Bridge decks and bridge waterproofing systems of tomorrow - Tested systems that point the way into the future

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1. Introduction

With a drive for more and more mobility and traffic volumes that increase every year, especially in industrialised countries, transport networks are becoming overloaded.

Tunnels and bridges connect multiple road axes and take traffic through critical pressure points. Any disruption in such key structures causes significant inconvenience to road users.

In the interest of more favourable life-cycle costs and to reduce bridge and tunnel congestion and the resulting costs, civil engineers are required to design sophisticated waterproofing and bridge deck systems with a high quality of planning and work execution.

2. Requirements for the bridge deck design

High volumes of traffic – with heavy vehicles accounting for as much as 35% - demand a waterproofing and bridge deck system that exhibits excellent resistance to deformation, even in high temperatures. To make this possible it is necessary that

- the deck base is bonded to the waterproofing system.
- the waterproofing is bonded to the protection layer and the protection layer is bonded to the binder/wearing course.
- all layers must attain a high level of stability.
A particular challenge is that this layer bonding is not only achieved in the condition when new, but is also ensured on a permanent basis.

Temperature-related length changes in the steel/concrete base structure play an important role - in summer/winter and day/night. On the Storebaelt Bridge in Denmark the changes in length from expansion joint to expansion joint in summer/ winter can be up to 2 m, and the elongation day/night, depending on temperatures, is 40 cm – 60 cm. The waterproofing system of the bridge deck must also be able to take up these length alterations. This demands highest quality standards in the deck construction, and, most importantly, the individual layers must remain bonded together on a permanent basis. The ever-increasing axle loads of heavy vehicles exert a particular strain on the pavement design and on the required layer bond.

During planning the pavement thicknesses, the laying stages and the longitudinal joints of the individual layers must be determined in such a way that in subsequent maintenance jobs the work can be carried out in a focused manner. This means that

- All profile corrections of the pavement are carried out in the protection/binder course so that the wearing course can be laid in a uniform thickness < +/- 5 mm.
- Traffic management for subsequent repair/maintenance work must be included in the planning. Work joints are to be arranged accordingly so that these do not impair the traffic regime of a repair job.

Great importance must be awarded to material compatibility. The waterproofing and pavement layers have to meet highest standards in terms of design life, durability, deformation resistance, etc. It has to be verified that the individual materials do not detrimentally interfere with each other. Any rising of bitumen from bituminous waterproofing into the mastic asphalt protection layer must be excluded.

The minimum or maximum overall thickness of the bridge/tunnel pavement structure is determined within the scope of detailed asphalt engineering where an important role is played by the following factors:

- Maximum length changes in the base structure summer/winter
- Maximum temperature summer / minimum temperature winter
- The expected volume of traffic per day: the current status and the assumed figure in 20 years time
- Percentage of heavy vehicles
- Maximum axial load of vehicles
- Load impact from moving/stationary traffic “stop and go”
- Oscillations and vibrations in the base structure
- Gradient
- Cross fall
- Number of days with road salting
- Number of winter days with minus temperatures that exceed - 20°C
- Number of summer days with temperatures ≥ 25°C at night
- Maximum speed/skid resistance
Depending on the set requirements, the minimum mastic asphalt layer thickness can be reduced through the use of special additives. The minimum/maximum ranges specified in the standards serve as a guiding principle. This applies in particular to pavement structures with thin layers and pavements that are subject to severe weather conditions and heavy traffic loads. To this end, project-specific recipes have to be developed/adjusted accordingly.

3. Life-cycle costs consideration

As is the case with a fridge or a car, performance parameters vary as a function of price. A fridge with a long service life, good cooling capacity and energy balance is more expensive than a cheaper appliance with a shorter life and questionable performance. In the life-cycle costs consideration, however, advantages become evident.

There is a similar situation in bridge deck structures. The expectations here are:

- Proper functioning of the waterproofing: 50 years
- Design life of deck structure: 25 years (wearing course)
- Low maintenance at joints and at the start/end interfaces

Good performance also means that as a result of fewer maintenance jobs and prolonged life of the waterproofing and pavement structures, less roadworks are required, and therefore there is less traffic congestion caused by roadworks.

For repair jobs on major roads/freeways the breakdown of costs is as follows:
The ancillary costs are very high due to the sharp increase in traffic volumes, and in large projects these costs can account for over 50%.

For engineering structures, especially major bridges and tunnels, neither the client, nor the planner or the contractor can accept anything short of cutting-edge technology and highest quality standards. Quality, however, does have its price, and initially a higher investment is required on which the client then gains returns in the form of favourable life-cycle costs. It is up to the engineers and contractors to explain these life-cycle cost aspects to decision makers and politicians.

**Waterproofing and bridge deck systems account for 2 – 4 % of the overall construction costs. With an additional investment of approx. 2 % for**

- improved planning
- better and more sustainable construction products (waterproofing/pavement systems)
- improved quality of the work,
the service life of the pavement structure can be almost doubled.

## 4. Modern bridge deck systems

Bridge waterproofing and bridge pavements are implemented very differently across Europe.

