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Experience in the UK of recycling with cement for the structural maintenance of pavements

Recycling of existing pavement materials has become an increasingly important feature of the maintenance of highways in the UK in order to address environmental concerns and reduce construction costs. As a result of this a major research project in the UK has concentrated on promoting the re-use of materials and in particular cold in situ recycling techniques. The 'Linear Quarry Project' aimed to promote cold-in situ recycling by providing evidence of acceptable in-service performance and to provide guidance on structural design and specification. The project built on previous experience and resulted in an extension to the design life of cold-in situ recycled roads, thus making this structural maintenance technique more economically competitive. The project was jointly funded by clients and industry, primarily the Highways Agency, and the research results has led to the increased use of this technique in the UK.

This paper provides details of the full-scale trial of deep cement-bound cold-in situ recycled materials. Risk assessment recommendations are outlined from the results of the trial. The objectives of the new SMART research project 'Sustainable MAintenance for Road Treatment' are also summarised. SMART aims to deliver a less prescriptive and more a more versatile performance based specification for a wider range of recycling applications.

KEY WORDS

in situ recycling, full-scale trials, pavement maintenance, sustainable roads

1. INTRODUCTION

Recycling of existing pavement materials has become an increasingly important feature of the maintenance of highways in the UK in order to address environmental concerns and reduce construction costs. As a result of this a major research project in the UK has concentrated on promoting the re-use of materials and in particular cold in situ recycling techniques. The 'Linear Quarry Project' aimed to promote cold-in situ recycling by providing evidence of acceptable in-service performance and to provide guidance on structural design and specification. The project built on previous experience and resulted in an extension to the design life of cold-in situ recycled roads, thus making this structural maintenance technique more economically competitive. The project was jointly funded by clients and industry, primarily the Highways Agency, and the research results has led to the increased use of this technique in the UK.

This paper provides details of the full-scale trial of deep cement-bound cold-in situ recycled materials. Risk assessment recommendations are outlined from the results of the trial. The objectives of the new SMART research project 'Sustainable MAintenance for Road Treatment' are also summarised. SMART aims to deliver a less prescriptive and more a more versatile performance based specification for a wider range of recycling applications.

2. THE LINEAR QUARRY FULL-SCALE TRIAL

2.1 Background

In the UK a research contract was awarded to TRL Ltd to verify through full-scale trial the possibilities for deep cold-in situ recycling and to produce specification and design guidance. The contract was primarily sponsored by the Highways Agency, though CSS (local authority liaison group) and the contractor Colas also contributed to the research fund. The project was then steering committee led and soon became known as the 'Linear Quarry Project' due to the nature of the construction work. The initial research contract spanned a three year investigative period. During the project data were collected from the construction and monitoring of full-scale trials, and a review and examination of in-service roads which had been maintained using cold in-situ recycling techniques over the preceding decade.

2.2 The trial

The trial took place on the A3088, a 15-year-old, two lane single carriageway road that was built as a major access route from the industrial estates and ferry ports to the A303 trunk road a strategic route in the south of England. The original pavement construction comprised 100mm of asphalt surfacing over 140mm of a granular "wet-mix macadam" roadbase, on a granular sub-base of variable thickness between 150 and 470mm, built reflecting the variations in the CBR of the subgrade.

The trial was carried out in two phases. Phase 1 of the trial was constructed in 1996 and occupied the full carriageway width over a scheme length of 1.25km. The trial was divided into ten sections including two control sections constructed using conventional materials, one of flexible design and the other of semi-rigid design. The trial sections were constructed using either a cement stabilised recycled roadbase or a foamed bitumen bound recycled roadbase. Details of the designs of the cement treated sections the associated control section are given in Table 1.

