International Workshop

Istanbul Technical University

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Concrete

Performance Based Infrastructure Asset Management

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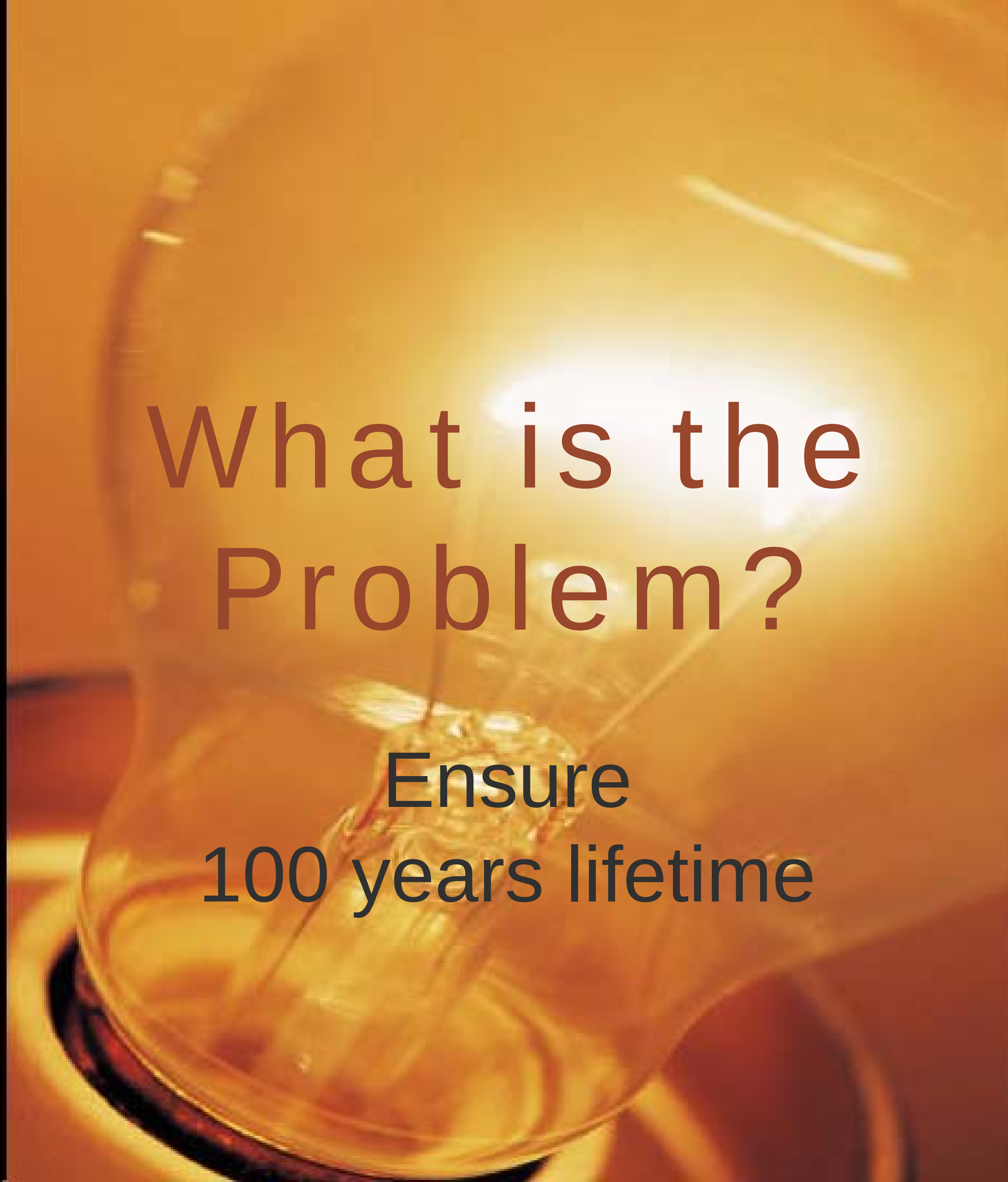
Contents

- Introduction to Marmaray and Oeresund Mega-Projects
- Oeresund versus Marmaray
- Concrete Strategy and Summary
- Some State of the Art Notes
- Lessons learned
- Status on the BC1 types of concrete

Project Logo

Marmaray

Introduction



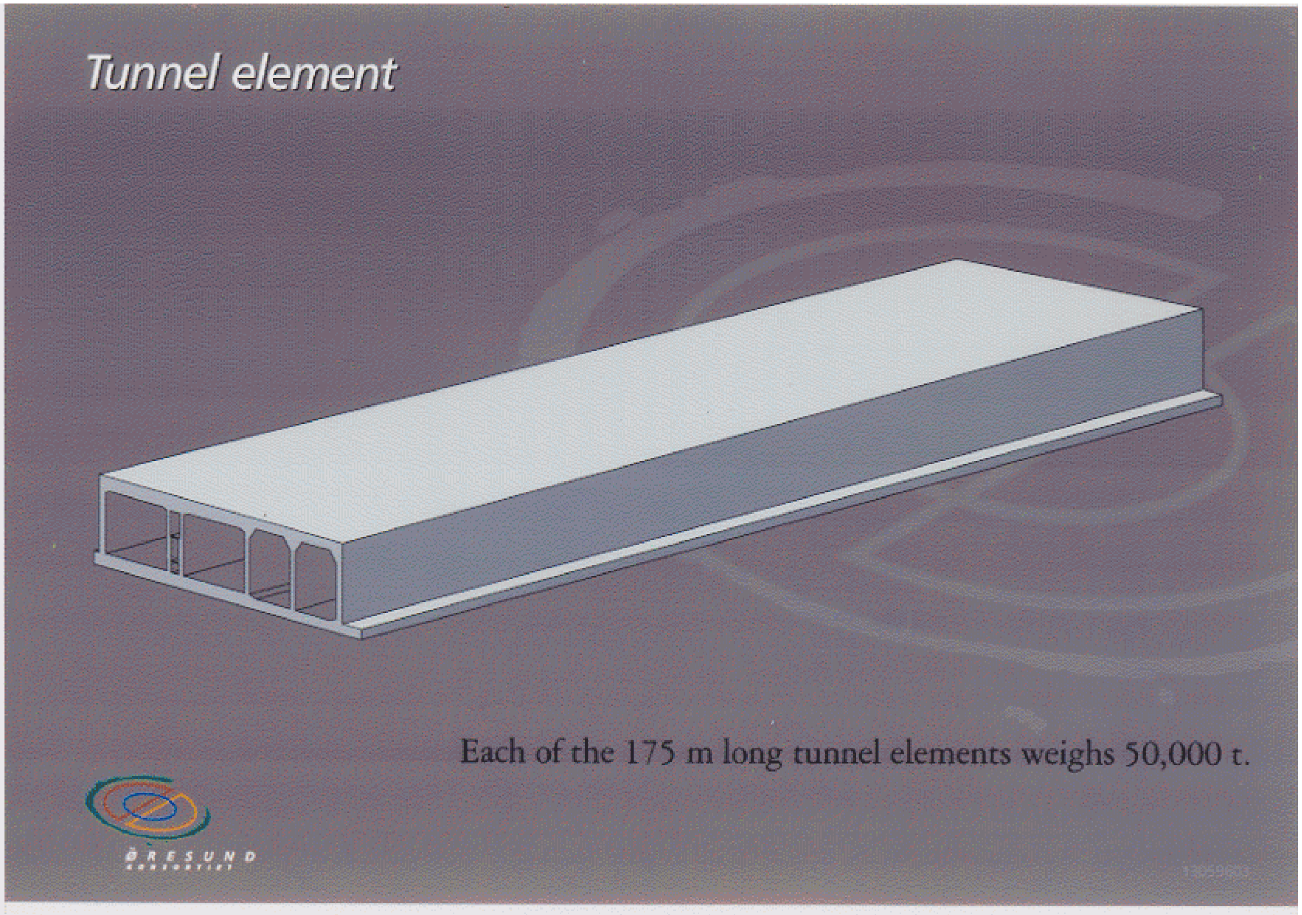
What is the Problem?

