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CONCRETE FOR DURABILITY AT MARMARAY PROJECT

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ABSTRACT

The aim of this paper is to present information about the study performed during the construction work of Marmaray Project to obtain the target of 100 years service life of RC concrete structures.

The Marmaray Project in İstanbul includes part of the upgrading of the 76 km commuter rail from Halkalı, in the European end, to Gebze, in the Asian end. This line includes 1.4 km of immersed tunnel, 10.1 km of bored tunnels, 1.3 km of cut and cover tunnel and four underground stations.

Serviceability is influenced from various effects such as cracking, deformation, vibration, durability, water tightness and fatigue. Durability is one of the parameters of serviceability of the structure and therefore during the design stage all parameters were evaluated together in order to check compliance with the service life time requirement which was targeted for the overall project.

In the Project, concrete classes were determined according to the design requirements of typical structures. The composition of the mixture was optimized by pre-testings and trials to resist the relevant exposure conditions that impact concrete's durability. This means appropriate cementitious materials for sulfate ressistance, air void system for freezing and thawing and scaling resistance, adequate protection to prevent corrosion either from carbonation, chloride ingress or depth of cover a low paste content to minimize the drying shrinkage and thermal cracking, and the appropriate combination of aggregates and cementitious materials to minimize the potential for expansive cracking related to alkali silica reactivity.

Methods to be applied during construction for ensuring durability requirements is another step of the studies which are; proper quality control system for constituent materials, hardening and hardened concrete besides curing of concrete and finally adequate repair method.

KEYWORDS

Concrete, durability, marmaray, immerse tube tunnel, crack control

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1 INTRODUCTION

The durability of concrete is one of its most important properties because it is essential that concrete should be capable of withstanding the conditions for which it has been designed throughout the life of a structure. Lack of durability can be caused by external agents arising from the environment or by internal agents within the concrete. Causes can be categorized as physical, mechanical and chemical. Physical causes arise from the action of frost and from differences between the thermal properties of aggregate and of the cement paste, while mechanical causes are associated mainly with abrasion and physical load conditions. Chemical causes are attacks by sulphates, acids, sea water and also by chlorides which include electrochemical corrosion of steel reinforcement.

Durability studies for Bored Tunnels (TBM) and Immerse Tube Tunnel (IMT) which are the major structures of the project will be presented here.

For the bored tunnel, durability was analyzed for the carbonation of concrete and the attack of chloride ion in consideration of the design life of 100 years. As a result, it was confirmed that the carbonation is no problem if the cover is 25 mm or above. However, for the attack of chloride ion it was decided to ensure a cover of 70 mm in all structures potentially exposed to salin water (the Bosphorus Strait). The concrete cover of 70 mm is decided according to the actual measurement value of chloride ion. The result show that chloride ion content in water is extremely small, thus the influence on the tunnel lining is considered to be small. Therefore a concrete cover of 70 mm is used from the strait part to the above mentioned boringhole location. The typical cross section of the Bored and Immerse Tunnel is shown in Figure 1.

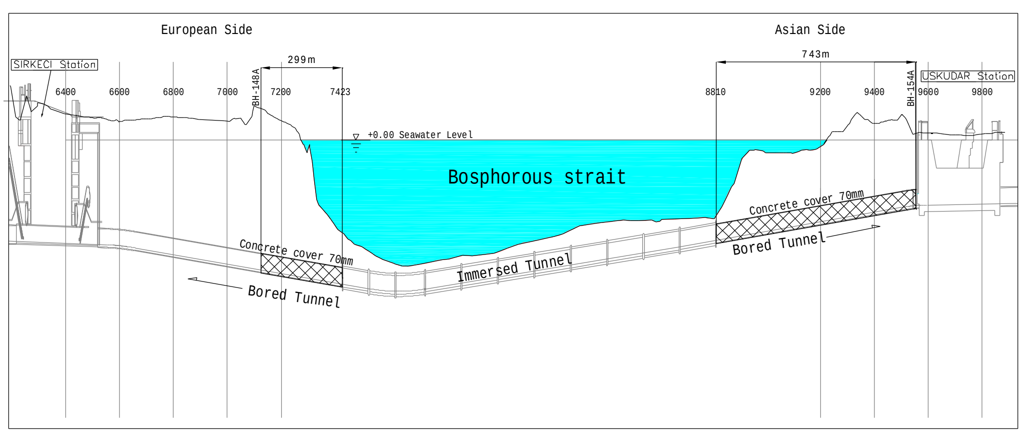

Figure 1. The range in which the concrete cover is 70 mm

For the Immersed Tunnel (IMM), reinforced structure is enclosed in a steel membrane and waterproofing sheet and isolated from the aggresive environment.

