PIARC INTERNATIONAL WINTER ROAD CONGRESS

Topic 8 – Road Bridges in Winter Conditions

Assessment and repair of bridges subjected to de-icing salts

Mr. Ulrik Sloth Andersen
Project Director, MSc
Ramboll Denmark
Hannemanns Alle 53
2300 Copenhagen S
Denmark
ulsa@ramboll.dk

Mr. Henrik Nielsen
Project Manager, MSc
Danish Road Directory
Niels Juelsgade 13
1020 København K
Denmark
hn@vd.dk

TOPICS: IMPACT OF DE-ICING SALTS ON BRIDGES, ALTERNATIVE DE-ICING METHODS, AND MEASURES FOR PROTECTION

ABSTRACT

Many highway bridges in Denmark were constructed during the period from 1960 to 1980. Most of the bridges were built from reinforced concrete, often using aggregate sensitive to alkali-silica reactions (ASR).

The use of de-icing salts in Denmark (Area 43.000 km2) is approximately 300.000 ton per year. The average temperature is close to 0°C in December, January and February thus leading to many days with frost and a heavy usage of de-icing salts.

This paper presents cases where reinforced concrete (RC) and post-tensioned bridges have undergone major rehabilitation in order to halt the deterioration primarily caused by de-icing salts. The de-icing salts have a major impact of the durability of a bridge deck due to the following mechanisms:

- High chlorides content leads to corrosion of the reinforcement.
- The de-icing salts usually consist of NaCl. The Na will provide additional alkali that can speed up ASR if the concrete can develop ASR.
- The cracks formed by the ASR will allow additional water ingress that will reinforce the chloride impact and subsequently the deterioration of the structure.

This paper will demonstrate how a complete rehabilitation of bridge decks subjected to de-icing salts can be undertaken. The rehabilitation methods can in many cases be combined with strengthening with respect to moment and/or shear capacity in a cost-efficient way.

INTRODUCTION

For some bridges in Denmark the combined effect of chloride, frost-thaw and ASR can over the course of a few years lead to a condition where it is not feasible to repair the bridge deck and a replacement is required.

The photo below shows the soffit of a RC bridge deck exposed to chlorides, alkali-silica reactions (ASR) and frost-thaw:

Fig. 1. A bridge deck subjected to de-icing salts.

One of the effects of ASR is a significant expansion of the concrete. The expansion takes place in the direction where a minimum of energy is required to cause the expansion. Hence, a slab with minor stirrups will often form a horizontal crack pattern as indicated in the photo above.

The number of bridges that were constructed by the Danish Road Directory in each year from 1960 to 1984 appears in figure 2 below:

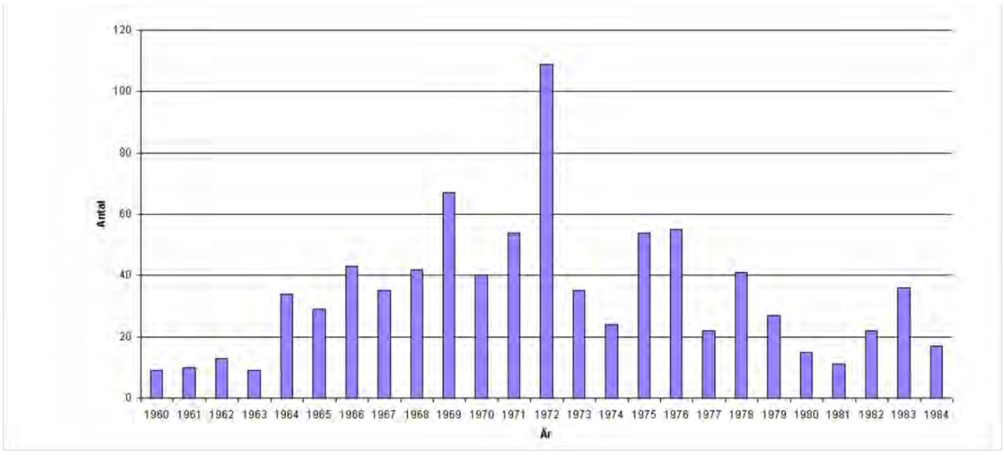

Fig. 2. Number of bridges constructed by the Danish Road Directory in the period from 1960 to 1984

Since the construction of the bridges, traffic intensity and loading has increased significantly. In addition, the bridges have been heavily exposed to de-icing salts. In most cases, the waterproofing consists of bitumen sheets with an expected lifetime of 30-40 years. Consequently, the waterproofing is due to be replaced on numerous bridges and the rehabilitation process is currently on-going.

