The Great Belt Link: Establishment of lifetime models

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Summary

The 18 km long fixed link crossing the Great Belt comprises two bridges and a tunnel: a 6.8 km suspension bridge, a 6.6 km combined road- and railway bridge and an 8 km long bored (twin) tunnel. The Great Belt Link was designed for a service life of 100 years, and to ensure this, an investigation has been carried out to establish lifetime models for the primary concrete structures. Existing reports from routine, principal and special inspections were analysed. Special focus on moist conditions, chloride ingress, air void structure, crack extent and chloride initiated reinforcement corrosion were some of the deterioration mechanisms used in determining the life time service. Primary and secondary deterioration mechanisms were identified, critical areas defined and future operation and maintenance plans for securing a technical and economical operation were drawn up. Recent results from special inspection with particular focus on corrosion in cracks, establishment of cathodic protection systems, potential frost related damages and surface treatment of critical areas are presented in the paper. Cores taken from the critical areas further indicate that special attention should be concentrated at areas with cracked concrete. The results of these investigations clearly indicate that the critical areas apparently only include areas in and around the splash zone and other distinct potential critical areas. This paper will outline some of the investigations used in establishing a lifetime model.

Keywords: Lifetime models, concrete structures, chloride ingress, chloride initiated reinforcement corrosion, frost/thaw damages, cathodic protection, deterioration mechanisms.

1. Introduction

Through the 1960s and the 1970s many concrete structures were built without regard to durability, resulting in extensive rehabilitation after 10-15 years of service. The problems could be traced back to de-icing salts, the use of additives without sufficient experience, and unsuitable aggregates (alkali-silica reactions and frost attacks), as well as inefficient work procedures during construction.

100 years durability was selected as the key requirement for the Great Belt project in order to obtain a long service life. The 100 year period was also selected as the basis for operational risk analysis, fatigue design, investigations of ice and wind forces, and for the general functionality of the bridge.

2. Special conditions for the Great Belt Link concrete

When the Great Belt in 1987 established an expert group to develop the basic concrete specifications, the requirement was that the concrete should have a service life of 100 years, but neither the concrete specifications nor the general specifications were targeted for a service life of 100 years. With the existing guidelines there would not likely be any significant deterioration from frost or alkali silica within 100 years, but the guidelines would not likely be able to prevent reinforcement corrosion from chloride ingress.

In preparing the specification requirements of the Great Belt concrete special emphasis was therefore given on the concretes' ability to stop chloride ingress. In contrast to frost and alkali silica damages, chloride ingress can only be slowed and not be countered completely by modifying the concrete specifications.

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3. The Great Belt lifetime models

Establishment of lifetime models and the subsequent adjustment of the future operation and maintenance were divided into 5 phases: establishing the basis for lifetime models, establishment of lifetime models, recent analysis of the primary concrete structures and trial casting, adjusting inspections and monitoring, development of an adaptable operation and maintenance plan.

4. Phase 1: Establishing the basis for lifetime models.

A series of routine, principal and special inspection of the majority of the East and West Bridge concrete structures were conducted. The special inspections were mainly focused on one or more of the following: moisture conditions, chloride ingress in cracked and non-cracked areas, air void structure and frost resistance, crack extent and its importance for moisture and chloride ingress, chloride induced reinforcement corrosion in cracked areas. Deterioration mechanisms were divided into primary and secondary deterioration mechanisms. In the non-cracked structural components and / or parts with limited crack extent we can basically assume that the concrete durability and service life is at least 100 years. Virtually all previously conducted investigations indicate that the sustainability-related critical areas of the structural components apparently only cover areas in and around the splash zone and a few other potentially critical areas.

5. Phase 2: Establishment of lifetime models

It was during the construction phase decided to establish a cathodic protection system on all caissons on the West Bridge and on selected parts of the East Bridge to minimize the risk of chloride induced corrosion of the reinforcement. To monitor the corrosion risk of the reinforcement throughout the 100 years' service life of the concrete structures, some parts of the structures have been provided with state-of-the-art monitoring devices.

6. Phase 3: Recent analysis of the primary structures and trial castings

A detailed frost/thaw investigation of selected piers on the East and West Bridges was carried out. The investigation showed no signs of development in the extent of frost damages in the last 5 years, either in depth or distribution. The investigation also showed that the initiation time of the chloride induced corrosion is found to be between 100 and 500 years in the non-cracked areas of the concrete. In 2009 a study on concrete's actual durability was conducted, as an overall summary of results for chloride induced corrosion in non-cracked concrete on the Great Belt concrete structures. The report is limited to non-cracked concrete. In addition to achieving the desired durability in the toughest exposed areas, the studies revealed that in all other areas of the concrete structures, a service life that is significantly longer than 100 years was achieved in non-cracked concrete.

7. Phase 4: Adjusting inspections and monitoring

Principal inspections of the concrete structures are planned for five-yearly intervals. With experience this interval is expected to increase. As well as principal inspections and the yearly routine inspections, special inspections are planned for certain structures at a more frequent interval.

Monitoring the concrete structures is carried out either continuously, by being linked to the SCADA system, or by portable logger, and consists of: corrosion monitoring, monitoring of cathodic protection, monitoring of movement, movement of bearings, measuring of temperatures.

8. Phase 5: Development of an adaptable O&M plan

The technical operation and maintenance (O&M) is based on guidelines in an O&M manual plus supplementary procedures and instructions. This is part of Great Belt's overall integrated management system for quality, environment and safety. Most activities are carried out by external parties, through out-sourcing contractors, suppliers and consultants, with the management alone staying with the Great Belt organisation. The technical O&M activities are concentrated on: inspections and surveys, monitoring of structures, installations i.e., maintenance and repair work, and cleaning of structures. For the purpose of managing the inspection and maintenance, the Great Belt Link uses the comprehensive management system Maximo.