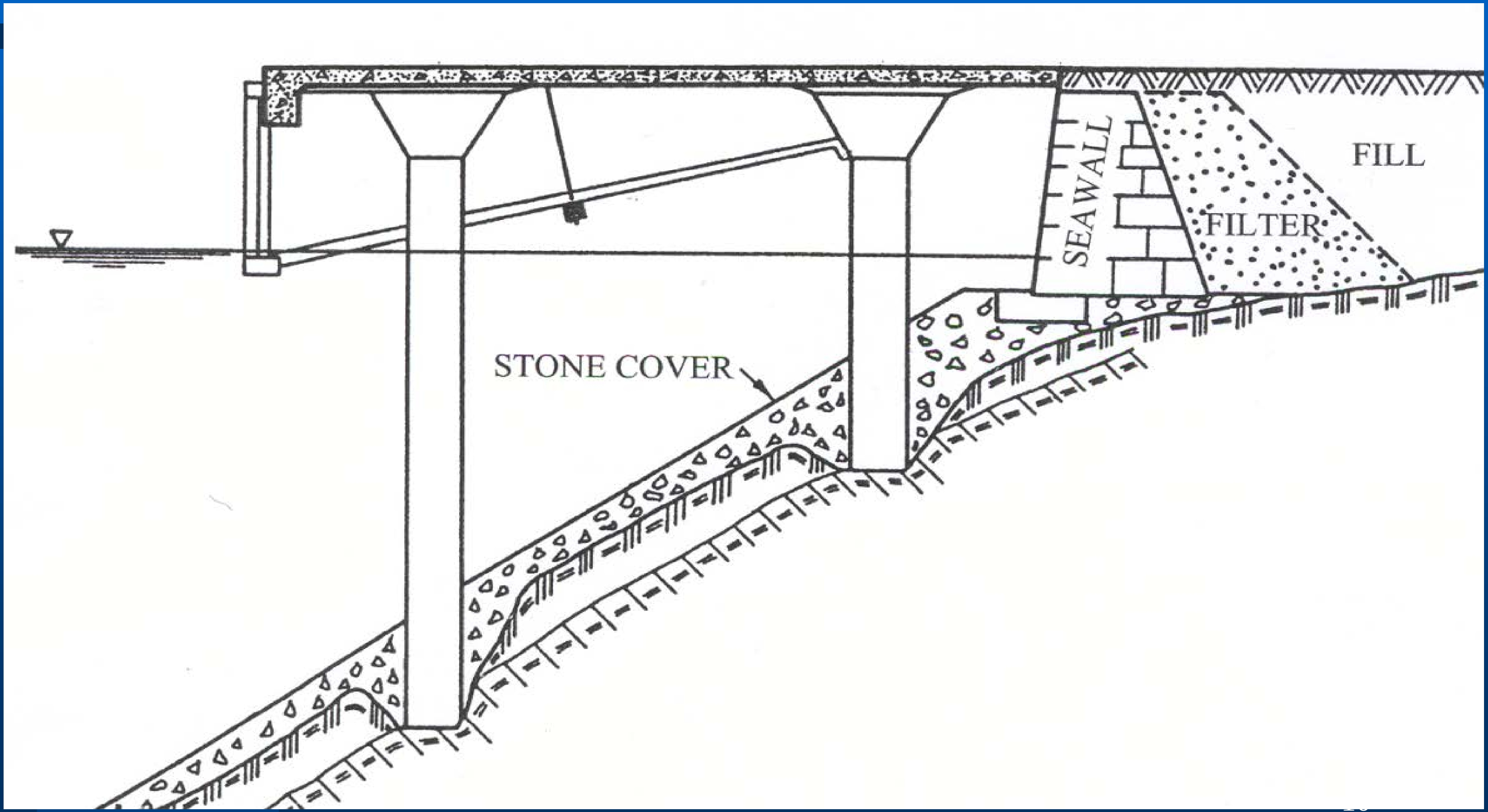
- **Concrete harbor structures**
- **Concrete coastal bridges**
- **Offshore concrete platforms**


TRONDHEIM
OSLO
BERGEN
SKIEN
STAVANGER
KRISTIANSAND

Concrete harbor structures

Along the Norwegian coastline there are more than 10.000 harbor structures, most of which are concrete structures which have typically started to corrode within a service period of about 10 years

Typical concrete harbor structure



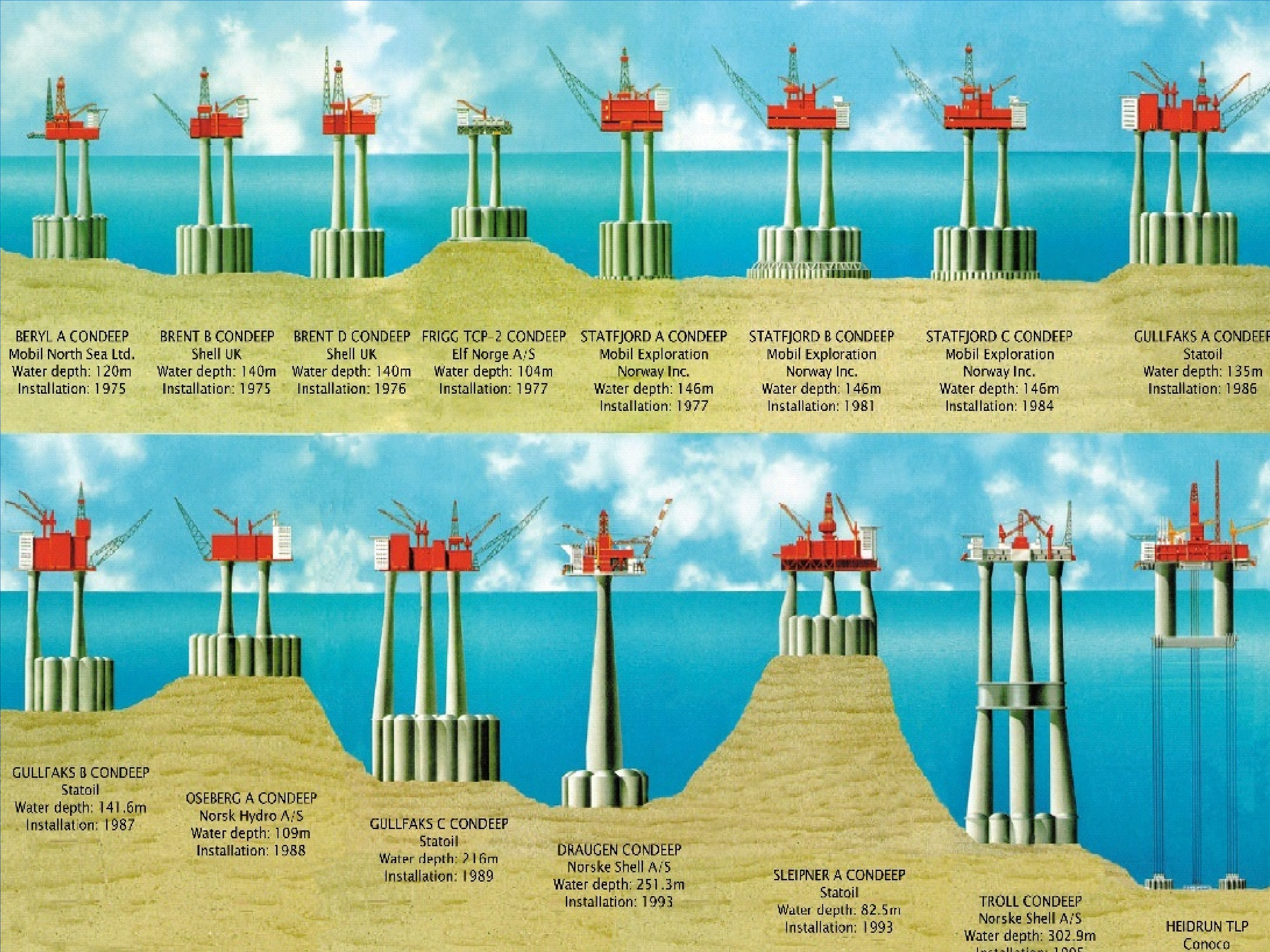
Concrete coastal bridges

Along the Norwegian coastline there are more than 300 large concrete bridges built after 1970, of which more than 50% are corroding

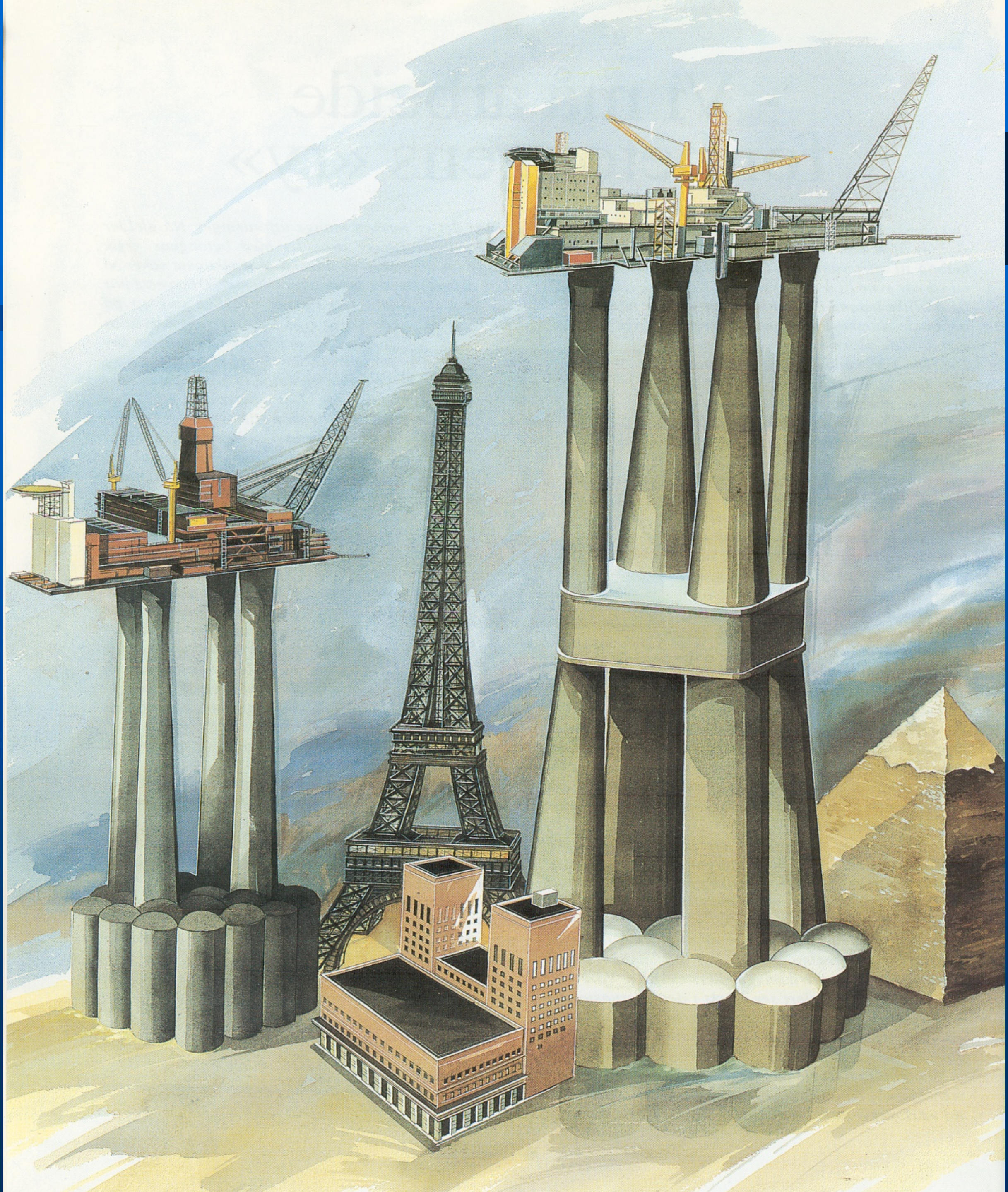
Offshore concrete structures

In the North Sea, 34 concrete platforms have been produced with high-performance concrete showing very good durability. However, still corrosion of embedded steel has caused some very costly repairs


