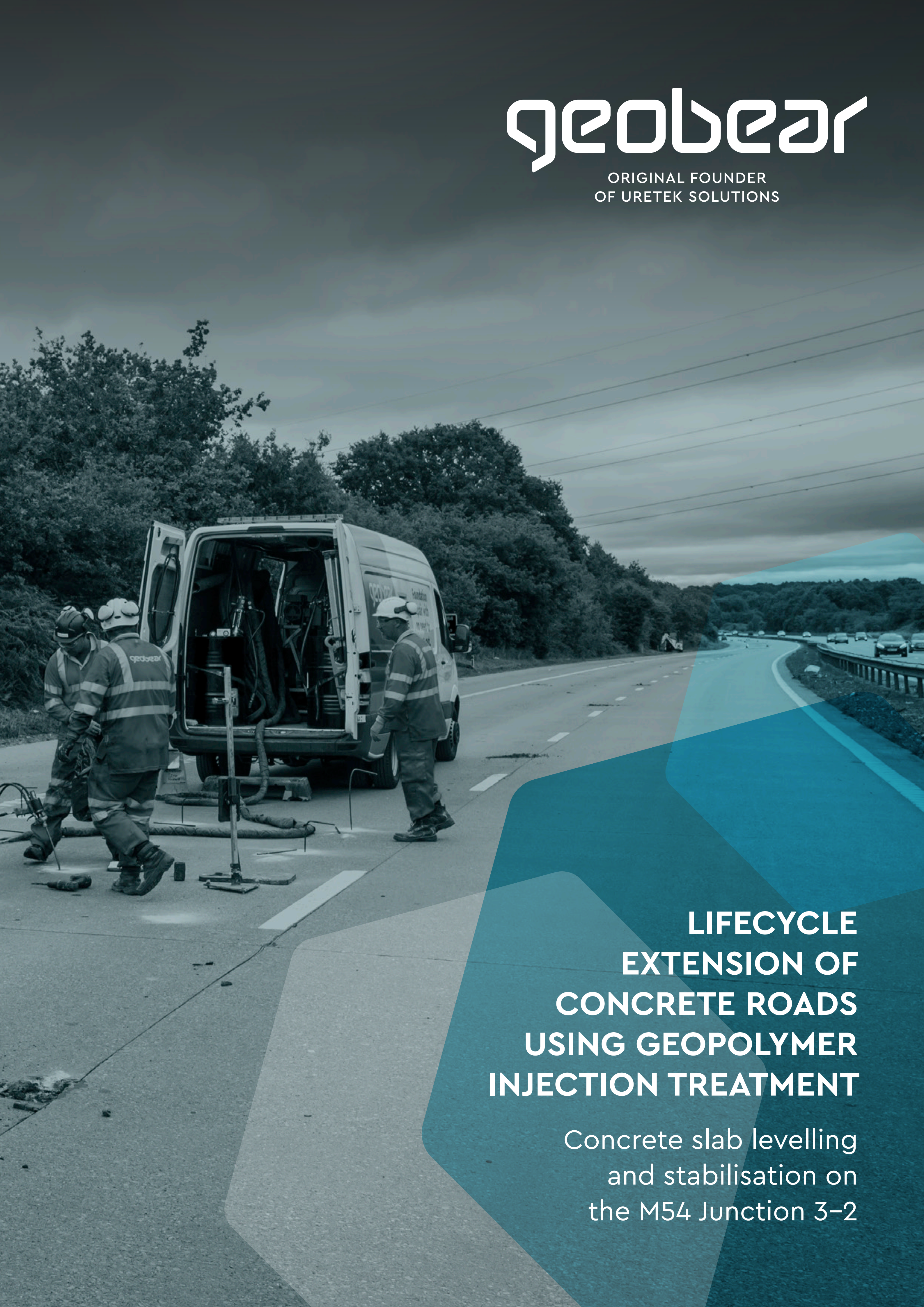

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LIFECYCLE EXTENSION OF CONCRETE ROADS USING GEOPOLYMER INJECTION TREATMENT

Concrete slab levelling and stabilisation on the M54 Junction 3–2

Introduction

The M54 is a 23 mile (37km) east to west dual carriageway passing through the counties of Shropshire and Staffordshire. The original dual carriageway was constructed in sections and has a construction history covering the period of 1975 – 1983. It is a two lane dual carriageway for the majority of its length with some shorter three lane sections.

