

## **PROJECT REPORT**

**Investigating the reliability of air void testing regime of  
Specification of the Reinstatement of Openings in Highways  
(SROH) for assessing the performance of a hand laid recipe mixed  
bituminous material in utility reinstatement**

**Prepared for NJUG by the LJMU-NJUG Research Project Team**

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## 1. Executive Summary

Initial research focussed on critical analysis of the available published standards and previous reinstatements trial results in the UK. The findings of this research project resulted in the publication of a white paper in 2014. Two significant outcomes of this initial research were:

- Compounding of errors, particularly in density measurement of core samples and subsequent variability, generate biased AV content results that make the compliance largely uncertain. This resulted in a broad range of predicted outcomes, putting both the contractor and the client at unacceptable risk
- Linkage between AV content of reinstatements (constructed by fully complying with the methods prescribed within the Specification of the Reinstatement of Openings in Highways (SROH)) and durability in recipe-mixed hand laid reinstatements with the limits currently in SROH is not proven.

To understand if the current AV compliance criterion in the SROH is able to provide a reliable indication of structural resilience throughout its service period, further laboratory and field experiments were conducted in this research. Results obtained from this research project suggest:

**1.1** Due to the method and nature of utility reinstatement construction (transportation from plant, unloading, laying and compaction in restricted areas), the homogeneity of the asphalt mixtures is likely to be distorted and as a consequence resulting maximum density will be varied within the reinstatement.

**1.2** The wide-ranging maximum density reported in every instance in the comparison pair coring experiments meaningfully rationalises the distorted homogeneity of materials. Although not only maximum density but also bulk density of adjacent cores located only 100 mm apart were found to be varied in the case of every pair in this study.

**1.3** The lack of material homogeneity is very unlikely in the case of any machine-laid asphalt work on major construction. Therefore, appropriateness relating to the compliance assessed only by measuring in-situ AV content using the material and method of construction quoted in the SROH is not justified. Material homogeneity was also specified as the main criteria to consider a spot sample as average sample in relevant British Standards.

**1.4** At 95% level of significance, enough evidence exists to conclude that, due to high uncertainty, very low repeatability and reproducibility and poor reliability with high chances of bias, the assessment of hand laid reinstatement work by AV testing will expose both the contractor and the client to unacceptable risk.

**1.5** As per the UKAS Technical Advisory Committee, *“a representative core sample taken and subjected to testing by a UKAS an accredited laboratory in accordance with BS EN 12697 for hand laid recipe mixtures may only provide confidence in the sample tested meeting the requirements of the SROH, and may therefore not be considered for the integrity in conformity of the whole reinstatement. In contrast, machine laid work is generally homogeneous and so the analysis of a single core is may provide a result that is representative of the material in the whole reinstatement”*

**1.6** Compliance relating to wheel tracking slope (WTS) was reported in all cases. Reasonable compliance relating to proportional rut depth (PRD) was reported in two cases, despite the reinstatements having 20.1% and 17.7% AV content and good in-service performance against 10 years and 1.5 years of ageing, weathering, oxidation and wearing. Hence, either the linkage between the reinstatement with non-compliant AV and its impact

on footways durability is non-proven, or the reported respective AV content is over estimated.

**1.7** The resilience shown during the in-situ performance assessment by non-compliant (AV) reinstatements across the country in service performance against ageing, weathering, oxidation, wear and different extreme environmental loading was also in conformity with the findings reported by the wheel tracking test observation in this research project.

**1.8** It is envisaged that numerous reinstatements will have to be reworked, based on an assessment method which is itself not only unreliable but also suffering from non-compliant precision relating to the British Standards. The revealed inherent embedded bias, as well as unreliability of current assessment method of SROH, for a hand laid bituminous work where non-homogenous materials are likely, places the contractor and the client at unacceptable risk and costs utilities, contractors and the community, without any additional benefit in performance.

## 2. Introduction

### 2.1 The Project

In 2013, a consortium of 23 members, representing utility undertakers, contractors, bituminous material suppliers, and a compaction equipment supplier, instigated a university-led research project on utility reinstatement, in partnership with Liverpool John Moores University (LJMU). Membership of the consortium includes representation from the gas, water, electric and telecommunications sectors in the UK.

Coring (the taking of samples of asphalt materials) programmes of utility reinstatements initiated by Local Authorities have been identifying consistent failure in respect of air voids (AV) content in surface course material of footways when assessed against the requirement of the Specification for the Reinstatement of Openings in Highways (SROH) (Department for Transport, 2010) for air voids content compliance only. This is an issue which currently affects all National Joint Utility Group (NJUG) members, presenting a significant and growing challenge as more Local Authorities apply the SROH air voids content standard to utility reinstatements.

### 2.2 The White Paper

Initial research focussed on critical analysis of the available published Standards and previous reinstatements trial results in the UK. The findings resulted in the publication of a white paper in 2014. The key features of the white paper was accepted as a technical article in a peer-reviewed international journal (Sadique et al., 2015) and can be found in Appendix E. This enabled the findings to be disseminated to a wider community, both in the UK and internationally. Among various findings, two significant outcomes of this initial research were;

**2.2.1** The use of air voids content determination on single cores is so inaccurate as to make compliance largely a matter of chance, as a result of compounding errors in the measurement of bulk density and maximum density. The use of air voids content other than for design mixtures, does not comply with UK best practice as outlined in BS594987: 2010, due to the expected and allowable variability for recipe mixtures and the use of hand laying as the principal method of installation. The application of a measured in-situ air voids content criteria in a Specification for recipe mixed reinstatements cannot be sustained on technical grounds;

**2.2.2** The linkage between AV content and durability in recipe mixed hand laid reinstatements with the limits currently in SROH is not proven.

### 2.3 Research Objectives

To further understand whether the current Air Voids criteria is consistently achievable as per the methodologies within the SROH and to understand if the current AV compliance criterion in the SROH is able to provide a reliable indication of structural resilience throughout its service period, this second stage research was conducted and this paper reports the findings. The following objectives were identified for further investigation within this research project:

**2.3.1** To identify if AV content varied significantly in a small reinstatement, pairs of cores were collected by two different independent laboratories from different reported failed (in terms of AV compliance) reinstatement sites;

**2.3.2** To determine the susceptibility of the reinstatement to deform under load, samples were collected from previously failed (in terms of AV compliance) reinstatement sites for testing under wheel tracking;

**2.3.3** To collect and review information from utility undertakers and contractors relating to in-situ performance of the reinstatement that previously reported failed (in terms of AV compliance) by the Highways Authority.

#### **2.4 Comparison Core Exercise**

To further understand if the current AV criterion is consistently achievable as per the methodologies within the SROH and to identify if voids content varied significantly across a small reinstatement, comparison core exercises were undertaken. The comparison sites for coring were selected in such a way that a range of road categories as well as differentials in degrees of failure from minor to extensive were examined. The comparison cores were all taken in close proximity (within 100 mm) to ensure that both cored test sites had been similarly compacted with similar (almost identical) material. In-situ performance of a number of reinstatements (footway and carriageway) of varying ages and varying only non-compliant AV contents were visually inspected by the respective undertakers/contractors and evidence was collated.

### **3. Uncertainty and reliability of AV content testing in hand laid reinstatement**

#### **3.1. Uncertainty of Testing**

The general approach to evaluating and expressing uncertainty in testing outlined in UKAS publication reference LAB-12 (United Kingdom Accreditation Service, 2000), was based on the recommendation produced in the guide by the International Bureau of Weights and Measures (BIPM et al., 2008). Providing a measure of uncertainty that defines an interval about the measurement result that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand was stated in this guide. Moreover, the general requirement for the estimation and reporting of uncertainty of measurement by all accredited laboratories has been specified with the implementation of the International Standard ISO/IEC 17025 (Birch, 2003), encompassing a number of influential quantities that affect the result obtained for the measurand in the case of uncertainty in the evaluation process.

#### **3.2. Repeatability and Reproducibility**

To quantify the agreement and reliability of measurements made by any particular method or observer/s, a repeatability and reproducibility study of that measurement should be investigated (Bartlett and Frost, 2008). The repeatability and reproducibility interval for testing air voids content has been specified in the Standard BS EN 12697-8 (European Committee For Standardization, 2003a) by multiplying the respective standard deviation with 2.77. It is similar to the statistical estimate of a 95% confidence interval for the difference between two readings stated by ASTM Standard (Ullman, 2009). Based on this, the reproducibility statement for single coring results on identical test material reported by two laboratories, the air void contents should differ by no more than 2.2% on average on 95% of occasions (British Standards Institution, 1987, Bartlett and Frost, 2008).

#### **3.3. Repeatability and Reproducibility Results from 5 Reinstatement Sites**

To investigate reproducibility, five sites (C1 to C5) were selected from an undertaker's reinstatement where cores were taken by three UKAS accredited laboratories. The locations of the cores have been shown in Figure 1 to Figure 3. The three test houses were named as Lab A, Lab B and Lab C, ensuring anonymity. During this test, the maximum density was determined in accordance with EN 12697-5 (procedure A) and the bulk density was determined in accordance with EN12697-6 (procedure C) in all laboratories. The details of the test results have been shown in Table 1.

#### **3.4. Statistical Analysis Using Paired Sample t-test**

A strong statistical tool 'paired t-test' was used to compare the AV content of two adjacent cores measured by two laboratories. During the t-test, the null hypothesis was assumed that the mean of two paired samples are equal, and the alternative hypothesis was assumed that the means of two paired samples are not equal. The appropriate hypothesis was tested in the form of a probability - the p-value (significance 2-tailed) at 5% level of significance. If p is small ( $p < 0.05$ ), the findings are unlikely to have arisen by chance and there is moderate evidence against the null hypothesis in favour of the alternative. If p is large ( $p > 0.05$ ), the observed difference is plausibly a chance finding and there is no evidence against the null hypothesis. Smaller p-values ( $p < 0.01$ ) are sometimes called 'highly significant' because they indicate that the observed difference would happen less than once in a hundred times if there was really no true difference.