PACIFIC
SIMSON



BERYL A CONDEEP
Mobil North Sea Ltd.
Water depth: 120m
Installation: 1975
BRENT B CONDEEP
Shell UK
Water depth: 140m
Installation: 1975
BRENT D CONDEEP
Shell UK
Water depth: 140m
Installation: 1976
FRIGG TCP-2 CONDEEP
Elf Norge A/S
Water depth: 104m
Installation: 1977
STATFJORD A CONDEEP
Mobil Exploration
Norway Inc.
Water depth: 146m
Installation: 1977
STATFJORD B CONDEEP
Mobil Exploration
Norway Inc.
Water depth: 146m
Installation: 1981
STATFJORD C CONDEEP
Mobil Exploration
Norway Inc.
Water depth: 146m
Installation: 1984
GULLFAKS A CONDEEP
Statoil
Water depth: 135m
Installation: 1986
GULLFAKS B CONDEEP
Statoil
Water depth: 141.6m
Installation: 1987
OSEBERG A CONDEEP
Norsk Hydro A/S
Water depth: 109m
Installation: 1988
GULLFAKS C CONDEEP
Statoil
Water depth: 216m
Installation: 1989
DRAUGEN CONDEEP
Norske Shell A/S
Water depth: 251.3m
Installation: 1993
SLEIPNER A CONDEEP
Statoil
Water depth: 82.5m
Installation: 1993
TROLL CONDEEP
Norske Shell A/S
Water depth: 302.9m
HEIDRUN TLP
Conoco




25/1-FRIGG
TCP2

”Oseberg A Platform” (1988): Repairs after 13 years (CP)

FIELD EXPERIENCE (cont.)

- For all the above concrete structures, chloride-induced corrosion has still been the most serious problem and threat to the operation and safety of the structures

FIELD EXPERIENCE (cont.)

- The achieved construction quality has typically shown a high scatter and variability, and any weaknesses and deficiencies have soon been revealed whatever durability specifications and materials have been applied

FIELD EXPERIENCE (cont.)

- **Much of the observed durability problems can be ascribed due to poorly achieved construction quality and absence of proper quality assurance**

FIELD EXPERIENCE (cont.)

- Descriptive durability requirements have been specified, the results of which are neither unique nor possible to verify and control for quality assurance during concrete construction

FIELD EXPERIENCE (cont.)

- During operation of the structures, the maintenance has typically been reactive. As a result, technically difficult and very costly repairs have been carried out

OFFSHORE vs. ONSHORE MARINE CONCRETE STRUCTURES

- **Why have all the offshore concrete structures in the North Sea shown such a much better durability and performance than all the land-based marine concrete structures built during the same period?**

SPECIFIED SERVICE LIFE

- **Offshore concrete structures:**
  - ***Typical 30 years increaseing up to 60 years***
- **Land-based marine concrete structures:**
  - ***Typical 60 years increaseing up to 100 years***

Offshore concrete structures

- When the first consept for use of concrete for offshore installations in the North Sea was introduced in the early 1970s, the international oil industry showed very great sceptisism

Offshore concrete structures (cont.)

Current field experience with concrete structures in marine environments in the early 1970s clearly demonstrated that:

- **Corrosion problems typically ocurred after 5 - 10 years of service**
- **The corrosion damage was very difficult to repair**

Offshore concrete structures (cont.)

- The operators in the international oil industry were very demanding; safe operation with as little interuption as possible and high safety and security of all installations were of highest importance

Offshore concrete structures (cont.)

- In order to get acceptance for use of concrete in any offshore installation, much stricter durability requirements and procedures for quality assurance had to be applied

Recommendations for the design and construction of concrete sea structures

Second edition

"FIP Recommendations" (1973)

Durability requirements:

- **W/C ≤ 0.45 (0.40)**
- **Min. cement content (C): 400 kg/m^3**
- **Nom. concrete cover: 75 (100) mm**

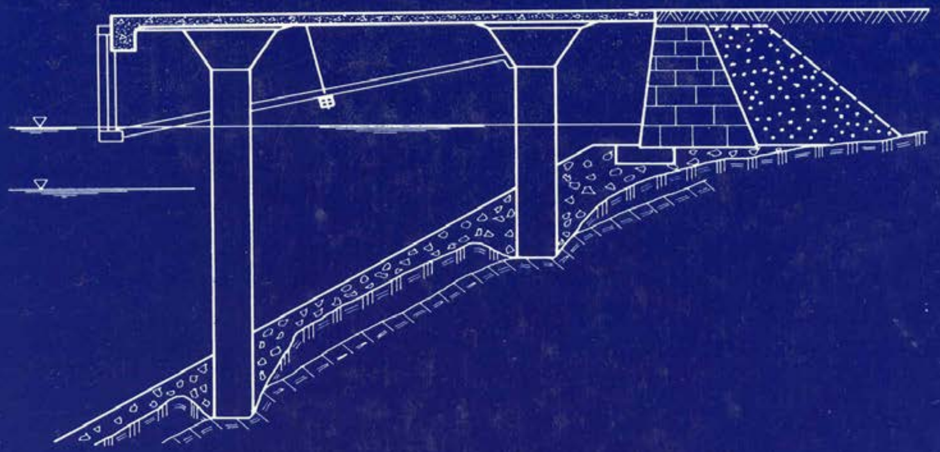
The Norwegian field investigations of 1962-68

- 219 concrete harbor structures
- Construction period: 1910 – 1960
- 190,000 m^2 concrete decks
- 5,000 tremie-cast concrete pillars

The Norwegian field investigations of 1962-68 (cont.)

- 84% of the structures had extensive steel corrosion
- First visible sign of corrosion after 5 - 10 years
- 34% of the structures had repairs with service life ≤ 10 years

THE NORWEGIAN COMMITTEE ON CONCRETE IN SEAWATER



Durability of Reinforced Concrete Wharves in Norwegian Harbours

INGENIØRFORLAGET A/S–OSLO

Durability requirements: *Offshore*

Apart from the first offshore concrete structure (Ekofisk-tank, 1973) which was produced with w/c = 0.45, all the other offshore structures have been produced with w/c = 0.35 – 0.40

Durability requirements: *Onshore*

1962-68	*Norwegian Committee on Concrete in Seawater*
1973 (1974,1976)	FIP: w/c ≤ 0.45/0.40 (OD, DnV) (5 years)
1986	NS: w/c ≤ 0.45 (18 years)
1988	SVV: w/c ≤ 0.40 (20 years)
1996	SVV: w/c ≤ 0.38 (28 years)
2003	NS-EN 206-1: w/c ≤ 0.40 (0.45) (35 years)

CODES AND PRACTICE

- A very slow upgrading of codes and practice compared to the development of new knowledge and state of the art

CODES AND PRACTICE (cont.)

- It has taken more than 30 years for the European Concrete Codes to reach the same strict durability requirements as that specified for the first offshore concrete structures in the early 1970s

CODES AND PRACTICE (cont.)

- The durability requirements have been descriptive, the results of which have neither been unique nor possible to verify and control for quality assurance during concrete construction

INTERNATIONAL EXPERIENCE

Annual bridge repairs in the USA

- 1986: US$ mill. 500
- 2001: US$ bill. 8.3
- 2007: US$ bill. 9.4

Annual bridge repairs in Western Europe in 1998: US$ bill. 5

CHALLENGE TO THE CONSTRUCTION INDUSTRY

Rapidly increasing proportions of limited construction budgets are being spent on costly repairs of existing concrete infrastructure rather on the production of new important infrastructure

CHALLENGE TO THE CONSTRUCTION INDUSTRY

A more controlled and increased durability and service life of new concrete infrastructure are not only important from a cost point of view; it directly affects the sustainability of our society

ADDITIONAL REQUIREMENTS

More and more owners are interested to invest somewhat more in order to obtain an increased and more controlled durability and service life beyond what is possible when only based on current standards; even small additional costs have proved to be an extremely good investment

Norwegian Association for Harbor Engineers (NAHE)

"Recommendations for a more controlled and increased durability and service life of new marine concrete infrastructure"

(TEKNA, Oslo, 2004)

Norwegian Association for Harbor Engineers (NAHE) (cont.)

2009: The third revised edition was also adopted by the Norwegian Chapter of PIANC

Norwegian Association for Harbor Engineers (NAHE) (cont.)

- In order to accomodate a high scatter and variability, the recommendations are based on a probability approach to the durability design ("DuraCrete", 2000)

Norwegian Association for Harbor Engineers (NAHE) (cont.)

- Greater control and improvements in durability also require the specification of performance-based durability requirements which can be verified and controlled for quality assurance during concrete construction

Norwegian Association for Harbor Engineers (NAHE) (cont.)

- The production of a service manual for future condition assessment and preventive maintenance of the structure is also an essential part of the durability design

Norwegian Association for Harbor Engineers (NAHE) (cont.)

Strategy and approach:

(1) *Probability-based durability design*

(2) *Quality assurance*

(3) *Preventive maintenance*

(1) *Probability-based durability design*

A certain "*service period* " for the given concrete structure in the given environment is specified before the probability of corrosion exceeds 10%

(1) *Probability-based durability design* (cont.)

As a result of the durability design, performance-based durability requirements are established:

- *28-day chloride diffusivity (RCM)*
- *Concrete cover*

(2) *Quality assurance*

The performance-based durability requirements are verified and controlled during concrete construction in order to achieve quality assuranace

(2) *Quality assurance* (cont.)

