Zeitschrift: IABSE reports = Rapports AIPC = IVBH Berichte

Band: 73/1/73/2 (1995)

Artikel: Post-tensioning of Limfjord Tunnel, Denmark

Autor: Vejlby Thomsen, Jens / Hededal, Poul

DOI: https://doi.org/10.5169/seals-55300

Post-Tensioning of the Limfjord Tunnel, Denmark

Précontrainte du tunnel de Limfjord, Danemark

Vorspannen des Limfjord Tunnels, Dänemark

Jens VEJLBY THOMSEN
Civil Engineer
Ministry of Transport
Copenhagen, Denmark

Jens Vejlby Thomsen, born 1940, received 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
Civil Engineer
Rambøll, Hannemann & Højlund A/S
Aalborg, Denmark

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

SUMMARY

By the early l990s, after 25 years in service, leakages and associated deterioration in the Limfjord Tunnel had reached a stage where an overall repair of the structure was needed to ensure and extend its lifespan. After studies of a wide range of possible repair methods, a post-tensioning repair strategy was chosen. The paper describes the post-tensioning project, focusing on the character and causes of the problems, the design basis and the design and construction works and the expected and the observed effect of the post-tensioning.

RÉSUMÉ

Au début des années 1990, et après 25 ans de service, les fuites et la dégradation du tunnel de Limfjord avaient pris de sérieuses proportions nécessitant une réparation majeure des structures afin de sauvegarder le tunnel et prolonger sa durée de vie. Après l'étude de nombreuses méthodes de réparation possible une stratégie de réparation comportant la précontrainte de la structure a été retenue. L'article expose le projet de précontrainte, le caractère et les causes des problèmes, les données de base des études et la conception, les travaux de construction et, finalement, les effets prévus et observés.

ZUSAMMENFASSUNG

In den frühen 90er Jahren, nach einer Dauer von 25 Jahren, hatten die entstandenen Undichtigkeiten und der damit verbundene Verfall im Limfjord Tunnel ein Ausmass erreicht, wo umfassende Reparaturarbeiten notwendig waren, um dessen Lebensdauer zu sichern und zu verlängern. Nach durchgeführten Untersuchungen von möglichen Reparaturmethoden wählte man ein Vorspannen. Der Artikel beschreibt das Vorspannprojekt mit Schwergewicht auf den Charakter und die Ursache der Probleme, die Bemessungsvoraussetzungen und Bemessung, Konstruktionsarbeiten und schliesslich den vorausgesehenen und den wahrgenommenen Effekt des Vorspannens.

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 40.000 vehicles pass through the tunnel; however, prognoses indicate that the traffic intensity will reach the capacity of the tunnel within the next 15-20 years.

Throughout its twenty-five 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.

The operation and the maintenance of the tunnel is handled by the Bridge Department of the Danish Road Directorate with the assistance of consultants, contractors and service companies, some of which perform a 24-hour service.

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.

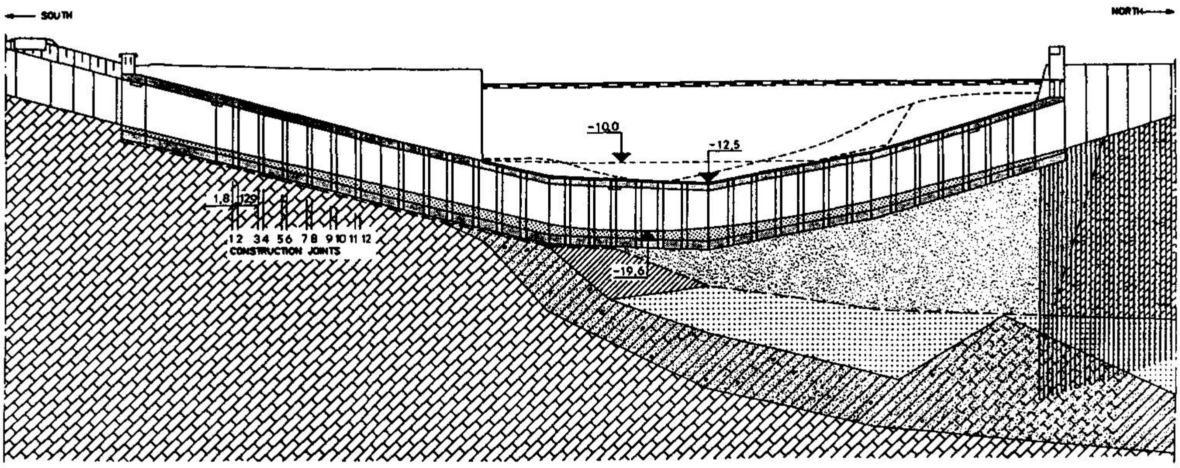


Fig. 1 Longitudinal section

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.

