UJO

Beton til Femerntunnel

Eksponeringsplads

Christian Munch-Petersen, 1. november 2022 hos IDA

Beton strategi

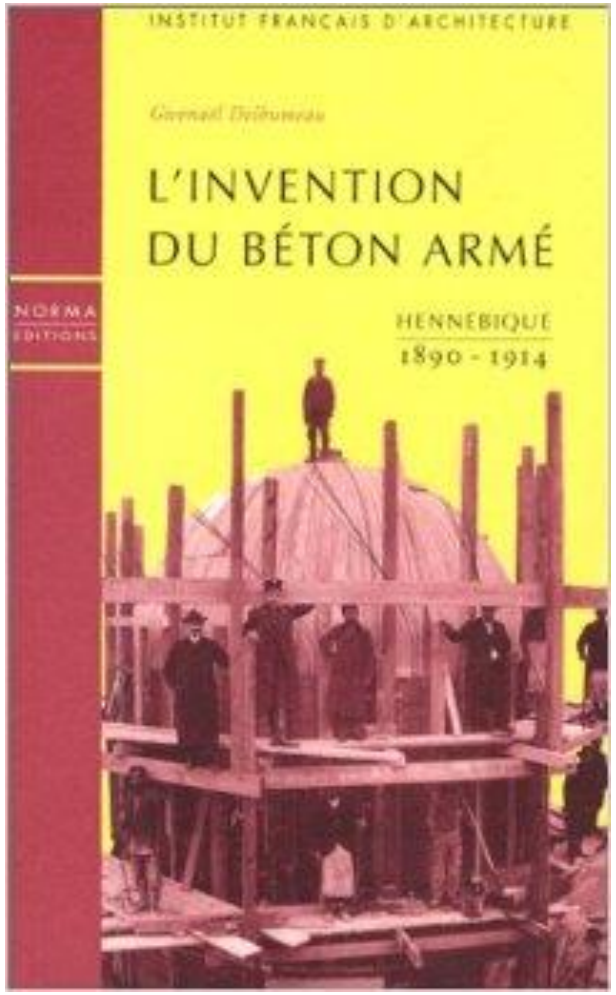
- 120 års levetid med brug af velkendt teknologi