Ensure
100 years lifetime

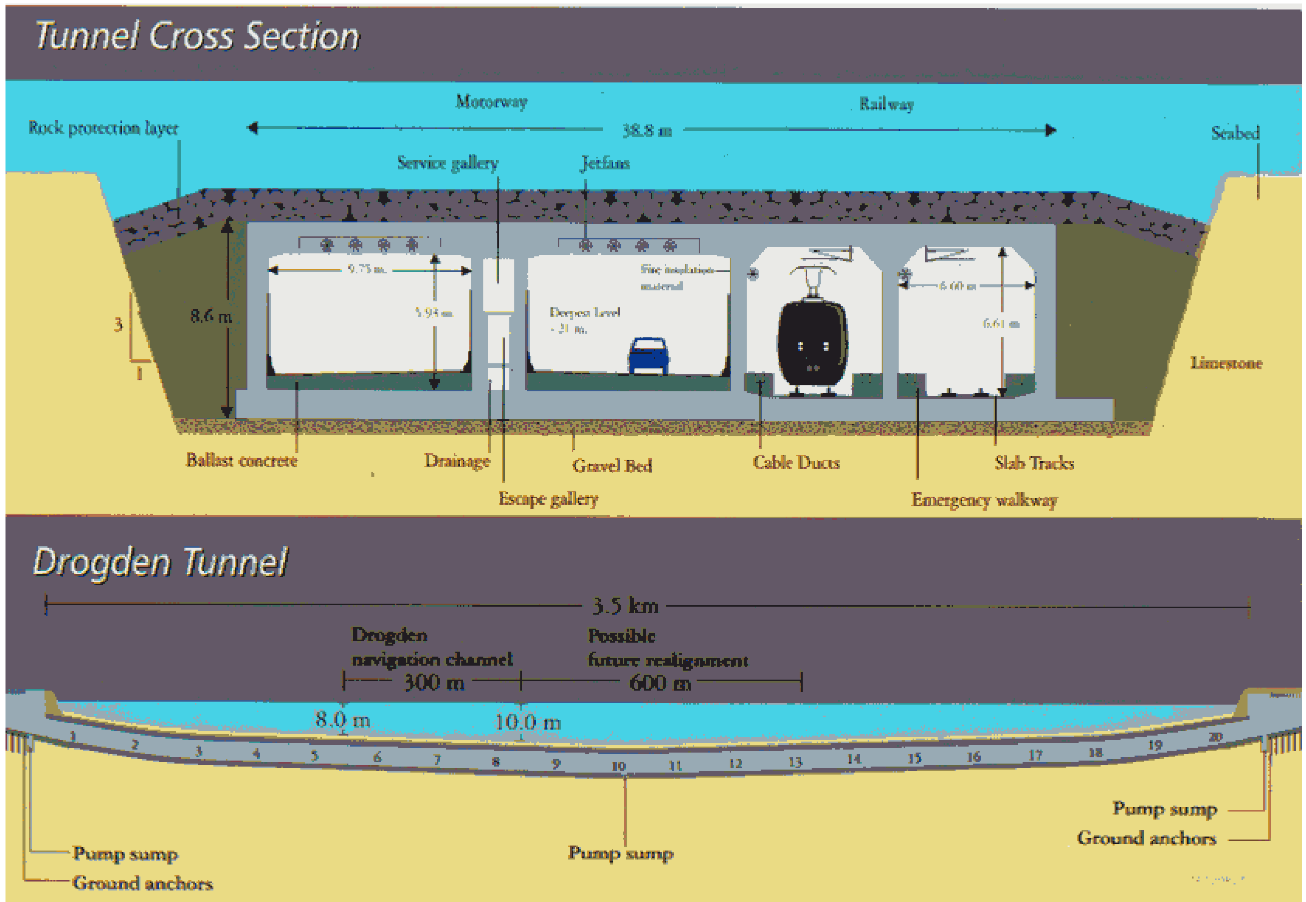
Introduction

- Facts and figures, Oeresund
  - Design & Build
  - 1,200,000 m3 of concrete
  - Includes IMT tunnel, C&C and Bridge
  - Saline, aggressive environment
  - Water tightness
  - 100 years lifetime
  - Biggest IMT tunnel ever constructed

