



HIGHWAYS DEPARTMENT

GUIDANCE NOTES ON THE USE OF WATERPROOFING MEMBRANES ON CONCRETE BRIDGE DECKS

THE USE OF WATERPROOFING MEMBRANES **ON CONCRETE BRIDGE DECKS**

1. Background

- 1.1. The precast segmental bridge construction method was introduced to Hong Kong in the late eighties and has subsequently gained popularity. Since water may seep through the joints between segments giving rise to corrosion of the steel elements, corrosion protection to the structure is required. Some bridge designers had chosen to lay a waterproofing membrane on the concrete bridge deck as an added line of defence against corrosion.
- 1.2. On some bridges with waterproofing membrane, the asphalt surfacing suffered premature deformation shortly after the bridges were opened to traffic. In November 1998, Highways Department (HyD) commissioned the University of Hong Kong (HKU) to carry out a study on the problem of premature deformation of asphalt surfacing on concrete bridge decks to which a waterproofing membrane had been applied. The study report considered that the two most significant factors causing the deformation were:
 - i) low adhesion between the waterproofing membrane and the asphalt surfacing; and
 - ii) moisture saturation in the asphalt surfacing.It recommended that further laboratory tests and site trials be performed to verify the postulation.
- 1.3. The laboratory tests and site trials recommended by HKU were conducted under the Ngong Shuen Chau Viaduct (NSCV) contract from 2004 to 2006. In addition, HyD carried out further tests and site trials to collect more data. The key findings of the laboratory tests and site trials have confirmed the findings of the HKU investigation and indicated that:
 - i) the low adhesion between the waterproofing membrane and the asphalt surfacing could cause premature deformation if the asphalt surfacing is not of sufficient thickness and the tack coat not properly applied;
 - ii) moisture saturation in the asphalt surfacing could cause premature deformation if the asphalt has cracked; and
 - iii) the tack coat between the waterproofing membrane and the asphalt surfacing could have been contaminated or damaged at the time of the construction of the four bridges¹.
- 1.4. Based on the above laboratory tests and site trials and previous successful cases of waterproofing membrane applications, these Guidance Notes are prepared to cover the choice of waterproofing systems and asphalt surfacing materials, the adhesion strengths required between the waterproofing membrane and asphalt surfacing, and assessment of the thickness of the asphalt surfacing. Successful examples of waterproofing membrane construction methods and associated quality control

¹ The four bridges are the West Kowloon Expressway Viaduct, the Kap Shui Mun Bridge, the Ma Wan Viaduct and the Ting Kau Bridge.

measures on site are provided for reference.

2. Basic Principles of Corrosion Protection Strategies for Concrete Bridge Decks

- 2.1. It is the responsibility of the designer to select the appropriate corrosion protection systems for concrete bridge decks, taking into account the design of the structure, the technologies available and the cost benefit of the corrosion protection systems adopted. It should be noted that the use of a waterproofing membrane is neither a mandatory nor a standard requirement for concrete bridge decks in Hong Kong. Any proposal to adopt or otherwise a waterproofing membrane system should be fully justified by the designer.
- 2.2. Highways Department Technical Report “Corrosion Protection of Concrete Bridge Decks” (RD/TR/039) provides a summary of corrosion protection technologies for concrete bridge decks and highlights the limitations of these technologies, if any. The designer should make reference to the above Technical Report and take into consideration other corrosion protection technologies currently available when determining the corrosion protection systems to be adopted.
- 2.3. In adopting any corrosion protection system, the designer should justify its use by comparing the life cycle costs of alternative systems, taking into account both the capital costs and the recurrent maintenance costs, including routine inspections and repairs that may be required.
- 2.4. The designer shall make reference to Highways Department Technical Circular No. 11/2001 “Running Surfaces of Bridge Decks” when designing the running surfaces of bridges.

3. Choice of Waterproofing Membrane Systems

- 3.1. If the designer chooses to adopt a waterproofing membrane system, it should be a polymer based waterproofing membrane system such as polyurethane or acrylic liquid membrane systems. These are considered to be the most effective in providing the required waterproofing properties. For the avoidance of doubt, bituminous waterproofing systems, such as bitumen emulsion paint systems, are not classified as waterproofing membrane systems for this purpose.
- 3.2. However, polyurethane and acrylic liquid membrane systems have the following limitations:
 - low adhesion with asphalt surfacing that might lead to premature deformation of the surfacing;
 - high cost; and
 - the waterproofing membrane could be damaged by construction plant such as milling machine during pavement maintenance work.The designer shall fully address these limitations when proposing to adopt a polymer waterproofing membrane system.

