Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 78 (1998)

Artikel: Repair of the Linfjord tunnel, Denmark

Autor: Vejlby Thomsen, J. / Hededal, Poul

DOI: https://doi.org/10.5169/seals-59067

Repair of the Limfjord Tunnel, Denmark

J. Vejlby Thomsen
B.Sc., Civ. Eng.
Road Directorate,
Copenhagen,
Denmark

Jens Vejlby Thomsen, born 1940, got his civil engineering degree at the Danish Engineering College, Copenhagen. Since 1980 he has been responsible for administering major bridges and tunnels on the national road network on behalf of the Road Directorate

Poul Hededal
Head of Department
RAMBØLL
Aalborg, Denmark

Poul Hededal, born 1960, got his civil engineering degree at the University of Aalborg. Since 1984 he has been employed in the consulting firm, RAMBØLL. He is now head of a department for design and maintenance of bridges and major concrete structures

Summary

By the early 1990's, after 25 years in service, leakages and the associated deterioration in the Limfjord Tunnel had reached a stage where an overall repair of the structure was needed.

A multiple phase repair strategy has been adopted to address both structural problems as well as maintenance and durability problems in the tunnel.

Phase 1 (completed in 1994) included a longitudinal post-tensioning of the tunnel structure to eliminate structural problems and facilitate a durable repair of the severely deteriorating areas in the tunnel, and phase 2 (completed in 1995) included injection of cracks and construction joints to stop leakages through tunnel walls and ceilings.

Phase 3 includes renovation of tunnel walls and -ceilings by repair of areas with deteriorating and chloride contaminated concrete and corroding reinforcement and installation of a new tile-covering on the tunnel walls.

Due to the large areas of deteriorating concrete and the extend in depth of the repair works in phase 3 special considerations concerning technical and practical aspects has been given to both the process of removing the concrete and to the following rebuilding processes.

1. Introduction

The Limfjord Tunnel in northern Jutland, opened in 1969, connects the cities of Aalborg and Nørresundby on each side of the Limfjord. At the same time the tunnel forms part of the continental highway, E45, connecting Scandinavia with the rest of Europe.

At present a daily average of nearly 48,000 vehicles pass through the tunnel; however, prognoses indicate that the traffic intensity will reach the capacity of the tunnel within the next 10-15 years.

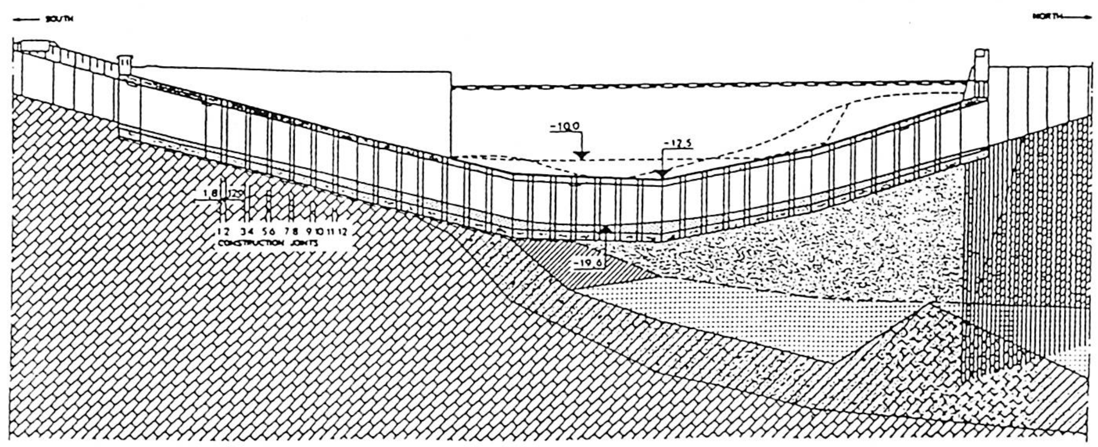
Throughout its nearly 30 years in service the Limfjord Tunnel has suffered from ingress of salt-laden water causing premature deterioration of the concrete and contamination with chlorides, which has led to extensive corrosion of the embedded reinforcement.

By the early 1990's the leakages and the associated deterioration had reached a stage where an overall repair of the structure was needed to ensure and extend its lifespan.