= ikke start af korrosion eller større reparationer

= velkendt teknologi med gode erfaringer

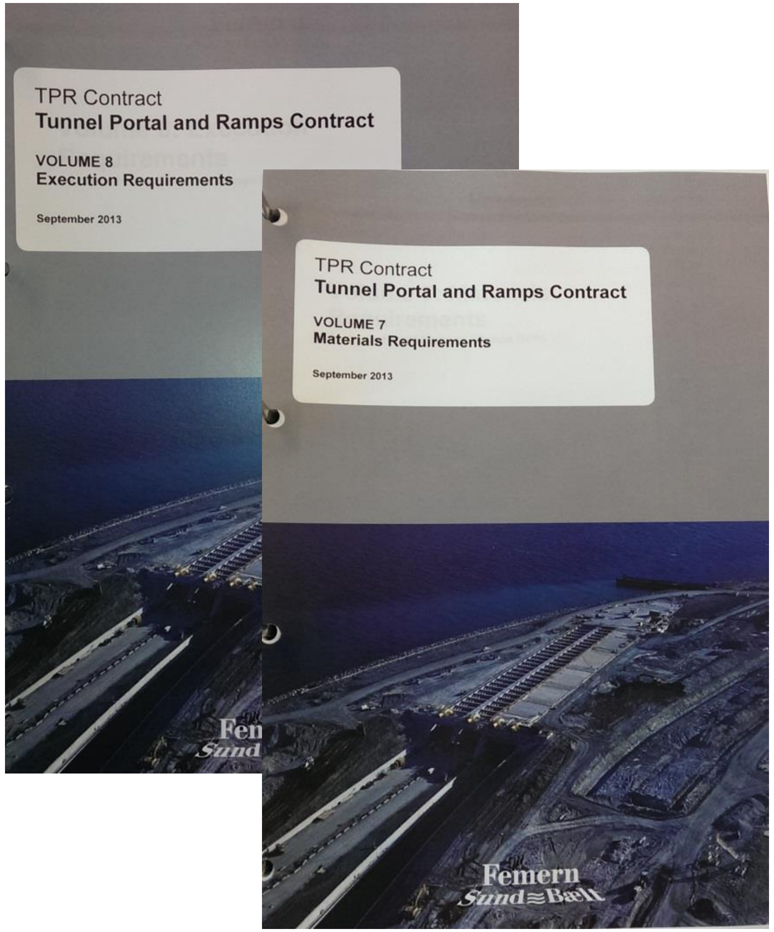
- Ikke konkurrence på kvalitet

- Bygherren definerer de krav, der sikrer levetiden



Hvordan er dette mål blevet opfyldt?

- EN 206-1 og EN 13670-1 brugt som ramme
- Omfattende Femern Materials and Execution Requirements" (120 års levetid og velkendt teknologi)
- Omfattende program for forprøvning og prøvestøbninger