4. **Requirement of Polymer Waterproofing Membrane System**

- 4.1. Polymer waterproofing membrane systems normally consist of four parts as follows (Figure 1):
- a primer for bonding the waterproofing membrane to concrete bridge deck;
 - a liquid applied polyurethane or acrylic liquid membrane;
 - a tack coat for bonding the waterproofing membrane to the asphalt surfacing; and
 - an asphalt surfacing.
- 4.2. The designer should consider the above four parts as an integral waterproofing system. The properties of the primer, waterproofing membrane, tack coat and asphalt surfacing materials shall be fully evaluated and specified by the designer.
- 4.3. The membrane itself shall be tested to meet all the requirements in the current version of 'Design Manual for Roads and Bridges, Vol.2, Section 3, Part 4 - Waterproofing and Surfacing of Concrete Bridge Decks' (BD 47).
- 4.4. The adhesion between the waterproofing membrane and the concrete deck shall be tested in accordance with BD 47 except that the testing temperature of $(-10 \pm 2)^{\circ}\text{C}$ shall be replaced by $(5 \pm 2)^{\circ}\text{C}$. The average tensile adhesion strength² shall be not less than 1.0 N/mm^2 and the minimum adhesion strength³ shall be 0.7 N/mm^2 . During construction, the above tensile adhesion strengths shall be verified on site using an Elcometer Adhesion Tester or products having equivalent functions or performance at ambient temperature.
- 4.5. The adhesion strengths between the waterproofing membrane and the asphalt surfacing shall be tested in accordance with BD 47 except that the asphalt surfacing mix shall be the same as that used for the permanent works. The tests at temperature of -10°C can be omitted. Based on a report^[5] issued by the Transport Research Laboratory (TRL), the adhesion strengths shall depend on surfacing thickness for surface with coarse mixtures as follows:

Surfacing thickness		$\geq 120\text{mm}$	$< 120\text{mm}$ $\geq 90\text{mm}$	$< 90\text{mm}$ $\geq 60\text{mm}$
Shear Adhesion Strength ⁴	@23°C	0.30 N/mm^2	0.30 N/mm^2	0.40 N/mm^2
	@40°C	0.10 N/mm^2	0.15 N/mm^2	0.15 N/mm^2
Tensile Bond Strength ⁵	@23°C	0.40 N/mm^2	0.45 N/mm^2	0.50 N/mm^2

Table 1 – Minimum adhesion and bond strength requirements (thickness of friction course is not included in the surfacing thickness).

² The tensile adhesion strength is the stress at failure for the sample tested under the Tensile Adhesion Test as stipulated in Appendix B of BD47.

³ The minimum adhesion strength is the minimum value recorded in the test carried out as mentioned in footnote 2.

⁴ The shear adhesion strength is the stress at failure for the sample tested under the Shear Adhesion Test as stipulated in Appendix B of BD47.

⁵ The tensile bond strength is the bond failure for the specimen tested under the Tensile Bond Test as stipulated in Appendix B of BD47.

The designer shall follow the requirements as stated in Table 1 above. It is worth noting that in the laboratory tests carried out under the NSCV contract, most systems could not meet the strength requirements stated above. Figures 2 and 3 show the average shear adhesion strengths and average tensile bond strengths of the eleven systems tested at different temperatures respectively. The shear adhesion strengths and tensile bond strengths of asphalt surfacing laid directly on concrete without a waterproofing membrane is also shown on these two Figures for reference.

- 4.6. Shear adhesion and tensile bond strengths between the asphalt surfacing and the concrete bridge deck will vary with the waterproofing membrane adopted, the tack coat used and the asphalt surfacing mix design. For the samples to be tested for shear adhesion and tensile bond strengths, the dimensions of the concrete blocks and thickness of the surfacing shall be in accordance with BD 47.
- 4.7. The sample preparation method under the NSCV contract is described below for reference. A panel was laid on site for sample preparation. The panel consisted of a 55mm thick concrete base slab at least 3m wide x 20m long. The concrete mix, surface finish and asphalt surfacing material were the same as those used for the actual concrete bridge deck. The polymer waterproofing membrane systems were applied on top of the concrete slab in the same manner as for the permanent works. A 50mm thick asphalt surfacing was laid on top of the waterproofing system on the panel. The material of this asphalt surfacing was the same as that to be laid on top of the waterproofing system on the bridge deck. Samples for testing were cut from the panels by saw cutting.
- 4.8. In addition to the laboratory testing of shear adhesion and tensile bond strengths in accordance with BD47, it is recommended that the performance of the complete waterproofing and surfacing system be assessed by a full size accelerated wheel-tracking test. The build-up shall comprise the asphalt surfacing, waterproofing material and a 55mm thick concrete slab. Where alternative membrane systems and surfacing thicknesses are being considered, the full scale test should cover the various combinations. The wheel-tracking device for the test shall be capable of applying a standard axle load repeatedly. The test shall be conducted at a pavement surface temperature of 55°C -60°C, which represents the pavement in-service temperature during summer in Hong Kong. The wheel tracking tests shall be performed for the first year designed traffic flow in terms of equivalent standard axles. There shall be no cracking on surface and rut depth shall not be greater than 13mm. The test and recommended criteria are summarised as shown in Table 2 below:

Performance Test	Recommended Criteria	Test Temperature
Full size accelerated wheel-tracking test	Average rut depth along the wheel tracks not greater than 13mm @ wheel passes equivalent to the first year designed traffic flow in terms of equivalent standard axles, and no surface cracking will occur.	55°C -60°C at pavement surface

Table 2 – failure criteria for the accelerated wheel-tracking test

Before and after the wheel-tracking test, six tensile bond tests should be carried out in

accordance with the surfacing to waterproofing system interface tensile bond test as stipulated in the Appendix B paragraph B4.2(I) of BD47. Before the wheel-tracking test the tensile bond strength should comply with the requirement of Table 1, and the tensile bond strength after the wheel-tracking test should be not less than 70% of the bond strength before the test.

