GEOTECHNICAL ASSET MANAGEMENT OF PAVEMENT FOUNDATIONS

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ABSTRACT RÉSUMÉ

This paper describes a methodology for assessing the asset condition of pavement foundations by principally non-intrusive methods. The methodology has been developed through a research programme undertaken in the UK.

The methodology brings together various existing data sets: pavement performance data (in the form of TRACS data), and existing earthworks asset information data sources; which is then coupled with non-destructive scanning undertaken by high speed ground penetrating radar ('GPR'). Combining these data sets enables an assessment to be made of likely sub-grade conditions, the route is then subdivided into a series of performance categories, and potential geotechnical problems can be identified.

Bringing data sets together in this way by a standard methodology enables pavement foundation or subgrade performance issues to be understood and allowed for within pavement condition assessments. This will assist with the planning of intrusive ground investigation, and selection of appropriate maintenance works. This method offers potential benefits to the asset management of roads by reductions in engineering works programme, cost, safety and traffic disruption.

1. INTRODUCTION

The performance of pavements is influenced by the pavement foundation, and this is something that reflects a variety of different factors many of which are geotechnical. However, pavement asset management is a discipline that has relatively little geotechnical input. This situation could be improved by developing a routine method of assessing foundation performance that would enable a geotechnical input to pavement asset management. This paper presents the results of a two year research project on this subject, undertaken by Atkins (with significant input from Zetica) on behalf of the Highways Agency (HA). The work has been possible due to the input from all those involved, the views presented here represent those of the principal author and not necessarily our respective companies.

2. RESEARCH OBJECTIVES

Our overall objective has been to use routinely available data in order to assess pavement foundation performance. The method used needed to enable the assessment to be:

- Quick
- Low cost

- Not disruptive to road users
- Reasonably accurate
- An effective planning tool
- Complementary to existing geotechnical and pavement asset management

The specific objectives set for the research project are as follows:

1. Develop a methodology for providing geotechnical interpretation of pavement performance data that can be incorporated into assessments of pavement operational performance / residual life.
2. Develop a GPR method of surveying that provides a reasonably accurate profile of the pavement foundation layers with only minimal intrusive GI. Thereby allowing pavement foundation performance to be fully assessed
3. Promote the technique developed within the pavement and geotechnical engineering communities.

3. BACKGROUND AND DEVELOPMENT OF APPROACH

During 2003 the author of this report explored opportunities to review the performance of pavement foundations for an operational road. The approach taken was to obtain existing geotechnical asset data sets and combine these with pavement performance "ride quality" data within a tabular format. The overall data set was viewed seeking trends in the data that might help explain the recorded ride quality, as summarised at Box 1. Subsequent discussions with the road operator confirmed that the approach had successfully identified geotechnical phenomena that were affecting pavement performance. The approach proved successful without intrusive ground investigation [1].

Pavement performance data "ride quality" + Asset data: geology, earthworks, structures, drainage + As built records of pavement foundation construction = Identify potential explanations for poor performance	} Identify data trends / variations

Box 1 – overall approach of data overlay

This early work gave confidence that the approach of using pavement ride quality data to understand pavement foundation performance had substantial potential. Although ride quality data only gives an indirect indicator of foundation performance, it was evident that by assessing it alongside other data sources it is possible to identify and often predict the nature of foundation issues. Based on this work the Highways Agency, who are responsible for the UK's motorway and trunk road network, commissioned a research programme (presented in this paper) to explore the potential to establish a routine asset management method of assessing pavement foundation performance.

4. PAVEMENT PERFORMANCE "RIDE QUALITY" DATA UTILISED

Ride quality information is routinely determined on the UK motorway and trunk road network for pavement (surface) asset management. The "TRaffic-speed Condition Survey" (TRACS) technique is used [2]. Relevant aspects of the survey method and data used for this geotechnical approach are briefly summarised below.

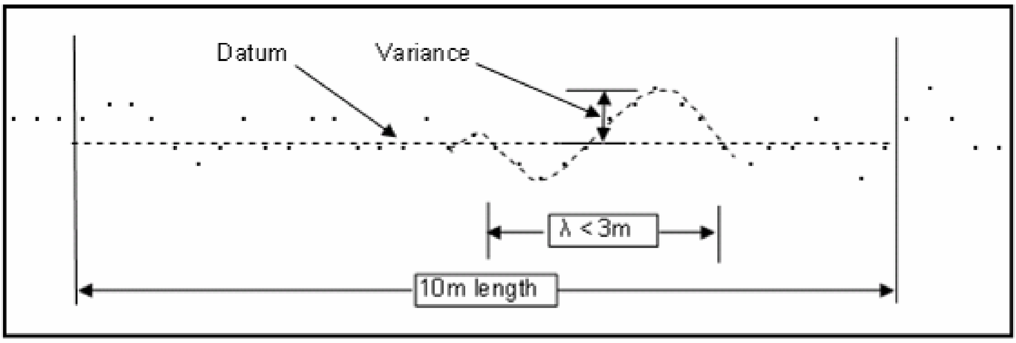
The surveys are undertaken at speeds of up to 100km/h using specially equipped vehicles fitted with lasers, video imaging techniques and inertial measurement apparatus to obtain survey information on the road surface condition. The survey results are produced in spreadsheet format of data tabulated against location. Up until the end of 2006 the survey outputs were only given relative to an approximate “chainage” to indicate the location on the road network (future surveys will record true co-ordinated position). The error in data location (of up to 50m maximum) was too small to be significant for pavement asset assessments; however, it was a significant restriction from a geotechnical perspective because true geographic position is required to be able to compare the data sets used.

TRACS surveys produce information as Raw Condition Data. This information is then processed using specialised software to generate Base Condition Data which provide:

- Rut depth data
- 3m, 10m and 30m Enhanced Longitudinal Profile Variance (LPV) calculated from the measured Longitudinal Profile over 10m lengths (see Box 2).
- Cracking, texture depth and fretting data – not utilised for our geotechnical studies.

Longitudinal Profile Variance (LPV):

- LPV is a measure of road profile unevenness used to assess ride quality
- Profile recorded by laser sensors at 0.1m centres
- Moving average datum points calculated for 3m, 10m & 30m wavelengths
- Variance from the datum averaged over 10m lengths = LPV
- 10m LPV (“LPV10”) is best indicator of foundation performance
- High 30m LPV (“LPV30”) can indicate subsidence



Box 2 – Simplified explanation of LPV data from a geotechnical perspective.

LPV and rut depth partly reflect geotechnical performance. We have found that the LPV data is most beneficial in our interpretations of pavement performance (see Box 2 for a simplified explanation of LPV data). However, this information is held within the HA’s Pavement Management System (HAPMS) which is not readily accessible to Geotechnical Engineers who generally are not aware of the existence of the data.