- Kvalitetskontrol understøttet af veldefinerede godkendelsesprocedurer
- Systemer for certificering og akkreditering sikrer kvaliteten af materialer og prøvning



State-of-the-art rapporter

Tekniske noter fra Øresund

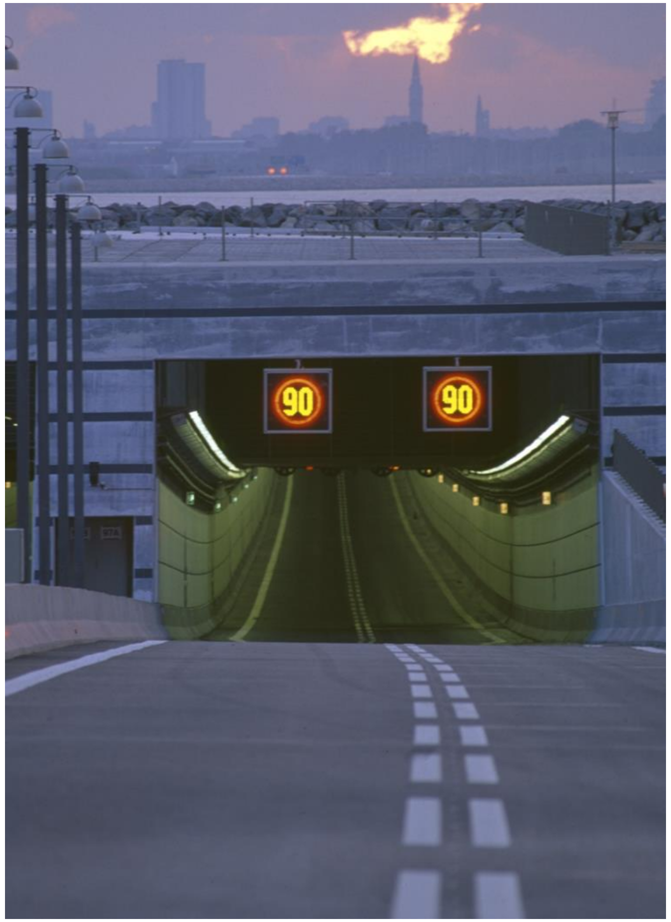
\+

Nye emner (fx SCC)

=

11 områder hvor baggrunds-rapporter er blevet produceret

- Udgør en videnskabelig basis for kravene
- Udgør sammen med strategien en fast basis for ledelsen under udførelsen (ved ændringsforslag og NCR)