**Figure 1:** Location of three cores taken by Lab A, Lab B and Lab C from site C1 and C2



**Figure 2:** Location of three cores taken by Lab A, Lab B and Lab C from site C3 and C5

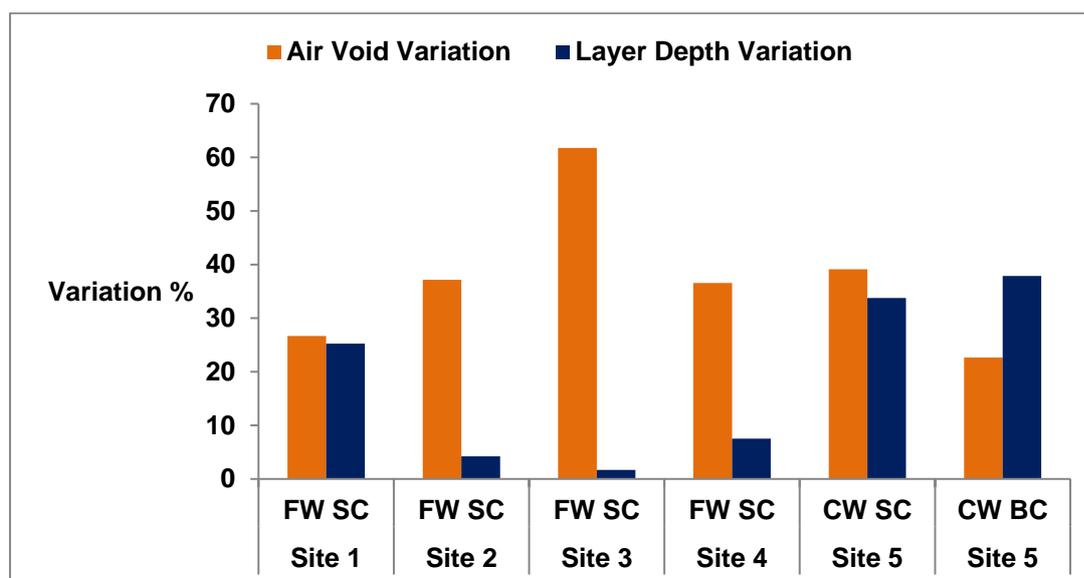


**Figure 3:** *Location of three cores taken by Lab A, Lab B and Lab C from site C4*

**Table 1: The core test results obtained from five sites from an undertaker's reinstatements**

Site Ref	Reinstatement Materials	Lab A				Lab B				Lab C			
		Layer Depth (mm)	Voids (%)	Max (Mg/m <sup>3</sup> )	Bulk (Mg/m <sup>3</sup> )	Layer Depth (mm)	Voids (%)	Max (Mg/m <sup>3</sup> )	Bulk (Mg/m <sup>3</sup> )	Layer Depth (mm)	Voids (%)	Max (Mg/m <sup>3</sup> )	Bulk (Mg/m <sup>3</sup> )
C1	AC6 DSC	69.0	20.7	2.554	2.027	113.0	12.2	2.467	2.165	110.0	15.4	2.472	2.092
C2	AC6 DSC	90.0	19.2	2.564	2.074	95.0	13.2	2.486	2.157	87.5	9.0	2.477	2.255
C3	AC6 DSC	92.0	21.8	2.496	1.953	89.0	6.3	2.39	2.239	90.0	10.7	2.45	2.188
C4	AC6 DSC	53.0	14.7	2.497	2.132	61.0	7.0	2.361	2.195	60.0	10.1	2.406	2.163
C5	AC10 DSC	102.0	15.0	2.561	2.179	80.0	8.0	2.507	2.306	50.0	8.0	2.451	2.254
	AC20 DBC	49.0	8.7	2.6	2.375	70.0	5.5	2.543	2.402	105.0	7.0	2.5	2.325

The wide variation of results relating to bulk and maximum densities, as well as layer depths obtained from three cores (located approximately 100 mm apart), are evident from Table 1, although the three test houses followed the same standards and procedure stated in SROH. The total recorded depths by the three test houses for site C5 were almost identical, however, in the case of identifying surface and binder course materials from the same core, a wide variance of layer depth between the three test houses was revealed. The maximum variations of layer depths were recorded in the case of Laboratory A and Laboratory C, where surface and binder course varied by 104% and 114% respectively. As the AV content compliant requirement in SROH for binder and surface course materials is not similar, this high range of observational variation will essentially affect the assessment outcome of a reinstatement. Moreover, no recurring correlation existed between the variation of layer depth and corresponding air void content in this comparison core analysis, as shown in Figure 4.


**Figure 4: The relation between AV content and layer depth variation**

The paired sample test results of Lab A-B, Lab B-C and Lab C-A have been shown in Table 2-4 respectively. It is evident from the t-test results that, statistically significant,  $p < 0.05$  ( $p = 0.005$  and  $0.006$ ,  $t = 4.75$  and  $4.58$ ) differences of measured air void were revealed in the case of core results of Lab A-B and Lab A-C when compared. Furthermore, the 95% confidence interval of the difference lies in the range of 3.6% to 12.3% and 2.9% to 10.3% respectively (as shown in Table 2 and 3). However, non-significant,  $p > 0.05$  ( $p = 0.342$ ,  $t = 1.05$ ) difference together with a lower range of the 95% confidence interval of the difference was reported in the case of Lab B-C (Table 4). The evidence of no recurring correlation between the variation of layer depth and corresponding air void content intensifies the significance of the reliable difference values that were observed in the t-test analysis for core results of Lab A-B and Lab A-C.

**Table 2: Paired t-test for Laboratory A and B**

	Paired Differences					t	df	Significance (2-tailed)
	Mean	Standard Deviation	Standard Error Mean	95% Confidence Interval of the Differences				
				Lower	Upper			
Pair 1 <b>Lab A – Lab B</b>	7.98	4.11	1.68	3.66	12.30	<b>4.75</b>	5	<b>0.005</b>

**Table 3: Paired t-test for Laboratory A and C**

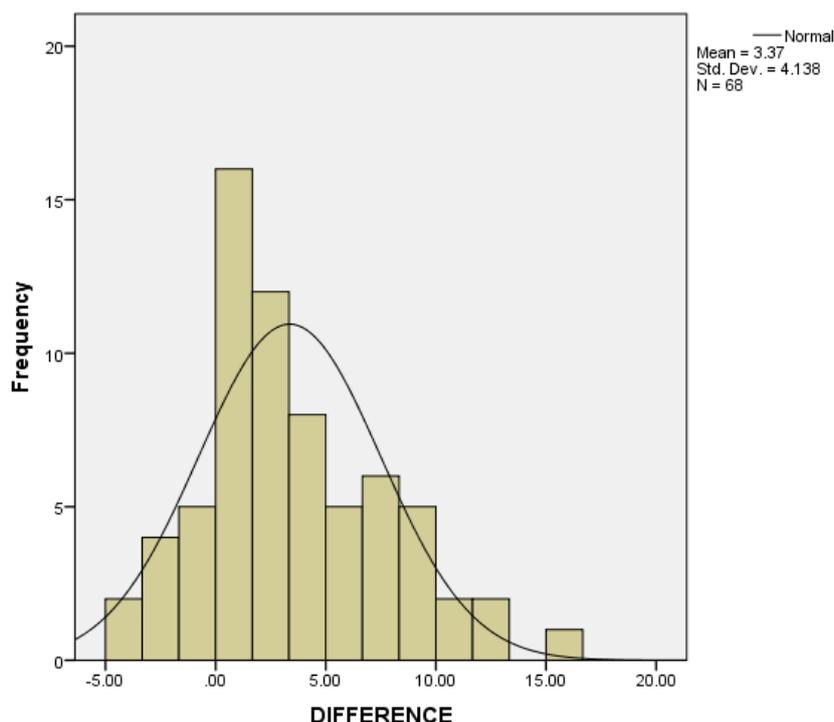
	Paired Differences					t	df	Significance (2-tailed)
	Mean	Standard Deviation	Standard Error Mean	95% Confidence Interval of the Differences				
				Lower	Upper			
Pair 1 <b>Lab A – Lab C</b>	6.65	3.55	1.45	2.92	10.37	<b>4.58</b>	5	<b>0.006</b>

**Table 4: Paired t-test for Laboratory B and C**

	Paired Differences					t	df	Significance (2-tailed)
	Mean	Standard Deviation	Standard Error Mean	95% Confidence Interval of the Differences				
				Lower	Upper			
Pair 1 <b>Lab B – Lab C</b>	-1.33	3.11	1.27	-4.56	1.93	<b>-1.05</b>	5	<b>0.342</b>

### 3.5. Repeatability and Reproducibility Results from 68 Reinstatement Sites

To make the analysis more assured and representative, a total of 68 further pairs of comparison cores were taken (including the five sites above) from the reinstatements constructed by different undertakers within different parts of the country, following the same procedure stated above. In this case, comparisons were made between the cores taken by Lab A (same as above) and those taken by different laboratories (here termed as Lab X). Detailed results from the 68 pairs of cores have been tabulated in Appendix A. The distribution of differences of AV content between the two laboratories in 68 reinstatement sites was found to be approximately normal, as shown in Figure 5.



**Figure 5:** Histogram of differences in AV content between Lab A and Lab X

The repeatability and reproducibility interval for testing AV content has been specified in BS EN 12697-8 (European Committee For Standardization, 2003a) and is similar to the statistical estimate of a 95% confidence interval for the difference between two readings stated by ASTM Standard (Ullman, 2009). Based on this, the reproducibility statement for single coring results on identical test material reported by two laboratories should differ by no more than 2.2% on average on 95% of occasions (British Standards Institution, 1987, Bartlett and Frost, 2008). However, in practice, acceptance (pass or fail against SROH AV content requirement) is evaluated based on the result from single core.

**Table 5:** Paired t-test for Laboratory A and X from 68 reinstatement sites

	Paired Differences				t	df	Significance (2-tailed)	
	Mean	Standard Deviation	Standard Error Mean	95% Confidence Interval of the Differences				
				Lower				Upper
Pair 1 <b>Lab A – Lab X</b>	3.36	4.13	0.501	2.36	4.37	<b>6.71</b>	67	<b>0.000</b>

The data from a t-test analysis of all 68 pairs of cores has been recorded in Table 5. A closer examination to the 'paired sample T-Test' among the pairs taken from 68 different sites reveals that, not only a statistically significant ( $T = 6.7$  and  $p = 0.000$ ) difference between the AV content measured by two laboratories exists, but also the range of difference at 95% confidence level lies between 2.3% to 4.3%. This wide range exceeds the 2.2% reproducibility limit set by the British Standard. Moreover, acknowledging the proficiency relating to coring and testing procedures of the UKAS accredited test houses in this research, the extremely low intra-class correlation coefficient from reliability analysis (as shown in

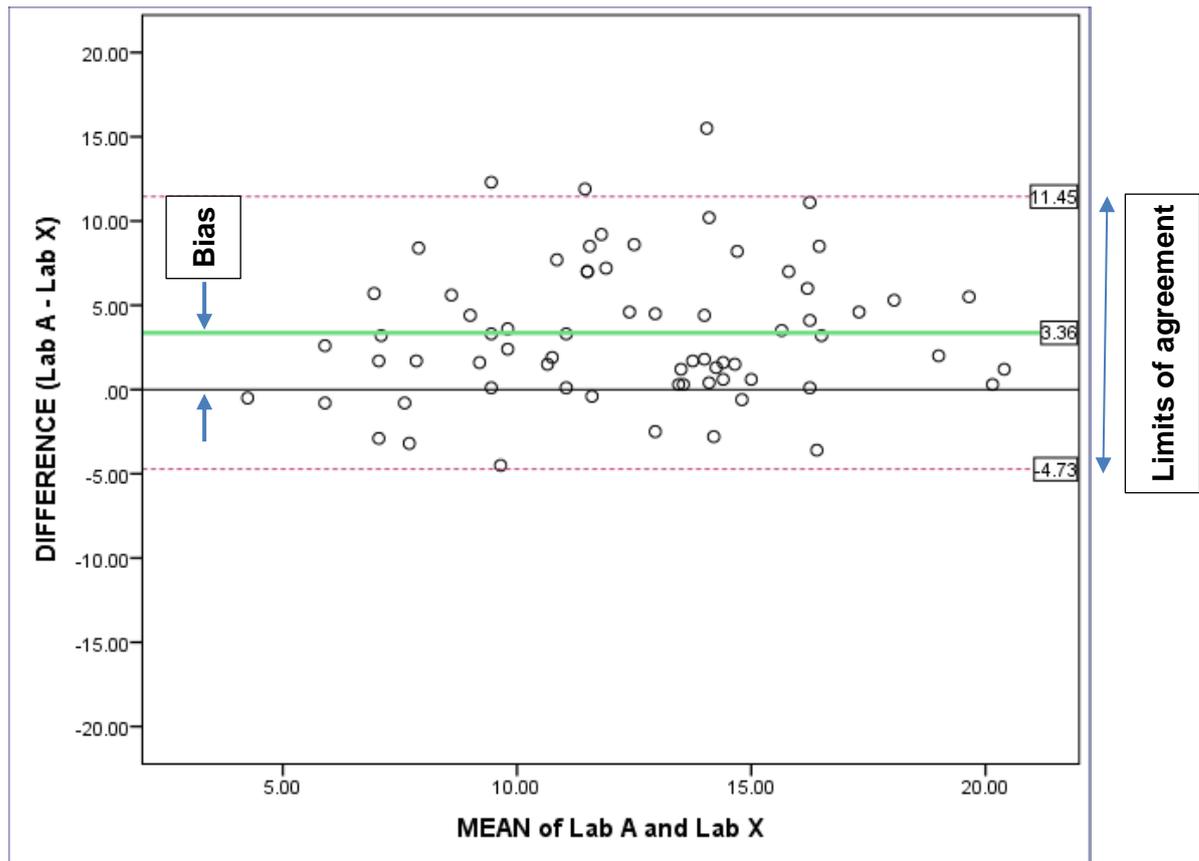
Table 6) of 68 pairs of air void content results, inevitably indicates the poor reliability of the coring method.

