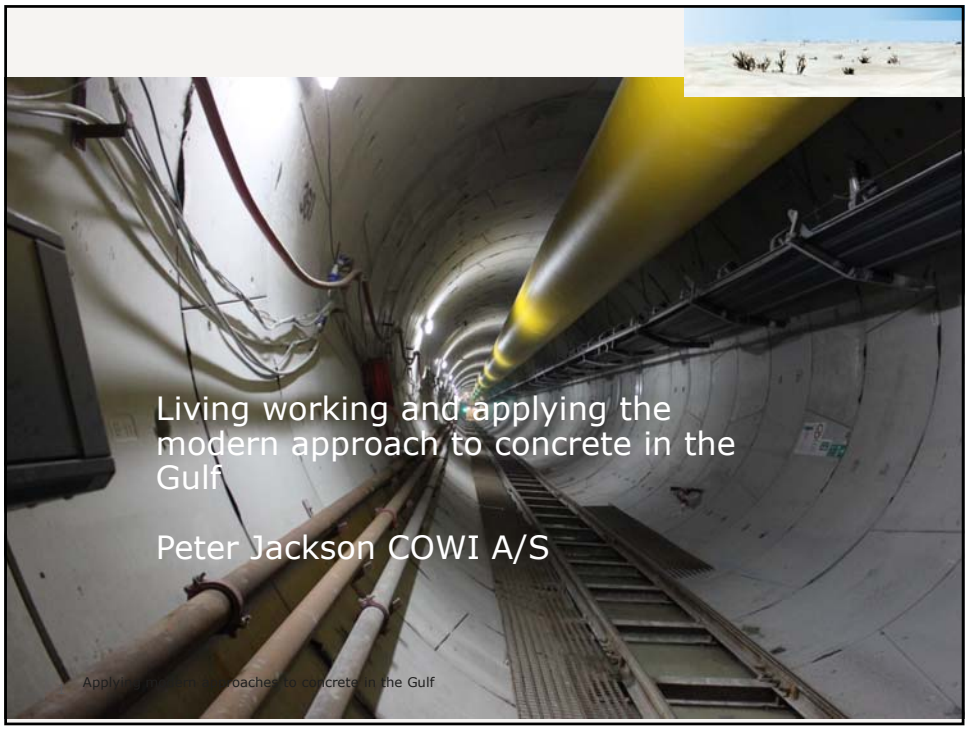

History

- 19th May 1994 formation of COWI's concrete department by Steen Rostam
- 19th May 1994 Carola Edvardsen joined COWI
- participation in a series of European Union supported durability research projects:
  - Duracrete 1998 to 2001 "The *Probabilistic Performance Based Durability Design of Concrete Structures"*
  - Duranet 1999 to 2001
- *participation the development of Fib Bulletin 34, published in 2006*

Implementation on Projects

Green Heart Tunnel, The Netherlands, 2000
Shatin Immersed tunnel, Hong Kong, 2004
Sitra Causeway, Bahrain, 2004
Yangzte River Crossing, Shanghai, 2005
Heating Shield tunnel, Denmark, 2005
Busan-Geoje Fixed Link, Korea, 2005
Bahrain Financial Harbour, 2006
Lusail Development project, Qatar, 2006
Seeb & Salalah International Airport, Oman, 2
Bahrain-Qatar Causeway, 2009
Puente Nigale Bridge, Venezuela, 2010
Izmit Bridge, Turkey, 2012
Step Tunnel, Abu Dhabi, 2009
Abu Hamour Tunnel, Doha, 2013
Tappan Zee Bridge (New York) USA, 2013
Ohio Bridge, USA, 2013
Doha Metro, Qatar, 2014