Femern Sund≈Bælt

Femern A/S eksponeringsplads

- Etableret i Rødbyhavn april 2010 (bro)
- Dataopsamling skal understøtte kravene
- Lang tids dataopsamling giver viden om levetiden
- Entreprenørens beton skal også indgå
- Giver supplerende viden under tunnelens drift
- Platform for forskningsaktiviteter

Femern Sund≋Bælt

CONCRETE EXPERTCENTRE

www.concreteexpertcentre.dk

Fehmarnbelt exposure site

The concrete was produced under strict control at the Concrete Centre's HighTech Concrete Laboratory. Altogether thirtyseven concrete blocks and a large number of small test specimens were produced. Fifteen large concrete blocks (400 litres – 2 x 1 x 0.2 m) each having different concrete composition and seven instrumented blocks have been placed partly submerged in Rødbyhavn harbour. The concrete blocks will be monitored closely at least until the end of the construction period, which is expected to be in 2020.

Ikke sikker | concreteexpertcentre.dk/30663

DTU Civil Engineering
Department of Civil Engineering

DANISH TECHNOLOGICAL INSTITUTE

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Fehmarnbelt Exposure Site

Femern A/S, the Owner
Technological Institute a

The contract involved th
instrumentation for mor
testing of concrete, mor

An extensive testing pro

- Workability, d
- Initial setting
- Strength deve
- Frost resistan
- Chloride ingre
- Microstructure

The concrete was produ
and a large number of s
concrete composition ar
monitored closely at lea

Expert Centre for Infrastructure Materials

DANISH TECHNOLOGICAL INSTITUTE

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FEHMARN BELT EXPOSURE SITE

Femern A/S, the Owner of the coming Fehmarnbelt Fixed Link, through an open tender process selected the Concrete Centre at Danish Technological Institute as its external concrete laboratory.

The contract involved the design, production and testing of a range of concrete types of interest to Femern including some concrete blocks with instrumentation for monitoring of the initaiation and

Had kan man finde?

⊟ **Fehmarnbelt Exposure Site**

Design and production of concrete

Testing 6 months

Testing 2 years

⊞ **Initial Concrete testing**

Microscopic investigations

Testing 5 years

Testing 10 years

Betonsammensætninger til eksponeringsplads

- Lav alkali sulfatbestandig cement CEM I SR5 (LA)
- Kombinationer med og uden mikrosilica og flyveaske
- Slagge cement CEM III/B og CEM I + GGBS
- Beton til vibrering og SCC
- Holdbarheds parametre måles (chloridindtrængen, tærskelværdi, frost påvirkning, mikrostruktur udvikling og betydning af revner)

Femern Sund≈Bælt

Concrete ID			Ren Portland	Lav flyveaske	Høj flyveaske	SCC flyveaske	Mikrosilica	3-pulver	3-pulver uden luft	3-pulver højt v/c	3-pulver lavt v/c	SCC 3-pulver	Slaggecement	Slaggecement uden luft	SCC slaggecement	Rapid og slagge	Superabsorberende polymer
			A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Powder composition (%-wt)	Low alkali SR cement	CEM I 42,5 N	100	85	75	75	96	84	84	84	84	84					96
	Cement	CEM I 52,5 N														30	
	Slag cement	CEM III/B 42,5 N											100	100	100		
	Fly ash	EN 450-1 N		15	25	25		12	12	12	12	12					
	Microsilica	50 wt% slurry					4	4	4	4	4	4					4
	GG blast furnace slag	EN 15167-1														70	
Concrete composition	Cement	kg/m^3	365	322	300	336	340	300	310	276	330	350	360	375	410	108	340
	Fly ash	kg/m^3		57	100	112		43	44	39	47	50					
	Microsilica, solid matter	kg/m^3					14	14	15	13	16	17					14
	GGBS	kg/m^3														252	
	Water content	l/m3	146	140	140	157	147	140	145	145	135	163	144	150	164	144	147
	Aggregate 0/2	kg/m^3	695	671	642	678	695	677	731	700	671	687	689	702	686	689	695
	Aggregate 4/8	kg/m^3	377	374	367	349	377	377	386	380	374	354	373	381	353	374	377
	Aggregate 8/16	kg/m^3	266	270	271	704	266	272	266	268	270	713	263	269	712	263	266
	Aggregate 16/22	kg/m^3	529	538	541	-	529	543	530	534	538		525	535		525	529
	Air Entraining Agent	kg/m^3	1,7	1,7	2,3	4,0	0,7	1,6	0,0	1,5	2,3	2,2	0,8	0,0	1,6	1,0	0,0
	Superplasticizer 1	kg/m^3							3,8								
	Superplasticizer 2	kg/m^3		2,3	2,2												
	Superplasticizer 3	kg/m^3	2,8			2,9	2,7	2,9		2,6	3,6	3,4	2,3	2,6	2,9	2,9	3,7