5. ASSET DATA UTILISED

The proposed approach depends on overlaying various routinely available data sets. We have sought to identify data sets that are readily and consistently available, and easily retrievable. Some other data sets have been identified that might be of potential value for further work at a site (e.g. a detailed desk study) but we identified this as being inappropriate for a standard method of asset management (normally because of being only sporadically available or too time consuming to analyse). The following sections describe the sources found to be most useful for geotechnical asset management of pavement foundations.

5.1. Route Information

In order to assist assessment and determine potential causes of pavement quality issues, a short desk study is carried out for each section utilising the sources listed at Box 3 to extract the relevant information.

Data from Highways Agency Pavement GIS "HAPMS"

- Ride quality 3m, 10m & 30m LPV
- Rut depth
- Pavement type – flexible, rigid or composite
- Section nodes – to confirm survey location
- Marker post locations – to determine survey chainage system

Data from Highways Agency Geotechnical GIS "HAGDMS"

- Earthworks type – cutting, embankment (height < or > 2.5m)
- Earthworks transition zones
- Structures – overbridges, underbridges, culverts
- Outline geology – general overview of geology
- (Drainage – streams & field boundaries are within the OS base map, carriageway drainage details can be checked if appropriate)
- (Historical Reports – Geotechnical Feedback Reports if appropriate)

Area maintenance team

- Road cores – bound pavement layers

British Geological Survey

- Drift geology – extent and material type at ground surface
- Solid geology – only the mapped strata at surface or below drift
- (Borehole records – can be used to clarify geology)

Box 3 – Geotechnical asset information used (items in brackets are not routinely used, but can be accessed when additional detail is required)

From the beginning the project sought to take advantage of the fact that the HA's asset management systems are well established, much of the information is available within the HA's Geographical Information Systems (GIS) known as HAPMS and HAGDMS. These systems provide information via a mapping interface (as illustrated at Figure 1) and appropriate data can be exported into spreadsheet format.

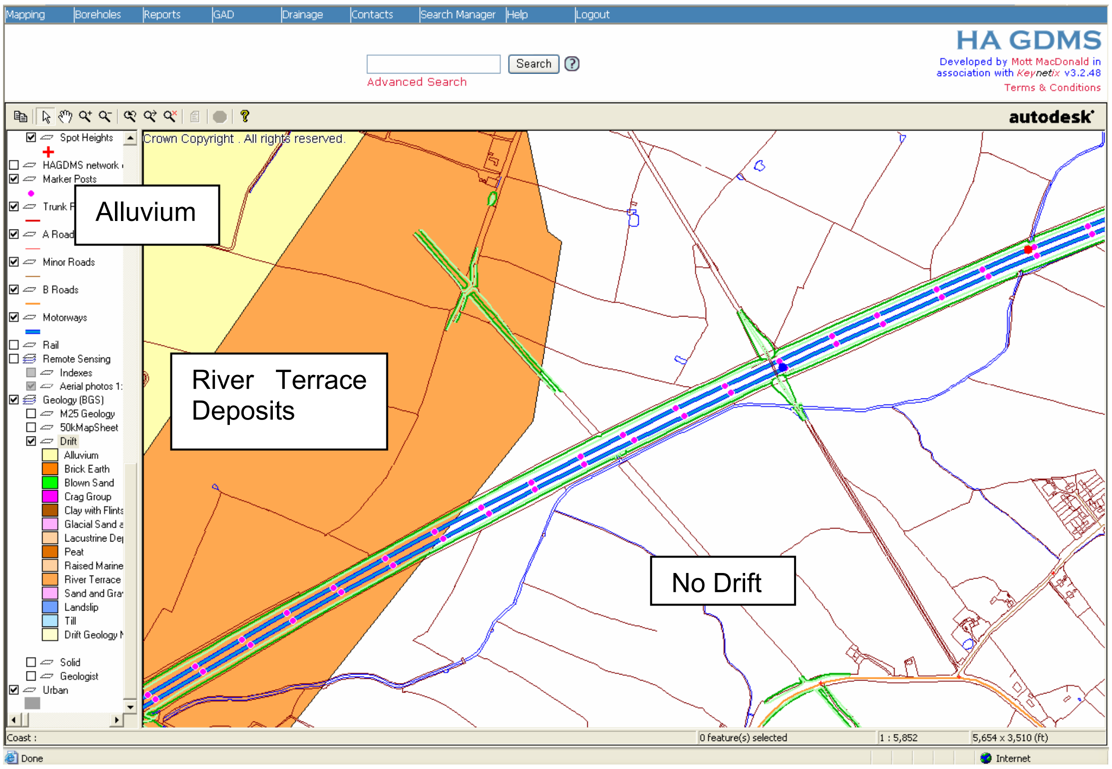


Figure 1. – HAGDMS screen view of drift geology, drainage and field boundaries.

5.2. Pavement Foundation Information Source

Detailed information is required on the pavement construction in order to carry out a reliable interpretation of the foundation performance. It was originally intended to use as-built records of the original pavement foundation constructed (as introduced at Section 3 above). However it was quickly identified that the majority of Geotechnical Feedback Reports and as-built record drawings do not include adequate details of the actual foundation construction along a road (foundation materials and construction depths).

This necessitated a rapid re-evaluation of the approach to be taken for the research project, and attention was focussed on exploring the potential for low frequency Ground Probing Radar (GPR) to determine the existing pavement foundation construction. GPR surveys are normally undertaken on the motorway at high frequency (1000MHz or greater) to assess the nature of the surfacing layers. We undertook a first phase of GPR trials using 200MHz and 900MHz antennae mounted in the standard way for high frequency surveys. The results were relatively successful in determining the pavement foundation layers and subsequent work has been focussed on developing GPR for this data set.

The advantage of GPR surveys is that they provide a reasonably accurate picture of the relative depth of the pavement layers along the route. For the asset management system that we have sought to develop, a good record of the relative thickness of the foundation along a route is of far greater interest than knowing the actual thickness at a particular location; therefore GPR was a very appealing option. The accuracy of the layer thickness determined and the depth of penetration could be improved by developing the system.

6. GEOPHYSICS SYSTEM DEVELOPED

A geophysics system was developed by the Atkins / Zetica team which has been shown to be appropriate for the surveying of pavement foundations for asset management studies.

It is important to note that the GPR system that we have used is an adaptation of an existing method, it is not an entirely new technology.

GPR profiling involves transmitting pulses of electromagnetic energy at microwave frequencies into the subsurface and measuring the amplitude and two way travel-time of the returned signals. A proportion of the pulses of energy transmitted returns to the surface after reflection at interfaces within the ground (e.g. layers of different soil type). The geophysicist's task is to capture and interpret the return signals.