Element, Oeresund



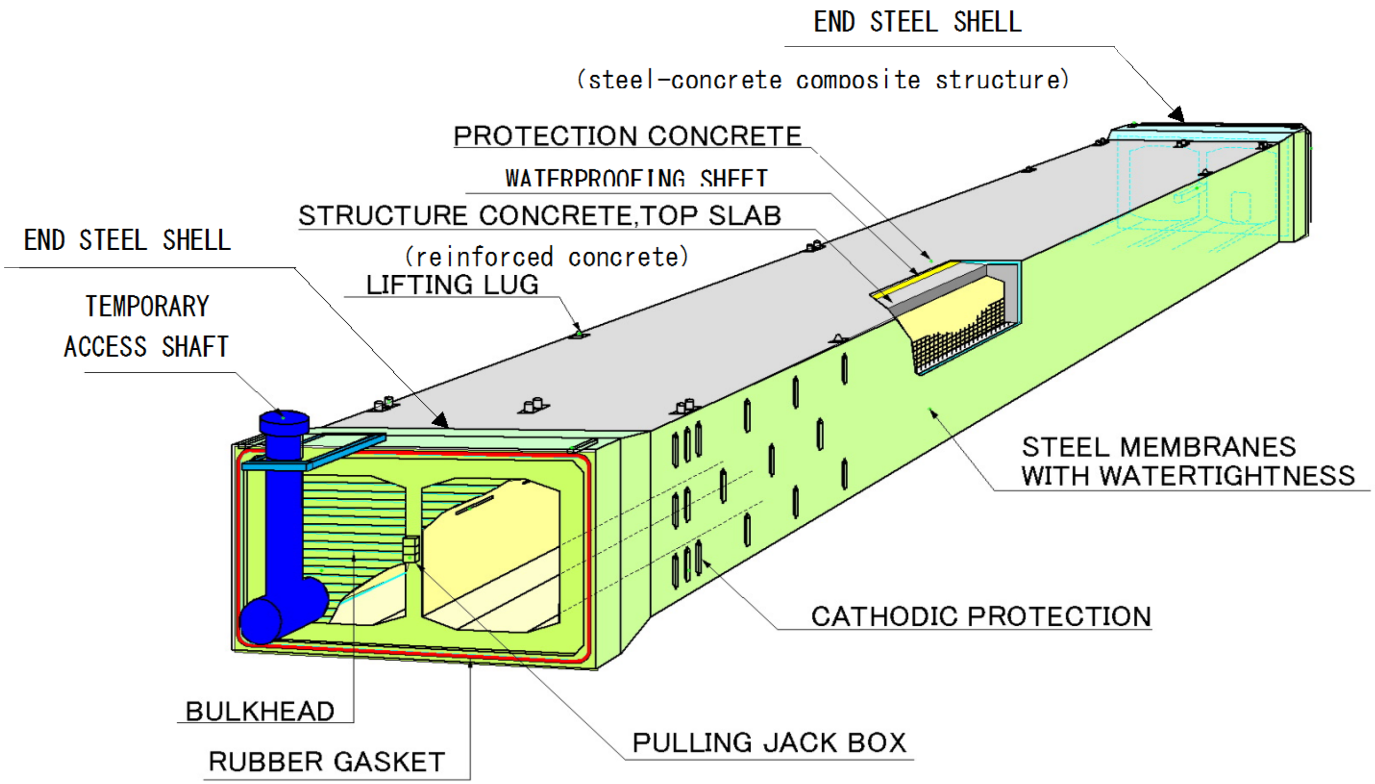
Cross section, Oeresund



Introduction

- Facts and figures, Marmaray
  - Design & Build
  - 1,300,000 m3 of concrete
  - Includes IMT tunnel, TBM tunnels C&C and NATM
  - Saline, aggressive environment
  - Water tightness
  - 100 years lifetime
  - Deepest IMT tunnel ever constructed

Element, Bosphorus

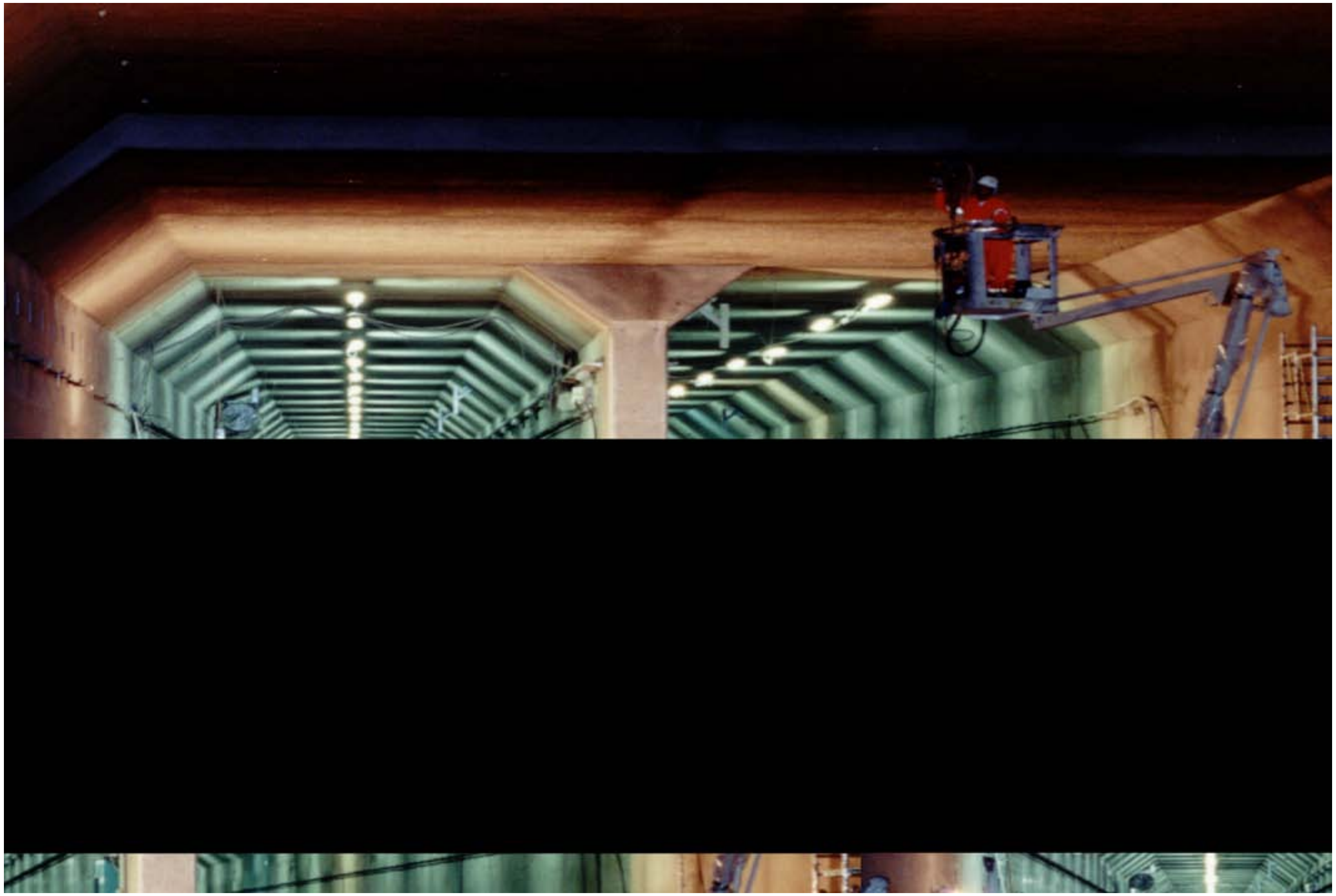


Introduction

- Facts and figures Immersed Tunnel, Oeresund
  - 20 elements, each 176x39x9 m
  - Max water depth 27 m
  - No external membrane
  - Approximately 100 kg reinforcement per m3

Reinforcement cage

The Railway tubes



Introduction

- Facts and figures Immersed Tunnel, Bosphorus
  - 11 elements each 135x16x8
  - Max water depth 58 m
  - External membrane mandatory
  - Approximately 280 kg reinforcement per m3

260 kg per m3!