3 | Applying modern approaches to concrete in the Gulf

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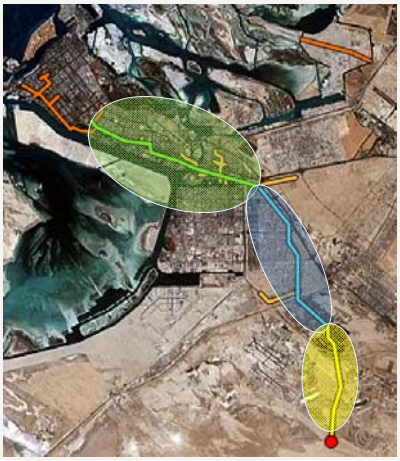
The STEP Project



STEP 2, Impregilo/COWI 15 km, 2010 - 2012
STEP 3, Impregilo/COWI 10 km, 2012 →

STEP Project:

- 41-kilometer long sewer tunnel
- 1.7 million m^3 of sewage a day
- Total of 6 Contracts
  - 3 tunnels,
  - 2 micro tunnels and
  - 1 pump station
- USD $ 1.6 billion

STEP = **S**trategic **T**unnel **E**nhancement **P**roject

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STEP T-02
Project in overall terms

- Segmental bored tunnel in 40 – 50 m depth, diameter Ø 5 m, 15 km long
- HDPE lining inside to avoid microbiologically induced concrete corrosion (sulfuric acid)
- 3 deep work shafts, Ø 18 m (WS)
- 3 deep access shafts, Ø 6 m (AS)

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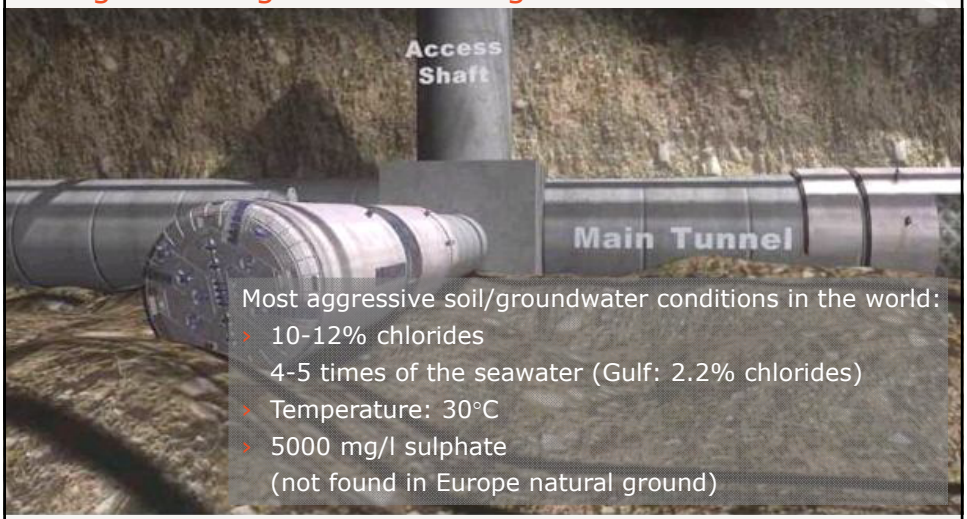
41 km long Sewer tunnel – 80 years design life
Huge challenges for the designers



Most aggressive soil/groundwater conditions in the world:

- 10-12% chlorides
  4-5 times of the seawater (Gulf: 2.2% chlorides)
- Temperature: 30°C
- 5000 mg/l sulphate
  (not found in Europe natural ground)

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The Team

- a COMMANDO job from Denmark, with a team of 6 people
- the majority of the design was carried out at the Contractor's office in Ab Dhabi
- Long working hours, but a very good and direct communication with the Contractor, Engineer and Client

Emirate of Abu Dhabi

Formula 1

When it started in 2010


هزاع بن زايد يشهد بدء العمل في النفق الاستراتيجي للصرف الصحي في أبوظبي

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Durability – concrete structures

- Reinforcement corrosion due to chloride ingress (10-12%)
- Sulphate attack (5000 ppm)
- Temperature around 30°C
- Corrosion and deterioration of concrete after few years

