Not Concrete or Asphalt but Concrete and Asphalt

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Abstract

In Sweden and many other countries, there is an intensive competition between asphalt and concrete pavement alternatives. Competition is generally beneficial for economy, development, and quality, but the debate between the two industries is sometimes not based on facts. The asphalt alternative may be the most suitable solution for most cases, whereas the concrete alternative is better in cases with especially high requirements such as cases with very high traffic volumes or through tunnels. There are also advantages in alternatives where you install concrete side by side with asphalt, e.g., by placing concrete in the most trafficked lane and asphalt in the second lane mainly devoted to passes. Furthermore, there exist successful solutions with both concrete on top of asphalt (so called whitetoppings) and asphalt on top of concrete or cement-treated base. The paper describes the advantages and disadvantages with concrete and asphalt as well as the conditions for the various combination alternatives from both a general and a specific Swedish perspective.

Introduction

Since very long time ago, there has been an ongoing fight between advocates for concrete pavements and promoters of asphalt pavements. This is the fact also in Sweden, despite that more than 99 percent of the main highway system is composed by asphalt pavements. Competition is important for development and we know that when the Swedish Transport Administration has promoted concrete pavement, e.g., through test sections and special roads dedicated to concrete pavements, not only the concrete alternative but also the asphalt alternatives have been further developed. It would be preferable to bury the tomahawk and conclude that both alternatives have both advantages and disadvantages. There are room for both.

Research Significance

Several research projects have been conducted in Sweden on various topics of concrete pavements. This paper aims at putting research results together in order to provide solutions based on concrete and asphalt, solutions that may be attractive in sparsely populated countries with moderate traffic intensities and strong asphalt traditions.

Advantages and Disadvantages with Asphalt and Concrete Pavements

Concrete and asphalt are both excellent construction materials for pavements despite that they are rather different. The fundamental aim of a pavement is to transfer and distribute stresses to the subgrade. The transition from the single wheel load to the distributed stresses at the subgrade level has to achieve such a degree that the stresses at the top of the subgrade do not cause any detrimental or permanent displacements. Concrete has both higher compressive strength and higher stiffness than asphalt. On the other hand, asphalt is more flexible and less sensitive to flexural stresses and displacements. The load-carrying capacity of a road is not solely dependent on the pavement. The entire pavement system consisting of several layers provides load-carrying capacity. However, the contribution from a concrete pavement layer is greater than that from an asphalt pavement layer of equal thickness if the underlying layers are not too poor to prevent cracking of the concrete layer itself.

Contrary to asphalt, concrete is fairly independent of temperature. Whereas concrete properties like strength, stiffness, and brittleness do not vary with the seasons, the asphalt stiffness might be 5 to 6 times higher during winter than during summer. During cold weather, also the brittleness of asphalt increases significantly. A special problem with asphalt pavements is concentrated and long-term loads that – especially during summer – can lead to extensive and irreversible deformations. During fire, moist and dense concrete may spall whereas asphalt is inflammable.

As described above, both the concrete pavement and the asphalt pavement have advantages as well as disadvantages. Based on the state-of-the-art knowledge, the various properties have been elevated and qualitatively assessed. For every property and for both alternatives, the author has discerned between three categories: (++) very good, (+) good, and (-) poor. The result is presented in Table 1. The aim of the table is not the final tool for a road owner or other client to select pavement alternative but to highlight the two different alternatives' positive and negative properties. The various properties will have different weight from project to project. There are also differences between different concrete alternatives where Jointed Plain Concrete Pavements (JPCP), Jointed Reinforced Concrete Pavements (JRCP), and Continuously Reinforced Concrete Pavements (CRCP) are the most frequently used ones. Table 1 is focusing on JPCP that is the most frequently used concrete pavement alternative in Sweden. There is a general change for roads outdoors and roads in the tunnel, a change that also is highlighted in the table. This change will be discussed in Section "Concrete Pavements in Tunnels".

Table 1 – Evaluation of important properties for two pavement alternatives

Property	Jointed plain concrete pavement			Asphalt pavement		
	General (outdoors)	Change in the tunnel	Sum	General (outdoors)	Change in the tunnel	Sum
Load-carrying capacity	++	+	+++	+	+	++
Resistance against concentrated loads	++	+	+++	–	+	0
Resistance to sustained loads	++	+	+++	–	+	0
Performance on uneven support	–	(0)*	(–)*	++	(0)*	(++)*
Flexural strength = resistance against flexural stresses	–	0	–	++	0	++
Resistance against deformation at elevated	++	0	++	–	+	0