- 4.9 If the above accelerated test is not performed, a site trial over a period of one year shall be carried out to assess the ability of the surfacing to resist early deformation under real traffic loading. The trial panels shall be constructed on a road or bridge section which carries a traffic flow similar to the bridge to be constructed. As recommended by the TRL^[5], six tensile bond tests shall be carried out in accordance with the surfacing to waterproofing system interface tensile bond test as stipulated in the Appendix B paragraph B4.2(I) of BD47 before and after one year of trafficking. The tensile bond strengths before trafficking should comply with the requirement of Table 1, and the mean tensile bond strength after trafficking should be not less than 70% of the mean bond strength before trafficking. The waterproofing system and the asphalt surfacing shall have satisfactory performance over the trial period of one year before they can be used. No cracking and obvious surface deformation should occur after the trial period.
- 4.10 The designer should review the specifications of the various components of the integral waterproofing system based on the actual products proposed and the test results above. The review should cover the asphalt surfacing mix design, asphalt surfacing thickness, tack coat, waterproofing membrane and primer to be used for the actual construction.
- 4.11 Where the performance of an integral waterproofing system has been proven in previous local projects, the tests and site trials may be waived.

5. Pavement Thickness and Composition

- 5.1. The types of bituminous material and individual layer thickness shall be determined by the designer in accordance with Highways Department Technical Circular No. 11/2001 – “Running Surfaces of Bridge Decks”.
- 5.2. In accordance with the Final Report of the study of “Road Surface Failure on Bridges in Tropical Areas”, of all the waterproofing / asphalt surfacing systems examined by HKU in the study referred to in paragraph 1.2, those systems appeared to function satisfactorily where the structural layer is at least 100mm. Conventional regulating course, base course, wearing course materials or combinations of these asphalt materials were used in the structural layers of these systems. Friction course is not considered as part of the structural layer.
- 5.3. The use of an Additional Protective Layer (APL) such as red sand asphalt as stated in BD47 is not recommended.
- 5.4. If the total thickness of the structural layer is less than 120mm, it is recommended to overlay the polymer waterproofing membrane with a 40mm thick layer of asphalt

material which is effectively impermeable or with a low air void content (no more than 4%). Fine aggregates shall be used for this layer. Special asphalt materials such as mastic asphalt or Gussasphalt should be considered for this effectively impermeable layer. Other asphalt surfacing materials may be laid on top of this layer. The compositions of bridge deck surfacing with polymer waterproofing membrane are shown on Figures 4 and 5.

- 5.5. Special asphalt surfacing materials and their respective thickness which have been used successfully with polymer waterproofing membranes locally (on steel deck bridges) are stated below for reference:
- A 40mm thick mastic asphalt layer on top of polymer waterproofing membrane. The mastic asphalt has bitumen coated stone chippings rolled in to form the running surface of the bridge deck (Figure 6); and
 - A 40mm mastic asphalt on top of polymer waterproofing membrane. The mastic asphalt is overlaid by 40mm stone mastic asphalt which forms the running surface of the bridge deck (Figure 7).

6. Site Quality Control

- 6.1. Site trial panels to verify the effectiveness of the methods to construct polymer waterproofing membrane systems and asphalt surfacing shall be carried out in accordance with BD 47.
- 6.2. All construction details such as surface preparation of concrete bridge decks, installation of the polymer waterproofing membrane systems, application of tack coat, rolling temperature of asphalt surfacing, etc. should be in strict accordance with the specifications and recommendations stated by the manufacturers and suppliers. Full time site supervision shall be provided to ensure that workmanship comply with the specifications and recommendations.
- 6.3. Tack coat should be uniformly applied on the polymer waterproofing membrane.
- 6.4. The tack coat can be contaminated and damaged by construction traffic and the paving machine during laying of the asphalt surfacing (Photo 1 and 2). The time gap between applying the polymer waterproofing membrane and the tack coat, and that between applying the tack coat and the asphalt surfacing should be as short as possible to minimise the possibility of contamination and accidental damage. No construction plant/vehicles should be allowed to ride on the polymer waterproofing membrane and tack coat surfaces except during the laying of asphalt surfacing. When the asphalt surfacing is laid, stone chips trapped at the tyres grooves of the construction plant/vehicles may cause damages to the tack coat surface and the polymer waterproofing membrane underneath. The contractor should give a proposal on how to prevent the damages, such as using paving machine mounted on rails; providing a protective layer under the wheels, or through removal of chips at the wheels (if practical) before riding onto the tack coat surface. Using timber planks for construction traffic may reduce the extent of damage. The waterproofing membrane and tack coat surfaces should be cleaned immediately prior to the laying of tack coat and asphalt surfacing respectively. Any damage to the tack coat during construction should be repaired immediately.