GPR survey data has been acquired using Zetica's High-Speed Pavement Assessment System (HiPAS) which follows the requirements of HD29/94 [3]. The HiPAS system was originally developed to survey bound pavement layers using high frequency antennae mounted on the back of a vehicle. We have adapted this with the use of lower frequency antennae mounted on a trolley. A summary of the system developed is provided here.

The surveys were undertaken at six different sites, the site work being undertaken one or two sites at a time to enable the approach to be fine-tuned. Importantly all of the surveys were undertaken by similar methods, much of the development was in the hardware such as the trolley system rather than the method of geophysics. The surveys during Phase 2 explored a number of variables including:-

- Prototype GPR trolley designed to get the relatively heavy low frequency antennae close to the road surface, and was modified to minimise trolley bounce which could reduce accuracy of results.
- Surveys were run with 200, 400, 900 and 1200MHz antennae. 400 & 1200 MHz antennae proved to be the optimum combination and became the standard arrangement utilised (this can be compared to the standard approach currently used for pavement surveys which are all run at > 1000 MHz)
- Surveys run at 60 – 80 kph
- 6 survey sites were selected to cover different pavement types, and covering differing geotechnical settings (where pavement cores or records were available).

The method comprises an integrated vehicle-mounted ground penetrating radar system, digital video and differential global positioning system (GPS). The GPR antennae are mounted behind the survey vehicle (a standard road van), which drives along lane 1 of the dual carriageway.

Acquisition of the GPR data is synchronised with acquisition of geographical position co-ordinates by GPS (referred to as 'differential positioning data'), and digital video as a check of location from defined features (e.g. overbridges). This approach enables the GPR datasets to be accurately located, and for locations to be cross-checked against defined features. The software developed by Zetica for data interpretation presents all the information on one screen to improve the interpretation of the data. The system resulted in a high level of positional accuracy being achieved, +/-1m of true OS co-ordinates is now regularly achieved.

The availability of a limited number of road cores for correlation purposes helps considerably by defining interfaces within the bound materials, which reduces the assumptions that have to be made in the unbound materials. The road cores only serve to improve the interpretation by the geophysics engineer. Without cores the interpretation can still pick up notable changes in layer thickness (major anomalies). The actual effect on calculated thicknesses is limited for an asset management study of this nature (but would become significant for a detailed site assessment). The main benefit of the cores is for the interpretation of the overall pavement construction.

7. PRESENTATIONAL FORMAT

The development of a presentational format has been an important aspect of the research as the approach will only be successful if the results can be presented in a way that is reasonably quick and low cost to collate and the results can be viewed in such a way as to enable interpretation. The interpretation must give reasonably equal weighting to the various different data sets. Various presentational options have been considered and are described within this section.

7.1. Geographical Information System (GIS)

GIS was considered first as much of the raw data is already held in existing HA GIS applications. However, this is complicated by the fact that the data resides in more than one GIS system, which are available as viewing tools rather than for data manipulation.

GIS has the advantage of showing data in it's true geographical position, and determining the relative location of each data set is a critical part of the process of data overlay. During our research we explored the potential to amalgamate data sets within one GIS system. This has potential benefits for visual interpretation as it would enable all the co-ordinate based data to be viewed on one map screen view.

We realised that, once the relative locations of data sets have been determined, large amounts of numerical data can be viewed together very easily within a table format. This would be difficult to replicate within a purely map based GIS, which would hinder interpretation. Therefore, we concluded that GIS will require software development before it will be an appropriate format for all the data manipulation that we require.

7.2. Tabulated / spreadsheet format

Our initial expectation was to develop a tabulated system for collation of the various data sets and overall interpretation. The benefits of this approach are:

- TRACS output data is in spreadsheet format.
- Quick to overlay data sets - data easily imported into spreadsheet columns.
- Ease of data manipulation (e.g. application of conditional formatting that highlights relatively thin unbound material thickness).
- Summaries of all data sets can be added on a page enabling overall review.
- Relatively simple to add interpretation.
- All computers can view data in this format.

Two disadvantages were identified: the system developed does not enable the clarity of GPR signal to be considered on the spreadsheet; and that whilst spreadsheets are good for data manipulation they do not provide a good visual image for presentational purposes.

7.3. GPR survey output drawings

The GPR results are presented as a picture prepared in CAD drawing format which provides a strong visual image for presentations. This has the advantage of making it easy to identify features and changes in construction, but this results in too much focus being given to the foundation issues at the expense of the numerical data. Our aim is to give equal weight to all the asset information. Other disadvantages are that TRACS data is not readily converted to a pictorial image, also CAD is not standard software on computers and it is not a good format for manipulation of numerical data.

7.4. Presentation format adopted

Allowing for the considerations summarised above it became clear that spreadsheets are the appropriate format for asset management, and a format optimised for interpretation has been developed (an example is included at Figure 2). The GPR findings are imported as a table of thickness values, and the GPR trace is viewed alongside the spreadsheet to ensure that the visual aspects of the GPR results are considered.

8. DATA OVERLAY METHODOLOGY

This section describes the process which is followed to collate the data within a standard worksheet, and the methodology utilised to interpret the data and assess potential geotechnical causes of ride quality issues identified.

8.1. Overlaying data sets

The process of overlay of data to populate the spreadsheet format involves the following:

- A continuous chainage system is established based on the network "marker post" system for ease of co-ordination of other data sets. We calculate a relative marker post reference chainage for the midpoint of each of the 10m road sections. This "midpoint chainage" allows us to correlate TRACS data to all other data sets that are identified in geographical space (including the GPS co-ordinated GPR survey).
- TRACS data is extracted from HAPMS in terms of chainage and road sections so can be instantly transferred into the pro-forma spreadsheet format without any adjustments to the spreadsheet being required.
- Conditional formatting is applied to the TRACS data in accordance with the "condition categories" defined for pavement management [2] but modified slightly to help identify early evidence of potential geotechnical problems (see Box 4).

Category	Description	LPV3m	LPV10m	LPV30m		Rut Depth
3/4	Moderate or severe deterioration	>2.2	>6.5	>66		>11
2	Some deterioration - lower level of concern	0.7-2.2	1.6-6.49	22-65.99		6-10.99
1 upper	Sound	0.35-0.7	0.8-1.59	11-21.99		3.5-5.99
1 lower	Sound	<0.35	<0.8	<11		<3.5

Box 4 – Condition Categories utilised for geotechnical asset management

- The location of structural features are determined and added to the spreadsheet.
- Geology is summarised from 1:50,000 scale solid and drift geology maps.
- An average thickness for the bound, unbound and total pavement construction for each 10m length of road is imported from the GPR results. Conditional formatting is then applied to this data to show notable variations in thickness at a given location compared to the average of the length 50m either side of that point.