Table 1 Details of reconstruction of Cartgate Phase 1 trial sections

Section No (Chainage) (m))	Existing construction depth (mm)	(Lower) Roadbase and Foundation Construction	Surfacing
1 (1200-1300)	 450	Control Section 1: (Composite construction - CBM3R) 200 mm plant mixed CBM3R lower roadbase. 100mm Type 1 sub-base remains.	50 mm HRA w/c 100 mm DBM b/c or DBM upper r/b
2 (1300-1400)	 450	40 mm HRA wearing course removed. 310 mm basecourse + granular rotovated. Excess 110mm removed. 200 mm recycled to CBM3R equivalent lower roadbase	As above
3 (1400-1500)	 450	40 mm HRA wearing course removed. 350 mm base course + granular rotovated. Excess 100 mm removed 240 mm recycled to CBM3R equivalent lower roadbase.	As above
4 (1500-1600)	 450	100 mm bituminous surfacing removed. 250 mm granular materials rotovated. Excess 50 mm removed. 200 mm recycled to CBM3R equivalent lower roadbase.	As above
5 (1600-1675) (1675-1700)	 450 660	100 mm bituminous surfacing removed. 290 mm granular material rotovated. Excess 50 mm removed. 240 mm recycled to CBM3R equivalent lower roadbase.	As above
Legend HRA Hot Rolled Asphalt DBM Dense Bitumen Macadam CBM3R cement bound crushed rock material grade 3, 10N/mm2 7 day strength			

Phase 2 of the trial was constructed in 1997 and consisted of two adjacent full-width, 600m long sections on another length of the A3088 to test the viability of draft specifications for both cement bound and foamed bitumen bound cold in-situ recycled material under normal contractual conditions. In both sections the granular roadbase and sub-base layers of the existing road, which were exclusively constructed using crushed carboniferous limestone from the Mendips, were recycled. The construction details of each section of the Phase 2 trial are given in Table 2.

Table 2 Details of construction of Cartgate Phase 2 trial sections

Section	Recycled roadbase construction	Asphalt surfacing details
1. Cement bound	100mm asphalt surfacing removed; 290mm granular materials rotovated; Excess 50mm removed; and 240mm stabilised with 4% cement to produce lower roadbase	50mm HRA surfacing 100mm DBM regulating
2. Foamed bitumen bound	100mm asphalt surfacing removed; 265mm granular materials rotovated; No excess removed; and 265mm stabilised with 4% foamed bitumen to produce roadbase	50mm HRA surfacing 50mm DBM regulating
Legend HRA Hot Rolled Asphalt DBM Dense Bitumen Macadam		

2.3 Measurement of performance and pavement condition

During construction of the trials quality control and compliance testing of the material was carried out examining: the particle (lump) size distribution; monitoring of moisture content;

cube refusal density determination; as placed density determination by Nuclear Density Meter; thickness of recycled layer; cube compressive strength of moulded samples; ITSM of moulded samples (foamed bitumen material only); and compositional analysis (foamed bitumen material only).

Following construction of the trials, the performance and condition of the test sections were assessed by: visual inspections; laboratory tests on cores (bulk density by gamma-ray scanner, bulk density by weighing in air and water, indirect tensile stiffness modulus (ITSM) using the Nottingham Asphalt Tester (NAT), and core compressive strength/estimated cube strength of cement-bound material); Falling Weight Deflectometer (FWD) surveys; and Deflectograph surveys (carried out routinely by the Highway Authority).

2.4 Performance compared with original design

The data collected from the A3008 trials was supplemented by data collected from in-service road monitoring of other locations. Compilation and subsequent analysis of the data collected as outlined above, enabled comparisons to be made between predictions of the in-service performance of the sites and their original design. The comparisons for the cement bound materials are summarised in Table 3.

Table 3 Summary of design life and predicted performance of cement bound recycled pavements

Site No.	Original 20 year design life (msa)	Predicted overall life of the recycled pavement (msa)
Valley Drive, Gravesend St Hildas/ Livingston	2.5	10
A1078 South Wooton Kings Lynn	10	10
A3008 Cartgate Road Yeovil	22	22

2.5 New specification

The findings from the roads that have been recycled with cement enabled a design curve for these materials to be formulated (TRL Report 386, Milton and Earland, 1999). For traffic loadings between 2.5msa and 20msa the cement-bound design curve assumes a standard foundation, dependant, on subgrade condition, and has associated with it a variable thickness of asphalt surfacing. For cement-bound in situ recycled roads, carrying less than 2.5msa, the depth of the existing road construction and the subgrade condition generally governs the thickness of the recycled material.