temperature						
Resistance against stresses at low temperatures	++	0	++	–	0	–
Shrinkage	–	+	0	+	0	+
Wear resistance	++	0	++	+	0	+
Resistance against chemical substances	++	0	++	–	0	–
Evenness	+	0	+	+	0	+
Friction	+	0	+	+	0	+
Noise	+	0	+	+	0	+
Fuel consumption	+	0	+	+	0	+
Brightness	+	+	++	–	–	––
Construction cost	–	0	–	++	0	++
Joint cost	–	0	–	++	0	++
Maintenance cost	++	0	++	–	0	–
Resistance against fire	++	+	+++	–	–	––
Ease at repair	–	–	––	++	+	+++
Possibility to recycling	+	0	+	+	0	+
Aesthetical possibilities	+	0	+	–	0	–
Sum +	25	6	30	18	5	18
Sum –	6	1	5	9	2	8

Note. +++ = outstanding, ++ = very good, + = good or improved, 0 = no change, - = poor or worsen, * = the property has negligible importance in the tunnel.

Asphalt Pavements outside Concrete Pavements

The construction cost is substantially lower for asphalt pavements than for concrete pavements. This means that concrete pavements are only competitive in cases where their other characteristics can balance this disadvantage. The superior load-carrying capacity implies that the concrete pavement is a competitive alternative in cases with very intensive and heavy traffic. The traffic is most intensive close to major cities but diminishes successively with the distance to the city center. The Canadian city Montreal is an example where concrete is used on the interior highway network and asphalt is used further away (Cormier & Thébeau, 2004). In Sweden, the latest concrete highway, from the fourth largest Swedish city Uppsala (in turn 70 km north of Stockholm, the Swedish capital) and northbound, was opened for traffic in 2006. The highway is 78 km but only the 23 km closest to Uppsala was paved with concrete. The selection of the pavement material was based on economical consideration taking the anticipated traffic and traffic growth into account.

Figure 1 – The highway network in Montreal (Cormier & Thébeau, 2004). White sections = concrete pavements, black = asphalt.

Concrete Pavements in Tunnels

Due to urbanization, high land prices, and environmental reasons, many new roads are constructed in tunnels. In Sweden, e.g., a new 21 km long motorway tunnel ("Förbifart Stockholm", the Stockholm Bypass Project) is planned under the western suburban of Stockholm. The specific conditions inside the tunnel make the concrete more competitive (Table 1).

If we compare a motorway outside and inside a tunnel, we may identify six important differences:

1) The subgrade consists of rock, crushed rock or structural concrete that all provide high and even stiffness for the pavement system.
2) The climate inside the tunnel is more even than outside the tunnel, i.e., the tunnel micro climate is warmer during winter and colder during summer than the conditions outside the tunnel. Furthermore, there is no rain, snow, or sunshine.
3) A road tunnel demands 24 hour illumination in order to provide sufficient traffic safety.
4) Repairs inside the tunnel are more complicated than outside the tunnel. Detours will be longer.
5) A fire inside the tunnel is much more severe than a fire outside the tunnel.
6) The particle production might be more critical in the tunnel than outdoors since particles may be trapped in the tunnel, at least in cases with insufficient ventilation.

As shown in Table 1, the advantages of both the concrete and the asphalt pavement alternative increase in number inside the tunnel whereas the sum of the shortcomings diminish or vanish. Reduced stresses (especially thermal stresses), increased importance of brightness (reduced illumination cost), importance of resistance against fire, and increased importance of minimized maintenance costs are the most important factors making concrete the number one choice inside the tunnel. In Sweden, also reduced fuel consumption and an anticipated reduction of (hazardous) particles generated when the concrete pavement is trafficked have supported the decision to select concrete for the pavement inside Stockholm Bypass Project. For a more thorough discussion of the Stockholm Bypass Project, see Silfwerbrand (2014).