**Table 6:** *Intra-class correlation coefficient (ICC) analysis of 68 pairs of AV content for reliability test*

	Intra-class Correlation	95% Confidence Interval		F Test with True Value 0			
		Lower Bound	Upper Bound	Value	df1	df2	Significance
Single Measures	<b>0.399</b>	0.035	0.640	3.190	67	67	<b>0.000</b>
Average Measures	<b>0.571</b>	0.068	0.780	3.190	67	67	<b>0.000</b>

### 3.6. Bias of Results from 68 Reinstatement Sites

To assess agreement between the measurements and presence of any bias within the reported AV content results produced by two test houses, a Bland-Altman plot was conducted. The Bland-Altman plot (Altman and Bland, 1983) and analysis is used to compare two measurements of the same variable and is a commonly referred method of comparison technique (Bartlett and Frost, 2008). The Bland-Altman plot of the AV content results from two independent laboratories has been shown in Figure 6. The solid green line indicates the mean of the paired differences (Lab A – Lab X) of air void content (3.36%) and its distance from zero provides the amount of bias between the two laboratories. The variability of the differences between the results of two laboratories indicates how well the method of assessment by AV content agrees. The limits of agreement give a range within which 95% of future differences in measurements between two core results by two different laboratories would be expected to lie. The limits of agreement in this study were found to be in the range of -4.73% to 11.45% (mean difference  $\pm$  1.96x SD of differences). So, AV content measured by Laboratory A may be 4.73% below or 11.45% above Laboratory X on 95% of occasions in future (represented by dashed lines in Figure 6).



**Figure 6:** Differences in AV content measured by Lab A and Lab X against their means (Bland-Altman plot)

### 3.7. Influence of Maximum and Bulk Density on AV Content

Density plays a very important role in AV content calculation and a small change in bulk and/or maximum density values affects the AV content significantly. Variations in the maximum and bulk densities between two specimens, which may be reasonably considered as the same (100 mm apart in this case) should rarely, if ever, occur, and if they do, they should be such a minimal amount that they do not impact on the integrity of the test results.

However, it was revealed in this research that, in the case of algebraic difference of measured densities between two test houses, the Lab A measured maximum density values were higher than Lab X for the same parameter in 88% of cases, whereas in 72% of cases, Lab A measured bulk density values were lower than Lab X (as shown in Table 7). It was also observed that the differences (Lab A-Lab X) of densities were not compensating each other when total 68 sites were considered.

As a consequence of this compounding difference of densities, a statistically significant difference between the AV content measured by two laboratories was revealed in a t-test analysis and the amount of bias in Bland-Altman analysis was in accordance with this finding. However, as both test houses were UKAS-accredited and followed the same procedures stated in the relevant British standards and SROH, the absolute difference between each pair (located 100 mm apart) was measured, as shown in Table 7. Furthermore, the 'Microsoft Excel Data Solver' tool was employed to investigate the sensitivity of the results

obtained from the 68 sites summarised in Table 7. Based on the reported pattern of differences of maximum and bulk densities, 0.066 Mg/m<sup>3</sup> (as close as possible to 0.0644 Mg/m<sup>3</sup>) decrease of maximum density and 0.057 Mg/m<sup>3</sup> (as close as possible to 0.0634 Mg/m<sup>3</sup>) increase of bulk density, was used during the AV content sensitivity (nearest to one decimal place) test and the following sensitivities were reported:

- Only 0.100 Mg/m<sup>3</sup> decrease of maximum density decreases AV by 3.6%
- Only 0.100 Mg/m<sup>3</sup> increase of bulk density decreases AV by 4.0%
- Combined, 0.066 Mg/m<sup>3</sup> decrease of maximum density and 0.057 Mg/m<sup>3</sup> increase of bulk density, decreases AV by 4.7%

**Table 7:** Summary of density measurements from 68 sites measured by Lab A and Lab X.

		<b>Lab A – Lab X</b>	
Average algebraic difference	Maximum Density	0.0576 Mg/m <sup>3</sup>	In 88% cases, Lab A measured maximum density values were <b>higher</b> than Lab B
Average algebraic difference	Bulk Density	-0.0321 Mg/m <sup>3</sup>	In 72% cases, Lab A measured bulk density values were <b>lower</b> than Lab B
Average absolute difference	Maximum Density	0.0644 Mg/m <sup>3</sup>	
Average absolute difference	Bulk Density	0.0634 Mg/m <sup>3</sup>	

### 3.8. Assessment by AV Content in British Standards

Through implementing the 2<sup>nd</sup> Edition of the SROH, the Department for Transport introduced an end result specification (ERS) in place of method specification for assessing asphalt material. However, the compaction for asphalt material for major road construction in British Standards BS 594987 (European Committee For Standardization, 2010) is assessed by stating the following:

*“End result compaction shall be applied to designed dense base and binder AC mixtures which have been type tested in accordance with BS EN 13108-20. A method of compaction shall be adopted and detailed in a suitable quality plan so as to ensure that the void content of the finished mat conforms to the required limits on void content.*

*NOTE: This method is applicable for works intended to carry heavy traffic. The scale of works should be such as to justify the cost of testing and control (clause 9.5.1.1).”*

The following note has been quoted concerning the compaction of asphalt materials in BS 594987:

*“End result compaction is more appropriate for machine-laid work on major road contracts” (clause 9.1).*

### **3.9. Material Homogeneity of Reinstatement Work**

According to SROH A2.0, the reinstatement work in footways and carriageways is considered to be carried out in confined or restricted areas. Hence, it is highly anticipated that, due to the method and nature of utility reinstatement construction (transportation from plant, unloading, laying and compaction in restricted areas), the homogeneity of the asphalt mixtures is likely to be distorted and as a consequence, the resulting maximum density will be varied within the reinstatement. The wide-ranging maximum density (average difference = 0.0481 Mg/m<sup>3</sup>) reported in every instance in the above comparison pair coring experiments also meaningfully rationalises the distorted homogeneity of materials. Material homogeneity was also specified as the main criteria to consider a spot sample as average sample in relevant British Standards (European Committee For Standardization, 2001). Although not only maximum density but also bulk density of adjacent cores located only 100 mm apart were found to be varied in the case of every pair (average difference = 0.0474 Mg/m<sup>3</sup>) in this study. So it can be stated that within a pair of adjacent cores, the variation of maximum density originates from the distorted material homogeneity whereas, due to intrinsic bias within the bulk density testing procedure in the relevant standard, the bulk density diverges from each other.

### **3.10. Reliability of Assessing Reinstatement Work by AV Content**

The lack of material homogeneity is very unlikely in the case of any machine-laid asphalt work on major construction. Therefore, appropriateness relating to the compliance assessed only by measuring in-situ AV content using the material and method of construction quoted in the SROH, is not justified. Moreover, the use of air voids content requirement and associated testing regime for recipe mixed hand laid reinstatement works is acknowledged to be not totally suitable in the relevant British Standard due to service load (footways), scale of work (utility reinstatement), nature of construction (hand laid) and material used (recipe mixed).

Hence, at 95% level of significance, there exists enough evidence to conclude that, due to high uncertainty, very low repeatability and reproducibility and poor reliability with high chances of bias, the assessment of hand laid reinstatement work by AV testing will expose both the contractor and the client to unacceptable risk.

## 4. Durability of Non-compliant Footways Reinstatement

### 4.1. Assessing Reinstatement Durability by SATS

For assessing the durability of adhesion in high modulus base and binder course mixture, the saturation ageing tensile stiffness (SATS) test was developed for trunk roads and motorways in the UK. However, the applicability of this test method was limited to bituminous specimens with consistent air void contents and hard binder, air void contents between 6% and 10% and 10/20 pen hard paving grade bitumen (European Committee For Standardization, 2012). This test generally involves specimens cored from a slab manufactured using a laboratory roller compactor, as research data on the performance of in-service specimens in the SATS test is currently unavailable.

### 4.2. Assessing Reinstatement Durability by Wheel Tracker

The wheel tracking test is a widely used performance-related test, which is known to correlate with an engineering property to predict performance and durability. The susceptibility of bituminous materials to deform is assessed by the wheel tracking test at constant temperature. The limiting value for resistance to permanent deformation has been specified in PD 6691 (European Committee for Standardization, 2015), appropriate only for the carriageway designed for Class 1 (1001 to 2000 commercial vehicle/lane/day) and Class 2 (2001 to 4000 commercial vehicle/lane/day) traffic sites, as classified in MCHW series 900 (Highways Agency, 2008).

Instead, the lowest penetration grade bitumen permitted in SROH is 40/60 and this research was intended to investigate both the performance and the structural integrity of in-service (not laboratory prepared) footway reinstatement (generally not high modulus) containing high air voids (more than 13%). Also, no performance or durability related test method for base and binder course materials has been specified in SROH, except measuring the resistance to permanent deformation of surface course mixture. Moreover, instances of mixtures performing poorly in the SATS test but demonstrating a proven record of good performance in-service (and vice versa) have also been reported (Nicholls et al., 2011). Hence, to check the resilience of in-service low modulus asphalt materials (generally surface course using 100/150 binder with non-consistent AV as a result of recipe mixed), but already experiencing sufficient (in the range of 6 years to 1.5 years) real life ageing, weathering and environmental loading; a more reliable and realistic judgement cannot be made from SATS test. Therefore, a wheel tracking test was scheduled to provide reasonable measure of the future performance of good in-service performing footway reinstatements despite reported high AV. Although, requirement for assessing the resistance to permanent deformation in non-traffic sites has not been stated in relevant British Standards.

### 4.3. Durability Performance of Aged In-service Reinstatement

The specimen extraction, preparation and testing for permanent deformation was carried out using wheel tracking apparatus in accordance with the procedure stated in the BS EN 12697-22 (European Committee For Standardization, 2003b) using a small size device. The wheel tracking slope (WTS) and proportional rut depth (PRD) were measured using Procedure B in air, whereas the wheel tracking rate (WTR) was measured according to Procedure A. The temperature for testing as well as conditioning up to required duration was kept at 45°C as stated in PD 6691 for moderate to heavily stressed sites (Class 1). Specimens were cut of sufficient size from the reinstatement to enable them to be sawn to form a rectangular test specimen of 260 mm × 300 mm for small size devices. Different stages of the sample extraction and testing have been shown in Figure 7. The results for one sample from each site have been tabulated in Table 8. Compliance relating to WTS was reported in all cases, and reasonable compliance relating to PRD was reported in two cases, despite the reinstatements having 20.1% and 17.7% AV content (reported by a UKAS accredited test house) and good in-service performance against 6 years and 1.5 years of ageing, weathering, oxidation and wearing.

