

Sustainability of the inner lining in Norwegian road tunnels

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Introduction: A distinctive feature of Norwegian road tunnels is their inner lining layout in case water or water and frost protection is required. This slender lining detached from the permanent rock support is held by fixation bolts to the rock mass. Apart from material differences, this solution layout has not changed since their first implementations in the early 70's. This short document aims to reflect the carbon footprint of a typical Norwegian inner lining compared to the traditional double shell lining.

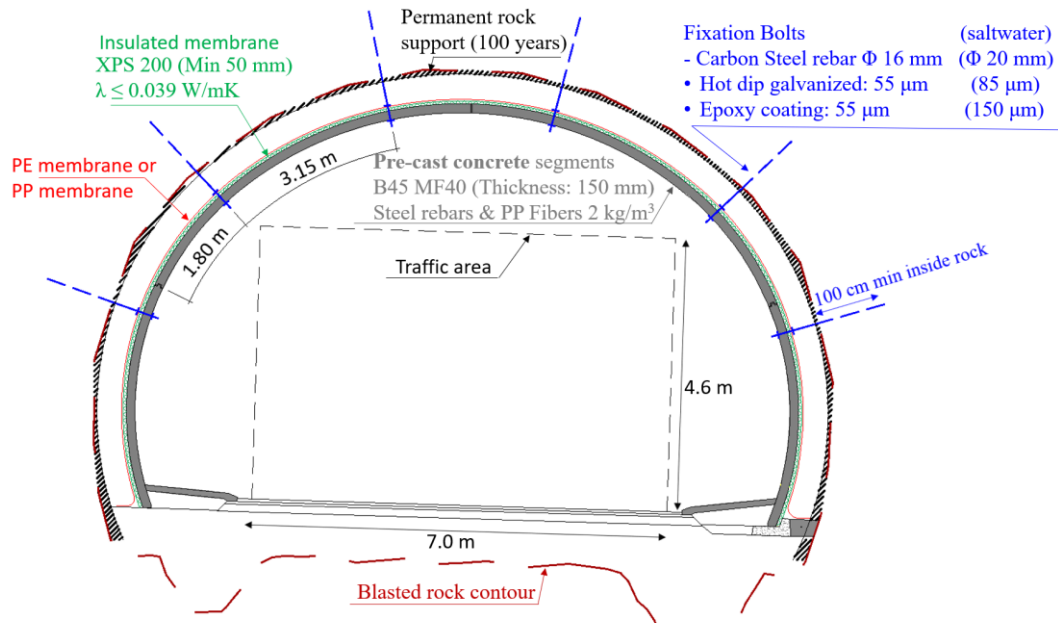


Figure 1: Inner lining of pre-cast concrete segments T10.5 Modified from (NPRA, 2016a).

It is implicit in the solution for water and frost protection inner lining in Norwegian road tunnels the confidence assigned in the long term to the rock support installed during construction, with more than 40 years of experience with such approach. Cast-in-place concrete lining has always been a solution used in extremely poor rock mass conditions, but avoided whenever possible.

In general, Norwegian road tunnels are designed as drained structures. The remaining water leakage not prevented by pre-grouting efforts is addressed normally by an inner water shielding detached from the rock support as shown in Figure 1. In frost zones, an insulated membrane is added to the inner lining in order to keep the heat from the rock mass behind the inner lining. In this manner, in-leakage water in between the permanent rock support and the inner lining can drain frost-free into the drainage system.

Today, rock support elements are intended to last for 100 years. In the case of the water and frost protection inner lining, they are intended to last for 50 years (NPRA, 2016b).

Concerns about environmental issues related to climate change have emerged globally in the construction industry. Taking into account that the carbon footprint in road tunnels is intimately related to the concrete consumption, the Norwegian approach for the inner lining has captivated international attention.

An interesting investigation was carried out in Ulvin railway tunnel, where a double shell lining was executed in Norway (Jakobsen et al., 2014). The solution implemented for this tunnel is shown in Figure 2.

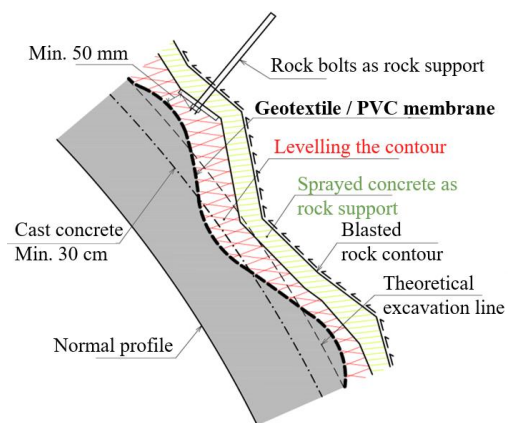


Figure 2: Double shell lining used in Ulvin railway tunnel. Modified from (NPRA, 2012)

Its theoretical excavation area (including gutters and invert) was 128.2 m² and its arc length (walls and roof) approximately 26.1 m. In this research, laser scanning was carried out after:

- Blasting
- Initial rock support
- Levelling (or smoothening) the contour
- Cast concrete was set

The results from this investigation showed that:

- The average overbreak depth measured from the theoretical excavation line was approximately 40 cm.