7. Successful examples of construction method of waterproofing membrane

- 7.1. A polymer waterproofing membrane has been laid successfully at the Route 3 Tsing Yi Kwai Chung Sections. A 60mm nominal thickness 37.5mm size base course and 40mm nominal thickness 10mm size wearing course has been used as the structurally effective asphalt layers. A 30mm nominal thickness polymer modified friction course is used as the running surface.
- 7.2. Mastic asphalt has been successfully laid on top of polymer waterproofing membrane locally. The self-levelling and self-compacting nature of mastic asphalt can minimize damage to the waterproofing membrane due to compaction of loose coarse aggregates into the membrane.
- 7.3. In a recent bridge project, standby workers have been deployed to re-apply the tack coat during laying of asphalt surfacing when damage to the tack coat caused by construction plant was observed.
- 7.4. The wheel of delivery trucks and paving machines can be prevented from running directly on the tack coat surface by mounting delivery and paving equipment on a rail system to avoid damage of the tack coat by the construction equipment.

8. Sub Surface Drainage

- 8.1. Sub-surface drainage should be provided to drain away water that have penetrated and accumulated in the asphalt surfacing. Edge channels or edge drains should be installed to collect the water.
- 8.2. Expansion joints on bridge deck should be provided with a drainage system in accordance with BA26 “Expansion Joints for Use in Highway Bridge Decks”.

9. Enquiries

- 9.1. Any enquiry on these guidance notes can be directed to the Research & Development Division of HyD.

10. References

- [1] Highways Department Technical Circular No. 11/2001 – Running Surfaces of Bridge Decks, Highways Department, November 2001.
- [2] Highways Department Technical Report RD/TR/039 – Corrosion Protection of Concrete Bridge Deck, Highways Department, August 2002.

- [3] BD 47/99 – Design Manual for Roads and Bridges, Vol.2, Section 3, Part 4 - Waterproofing and Surfacing of Concrete Bridge Decks, the Highways Agency, August 1999.
- [4] Final Report of the study of “Road Surface Failure on Bridges in Tropical Areas”, the University of Hong Kong, October 1999.
- [5] Transport Research Laboratory Published Project Report PPR221 – The Performance of Surfacing Overlaying Bridge Deck Waterproofing Systems, TRL Limited, 2007.

11. Appendices

Appendix A – Figures

Appendix B – Photos

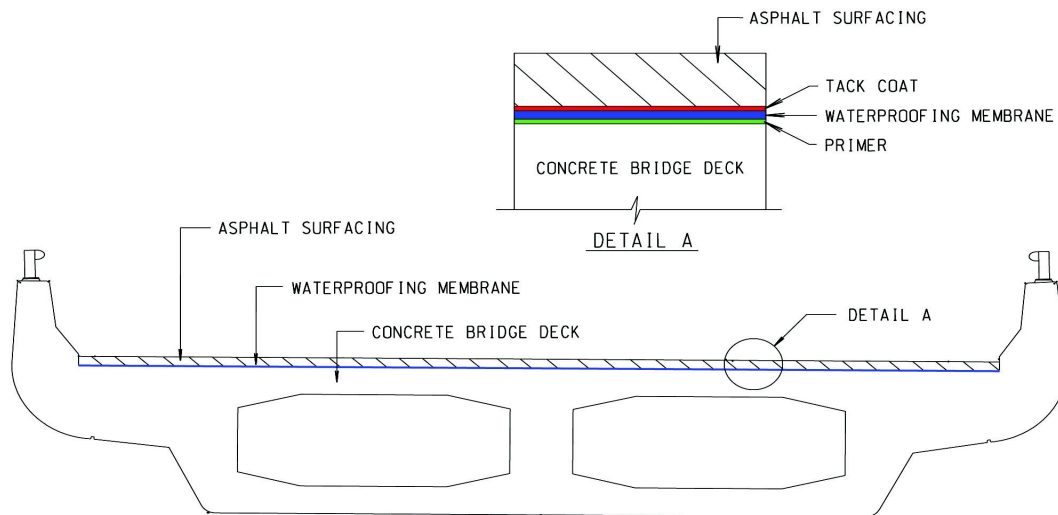


Figure 1 – Typical cross section of asphalt surfacing and bridge deck waterproofing membrane on a Concrete Bridge