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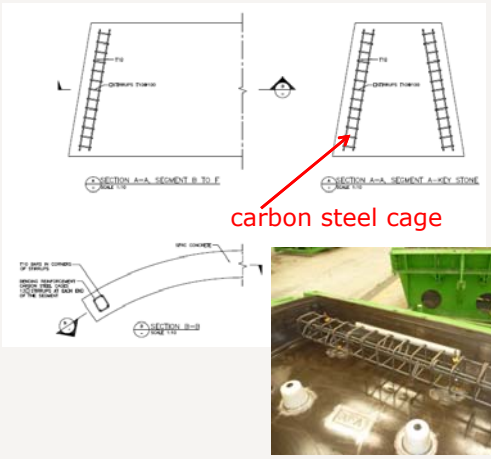
Service life

Additional rebar splitting reinforcement at the joints is needed – combined carbon steel reinforcement and SFRC



Durability of the carbon steel to be considered !

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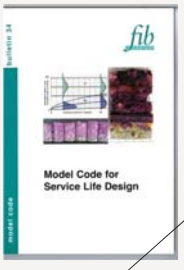
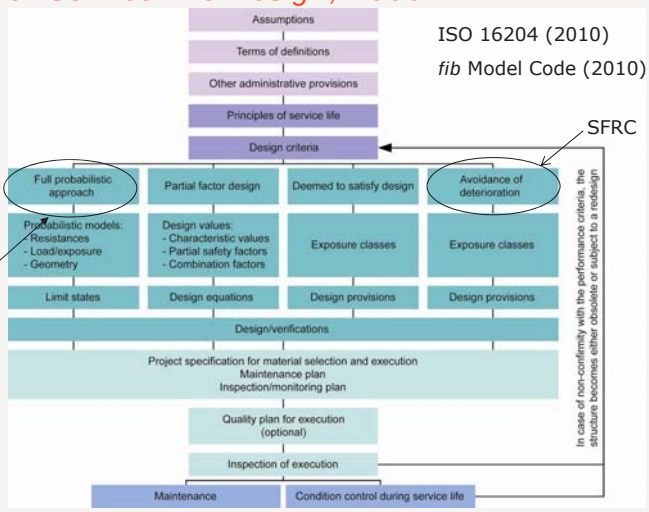
fib Bulletin 34, *Model Code for Service Life Design, 2006*





ISO 16204 (2010)

fib Model Code (2010)

SFRC

Carbon steel reinforcement

DuraCrete/ *fib* Bulletin 34 approach

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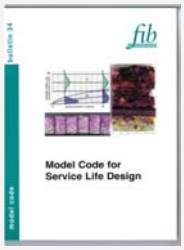
Service life

Measures:

- High quality and impermeable concrete
  - low chloride diffusivity
  - sufficient concrete cover

→ **DuraCrete tool *fib* 34**



Verification of 80 years service life for 10% onset of corrosion (β=1.3)

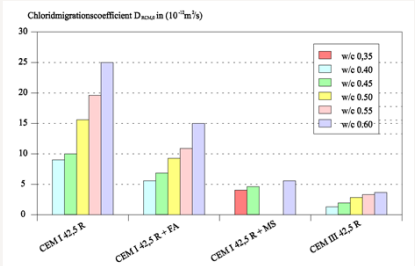
→ min. cover
max. D_{cl}

Concrete mix options

- **Sulphate attack (5000 ppm SO_4) + Chlorides (12%):**

	Sulphate	*Chloride*
OPC + Flyash + Micro silica:	👍	👍
OPC + GGBS:	👍	👍
Sulphate resistant OPC :	👍	👎

- **Selected concrete mixes foreseen during pre-testing:**
  - OPC + FA + MS
  - OPC + FA + GGBS
  - OPC + GGBS
  - OPC + GGBS + MS
- **Max. cover 65 mm**



Concrete mix requirements

Concrete grade: C50/60

Triple blend:
50% OPC + 20% FA + 30% GGBS

Max. chloride migration coefficient:
2.4×10^{-12} m^2/s

Fibre class: F1.4/0.6
Steel fibres: l = 47 mm
d = 0.8 mm

cover rebars: 65 mm

• Cement CEM I:	220	kg/m³
• Fly ash:	90	kg/m³
• GGBS:	130	kg/m³
• Sand:	673	kg/m³
• Aggregate 10 mm:	182	kg/m³
• Aggregate 20 mm:	728	kg/m³
• Water:	145	kg/m³
• Steel fibres:	40	kg/m³

