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Concrete Pavements in Tunnels

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Summary

Road tunnels will be more common in the future. Concrete pavements constitute an interesting alternative to asphalt pavements, since they have high bearing capacity, wear resistance, and fire safety as well as low maintenance costs and a bright colour. Two concrete pavement solutions have been proposed to be used in Swedish road tunnels. The main alternative consists of a 190 mm thick, high strength, jointed concrete pavement placed on 300 mm unbound layers. Unsorted crushed-rock masses must be removed. The concrete pavement thickness is less than the corresponding one in the open, since the tunnel floor constitutes a stiff subgrade and the thermal gradient is low due to the absence of solar radiation. In the paper, factors that may influence the choice of pavement solutions are discussed. Finally, research needs are outlined.

1. Introduction

The amount of road tunnels constructed underground is expected to increase greatly in the coming years. The main reason is environmental demands that force new roads to be placed underneath the ground surface. In Sweden, long road tunnels are either under construction or planned both in Stockholm and Göteborg. The tunnel surrounding leads to special conditions for a pavement; both advantageous and disadvantageous. A stiff subgrade and a more constant climate without rain and snow are two advantages. Disadvantages are lighting needs both day and night, consequences after fires and other accidents, possible drainage problems, and difficulties and costs connected with repair and maintenance works.

Concrete pavements constitute an interesting alternative to more traditional asphalt pavements. Concrete offers higher wear resistance, higher bearing capacity, improved fire safety, lower maintenance costs, and better light conditions. All these advantages are especially important in a tunnel.

2. International Experience

According to a Swiss handbook [3], concrete pavements in Swiss road tunnels have usually a thickness varying between 120 and 190 mm. Both plain jointed concrete pavement (PJCP) and continuously reinforced concrete pavements (CRCP) occur. The concrete pavement is resting on an unbound gravel base. Between tunnel floor and gravel, there is a cement or asphalt bound layer of varying thickness. The purpose is to adjust the uneven tunnel floor and to protect the gravel layer against erosion. In short tunnels and in the exterior parts (0-1000 m from the opening) of long tunnels, the pavement thickness is the same as the thickness of the pavement outside the tunnel. In Austria, the concrete pavement thickness does not change when the road is going through a tunnel. That gives an increased safety against damage in the tunnel. It is valuable, since repair and maintenance costs are higher in the tunnel.

During the 1970s, a couple of Norwegian road tunnels were constructed and provided with concrete pavements, see, e.g., Silfwerbrand [5]. Both PJCP and CRCP were used. The concrete thickness varied between 100 and 180 mm. Very thin PJCP cracked considerably. In a recent Norwegian road tunnel, the concrete pavement thickness is 220 mm. The concrete pavement is resting on three unbound gravel layers with a total thickness of 200 mm. The concrete thickness includes an extra thickness in order to enable a couple of millings. Millings are needed in Norway to solve rutting problems that occur, since both cars and lorries are allowed to use studded tyres during winters.

3. Proposed Concrete Pavements in Swedish Road Tunnels

3.1 Design Requirements and Precautions

The following design requirements established the basis for the design:

- Design period: 40 years.
- Number of 100 kN standard axes during the design period: 60 millions.
- Distance between wheel edge and pavement edge: > 0.5 m.
- The proposed pavement is suitable for the interior parts of the tunnel, i.e., parts located > 800 - 1000 m from the tunnel openings.
- Unsorted crushed-rock masses and debris, that also might be connected to frost heave risks, should be removed.
- The removal of crushed-rock masses and debris should result in a solid and even tunnel floor.
- The tunnel should be provided with an adequate drainage in order to prevent water flow, if any, to undermine the pavement.
- Use of high strength concrete (HSC) with characteristic flexural strength equal to 7 MPa.
- Proposed concrete pavement thickness constitutes a minimum value, not an average.
- Proposed concrete pavement thickness includes an extra thickness amount enabling milling twice with a total milling depth of 30 mm.
- The concrete pavement should be provided with doweled transverse joints every fifth meter.

The consequences of a pavement damage might be more serious within the tunnel than in the open. This fact was considered by increasing the safety against failure. The pavement design followed the current Swedish pavement design practice, see, e.g., Petersson [4] or Silfwerbrand [6]. It is a mechanic design method based on Eisenmann [1]. Stresses due to traffic loads and thermal gradients are superimposed and compared with an available flexural strength that is fatigue dependent.

The tunnel pavement has two advantages compared to the pavement in open: (i) the rocky tunnel floor constitutes a stiff subgrade (especially compared to clay subgrades) leading to reduced traffic stresses and (ii) the interior tunnel climate means thermal gradient with less magnitude and less duration leading to reduced thermal stresses. According to the Swedish pavement design practice, the thermal gradient is assumed to be 0.06 °C/mm during 5 % of the year, 0.04 °C/mm during 20 %, and 0 during the rest of the year. In the tunnel, the thermal gradient is assumed to be 0.02 °C/mm during 5 % of the year and 0 during the rest of the year. The assumed thermal gradient was based on temperature measurements in a concrete pavement located in a Norwegian tunnel (Hakvåg [2]).