Since many of the bridges were built within a limited time period, the same structures have often been due for repair within the same period. The main repair works comprises:

1980s: Many columns were repaired/replaced due to corroded reinforcement as a result of de-icing salts. (The actual lifetime of columns constructed in this period was 15-20 years.)
1990s: Many edge beams were replaced. (Actual lifetime 20-30 years.)
2000->: Replacement of waterproofing including resurfacing.

Since waterproofing replacement is very expensive and causes great inconvenience to road users, it is important that the load capacity is fully assessed during the planning process. In many cases, a complete rehabilitation, including replacement of the waterproofing, can be combined with a strengthening in a cost-efficient way.

This paper presents cases where RC and post-tensioned bridges have undergone major rehabilitation primarily due to impact from de-icing salts leading to corroded reinforcement and aggravated alkali-silica-reactions (ASR). In addition frost-thaw can enhance the deterioration if the concrete is not sufficiently air-entrained.

INSPECTION AND TESTING OF BRIDGES

Operation and maintenance of bridges usually follow the processes indicated on figure 3 below:

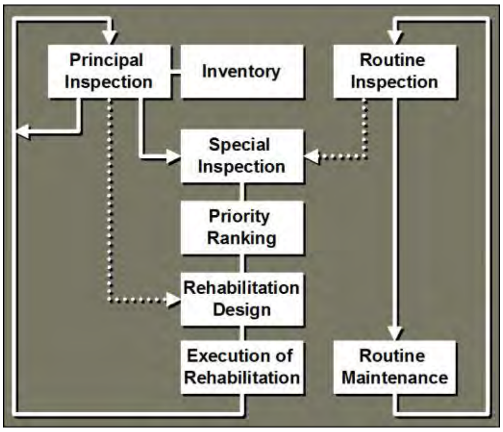

Fig. 3. Operation and maintenance flow.

Before a major rehabilitation of a concrete bridge is planned the following basis should be provided:

- All relevant existing drawings from the construction and subsequent repair works including structural analysis
- Principal inspections
- Special inspections
- Geometrical survey
- Load capacity rating

Special Inspection

The special inspection is the key document as a basis for the rehabilitation design. A special inspection usually contains the following subtasks:

- A desk study of all relevant documents
- Load capacity rating
- A visual inspection
- Preparation of a hypothesis for the cause and extend of the defects
- Planning and execution of testing (destructive or non-destructive (NDT) testing)
- Finding the reasons for and extent of the located defects. Evaluation to determine if the hypothesis was correct.
- Analysis of the expected rate of deterioration if no repair is carried out.
- Outline 2-4 rehabilitation strategies
- Preparing cost estimates including road user cost for traffic delay or de-routing
- Calculation of technical and financial consequences if the rehabilitation is postponed
- Calculation of the net present value for 2-4 strategies to locate the feasible strategy over a period of 20-50 years.

The visual inspection provides an overview of the actual condition and provides the basis for the hypothesis regarding the cause of the defects.

The NDT testing provides knowledge of the extent of the defects. The most used methods comprise:

- Half-Cell potential mapping
- Covermeter
- s'MASH (Impulse response)
- Thermographic pictures to locate concrete defects
- Georadar
- Crack-width measurements

NDT testing with s'MASH is shown in Fig. 4 below:

Fig. 4. NDT testing using s'MASH

Destructive testing provides detailed information of small areas of the structure e.g.:

- Breakouts in surfacing or concrete
- Chloride testing
- Measurements of the degree of corrosion for mild reinforcement or prestressed bars/strands
- Concrete cores for testing in a concrete laboratory

Concrete and steel testing in the lab may include:

- Chloride content
- Moisture content in concrete
- Concrete quality (micro structure, water-cement ratio, cracks, ASR etc.)
- ASR
- Steel bars: Ultimate strength, ductility etc.

The effect of the various methods is indicated in Fig. 5:

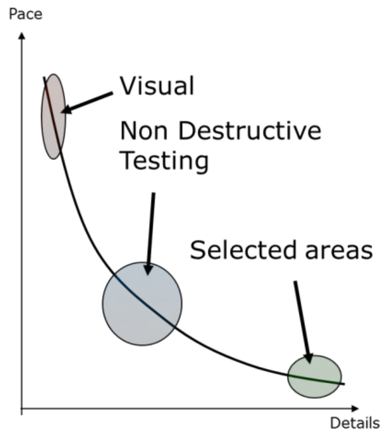

Fig. 5. Various testing methods. Pace versus details.

The combination of the above methods provides the full picture of the condition of the bridge.