Similarities

- Concrete is the dominating construction material
- Requirements to durability
- Destructive mechanisms
- Absolute Water tightness
- Conditions during hardening dictated by the material itself

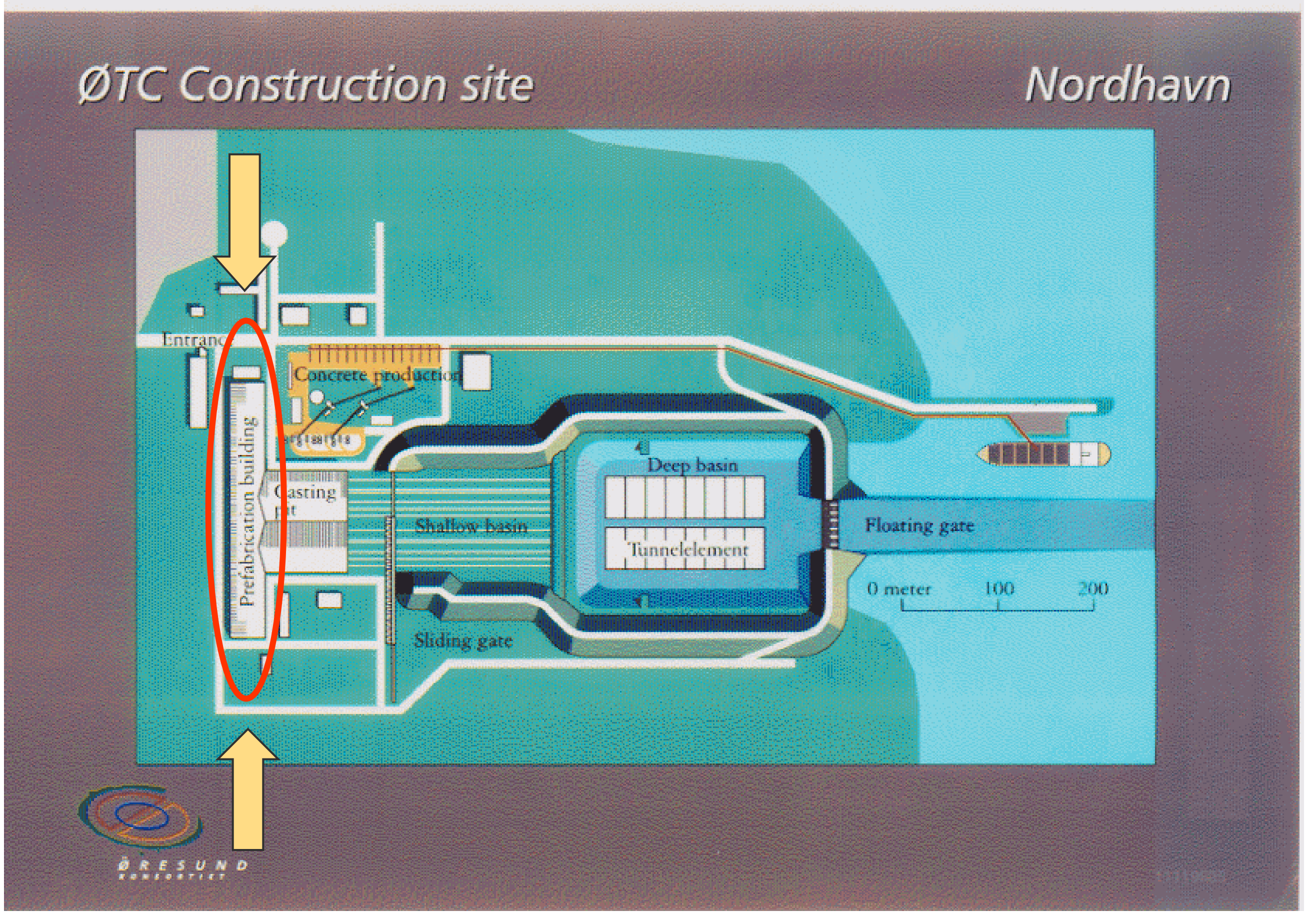
Differences

- Construction methods
- Casting section principles
  - Full section 22 m length
  - Part section, full 135 m length
- Membrane principles
- Climate during casting of Concrete
- Physical support during casting of Concrete, (semi floating)
- Production Plant on site versus off-site