The M54 forms part of the strategic route connecting England to North Wales. Interestingly, it is the only motorway in Shropshire and forms an important part of the County's economic corridor. The motorway is managed by Highways England and is included within the West Midlands region, known as Area 9. The highway maintenance contract for Area 9 is currently operated by Kier Highways under an extension to their Asset Support Contract (ASC) arrangements through a new system of asset management introduced by Highways England known as Progressive Asset Delivery (PAD).

This report is concerned with the eastbound section of carriageway from Junction 3 Tong Interchange, a roundabout interchange to Junction 2 Coven Heath Interchange, also a roundabout interchange. This section of motorway covers 8 miles (17.8km) of two lane dual carriageway and carries an average annual daily traffic (AADT) flow of 50,300 vehicles. The AADT is the total volume of vehicle traffic using a highway for a year divided by 365 days. In simple terms the AADT flow is a measurement of how busy the road is and is used as a standard method for assessing the vehicle traffic load on this section of the motorway.

The form of construction is a mixture of continuously reinforced concrete (CRCR) and unreinforced concrete (URC) bays laid over sub-base materials. This eastbound carriageway between junction 3–2 is constructed of URC slabs – see Diagram 1 showing core photo.

Pavement maintenance – defects and solutions

An investigation had been carried out by others, on the carriageway including hard-shoulder, lane 1 and lane 2, and a programme of pavement maintenance requirements was prepared. The URC slabs in lane 1 had undergone settlement and an average uplift of 10mm was required to bring the traffic running surface back to level with adjacent slabs. The URC slabs were constructed in bays and are typically 4000mm (W) x 6000mm (L) x 280mm thick. Slabs in lane 1 had been identified for geopolymer injection treatment – slab stabilisation and relevelling and the location of the identified maintenance works is described in the contract scope of works document extracted from Appendix 7/1 and is shown in Appendix A.

Geopolymer injection process

The specialist site injection equipment used by Geobear Infrastructure utilises a self-contained vehicle. The vehicle acts as a confining bund for the material components and contains all of the individual elements briefly described below:

- Pump : A pumping unit capable of injecting geopolymer material is used to pump material through a drilled hole, beneath the slab. The pump is also capable of controlling the flow rate of the material to provide the required amount of geopolymer to stabilise and lift the slab.
- Control devices : Control devices are used to maintain the temperature and proportionate mixing of the geopolymer material according to Geobear's patented specification.
- Electric drills : Electrically operated drills are used to cut 16mm diameter holes through the concrete pavement.
- Laser levelling : Laser levelling devices are used to detect compaction and slab movement of 0.5mm increments with an instantaneous readout system.

Method of geopolymer injection and construction requirements

A series of holes were drilled at predetermined design intervals throughout the concrete slab. The 16mm diameter holes are drilled in the concrete slab to sufficient depth to penetrate the concrete pavement and the geotechnical layers.

Drill holes were kept as perpendicular as possible to the pavement surface.

Photo 1: The drilling process at predetermined locations

Photo 2: Geopolymer injection process

Geobear's geopolymers are formed when a number of chemical components are combined together during the injection process. The process is carried out under a small injection pressure that causes a controlled chemical reaction to take place, known as polymerisation. During the polymerisation the newly formed geopolymer changes physical state changing from a liquid into a solid and undergoes expansion of up to 10 times its volume depending on the specific geopolymer properties and level of confinement provided by the surrounding ground..

The geopolymer material is injected under the slab to fill any air voids. The amount of slab movement was controlled by the pumping unit and injection gun, by measuring the rate of injection. The actual slab lifting process was measured in 0.5mm increments until the proposed profile elevations were reached.

The geopolymer was also injected into the sub-base layer to stabilise and enhance the load carrying characteristics of the granular material.