Concrete ID			Ren Portland	Lav flyveaske	Høj flyveaske	SCC flyveaske	Mikrosilica	3-pulver	3-pulver uden luft	3-pulver højt v/c
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	Slag cement	CEM III/B 42,5 N								
	Fly ash	EN 450-1 N		15	25	25		12	12	12
	Microsilica	50 wt% slurry					4	4	4	4
	GG blast furnace slag	EN 15167-1								
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	Fly ash	kg/m^3		57	100	112		43	44	39
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Concrete ID			3-pulver lavt v/c	SCC3-pulver	Slaggecement	Slaggecement uden luft	SCC slaggecement	Rapid og slagge	Superabsorberende polymer
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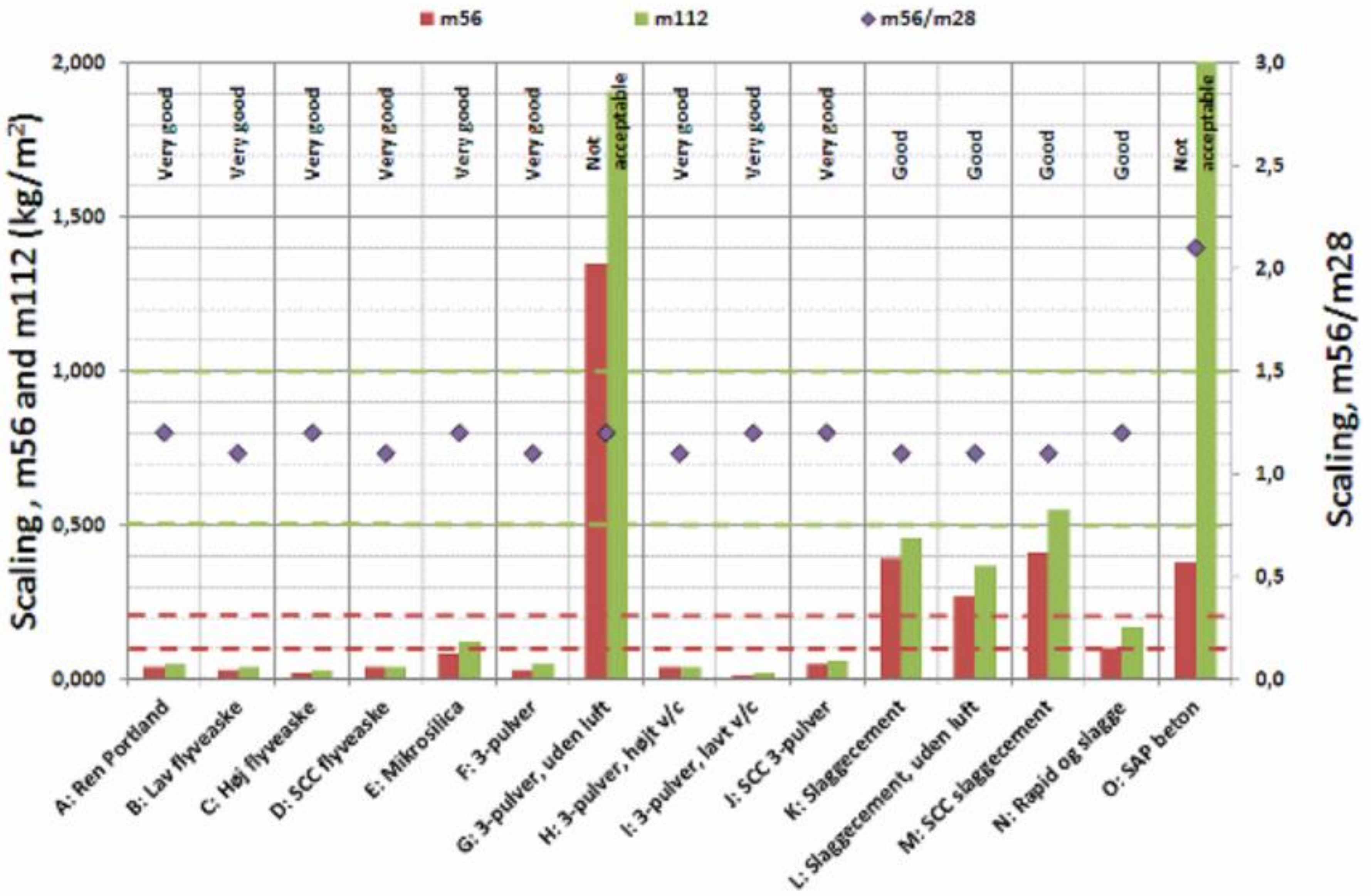
	Cement	CEM I 52,5 N						30	
	Slag cement	CEM III/B 42,5 N			100	100	100		
	Fly ash	EN 450-1 N	12	12					
	Microsilica	50 wt% slurry	4	4					4
	GG blast furnace slag	EN 15167-1						70	
on	Cement	kg/m^3	330	350	360	375	410	108	340
	Fly ash	kg/m^3	47	50					
	Microsilica, solid matter	kg/m^3	16	17					14
	GGBS	kg/m^3						252	