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"Tuning" of concrete

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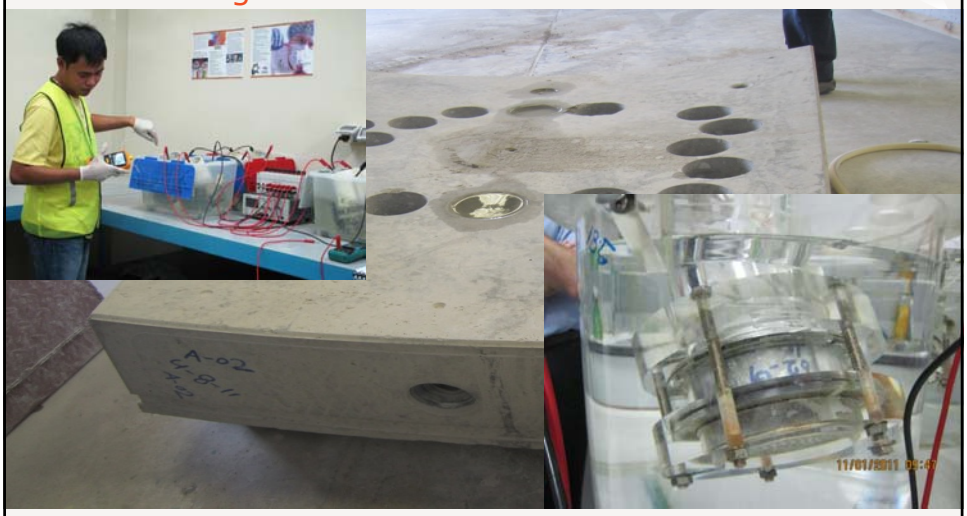
Concrete tests

- Flow table test (each batch)
- Water/cement ratio (2 x daily)
- Un-confined compressive strength test (3 spec./day)
- 4-Point bending test (3 spec./month)
- Splitting test (3 spec./month)
- Petrographic analysis (plan section) to determine fibre amount and distribution (1 spec./month)
- Wash-out test of fresh concrete ("fast" test to determine the fibre content) (1 spec./week)
- Chloride migration testing, NT Build 492 (lab cylinders and cubes from segments)

Amount & distribution of fibres

Durability testing
Chloride migration – NT Build 492



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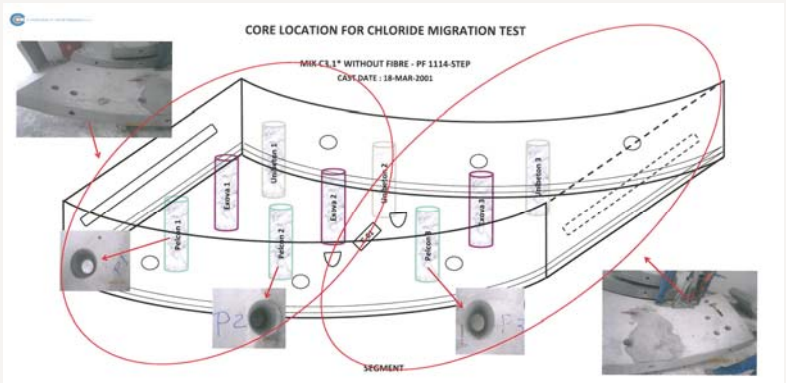
Lab cross check of chloride migration
Denmark – Abu Dhabi



	Lab 1 (DK)	Lab 1 (AD)	Lab 2 (AD)
September 2011	0.7x 10^{-12} m^2/s	0.9x 10^{-12} m^2/s	1.0x 10^{-12} m^2/s
October 2011	1.2x 10^{-12} m^2/s	0.9x 10^{-12} m^2/s	1.5x 10^{-12} m^2/s