REHABILITATION OF CONCRETE BRIDGES SUBJECED TO DE-ICING SALTS

When a repair work is designed for a structure exposed to chlorides, the strategy depends highly on the actual chloride contents.

If the chloride content is low, less that approximately 0.05% weight percent of the concrete, and no corrosion is present, the following strategy can be applied:

- Reparation of any defects with special mortar or shotcrete
- Optional: Cathodic Protection
- “Surface treatment” (replacement of bitumen sheets for a bridge deck, paint system for other surfaces) including a proper cleaning (sand blasting or similar) of concrete

If the chloride content is high, more than approximately 0.05% of the weight percent, and corrosion of the reinforcement is on-going, the following repair strategy can be utilized:

- Repair all areas with high chloride content by removing contaminated concrete and applying special mortar or shotcrete. If corrosion is present at the reinforcement it may be necessary to add additional reinforcement.
- Option: Cathodic Protection
- “Surface treatment” (replacement of bitumen sheets for a bridge deck, paint system for other surfaces

The photo below shows an example of corroded prestressed reinforcement due to chlorides:

Fig 6. Corroded prestressed reinforcement due to chlorides.

Corrosion of prestressed strands is critical since the strands consist of several wires with a small diameter. Hence, a minor degree of corrosion can cause a high reduction of the cross section of each wire.

If corrosion and high levels of chlorides are present at the upper side of a bridge, deck repair can be carried out by removing chloride contaminated concrete, performing a proper cleaning, drilling vertical reinforcement to accommodate the shear stresses and applying a new (or existing) reinforcement. After this a new concrete layer can be casted. The method is indicated below:

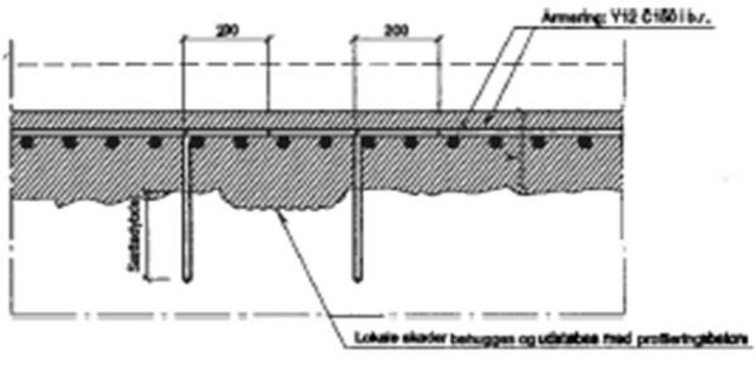

Fig. 7. Repair of upper side of a bridge deck.

The method is also indicated on the photo below:

Fig. 8. Bridge deck with reinforcement for concrete overlayer

CASES

CASE no. 1. Rehabilitation of a slab with corroded, prestressed reinforcement

This project comprises a complete rehabilitation and strengthening of a two-span post-tensioned motorway bridge situated in Roskilde approximately 30 km east of Copenhagen.

Fig. 9. Elevation of bridge

The findings during the special inspection were:

- Defective waterproofing leading to water leakage through the slab
- Corrosion of the pre-stressing tendons at a cold joint.
- Insufficient load-carrying capacity