3.2 Concrete Pavement Solutions

The proposed concrete pavements are shown in Fig. 1. The main alternative consists of a 190 mm thick HSC pavement on an unbound gravel base. The second-hand alternative consists of 180 mm HSC and 80 mm lean concrete on an unbound gravel base. The difference in concrete thickness is very limited. The reason is that a lean concrete layer only to a minor extent contributes to the load carrying capacity in a case of a concrete pavement on a stiff subgrade like a rocky tunnel floor.

Comparison calculations in Silfwerbrand [5] show that the tunnel pavement might be 25 % thinner than corresponding pavement in the open.

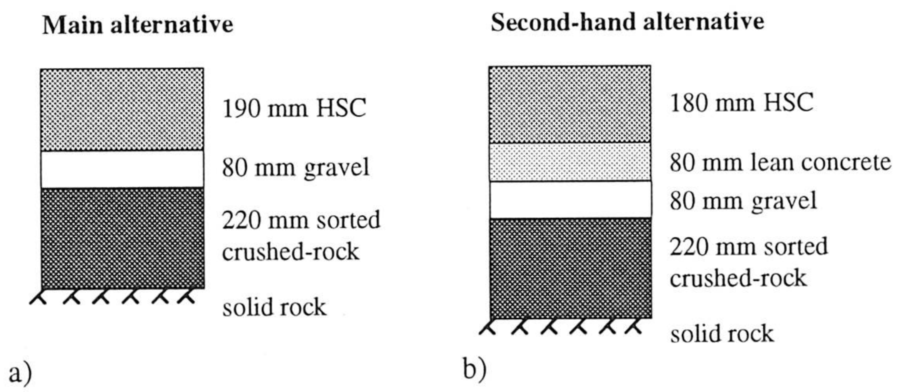

Fig. 1 - Proposed concrete pavements

4. Factors That May Influence the Proposed Pavement Solutions

4.1 Effects of Remaining Unsorted Crushed-Rock Masses

In order to save time and money, the contractor might wish to keep the unsorted crushed-rock masses instead of removing them. It will cause two problems: (i) the stiffness of the subgrade is reduced leading to increased traffic stresses and (ii) the risk of frost heave is increased. The second problem is the most serious one, especially in countries like Sweden with minimum winter temperatures considerably below zero. If the masses cannot be removed, first-class drainage and insulation are needed. The stiffness problem can be solved by increasing the concrete thickness with 10-20 %. Thick layers of crushed-rock masses might cause increased deflections under heavy vehicles. In order to prevent pumping effects, the second-hand alternative (Fig. 1b) with a lean concrete layer underneath the concrete pavement ought to be chosen in that case.

4.2 Effects of Tunnel Ventilation

The effects of the necessary tunnel ventilation has been a major concern in Swedish discussions on tunnel pavement design. In Austria, e.g., the ventilation is considered to influence the climate substantially also in the interior parts of the tunnel. That means that the concrete pavement within the tunnel would be exposed to thermal and moisture movements like the pavement in the open. The proposed concrete pavement solutions are based on the assumption of a rather small thermal gradient. It is in turn based on Norwegian measurements. Intensive ventilation might increase the thermal gradient but the gradient will hardly reach the values obtained in the open, since these gradients are results of solar radiation. However, thorough measurements of thermal gradients in tunnel pavements exposed to intended ventilation conditions are desirable.

4.3 Effects of Uneven Subgrade

According to the requirements, the tunnel floor should be solid and even. However, it might be difficult to succeed. What happens if the rock shoots up in a point under the pavement slab? Will it cause stress concentrations? The problem has been studied using a model of a concrete slab resting on a Winkler foundation (elastic foundation) (Fig. 2a) and solving the well-known differential equation (see, e.g., Timoshenko & Woinowsky-Krieger [7]) by using the finite difference method. A "rigid" point support was created by giving one of the springs a stiffness equal to 1000 times the ordinary spring stiffness.

Flexural stresses due to a point load at different locations were computed. Results for slabs with point support were compared with results for slabs without point support. If the point support happened to be located directly under the load, the flexural stress under the load is reduced considerably. Other locations of the point support only caused minor differences in flexural stresses. The maximum stress increase found was limited to 3 % (Fig. 2b).