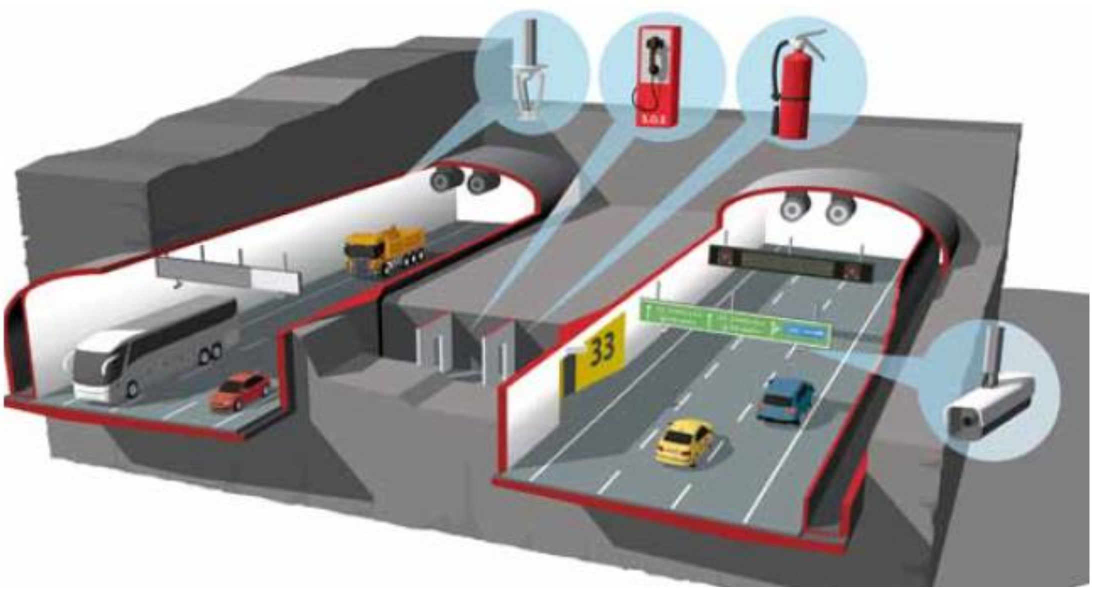

Figure 2 – The Stockholm Bypass Project consists of three lanes in each direction in two separated tunnel tubes. Swedish Transport Administration (2013).

Concrete Pavements side by side with Asphalt Pavements

A wide road with several lanes and shoulder may contain both concrete and asphalt areas. In Sweden, concrete pavements usually have asphalt shoulders. On city streets subjected to intensive bus traffic, the bus stops may be strengthened with a concrete layer. A third example is multi-lane roads where the exterior lanes (low speed lanes) are made of concrete and the interior lanes (high speed lanes carrying less heavy traffic) are made of concrete. These three examples will be described in the following Subsections.

Concrete pavement with asphalt shoulders. Swedish concrete motorways are provided with asphalt shoulders. The shoulders are not intended to be used for carrying traffic but might carry traffic in cases of accidents and road maintenance. The reason for making the shoulder in asphalt is primarily economical.

Bus stops. Buses are heavy vehicles with rather large wheel loads. When the bus stops at a bus stop the wheel loads are static loads with duration that can vary from minutes to hours. Asphalt pavements are sensitive to sustained, concentrated loads, especially at high temperatures. This may lead to permanent displacements. In Sweden, some cities have introduced concrete pavements locally at the bus stops. Both JPCP and CRCP have been used as well as steel fiber concrete pavements.

Figure 3 – Bus stop in Linköping, Sweden, area = 40 m^2, thickness = 200 mm (Svensk Byggtjänst, 2002).

The Swedish experience with concrete pavements for bus stops is mixed. On one hand, the problematic displacements that can constitute problems for smooth riding of vehicles, bicycles and disabled pedestrians have been avoided. On the other hand, cracking has appeared in several cases. A Swedish survey (Löfsjögård & Silfwerbrand, 2005) showed that the problem usually had its origin in the absence of top reinforcement that could control the cracking due to a heavy wheel load standing at the edge of a concrete slab not sufficiently supported by underlying unbound gravel layers. Our recommendation is to make the slab thicker at the edge, install top reinforcement, and improve the compaction of underlying unbound materials.