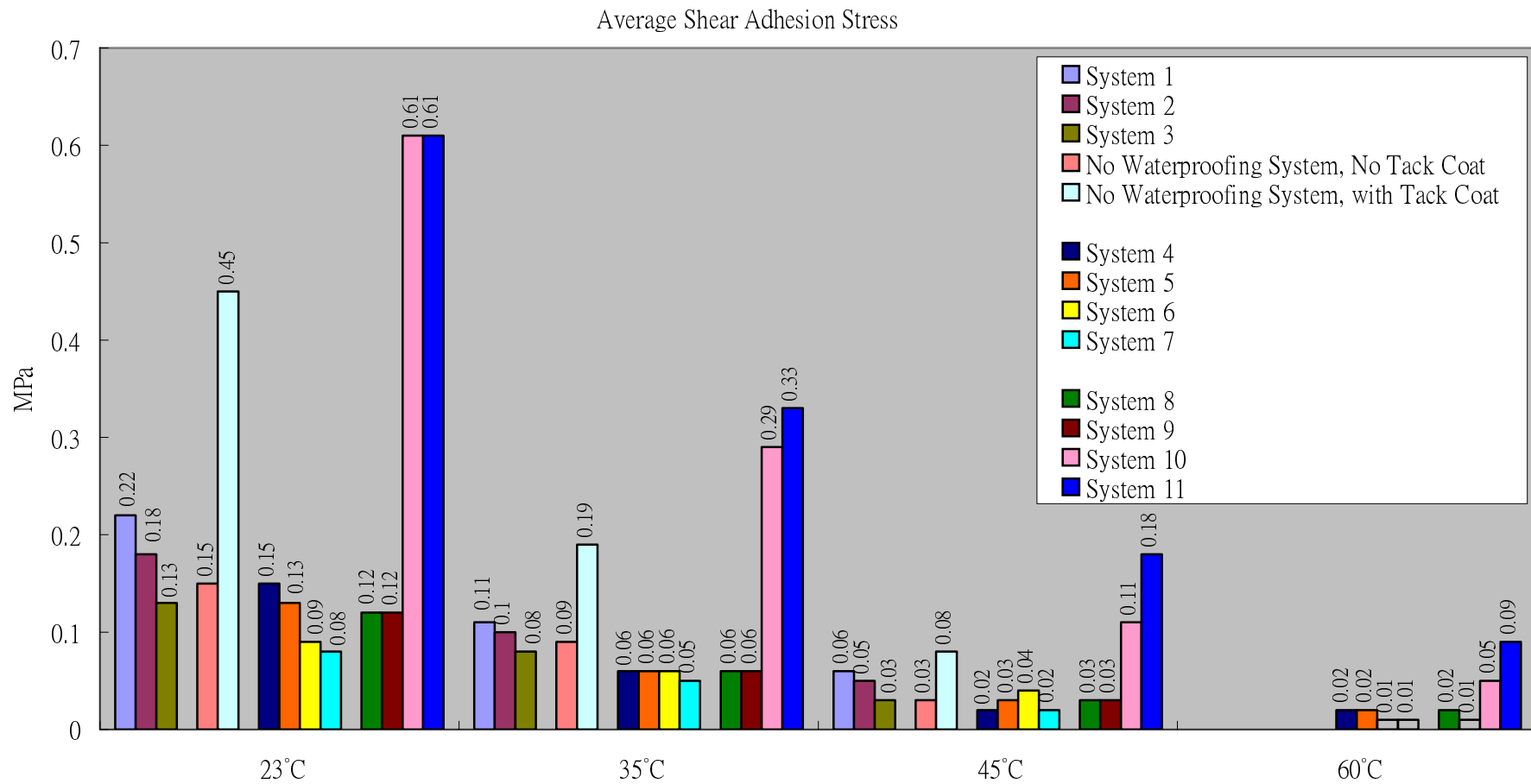


Figure 2 – Average shear adhesion strengths of polymer waterproofing systems

Average Tensile Bond Stress

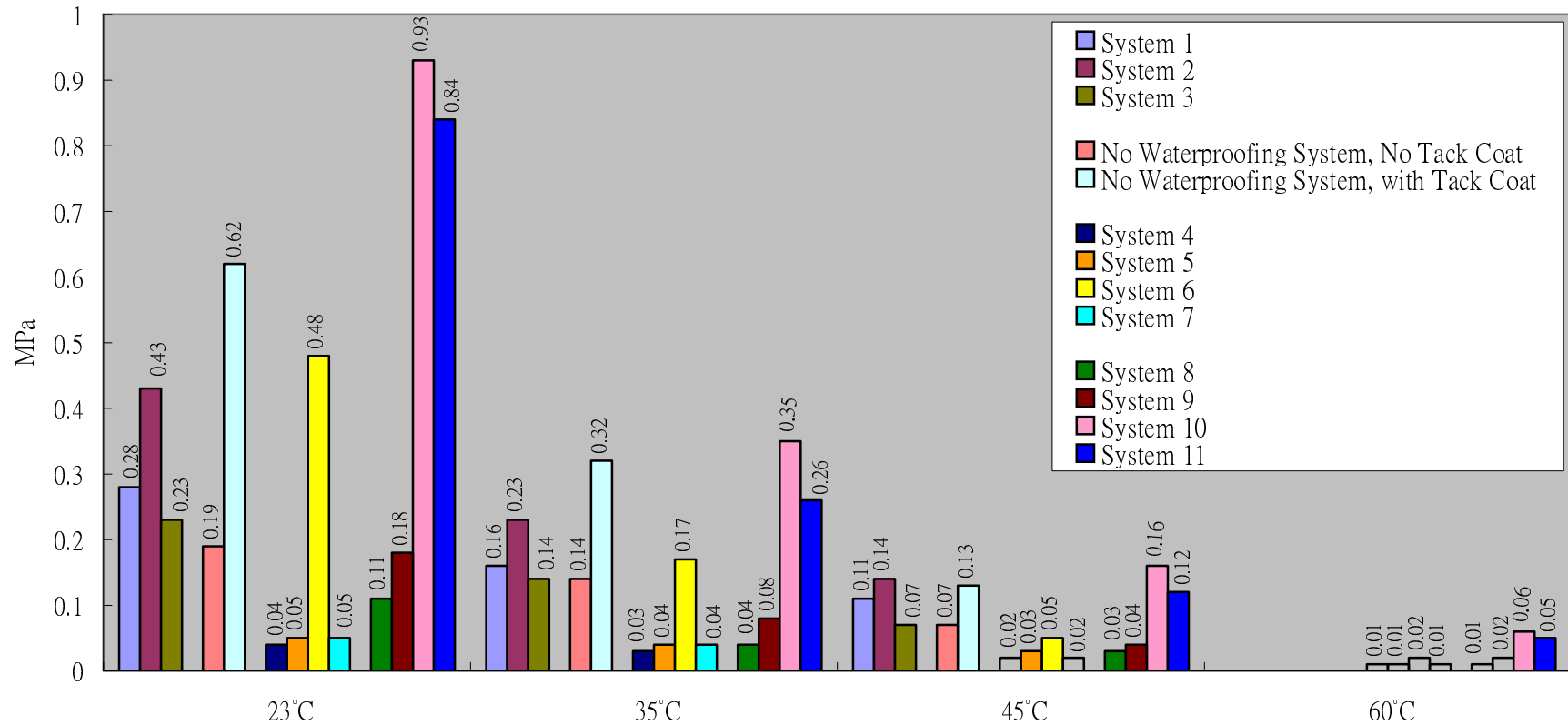