From the quality control, documentation of achieved construction quality and compliance with the specified durability is obtained

(3) *Preventive maintenance*

As part of the durability design, a service manual for monitoring and control of the future chloride ingress during operation of the structure is produced

(1) PROBABILITY-BASED DURABILITY DESIGN

Durability analysis

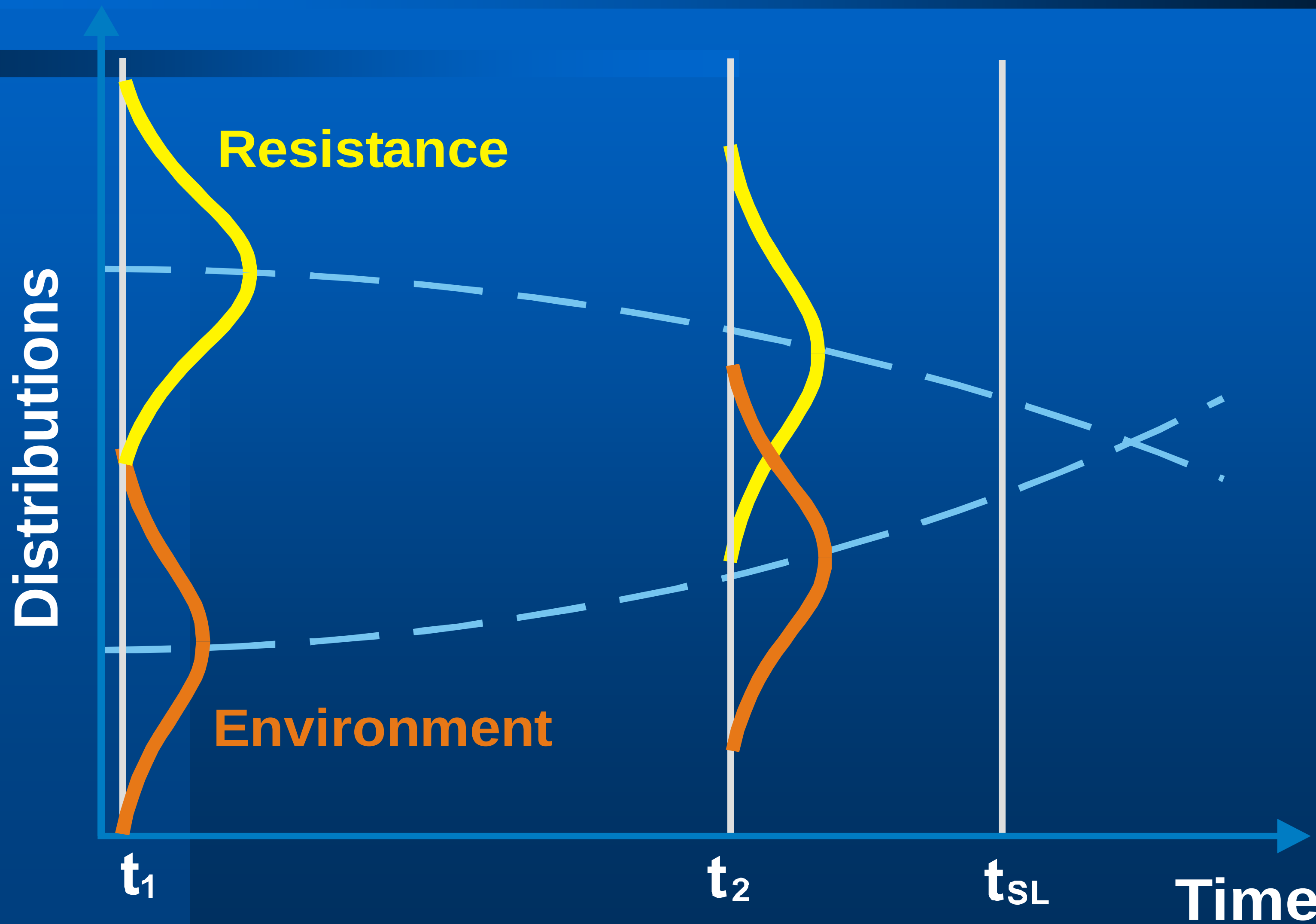
- Time-to-corrosion analysis
- Time-dependent reliability analysis

↓

Probability of corrosion

(Construction quality)

Time-dependent reliability analysis



Durability requirement

For the given concrete structure in the given environment, a certain ”service period” (≤ 150 years) is specified before the probability of steel corrosion exceeds 10%

Durability requirement (cont.)

For "service periods" of more than 100 but less than 150 years:

- ***Corrosion probability must be as low as possible (≤ 10%)***
- ***Additional protective measures are recommended***

Durability requirement (cont.)

For "service periods" of more than 150 years:

- Corrosion probability must be as low as possible (≤ 10%)

- Additional protective measures are required

Durability analysis

A simple software (DURACON) has been established, primarily based on Fick´s 2. Law of Diffusion in combination with a Monte Carlo Simulation

DURACON Software

Input parameters

- Environmental loading
  - *Chloride loading (C_S)*
  - *Age at chloride loading (t')*
  - *Temperature (T)*
- Concrete quality
  - *Chloride diffusivity (D)*
  - *Time dependence (α)*
  - *Critical chloride content (C_{CR})*
- Concrete cover *(X)*

(2) QUALITY ASSURANCE

Performance-based concrete quality control

- ***Control of chloride diffusivity***
- ***Control of concrete cover***

Chloride diffusivity *(D_{28})*

For the above durability analysis, the 28-day chloride diffusivity (D_{28}) is a very important input parameter which is being tested very rapidly independent of concrete age

Chloride diffusivity (D_{28}) (cont.)

The chloride diffusivity (RCM) is a very important durability parameter reflecting the resistance of the concrete against chloride ingress

Chloride diffusivity (D_{28}) (cont.)

The 28-day chloride diffusivity (D_{28}) is a very simple relative index reflecting both the density, permeability and mobility of ions in the pore system and hence, both the resistance to chloride ingress as well as the general durability properties of the concrete

Chloride diffusivity (D_{28}) (cont.)

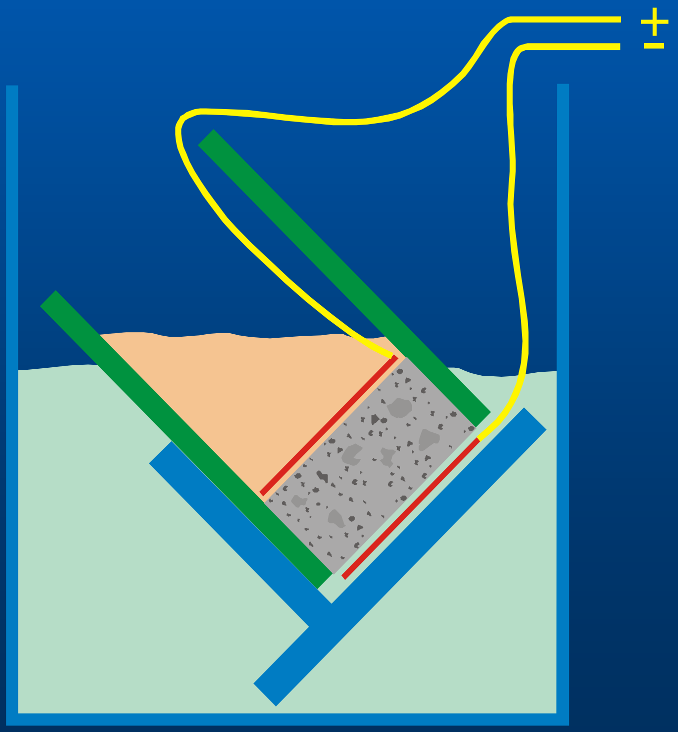
The 28-day chloride diffusivity (D_{28}) may be comparable to that of the 28-day compressive strength (f_{28}), which is also only a very simple, relative index primarily reflecting the compressive strength but also reflecting the general mechanical properties of the concrete

Chloride diffusivity (D_{28}) (cont.)

For the above durability design, the 28-day chloride diffusivity (D_{28}) is an input parameter as important as the 28-day compressive strength (f_{28}) is for the structural design

Testing of chloride diffusivity

Rapid chloride migration testing (RCM) (NT Build 492)



Control of the 28-day chloride diffusivity (D_{28})

Regular control of the 28-day chloride diffusivity (D_{28}) has to be carried out during concrete construction

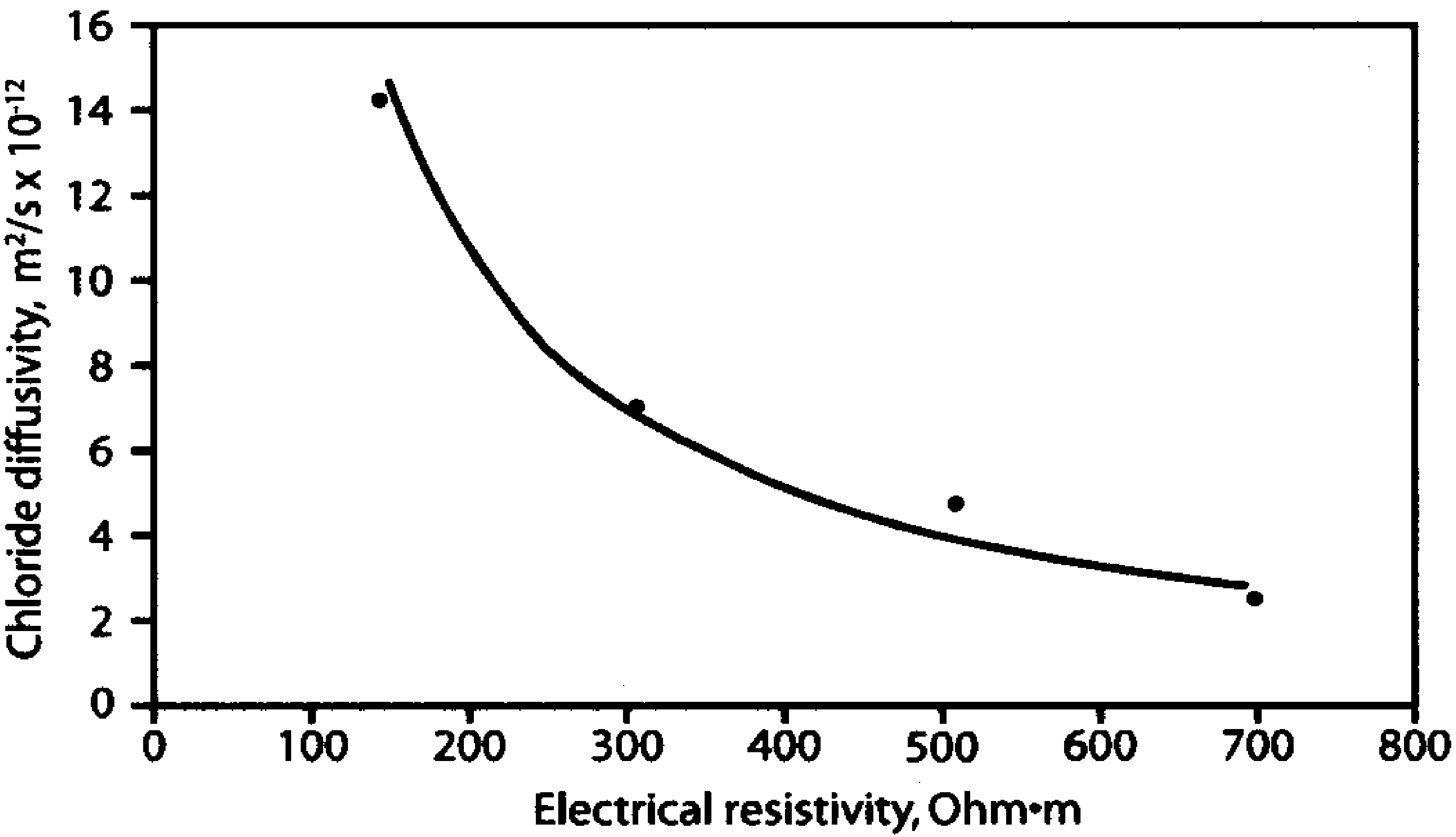
Relationship between diffusivity and electrical resistivity