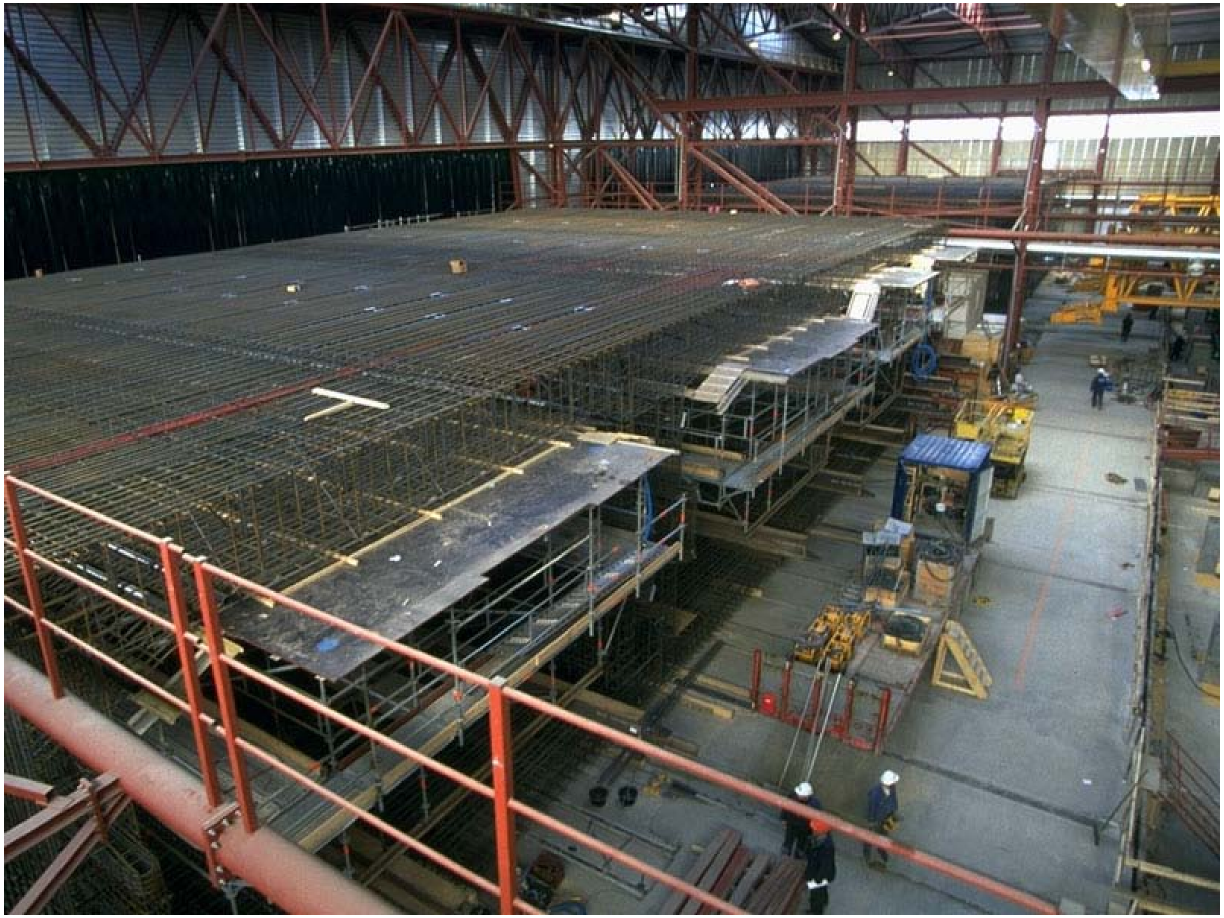
Semi Dry Dock, Marmaray

Semi Dry Dock, Marmaray

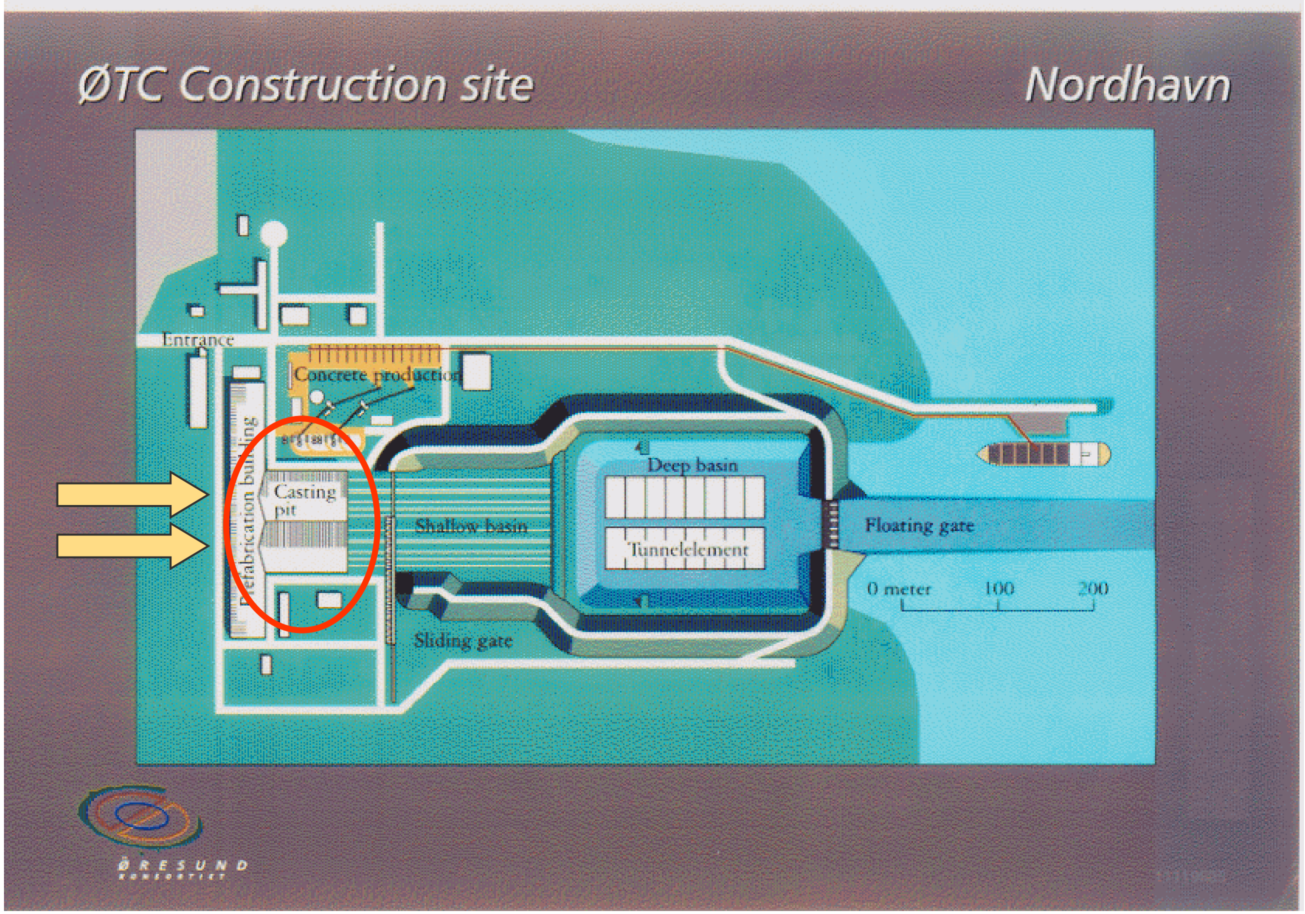
Yard, Oeresund, Reinforcement



Production Hall, Oeresund

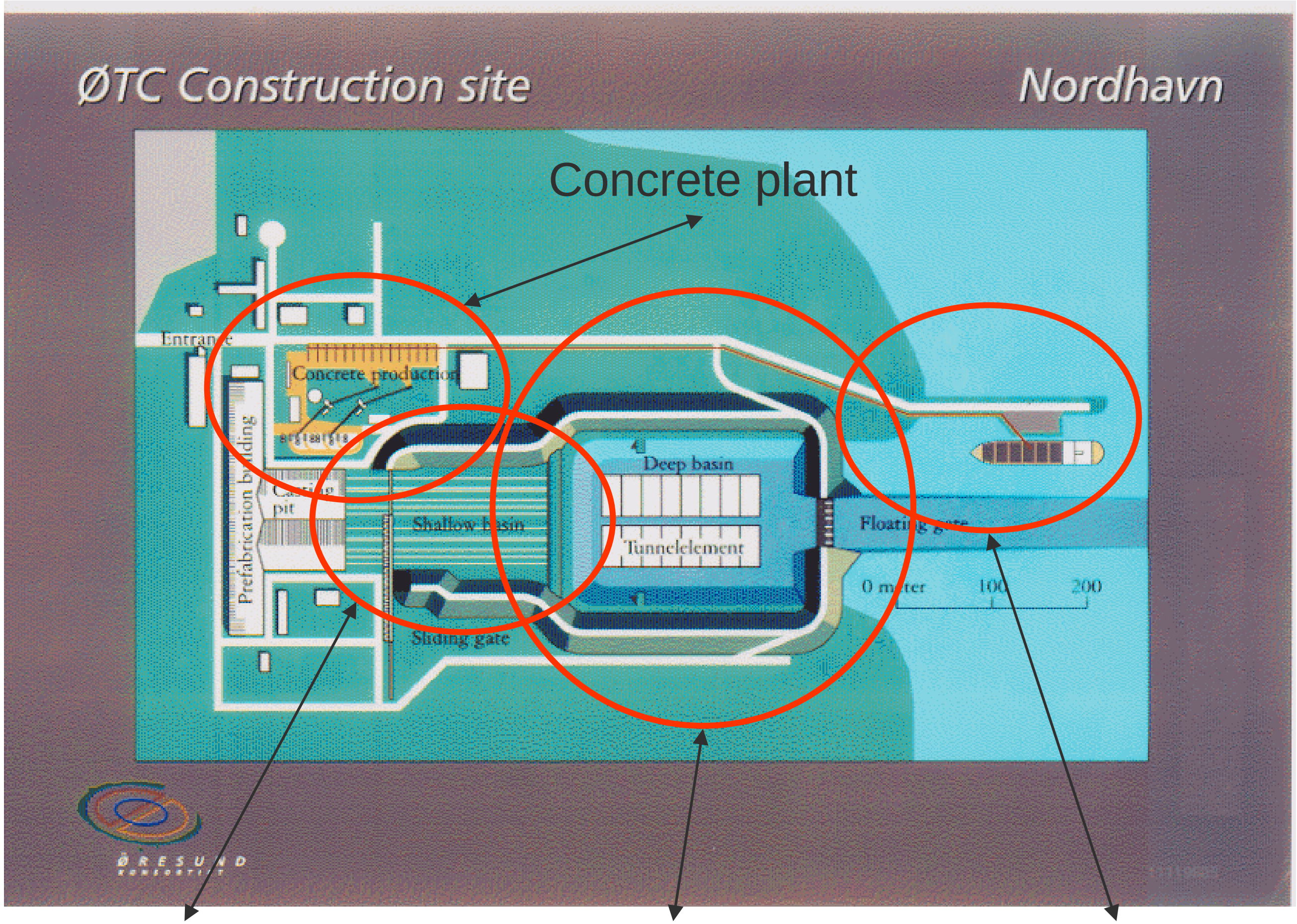


Yard, Oeresund, Casting of 22 m sections



Production Hall, Oeresund

Yard, Oeresund, Other facilities

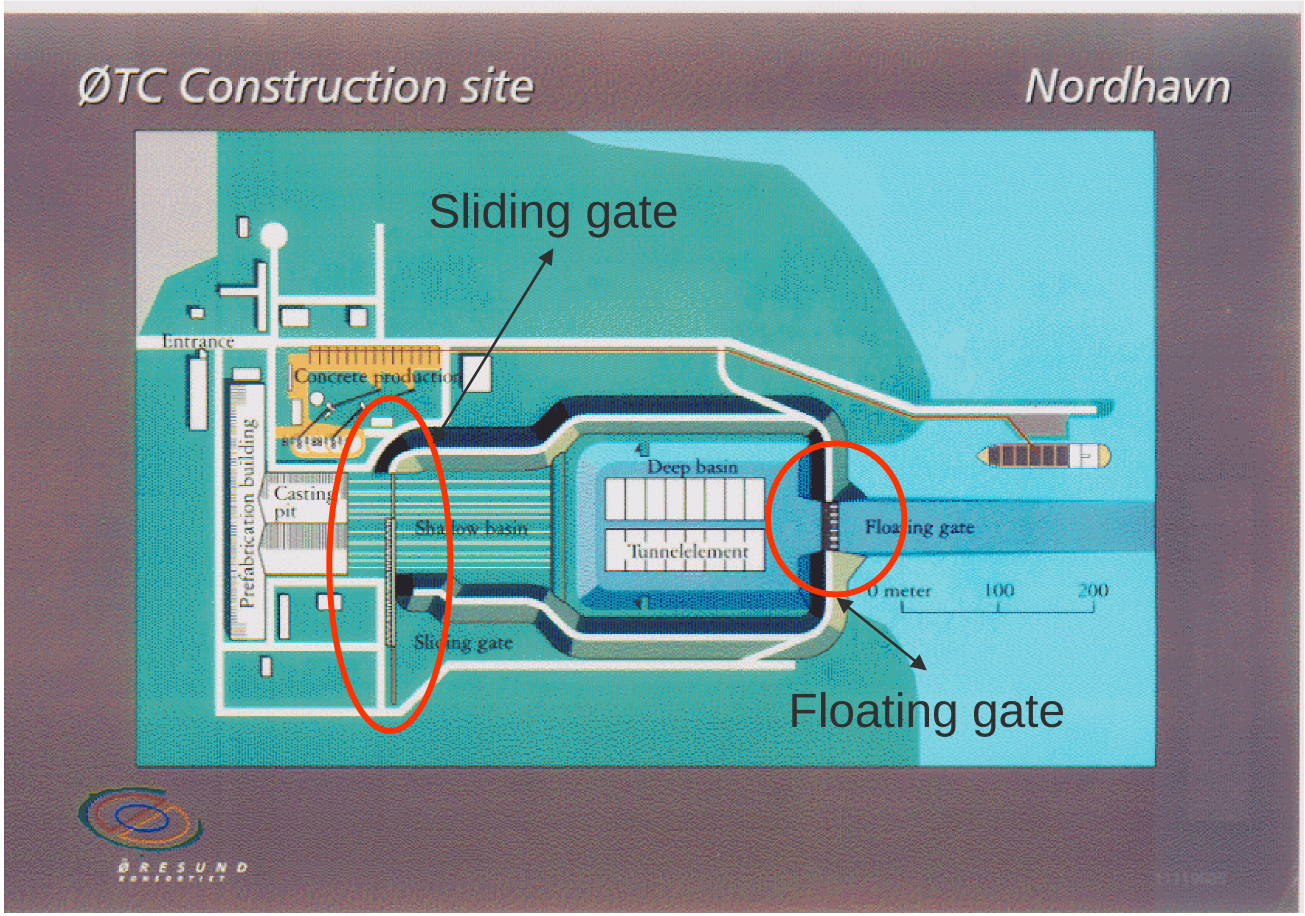


Skidding beams

Deep basin

Aggregate pier

Yard, Oeresund, Other facilities



Yard, Oeresund

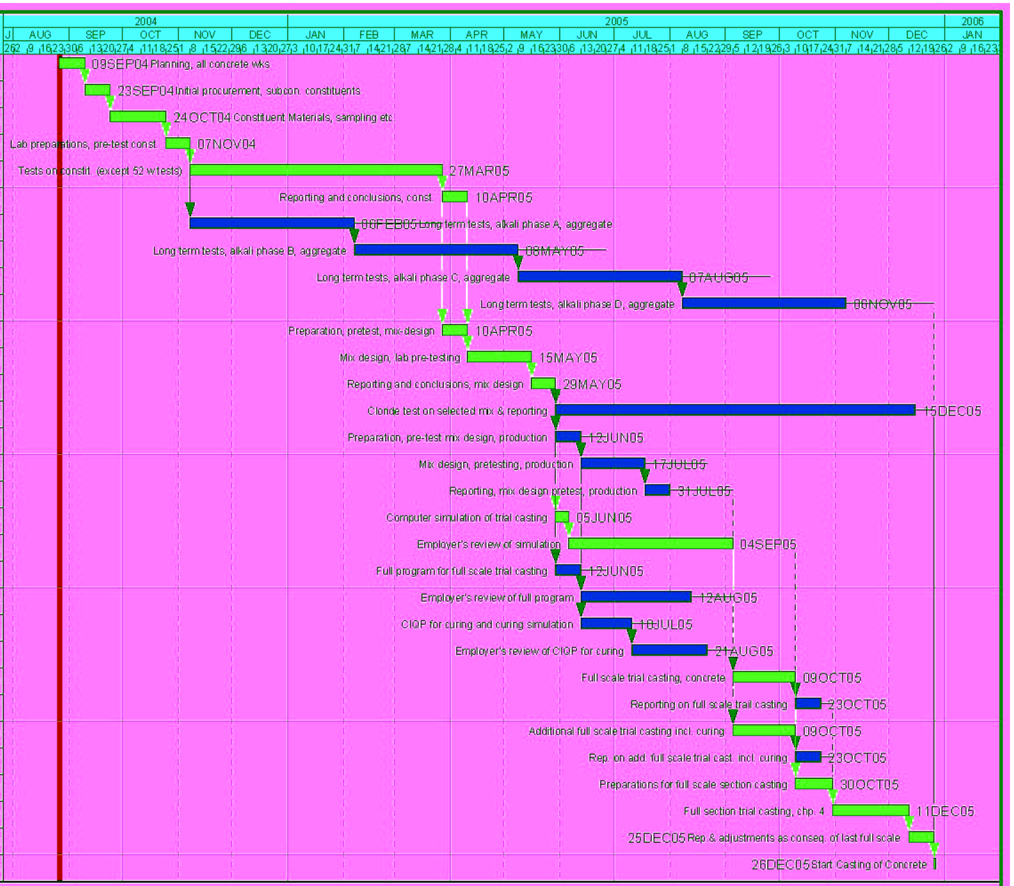
Strategy, both

Strategy

- The Employer defines and controls the Quality (min. requirements)
- Contractors must not compete on quality
- A sequence of controlled processes (ISO 9000/2000)
- Proven, well known technology
- Robust solutions
- 100 years lifetime without active protection systems
- As much freedom as possible

Controlled Processes

Activity ID	Activity Description	Orig Dur	Total Float
0010	Planning, all concrete wks	14	0
0020	Initial procurement, subcon. constituents	14	0
0030	Constituent Materials, sampling etc.	31	0
0040	Lab preparations, pre-test const.	14	0
0050	Tests on constit. (except 52 w tests)	140	0
0060	Reporting and conclusions, const.	14	0
0070	Long term tests, alkali phase A, aggregate	91	49
0080	Long term tests, alkali phase B, aggregate	91	49
0090	Long term tests, alkali phase C, aggregate	91	49
0100	Long term tests, alkali phase D, aggregate	91	49
0110	Preparation, pretest, mix-design	14	0
0120	Mix design, lab pre-testing	35	0
0130	Reporting and conclusions, mix design	14	0
0136	Cloride test on selected mix & reporting	200	10