8.2. Interpretation

Collating all the data into one spreadsheet in this way allows the performance records to be compared to the subgrade and construction conditions, and any geotechnical explanations of the performance data identified. Applying conditional formatting to the TRACS and GPR information helps identify trends in the data. We have divided the interpretation process into a series of steps (see Box 5), the actual process may vary slightly depending on the nature of each site, but definition of the basic approach is still useful to provide a level of consistency in the method of working.

Methodology – seeking data trends:-	
Step 1 -	Collate data
Step 2 -	Divide route into sections of similar performance
Step 3 -	Identify <u>notable</u> geotechnical trends in the data (e.g. at culverts)
Step 4 -	Look for <u>apparent</u> geotechnical trends and potential explanations (e.g. soft ground with no corresponding capping thickness increase)
Step 5 -	Identify foundation changes that do not tie in with performance data
Step 6 -	Revisit remaining sections of poor performance that don't tie in with any apparent geotechnical issue
Step 7 -	Conclude on likely cause of poor performance: • Surfacing problems • Geotechnical problems • Undefined (no clear cause)
Step 8 -	Plan detailed Ground Investigation (if appropriate)

Box 5 – Methodology for geotechnical interpretation of asset data.

The reasons why trends (or patterns) in the various data sets are important from a geotechnical perspective are as follows. Poor performance often reflects changes in sub-grade stiffness, the degree of variation in stiffness is often of greater significance than the actual overall stiffness. Changes in asset conditions along a route commonly result in a change in sub-grade stiffness, (e.g. soft ground at earthworks transition zones). We have attempted to bring together the most notable geotechnical asset data that might influence such a change in the overall stiffness of the sub-grade and foundation that might influence the pavement surface. If there is no change in any of the data sets then the chances of a significant change in stiffness at the surface of the pavement foundation is relatively low. Using engineering experience we can identify the condition change most likely to affect performance in the way observed, and thus determine any potential geotechnical explanations. With this information we can plan any further desk study or intrusive GI to clarify the issues identified.

Existing methods such as ride quality data and measuring stiffness by falling weight deflectometer (FWD) testing are good at revealing the problem, but there can be various potential causes of each problem revealed. When this geotechnical assessment approach is successfully applied we can identify the problem, then determine the probable underlying cause before we assess the appropriate treatment.

Key

		Lpv 3m	Lpv 10m	Lpv 30m	Rut Depth
moderate or severe deteriorati	CAT 3 / 4	>2.2	>6.5	>66	>11
lower level of concern	CAT 2	0.7-2.2	1.6-6.49	22-65.99	6-10.99
Sound	CAT 1 upper	0.35-0.7	0.8-1.59	11-21.99	3.5-5.99
Sound	CAT 1 lower	<0.35	<0.8	<11	<3.5

Shading used indicates variations from a 100m running average:		
thicker than average:		
+2%	+10%	-5%
thinner than average		
-2%	-10%	-5%