***Nernst-Einstein*:**

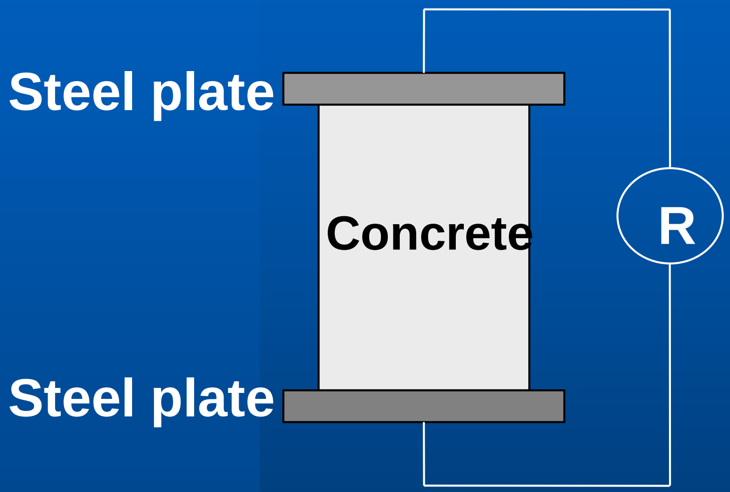
$$D = \frac{R.T}{Z^2.F^2} \cdot \frac{t_i}{\gamma_i.c_i.\rho}$$

$$D = k \cdot \frac{1}{\rho}$$

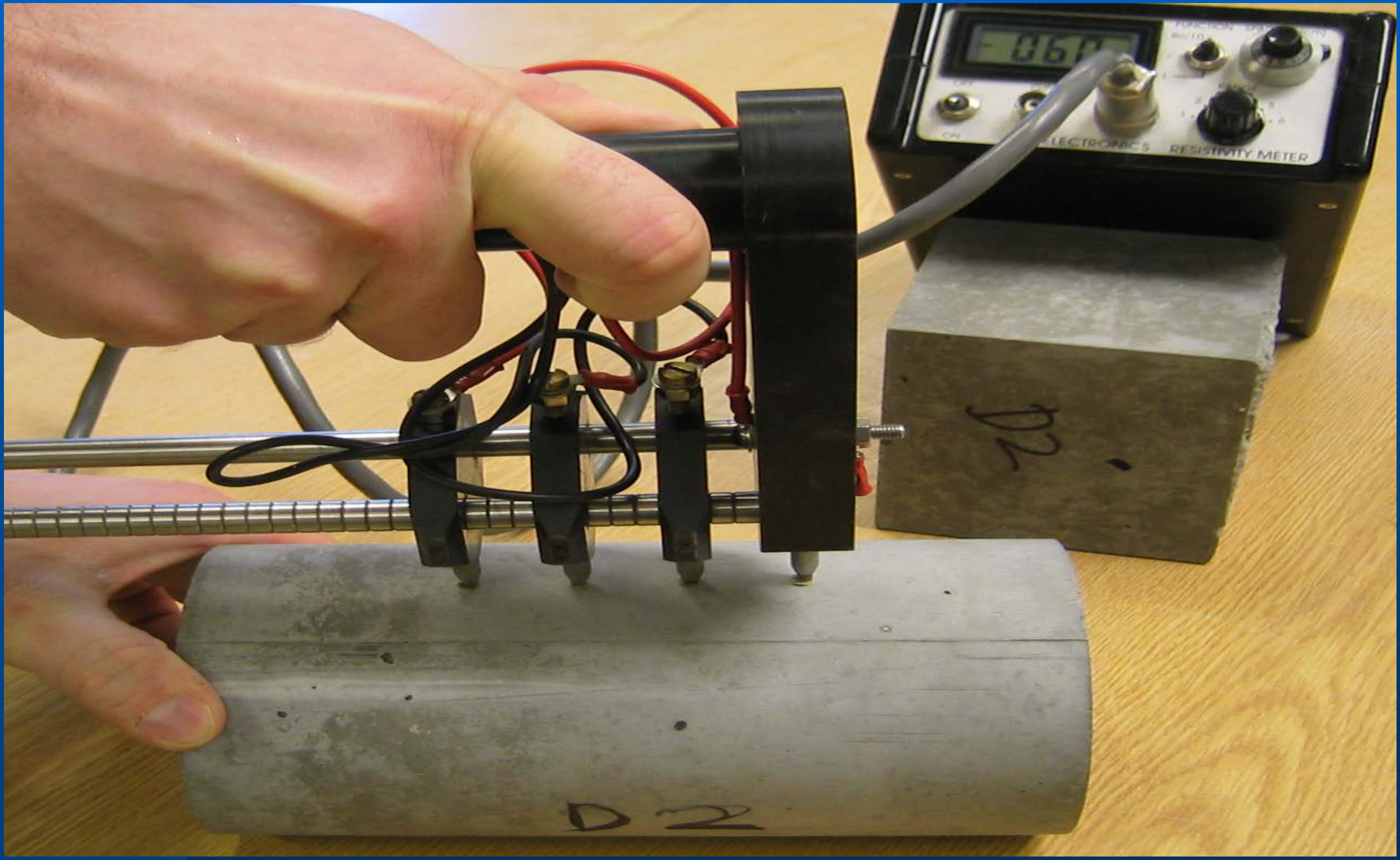
Calibration curve



Indirect control of the 28-day diffusivity based on the electrical resistivity (2-electrode method)



Indirect control of the 28-day diffusivity based on the 4-electrode method



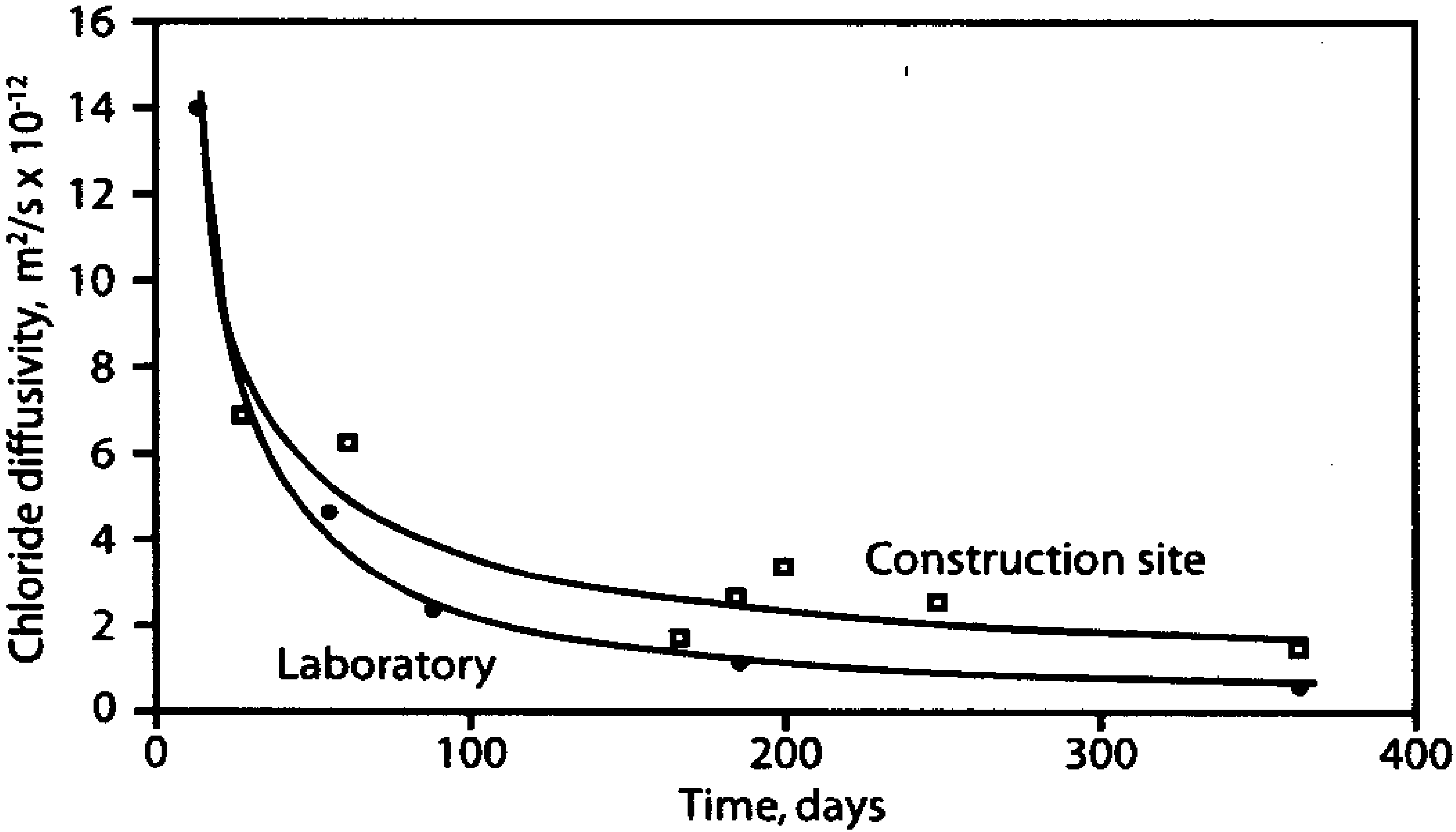
Control of in the in situ chloride diffusivity

Control of in situ chloride diffusivity is based on testing of concrete cores from the construction site during the construction period (one year)

Control of the potential chloride diffusivity

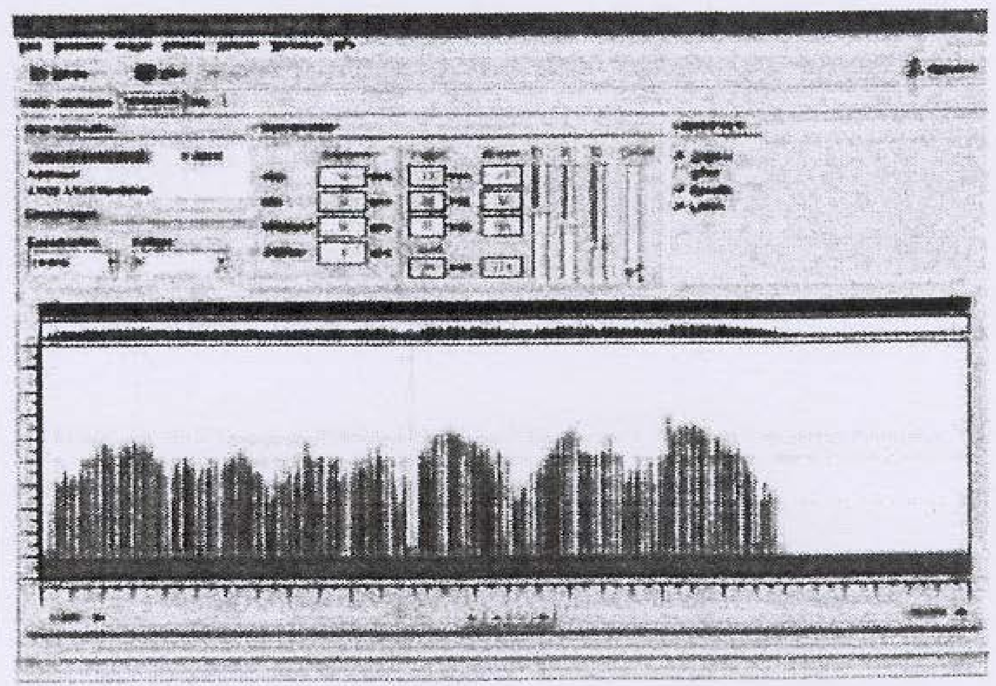
Control of the potential chloride diffusivity is carried out under controlled laboratory conditions (one year)