#### 4.4. Linkage between Durability and Reported Non-compliant Reinstatement

Withstanding occasional overrun by non-commercial vehicles (less than 1.5 tonnes unladen) has been specified as performance compliance for any footway reinstatement in SROH (S2.1.6). However, complying with the requirement relating with WTS by non-compliant reinstatement (in terms of only AV content) in this research predictably indicates either:

- The reported AV content is extremely over estimated;  
or
- The linkage between the reinstatement with non-compliant AV and its impact on footways durability is not proven



**Figure 7:** Specimen extraction and testing in wheel tracking apparatus

**Table 8:** Wheel tracking test results on footways specimens with non-compliant AV content

Sample reference	Reinstatement date	% AV reported by HA	Coring date	WTR test date	WTR results	Maximum allowable limit in PD6691
WTR-C2	February '14	19.3%	September '14	March '15	WTS <sub>Air</sub> = 0.729 mm/1000 cycle PRD <sub>Air</sub> = 15.68% WTR <sub>Air</sub> = 1.60 µm/cycle	WTS <sub>Air</sub> = 1.0 mm/1000 cycle PRD <sub>Air</sub> = 9.0%
WTR-3rd - 2	April '2009	20.1%	July '14	March '15	WTS <sub>Air</sub> = 0.414 mm/1000 cycle PRD <sub>Air</sub> = 10.42% WTR <sub>Air</sub> = 0.53 µm/cycle	
WTR-A2	November '13	17.7%	November '14	April '15	WTS <sub>Air</sub> = 0.184 mm/1000 cycle PRD <sub>Air</sub> = 4.35% WTR <sub>Air</sub> = 0.747 µm/cycle	

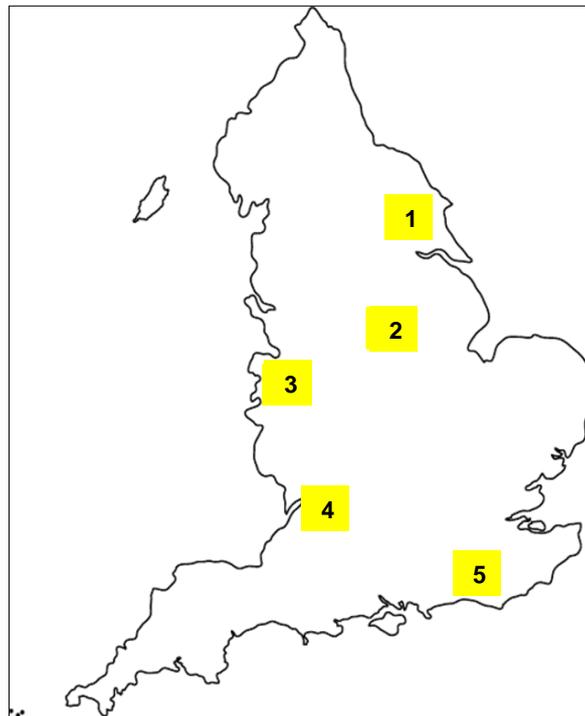
## 5. In-situ performance of Reinstatement reported non-compliant AV

### 5.1. In-situ Performance Observation of Non-compliant Reinstatements across the UK

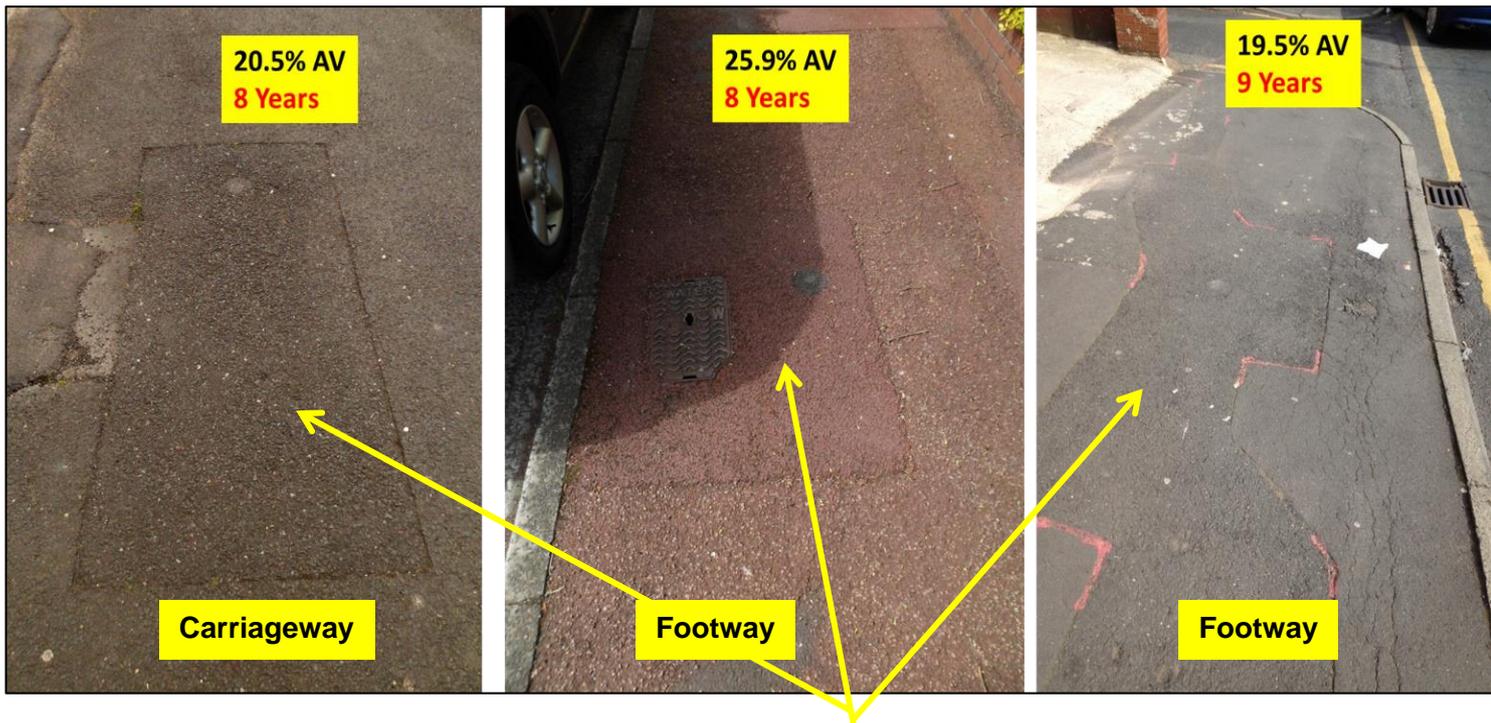
In-situ performance of a number of reinstatements (footway and carriageway) of varying ages and varying only non-compliant AV contents were visually inspected by the respective undertakers/contractors across five various parts of the country (as shown in Figure 8) and reports were collated. The samples were selected at random and include reinstatements with AV in the range of 14.4% to 25.9% and in-situ performance life was in the range of 1.5 years to 10 years. During this range of assessment periods, the UK experienced various extreme weather events including record rainfall, flood, wettest winter, record low temperatures, exceptionally heavy snow fall and warmest month on record (Met Office, 2015). Visual inspection reports from 20 sites out of the inspected 50 reinstatement sites can be found in Appendix C.

### 5.2. Visual In-service Performance of Aged Reinstatement

Evidence was collated from almost 50 sites across various areas of the country and no visual failures were recorded that would have breached the performance tolerance permitted by section S2 of SROH. In many instances, the reinstated area was performing better than the surrounding highway and none of the reinstatements were found to be inferior in any respect to the condition of the adjacent surface. Three typical visual in-situ assessments have been shown in Figure 9 and the location of the reports are available from all assessments, as are the associated UKAS air void testing certificates (from the original core tests). Hence the resilience shown during this in-situ performance assessment by these non-compliant reinstatements across the country in service performance against ageing, weathering, oxidation, wear and different extreme environmental loading was also in conformity with the findings reported by the wheel tracking test observation in this research.



**Figure 8:** Location of visually assessed in-situ performance of reinstatement across the UK



**Figure 9:** Visual in-situ performance of different reinstatement containing non-compliant AV

## **6. UKAS Position Statement on Reliability of using AV Content for Assessing Utility Reinstatement**

### **6.1. Sharing the Research Findings with UKAS**

Based on the above findings, this research team forwarded a letter (Appendix B) to the Technical Advisory Committee for Construction Industry in UKAS requesting their thoughts on the issues outlined above, with a focus on the inconsistencies highlighted within UKAS accredited providers. Accordingly a two team delegate from UKAS visited Liverpool John Moores University on 14<sup>th</sup> January 2016 and the research team shared the research findings as stated in this report. After the discussion on the findings from this research, the UKAS Technical Advisory provided following position statement.

### **6.2. The Statement by UKAS**

Technical Advisory Committee for Construction Industry Committee of UKAS provided the following statement, focusing the unreliability of air void testing for reinstatement works:

*“A representative core sample taken and subjected to testing by a UKAS an accredited laboratory in accordance with BS EN 12697 for hand laid recipe mixtures may only provide confidence in the sample tested meeting the requirements of the Specification for Reinstatement of Openings in Highways, and may therefore not be considered for the integrity in conformity of the whole reinstatement. In contrast, machine laid work is generally homogeneous and so the analysis of a single core is may provide a result that is representative of the material in the whole reinstatement than would be the case for hand laid material. However, whatever the method of laying, test results can only accurately represent the sample that has been analysed and cannot validly be used to represent the composition of adjacent material” (Giles and Chapman, 2016).*

## 7. Independent Peer Review



### 7.1. Evaluation Report by Dr J C Nicholls

The paper looks at the precision of the results from the air voids content calculation, as determined from measuring the bulk and maximum densities of cores taken in asphalt reinstatements. The conclusions from the report are that the variability in hand-laid recipe asphalt mixtures makes air voids contents determined from cores extremely unreliable; that there is no apparent correlation between air voids content and the durability of reinstatements; and that reinstatements that fail the air voids content requirement can still withstand structural and extreme environmental loading beyond the guarantee period.

The cores from the first five sites investigated were from a mixture of footway and carriageway reinstatements with each set of cores appearing to be from the same reinstatement and, presumably, not through any prior core reinstatements. It is assumed that the same is true of the remaining sites, although there are no pictures of them for confirmation. Given this apparent equivalence between samples, the variability in results does indicate that the material densities and, possibly more surprisingly, the depth appear to vary markedly over very short distances. This variability indicates that the equipment and methods used to lay reinstatements could be usefully developed further to try to reduce these inconsistencies.

It was interesting to see the inter-laboratory differences for bulk and maximum densities are reversed, exaggerating the precision of the air voids content values given that an increase in bulk density and decrease in maximum density both reduce the air voids content and vice versa. In practice, the variability of the maximum density should be less than that of the bulk density; the bulk density of a mixture depends on the compaction achieved as well as the material properties whereas the only extra variable in the maximum density should be the precise grading of the sample. However, the values in Table 7 indicate the reverse, with greater variability in the maximum rather than bulk densities. Assuming that the same procedures were used for these determinations, the greater differences in maximum density indicate that it is the composition that is more variable and not the extent of compaction, the latter being what would be expected.

The most important finding is the lack of apparent correlation between the air voids content and durability. It is generally accepted that, in the extreme, there must be some correlation given that asphalts with air voids contents over, say, 25 % are highly unlikely to be durable. Although the findings of this team have demonstrated that the precision of the tests is not adequate for single core samples, the mean air voids contents results must be representative of the overall level and be higher than the values expected for new construction.

