Sustainability - Developments in Waterproofing & Surfacing on Highway Structures

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Abstract

Developments in the Waterproofing and Surfacing of structures

In the United Kingdom over the last 10 years there have been major advances in the bridges industry with the waterproofing and surfacing of structures both in the development of new materials and the performance based criteria demanded by clients.

In 2000 Mott MacDonald expressed concerns to the Highways Agency that the design manuals and specifications needed to be amended to take account of the effect of increased interface stresses and shear forces induced by the new super single high pressure truck tyres on the modern “thin surfacing materials” being used as some approved waterproofing systems had failed prematurely.

This however had not been the case on the Rochester Bridge in Kent where in conjunction with Contractors Tarmac and Nottingham University, Stirling Lloyd proved that their Eliminator system in conjunction with the special SA 1030 bond coat was acceptable under even under only 2 ½”of Asphaltic Concrete surfacing.

Subsequently Stirling Lloyd commissioned Mott MacDonald in conjunction with Pavement Innovations to carry out research to prove that their system was robust and to develop design criteria and site application procedures to further enhance their products.

Following the 2 year research investigating over 20 highly stressed structures Mott MacDonald found that where other systems had failed prematurely, the Stirling Lloyd Eliminator system performing satisfactorily and that the future maintenance needs were reduce by as much as 50%.

Keywords
Waterproofing of structures, Asphalts projection layer, Eliminator system, Enhanced bond performance, Durability of surfacing on structures:

Introduction

In 2000 Mott MacDonald / Stirling Lloyd expressed concerns to the / Highways Agency that the design manuals and specifications needed to be updated for the waterproofing and surfacing on highway structures as it was now being accepted that “super single” high pressure truck tyres increased pore water pressure in the new generation of low noise, more permeable “thin surfacing materials” that were specified.

In addition it was reported by road managers that when carrying out resurfacing works systems were being damaged when milling off the existing worn out surfacing, necessitating the unplanned replacement of the binder course and waterproofing.

Designers were aware that this did not comply with the “government’s sustainability agenda” requiring engineers to design for minimising future maintenance and whole life costs.

Waterproofing performance Research Project

Subsequently Mott MacDonald in conjunction with Pavement Innovations carried out research to ensure that their specified systems were robust for all applications, particularly on the heavily trafficked and highly stressed Major Highways structures, irrespective of surfacing thickness.

It was noted that the research should be expanded to include site survey and investigation techniques and include a review of the complete process from design to construction and make recommendations to further enhance quality / sustainability and ensure contractors complied with design criteria.

Observed defects

On many of the structures evaluated that had failures it was apparent that many had occurred where the surfacing overlay was less than minimum of 5” of surfacing specified in the Design Manual for Roads and Bridges this was mainly due to site constraints and the camber in the bridge beams.

Failures were also prominent on the heavily traffic sites where structures were located on converging lanes / slip roads sharp bends etc where there was increased traffic stresses.

In addition it was noted that the ¾” thick “traditional Sand Asphalt “protection to waterproofing systems created a weakness and did not bond well with the waterproofing layers that often broke up when planing off the upper layers took place.

It was also apparent that failures were occurring where there was no or inadequate subsurface drainage provided. This was particularly adjacent to transverse / movement joints where trapped surface water that had permeated through the modern porous surfacing material could not escape

One spray applied Highways Agency "approved" polyurethane waterproofing system acceptable under normal site conditions, appeared to be problematic at all locations under thin surfacing. It was concluded that this materials lack of stiffness allowed compression to take place and premature failure to occur under asphalt < 5" thick

Failure of surfacing at joint in bridge

Unbonded membrane easily removed

Typical examples of structures with problems;

- M56 Bidston Moss Viaducts — Polyurethane / Asphaltic Concrete
- Wessex Way Bournemouth — Polyurethane / Asphaltic Concrete
- M1 / M62 Lofthouse interchange — Polyurethane / Asphaltic Concrete
- M6 Bromford Birmingham — Polyurethane / Asphaltic Concrete

Conclusions from surveys

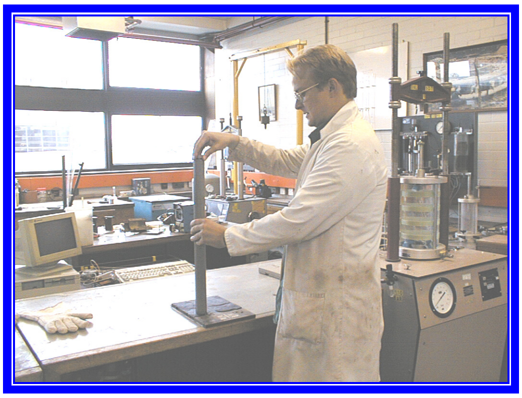
After investigating over 20 highly stressed structures Mott MacDonald and Pavement Innovations concluded that site location, traffic loading, and substandard surfacing thickness, poor detailing of sub-surface drainage and the presence of the weak Asphalt Protection Layer (APL) were the main factors causing failure.