0140	Preparation, pre-test mix design, production	14	14
0150	Mix design, pretesting, production	35	35
0160	Reporting, mix design pretest, production	14	35
0170	Computer simulation of trial casting	7	0
0180	Employer's review of simulation	91	0
0190	Full program for full scale trial casting	14	14
0200	Employer's review of full program	61	23
0210	CIQP for curing and curing simulation	28	14
0220	Employer's review of CIQP for curing	42	14
0230	Full scale trial casting, concrete	35	0
0240	Reporting on full scale trail casting	14	7
0250	Additional full scale trial casting incl. curing	35	0
0260	Rep. on add. full scale trial cast. incl. curing	14	7
0270	Preparations for full scale section casting	21	0
0280	Full section trial casting, chp. 4	42	0
0290	Rep.& adjustments as conseq. of last full scale	14	0
0300	Start Casting of Concrete	1	0



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CI01 Sheet 1 of 1

TGN

Concrete Planning Works - IMT

Classic Schedule Layout

Summary of requirements

- Design and materials
  - First class constituents
  - Blast furnace cement, silica and fly-ash are all allowed
  - w/c <= 0.40 and 0.45 respectively
  - Cover layer typically 50 or 75 mm depending on calculations
  - Extensive requirements to Quality Management and Conformity Procedures

Summary of requirements

- Pre-testing and Workmanship
  - Planning, planning and planning again
  - Quality Control Procedures
  - Comprehensive Pre-testing and Production-testing including correlation
  - Full Scale curing testing
  - Control of Early Age Cracking
  - Full Scale trial castings

Summary of requirements