2. The Tunnel Structure

The tunnel is a reinforced concrete structure with a total length of 945 m, of which 510 m is immersed precast tunnel units and 43 m is in-situ cast tunnel.

The immersed part consists of five 102 m long precast reinforced concrete units joined together to form a monolithic structure. The units were cast in a dry dock in 12,8 m long sections, separated by 1,8 m wide gaps into which reinforcement bars protruded. The concrete for these gaps was poured after the sections had shrunk.



The units were waterproofed with a 2 mm butyl membrane which, as described in the introduction, has never been fully effective.

The tunnel has a typical box type cross-section with two separate tubes each carrying 3 traffic lanes of 3.5 m and 2 pavements of 0.75 m.

3. Previous Repairs

Leakages were observed in tunnel walls and ceilings shortly after the tunnel was put into service.

The leakages were primarily located in the immersed part of the tunnel at construction joints between the 12,8 m sections and the 1,8 m gaps where cracks extend in full depth through walls, top and bottom.

To stop seasonal movements of these cracks and make it possible to stop leakages by injection a longitudinal post-tensioning of the tunnel was established in 1993-94 (J. Vejlby Thomsen, P. Hededal, Post-tensioning of the Limfjord Tunnel, Denmark, IABSE Symposium, San Francisco 1995), being the first and very important step in the overall repair of the structure.

In 1995 cracks and leakages were injected to stop further ingress of water.

4. Repair of Tunnel Walls and Ceilings, Phase 3

Phase 3 of the tunnel repair strategy, starting in early August 1997 and lasting for 10 months, comprises the following main activities on tunnel walls and ceilings:

- Removal of damaged concrete
- Placing of new concrete
- Supplementary injection of cracks
- New tile-covering

4.1 Conditions in the Tunnel before Repair

Measurements have confirmed that the structural concrete in large areas of both walls and ceilings inside the tunnel is severely contaminated with chlorides.

High chloride contents - well beyond the level that is generally recognized to cause corrosion on the embedded reinforcement - are found in the concrete, especially in areas where cracks and casting joints in the structure have allowed ingress of salt-laden water from the Limfjord and in the lower parts of the walls exposed to splashes of salty water from vehicles passing the tunnel in the winter season.

Extensive corrosion of the embedded reinforcement have been observed in these same areas - in some areas corrosion of the reinforcement has even led to delamination of the concrete causing hazardous areas with the potential risk of pieces of concrete falling from walls or ceilings on passing vehicles. Since 1996 removal of such hazardously delaminated concrete has been part of the routine maintenance procedure in the tunnel.

Besides contaminating the concrete with chlorides, the excessive ingress of water though cracks and casting joints has locally caused severe leaching and degradation of the concrete accelerating the delay of the structure even more.

4.2 Removal of Concrete

Removal of chloride contaminated and deteriorating concrete is carried out by hydro-demolition (water-jetting), i.e. making use of water jets with extreme high pressure to chip of or cut the concrete.

The water jetting technique is well known in Sweden and Germany but has not yet been fully recognized in Denmark.

In the actual case, however, water jetting seems to be the only viable demolition method of the following reasons:

- Large areas of concrete (approximately 12,000 m^2) have to be removed to an average depth of 80-100 mm - in some areas even up to 250 mm depth which favours a high capacity, high effective, and rational method

- Generally the reinforcement in both the tunnel walls and the ceilings is very congested and consist in some areas of up to 4 layers, which, in combination with the expected depth to sound concrete, makes conventional demolition by jack-hammering extremely difficult and time consuming

Besides being the most efficient demolition method the water jetting method is also advantageous from a more technical point of view:

- the method leaves the demolished concrete surface very rugged and uneven but without micro-cracks enabling a very effective bond to shot-crete repairs and casted repairs