Class Key

Surfacing Issue	S
Geotechnical Issue	G
No clear origin of issue	N

A50 Doveridge to Sudbury Eastbound
MP 108/8 - 106/8

TRACS		Marler Post (km)	TRACS			TRACS				Determined from GPR			HAGDMS, BGS + OS Mapping				Overall		Local			
Section	Start Chainage	Midpoint (km)	LPV 3m	LPV 10m	LPV 30m	Left Rut	Right Rut	Surfacing Type	Pavement Foundation Type	Bound Thickness (mm)	Unbound thickness (mm)	Depth to sub-formation (mm)	Fixed Features	EWK Type	Drift Geology	Solid Geology	Performance of section	LPV Cat	Performance Issues	LPV Cat	Proposed Interpretation / notes	Class *
1000A50/209	1070.705	107.596	0.13	0.45	1.81	1.8	1.5	Continuous Reinforced PQ Concrete (CRC), average thickness 325mm	As-builts show 150mm sub base over 330 (-600)mm cement stabilised silt as capping.	315.56	187.11	N/A			Fluvio-glacial Gravel over Fluvio Glacial Channel infill deposits.	Mercia Mudstone	Road generally of sound quality. Surfacing generally good condition. Cat 1 upper maximum issues noted. GPR shows quite varied thickness of pavement material at all depths throughout section.	1 upper / 2	LPV 3 and 10m issue.GPR showing thinner bound layers	1 upper	Surfacing issue, thinner bound material causing	S
1000A50/209	1080.693	107.587	0.18	0.56	1.79	1.4	1.3			316.44	169.33	N/A										
1000A50/209	1090.681	107.578	0.51	1.54	2.41	1.4	1.6			316.22	161.33	N/A										
1000A50/209	1100.669	107.569	0.08	0.49	2.54	1.8	1.6			337.73	128.18	N/A							Sporadic LPV 10m problems. Localised LPV 3m issues noted. No LPV30m subsidence issues recorded for complete section. GPR showing irregularity of overall construction thickness within a cutting on glacial material.	1 upper / 2	LPV 10m issues indicating foundation issue as surfacing issues are not greatly evident.	G
1000A50/209	1110.657	107.560	0.12	0.66	2.48	1.5	1.4			313.11	150.00	N/A										
1000A50/209	1120.645	107.551	0.07	0.58	2.72	1.7	1.2			334.00	156.00	N/A										
1000A50/209	1130.633	107.542	0.08	0.98	1.83	2.4	1.4			332.89	141.56	N/A										
1000A50/209	1140.621	107.533	0.08	0.37	2.05	1.9	1.7			340.00	138.44	N/A										
1000A50/209	1150.609	107.524	0.13	0.6	3.88	1.6	1.9			328.22	180.67	N/A										
1000A50/209	1160.597	107.515	0.05	0.7	2.39	1.6	0.9			321.56	207.33	N/A										
1000A50/209	1170.585	107.507	0.11	0.85	2.03	1.7	1.1			337.32	224.15	N/A										
1000A50/209	1180.572	107.498	0.06	0.28	3.46	2	1.2			344.05	149.52	N/A										
1000A50/209	1190.560	107.490	0.13	0.89	1.96	1.9	1.5			347.56	116.83	N/A										
1000A50/209	1200.548	107.482	0.21	0.4	1.14	2	1.4		Sub base layer (SB) average thickness + capping layer throughout all section, very discontinuous	342.20	532.51	874.71										
1000A50/209	1210.536	107.474	0.1	0.91	1.99	2	1.3			340.00	658.33	998.33										
1000A50/209	1220.524	107.465	0.04	0.46	3.25	1.8	1.6			340.00	507.32	847.32										
1000A50/209	1230.512	107.457	0.03	0.28	1.53	1.9	1.4			345.85	520.00	865.85										
1000A50/209	1240.500	107.449	0.08	0.88	3.35	1.7	1.2			340.00	645.00	985.00										
1000A50/209	1250.488	107.441	0.1	0.75	3.39	1.8	1.2			340.73	681.46	1022.20										
1000A50/209	1260.476	107.432	0.07	0.77	3.02	1.8	1.5			350.00	633.17	983.17										
1000A50/209	1270.464	107.424	0.07	0.9	2.11	2	1.3			338.54	569.27	907.80										
1000A50/209	1280.452	107.416	0.29	1.76	3.43	1.8	1.9			322.38	529.29	851.67										
1000A50/209	1290.440	107.408	0.05	0.46	1.22	1.9	1.5			338.05	567.07	905.12	O/B									
1000A50/209	1300.428	107.399	0.06	1.01	2.62	2	1.4			330.00	637.50	967.50										
1000A50/209	1310.415	107.390	0.06	0.76	2.87	1.8	1.6			344.09	560.91	905.00										
1000A50/209	1320.403	107.382	0.05	0.7	2.92	1.6	1.4			334.42	521.63	856.05										
1000A50/209	1330.391	107.373	0.05	0.67	2.48	1.6	1.5			332.33	527.91	860.23										
1000A50/209	1340.379	107.364	0.12	0.45	0.86	1.9	1.7			347.50	471.36	818.86										
1000A50/209	1350.367	107.356	0.05	0.38	2.99	1.7	1.8			345.35	497.67	843.02										
1000A50/209	1360.355	107.347	0.07	0.44	1.48	2	2.2			345.12	477.67	822.79										
1000A50/209	1370.343	107.338	0.06	0.95	1.47	1.4	1.2			340.00	538.41	878.41										
1000A50/209	1380.331	107.330	0.07	0.48	2.1	1.6	1.3			339.53	526.28	865.81										
1000A50/209	1390.319	107.321	0.07	0.45	1.24	2.1	1.1			333.95	494.42	828.37										
1000A50/209	1400.307	107.312	0.05	0.56	1.56	1.9	1.3			348.86	610.91	959.77										
1000A50/209	1410.295	107.303	0.08	0.5	1.56	1.4	1.5			337.80	677.60	1015.40										
1000A50/209	1420.283	107.293	0.05	0.31	1.4	2.3	1.3			344.60	562.60	907.20										
1000A50/209	1430.271	107.283	0.09	0.4	3.35	3.6	1.1			350.40	444.80	795.20										
1000A50/209	1440.258	107.273	0.17	0.32	0.91	2.7	1.7			340.96	499.04	840.00										
1000A50/209	1450.246	107.263	0.3	2.24	3.06	3.2	0.9			348.16	515.31	863.47										
1000A50/209	1460.234	107.253	0.14	0.31	0.48	4.3	1.8			333.80	576.00	909.80										
1000A50/209	1470.222	107.243	0.08	0.26	0.39	2	2.1			343.80	583.60	927.40										
1000A50/209	1480.210	107.233	0.13	0.33	0.44	2.6	1.5			341.40	560.80	902.20										
1000A50/209	1490.198	107.223	0.05	0.15	0.42	2.3	1.7			347.00	534.20	881.20										
1000A50/209	1500.186	107.213	0.06	0.54	2.89	2.1	1.4			339.00	579.60	918.60										
1000A50/209	1510.174	107.203	0.08	0.24	0.75	2.5	1.3			342.92	597.71	940.63							LPV3 & 10m issue. GPR shows no thinning	2	No obviuos cause of issue.	S
1000A50/209	1520.162	107.193	0.79	1.94	2.36	2.1	1.7			331.43	596.12	927.55										
1000A50/209	1530.150	107.184	0.08	0.41	1.27	2.4	1.6			331.84	588.16	920.00							Sound condition	1 lower	Variation in construction thickness does not affecr ride quality.	N
1000A50/209	1540.138	107.174	0.19	0.56	1.48	1.7	1.4			343.88	564.90	908.78										
1000A50/209	1550.126	107.164	0.04	0.45	1.4	2	1.4			330.20	529.59	859.80										
1000A50/209	1560.114	107.154	0.08	0.52	2.39	2	1.5			317.14	568.78	885.92										
1000A50/209	1570.101	107.144	0.03	0.2	2.18	2.2	1.6			350.00	688.98	1038.98										
1000A50/209	1580.089	107.135	0.05	0.31	0.45	1.7	1.2			343.54	685.21	1028.75										
1000A50/209	1590.077	107.125	0.07	0.37	1.51	1.7	1.7			344.29	681.22	1025.51										
1000A50/209	1600.065	107.115	0.06	0.33	1.73	2	2			340.00	620.80	960.80										
1000A50/209	1610.053	107.105	0.04	0.3	2.71	1.9	2			342.86	583.06	925.92		Transition			Poor foundation performance LPV10m issues.	2	LPV10m severe problem, LPV30m subsidence issue associated with the foundation problem.	2 / 3	Transition zone like cause of problem worsened by the slight reduction in construction thickness of the foundation layers over the drift material.	G
1000A50/209	1620.041	107.096	0.37	3.4	12.94	2.2	2.5			346.67	546.67	893.33										
1000A50/209	1630.029	107.086	0.62	6.6	19.56	3.4	2.6			340.00	554.48	894.48										
1000A50/209	1640.017	107.079	0.75	10.88	55	2.7	3.1			340.00	546.32	886.32										
1000A50/209	1650.005	107.082	0.18	1.98	13.58	2.1	1.8			340.00	546.32	886.32										
1000A50/211	0.000	107.082	0.18	1.98	13.58	2.1	1.8			340.00	551.28	891.28										
1000A50/211	6.545	107.069	0.13	5.5	22.62	1.9	3.9			340.00	550.82	890.82										
1000A50/211	17.455	107.052	0.11	1.86	32.09	1.8	4.1			346.48	558.68	905.16		Embankment								
1000A50/211	28.364	107.039	0.08	0.83	21.76	2.2	3			326.67	633.33	960.00			None							
1000A50/213	0.000	107.031	0.08	0.83	21.76	2.2	3			N/A	N/A	N/A										
1000A50/213	3.017	107.021	0.15	1.2	11.26	2.4	3.3			N/A	N/A	N/A							LPV10 and 30m issue. Poor GPR information.	1 up	No obvious casue, GPR trace shows	N
1000A50/213	13.075	107.006	0.05	1.33	32.2	2.7	3.5			368.50	N/A	N/A										
1000A50/213	23.132	106.993	0.06	0.38	20.68	2.3	3.9	Dense Bituminous Macadam (DBM), avg thickness 340m		366.00	N/A	N/A			Alluvium		Construction change at start of section o flexible pavement. Sub base thickness approx 150mm with no underlying capping visable on GPR	1 / 2	LPV10m CAT 2 issue. No thicknesses determined from GPR. GPR trace however, shows very strong interface at base of unbound layers.	1 /2	Thinning of surfacing not causing any issues. LPV10m issues caused by thinner capping on GPR trace.	G
1000A50/213	33.190	106.984	0.32	3.16	14.56	2.7	3.4			347.14	N/A	N/A										
1000A50/213	43.247	106.974	0.19	1.07	6.35	1.7	1.8			366.73	N/A	N/A										
1000A50/213	53.305	106.964	0.24	1.13	4.61	1.9	2.2			347.35	N/A	N/A										
1000A50/213	63.362	106.954	0.22	1.26	5	1.9	1.7			331.84	N/A	N/A										
1000A50/213	73.420	106.944	0.18	0.79	10.4	1.5	2.2			320.00	N/A	N/A										
1000A50/213	83.477	106.934	0.18	1.78	9.7	1.6	2.4			329.59	N/A	N/A										
1000A50/213	93.534	106.924	0.26	1.13	1.78	3.1	2			344.80	N/A	N/A										
1000A50/213	103.592	106.915	0.16	0.25	9.66	2.5	1.5			367.76	N/A	N/A										
1000A50/213	113.649	106.905	0.13	4.83	24.95	2.3	1.7			368.37	N/A	N/A	U/B						Potentially severe future LPV30m subsidence issue. Poor GPR results, casued potenially by similarity of foundation and embankment material. Culvert is located beneath embankment.	2	Presence of river underbridge causing LPV30m issue and assoicated foundation deoth issue also. No surfacing problems being caused however.	G
1000A50/213	123.707	106.895	0.14	0.39	1.5	2.1	2.4			364.71	N/A	N/A			None							
1000A50/213	133.764	106.884	0.18	0.46	7.81	2.6	2.8			370.00	N/A	N/A										
1000A50/213	143.822	106.874	0.51	1.1	8.46	2.9	2.2			373.27	N/A	N/A										
1000A50/213	153.879	106.864	0.15	2.44	22.69	2.8	2			353.53	N/A	N/A										
1000A50/213	163.937	106.854	0.13	0.85	45.58	2.9	2.1			365.49	N/A	N/A	River Bridge									
1000A50/213	173.994	106.843	0.17	3.99	44.93	2.7	2			360.00	N/A	N/A			FluvialGlacial Gravel							
1000A50/213	184.052	106.833	0.14	1.06	28.85	2.7	2.3			366.47	N/A	N/A										
1000A50/213	194.109	106.823	0.27	1.29	13.45	4.3	2.8			355.77	N/A	N/A		Transition zone								
1000A50/213	204.167	106.813	0.25	1.2	6.89	4.4	2.2			359.20	N/A	N/A										
1000A50/213	214.224	106.802	0.42	1.18	7.5	2.4	2			335.00	N/A	N/A										