Once completed the injection tubes were removed and the holes were filled with a non-shrinking, sand cement grout. The drill arisings and any excess geopolymer material were cleaned up at the end of each shift before the motorway was opened to traffic.

Test methods and procedures

On site testing was subcontracted to materials testing specialists Nicholls Colton Group (NCG). NCG are UKAS accredited for onsite testing activities including; sampling through coring and Dynamic Cone Penetrometer (DCP) testing.

Sampling & coring

Twenty two cores, twelve of nominal 150mm diameter, C1 to C12 and ten of nominal 100mm diameter, C13 to C22 were taken through the road pavement using a trailer mounted coring rig at locations identified in the scope of works. Each core was examined and logged on site prior to wrapping and transferred to the laboratory for storage.

Dynamic cone penetrometer testing

The Dynamic cone penetrometer (DCP) is an instrument designed for the rapid in-situ measurement of the structural properties of existing road pavements constructed of unbound materials.

The robust and simple design means that the DCP is quick and easy to use and portable. A typical test takes only a few minutes and therefore the DCP instrument provided a very efficient method of obtaining pavement information. An office based desk study had pre-identified that there were no areas of potential risk of buried services in the vicinity of the treatment areas.

However, as an additional check the predetermined test locations were checked for the presence of buried services by using a cable avoidance tool (CAT) scanner so that a 'permit to work' certificate could be issued and any areas of potential uncharted cable strikes were avoided.

Photo 3: Night time DCP testing

The DCP test was carried out through a 150/100mm diameter core hole extracted from the 280mm thick concrete pavement at the base of the core hole. This approach removed the requirement for digging test pits and consequently DCP was judged suitable for use on the M54 motorway.

The core holes were located in the centre of each lane. This approach prevented core hole reinstatements being carried out in the wheel path of traffic, reducing the risk of future pot-holing. The overall geopolymer injection process was carried out under a full weekend closure traffic management system.

The frequency of the test positions was pre-determined so that the number and location of the test positions were easily managed on site.

In order to measure the improvement in load bearing capacity it was decided to carry out the DCP testing 'before' and 'after' the geopolymer injection process.

The testing frequency was divided into two types; A & B.

A) A treatment section consisting of continuous sections of multiple 6m long bays, where each bay was tested in sequence as described below;

Bay 1 'pre' treatment

Bay 2 'post' treatment

Bay 3 'pre' treatment. With ongoing alternation to the end of the treatment section.

The bays are approximately 6m long. This meant that the 'pre' and 'post' tests were carried out in adjacent bays at approximately 6m centres

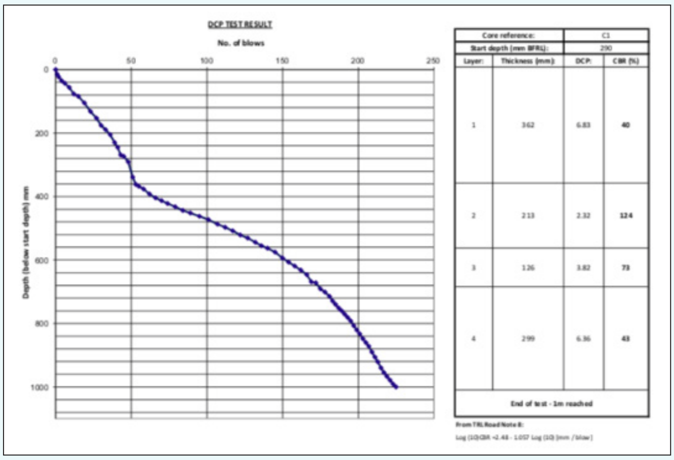
B) An isolated treatment section consisting of a single, 6m long bay.

The penetrometer, 8kg free fall hammer was lifted and dropped through a height of 575mm in accordance with the manufacturer's requirements. The distance of penetration of the 60o cone tip was recorded and the cycle repeated. The standard DCP equipment allows continuous measurements to be made down to a depth of around 850mm. This meant that a CBR 'strength profile' could be established for each of the sub-base and lower foundation layers. A typical CBR profile with depth is shown in the Diagrams below.