Overall, the report is interesting raising several issues, if only in terms of identifying addition subjects requiring research and development.

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Infrastructure Division, TRL Limited  
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## 7.2. Acceptance of Research Findings in International Platforms

For dissemination of research and development in the field of asset management of utility reinstatement to international forum, key findings from this research project has been published in following different international journals and conferences:

- After rigorous triple-blind peer review, based on initial editor screening and anonymous refereeing by independent expert referees from around the world, the final findings of this research have been published in the **International Journal of Pavement Engineering** published from Taylor & Francis (Sadique et al., 2017). The published copy of this article can be found in Appendix D.
- The key findings of this research project has been accepted as a technical article (Sadique et al. 2016) in the peer reviewed proceedings of the **6<sup>th</sup> Eurasphalt Congress** held on 1-3 June 2016 in Prague.
- The white paper that emerged from initial stage of this research project, highlighting the current issues on utility reinstatement, has been published as scientific paper in **Construction and Building Materials journal** in 2015 (Sadique et al., 2015). Construction and Building Materials is an international journal dedicated to the investigation and innovative use of materials in construction and repair published by Elsevier. The journal only publishes paper following careful reviewing relating to the validity, significance and originality of the work by three independent anonymous expert reviewers on this topic. The published copy of this paper can be found in Appendix E.

## 8. Conclusion

The comparison pairs of cores (each 100mm apart) from 68 reinstatement sites from various parts of the UK, revealed that the compounding consequences of generic non-homogeneous characteristics of hand laid recipe mixed materials (specified in SROH) and high likeliness of being biased during AV testing makes the coring method extremely unreliable with very low repeatability and reproducibility. The position statement provided by UKAS technical committee (as reported in the previous section) is also completely in accordance with the findings (distorted homogeneity of hand laid recipe mixed material).

Furthermore, the in-situ performance shown by from 50 reinstatements after experiencing 1.5 years to 10 years real life aging from various parts of the UK predictably indicates that either the linkage between the reinstatement with non-compliant AV and its impact on footways durability is non-proven or the reported AV content is extremely over-estimated. The resilience shown by the non-compliant AV content reinstatement to withstand structural loading as well as extreme environmental loading beyond the guarantee period across the country validates the above finding.

Moreover, the peer review observations based on the findings from this research project forwarded by TRL also revealed issues relating to poor repeatability and reproducibility of AV testing regime and the lack of apparent correlation between the air voids content and durability shown by various sampled reinstatements across the country.

It is envisaged that numerous reinstatements will have to be reworked based on an assessment method which is itself not only unreliable but also suffering from non-compliant precision relating to the British Standards. The revealed inherent embedded bias, as well as unreliability of current assessment methods of SROH, for a hand laid bituminous work where non-homogenous materials are likely, situating both the contractor and the client at unacceptable risk and costs utilities, contractors and the community without any additional benefit in performance.

A specification should be realistic, practical, and sustainable and be able to predict performance. The current specification for a hand laid recipe mixed material, based upon coring for air void content, fails on all of these basic requirements. It could lead to a very wide range of unpredicted outcomes, putting both the contractor and the client at unacceptable risk.

## **9. Acknowledgements**

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## Appendix A

### Core test results from different sites

Site Ref	Reinstatement Material	Laboratory A				Laboratory X			
		Layer Depth(mm)	Voids (%)	Max	Bulk	Layer Depth	Voids	Max	Bulk
1	AC6 DSC	79	14.6	2.488	2.125	79	12.9	2.477	2.157
2	AC6 DSC	87	15.3	2.485	2.105	83	14.7	2.477	2.113
3	AC6 DSC	81	15.2	2.522	2.138	77	13.6	2.47	2.134
4	AC6 DSC	77	14.9	2.732	2.324	82	13.1	2.731	2.372
5	AC6 DSC	71	13.6	2.437	2.104	87	13.3	2.48	2.149
6	AC6 DSC	92	14.3	2.517	2.158	90	13.9	2.489	2.143
7	AC6 DSC	65	14.5	2.477	2.117	66	15.1	2.469	2.097
8	AC6 DSC	76	14.7	2.483	2.117	87	14.1	2.483	2.134
9	AC6 DSC	77	16.3	2.458	2.058	86	16.2	2.419	2.026
10	AC6 DSC	78	15.2	2.511	2.128	77	10.7	2.498	2.231
11	AC6 DSC	86	14.1	2.481	2.131	92	12.9	2.494	2.172
12	AC6 DSC	88	15.4	2.472	2.092	77	13.9	2.477	2.132
13	AC6 DSC	67	14.6	2.498	2.133	74	18.2	2.48	2.028
14	AC6 DSC	71	20	2.512	2.015	83	18	2.485	2.038
15	AC6 DSC	73	21	2.464	1.949	78	19.8	2.5	2.005
16	AC6 DSC	84	18.1	2.535	2.077	94	14.9	2.486	2.116
17	AC6 DSC	80	18.3	2.541	2.076	90	14.2	2.492	2.139
18A	AC20BC	154	16.4	2.489	2.082	94	7.2	2.41	2.237
19A	AC20BC	130	11.2	2.476	2.199	127	6.8	2.383	2.235
20A	AC20BC	110	15.8	2.647	2.23	118	7.3	2.48	2.308
21A	AC20BC	136	5.6	2.441	2.303	134	8.5	2.423	2.217
22A	AC20BC	160	11	2.473	2.202	154	8.6	2.415	2.208
23A	AC20BC	149	11.1	2.465	2.192	146	11	2.439	2.171
24A	AC20BC	137	11.4	2.453	2.173	132	11.8	2.41	2.126
25A	AC20 BC	161	11.6	2.462	2.176	162	8	2.469	2.235
26A	AC10 CSC	154	5.5	2.481	2.346	94	6.3	2.415	2.262
27A	AC10 CSC	117	11.4	2.436	2.159	156	9.9	2.403	2.165
28A	AC10 CSC	130	7.2	2.51	2.33	127	8	2.456	2.271
29A	AC10CSC	137	18.8	2.502	2.033	137	10.6	2.496	2.242
30A	AC10CSC	110	4	2.452	2.355	118	4.5	2.429	2.334
31A	AC10CSC	136	11.7	2.498	2.205	134	9.8	2.437	2.21
32A	AC10CSC	160	9.5	2.442	2.21	154	9.4	2.439	2.21
33A	AC10CSC	149	10	2.467	2.229	146	8.4	2.4	2.198
34A	AC10CSC	137	7.4	2.453	2.271	132	11.9	2.424	2.136
35A	AC10CSC	161	6.1	2.474	2.322	162	9.3	2.393	2.172
36B	AC6 DSC	111	20.3	2.498	1.991	134	20	2.53	2.024
37B	AC6 DSC	88	14.9	2.412	2.052	92	13.6	2.38	2.056
38B	AC6 DSC	116	16.8	2.514	2.092	83	8.2	2.415	2.218
39B	AC6 DSC	109	13.7	2.469	2.131	83	13.4	2.455	2.127
40B	AC10CSC	102	12.7	2.528	2.207	74	9.4	2.468	2.236
41B	SMA SC	49	12.8	2.517	2.194	50	15.6	2.523	2.13
42B	SMA SC	122	11.7	2.486	2.194	52	14.2	2.574	2.208

## Appendix A

### Core test results from different sites

Site Ref	Reinstatement Material	Laboratory A				Laboratory X			
		Layer Depth	Voids	Max	Bulk	Layer Depth	Voids	Max	Bulk
43N	AC6 DSC	69	20.7	2.554	2.027	113	12.2	2.467	2.165
44N	AC6 DSC	90	19.2	2.564	2.074	95	13.2	2.486	2.157
45N	AC6 DSC	92	21.8	2.496	1.953	89	6.3	2.39	2.239
46N	AC6 DSC	53	14.7	2.497	2.132	61	7	2.361	2.195
47N	AC10 CSC	102	15	2.561	2.179	80	8	2.507	2.306
48N	AC BC	49	8.7	2.6	2.375	70	5.5	2.543	2.402
49N	AC6 DSC	76	19.3	2.511	2.208	73	12.3	2.423	2.125
50N	AC6 DSC	67	19.6	2.497	2.009	70	15	2.447	2.08
51N	AC10 CSC	61	22.4	2.601	2.019	60	16.9	2.472	2.053
52N	AC BC	157	7.9	2.605	2.4	180	6.2	2.601	2.44
53N	AC6 DSC	72	17.4	2.573	2.127	70	13.9	2.511	2.162
54N	AC BC	49	11.4	2.626	2.329	80	5.8	2.534	2.387
55N	AC6 DSC	69	20.7	2.554	2.027	110	15.4	2.472	2.092
56N	AC6 DSC	90	19.2	2.564	2.074	87.5	9	2.477	2.255
57N	AC6 DSC	92	21.8	2.496	1.953	90	10.7	2.45	2.188
58N	AC6 DSC	53	14.7	2.497	2.132	60	10.1	2.406	2.163
59N	AC10 CSC	102	15	2.561	2.179	50	8	2.451	2.254
60N	AC BC	49	8.7	2.6	2.375	105	7	2.5	2.325
61E	HRA SC	42.5	15.6	2.415	2.039	48	3.3	2.127	2.056
62E	AC20 BC	72	11.1	2.591	2.305	79	7.8	2.516	2.32
63E	AC10 CSC	41.25	15.5	2.628	2.221	44	8.3	2.463	2.259
64E	AC20 BC	88.25	7.2	2.544	2.361	73	4.6	2.456	2.344
65E	AC20 BC	62	17.4	2.621	2.167	67	5.5	2.447	2.471
66E	AC20 BC	54	16.2	2.63	2.204	42	11.8	2.465	2.173
67E	HRA SC	38.75	12.1	2.533	2.227	40	3.7	2.367	2.28
68E	AC20 BC	83	9.8	2.576	2.325	80	4.1	2.418	2.319

## **Appendix B**

16th October 2015

To  
Technical Advisory Committee for Construction Industry  
UKAS

### **RE: LJMU-NJUG Research on Utility Reinstatement**

In 2013, a consortium of 23 members, representing utility companies, contractors and bituminous material suppliers, instigated a research project on utility reinstatement in partnership with Liverpool John Moores University (LJMU) and the National Joint Utilities Group (NJUG). The overarching principle of the research was “To investigate the fundamental causes of utility air voids content failures in asphalt layers, measured against the Specification for the Reinstatement of Openings in Highways (SROH) compliant performance”. The main driver for undertaking this research is the significant increase observed in the number of laboratories/ coring companies engaging in the sampling and testing of cores from utility works for compliance over the past four years. The economic cost to works promoters and the disruption caused to networks through potentially unnecessary remedial works to performing reinstatements has also seen an increased amount of activity

As a result of this two year-long research program LJMU published a “White Paper” of initial findings which was independently peer reviewed and has recently been published in an international journal. There has also been further research evidence on the topic provided by member companies in order to supplement that already reported.

One of the key findings of the research was that the results provided by several UKAS accredited laboratories on the presence of air voids in a single reinstatement showed considerable variation in the final results even though they all used permitted and accredited methods. These anomalies, (which could not be explained by the research team), in air void testing results could expose both the contractor and the client to unacceptable risk and mean that the evidence provided by these results could be inconclusive.

The consortium would appreciate if the UKAS Technical Advisory Committee could contribute to the development of the research findings and deliver if possible any reasoning behind the inconsistencies in results between laboratories accredited under UKAS. One of the key areas of discrepancy is the measurement of the bulk and maximum densities of the material which is the foundation for the calculation of air void content. A brief summary of this issue has been provided (Summary Paper enclosed). The laboratories remain anonymous in the report for parity reasons; however, the detailed test reports and the original White Paper can be made available if required.