	LPV3	LPV10	LPV30
106.884	0.18	0.46	7.81
106.874	0.51	1.1	8.46
106.864	0.15	2.44	22.69
106.854	0.13	0.85	45.58
106.843	0.17	3.99	44.93
106.833	0.14	1.06	28.85
106.823	0.27	1.29	13.45
106.813	0.25	1.2	6.89
106.802	0.42	1.18	7.5

Action	By	Date
Prepared	SP	20/01/2007
Formatted	MD	15/02/2007
Interpreted	VS	20/02/2007
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Figure 2 - Example of collated data for Site 4. The responses to two sets of features are identified by ovals: upper two illustrate a transition zone, lower two an underbridge.

9. STUDY SITES

Eight study sites were selected to give a range of different conditions: geology, expected pavement performance and pavement type (see Figure 3 and Table 1). The site lengths were short as this was all that was required to check the applicability of the method.

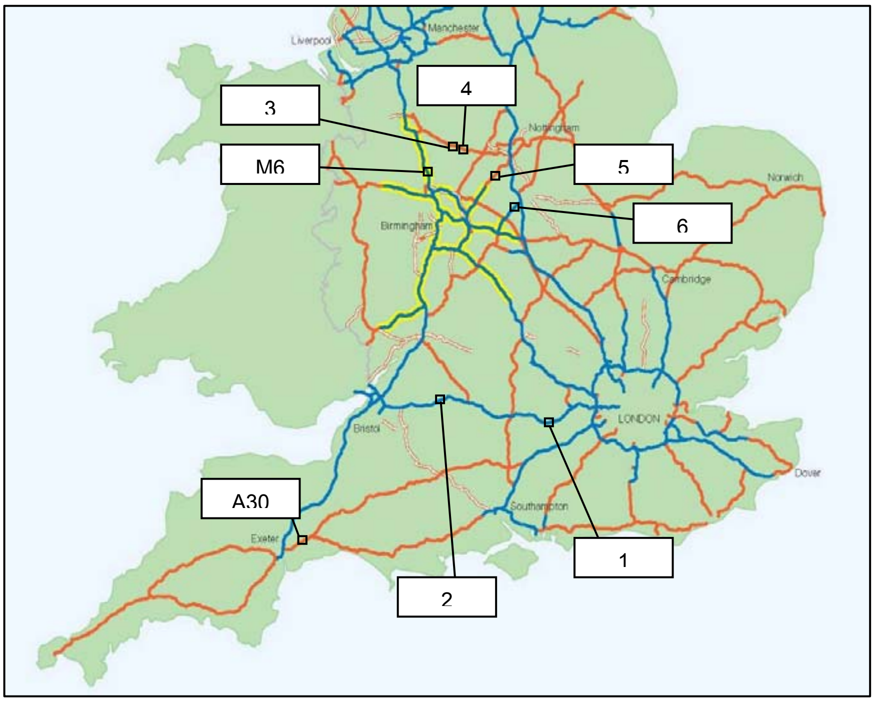


Figure 3 - Study site locality plan, GPR surveys undertaken at sites 1 to 6.