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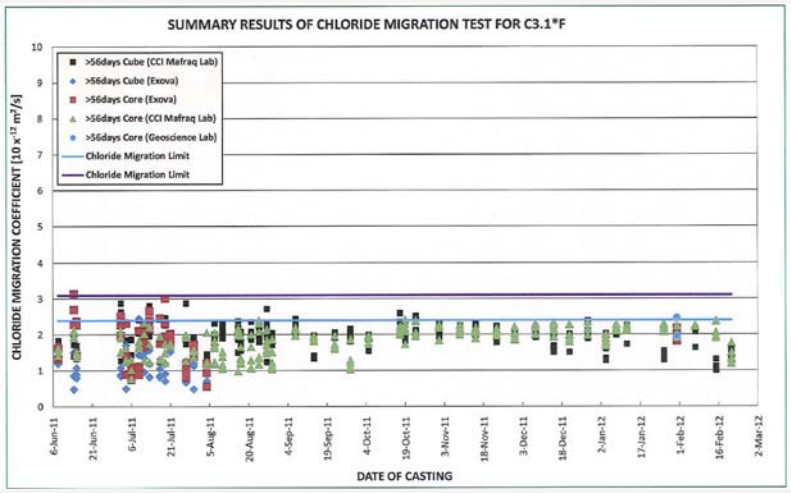
Concrete durability testing at CCI Mix 3.1*F



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Production of segments

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Conclusions

- 1 year to fix the final concrete mix
- No compromise in terms of durability
- first 400 rings produced were destroyed
- stainless steel used for next 2500 rings produced
- after that the chloride migration coefficient met the requirements

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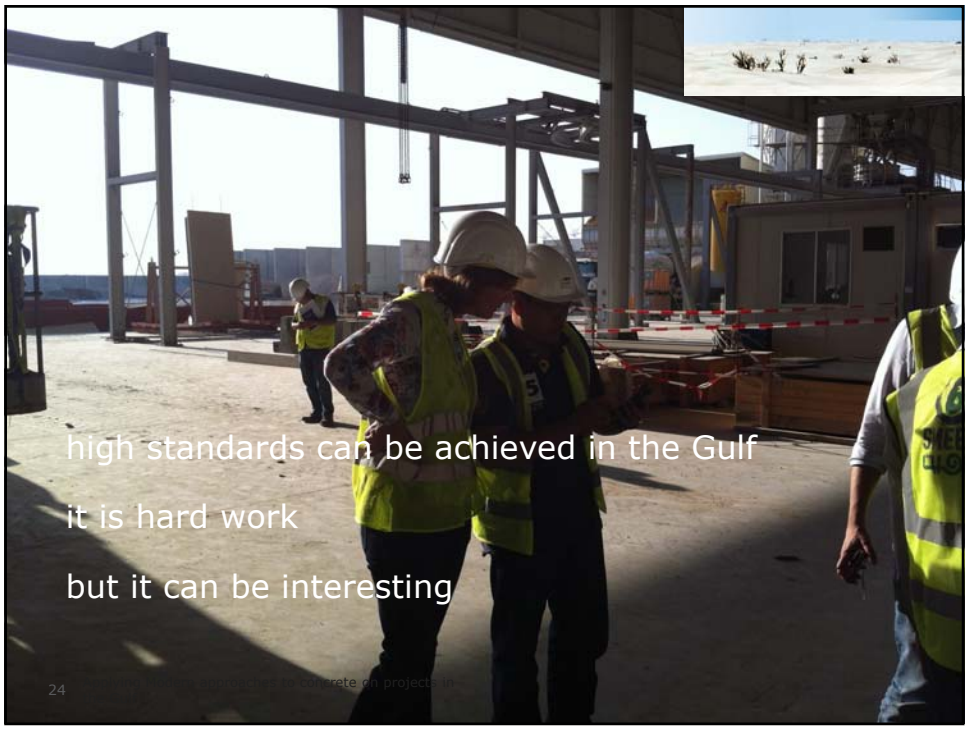

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