Figure 3 – Average tensile bond strengths of polymer waterproofing systems

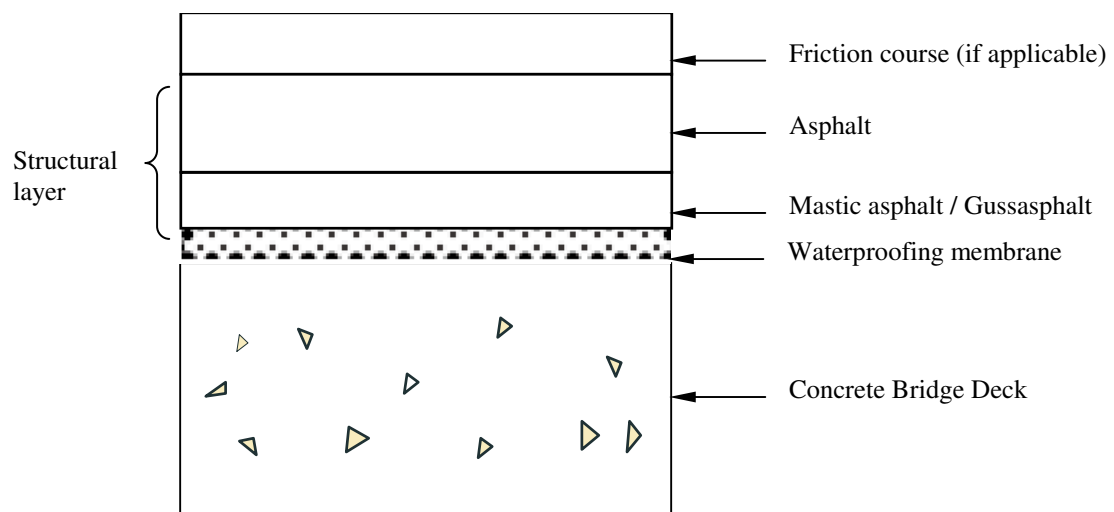


Figure 4 – Composition of asphalt surfacing with structural layer less than 120mm thick