Table 1 - Summary of sites considered within research project

Phase 2 Site No.	Location	Study length (m)	Pavement type	Phase 1 study	Phase 2 study	GPR (cores)	Comments
Site 1	M4 Reading	2000	Flexible composite over lean concrete	✓	✓	✓ (✓)	Site of TRL trial. Boreholes used to confirm geological conditions.
Site 2	M4 Swindon	2000	Flexible	✓	✓	✓ (✓)	Site of TRL trial.
Site 3	A50 Uttoxeter	2000	Flexible	**x**	✓	✓ **(x)**	Results checked v as-built records re difficult ground.
Site 4	A50 Doveridge	2000	CRCP	**x**	✓	✓ **(x)**	Results checked v as-built records re construction details.
Site 5	A42 Flagstaff	2000	Flexible	**x**	✓	✓ (✓)	Known problems at infilled quarry.
Site 6	M69 Hinkley	2000	Treated joint reinforced concrete	**x**	✓	✓ **(x)**	Good ground conditions. Results checked v construction records.
N/A	A30 Exeter	6495	CRCP	✓	**x**	**x (x)**	Foundation details from as-built records.
N/A	M6 Dunston	3105	Flexible	✓	**x**	**x** (✓)	Known problems at underbridge.

10. RESULTS

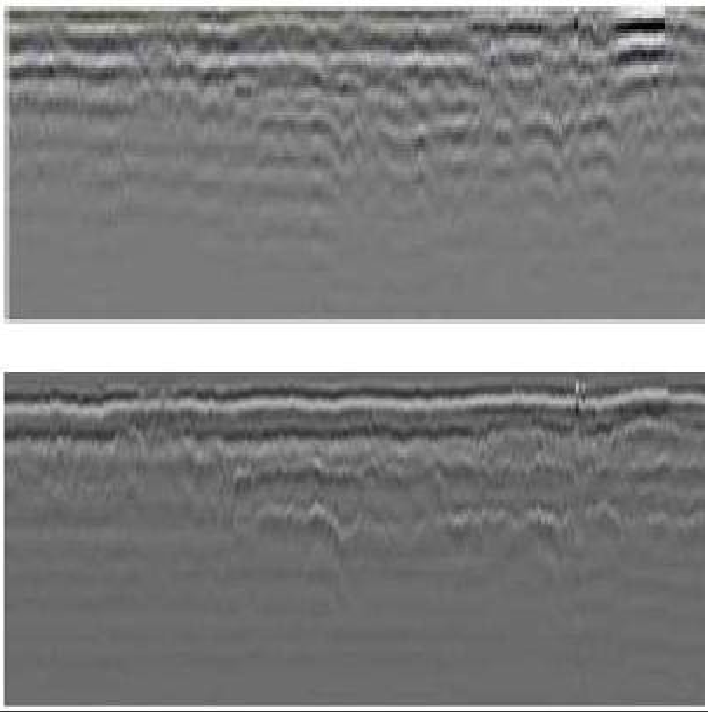
10.1. GPR system

The modified geophysics system developed has delivered significant improvements in the information obtained on the unbound pavement foundation layers. Significantly the approach of surveying with one standard set up, utilising 400MHz antennae for the foundation layers and 1200MHz for the surfacing layers, has provided a clear image of the overall construction within all the various pavement types considered (Table 2).

Table 2 - Summary of GPR performance in different pavement types

Pavement type	Sites	Typical penetration	Signal clarity	Overall rating
Flexible	2, 3, 5	1m	Clear layering	Excellent
Jointed concrete	6	0.7m	Clear layering (re-bar is visible but not a problem)	Good
Flexible over mass concrete	1	0.7m	Few material layers so difficult to interpret if base of concrete not proven	Fair
CRCP	4	0.5 – 0.7m	Successful, although close spaced re-bar can affect clarity.	Adequate, but scope to improve

The trials undertaken resulted in a number of improvements in the GPR methods, including clarifying the appropriate values of radar signal velocities to use in unbound pavement layers. The adjustments made between phase 1 and 2 GPR trials demonstrated significant improvement in accuracy of prediction of unbound layer thickness compared to available records of expected thickness, and a marked improvement in the quality of the GPR profiles produced by the low frequency antenna (see Figure 4).



Phase 1 - 200MHz profile – layers are fuzzy and poorly defined, depth of penetration of signal is limited and confused by multiple reflections.

Phase 2 - 200MHz profile - distinct improvement in the clarity and definition and depth of the GPR profile. The mounting of the low frequency antenna as close to ground surface as possible reduces multiple reflections and improves the clarity of interfaces. The improvement enables easier and more reliable interpretation.

Figure 4 - Improvement in low frequency GPR signal achieved.

10.2. Geotechnical Assessments

Presentation of the results of this research within a technical paper is made difficult by the nature of the work which looks for trends (an extract of which is presented as an example at Figure 2), and thus does not produce numerical results that can be graphed to prove a theory. Therefore, this section provides a summary of some of the features that have been identified at the study sites and our overall observations of what can be achieved.

The different sites studied included examples of known good ground (Site 6) through to a section of very poor performance due to subsidence at an infilled opencast coal mine (Site 5). The subsidence problem is very clearly illustrated by very poor LPV30 data and dramatic variations in thickness of the existing pavement layers revealed by the GPR profiling (clearly this would not be evident from as built records). These sites give extremes of performance that have been utilised as examples for comparison purposes.

Site 2 included sections of reasonably good performance with localised deterioration at culverts, and two sections of poor performance where the pavement suffers from both ride quality and rutting problems. One of the problem sections is where the alignment changes from at grade to shallow embankment, the GPR results show that the foundation construction thickness is thin at the transition and then increases on the shallow embankment; this earthworks transition zone treatment was inappropriate for the clay sub-grade conditions, which appears to have resulted in the poor performance. By contrast the second section of poor performance was judged as being dominated by surfacing problems. At one section two distinct problems are evident at depth (from the LPV10 and LPV30 data) at 100m separation beneath a 3m high embankment; the asset data routinely assessed and the GPR profile revealed that one problem was due to an infilled railway underbridge. Additional checks of the HAGDMS geotechnical database indicated that the most likely explanation for the second feature was an old stream channel that may pass below the embankment. This knowledge can help plan appropriate GI for each location.

Differential settlement problems either side of culverts and underbridges are commonly experienced. Consequently there is a tendency to assume any problem at a structure is of this nature. The combined LPV and GPR data enables this possibility to be more logically considered. The LPV10 and LPV30 trace encountered at culverts is very distinctive; a feature from Site 4 with no other apparent explanation was interpreted as being due to a minor culvert not recorded within the GIS system which was later proven to be correct by checking the as built records.

Overbridges have at some locations coincided with areas of poor performance where there is no other geotechnical explanation for these localised phenomena. At these locations the next action would be to check the history of bridge deck maintenance works to see if temporary propping may have overstressed the pavement.

Pavements on low embankment at two locations reveal generally good performance but with a cyclical pattern of short lengths of elevated LPV10 and LPV30 data. Potential foundation issues considered at these locations are agricultural field boundary patterns, and dipping stratified solid geology strata; these were checked by further study of historical maps and borehole records respectively.