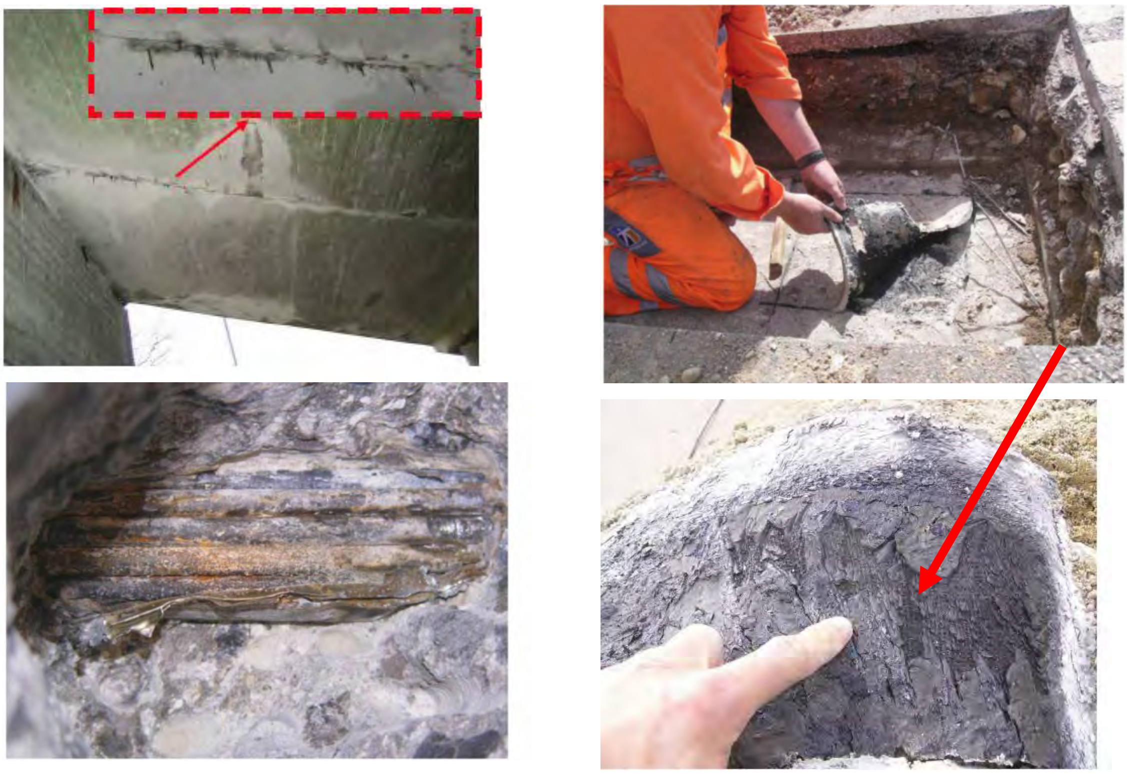

Fig. 10. Defective water proofing and corroded post-tensioned reinforcement

The bridge was repaired by the following means:

- Chloride-contaminated concrete was removed by water jetting (made it possible to remove concrete without harming the reinforcement including the prestressed reinforcement)
- Drilled reinforcement and additional reinforcement (to obtain a higher load capacity) was installed.
- Casting of new concrete overlayer
- Waterproofing comprising epoxy base and bitumen sheets.

The repair method is indicated below:

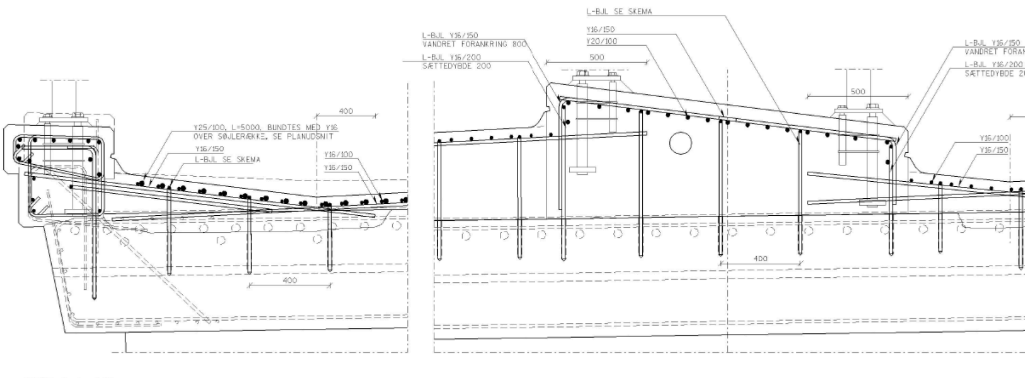

Fig. 11. Cross section of the slab and edge beam.

Conclusions after complete rehabilitation:

- Corrosion of the prestressed tendons has been halted
- The waterproofing has been replaced, expanding the remaining life time of the bridge.
- Strengthening was successfully integrated with the repair works.

CASE no. 2. Rehabilitation of a RC slab with ASR

This project comprises a complete rehabilitation and strengthening of a post-tensioned bridge. The bridge is situated near Roskilde on Sealand, Denmark

Fig. 12. Map and aerial photo of the bridge.

The bridge was constructed in 1972 with a RC slab of a total length of 114 m with a width of 13.7 m thus a total area of 1560 m2.

The cross section appears below.

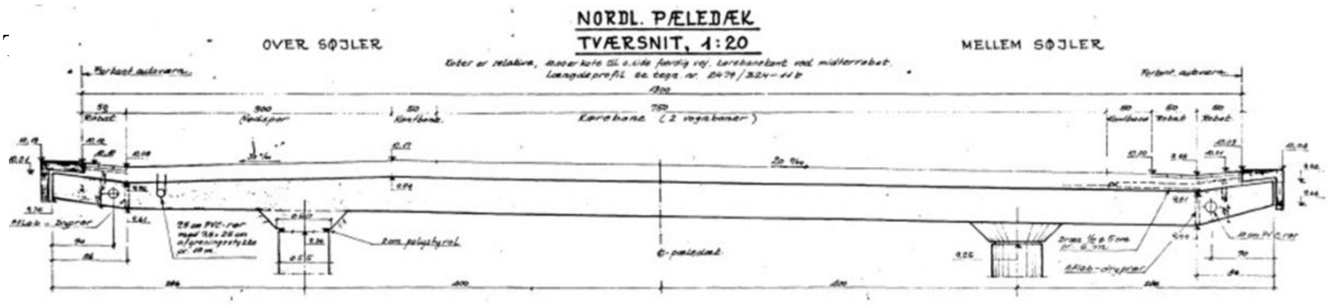

Fig. 13. Cross section of the slab.