According to British Standard BS 6349 for Maritime Structures, the condition of exposure for the immersed tunnel can be classified as frequently wetted condition, designated as XC2, with the structure totally submerged in seawater at all time. For this exposure condition, the nominal cover required by standard is 50 mm. Although there is an isolation of concrete with a layer of steel membrane and waterproofing sheet, 70 mm minimum cover is appropriate for severe environmental exposure conditions in case the external face of the member should have the waterproofing membrane fail and exposes the concrete structure to seawater seepage. Additionally, steel membrane is protected against corrosion by cathodic protection. Figure 2 shows that the thypical section of Immerse Element.

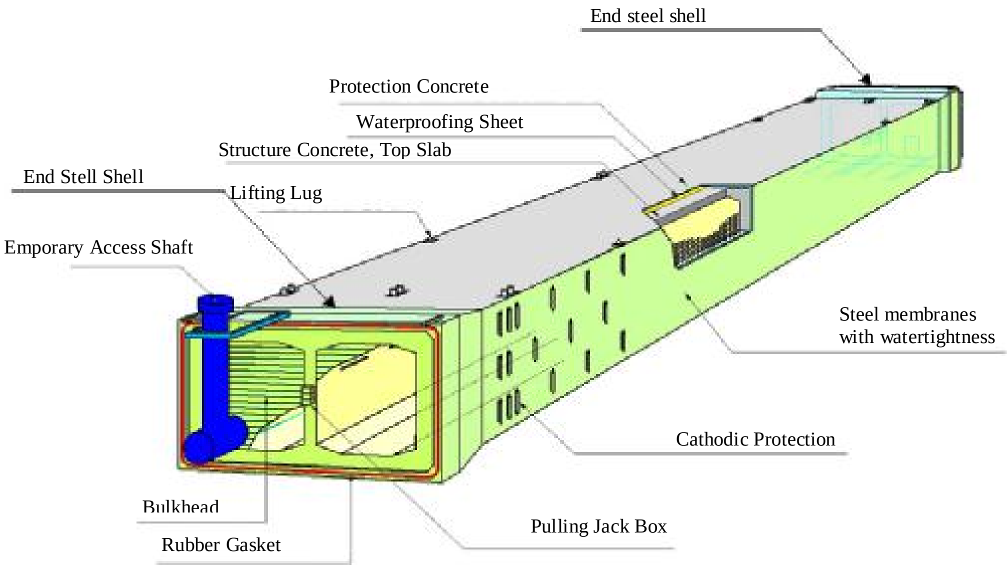

Figure 2. Typical Section View of Immersed Element

2 DESIGN OF CONCRETE

2.1 Concrete Mix Design

For ensuring durability of concrete, mix design has been optimized according to the following limits;

- Maximum free water/cement ratio : 0.4
- Minimum cement content : 375 kg/m^3
- Minimum strength class : C40
- Minimum nominal cover : 70 mm (external faces), 32 mm (internal faces)
- Maximum crack widths : 0.2 mm (except early-age cracking)

The main characteristics of the mix determined by considering the limitation mentioned above used in the project are;

- High characteristic cylinder compressive strength (fck : 40-50 MPa)
- Low water/cement ratio (Between 0,30 to 0,40)
- Well graded aggregate
- Admixture for water reducer
- Air-entraining admixture
- Supplementary cementitious materials (Fly ash and Micro Silica)

2.2 Pre-testing of Concrete

A comprehensive pre-test programme was developed and executed. A part of the pre-testing was full scale trial casting (FSTC) executed under realistic circumstances. FSTC was not allowed to start until the pre-testing of the concrete mix was completed and should be done using the proposed construction methods and equipment performed by operators and staff whould be involved in the execution of the concreting works.