- The average unreinforced shotcrete thickness used to smoothen the contour in order to properly install the geotextile and the waterproof membrane turned out to be around 20 cm.
- The minimum thickness of 30 cm for cast-in-place concrete turned out to be close to 50 cm in average.

Based on this information, it is possible to provide an estimate of the average carbon footprint $\text{CO}_2_{\text{equiv}}$ per tube meter released by the cast-in-place concrete solution from manufacturing until end of the construction phase. In parallel, a theoretical exercise of installing an inner lining with pre-cast concrete segments can be adapted for the larger cross section in Ulvin tunnel. The comparison between these two inner linings will consider updated requirement in Norway about material quality. The rock mass conditions and the initial rock support are considered the same for both inner lining solutions.

With regard to carbon footprint estimation in concrete, data was obtained either from the Norwegian concrete Association (NB, 2019) or from the Norwegian EPD foundation. The latter source was also used for steel reinforcement and the different geosynthetics.

Specific considerations for pre-cast concrete segment solutions are described below:

- Concrete quality B45 MF40 was considered for pre-cast concrete segments (*C55, w/c < 0.4 and frost resistant*).
- Steel reinforcement (dia. = 6 mm) $\approx 7 \text{ kg/m}^2$ (NPRA, 2017)
- Polypropylene fibers for fire protection = 2 kg/m^3
- Fixation bolt density of 4.7 bolts / tube meter; dia. = 20 mm; L = 1.5 m.
- Insulated membrane XPS 200 of 50 mm.
- PE waterproof membrane of 2 mm.

With regard to the cast-in-place concrete as inner lining, the following considerations were adopted:

- The quality of unreinforced shotcrete for levelling the tunnel contour is B35 M45. (*C45; w/c < 0.45*).
- Non-woven geotextile of 900 gr/m^2 .
- PVC waterproof membrane of 2 mm.
- The quality of cast-in-place concrete equals to B35 MF45 (*C45; w/c < 0.4 and frost resistant*).
- Actual average of cast concrete thickness = 45 cm.
- Polypropylene fibers in cast concrete for fire protection = 2 kg/m^3

Figure 3 shows the results. The total carbon footprint with an inner lining of pre-cast concrete segments per tube meter is estimated as $1496 \text{ kCO}_2_{\text{equiv}}$. In the case of cast-in-place concrete as inner lining the results give $5363 \text{ kCO}_2_{\text{equiv}}$ per tube meter.

Final remarks:

With regard to durability, one could expect that cast-in-place concrete lining would last longer since it is a massive structure. The Norwegian railway authority expects that this solution will make Ulvin tunnel to last for 100 years without major interventions. On the other hand, the Norwegian Public Roads Administration NPRA expects that the pre-cast concrete segment solution will last at least 50 years. If these life expectancies are considered, the inner lining with precast concrete segments is still more environmentally friendly.

References:

Jakobsen, P.D., Buvik, H., Ausland, J., 2014. Experience with double shell lining from Ulvin Tunnel, Common research project between the Norwegian Public Roads Administration (NPRA), the Norwegian Railway Authority Jernbaneverket and Norconsult. (In Norwegian).

NB, 2019. Low carbon concrete, Norwegian concrete association, Publication No. 37. (In Norwegian).

NPRA, 2017. Design of concrete segmental lining for T10.5, in: Norwegian Public Roads Administration. Report No. 509. (In Norwegian).

NPRA, 2016a. Best practice for tunnel lining, in: Norwegian Public Roads Administration. Report No. 510. (In Norwegian).

NPRA, 2016b. Handbook N500: Road Tunnels, Norwegian Public Roads Administration (In Norwegian).

NPRA, 2012. Major research and development projects. Modern road tunnels 2008-2011. Main Report., Norwegian Public Roads Administration. Report No. 127. (In Norwegian).

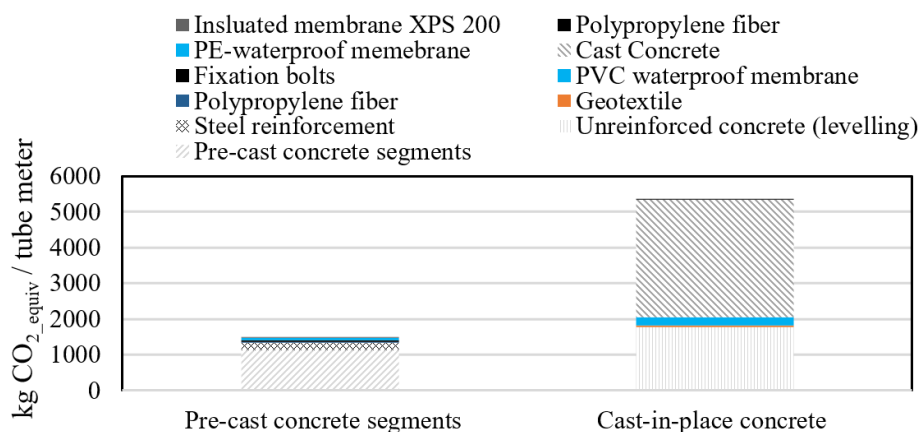


Figure 3: Carbon footprint comparison between pre-cast concrete segments as inner lining and cast-in-place concrete.