It would be appreciated if the Committee could take the time to look at the findings and the enclosed summary paper and let us have your thoughts on the issues outlined above with focus on the inconsistencies highlighted within UKAS accredited providers.

Yours sincerely,

Monower



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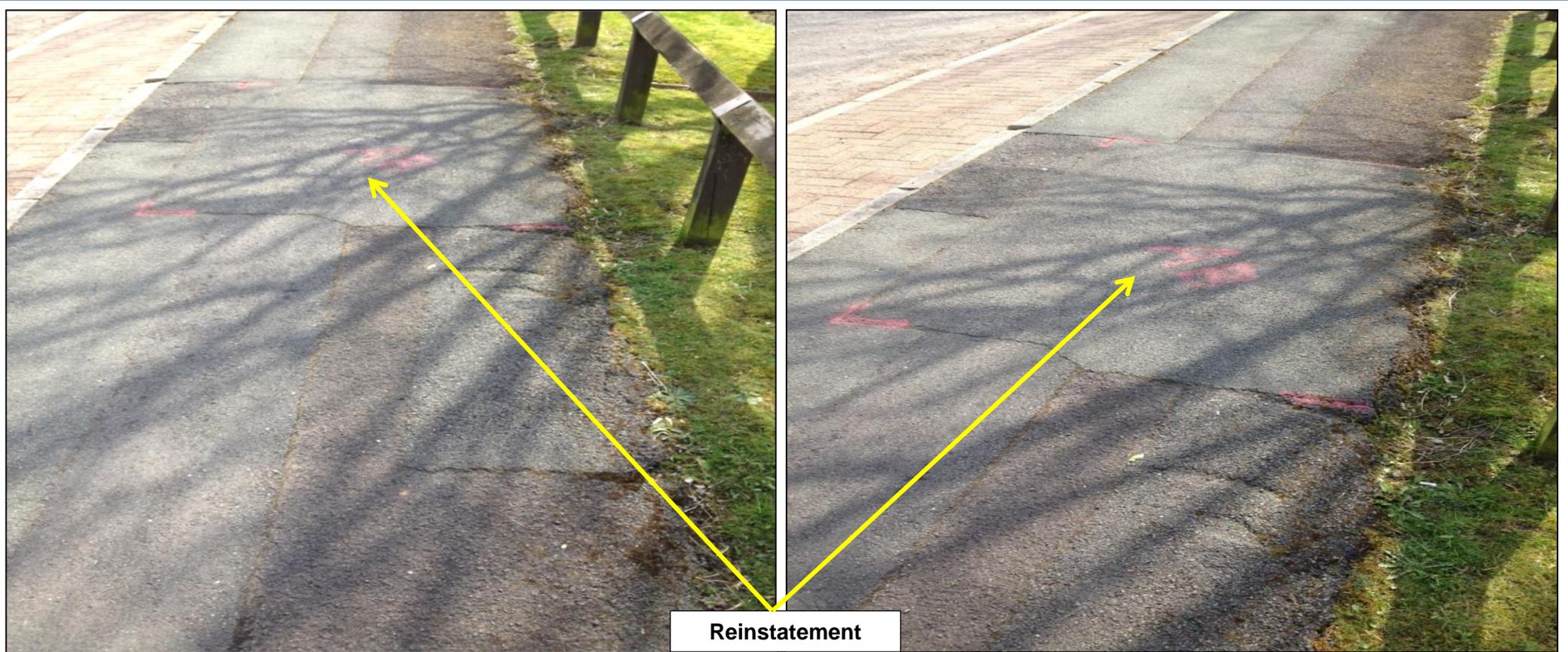
## Appendix C



Reinstatement

Agency: ENWL  
Location: O/S 9 Grafton Street, Blackburn  
Construction Date: July 2006  
Capita Air void content: **19.7%** (February 2012)

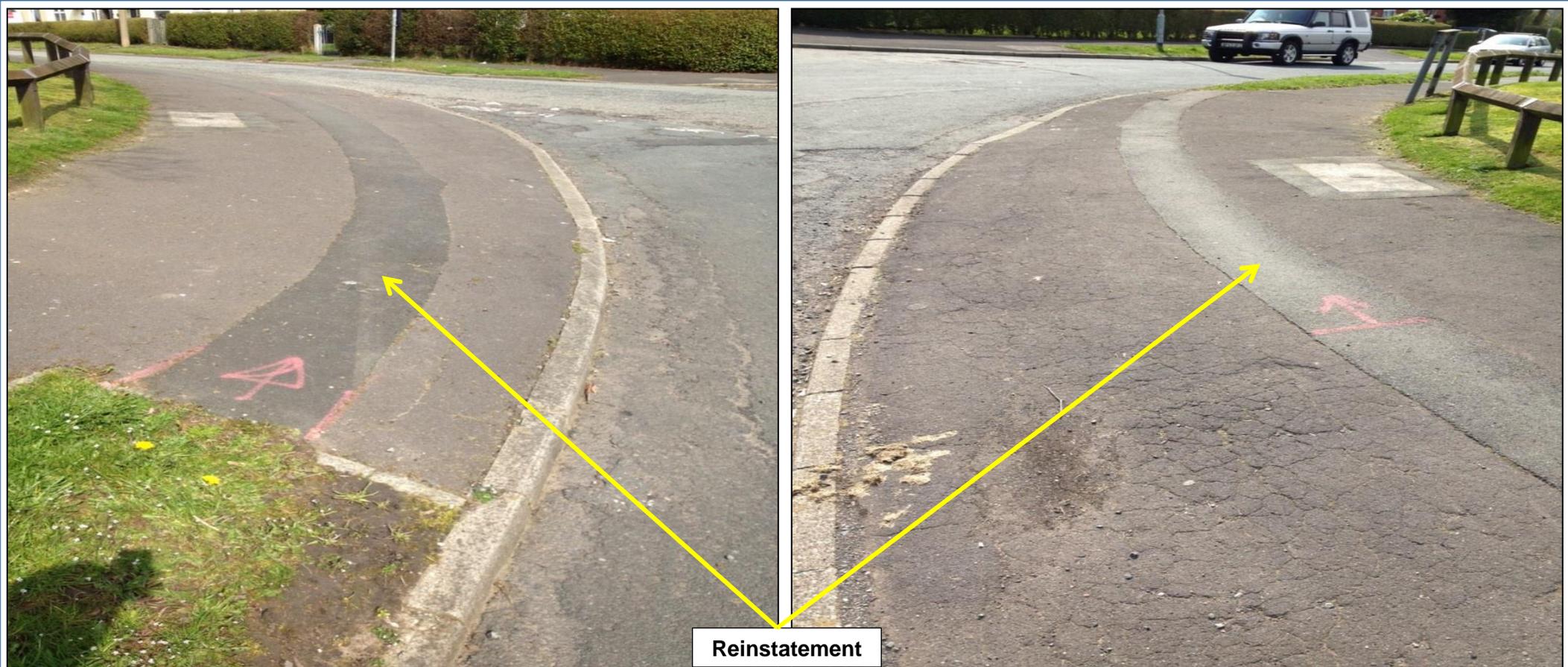
Picture taken on: 8<sup>th</sup> April 2015  
Reinstatement in service : **9 years**



Reinstatement

Agency: ENWL  
Location: O/S 10 Sunny Bank Gardens,  
Blackburn  
Construction Date: April 2005  
Capita Air void content: **15.7%** (March 2012)

Picture taken on: 8<sup>th</sup> April 2015  
Reinstatement in service : **10 years**



Reinstatement

Agency: ENWL  
Location: Junction Snafell Road, Tynwald Road, Blackburn  
Construction Date: April 2005  
Capita Air void content: **18.8%** (March 2012)

Picture taken on: 8<sup>th</sup> April 2015  
Reinstatement in service :**10 years**



<p>Agency: ENWL Location: O/S 13 Randal Street, Blackburn Construction Date: August 2006 Capita Air void content: <b>19.6%</b> (March 2012)</p>	<p>Picture taken on: 8<sup>th</sup> April 2015 Reinstatement in service: <b>9 years</b></p>
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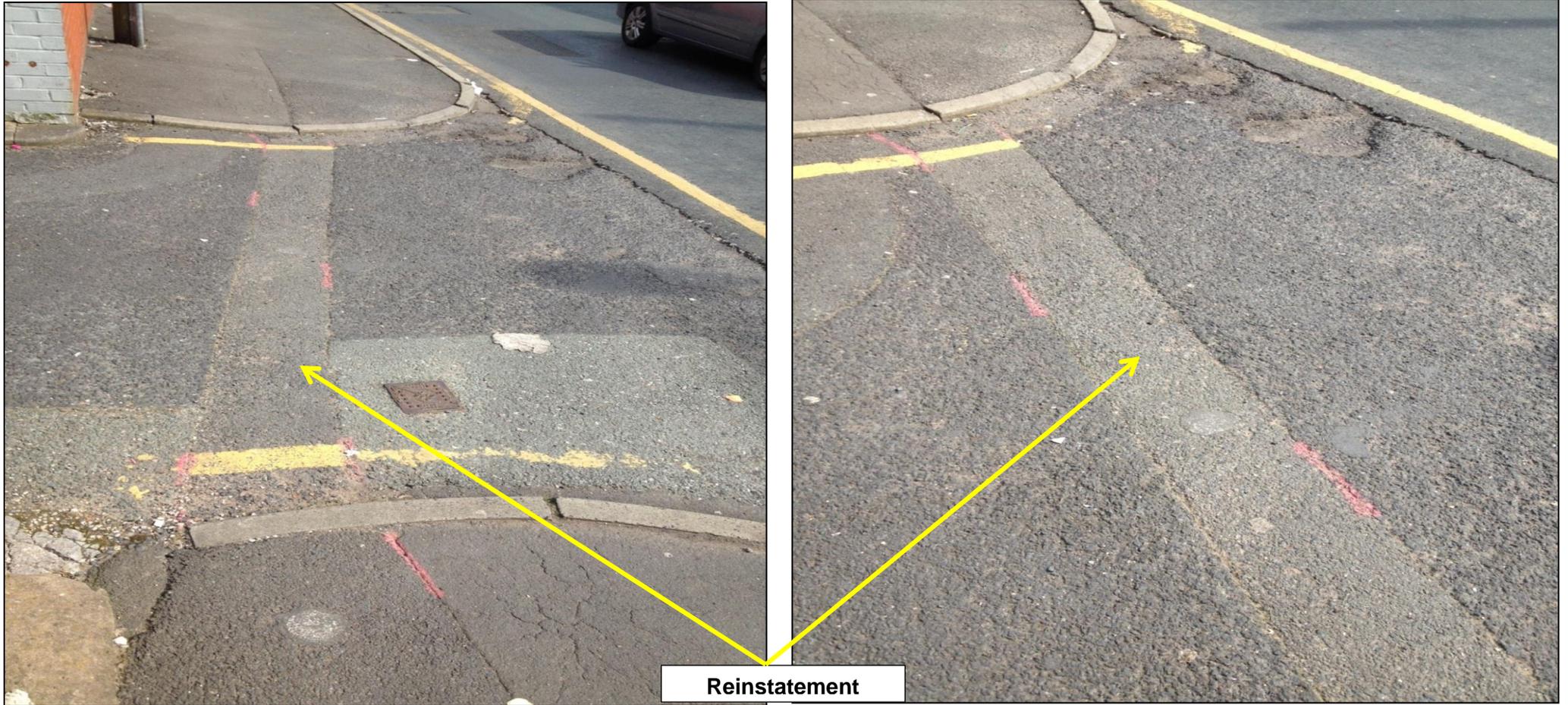