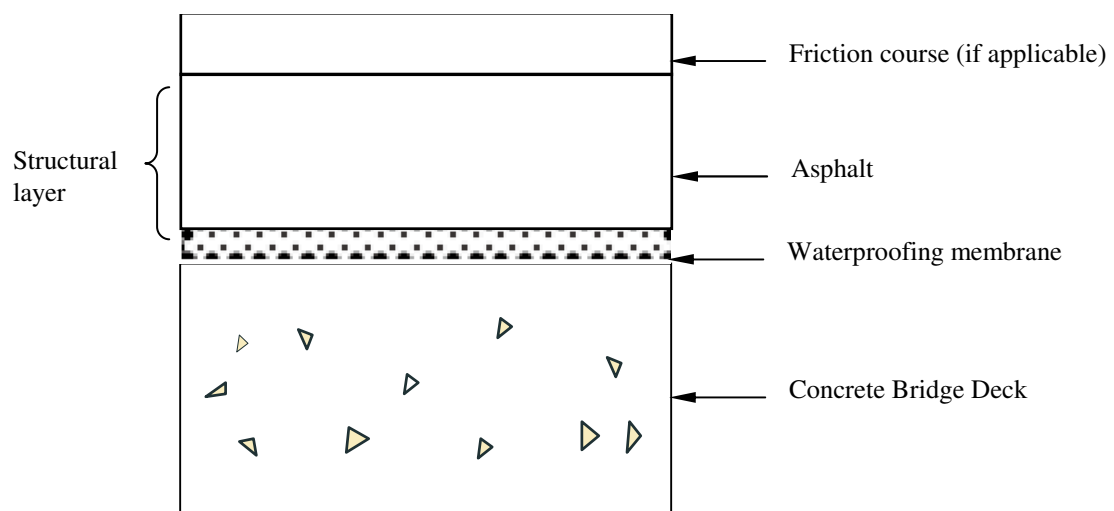


Figure 5 – Composition of asphalt surfacing with structural layer 120mm thick or more

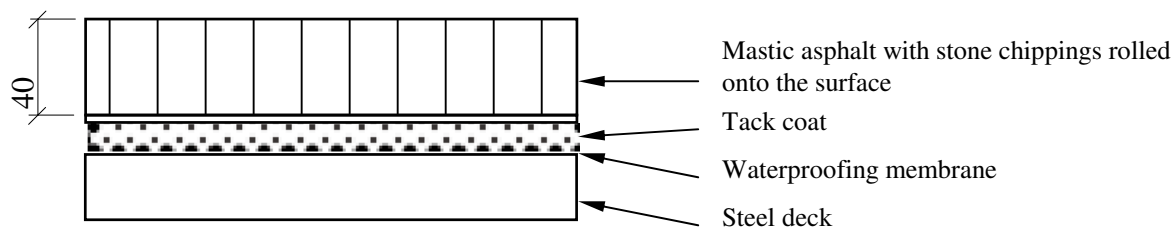


Figure 6 – Example of special asphalt surfacing and polymer waterproofing system used in Hong Kong I

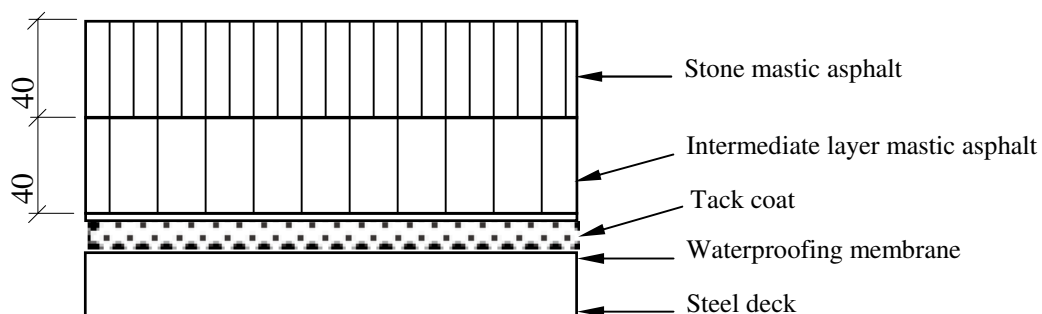


Figure 7 – Example of asphalt surfacing and polymer waterproofing system used in Hong Kong II