Visual examination, measurement and photograph of structural core no. 1

General			
Diameter of core (mm)	150		
Overall length (mm)	275		
No. of pieces	1		
Piece	Size (mm)	Piece	Size (mm)
1	275	3	-
2	-	4	-
Concrete aggregate			
Distribution of aggregate	Even		
Nominal max size (mm)	40		
Aggregate type	Gravel		
Aggregate shape	Rounded		
Concrete			
Compaction	Good		
Honeycombing	None		
Any other defects	No		
Concrete matrix			
Colour	Grey		
Sweaty patches	None		
Reinforcement			
No. of bars	None		
Bar no.	N/a		
Bar size (mm)			
Type of bar			
Depth of cover (mm)			
Screed			
Thickness (mm)	N/a		
Distribution			
Nominal max size (mm)			
Aggregate type			
Aggregate shape			
Concrete cracks			
Width (mm)	N/a		
Length (mm)			
Filling			
Concrete voids			
Maximum size (mm)	10		
Average size (mm)	4		
Excess voidage (%)	0.5		
Distribution	Even		
Surface characteristics at top of screed and bottom of concrete			
Surface deposits	Top	Bottom	
	None	None	
Condition of outer faces	Top	Bottom	
	Flat rough	Uneven smooth	

Photograph



Core reference:		C1	
Start depth (mm BFRL):		290	
Layer:	Thickness (mm):	DCP:	CBR (%)
1	362	6.83	40
2	213	2.32	124
3	126	3.82	73
4	299	6.36	43
End of test - 1m reached			

From TRL Road Note 8:
Log (10)CBR =2.48 - 1.057 Log (10) (mm / blow)

Diagrams show a typical coring report and DCP / CBR profile

The foundation surface modulus position within the overall carriageway construction is described in the diagram below extracted from the current version of CD225 design for new pavement foundations.

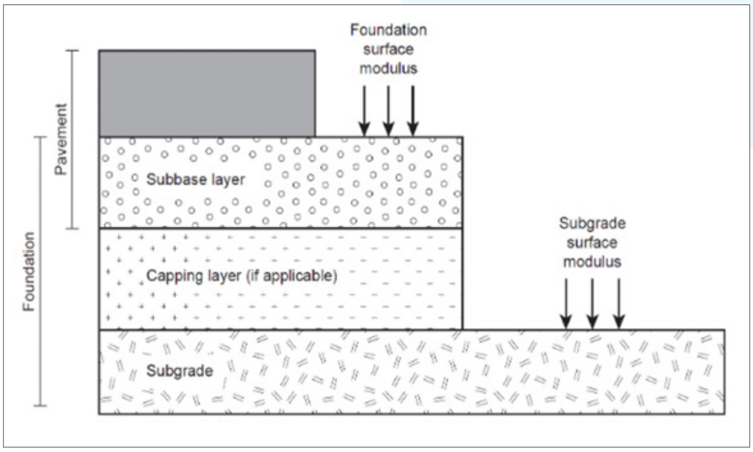


Diagram 2 shows the position of the foundation surface where DCP / CBR measurements were taken

Interpretation of results

Correlations have been established between measurements with the DCP and conventional in-situ California Bearing Ratio (CBR). This means that the site measured test results can be interpreted and compared with CBR specifications used for pavement design. In the case of the M54 project, DCP measurements were carried out 'pre' and 'post' the geopolymer treatment process. This approach provided test data that was suitable to demonstrate the improvement in the bearing capacity of the unbound granular sub-base and foundation layers.

TRL Road Note 8 has been used to convert DCP measurements to insitu CBR percentages.

Equation 1: $\log_{10} CBR = 2.48 - 1.057 \log_{10} [mm / blow]$

A summary of the CBR calculations are shown in table 1 below:

Location between two marker posts (MP)		Insitu CBR before treatment (%)	Insitu CBR after treatment (%)
1st MP	**2nd MP**		
15/8	15/7	40 51	107
13/3	13/1	42	75
12/1	12/0	41	80
11/8	11/7	36 43	67
11/6	11/6	47 43 34	70 64
11/1	10/9	46	78
6/4	6/3	29 32	80 136
	Mean	40.3	84.1
	Improvement Factor		**2.09**
	Std dev	6.2	21.7
	95% confidence limits	42.1 (upper)	76.9 (lower)
	Improvement Factor		**1.83**

Table 1 : summary of insitu CBR calculations 'pre' and 'post' geopolymer treatment

The 'pre treatment' mean test result of 40% for the insitu CBR measurement is typical for a well compacted granular type 1 sub-base material.