- Ensuring Conformity of durability
  - Identify each important paramater
  - Identify direct, relevant and robust test methods
    - Long term but (more) reliable tests
    - Short term but less precise tests
    - Correlation between them
  - Integrate local knowledge and experience
  - Ensure traceability (90% upstream 100% down stream)

State of the Art Notes

- Frost Resistance
- Temperature and Stress Requirements
- Protection against evaporation
- Conformity Procedures
- Comparison of Concrete Requirements and Properties for other Structures

State of the Art Notes

- Chloride Penetration in Concrete
- Alkali-Silica Reactions
- Blast furnace Cement
- Casting Methods
- Crack Investigation
- Fire Resistance

Frost resistance

- Destruction Mechanisms
  - Internal damage
    - Critical dilation tests
    - Air void structure, specific surface and content
  - Salt Scaling of surface
    - Salt scaling tests
- Environment in Istanbul (not all of Turkey) and Scandinavia is different, yes – but?

Temperature and Stress

- Temperature simulations based on documented data
  - Acceptance criteria:
  - $D_{ext} < 15°C$
  - $D_{int} < 15°C$
  - Check against Delayed Ettringite Formations (DEF) if $T > 50°C$

Temperature and Stress

- Stress simulations based on documented data
  - Crack risk < 0.7
  - Limiting temperatures must be established accordingly
  - Boundary conditions, creep and shrinkage during full hardening process
  - Curing

Temperature - Stress

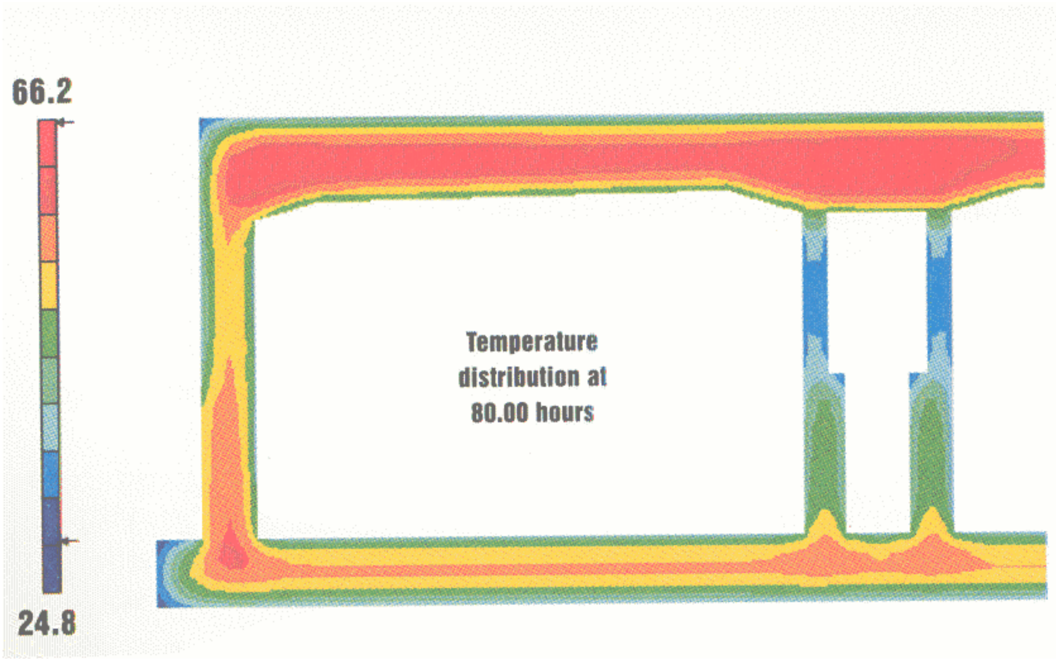

Figure 2
Typical example of early-age stresses in part of the tunnel cross section