Following tests were conducted during pre-testings and also production;

2.2.1 Constituent Materials

All tests of constituent materails (Cement , Aggregates (Fine & Coarse), Sand, Fly-Ash, Micro -Silica, Admixtures and Water) according to related standards were realized and certified as Inspection Section.

2.2.2. Fresh Concrete Tests
Workability, Density, Temperature, Air-content

2.2.3 Hardening Concrete Tests

Activation Energy, Compressive Strength Tets, Tensile Strength Test, Modulus of Elasticity, Adiabatic Heat, Early-age Shrinkage, Strains due to Creep, Thermal Expansion, Maximum Temperature.

2.2.4. Hardened Concrete Tests

Compressive Strength, Density, Air Content, Chloride Diffusion, Petrographic Testing (Thin & Plane Section)

Figure 3. Polished impragneted plane section and thin section analysis

Concrete Petrography Laboratory which is a part of İTÜ Marmarmaray Laboratory is the first in Turkey. At this laboratory concrete characteristichs are investigated closely during the production. Figure 3 is showing the image of polished impragnated plane and thin section.

3 CRACK CONTROL

Crack control studies of concrete comprises evaporation protection, early age crack control and frost resistance.

3.1 Evaporation Protection

All surfaces of the newly cast concrete is protected against evaporation. The protection is established after completion of compaction and surface treatment is applied to prevent cracking due to plastic shrinkage. The protection against evaporation is maintained until a minimum degree of hydration of 90% has been reached at the concrete surface, except for internal formed surfaces in tunnel items where the requirement for 90% degree of hydration may be replaced by a requirement to reach 96 maturity hours.The degree of hydration in the concrete surface is determined from measurements of the temperature at a depth of a maximum 10 mm, except for construction joints where a maximum depth of 20 mm is allowed. For concrete surfaces cast against formwork, an accaptable evaporation protection to leave the formwork in place.

3.2 Early-Age Crack Control

For hardening concrete structures, early-age cracks may be caused by reastraint to deformations due to combinations of thermal movements, early shrinkage, creep and settlements. Theoratical crack risk must not exceed 0.7. In the project early age cracking is generally not allowed.

For each type of structural element and all water-retaining structures planned risk of early-age cracking are determined through temperature and stress analysis (Figure 4). If cracking occurs, craks are injected in case they exceed the design crack widths.

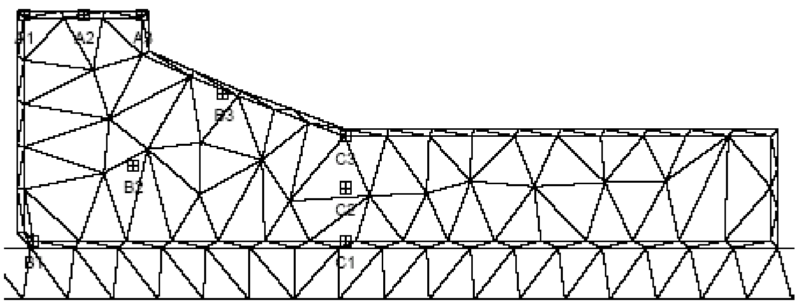

Figure 4. Temperature and Stress Simulation Model

3.2.1 Temperature simulation is based on all relevant input data such as;

- the model (geometry, element mesh and boundary conditions),
- the maturity function for the concrete,
- the documented values for the adiabatic heat development, the content of powder in the concrete,
- the thermal conductivity of the concrete,
- the specific heat of the concrete,
- the concrete density, the fresh concrete temperature,
- the ambient temperature and wind velocity, the temperature, thermal conductivity, specific heat and density of surrounding materials,
- the documented values for the thickness and thermal conductivity of formwork and insulating materials,
- the design and control of arrangements for temperature control,
- the control of curing activities,
- casting sequence.

3.2.2 The output from the temperature simulation comprise information such as;

- temperature graphs showing the development of the mean temperatures of the structural elements (figure 5),
- graphs showing the development of the mean temperature of the newly cast items and the mean temperature of previously cast items (Dext),
- graphs showing the temperature difference between the mean temperature of newly cast items and the surface temperature of the newly cast items (Dint),
- graphs showing the maximum temperature in the concrete.