The 'post treatment' mean test result of 85% for the insitu CBR measurement for granular sub-base has been increased by a factor of 2 when treated with Geobear geopolymer.

The improved CBR results can be further interpreted by conversion into standard axles. The TRL1132 and TRL RR87 relationship shown in equation 2 below can be used. This relationship was used at the time of the original pavement design process when unreinforced jointed concrete pavements were constructed on the M54 in the 1970's.

Equation 2: $Ln(H) = \{Ln(T) - 3.466Ln(Rc) - 0.484Ln(E) + 40.483\} / 5.094$

Which can be rearranged to give the design traffic directly.

Equation 3: $Ln(T) = \{5.094Ln(H) + 3.466Ln(Rc) + 0.484Ln(E) - 40.483\}$

where:

H is the thickness (mm) of the concrete slab without a tied lane or 1m edge strip.

Ln is the natural logarithm

T is the design traffic (msa)

Rc is the mean compressive cube strength (N/mm2 or MPa) at 28 days

E is the confined foundation stiffness (MPa) and relates to foundation classes shown in table 2 below:

Foundation class	Assumed long-term confined foundation surface modulus E (MPa)	Form of construction
1	≥ 50	Capping layer only
2	≥ 100	Sub-base only and Capping layer and sub-base
3	≥ 200	Hydraulically bound materials (HBM)
4	≥ 400	

Table 2 : long term surface foundation modulus used in modern pavement designs

Note : Only Classes 3 & 4 hydraulically bound materials would be compliant for use in current designs for rigid pavements.

In order to show the effect the sub-base improvement has made to design traffic loading and lifecycle enhancement of the M54 concrete pavement the following assumptions have been made;

Rc = 40N/mm2

H = 280mm

E = 400MPa before & 840MPa after treatment

Using equation 3 the design traffic can be calculated as 49.4msa 'pre' treatment compared to 69.9msa 'post' treatment.

This analysis demonstrates that the Geopolymer treatment has enhanced the design life traffic loading of the M54 eastbound pavement by an additional 20.5msa.

Using traffic flow counters at Junction 4, the AADF of commercial vehicles (HGV) travelling in lane 1 is approximately 2100 (2017 data). This flow of traffic equates to 2.3msa per year travelling on the eastbound carriageway.

In conclusion the theoretical lifecycle of the Geopolymer treated sections of the M54 motorway have been extended by 9 years.

Appendix A : extract from contract documents

APPENDIX 7/1: PERMITTED PAVEMENT OPTIONS

1. PERMITTED PAVEMENT OPTIONS – SCHEDULE 1

The permitted pavement options are shown in schedule 1 below. Each pavement treatment has a unique reference number (e.g. A1) as shown in table 1 below. Throughout the site refer to Drawings HE604880-Area9 ASC-HPV-M54_J3_J2-DR-Z-0700_01 to 0700_13.

Table 1: Pavement Treatment Unique References

Pavement Treatment Reference	Pavement Treatment	Allocated Contractor
A1	Existing concrete bay to be replaced with new concrete bay	
	All four concrete bay joints to be sealed following installation of new bay	
A2	Existing asphalt bay to be replaced with new concrete bay	
	All four concrete bay joints to be sealed following installation of new bay	
B1	Existing concrete bay to be repaired with part-width full depth repair	
B2	Existing concrete bay to be repaired with cored repair	
C1	Existing lane width crack to be treated	
C2	Existing concrete bay joints to be re-sealed	
D1	Existing concrete bay to be stabilised/re-levelled	Geobear infrastructure
	All four concrete bay joints to be re-sealed following stabilisation/re-level	
E1	Plane out and inlay of asphalt carriageway section	