Agency: ENWL  
Location: O/S 13 Randal Street, Blackburn  
Construction Date: August 2006  
Capita Air void content: **19.5%** (March 2012)

Picture taken on: 8<sup>th</sup> April 2015  
Reinstatement in service: **9 years**



<p>Agency: ENWL Location: O/S 13 Randal Street, Blackburn Construction Date: August 2006 Capita Air void content: <b>21.2%</b> (SC), <b>17.5%</b> (BC) (March 2012)</p>	<p>Picture taken on: 8<sup>th</sup> April 2015 Reinstatement in service: <b>9 years</b></p>
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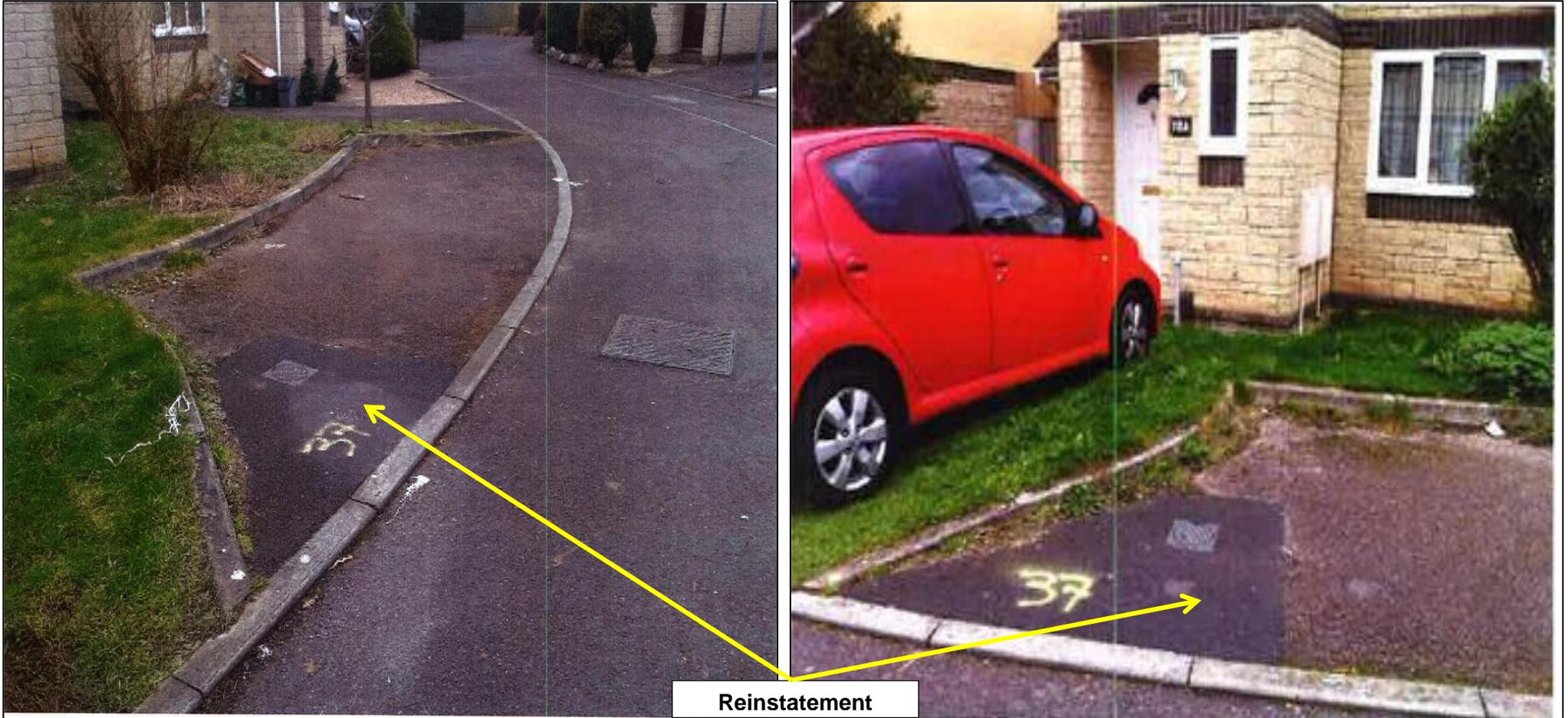
Agency: ENWL  
Location: O/S 13 Randal Street, Blackburn  
Construction Date: August 2006  
Capita Air void content: **18.4%** (SC), **16.4%** (BC) (March 2012)

Picture taken on: 8<sup>th</sup> April 2015  
Reinstatement in service: **9 years**



Agency: Bristol Water  
Location: 218 Ormonds close, Bradley stoke, Bristol  
Construction Date: **June 2008**  
All about holes Ltd Air void content: **14.4%** (SC), 8.5% (BC) (November 2014)

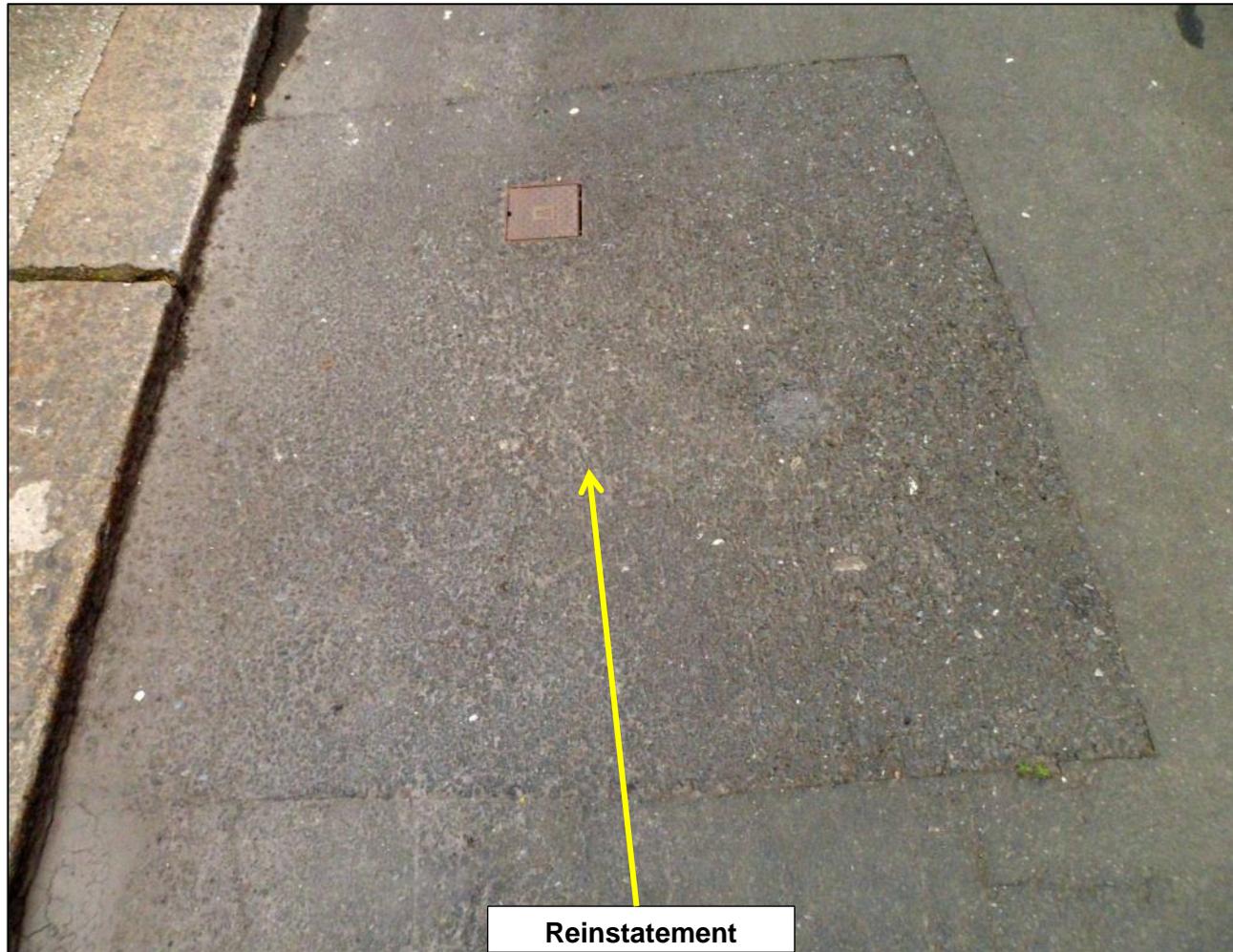
Picture taken on: 12<sup>th</sup> February 2015  
Reinstatement in service: **7 years**



**Reinstatement**

Agency: Bristol Water  
Location: 118a Palmers Leaze, Bradley stoke, Bristol  
Construction Date: **November 2009**  
All about holes Ltd Air void content: **15.5%** (BC) (November 2014)

Picture taken on: 12<sup>th</sup> February 2015  
Reinstatement in service: **6 years**



Reinstatement

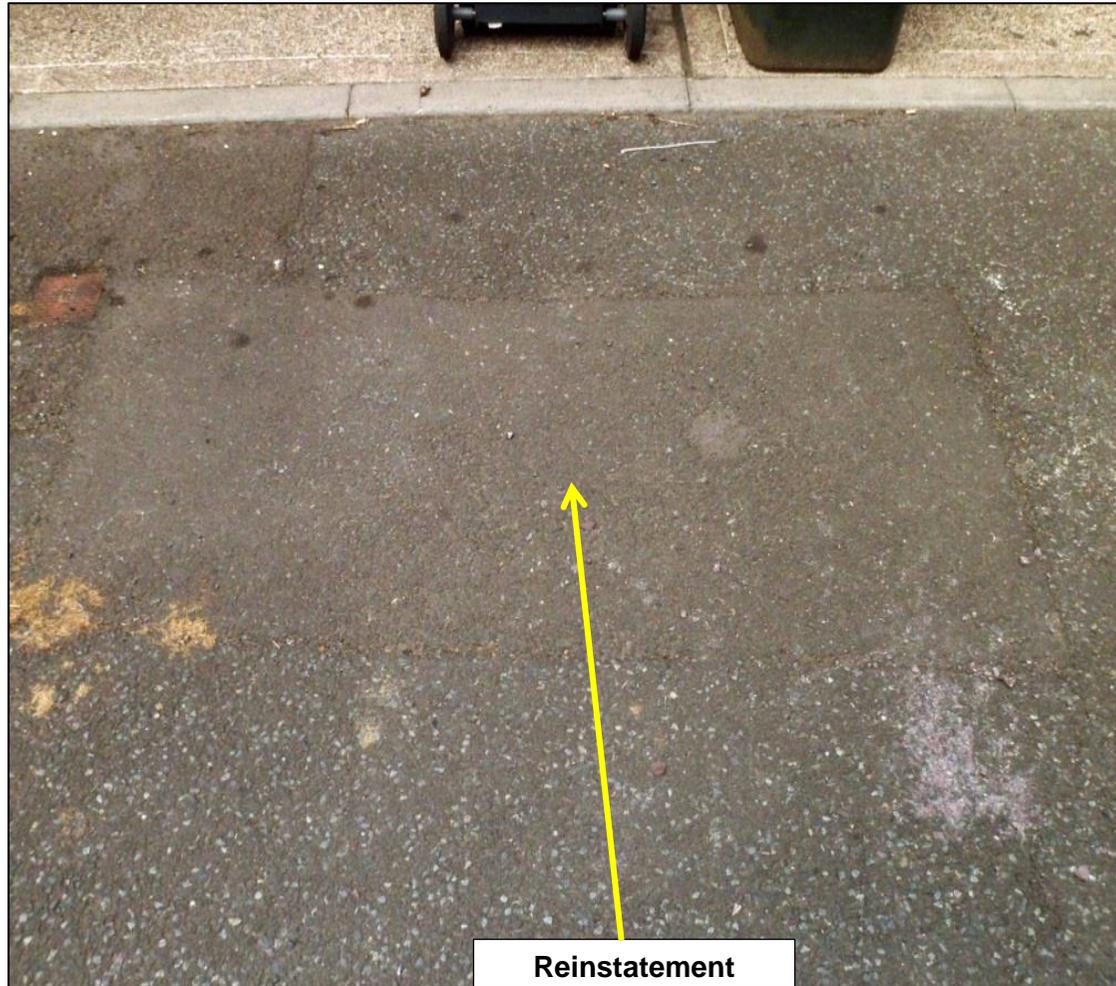
Agency: Northumbrian Water  
Location: High St East r/o 242, Wallsend  
Construction Date: **October 2007**  
Capita void content: **21.0%** (May 2014)