The draft specification for in situ recycling that was prepared for construction of Phase 2 of the A3008 trial. It was written with the aim of moving away from recipe/method requirements towards those of end-product performance, measured by laboratory tests on core specimens extracted from the finished pavement or by non-destructive in situ tests. However, to ensure durability from the recycled material some method specification clauses were retained. A further research contract is now ongoing aiming to improve upon this specification and provide a comprehensive performance specification. Overall, to date in the UK the draft specification was found to be workable and robust under normal contractual conditions. The SMART project is discussed further in section 4.

3. RECOMMENDATIONS FROM THE FULL-SCALE TRIAL FOR RECYCLING

In keeping with environmental objectives it is increasingly important that any road rehabilitation project considers the potential for re-use of the existing materials. UK guidance for the site investigation requirements for cold recycling projects on medium to heavily trafficked sites are given in TRL Report 386 (Milton and Earland, 1999). Figure 1 provides a guideline of how to consider in situ recycling at the beginning of scheme assessment. A thorough assessment should be made of the existing pavement materials, either separately or as a mixture, to determine whether or not, all or part of the reclaimed product is acceptable for re-use.

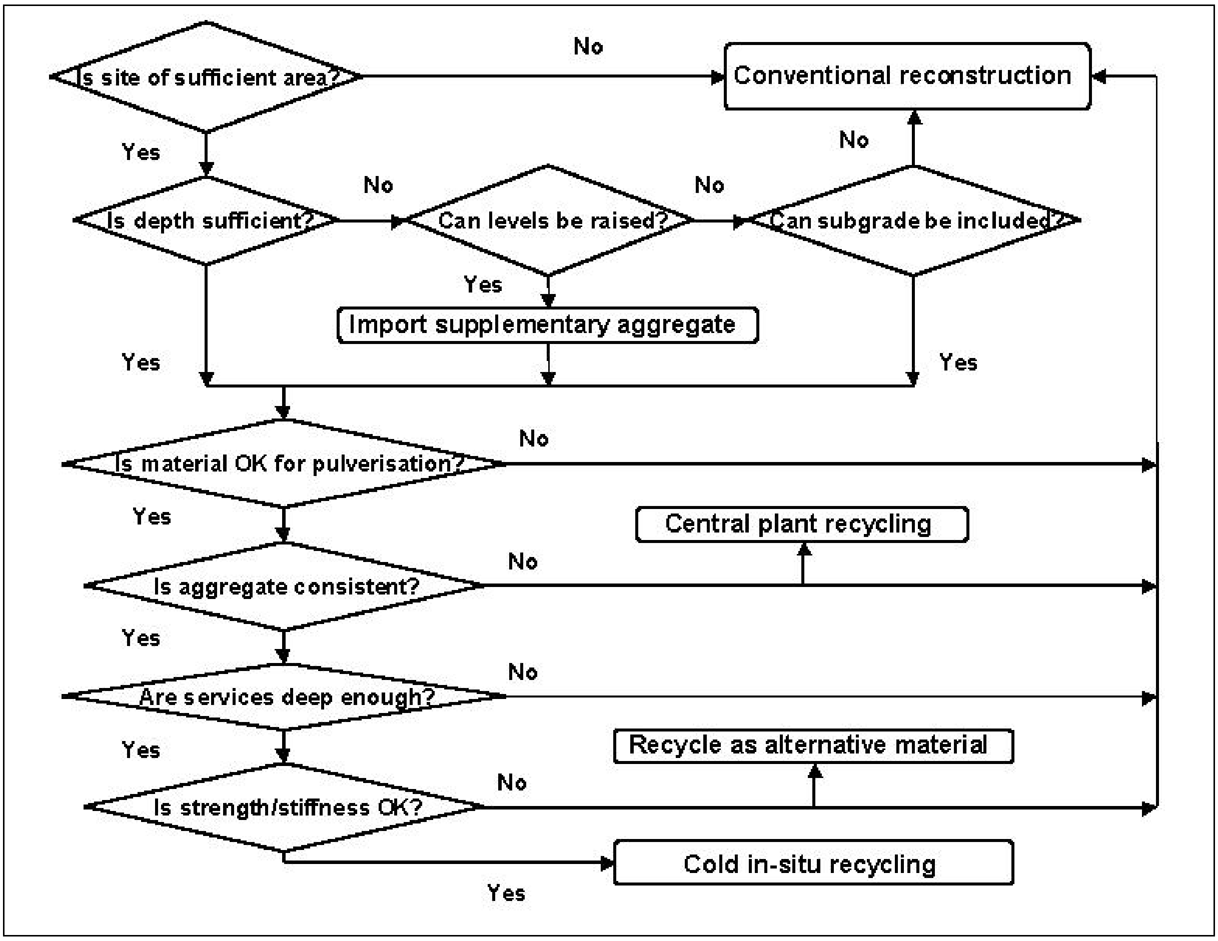

Figure 1 Evaluation of a site for cold in situ recycling

Where available, as-constructed records are always useful, but it is important to carry out sufficient cores or trial pits to check these data, since the actual as-constructed situation does not always reflect in detail what was recorded, or any subsequent changes that may have taken place.

Furthermore, it is important during the initial period to consider the costs associated with a recycling project. A recycling job will necessitate the use of a substantial amount of plant and equipment unique to such works, this involves significant mobilisation costs. In order to achieve an economic solution with this process, it is desirable that the size of each scheme is above a suitable minimum area or can be combined with similar works in an adjacent location.

3.1 Risk assessment

The use of recycling techniques uniquely involves a number of unique risks, which should be assessed prior to implementing any work. These risks are often difficult to quantify in terms of any standard measure, but their consideration and equitable allocation may provide the best chance for improved design and supervision techniques. In all types of construction work, even where comprehensive site evaluation has been carried out, unexpected situations may arise. For recycling works, such situations are more likely to be important to the quality of the finished product because the materials present are intended to form part of the works. For cold-in situ recycling, the potential for variability in materials to be included in the works can be higher.