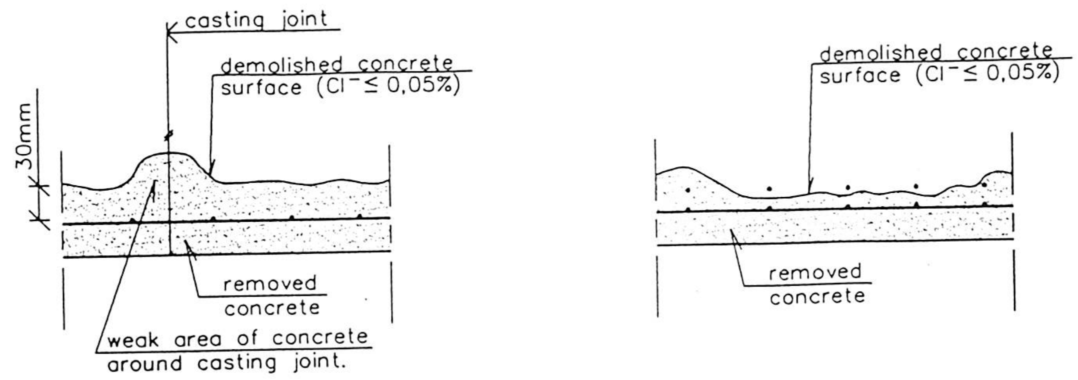
- corrosion products and chlorides are removed from exposed reinforcement to an effect that is comparable to sand-blasting

The actual extend of removed concrete is governed by three factors:

- the depth of the reinforcement
- the amount of chlorides in the concrete
- the concrete strength

Generally concrete is removed until the amount of chlorides in the concrete is less than 0.05% by weight of concrete, however, never deeper than 30 mm behind the deepest layer of reinforcement unless weak areas of concrete facilitate deeper demolition.

Two typical demolition profile is schematically shown below.



Due to the large extend of concrete needing to be removed and the amount of reinforcement being exposed in this process, static considerations have necessitated guidelines on how the demolition work must be carried out, imposing the contractor to split up larger continuous demolition areas - especially on ceilings - into smaller sections, and replacing concrete in one section before removing damaged concrete from adjacent sections.

4.3 Replacing Concrete

Concrete is replaced either by

- pumping high-slump concrete in a singled-sided form
- shot-creting

depending primarily on the depth of the removed concrete. Generally shot-crete will be used only in depths up to 70 mm.

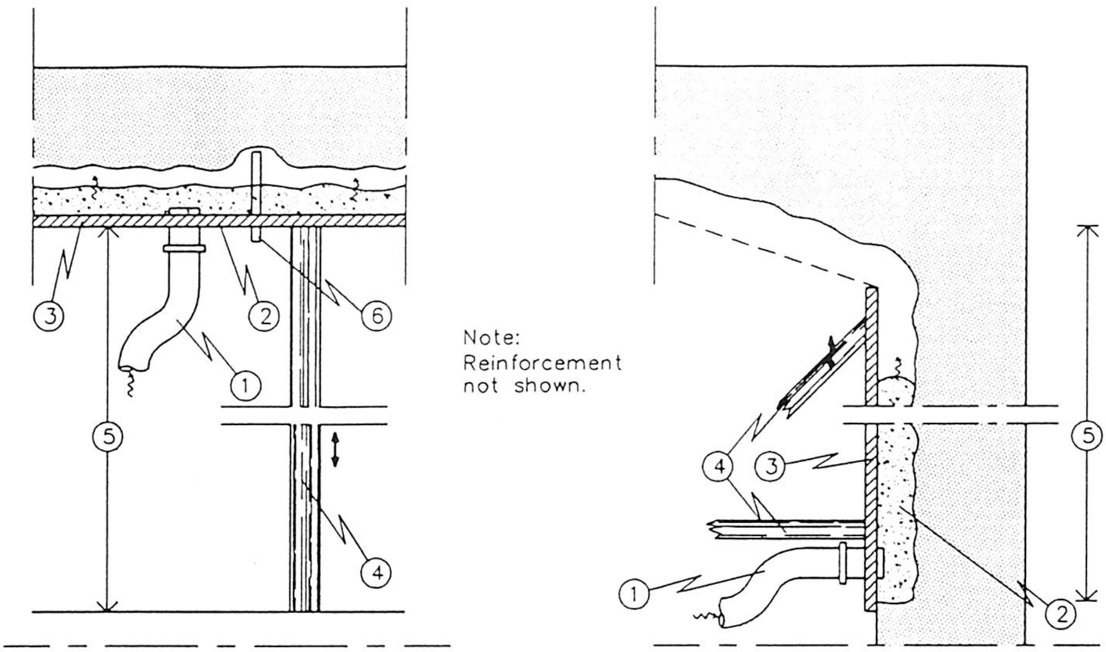
The concrete specification can be summarised as follows:

- 340 kg/m³ low alkali, sulphate resistant Portland cement
  60 kg/m³ fly ash
  16 kg/m³ micro silica
- 886 kg/m³ fine aggregate (0-2 mm)
- 856 kg/m³ coarse aggregate (2-8 mm)
- water-cement ratio (equivalent) = 0.36

Furthermore the concrete contains a variety of additives to enhance pumping ability, bond strength, frost resistance, casting properties and to minimize shinkage of the concrete.