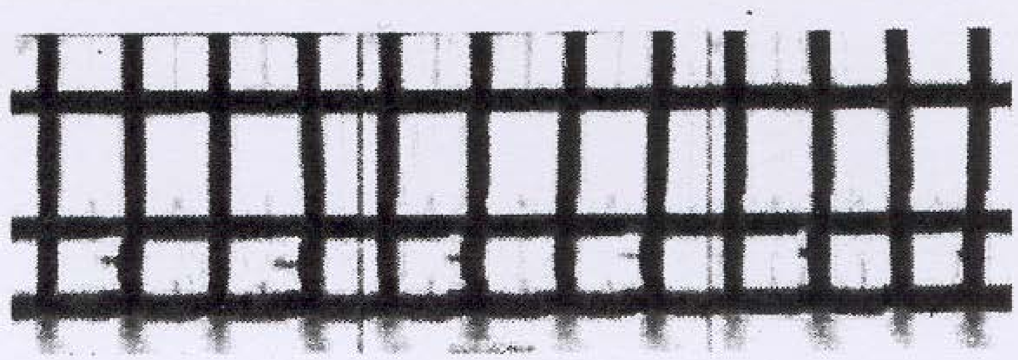
Development of chloride diffusivity



Control of concrete cover

Scanning equipment





Construction joints

Achieved construction quality

Durability analyses based on achieved chloride diffusivity and concrete cover:

(1) ***Compliance with specified durability***

(2) ***In situ construction quality***

(3) ***Potential construction quality***

(3) PREVENTIVE MAINTENANCE

Control of future chloride ingress

Even if the strictest durability requirements both have been specified and achieved, a certain rate of chloride ingress will allways take place during operation of the structures

Control of future chloride ingress (cont.)

A regular monitoring and control of the real chloride ingress during operation of the structure must be carried out

Probability of corrosion

Updated estimates on the probability of corrosion are made based on data from the observed rate of chloride ingress during operation of the structure

Probability of corrosion (cont.)

Before the probability of corrosion becomes too high, appropriate protective measures measures must be implemented

PRACTICAL APPLICATIONS

In recent years, the above Recommendations have been applied to a number of new commercial projects, one of which is shown as a Case Study in the following

Case Study: "Tjuvholmen" Oslo, (2010)

”Tjuvholmen” Oslo (2010)

Owner´s durability requirements:

(1) *”Service life” of 300 years*

(2) *Documentation of achieved construction quality (NAHE)*

”Tjuvholmen”Oslo (2010) (cont.)

The project included a number of sea spaced concrete substructures:

- In situ cast concrete structures for shallow water
- Prefabricated concrete caisons for deep water

In situ cast structures

Prefabricated structures (dry dock)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EXECUTION OF WORK

The whole project was carried out in two parts by two different contractors having two different strategies and approaches to the durability and service life of the structures

Contractor A: Probability-based durability design

- *"NAHE Recommendations for a more controlled and increased durability and service life of new major concrete infrastructure in Norwegian harbors" (TEKNA, Oslo, 2004)*
- *Concrete structures No. 1 - 4*

Contractor A: Probability-based durability design (cont.)

- ***Service period of 150 years with a corrosion probability as low as possible (≤ 10%)***
- ***Partly use of stainless steel reinforcement (W 1.4362)***

Contractor A: Probability-based durability design (cont.)

Established construction quality parameters:

1) *28-day chloride diffusivity (RCM):* $D_{28} \leq 2.0 \times 10^{-12}\ m^2/s$

2) *Nom. concrete cover: 85 ± 10 mm*

Contractor B: Descriptive durability requirements

- ***Current European concrete codes (NS-EN 206-1, 2003) + some additional requirements***
- ***Concrete structures No. 5 - 8***

Contractor B: Descriptive durability requirements (cont.)

1) Concrete quality:

- *$W/(C+k \cdot S) \leq 0.40$*
- *Binder content $C \geq 330$ kg/m^3 (30% FA cement)*
- *Silica fume $S \geq 4\%$ by wt. of C*
- *Air content $\geq 4\%$*

Contractor B: Descriptive durability requirements (cont.)

2) Min. concrete cover :

   - Under water: 50 mm → 70 mm

   - Over water : 60 mm → 90 mm

3) Provisions for CP + embedded instrumentation for future chloride control

ACHIEVED CONSTRUCTION QUALITY

- *Compliance with specified durability*
- *In situ construction quality*
- *Potential construction quality*

ACHIEVED CONSTRUCTION QUALITY (cont.)

As a consequence of the required documentation of achieved construction quality, a performance-based concrete quality control also had to be carried out for the structures based on descriptive durability requirements

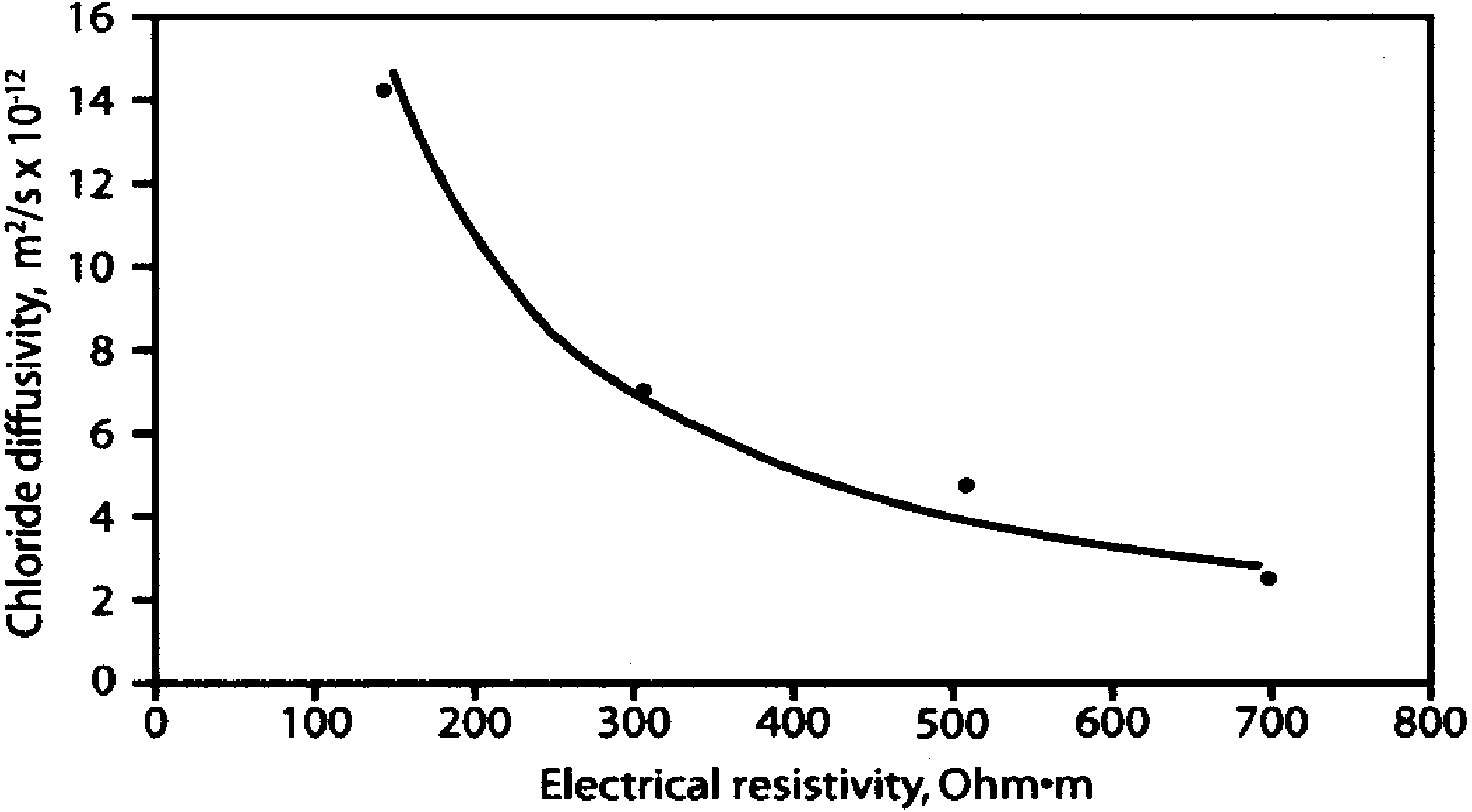
ACHIEVED CONSTRUCTION QUALITY (cont.)