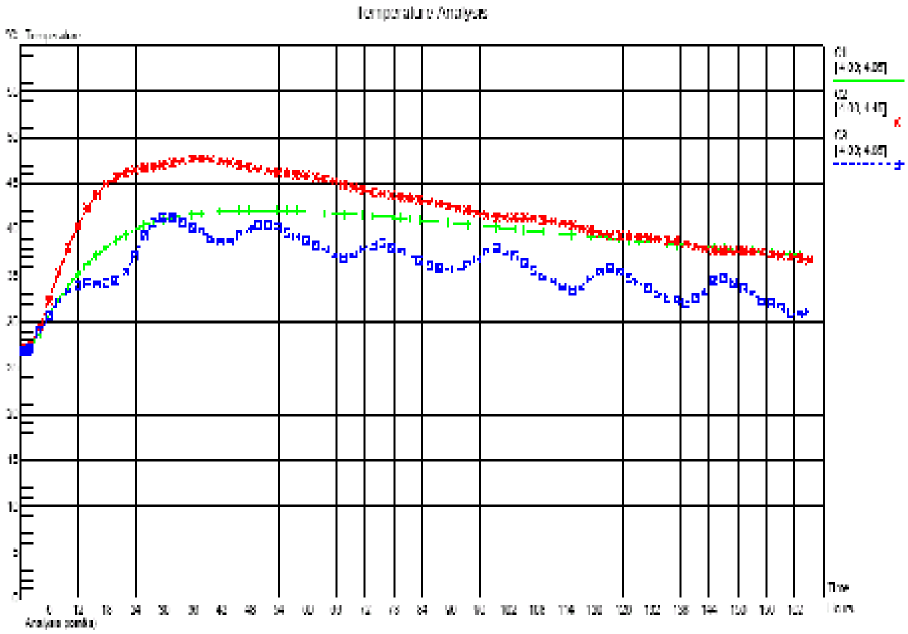

Figure 5. Temperature simulation model

3.2.3. Stress simulation is performed using a well-documented computer program based on the Finite Element Method. Stress simulation shall be based on documented values for the thermal expansion coefficient, the E-modulus, the early-age shrinkage and the creep for the actual concrete. Stress simulation is based on all relevant input data such as;

- the model (geometry, element mesh and boundary conditions/restraint)
- the simulated temperatures,
- the documented value for the thermal expansion coefficient,
- the documented value for the thermal expansion coefficient,
- Poission's ratio
- The documented development of the early-age shrinkage,
- The documented development of the parameters that describe the development of strains due to creep.

3.2.4 The output from stress simulation shall comprise information such as,

- a general presentation of the stress level in the structure (iso-curves)
- the development of the principal tensile stresses in selected points
- the development of the risk of cracking (P) shall at any time be defined as:

3.2.5 The risk of cracking (P) is at any time be defined as:

P= maximum principal tensile stress / the axial tensile strength

The maximum crack risk simulation is shown in figure 6.

3.2.6 The axial tensile strength of the concrete ($f_{ct,ax}$) is determined from the splitting tensile strength ($f_{ct,sp}$) according to:

$$f_{ct,ax} = 0.9 \text{ x } f_{ct,sp}$$

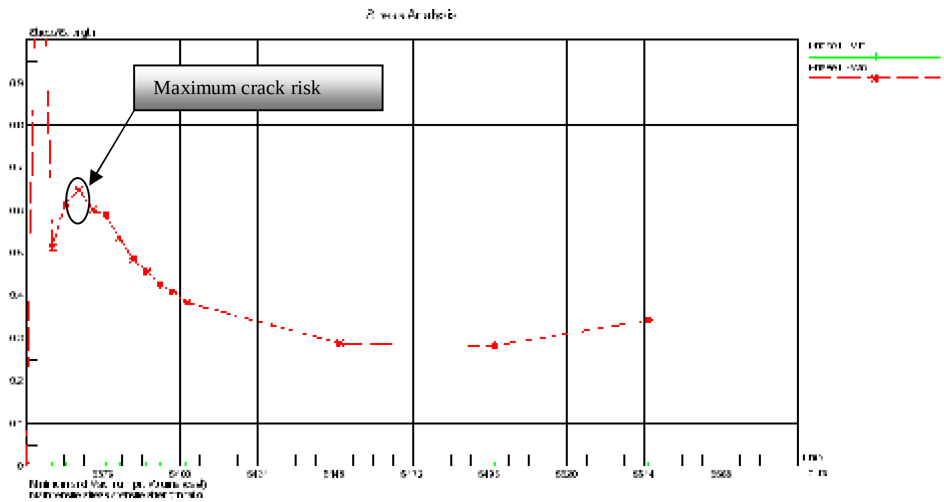

Figure 6. Crack risk simulation

3.2.7 The risk of cracking must comply with the requirements given in Table 1.

Location/Structure	**Max. W (mm)**	**Max P**	**Max D_{ext} (^{o}C)**	**Max ΔT_{inc} (^{o}C)**
Tunnels				
- water-retaining parts	0,2	0,70	15	8
- other parts		1,00	20	12
Ramps and C&C				
- water- retaining parts	0.2	0.70	15	8
- other parts		1.00	20	12
Stations				
- water- retaining parts	0.2	0.70	15	8
- other parts		1.00	20	12

Table 1. Overview of Parameters Reletad to Early-Age Cracking

3.2.8 Based on stress analysis, limiting temperature differences for each structural element are established corresponding to the following two limits;

(a) For structural items that are restrained by neighbouring elements, a maximum temperature difference between the mean temperature of the newly cast element and the mean temperature of previously cast items (D_{ext}) should be defined. The maximum allowable temperature difference during hardening should comply with the requirements given in table 1, regardless of the result of the stress simulation.

(b) For all structural elements, a maximum temperature difference between the mean temperature of the element and the temperature of the element (D_{int}) should be defined. The maximum allowable temperature difference during hardening shall be less than 15 ^{o}C regardless of the stress simulation.

3.2.9 The maximum temperature of the concrete is 50 ^{o}C in the central part of bottom slabs. If higher than 50 ^{o}C special consideration of Deleyaed Ettringite Formation (DEF) must be given.

3.2.10 A graphical comparison to the requirements is possible. Graphs showing the temperature developments is available on site for execution of the temperature control and other actions related to the temperature and maturity development, e.g. stripping of formwork.

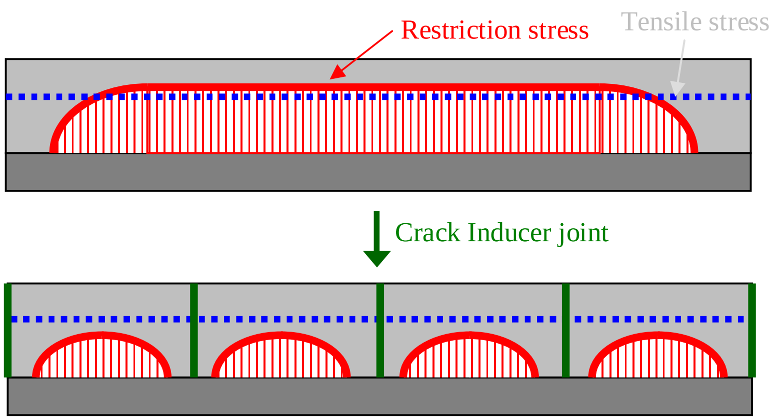

Figure 7. Effect of crack inducer joint

In the project, temperature and Stress Simulation program is being effectively used in order to determine the casting method. As shown in figure 7, location of crack inducer joints are determined according to the outputs getting from T&S Analysis.

3. 3 Frost Resistance

The concrete is protected against freezing until frost resistance is obtained. Frost resistance is considered obtained when the concrete has reached a compresive strength of 10 Mpa.

In order to provide resistance to the damaging mechanism resulting from freezing is achieved through the use of air-entraining admixtures that stabilize and help distrubute air bubbles within the concrete.

4 CONCLUSION

In conclusion, sub-aqueous tunnels are subject to extraordinary conditions with regard to outside pressure and chemical aggresivity. Therefore, special measures with regard to avoiding or delaying the development of concrete deterioition and reinforcement corrosion needs to be considered. In this paper, studies regarding the concrete durability have been presented to obtain the target of 100 years of service life of the structures in Marmaray Project.

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