Schedule 1: Permitted Pavement Options

Treatment Reference on Drawing	Location Between Two Marker Posts (MP)		Site Chainage (m)	Pavement Treatment	No. of Treatments	Drawing Reference	Typical Dimensions per Treatment (see schedule 5)
	1st MP	2nd MP					
1	17/7	17/6	235	C2	1	Sheet 1 of 13	20m
2	17/6	17/5	322	D1	1	Sheet 1 of 13	See Schedule 5
3	17/6	17/5	325	A1	1	Sheet 1 of 13	
4	16/7	16/6	1248	C1	1	Sheet 2 of 13	
5	16/6	16/5	1356	E1	1	Sheet 2 of 13	710m²
6	16/3	16/2	1636	C1	1	Sheet 2 of 13	See Schedule 5
7	15/8	15/7	2331	D1	3	Sheet 3 of 13	
8	15/5	15/4	2421	A1	1	Sheet 3 of 13	
9	15/2	15/1	2768	C1	1	Sheet 4 of 13	
10	14/3	14/2	3656	D1	1	Sheet 5 of 13	
11	14/3	14/2	3677	D1	1	Sheet 5 of 13	
12	14/2	14/1	3737	C1	1	Sheet 5 of 13	
13	14/1	14/0	3852	C2	1	Sheet 5 of 13	12m
14	13/8	13/7	4172	C1	1	Sheet 5 of 13	See Schedule 5
15	13/8	13/7	4177	C1	1	Sheet 5 of 13	
16	13/6	13/5	4342	B1	1	Sheet 5 of 13	800mm x 300mm
17	13/6	13/5	4392	A1	1	Sheet 5 of 13	See Schedule 5
18	13/6	13/4	4396	A2	3	Sheet 5 of 13	
19	13/6	13/4	4411	A1	1	Sheet 5 of 13	
20	13/3	13/1	4690	D1	3	Sheet 6 of 13	

Schedule 1: Permitted Pavement Options (continued)

Treatment Reference on Drawing	Location Between Two Marker Posts (MP)		Site Chainage (m)	Pavement Treatment	No. of Treatments	Drawing Reference	Typical Dimensions per Treatment (see schedule 5)
	1st MP	2nd MP					
21	12/7	12/6	5292	C2	1	Sheet 6 of 13	12m
22	12/7	12/6	5298	D1	1	Sheet 6 of 13	See Schedule 5
23	12/6	12/5	5326	B1	3	Sheet 6 of 13	500mm x 2000mm
24	12/3	12/2	5619	B1	4	Sheet 6 of 13	600mm² (total)
25	12/2	12/1	5723	C1	1	Sheet 7 of 13	See Schedule 5
26	12/2	12/1	5728	D1	1	Sheet 7 of 13	
27	12/2	12/1	5774	B2	1	Sheet 7 of 13	300mm diameter
28	12/1	12/0	5830	A1	1	Sheet 7 of 13	
29	12/1	12/0	5885	D1	2	Sheet 7 of 13	See Schedule 5
30	12/0	11/9	5977	C1	1	Sheet 7 of 13	
				D1	1	Sheet 7 of 13	
31	11/9	11/8	6011	C1	1	Sheet 7 of 13	
32	11/8	11/7	6114	C1	1	Sheet 7 of 13	
33	11/8	11/7	6122	D1	4	Sheet 7 of 13	
34	11/8	11/7	6142	C1	1	Sheet 7 of 13	See Schedule 5
35	11/7	11/6	6254	C1	1	Sheet 7 of 13	
36	11/6	11/5	6317	D1	6	Sheet 7 of 13	
37	11/2	11/1	6719	D1	1	Sheet 8 of 13	
38	11/1	11/0	6862	B2	1	Sheet 8 of 13	150mm diameter
				C1	1	Sheet 8 of 13	See Schedule 5
39	11/1	10/9	6900	B2	1	Sheet 8 of 13	500mm x 200mm
				C1	1	Sheet 8 of 13	See Schedule 5
				D1	1	Sheet 8 of 13	
40	11/0	10/9	6961	B1	1	Sheet 8 of 13	600mm x 500mm
41	11/0	10/9	6974	B2	1	Sheet 8 of 13	150mm diameter
				C1	1	Sheet 8 of 13	See Schedule 5
				D1	1	Sheet 8 of 13	
42	10/9	10/8	7004	C1	3	Sheet 8 of 13	
				D1	3	Sheet 8 of 13	
43	10/9	10/8	7034	B2	1	Sheet 8 of 13	150mm diameter
				C1	1	Sheet 8 of 13	See Schedule 5
				D1	1	Sheet 8 of 13	
44	10/9	10/8	7059	D1	1	Sheet 8 of 13	
45	10/8	10/7	7164	C1	1	Sheet 8 of 13	
46	10/8	10/7	7169	C1	1	Sheet 8 of 13	
47	10/7	10/6	7221	A1	1	Sheet 8 of 13	
48	10/4	10/3	7523	A1	1	Sheet 8 of 13	
49	10/2	10/1	7768	C1	1	Sheet 9 of 13	
50	9/9	9/8	8000	B1	1	Sheet 9 of 13	500mm x 200mm
51	9/7	9/6	8274	C1	1	Sheet 9 of 13	See Schedule 5
52	9/7	9/6	8279	C1	1	Sheet 9 of 13	
53	8/7	8/6	9225	A1	1	Sheet 10 of 13	
54	8/7	8/6	9233	A2	2	Sheet 10 of 13	
55	8/3	8/2	9605	E1	1	Sheet 10 & 11 of 13	1020m²
56	8/2	8/1	9708	C1	1	Sheet 11 of 13	See Schedule 5
57	8/2	8/1	9794	B1	1	Sheet 11 of 13	300mm x 300mm