A regular control of both chloride diffusivity and concrete over had to be carried out for the structures based on the descriptive durability requirements

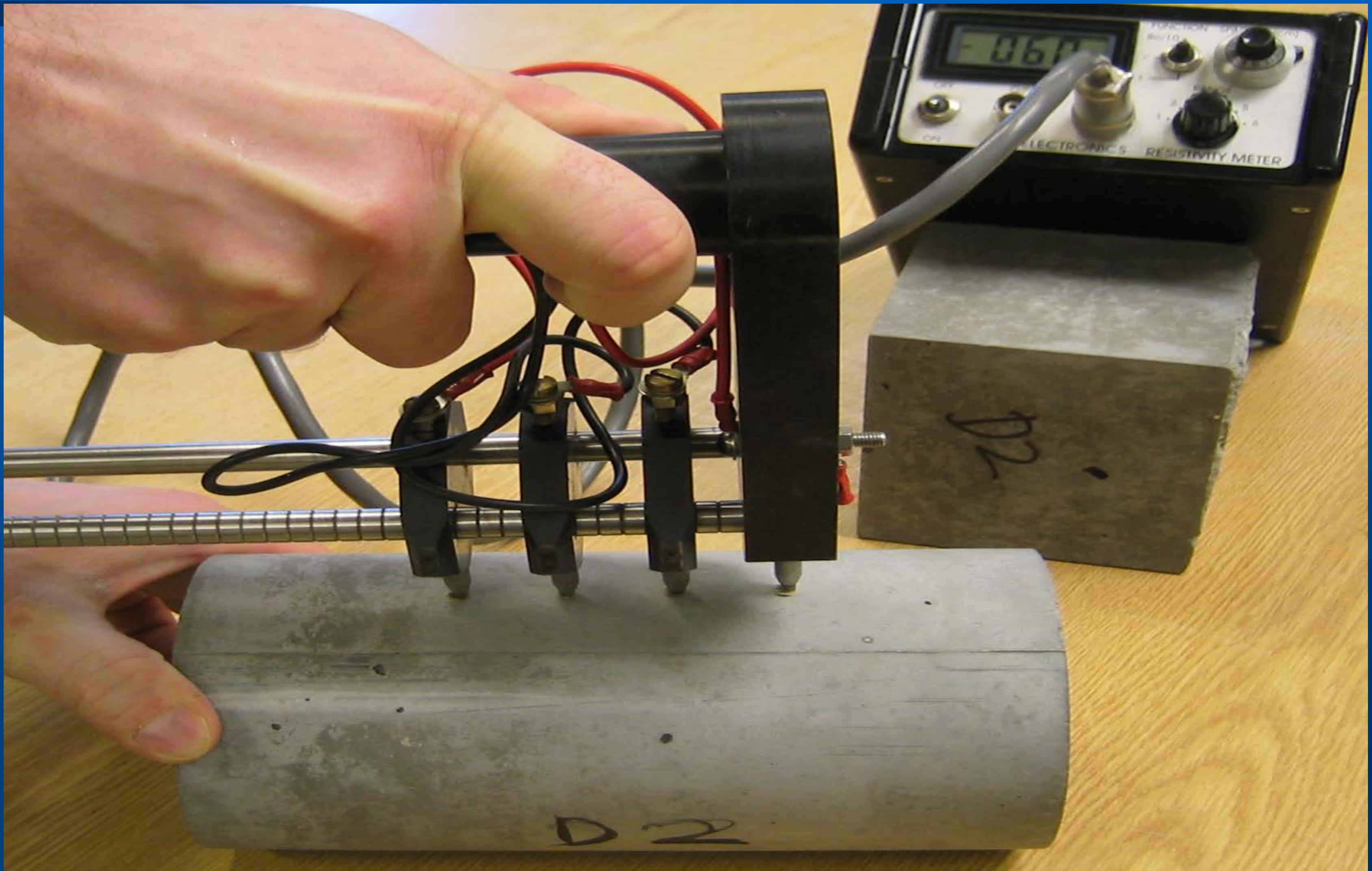
Control of chloride diffusivity (RCM) for all concrete structures

- ***Control of 28-day chloride diffusivity***
- ***Control of chloride diffusivity on construction site (in situ) (≤ 1 year)***
- ***Control of chloride diffusivity in laboratory (potential) (≤ 1 year)***

Typical calibration curve for control of the 28-day chloride diffusivity (D_{28})



Indirect control of the 28-day chloride diffusivity (D_{28})



Control of concrete cover

ACHIEVED CONSTRUCTION QUALITY: *Compliance*

Compliance (Contractor A):
Corrosion probability after 150 years (%) (≤ 10%)

Structure No.	Bottom slab	Walls	Deck
1	0.24	2.1	0.13
2	0.92	0.02	-
3	0.64	0.002	-
4	0.01	‹ 0.001	-

28-day construction quality (Contractor B): *Corrosion probability after 150 years (%)*

Structure No.	Bottom slab	Walls	Deck
5	15	3	6
6	-	11-13	-
7	14	1.3	-
8	-	-	4.5

Compliance (cont.)

- For all structures No. 1- 4 (Contr. A) the specified durability was achieved with very good margin
- For all structures No. 5 - 8 (Contr. B) it was not possible to verify and control the specified durability

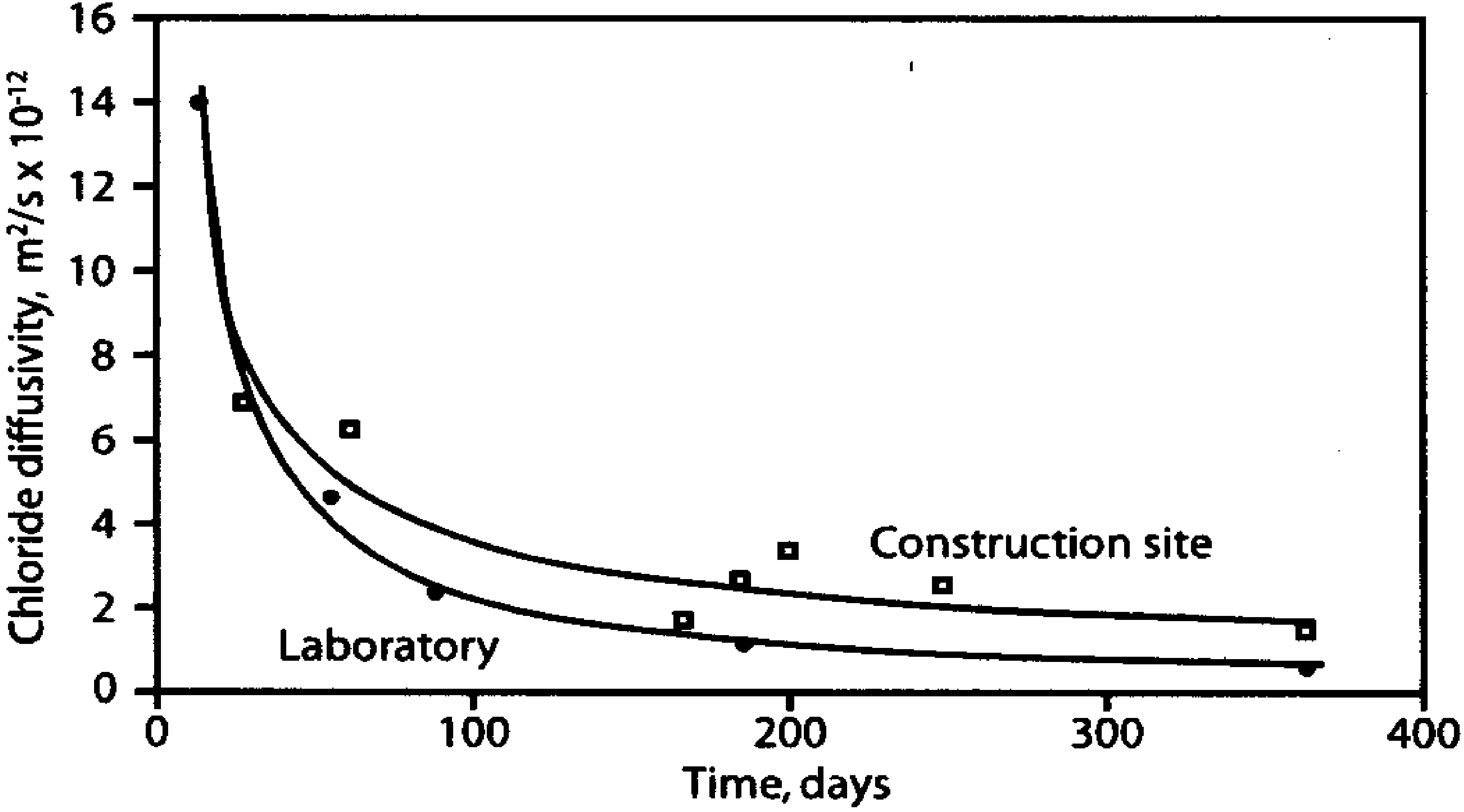
ACHIEVED CONSTRUCTION QUALITY: *In situ quality (≤ 1 year)*

Control of chloride diffusivity on construction site (in situ)

- Concrete cores from the given structures
- Concrete cores from corresponding dummy-elements

Production of dummy-elements

Development of chloride diffusivity on construction site and in laboratory



In situ quality (Contractor A): *Corrosion probability after 150 years (%)*

Structure No.	Bottom slab	Walls	Deck
1	‹ 0.001	‹ 0.001	0.02
2	‹ 0.001	‹ 0.001	-
3	‹ 0.001	‹ 0.001	-
4	‹ 0.001	‹ 0.001	-

In situ quality (Contractor B): *Corrosion probability after 150 years (%)*

Structure No.	Bottom slab	Walls	Deck
5	70	25	35
6	-	30	-
7	20	0.6	-
8	-	-	1.2

Achieved construction quality:
In situ quality (≤ 1year)

- For all structures No. 1- 4 (Contr. A) the corrosion probability was very low (‹ 0.001%)
- For all structures No. 5- 8 (Contr. B) the corrosion probability was very variable and partly very high (0.6 - 70%)

ACHIEVED CONSTRUCTION QUALITY: *Potential quality*

Potential quality (Contractor A): *Corrosion probability after 150 years (%)*

Structure No.	Bottom slab	Walls	Deck
1	‹ 0.001	‹ 0.001	0.002
2	‹ 0.001	‹ 0.001	-
3	‹ 0.001	‹ 0.001	-
4	‹ 0.001	‹ 0.001	-

Potential quality (Contractor B): *Corrosion probability after 150 years (%)*

Structure No.	Bottom slab	Walls	Deck
5	0.04	0.01	0.01
6	-	0.05	-
7	0.5	0.01	-
8	-	-	0.5

Achieved construction quality: *Potential quality*

- For all structures No. 1- 4 (Contr. A) the corrosion probability was very low (‹ 0.001%)
- For all structures No. 5 - 8 (Contr. B) the corrosion probability was also very low but much higher (0.01 - 0.5%)

SUMMARY

(1) *Probability-based durability design:*

- **It was possible to select a very good durability for the given concrete structures in the given environment during the required period of service**

SUMMARY (cont.)

(2) ***Probability-based durability design:***

- **For the durability desgn, it was possible to accomodate a high scatter and variability of all input parameters involved**

SUMMARY (cont.)

(3) *Probability-based durability design:*

- **It was possible to quantify how much of the black steel which was necessary to replace by stainless steel**

SUMMARY (cont.)

(4) ***Probability-based durability design:***

- **Possible to quantify the performance-based durability requirements:**
  - ***28-day chloride diffusivity (D_{28})***
  - ***Concrete cover***

SUMMARY (cont.)

(5) ***Performance-based durability requirements:***

- Possible to detect and correct possible deviations during concrete construction; reduced scatter and variability of achieved construction quality were observed

SUMMARY (cont.)

(6) ***Performance-based durability requirements:***

- Possible to document achieved construction quality

- Possible to document compliance with specified durability

SUMMARY (cont.)

(7) ***Descriptive durability requirements:***

- **Not possible to verify and control specified durability**
- **Higher scatter and variability of achieved construction quality were observed**

SUMMARY(cont.)

(8) *Descriptive durability requirements:*

- **Very difficult to argue about any weaknesses and deficiences which occurred during concrete construction as long as the requirement to compressive strength was still fulfilled**

SUMMARY (cont.)

(9) *Documentation of achieved construction quality:*

- The required documentation of achieved construction quality distinctly clarified the responsibility of Contractor A for the quality of the construction process

SUMMARY (cont.)

(10) *Documentation of achieved construction quality:*

- The required documentation of achieved construction quality distinctly improved the workmanship giving reduced scatter and variability of achieved construction quality

SUMMARY (cont.)