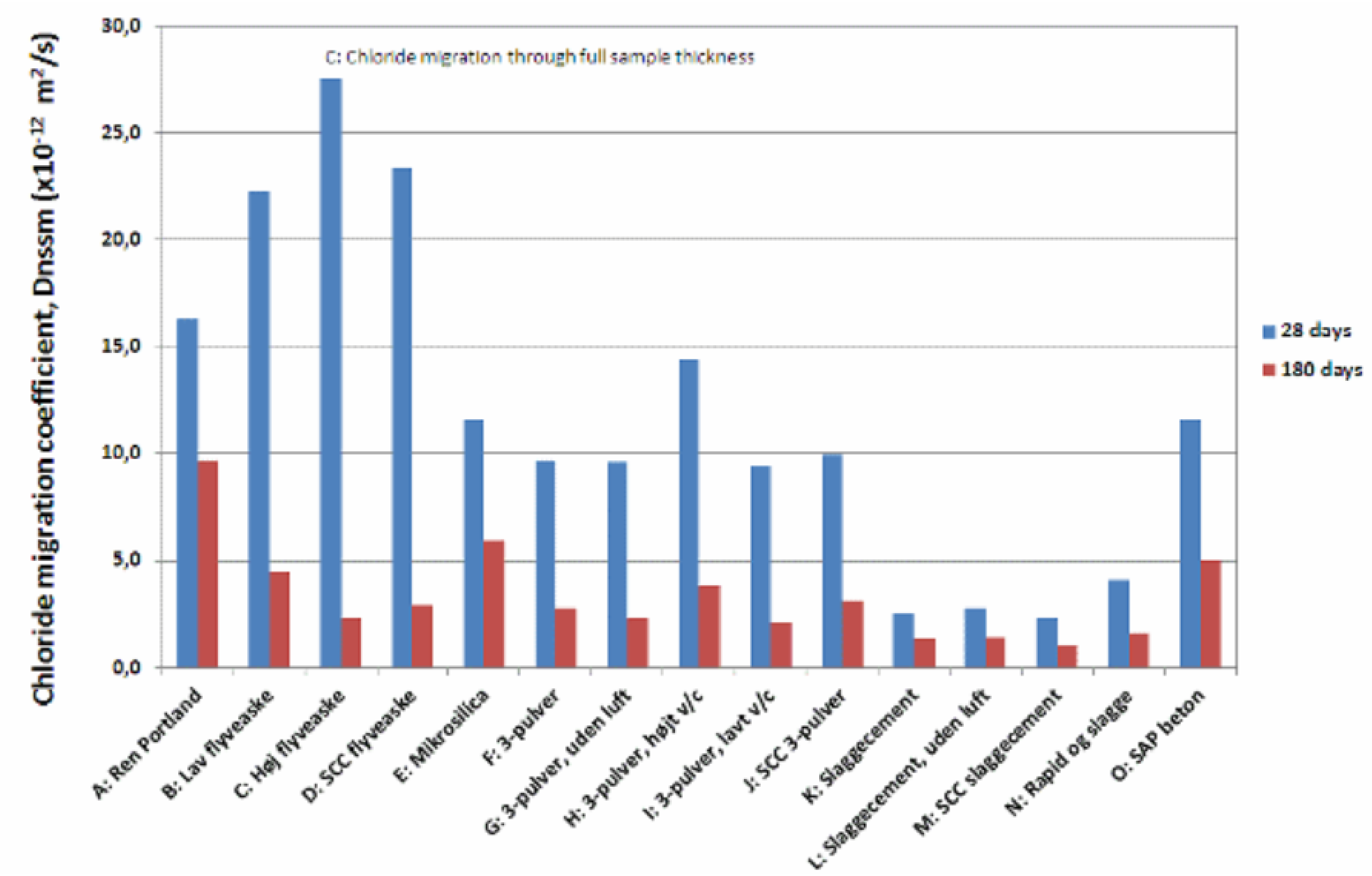
The maximum deviation on the w/c-ratio was 0,86 % corresponding to values between 0,397 - 0,403 for a nominal value of 0,400, i.e. roughly 10 times better than what is typically achieved by industrial concrete mixing stations.