The overall condition of the bridge prior to rehabilitation was:

- Defective waterproofing leading to water leakage through the slab

- Corrosion of the reinforcement due to de-icing salts
- ASR in the slab
- Insufficient load-carrying capacity (lack of shear capacity over columns)

The rehabilitation comprises a new reinforced concrete overlayer. The chloride infected and damaged concrete was removed before the reinforcement (drilled and horizontal reinforcement) was installed. In addition vertical bars (quality M30 8.8) were drilled through the slab around each column with a steel plate on top and soffit of the slab as indicated below:

Fig. 14. Repair and strengthening

When the overlayer and new edge beams had been cast, new bitumen sheets and surfacing were applied.

A major part of the work was carried out in the winter season.

Fig. 15. Tent placed on a semilar bridge

The traditional way to ensure the needed climate to continue the work would be a tent combined with hot air provided from oil burners.

However, in this case a system with hoses containing hot water was installed in the concrete overlayer. The heating system was utilized when the concrete overlayer was cast and subsequent when the water proofing (comprising a primer and two layers of bitumen sheets) and surfacing were carried out:

Fig. 16. Bridge deck with hoses for hot water.

The effect appears on the thermographic photos below:

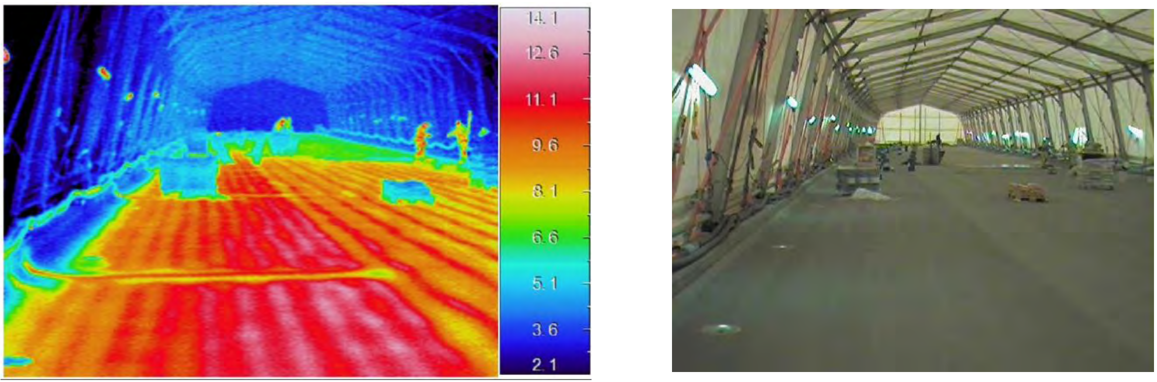

Fig. 17. Thermographic photos of the deck heated with hoses

The method proved very efficient since the heat is applied directly where it is needed. The use of oil was limited to approximately 400 litres per day over a period of ten days with outside temperatures in the range of -2 to +5°C. The upper side of the slab had a temperature of around +10°C allowing for the work to be carried out. When the work had been completed the hoses were injected with mortar by using the same method as for ducts for prestressed reinforcement.

Conclusions after complete rehabilitation of the bridge:

- Corrosion of the reinforcement and the ASR has been halted
- The waterproofing has been replaced thus expanding the remaining life time of the bridge.
- Strengthening was successfully integrated with the repair works.
- The work could be carried out during the winter period at very low additional cost due to the cast in hoses.

CONCLUSIONS

The climate in Denmark with average temperatures of approximately 0°C in the winter period has led to an extensive use of de-icing salts. In many cases, these de-icing salts penetrate directly into the bridge decks and columns causing severe deterioration of the structures due to corroded reinforcement and an enhancement of alkali-silica reactions (if the concrete is ASR sensitive).

In this paper it has been demonstrated how a complete rehabilitation of bridge decks subjected to de-icing salts can be undertaken.

Often rehabilitation can be combined with a simultaneous and cost-effective strengthening of moment and/or shear capacity.