To manage this, shared risk should be accepted, where both parties to the contract are given the opportunity to verify that the existing pavement materials are suitable to be recycled by pulverisation to form the primary aggregate component of the new in situ recycled mixture. End-product performance requirements should be specified and it must be demonstrated that the recycled mixture is capable of being produced. These issues can be resolved by considering the results of a series of laboratory tests as part of the site investigation.

For the purposes of competitive tender arrangements, it is advisable for the Client to organise and implement the site investigation works separately, as part of the general design process. In these circumstances, if risk is to be shared, the investigation must be comprehensive, and offer all potential contractors suitable data for designing and programming their individual method of working, appropriate to the particular site conditions.

The risks associated with any particular pavement recycling scheme also need to be assessed in the light of likely life cycle costs. Experience to date has indicated that even where quite pessimistic projections for the service life of cold-in situ recycled pavements are used, significant whole life cost savings are possible.

Risks can be broadly classified into design and construction risks.

Design Risks

A comprehensive site investigation needs to be carried out to minimise the risks in the calculation of the design of the pavement structure. This, needs to include a detailed subgrade study looking at such aspects of moisture, density and strength of the subgrade where these properties need to be taken account in the design process.

The fatigue life of cemented pavements is very sensitive to thickness and stiffness. It is imperative that the pavement thickness design and material parameters are achieved in construction otherwise substantial reductions in performance may occur. Also, the type of binder will affect the workability and setting time to achieve the specified layer density.

The cement content will also influence the stiffness and strength of the recycled mixture. An inadequate quantity may lead to the material being susceptible to moisture. Too much bitumen could lead to premature deformation problems or too much cement to increased likelihood of thermal cracking.

Construction Risks

Because the recycling process is generally much quicker than conventional reconstruction techniques, there is a corresponding reduced risk of exposure of the lower pavement layers to inclement weather and traffic during construction.

4. SMART

Research work in the UK has now moved to a new research contract, SMART, Sustainable MAintenance for Road Treatment. There is a new national Steering Committee directing the project onwards from the recommendations of the previous Linear Quarry project.