The concrete specification has been determined from numerous laboratory tests and large scale tests on mock-ups of typical areas on tunnel walls and ceilings.

The principle of pumping high-slump concrete is schematically shown on the illustrations below.



Principle - replacing concrete on tunnel ceiling

Principle - replacing concrete on tunnel wall

① Concrete supply, maximum pumping pressure: 1 atm

② High-slump concrete

③ Form, adjustable in height to comply with varying casting heights, see ⑤. The stiffness and capacity of the form is designed to meet specified requirements on straightness of wall/ceiling at maximum pumping pressure, see ①

④ Scaffolding - supporting the form, the scaffolding is accordingly designed to be adjustable in height, and to meet specified stiffness and capacity criteria at maximum pumping pressure. Furthermore, both form and scaffolding is designed to be easily relieved, moved, adjusted and re-established in another location

⑤ Casting height varying from approximately 4,5 meters to 5,5 meters

⑥ Ventilation tubes to avoid air being enclosed in voids during casting

The quality of all castings are controlled by close examination - both on site and in laboratory - of concrete cores and by testing the bond strength between old and new concrete in locations pointed out by the supervisors.

It is worth noting that shot-crete tests have been carried out parallel to the tests of the pumping method, however, for depths beyond approximately 100 mm and a dense reinforcement arrangement the pumping method especially on the tunnel ceilings has proven to be far superior to the shot-crete method.

Typically the shot-crete method leaves voids behind congested reinforcement and fails to obtain acceptable bond to old concrete when casted in thick layers.

4.4 Supplementary injection of cracks

As previously mentioned cracks and leakages in tunnel walls and ceilings were injected in 1995, however, at that time without removing any concrete. Therefore, in some areas leakages would not be precisely located, hence, injection was not completed, allowing ingress of water to continue.

Having removed damaged concrete the injection work will be completed in these remaining areas, a thorough inspection of all demolished surfaces will be performed and supplementary injection will be carried out to ensure that all leakages are effectively tightened.

4.5 Tile-covering af Walls

After completion of the concrete repairs and water-blasting of remaining parts of the walls a new tile-covering will be installed on the walls.

The tile-covering serves three main objectives:

- From a maintenance and technical point of view the tiles must be easy to clean and durable to withstand the environmental and traffical impacts in the tunnel
- Furthermore from an operating and economical point of view the tiles must have a light colour so that the required illumination in the tunnel can be obtained without excessive use of lights and electrical power
- From a traffic safety point of view the tile-covering must reduce reflections from car-lights but must at the same time form a distinct contrast to traffic ahead in the tunnel

Since water from the Limfjord will continue to diffuse through the tunnel walls, the tiles are mounted in a relatively thick layer of frost resistant mortar and separated by 6 mm wide mortar joints.

The adhesive strength between the tiles and the mortar and between the mortar and the concrete surface is systematically controlled after installation.

5. Concluding Remarks

The phase 3 repairs concludes the structural repairs in the tunnel.

Future works will amongst others include installation of a new lighting system and fire protection of the tunnel ceiling.

A primary objective in the whole repair process on both structural components and technical installations is to generally enhance the safety standard in the tunnel.

The decision on fire protection of the tunnel ceiling, for example, is a direct result of this "enhanced safety approach".

Similarly, in connection with the phase 3 repairs new fire protective cable ducts for future cabling of the technical installations in the tunnel have been established in tunnel walls and ceilings.

The total renovation of the tunnel is expected to be completed in 1998, at a total cost of approximately Dkr. 100 mio., of which the phase 3 repairs amount to approximately Dkr. 35 mio.

Leere Seite
Blank page
Page vide