Conformity Procedures

- No.1: Product standards, ref. actual product standard
- No.2: 100% inspection
- No.3: Variables, Average Outgoing Quality Level (AOQL)
- No.4: Attributes, Acceptable Quality Level (AQL), ref. ISO 2859-1 191
- No.5: Attributes, Limiting Quality (LQ), ref. ISO 2859-2/101
- No.6 Rolling approval, AOQL
- No.7 Representative samples

Chloride Penetration

- Theoretical model:
  - Coefficient of diffusion (D)
  - Cloride Surface Concentration (C)
  - Works well in the laboratory
  - Poor correlation to accelerated tests and reality
  - Fortunately, a conservative model

Chloride Penetration

- Main features of protection:
  - Un-cracked Concrete (defects in mix and/or workmanship)
  - Impermeability (W/C ratio, correct aggregate corn-curve)
  - Chloride binding
  - Thickness of (Un-cracked) cover layer

Marine environment

Marine Environment

A-S Reactions (ASR)

- Upper limit to Na_2O-equivalent per m^3 of Concrete required
- Slow reactions can be difficult to detect
- Presence of fly-ash and blast-furnace is positive
- Risk for ASR is latent if external alkali sources are available (Sea-water)

A-S Reactions (ASR)

- Test methods
  - Slow test (52 weeks), concrete bars
  - Quick test (2 weeks), mortar bars
  - Petrographic testing
- Correlations required and or recommended:
  - Between slow and quick tests
  - Quick test and Petrographic testing for slow reactions

Oeresund, construction

Filling of basin

Recipe, comparison

Constituent	Oeresund	Bosph.1*	Bosph.2*
P. Cement	324	-	275
Slag Cement		375	-
Fly-ash	52	-	50
Micro Silica**	24	-	30
Water	123+12+8	140+3	111+15+3

* 1st and 2nd mix design

** slurry, 50% Water

Recipe, comparison

Constituent	Oeresund	Bosph.1*	Bosph.2*
Fine Agg.0/2	633	462	640
Fine Agg.0/8	-	366	280
Coarse Ag.2/8	404	-	
Coarse Ag.4/16	-	445	473
Coarse Ag.8/16	476	-	
Coarse Ag.8/22		557	475
Coarse Ag.16/25	374	-	

Recipe, summary

Constituent	Oeresund	Bosph.1*	Bosph.2*
Powder total	388	375	340
Aggregates total	1887	1830	1868
Additives (excl. w.)	3	3	3
Chemical water	143	143	129
Density	2421	2351	2340

Plants on Sites

Inside Railway Tunnel

Lessons learned Oeresund

- Extended Employer's Requirements were a success
- Only minor initial problems related to workmanship
- Placing and compaction methods must be in focus
- Reliable modeling of parameters can and must be done

Lessons learned Oeresund

- Do not underestimate Pre-testing efforts (minimum 15 months)
- It pays off to do comprehensive testing to ensure suitable construction methods
- Addition of micro-silica improves parameters like workability, density, resistance against cloride

Lessons learned Oeresund

- It is not easy to control amount of air (and therefore density) under site conditions
- Establishing a comprehensive database (>700 MB) was essential to organize and analyze data and experience

Lessons learned Oeresund

- Heating during winter and cooling during summer of aggregates was necessary
- High capacity storage of aggregates was needed. 14 bins, each 1,500 tons capacity
- High capacity and skilled laboratory facilities on site needed

Lessons learned Oeresund

- A precise adjustment of (different) setting times was essential for preventing early age cracking
- Control of fresh concrete temperatures was essential

Lessons learned Oeresund

- Correlation between laboratory cubes and in situ drilled cores for frost resistance was very poor (non-conservative)
- Correlation of frost scaling tests were considerably more reliable after 42 cycles than after 28 cycles

Lessons learned Oeresund

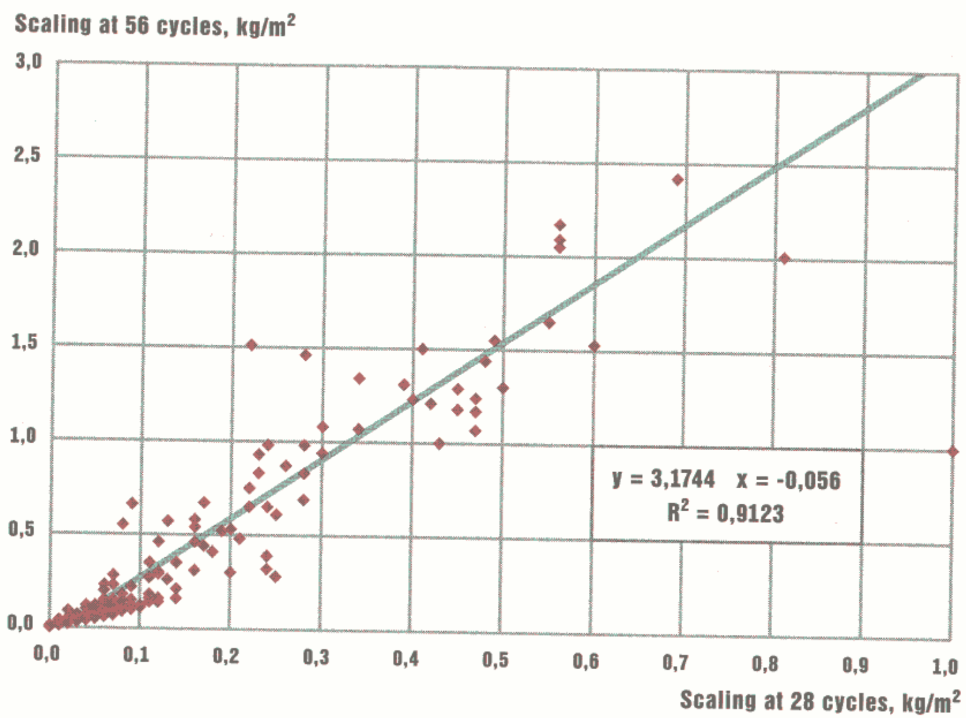

Figure 11
Relation between frost scaling at 28 and 56 cycles, single test results

Lessons learned Oeresund

- Considerable air loss from fresh concrete to hardened concrete was observed, average 3-4 %
- Air loss after pumping was typically 0-2%
- Compaction close to form => big air loss

Lessons learned Oeresund

- No early age cracking occurred in the tunnel elements due to the casting method
- In ramps and portals very good correlation between calculations of cracking risk and temperatures were observed in reality

The Question is:

Can lessons be Confirmed from Marmaray

???

YES!

Lessons learned Marmaray

- Slag cement with high slag content is vulnerable in relation to Early Age Cracking
- Long section casting of walls and roof slabs almost impossible
- Long section bottom slab is possible (135 meter)
- Max section length walls ~ 20 – 25 meter


Thank you
for listening
Questions
&
Answers