(11) *Documentation of achieved construction quality:*

- **For the owners it was very important to receive a documentation of achieved construction quality and compliance with the specified durability before the structures were formally been handed over from the contractors**

CONCLUSIONS (cont.)

(12) ***Service manual for preventive maintenance:***

- Upon completion of the structures, it was very important for the owner to receive a a service manual for regular condition assessment and preventive maintenance of the structures


NANYANG TECHNOLOGICAL UNIVERSITY

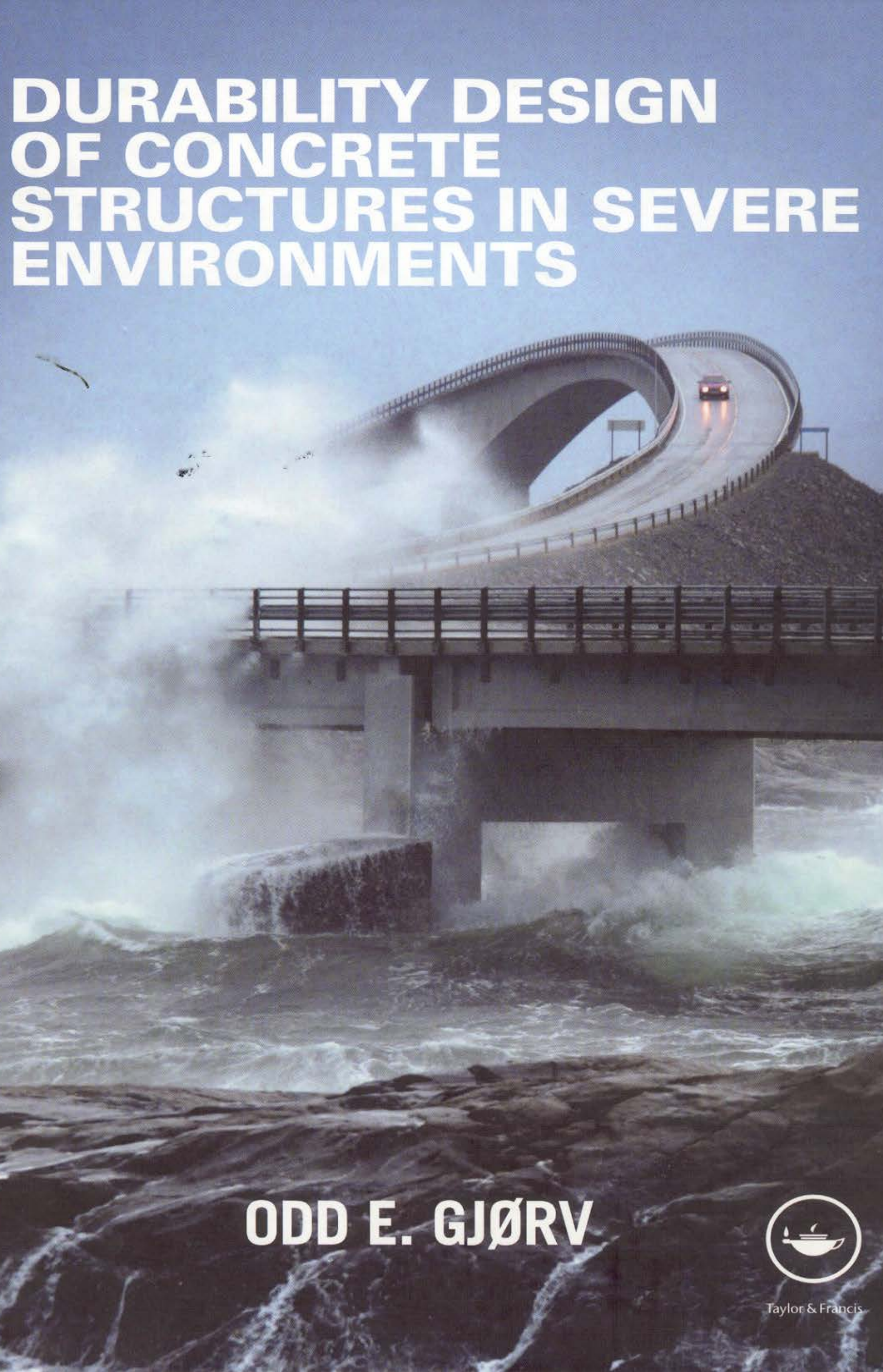
Future development of Singapore City

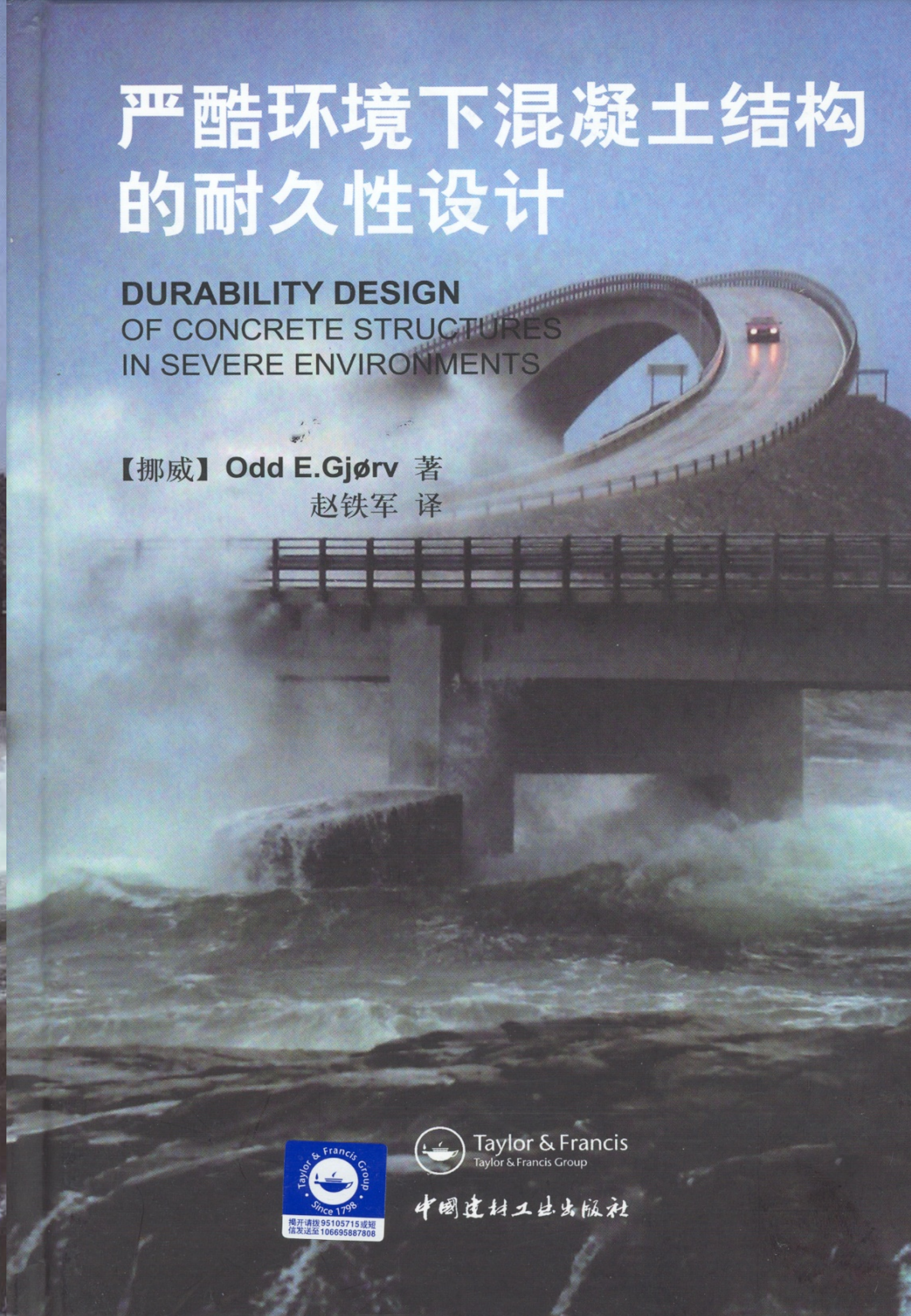
- **CRP Program “Underwater Infrastructure and Underwater City of the Future” (2011 – 2015)**
- ***“To create space for the future development of Singapore City based on a large number sea spaced concrete substructures”***


OUE


DONGAM


WGS84
MPA
PORT OF SINGAPORE
JOHOR
JOHOR
SINGAPORE
YOU ARE HERE
MAIN STRAIT


DURABILITY DESIGN
OF CONCRETE
STRUCTURES IN SEVERE
ENVIRONMENTS
ODD E. GJØRV
Taylor & Francis


严酷环境下混凝土结构
的耐久性设计
DURABILITY DESIGN
OF CONCRETE STRUCTURES
IN SEVERE ENVIRONMENTS
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CASE STUDY: Durability design of a marine concrete structure

Durability requirement: A ”service period” of 120 years with corrosion probability ≤ 10%

Step 1: Selection of proper concrete quality (*28-day chloride diffusivity*)

Step 2: Selection of proper concrete cover

Step 1: Four trial mixtures

- W/(C+kS): 0.38
- Cement content[1)] (C): 390 kg/m^3
- Silica fume content (S): 39 kg/m^3 (10%)

[1)] *Four commercial types of cement (Type 1-4)*

Step 1: Four trial mixtures (cont.)

Types of cement:

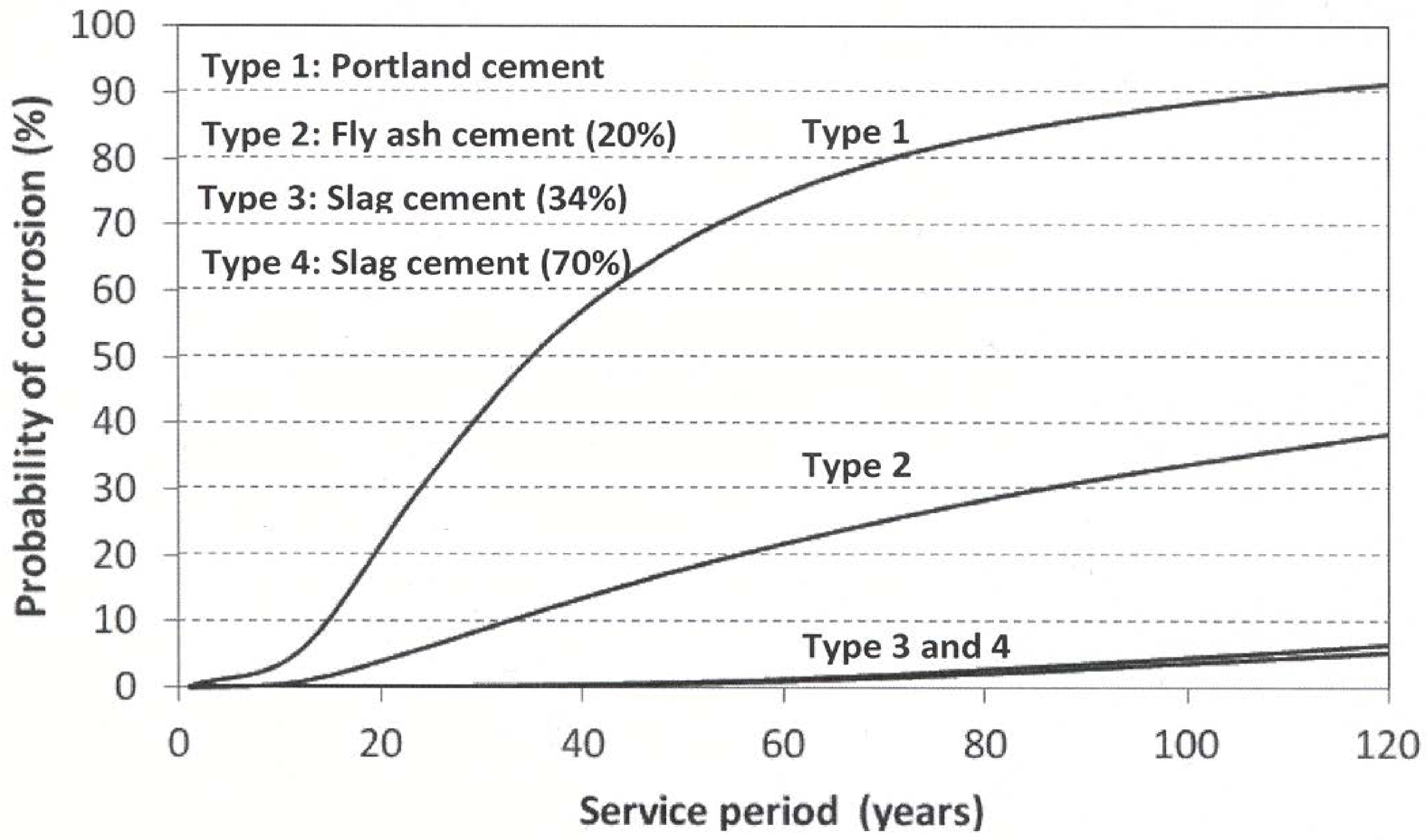
- Portland cement: Type 1
- Fly ash cement (18%): Type 2
- Slag cement (34%): Type 3
- Slag cement (70%): Type 4

Durability analysis - Step 1

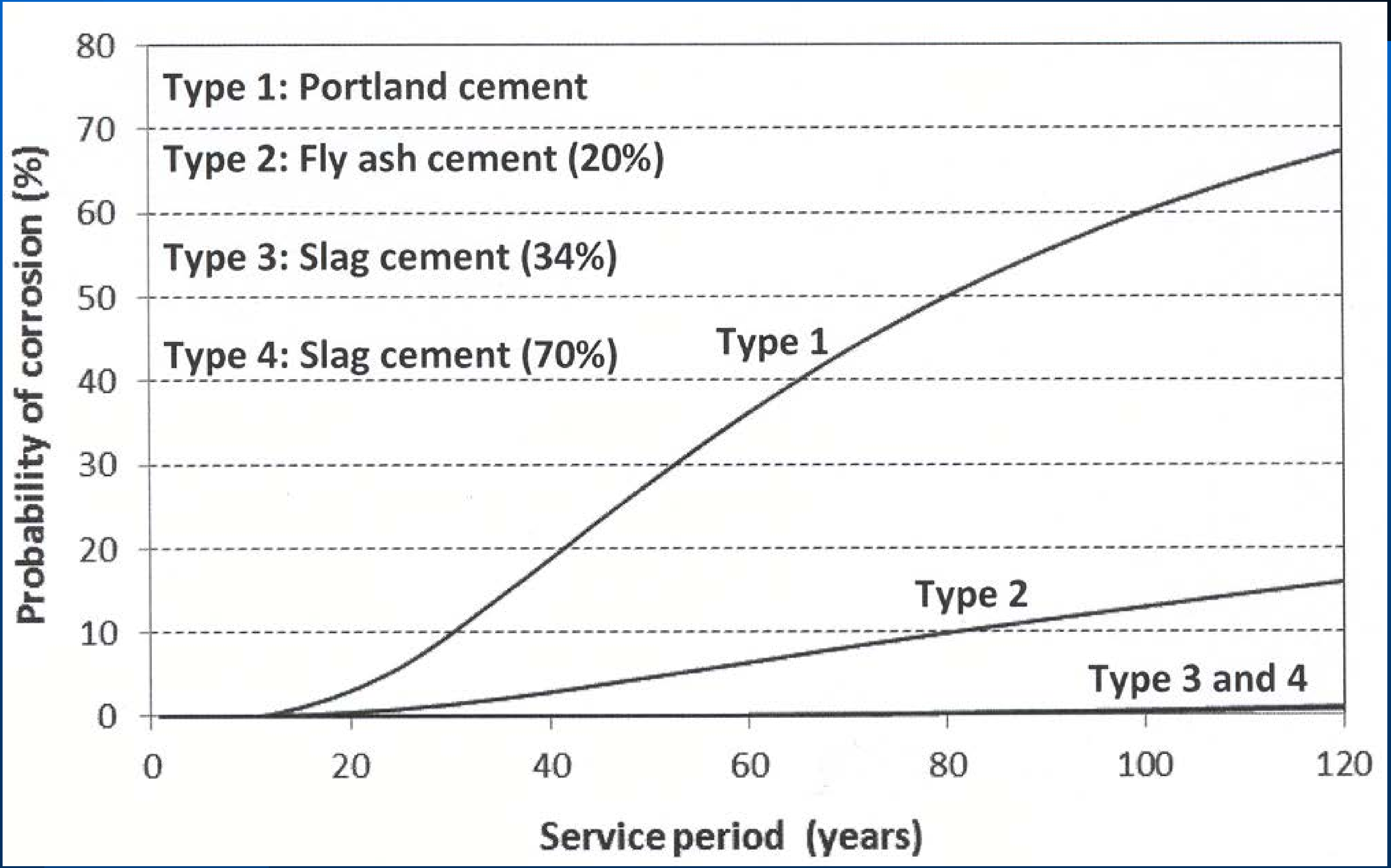
Concrete quality	Input parameter		
	D_{28} ($m^2/s \times 10^{-12}$)	α	C_{CR} (% by wt. of binder)
Type 1 (Portland cement + 10% CSF)	N[1](6.0;0.64)	N(0.40;0.08)	N(0.40;0.10)
Type 2 (18% Fly ash cement + 10% CSF)	N(7.0;1.09)	N(0.60;0.12)	
Type 3 (34% Slag cement + 10% CSF)	N(1.9;0.08)	N(0.50;0.10	
Type 4 (70% Slag cement + 10% CSF)	N(1.8;0.15)		

[1] *Normal distribution*

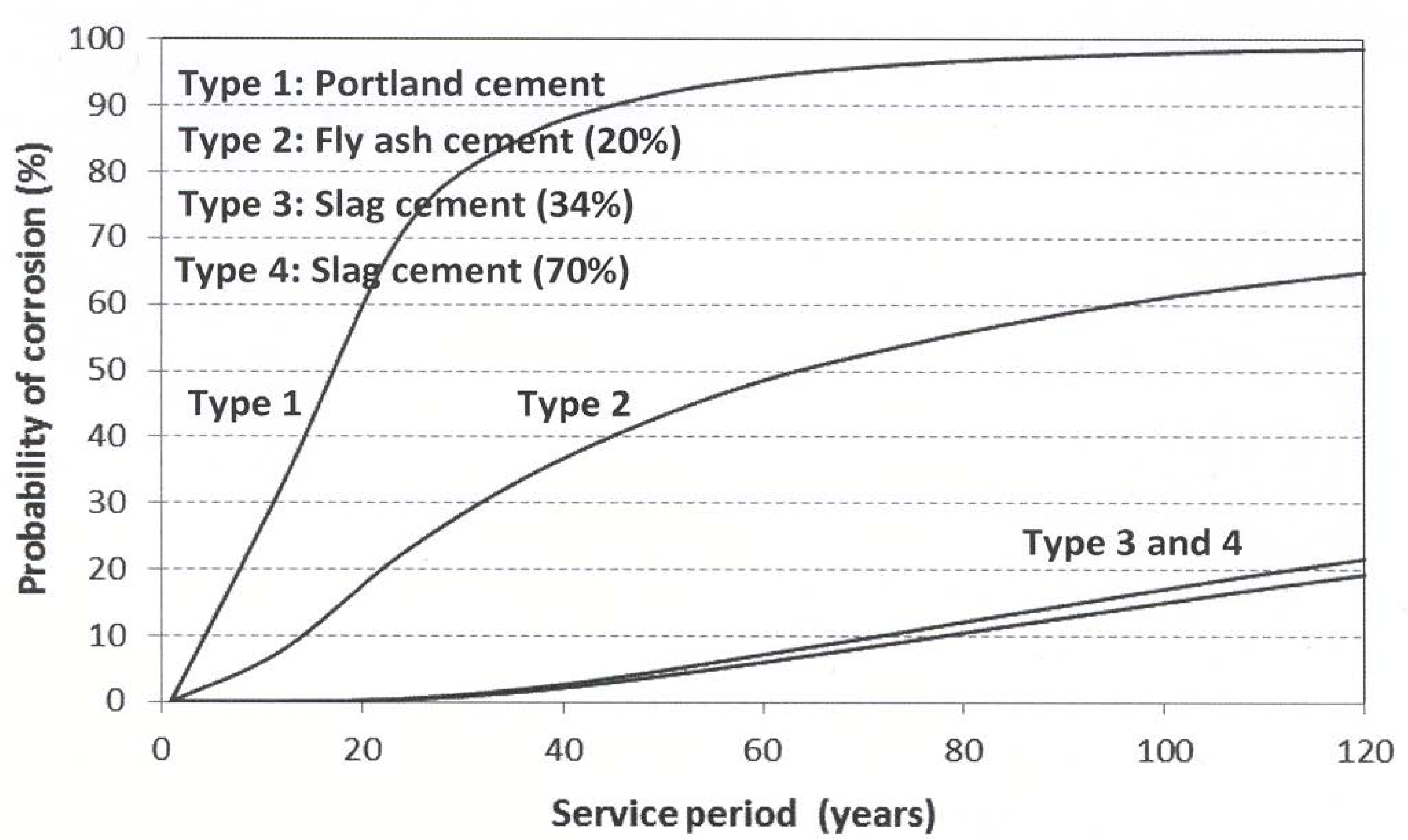
Effect of cement type (w/b = 0.38) Temperature : 20^0C



Effect of cement type (w/b = 0.38) Temperature : 10^0C



Effect of cement type (w/b = 0.38) Temperature : 30^{0}C



Durability analysis - Step 2

Input parameter	Average	Standard deviation	Comments
D_0	6.0	0. 64	Chloride diffusivity ($m^2/s \times 10^{-12}$)
α	0.40	0.08	Time dependence
C_{CR}	0.40	0.10	Critical chloride content (% by wt. of binder)
C_S	5.5	1.3	Chloride loading (% by wt. of binder)
X_C	70	6	Concrete cover (mm)
	90	6	
	120	6	

Effect of concrete cover (Type 1 Cement)