Picture taken on: 22<sup>nd</sup> May 2015  
Reinstatement in service: **8 years**



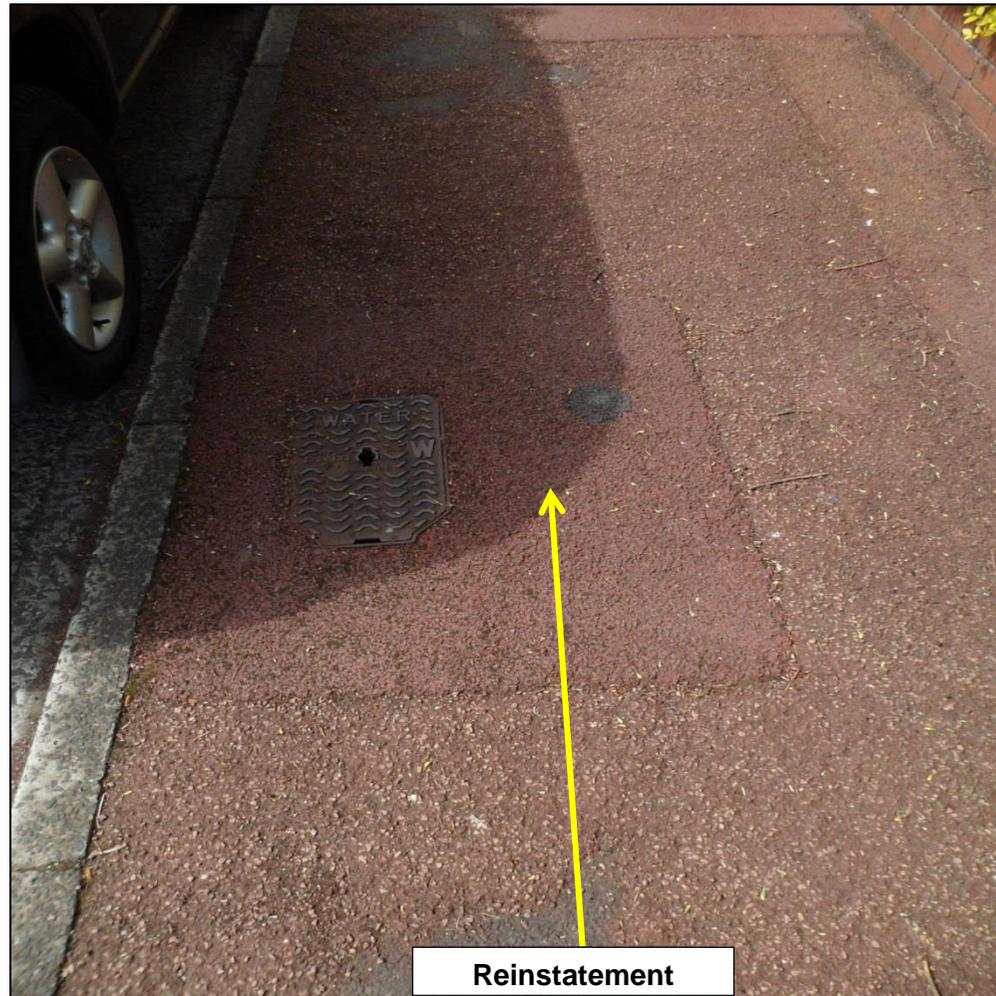
**Reinstatement**

<p>Agency: Northumbrian Water Location: Jubilee Street r/o 21, Wallsend Construction Date: <b>September 2007</b> Capita void content: <b>20.5%</b> (April 2014)</p>	<p>Picture taken on: 22<sup>nd</sup> May 2015 Reinstatement in service: <b>8 years</b></p>
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Agency: Northumbrian Water  
Location: Burn Avenue r/o 17, Wallsend  
Construction Date: **October 2007**  
Capita void content: **22.1%** (April 2014)

Picture taken on: 22<sup>nd</sup> May 2015  
Reinstatement in service: **8 years**



**Reinstatement**

Agency: Northumbrian Water  
Location: Monkhouse Avenue, o/s 19, North Shields  
Construction Date: **November 2007**  
Capita void content: **25.9%** (May 2013)

Picture taken on: 22<sup>nd</sup> May 2015  
Reinstatement in service: **8 years**



Agency: Northumbrian Water  
Location: Station Rd rear s/o 1 Burn Ave , Wallsend  
Construction Date: **September 2007**  
Capita void content: **22.8%** (May 2014)

Picture taken on: 22<sup>nd</sup> May 2015  
Reinstatement in service: **8 years**



<p>Agency: Northumbrian Water Location: Jubilee Street Lane r/o 3, Wallsend Construction Date: <b>September 2007</b> Capita void content: <b>22.5%</b> (April 2014)</p>	<p>Picture taken on: 22<sup>nd</sup> May 2015 Reinstatement in service: <b>8 years</b></p>
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Reinstatement

Agency: Yorkshire water  
Location: O/S 11 Waincliffe Mount Beeston  
Construction Date: October 2013  
First Intervention Air void content: **17.0%** (July 2014)

Picture taken on: 14<sup>th</sup> April 2015  
Reinstatement in service: **1.5 years**



Reinstatement

Agency: Yorkshire water  
Location: O/S 6 Fulmar Court Middleton Leeds  
Construction Date: November 2013  
First Intervention Air void content: **23.0%** (June 2014)

Picture taken on: 14<sup>th</sup> April 2015  
Reinstatement in service: **1.5 years**



Agency: Yorkshire water  
Location: O/S 9 , Whitecote Rise , Bramley , Leeds  
Construction Date: November 2013  
First Intervention Air void content: **19.0%** (April 2014)

Picture taken on: 14<sup>th</sup> April 2015  
Reinstatement in service: **1.5 years**



Agency: Yorkshire water  
Location: Wyther Lane J/W , Wyther Drive , Bramley ,  
Leeds  
Construction Date: December 2013  
First Intervention Air void content: **19.0%** (April 2014)

Picture taken on: 14<sup>th</sup> April 2015  
Reinstatement in service: **1.5 years**



Agency: Yorkshire water  
Location: O/S 15 , Vesper Road , Kirkstall , Leeds  
Construction Date: January 2014  
First Intervention Air void content: **17.0%** (April 2014)

Picture taken on: 14<sup>th</sup> April 2015  
Reinstatement in service: **1.5 years**

**Appendix D**

## Appendix E

The white paper published was peer reviewed in an international journal as a technical paper in 2015. Until now (as on February 2017) the paper has received 379 views globally. The viewers of this paper were from 35 different countries around the world and the distribution of viewers of top countries shown in Exhibit 1. Brief information about the publisher of the paper can be found in Exhibit 2 and the comment on the content of the paper forwarded by anonymous reviewers can be found in Exhibit 3.

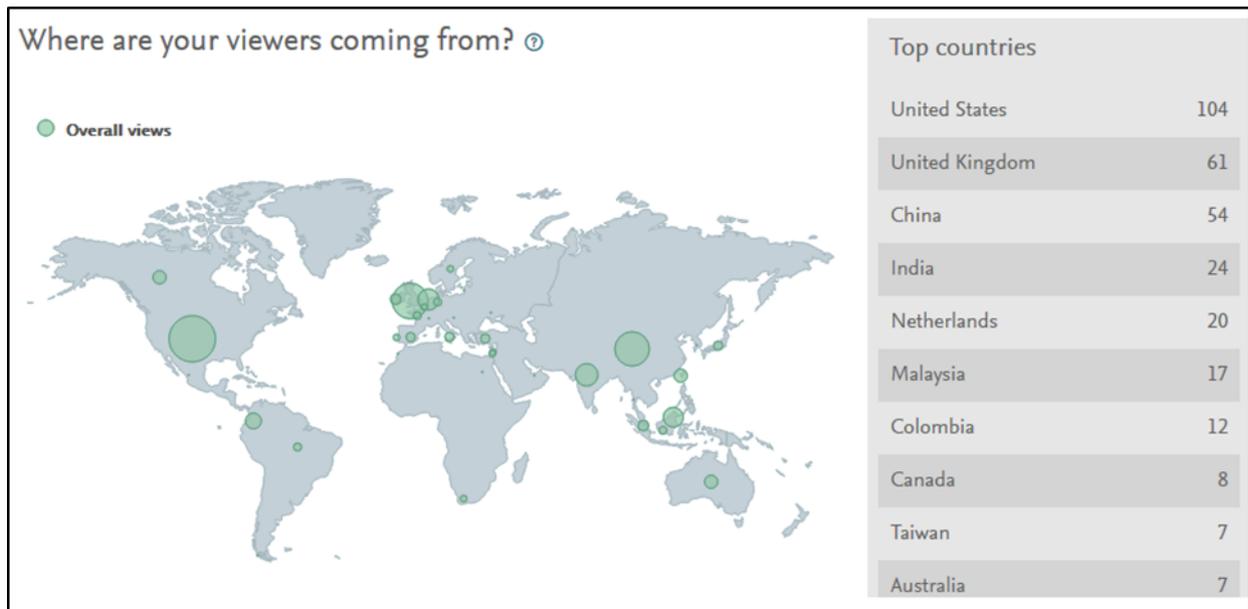
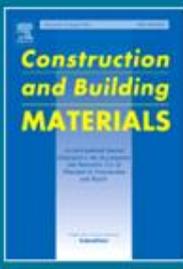


Exhibit 1: Number of viewers in top five countries

**White Paper** Now further peer reviewed and Published in International Forum

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Exhibit 2: Journal brief information

Comments from **3 Reviewers** on our Research:



*"The topic is very much needed in the UK market and the subject is timely"*

*"I believe this paper provides an appropriate and valuable contribution, addressing the issues associated with unreasonable over-specification of utility reinstatement"*

Comments from **3 Reviewers** on our findings:



*"This is terrific work that provides a positive review of a real problem. The problem being the specification of unreasonable or 'main carriageway' quality outcomes that simply cannot be achieved in a reliable manner in constrained areas such as footpath and services reinstatements"*

Comments from **3 Reviewers** on our research:



*"The conclusion is made here that the testing repeatability of test results are to blame for the high differences in the results. I suspect what you really mean (and my personal view) is that the constraints placed on the work being performed are such that one cannot repeatedly achieve good compaction in the field. That would not be a testing issue, it would be a practical limitation of construction in constrained areas"*

**Exhibit 3:** Reviewer comments on content of the white paper/ journal paper