Schedule 1: Permitted Pavement Options (continued)							
Treatment Reference on Drawing	Location Between Two Marker Posts (MP)		Site Chainage (m)	Pavement Treatment	No. of Treatments	Drawing Reference	Typical Dimensions per Treatment (see Schedule 5)
	1st MP	2nd MP					
58	8/0	7/9	9972	A1	1	Sheet 11 of 13	See Schedule 5
59	8/0	7/9	9977	A1	1	Sheet 11 of 13	
60	8/0	7/9	9992	D1	1	Sheet 11 of 13	
61	7/8	7/7	10127	D1	1	Sheet 11 of 13	
62	7/8	7/7	10162	C1	1	Sheet 11 of 13	
63	7/8	7/7	10167	C1	1	Sheet 11 of 13	
64	7/8	7/7	10172	C1	1	Sheet 11 of 13	
65	7/7	7/6	10277	C1	1	Sheet 11 of 13	
66	7/4	7/3	10545	A1	1	Sheet 11 of 13	
67	7/4	7/3	10550	C1	1	Sheet 11 of 13	
68	7/0	6/9	10906	C1	1	Sheet 12 of 13	
69	7/0	6/9	10941	C1	1	Sheet 12 of 13	
70	6/9	6/8	11030	A1	3	Sheet 12 of 13	
71	6/9	6/8	11040	A2	3	Sheet 12 of 13	
72	6/7	6/6	11257	A1	1	Sheet 12 of 13	
73	6/5	6/4	11442	C1	1	Sheet 12 of 13	
74	6/5	6/4	11447	C1	1	Sheet 12 of 13	
75	6/5	6/4	11482	A2	2	Sheet 12 of 13	
76	6/4	6/3	11552	C1	1	Sheet 12 of 13	
				D1	1	Sheet 12 of 13	
77	6/4	6/3	11557	D1	1	Sheet 12 of 13	
78	6/4	6/3	11562	D1	1	Sheet 12 of 13	
79	6/4	6/3	11573	D1	2	Sheet 12 of 13	
80	6/3	6/2	11593	A2	1	Sheet 12 of 13	
81	6/2	6/1	11705	A1	1	Sheet 13 of 13	
82	6/0	5/9	11938	A1	1	Sheet 13 of 13	
83	6/0	5/9	11986	A1	1	Sheet 13 of 13	
84	5/9	5/8	12044	A1	1	Sheet 13 of 13	

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