4.1 The Linear Quarry performance assessment

During the Linear Quarry research project, the end-product performance specification for the cold-in situ recycled materials passed, through a number of different stages. The initial intention was to define performance in terms of either the compressive strength of cored cement-bound material or by the Indirect Tensile Stiffness Modulus (ITSM), obtained for the bitumen-bound material. This option was set aside when it was decided that the destructive coring should only be performed as a last resort. This decision was reinforced by the difficulties experienced on the trial and several of the other monitored sites, where the coring itself was sometimes found difficult and insufficient test specimens were obtained, to the extent that there was no certainty of consistently extracting whole cores from the road. The current specification now retains the core testing option only as the last resort, where other methods indicate that the performance specification has not been met.

Compliance testing currently relies on a non-destructive measurement of stiffness, where pavement stiffness must reach a value pre-stated in the contract, obtained using the analysis of the FWD survey data. Where the FWD stiffness values do not reach the required level, then the coring and testing of core samples option may be invoked.

Prior to either of the above assessments, the specification also requires that the as-installed performance of the stabilised layer is evaluated using a dynamic plate loading or penetrometer technique to determine values of elastic modulus at points on a closely spaced grid pattern. The average elastic modulus for the assessment areas must comply with a stated minimum standard and furthermore, before proceeding with the surfacing construction, repeated values shall be expected to demonstrate that the respective elastic modulus values have increased by a stated minimum percentage.

A more versatile specification is required that will develop more easily used performance tests for a wide ranging set of recycling, both in situ and ex situ with cement, foam bitumen or a combination of the two.

4.2 The SMART objectives

The overall objective of the research project is to develop a versatile specification for cold in situ recycled mixtures that caters for a wide range of aggregates (for example, in situ RAP, ex situ natural aggregate and ex situ secondary/recycled aggregate) and stabilising binders (foamed bitumen, hydraulic cement, natural or secondary pozzolanic materials). To achieve this goal, the research has been divided into four main research phases of work.

Recognising the potential for the performance of different material types and combinations to vary considerably, groups, or families, of similarly behaving materials must initially be identified in Phase 1. If necessary, separate suites of material tests and design criterion may then be assigned to each material family in subsequent project phases.

Owing to the proposed ‘end-performance’ nature of the specification, Phase 2 will involve the identification of suitable in situ test methodologies capable of demonstrating the onset of curing and providing a basis for contractual payment.

Similarly, the scope of Phase 3 will be to develop suites of laboratory tests to obtain material performance properties. These tests may form part of the mixture design process and/or provide performance values required in pavement design calculations.

In Phase 4, a versatile design approach for cold in situ recycled materials will be developed. Initially, this work will entail a review of applicable design methods currently in existence. Based on this review and the findings of the preceding phases, a specification document will be compiled for internal review by the funding partners.

Through all of these actions the current driver in the UK is revise the design curves published in TRL Report 386 to make it a less prescriptive and more permissive specification. There has been good progress through the SMART project objectives and a new performance specification will be available by mid 2003.

5. CONCLUSION

In the UK the construction industry is familiar with the existing conventional standards that use recipe specifications and prescribe materials to be used that are primary resources, for example crushed rock limestone aggregate, Engineering Block concrete. The selection of these options in construction is detrimental to the sustainable objectives of the UK and the world. At the earliest stage possible it needs to become second nature to consider the alternatives, and in particular to review the latest specification options. When a construction contract is being considered it is important that at the earliest opportunity questions are asked in relation to the selection of materials:

The research summarised in this paper is aimed at raising awareness to the possibilities for recycling with cement. There are pointers and all should be aware that there is lot of information available to consider on construction materials, in the UK there is an Aggregate Information Service that is an easy source of information on the possibilities that are available for re-use and recycling of materials (www.viridis.co.uk/ais).

Sustainability is an important factor in the longevity of the Earth; hence its driver from internationally attended Earth Summits. Much progress has been made in the UK and it is important that the developments achieved in research are successfully implemented through industry. Simple ‘sustainability’ advances can be made, for example, through direct savings in material consumption (including reduced vehicle movements). In the outrun organisations will be able to turn recycling and sustainability into an economical advantage.

For further information on any of the topics raised or any aspects of sustainability in construction, contact Sally Ellis, Centre for Sustainability, TRL Limited at sjellis@trl.co.uk

6. REFERENCES

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