Appendix B

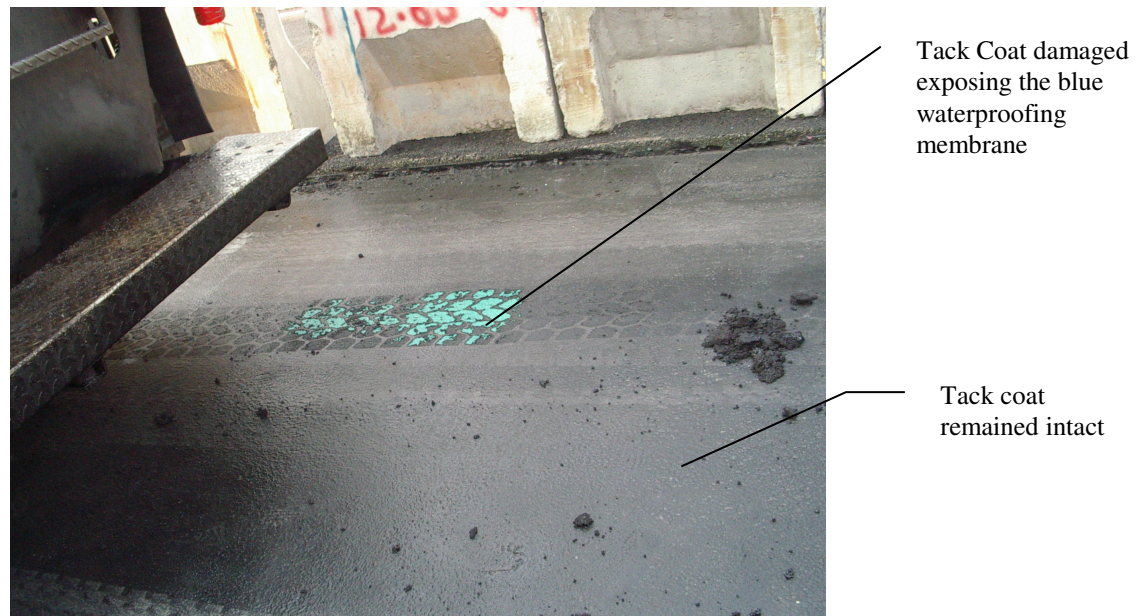


Photo 1 – Damage to tack coat by paving machine during laying of asphalt surfacing

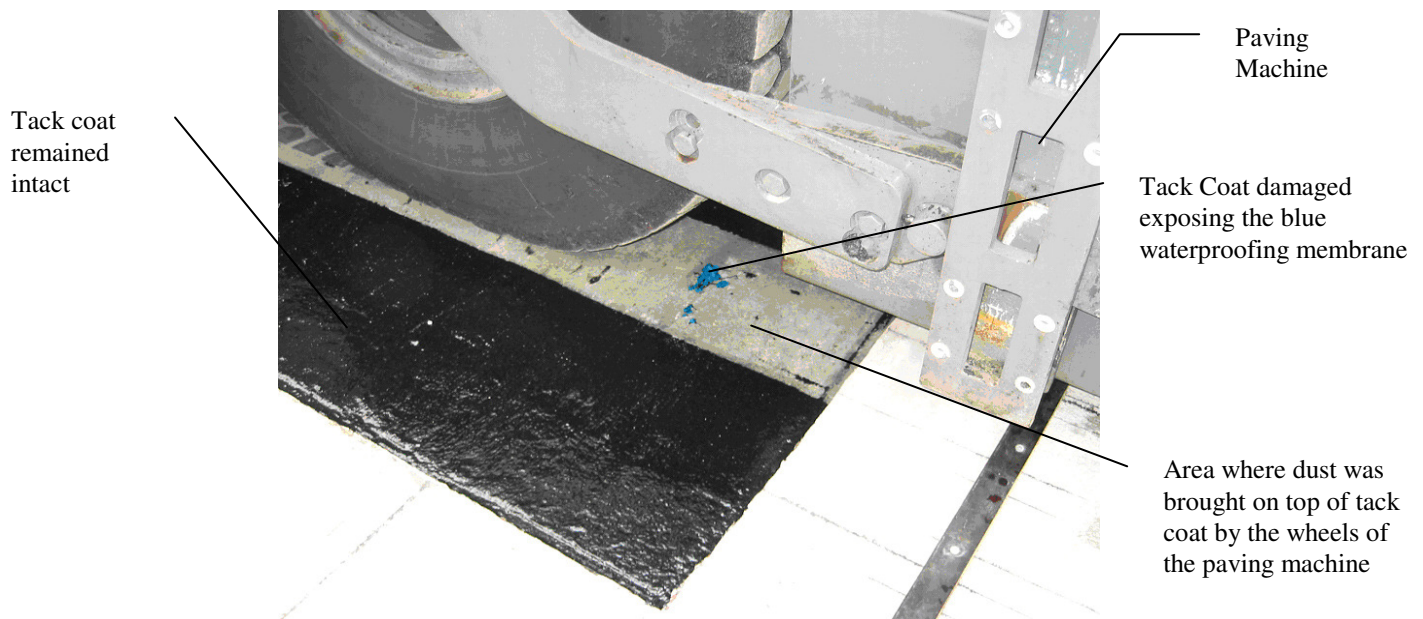


Photo 2 – Damage and contamination to tack coat by paving machine during laying of asphalt surfacing.



Protective layer to avoid damage to the tack coat due to the wheels of the paving machine

Photo 3 – Laying of mastic asphalt on top of polymer waterproofing membrane on a steel bridge deck of Shenzhen Western Corridor. To avoid damage to the tack coat and polymer waterproofing membrane, the paving machine rode on a protective layer laid on top of the tack coat.



Photo 4 – Damage to the tack coat by the wheels of delivery trucks during laying mastic asphalt on a steel bridge deck of Shenzhen Western Corridor.



Photo 5 – The damage to the tack coat was made good by reapplying tack coat immediately.