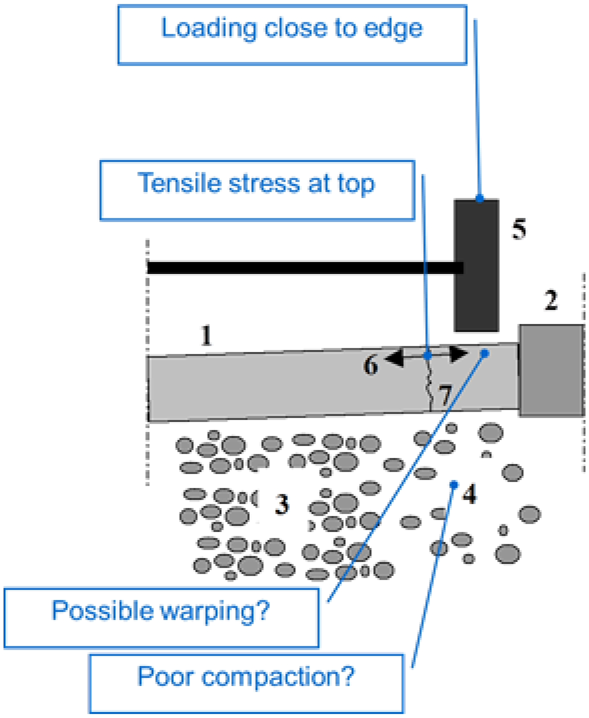

Figure 4 – Frequent cracking in concrete slabs at bus stops and possible causes. Löfsjögård & Silfwerbrand (2005). 1 = concrete pavement (here drawn with certain warping, not needed for cracking), 2 = sidewalk, 3 = compacted unbound layers, 4 = insufficiently compacted unbound layers, 5 = bus wheel, 6 = flexural tensile stress in the top layer of the pavement slab, 7 = longitudinal crack.

Concrete pavement in the low speed lane. Analyses on traffic pattern on multi-lane highways show that most of the traffic and especially trucks and other heavy vehicles use the low speed lane closest to the shoulder (in Sweden denoted K1). The high speed lane (K2) is primarily used by personal cars at passing. This behavior means that the low speed lane is subjected to both heavier and larger number of traffic loads. Usually, both lanes are constructed with the same material and a constant thickness, despite that attempts with tapered cross sections (increasing thickness towards the shoulder) have been carried out. Another way of taking the uneven loading into account is to construct the lanes of different pavement materials (Figure 5). In some countries (e.g., Germany, South Africa, and USA), there is experience of K1 in concrete and K2 in asphalt (Hultqvist & Dolk, 2015). The challenges are (i) how to select the best solution for the underlying layers and (ii) how to construct the longitudinal joint between the two lanes.

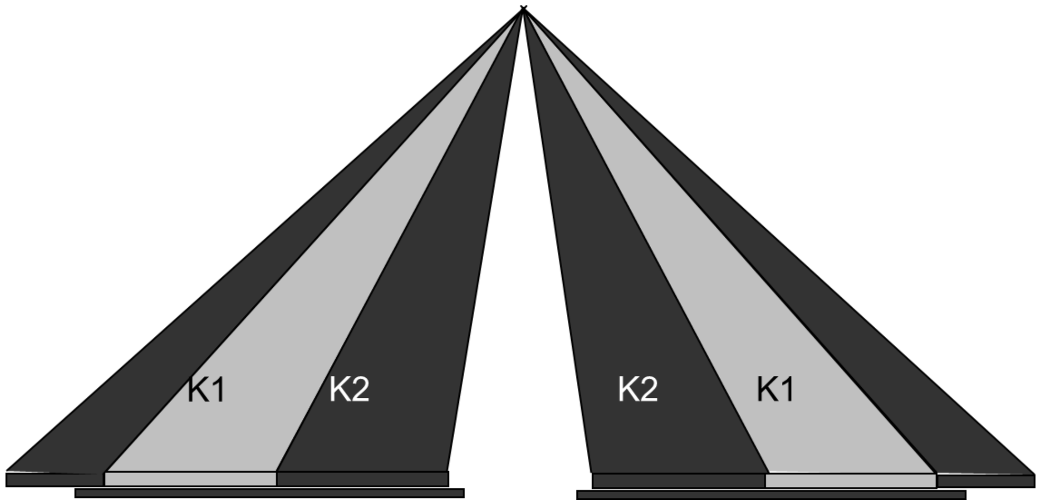

Figure 5 – Pavement with shoulders and high speed lane (K2) in asphalt and low speed lane (K1) in concrete.

Asphalt on Concrete

A pavement system consisting of an asphalt wear layer on a concrete or, more frequently, a cement-treated base is a rather common pavement alternative. The idea is to combine the stiffness and strength of the cementitious layer with the evenness and riding comfort of the asphalt layer. In Sweden, this alternative is rarely competitive since the design praxis is to construct the cement-treated base thicker than the asphalt-treated base in the corresponding (fully) flexible pavement alternative. A problem with this semi-flexible pavement alternative is the condition that unavoidable shrinkage cracks are reflected through the asphalt layer. This phenomenon is called reflective cracking and has been devoted to a special series of conferences organized by RILEM. Among measures to prevent or minimize reflective cracking are special cementitious mixes, special asphalt mixtures, reinforcement, fibers, devises for introducing cracks with suitable spacing (crack control), and various interlayer products.

Concrete on Asphalt

The solution concrete on asphalt is younger than the solution asphalt on concrete. This alternative was originally developed for repairing or strengthening old asphalt roads and is usually called whitetopping. Besides, there is a pavement alternative with an asphalt base supporting the full-depth concrete pavement. This alternative will not be further discussed since the focus of this paper is not the base layer. Both solutions with asphalt-treated bases and cement-treated bases are here denoted concrete pavements if the primarily load-carrying layer is concrete.