A conclusion of no apparent geotechnical explanation for an area identified as being of poor performance can often be of significant value as these demonstrate to the overall pavement assessment that there is no apparent geotechnical cause and hence the most probable explanation will be a surfacing problem. One such example which proved beneficial was demonstrated during the initial studies referred to at Section 3 [1].

11. POTENTIAL LIMITATIONS OF THE METHOD

Whilst undertaking this research we have identified a number of potential problems that may need further consideration. Most significant is the need to obtain data that is consistently and accurately geographically positioned, without this the process is slowed down and interpretations of some features remain uncertain; this problem appears resolvable by the proposed introduction of GPS recording as part of the TRACS surveys.

By its very nature the approach will remain subjective, and there is a risk of interpreting too many features as being geotechnical. Although this should be borne in mind by the engineer doing the interpretation, it is not seen as a major problem since this is only a planning tool that will be part of the process contributing to maintenance decisions. Greater consistency in the interpretation approach would be achieved through routine use.

12. COST BENEFIT CONSIDERATION

We have reviewed the likely costs of undertaking this form of geotechnical asset management to consider whether it might provide value for money. We estimate that this method of assessment would cost £1.5k/km if it became a routine activity, this assumes:

- Development of a production level GPR system.
- Data collation simplified by new co-ordinate located TRACS data.
- Automated calculation of average construction thicknesses for each 10m section.

This cost estimate enables the viability of the approach to be considered in terms of cost of activity versus potential benefit of improved understanding of performance. The assessment cost per kilometre is estimated to be approximately 0.5% of the overall resurfacing cost (for a typical wearing and binder course replacement) for 3 lanes of a motorway. On this basis the activity has the potential to deliver value for money, either by increasing time between resurfacing activities (e.g. identifying geotechnical problems to be addressed without the need for pavement works), or improved assessment of when more than just resurfacing is required.

13. RESEARCH CONCLUSIONS

We believe that the research objectives set out at Section 2 have been satisfied; we have developed a method for undertaking geotechnical asset management of pavement foundations. Probably the hardest task remains which is implementing the approach.

The research explored an alternative option to the current practice of using the falling weight deflectometer (FWD) which is essentially a numerical exercise to model overall pavement performance. The FWD testing approach has the advantage of determining approximate stiffness values for the various pavement layers. The geotechnical asset management approach that we have developed has the advantage of enabling geotechnical interpretation of underlying causes. The GPR survey provides a continuous trace of pavement layer thicknesses (which could be utilised to assist with FWD interpretation). Essentially the two approaches are very different, and could be combined to be complementary, which would offer significant potential for improved interpretation.

14. RECOMMENDATIONS FOR ASSET MANAGEMENT

This section provides an overall consideration of the asset management process utilised by the HA on the UK motorway and trunk road network, and comments on how this research could be taken forwards as part of the process.

Experience shows that geotechnical considerations are not common place within the overall process of pavement engineering asset management and assessment of maintenance schemes. Our work has shown that one probable factor that separates the two is the difference in overall method of working. Pavement engineering is well suited to asset management, utilising numerical methods to assess continuous data strings (including LPV and rut depth) and determine the overall residual life of an asset. By contrast the geotechnical engineers normal approach is to review overall ground conditions at a site and consider how these might influence the structure, then if required these individual site assessments are brought into an asset management system.

To date there has not been a low cost method of working available that enables the geotechnical engineer to provide to the pavement team a continuous data set along a route to allow them to consider this aspect within their asset management model. Instead it has been necessary for the pavement engineer to identify a potential problem site, and then ask the Geotechnics team to undertake a study of the site (often requiring a disruptive and costly ground investigation) so that they can comment on the possible ground issues. For the Geotechnics team the existing road surface prevents access to the ground that they need to understand, and the pavement is greatly effected by relatively small magnitudes of movement. These factors make it difficult for the geotechnical engineer to provide affordable advice that will assist the pavement engineer. This situation is not ideal and appears to limit the interaction between pavement and geotechnical teams with regard to asset management.

There are examples where the lack of consideration of ground engineering within pavement maintenance schemes has resulted in expensive works to replace the wearing course (by overlay or inlay) when the fundamental cause of the problem was in the ground below and remained both unidentified and unresolved. Clearly in these cases the aspiration to achieve a full assessment of value for money was not met.

We believe that our work has provided a method for a broad geotechnical assessment to be included as part of the overall pavement asset management process. The interpretation of the data should be led by a geotechnical engineer with experience of pavement foundation construction and design, geotechnical asset management and engineering geology. The assessment can be made by junior engineers who have some geophysics experience, an aptitude for engineering geology, and most importantly an ability to seek trends in various data sets and identify potential causes of problems.

15. OTHER POTENTIAL USES

The previous section described how the method developed could be utilised as part of the HA's asset management process. This section presents some additional potential uses for assessment of issues at particular sites outside of the routine asset management process.

There is a major programme of motorway widening being undertaken in the UK at present. For these schemes the geotechnical engineer is generally asked to comment on the performance of the existing pavement foundation performance prior to design of the widening, yet options for making this assessment are limited. The approach set out within this paper is ideal for making an initial assessment (Atkins have already utilised it for this purpose) so that a decision can be made on whether intrusive GI is required, and to design the GI to understand any geotechnical issues.

The method developed provides a potential mechanism to form part of a performance specification for road construction. It enables identification of foundation performance problems during early years of operation, but requires an appropriate form of Contract.

There is potential to utilise this method of geotechnical assessment to set differential settlement tolerances as performance targets for geotechnical works that will affect the pavement (e.g. directional drilling or tunnelling under dual carriageways). The process would be to first check the geotechnical condition of the pavement prior to the works, asses the tolerable deterioration before pavement maintenance would become necessary, determine the amount of vertical movement between points that this deterioration in LPV would equate to, then following the works re-survey after an appropriate settlement period to review the actual performance and deterioration.

16. FUTURE DEVELOPMENTS

There is scope for further improvement to the process. Improved GPS positioning systems will help to greatly simplify the data overlay process and accuracy of interpretation. Accurate GPS recording of vertical elevation would enable low points in pavement elevation to be identified, and this would assist with identification of potential foundation moisture problems.

The development of the rolling deflectometer to undertake “road speed FWD”, giving a continuous record of pavement stiffness, offers an ideal opportunity for improving this geotechnical assessment approach. If geotechnical asset management for pavement foundations became a routine part of operating the network then development of GIS software that enabled on screen interpretation might be justifiable.

For the method to be utilised outside the UK an adaptation would be required to utilise the “International roughness Index” (IRI), in place of LPV, as the measure of ride quality.

17. CONCLUSIONS

This paper presents research undertaken to develop a method for geotechnical asset management of pavement foundations. We believe that the method developed is appropriate to form part of the overall routine pavement asset management process.

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