The tunnel is founded on an approximately 1 m thick sand bedding jetted in place after positioning of the tunnel units, and is supported by the portal buildings at the north and south ends, the northern portal building being founded on piles.

Longitudinal movements are taken up by expansion joints at the portal buildings.

3. HISTORICAL REVIEW

As described in the introduction, leakages were observed in tunnel walls and ceilings shortly after the tunnel was put into service.

The leakages are 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.

The repair of the leakages and the deteriorating concrete is complicated because of the natural tendency of the structure to expand and contract in warm and cold weather. When the tunnel contracts in cold weather, longitudinal tensile stresses are introduced in the structure as friction between the surrounding sand filling and the structure hinders it from moving freely. Therefore, as the tunnel has intentionally been under-reinforced in the longitudinal direction, the cracks at construction joints are wider in winter than they are in summer.

Furthermore, repair is complicated by settlement of the northern part of the tunnel which has caused additional tensile stresses in the bottom tunnel slab, due to the deformation of the structure.

The post-tensioning repair strategy was chosen after detailed studies and analyses of a wide range of possible repair methods with respect to technical, economic and traffic aspects as well as elements of risk involved.

4. THE POST-TENSIONING REPAIR STRATEGY

The basic idea of the longitudinal post-tensioning of the tunnel is to impose a permanent compressive force sufficient to ensure that the entire tunnel cross-section is always under compression.

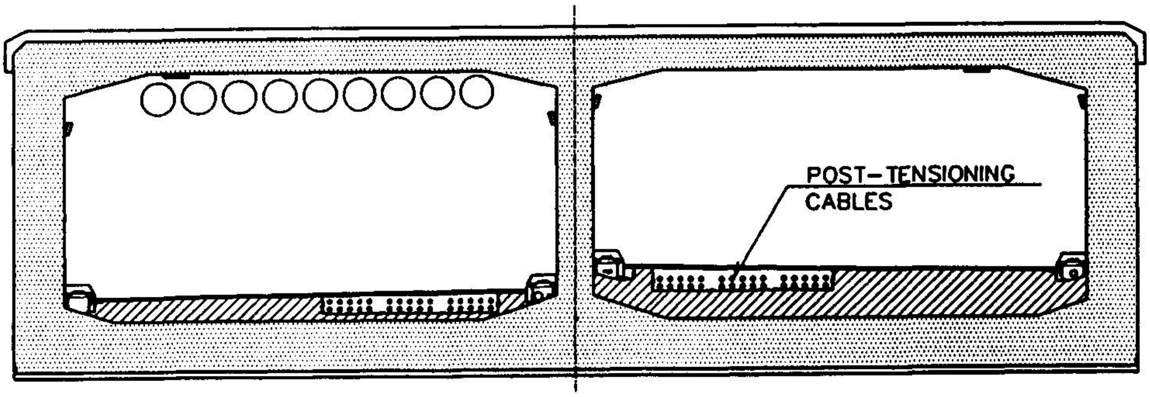
Consequently and most importantly, the post-tensioning is expected to eliminate tensile stresses and crack movements caused by the thermal contraction of the tunnel structure in the cold season. This is considered to be a fundamental condition of a future successful, durable and effective overall repair of the structure.

The necessary post-tensioning force was determined from detailed analyses of the varying longitudinal forces acting on the tunnel structure when the structure expands or contracts. The assessment of all the parameters influencing the longitudinal forces and their ranges of variation is based on comprehensive registrations, laboratory analyses and expert's opinions.

A fundamental part of the design basis was established from registrations and analyses of the longitudinal movements of the tunnel at the expansion joints at the north and south ends of the tunnel, recorded since the tunnel was put into service in 1969. Furthermore, from registrations and analyses of the corresponding temperature in and around the tunnel, and from laboratory determinations of the thermal expansion coefficient and the modulus of elasticity of the concrete, it was possible to determine the probable magnitude and distribution of the longitudinal force, the fixation force, caused by friction between the tunnel structure and the surrounding sand filling.

Having established the design basis, the necessary post-tensioning force was found to be approximately 120 MN.

The post-tensioning was established by installation of a total of 60 post-tensioning cables in the bottom slab of the tunnel, extending from the expansion joint at the north end to the expansion joint at the south end.



5. CONSTRUCTION WORKS

Construction works in the tunnel, including application of the post-tensioning, commenced in late October 1993 and were completed in June 1994. The works included the following main activities

- Removal of existing asphalt covering
- Removal of mass concrete
- Construction of anchorage blocks for post-tensioning cables
- Installation and tensioning of cables
- Casting of new mass concrete
- New asphalt covering

The construction works were completed in the north-bound tunnel tube before starting in the south-bound tube, i.e. post-tensioning was first applied in the north-bound tube, and completed 3 months later in the south-bound tube.