The Highways Agency recognised problems of poor performance on heavily trafficked high stress sites and issued interim advice guidance that only tried and tested products be adopted when specifying designs on structures with < 5" of surfacing.

Design of waterproofing / surfacing systems

When designing the replacement of the 2 ½ " thick Mastic Asphalt waterproofing and surfacing on the A2 Rochester Bridge in Kent, Mott MacDonald were concerned that the high site stresses and thin surfacing depth on the structure needed to be taken into account . Contractors Tarmac proposed to use Stirling Lloyd Eliminator System with a High performance bond coat with 1" Stone Mastic Asphalt binder course and 1 ½" of Stone Mastic Asphalt surfacing to replace the existing Mastic Asphalt.

Following testing in conjunction with Nottingham University, Tarmac proved that the Stirling Lloyd Eliminator system in conjunction with the special bond coat could meet the high stresses anticipated and would not puncture during surfacing.



Chisel Impact test

Shear / Tensile Bond tests

Laboratory tests carried out on samples designed for the Rochester Bridge with the Eliminator system bonded to only 2 ½" of surfacing were successful and exceeded comfortably the specified values for 5" surfacing specified in Current Standards.

Development of a design procedure

From the past failures it was clear that a procedure for needed for designing Waterproofing & Surfacing on highly stressed structures to account for;

- Asphalt thickness - thinner layers need higher bond
- Site location - bends etc caused needed higher bond
- HGV traffic flows increased stresses
- Waterproofing hardness / properties / tensile bond
- The asphalt in contact with the waterproofing needed to be tough to remain undamaged when future milling and surfacing replacement takes place

It was concluded that these factors were not being addressed a new design approach was needed to include for increasing design values by adopting site specific factors.

Suggested site specific design factors

The design values for tensile / shear bond in the current design standards (BD47/99) were derived for 5" thickness of surfacing and these were considered acceptable for standard situations but needed to account for;

- Thickness factor (tf) based on contact area
- Stress factor (sf) based on location
- Traffic loading

Example

Consider a bridge with a surfacing thickness of 2 ½" (situated on a bend on single carriageway road carrying in excess of 3000 Cv/ day referring to Table 1 and 2 in the Appendix the design test values to be specified are as follows;

From **Table** 1 thickness factor (TF) of 2.09 is obtained for 2 ½"mm

BD47/99 TEST TYPE APPENDIX B				B4.2(d)		B4.2 (k)		B4.2(l)
THICKNESS (mm)	**CONTACT AREA (Sq.m)**	**STANDARD AREA (Sq.m)**	**TF**	**10,23C**	**40C**	**10,23C**	**40C**	**23C**
120 (5")	119475	119475	1.00	0.3	0.2	0.20	0.10	0.10
110	107535	119475	1.11	0.33	0.22	0.22	0.11	0.11
100 (4")	96224	119475	1.24	0.37	0.25	0.25	0.12	0.12
90	85541	119475	1.40	0.42	0.28	0.28	0.14	0.14

80	75487	119475	1.58	0.47	0.32	0.32	0.16	0.16
70	66061	119475	1.81	0.54	0.36	0.36	0.18	0.18
60 (2 ½”)	57263	119475	**2.0**	**0.6**	**0.4**	**0.4**	**0.2**	**0.2**
50	49094	119475	2.43	0.73	0.49	0.49	0.24	0.24
40	41553	119475	2.88	0.86	0.58	0.58	0.29	0.29

From **Table 2** a Stress Factor (SF) f 1.4 is obtained for the traffic level at this site

Site Categories	**SITE DEFINITION/AADT, CV/D**	**0 - 250**	**251 - 500**	**501 - 750**	**751 - 1000**	**1001 - 2000**	**2001 - 3000**	**3001 - 4000**	**4001 - 5000**	**5001 - 6000**	**Over 6000**
1	Motorway Main Line, Dual C'ways non-event	1	1	1	1	1	1.1	1.2	1.2	1.3	1.3
2	Motorway m'line 300m approaches to on / off slip roads	1	1	1	1.1	1.1	1.2	1.2	1.3	1.3	1.3
3	Dual c'ways approach to minor jcn, Single c'way non-event	1	1	1	1.1	1.2	1.2	1.3	1.3	1.3	1.4
4	Single C'ways minor jcns app / across major jcns, gradients 5-10% > 50m (dual downhill only) bends <250 m radius>40mph	1.1	1.2	1.2	1.3	1.3	1.3	**1.4**	1.4	1.4	1.4
5	Gradients > 50m long >10 %	1.2	1.2	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4
6	Approaches to Roundabouts, Traffic Signals, Pedestrian Crossings, Level crossings	1.2	1.3	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
7	Roundabouts	1.3	1.4	1.4	1.4	1.4	1.4	1.4	No value		
8	Bends < 100m	1.4	1.4	1.4	1.4	1.4	1.4	1.4	No value		