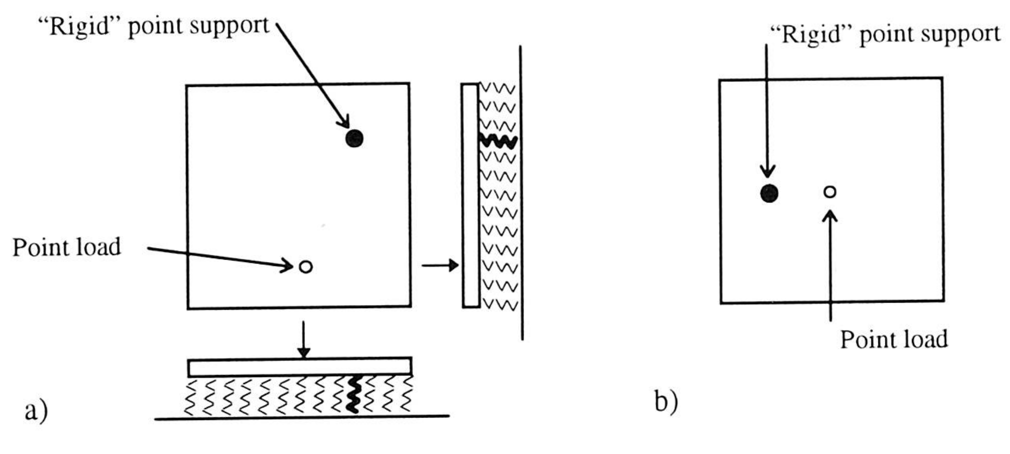

Fig. 2 - Model of concrete pavement on Winkler foundation (a) and example of load and support locations giving 3 % increased flexural stress (b).

4.4 Effects of Rigid Pavement Edge

In Stockholm, it has been suggested that the power supply should be provided by electric cables within concrete conduits along the exterior edge of the pavement. Structurally, the concrete conduit would constitute a continuous rigid support for the concrete pavement (Fig. 3a). Will this continuous simple support cause any stress increases? The problem has been studied using a model of a concrete slab resting on a simply supported edge and the remaining parts on a Winkler foundation (Fig. 3b).

Flexural stresses due to a point load at different locations were computed. The conclusion is that the continuous support did not influence the flexural stresses due to the point load.

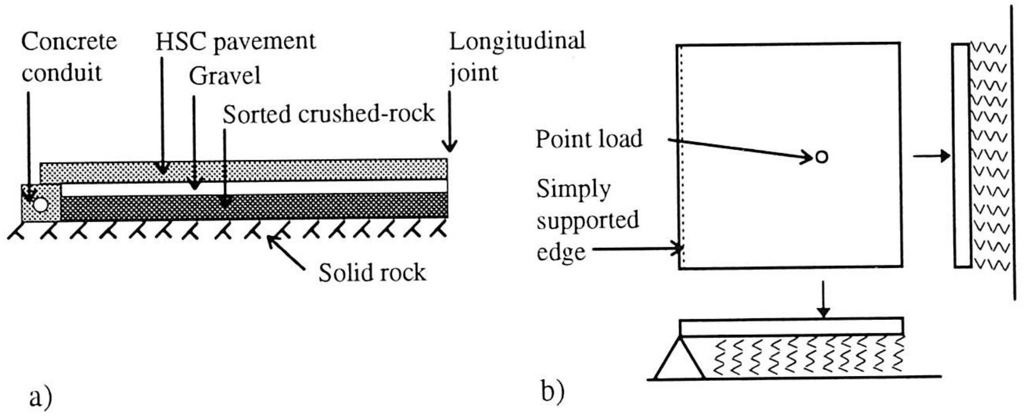

Fig. 3 - A longitudinal concrete conduit is placed on the exterior edge of the pavement (a) and model of concrete pavement with a simply supported edge and remaining parts on Winkler foundation (b).

5. Research Needs

The calculation method used to calculate traffic stresses at a certain distance from the road edge is approximate but has a large impact on the calculation result. Does the calculation method agree with reality? Do current calculation methods overestimate the real traffic stresses close to the pavement edge? Stiffness values of unbound layers are needed to calculate traffic stresses. Can stiffness values estimated by falling weight deflectometer measurements on thick unbound layers on soft subgrades be used also for thin unbound layers on solid rock? Is the constant and thereby favourable climate in the inner part of the tunnel destroyed by ventilation? More research is required to answer these questions.

6. Concluding Remarks

Road tunnels will be more common in the future. Concrete pavements constitute an interesting alternative, since they have high bearing capacity, wear resistance, and fire safety as well as low maintenance costs and a bright colour. Two concrete pavement solutions have been proposed to be used in Swedish road tunnels. The concrete pavement thickness is less than the corresponding one in the open, since the tunnel floor constitutes a stiff subgrade and the thermal gradient is low due to the absence of solar radiation. Unsorted crushed-rock masses should be removed before paving. Otherwise, the pavement thickness ought to be increased with 10-20 % and special care has to be taken to prevent frost heave. Calculations show that an uneven tunnel floor only negligibly effects the pavement stresses.

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