The whitetopping combines several of the advantages of concrete with the advantages of asphalt. You may also state that you avoid both concrete and asphalt disadvantages. By analyzing Table 1, it can be concluded that the concrete top layer contributes with resistance against concentrated and sustained loads, extreme temperatures (low, high, fire), wear resistance, and brightness, whereas the underlying asphalt layer contributes with flexural strength and reduced construction costs. The potential of the whitetopping has been further discussed in Silfwerbrand (2004).

Sweden was one of the pioneering countries testing whitetoppings in full-scale (Silfwerbrand, 1998). The tests consisted of three test sections totaling 298 m (Figure 6). The concrete layer was just 70 mm thick (Figure 7) but performed very well during the 10 years of testing despite heavy loads (Figure 6). The only damages that occurred were some minor joint spalling that developed already at time of saw-cutting the joints. The keys to the excellent behavior were a well-performing old asphalt layer and good bond between asphalt and concrete. Whitetoppings should not be used as repair measure on old asphalt pavements with improper load-carrying capacity but preferably on asphalt roads in need of improved resistance against wear and rutting. Good bond is mandatory for composite action between asphalt and concrete and without bond the thin concrete layer will not be able to carry its part of the load without severe cracking.

Figure 6 – Swedish field tests on whitetoppings.

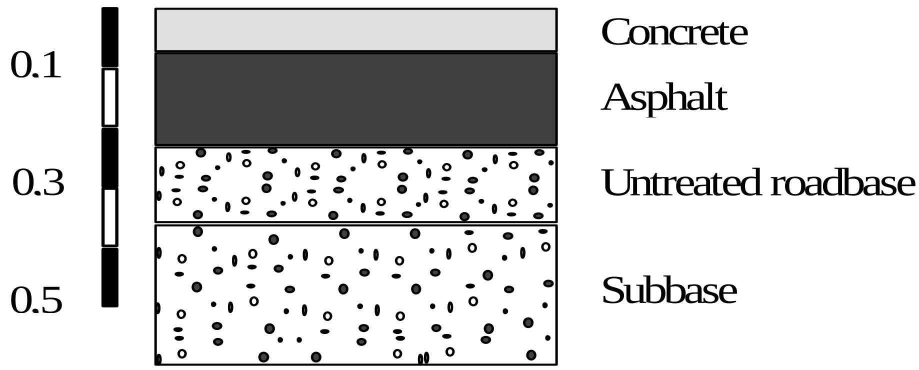

Figure 7 – The pavement system of the Swedish field tests on whitetoppings.

Concluding Remarks and Research Needs

Concrete and asphalt are two excellent pavement alternatives and there are several possibilities to combine the two materials in order to benefit from both materials' advantages. This paper describes various types of geometrical alternatives where you either place the materials after each other or side by side or on top of each other. Seven different alternatives are described in the paper and they are summarized in Table 2.

Table 2 – Summary of alternatives with concrete and asphalt

No.	Relation between asphalt and concrete	Example	Reason for selecting concrete
1	Asphalt outside concrete	Roads remote from or close to cities	High traffic volume
2	Asphalt outside concrete	Roads outside or inside tunnels	Long service-life with minor maintenance
3	Asphalt beside concrete	Concrete lanes with asphalt shoulders	High traffic volume
4	Asphalt beside concrete	Asphalt streets with concrete bus stops	Static loads
5	Asphalt beside concrete	Asphalt in low speed lane, concrete in high speed lane	High traffic volume
6	Asphalt on concrete	Asphalt wear layer on cement-treated base	Enhanced load-carrying capacity
7	Concrete on asphalt	Whitetopping	Enhanced wear resistance

Some of the alternatives have been used successfully during long times in several countries while others need further development and optimization. Further research is recommended in the following areas:

- Development of objective decision support tools in order to facilitate the client's selection of pavement alternatives for different conditions.

- Concrete materials and concrete pavements with enhanced wear resistance, durability, cracking resistance, and brightness for tunnel conditions in order to further extending the service life and maintenance intervals while reducing particle production, fuel consumption, and lightening energy.
- Repair methods that easily and efficiently can be used in tunnels during a minimum closing time if damages at rare occasions would develop.
- Robust solutions for concrete pavement slabs for bus stops and roundabouts next to streets with asphalt pavements.
- Improved detailing for multi-lane roads with both concrete and asphalt lanes especially focusing on drainage and longitudinal joints.
- Optimization of the whitetopping alternative developing optimal thickness for the concrete and asphalt layers and optimal joint spacing.

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