### 4.1. Waterproofing

- Waterproofing with mastic asphalt/asphalt mastic
- Liquid rubber mastic sealant
- Waterproofing with bituminous sheets, 2 layers
- Waterproofing in B3A system
- Modified bitumen sheets on SBS basis
- Modified bitumen sheets on APP basis
- Liquid resin waterproofing on PU basis
- Liquid resin waterproofing on PMAA basis etc.
4.2. **Bridge decks**

- Sealed pavement structures with mastic asphalt protection layer and mastic asphalt wearing course
- Combination solution: mastic asphalt protection layer and AC wearing course
- AC pavement layers

On bridges rainwater/salt water on the surface should run off into the drain manholes. If an AC or open-graded pavement is laid on a bridge, infiltrating surface water/salt water is retained in the pavement and above the waterproofing system.

Driving over an open-graded pavement, where water cannot be relieved of tension in downward direction, leads to a ‘washing effect’ and quickly results in brittleness of the binder and a short life of the AC pavement structure. Noise emissions of a sealing layer (mastic asphalt, asphalt mastic) are much higher than those of a PRA, LNA, AC pavement. The advantages of a sealed pavement structure (mastic asphalt) are substantial and these quality aspects should be included in the pavement assessment. Mastic asphalt paving has undergone further development and now boasts high durability as well as good noise reducing properties. Depending on the respective surface design a noise reduction of up to 3 decibels can be achieved.

International observations over the past 20 years have shown that - particularly in large projects - liquid resin waterproofing systems based on PMMA with mastic asphalt protection layer / mastic asphalt wearing course have become widely accepted. There are extensive references on PMMA waterproofing systems that are based on some 20 million m² of experience.
Standard Specifications of the EU have led to various countries adjusting their own standards accordingly. Quality requirements today are very different to directives of the nineteen eighties and nineties. Implemented correctly, these standards lead to improved qualities, less damage and longer service life. The following requirements are picked out as being particularly important:

1. The evaluated waterproofing and pavement system must be coordinated with the bridge structure and the properties of the supporting base structure.
2. For major projects the full bonding design should be chosen, wherein the tensile bond values of the individual layers must meet the requirements set out in standards:
   - Waterproofing to base
   - Waterproofing to protection layer
   - Protection layer to binder/wearing course

3. The edge starting and end interfaces are to be executed joint-free with the waterproofing, wherever possible.

4. Under bonded waterproofing systems, excl. liquid resin basis PMMA, the concrete base structure must be treated with a sealer (usually 2 layers of epoxy).

5. The concrete base must be checked prior to treatment (primer application, scratch coat, sealer) for the qualitative properties of the concrete surface, especially regarding
5. Implementation / examples

5.1. Sealed pavements on bridges are essential and have a decisive impact on the design life. Utmost attention must be awarded to the layer bond. Standards therefore stipulate that the protection layer is to be implemented using mastic asphalt. To attain a good layer bond it is recommended to also design the wearing course in mastic asphalt. AC pavements on a bridge with a large void content are not suitable.

5.2. Bridges differ in their static behaviour and different pavement solutions are required for transferring vibrations and static/dynamic loads from traffic. The location of the bridge, summer maximum temperature / winter minimum temperature etc. also pose different requirements. Furthermore, the base structures of concrete/steel/element bridge designs also place different requirements on the bridge deck. The bridge pavement structure therefore necessitates a coordinated design concept. Asphalt engineering delivers guidelines for these requirements and values.

5.3. It is possible to meet the set requirements for larger bridges using liquid resin waterproofing based on PMMA and with a 2-layer mastic asphalt structure.

5.4. Evenness during the laying process: To accomplish evenness on the bridge the laying of the pavement has to performed meticulously. A mastic asphalt finisher running on lateral mastic asphalt strips will hardly be able to deliver the expected results. The following laying methods have proven their value in practice

- Mastic asphalt finisher running on rails, where the rails are laid at least 10 – 20 m into the alignment on both sides at the expansion joints.

- Mastic asphalt finisher with automatic levelling, running on a suitable vertical guide. Here also the transition areas outside the expansion joints should be considered.
5.5. Gubrist Tunnel, Zürich

5.6. Storebaelt Bridge, Denmark

5.7. Cai Yuan Ba Bridge, Yangtze River
5.8. Chao Tian Men Bridge, Yangtze River

5.9. Avonmouth bridge, Bristol

5.10. Tsing Ma bridge, Hong Kong

5.11. Darnetskij bridge, Kiev
5.12. STRABAG Torun, Poland

5.13. Hongkong Zhuhai-Macao bridge
6. **Summary**

- Waterproofing and bridge decks must be seen as an overall system.
- Bridge/tunnel pavement structures are to be designed taking the oscillations, vibrations and geometric changes of the bridge into account and therefore require special asphalt engineering.
- Additional investments of approx. 2% of the total bridge construction costs are decisive and enable a prolonged and more sustainable life of the bridge.
- Bridge deck structures are to be designed in such a way that the deck structure is sealed and neither air nor water can penetrate the deck structure.
- The evenness of the bridge deck has a decisive impact on its service life.
- The chosen system and the quality of the work implementation significantly influence the life-cycle costs.
- Ancillary costs (traffic management, signalling, congestion) cost the economy an additional 30-50% (tendency rising).
- Improved quality in the planning, supervision and execution of the work involves extra costs, however, this investment is returned multiple times over and reduces life-cycle costs.

**Better quality = longer design life = less maintenance**

To the benefit of the bridge operator, and also in the interest of road users and the economy.