The design test values (DTV) to be specified are as follows;

BD47/99	TEST	Standard	SF	TF	DTV
APPENDIX B4.2 (d)	Tensile adhesion test @ -10,23 C	0.3	1.4	2	0.84
APPENDIX B4.2 (d)	Tensile adhesion test @ 40C	0.2	1.4	2	0.56
APPENDIX B4.2 (k)	Shear adhesion test @ -10 & 23C	0.2	1.4	2	0.56
APPENDIX B4.2 (k)	Shear adhesion test @ 40C	0.1	1.4	2	0.28
APPENDIX B4.2 (l)	Tensile bond test @ 23C	0.1	1.4	2	0.28

Only waterproofing products that achieve these higher values from laboratory tests or from site trials should be permitted as other inferior results will risk failure from debonding.

Design of asphalt surfacing over waterproofing membranes.

Many major bridges are located on exposed sections of highways as elevated viaducts and interchanges, over rivers, estuaries, valleys etc. and are subjected to a high degree of exposure due to the effect of wind speed, de-icing salts – sea spray.

Road surfaces over bridges also have to endure a larger temperature range compared with normal highways and are significantly hotter in summer and cooler in winter and therefore the asphalt has to be specifically designed to.

- resist wheel track rutting at high temperatures,
- remain flexible at low temperatures particularly on "lively" bridges

The asphalt immediately in contact with the waterproofing therefore needs to have high performance to meet suit the above conditions and be designed for at least 60 year traffic and have the following qualities.

- Good internal strength and have a strong bond to resist milling action
- Dense grading with good binder film to enhance durability,
- Good deformation resistance and low air voids to resist rutting and keep out salt
- High contact area with interface with waterproofing layer (small aggregate)

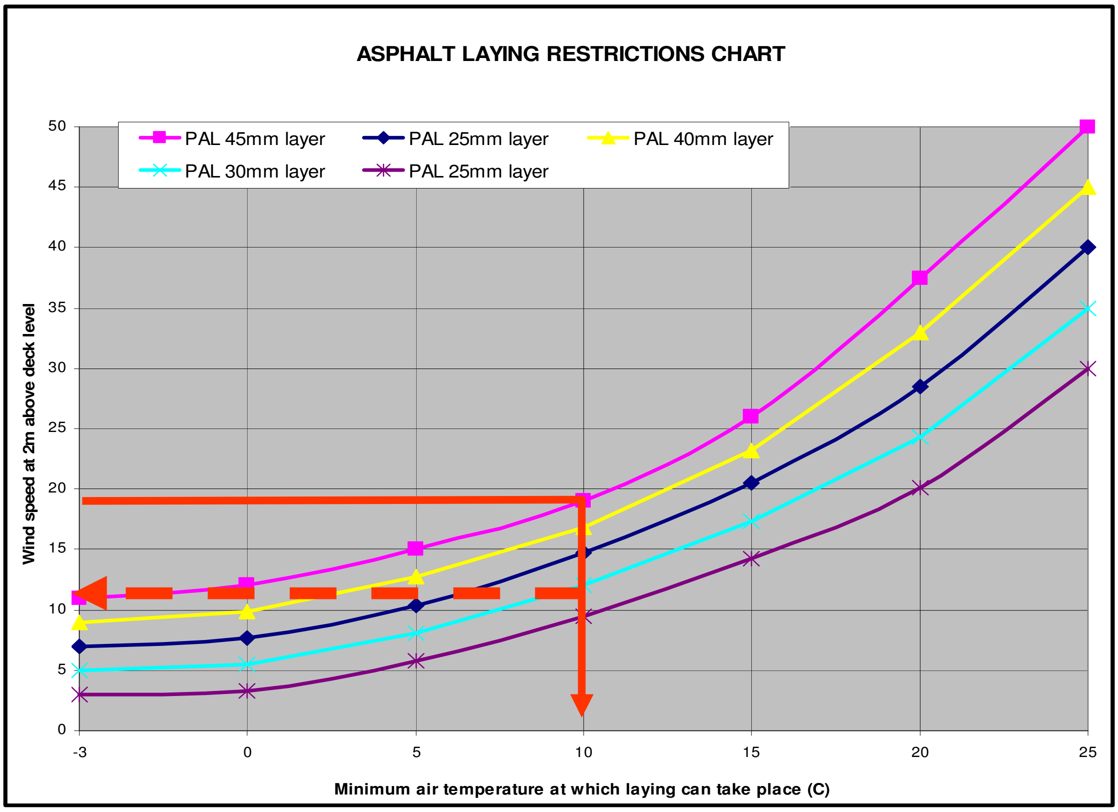
- Be capable of being laid in difficult site conditions **and e**asy to compact as **vibratory rollers** are not allowed on bridge decks.