Frostbestandighed – støbte terninger



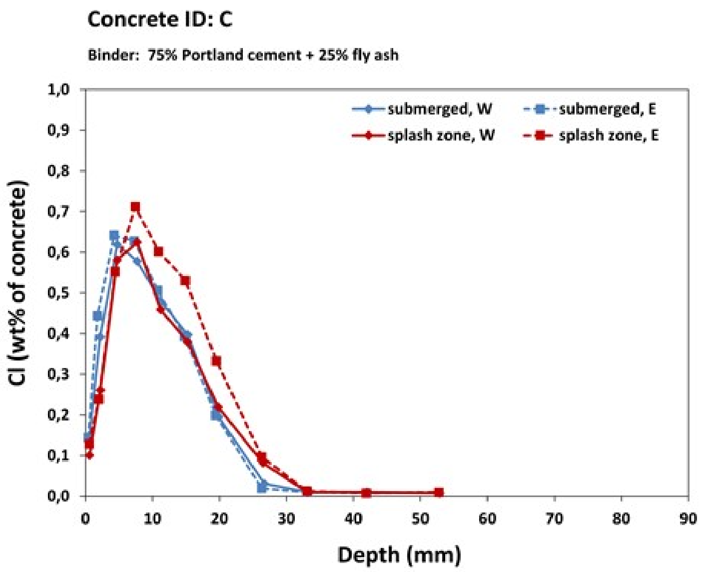
Femern Sund Bælt

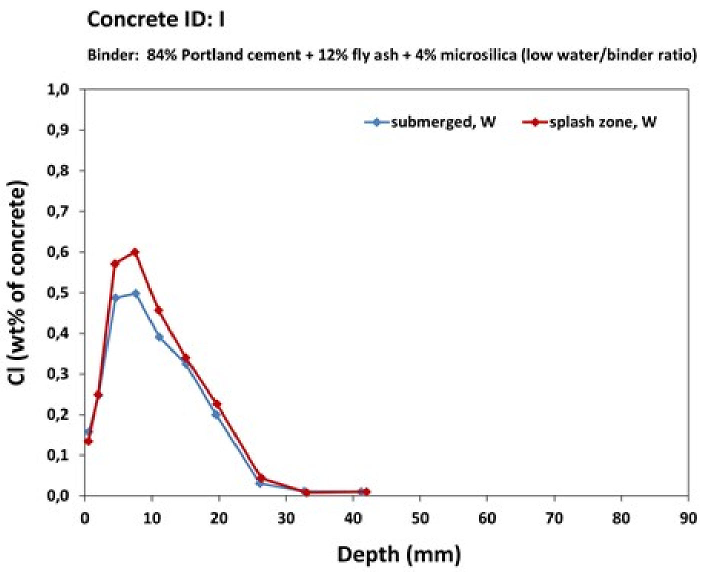
Chlorid migration

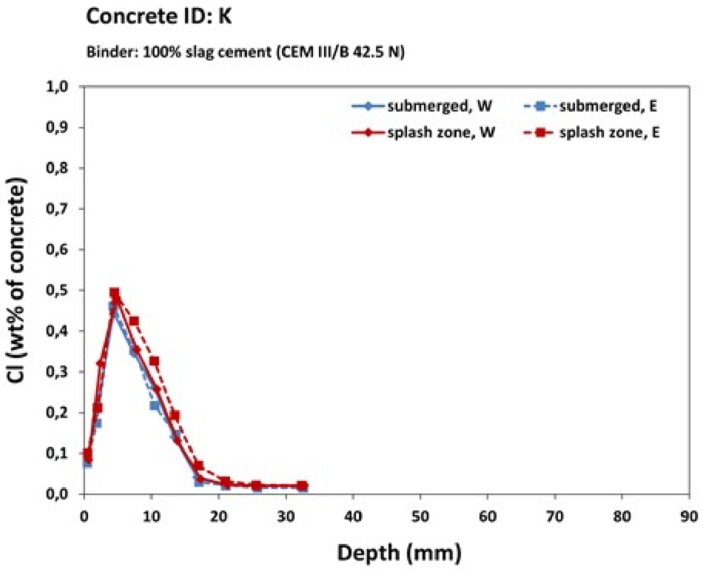


Eksponeret i havvand
fra ca. 45 dage

Chloridindtrængen efter 10 år







Nødvendigt dæklag = Kritisk indtrængningsdybde x √ 120/10 = Kid x 3,46

Betonhåndbogen, 19 Betons holdbarhed

BETON HÅNDBOGEN

19.3 Chloridindtrængning

Af Jens Mejer Frederiksen

(19.3-5) $$x = 2 \cdot D_a \cdot \mathrm{erfc}^{-1}\left(\frac{C(x,t)-C_i}{C_{sa}-C_i}\right)\sqrt{(t-t_{ex})}$$

Og idet

(19.3-6) $$K = 2 \cdot D_a \cdot \mathrm{erfc}^{-1}\left(\frac{C(x,t)-C_i}{C_{sa}-C_i}\right)$$

fås den endnu simplere form givet i formel (19.3-7), idet man samtidig ser, at $t >> t_{ex}$, hvorfor $(t-t_{ex}) \cong t$

(19.3-7) $$x = K \cdot \sqrt{t}$$