Traffic through the tunnel was maintained throughout the construction period in the tube free of construction works, constantly adjusting the direction of the traffic in the center lane to correspond to the dominating traffic direction.

Removal of both asphalt covering and mass concrete was done by large scale milling. Milled materials were immediately loaded on waiting trucks and removed from the construction site.

After removal of the mass concrete the reinforced concrete anchorage blocks for the post-tensioning cables were constructed. To ensure that the post-tensioning force is effectively transferred from the anchorage blocks to the existing tunnel structure approximately 35,000 anchors of reinforced steel and threaded rods were fastened in drilled holes (0.5-1.0 m depth) in the bottom slab of the tunnel before casting the anchorage blocks.

After completion of the anchorage blocks and installation of cable ducts the post-tensioning cables were installed. The cables were tensioned in a predetermined order using conventional technique and equipment.

6. EFFECT OF POST-TENSIONING

The primary goal of the longitudinal post-tensioning is to ensure that any cross section of the tunnel is permanently subjected to a compressive force, thereby eliminating the seasonal movements of the cracks occurring primarily at casting joints.

The post-tensioning is expected to result in an overall compression of the tunnel structure which will widen the gaps at the expansion joints at the north and south ends of the tunnel.

Furthermore, the post-tensioning is expected to reduce future settlements of the northern part of the tunnel.

In order to establish whether expectations have been fulfilled, relevant data have been collected on the tunnel movements and temperature during and after the tensioning process.

For reasons of continuity and comparability with past registrations, collection of data is primarily based on existing points of measurement.

6.1 Longitudinal Movements

Measurements of the tunnel movements at the expansion joints show that the tunnel, six months after completion of the post-tensioning, has shortened by approx. 15 mm at the north expansion joint and 5-6 mm at the south expansion joint.

The theoretical values, computed on the basis of the design model used for determining the post-tensioning force, are a 16 mm shortening at the north expansion joint and an 8 mm shortening at the south expansion joint.

The previous discussion concerns the recorded movements and the corresponding theoretical values before and after the post-tensioning only. Similar registrations and analyses of the tunnel movements during the two post-tensioning phases have shown equally good agreement between the theoretical values and the corresponding registrations.

The results are summarized in the table below.

	Shortening Post-Tensioning Cables East Tube [mm]		Shortening Post-Tensioning Cables West Tube [mm]		Total Shortening [mm]	
	Measured	Calculated	Measured	Calculated	Measured	Calculated
North End Tunnel	9-10	app. 11	app. 6	app. 5	15-16	app. 16
South End Tunnel	3-4	app. 3	2-3	app. 5	app. 6	app. 8

Table 1 Summarized results

It is worth noting that additional permanent compression is expected, especially in the northern part of the tunnel, as the tunnel temperature reaches its minimum. The magnitude of the additional shortening is estimated at approximately 10 mm.

6.2 Settlements

The most recent levellings in the tunnel prior to the post-tensioning indicated that settlement of the northern part of the tunnel had resumed after years of stagnation.

Levellings in the tunnel after the post-tensioning indicate as expected that the settlement has again stagnated. However, given the short period of time since the completion of the post-tensioning, it is still too early to draw a conclusion on this issue.

6.3 Local Measurements

Strain-gauge measurements at cracks and casting-joints in representative areas confirm that the tunnel has been compressed at all locations, as a result of the post-tensioning. However, the magnitude of the compression varies, which is ascribed to the varying character of the cracks and their location in the tunnel.

6.4 Summary

To summarize, all measurements on the tunnel during and after the post-tensioning have confirmed the expected effect of the post-tensioning on the tunnel.

Finally, although the post-tensioning has resulted in an overall compression of the structure as well as local compression of cracks, and although leakages have been reduced after the post-tensioning, the authors wish to stress that:

- The post-tensioning is not expected to stop leakages

- The post-tensioning is expected to stop the seasonal movements of cracks and make it possible to stop leakages by injection

7. CONCLUDING REMARKS

The post-tensioning of the tunnel was the first and most important step in an overall repair of the structure. Future repair phases include the following activities:

- Watertightening, i.e. injection of cracks and leakages
- Repair of concrete and reinforcement in deteriorating areas
- Preventive measures

Furthermore, future activities also include fire protection of tunnel ceilings, new covering on tunnel walls and other activities aimed at generally enhancing the standard of both the structural components and the technical installations.

When these repairs have been completed, no further major repairs are expected within the following approximately 30-40 years.

The total cost of the repairs, including the post-tensioning, is expected to amount to approximately Dkr 100 mio., or one tenth the cost of a new tunnel.