Asphalts that work well in the UK are designed to British Standard 594 and Highways Specification Clause 943 using polymer modified bitumen's providing elasticity at low temperatures such as; - Shell Carriphalt and BP Elexonbit

Site works on structure - fast track contracts

The site restrictions on major works increase the difficulties of achieving good workmanship as lane availability, restricted hours / night time operations, often leads to surfacing in low temperatures with the sub sequential rapid cooling of the asphalt layers resulting in poor bond high with the membrane and high voids in the asphalt.

To avoid this surfacing needs to be controlled by monitoring the wind speed and air temperature to ensure that the laying and compaction is completed in the optimum time as shown on the attached graph



In the absence of a proven track records preliminary site trials and end performance testing are essential to ensure contact compliance can be achieved.

Whole life user cost benefits

With this careful adherence to design the wearing surface life on the structure will be enhanced as this will only need to be replaced to restore its texture and deterioration from normal trafficking.

The waterproofing layer with its enhanced asphalt protection designed for a 60 year traffic loading can be expected to remain intact with the waterproofing when replacement of the surfacing has to take place.

The short life of waterproofing experienced on many of the structures will be avoided and the decks and other components of the structure will be assured of long term protection from salt attack and hence avoid concrete decay and reinforcement corrosion.

The maintenance repair options of the two scenarios are presented below;

Year	Standard Specification		High Specification system
1	Waterproof and resurface	1	Waterproof and resurface
12	Resurface		
		15	Resurface
24	Waterproof and resurface		
		30	Resurface
36	Resurface		
		45	Resurface
48	Waterproof and resurface		
60	Resurface	60	Replace High Spec system

Examples of the structures renewed

Since 1998 numerous high profile structures have been renewed using this process where previously waterproofing failure prematurely.

The following structures that all have less than 4” asphalt surfacing and very high traffic flows and a history of failures with sheet or polyurethane waterproofing systems are now all performing well;

- Silver Jubilee BR 1 ¾” Performance Asphalt + 1 ¼” AC
- M6 Bromford Viaduct 1 ¾” Performance Asphalt + 1 ¼” AC
- M6 Rayhall Viaduct 1 ¾” Performance Asphalt A + 1 ¼” AC
- M53 Bidston Moss Viaduct 1 ½” Performance Asphalt + 1” AC
- A38(M)Tame Viaduct BCC 1 ½” Performance Asphalt + regulating + 1” AC

A38 (M) Aston Expressway Birmingham

Planing trials removed the old sheet waterproofing membrane and revealed unbonded membrane with moisture present under bituminous sheet system

A38 (M) Test results showing failure mechanism in asphalt or concrete substrate

Cost Estimate for Maintenance Interventions Over 60 Years A38(M)		
Year of Treatment	**Traditional Specification**	**Enhanced design approach**
0	£31,000	£26,000
12	£3,250	
15		£3,250.
24	£46,500*	
30		£3,250
36	£3,250	
45		£3,250
48	£46,500*	
60	£3,250	£26,000
Whole Life Works Cost:	£133,750	£61,750

*Included estimate of additional concrete deck repairs

Saving over a 60 year period estimated to be £72,000 = 54%
Mott MacDonald - Pavement Innovations Report Conclusions

1. Interface stresses increase as the thickness of the surfacing thickness reduces.
2. Traffic loading from vehicles and site location of braking and turning increase the stresses in the pavement below and stresses on waterproofing membranes
3. A tough 1 ¾ "Performance Asphalt Layer (PAL) using modified bitumen together with properly specified subsurface drainage is ESSENTIAL to enhance durability under asphalt surfacing on structures
4. Modern asphaltic concrete surfacing materials with high voids increase the risk of deterioration where road de-icing salt and airborne sea spray are present
5. Eliminator Waterproofing membrane provided superior properties to other systems and met the highest stresses even with only 1 ½" of asphalt cover
6. The design procedure has been proven for structures at high risk sites and those that fail their assessment and need to reduced dead load.
7. The rehabilitation process provides value for money and does not put the integrity of structures and road users at risk.
8. The strategy now being adopted is delivering savings of in excess of 50% in WLC's excluding user delay costs.