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Simplified Crack, Seat, and Overlay Design for Scottish Roads

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ABSTRACT

In the 1970s the use of flexible composite road construction became popular in the UK and around 20% of the existing Scottish trunk road network comprises pavements constructed with a lower cement bound material (CBM) overlaid with asphalt. In Scotland, structural maintenance of this type of pavement has typically entailed reconstruction. More recently, however, the crack, seat and overlay (CSO) and rubblisation processes have been shown to offer cost-effective sustainable alternatives. This paper describes ongoing research funded by Transport Scotland to promote the use of sustainable techniques and the development of a new simplified design approach. The maintenance techniques are described, including examples of schemes that have delivered substantial reductions in CO₂ equivalent emissions. The current design process is reviewed and the weaknesses of the present method are discussed. The paper describes a partnering approach between Transport Scotland, Scotland Transerv and TRL to develop a new simplified approach.

INTRODUCTION

Up until the mid-1980s, the design of UK roads was based on the observations of road experiments. The third edition of Road Note 29 [Road Research Laboratory, 1970] included information on many variations of materials and methods of construction, including a rolled asphalt with a lean concrete base layer known as a flexible composite construction. Road Note 29 recommended a design life of 20 years. In the 1970s traffic forecasts typically required a new pavement to carry a cumulative number of standard axles corresponding to around 10msa. It is worth noting that in some instances some of these designs have been known to carry up to 10 times their original design life, i.e. 100 msa. However, the predicted growth in traffic combined with the damaging power of heavier goods vehicles, and the availability of new materials meant a more flexible design method was required. An analytical design approach was developed and is described in TRL's Report LR1132 [Powell et al, 1984].

It is estimated that around 20% of the existing Scottish trunk road network comprises flexible composite construction. Figure 1 shows the upper construction of a typical pavement

MODE OF DETERIORATION

Cement-bound materials (CBM) contain large amounts of water when they are laid in order

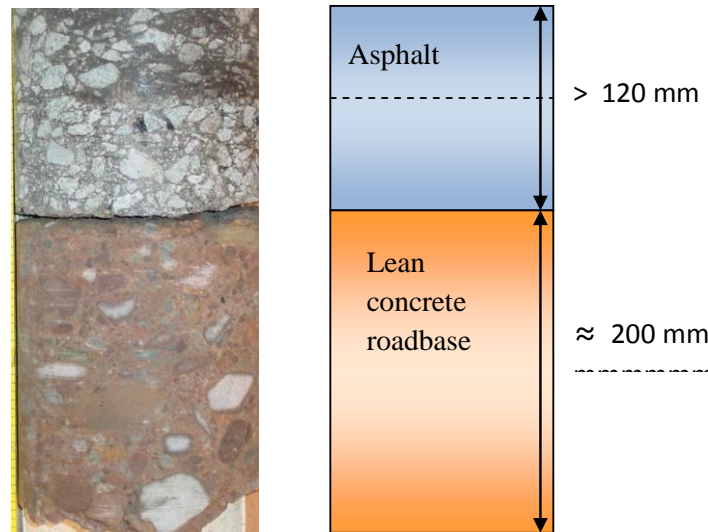


Fig. 1. Typical bound construction of flexible composite pavement

to facilitate both chemical curing reactions and placement. As this water is lost through evaporation and chemical processes, the volume of material reduces, often leading to regular, mainly transverse, shrinkage cracks. Subsequent surface initiated cracking often follows due to the thermal expansion and contraction of the cracks in the underlying CBM layer. Initially, the propagated crack widths are barely visible to the naked eye and are not considered to affect serviceability. However, with time the cracks commonly propagate to the full depth of the asphalt layer, and subsequent ingress of water can cause the surfacing to ravel back from the crack impairing ride quality and allowing ingress of water into the sub-base. Without timely maintenance, further deterioration caused by environmental effects and trafficking can cause localised failures of the whole pavement structure.

SUSTAINABLE MAINTENANCE

Conventional maintenance treatments often involve expensive crack treatments or thick strengthening overlays, usually a minimum of 180mm, to delay the onset of this reflective cracking and provide the required design life from the pavement. None of these treatments addresses the issue of continued thermal induced stresses within the pavement, and therefore the reappearance of reflective cracking is likely.

Crack, seat and overlay

Experience has demonstrated that the crack, seat and overlay (CSO) process is a sustainable method for the maintenance of rigid pavements or pavements containing a cement-bound base. The method is very quick and cost effective when compared to other conventional procedures. The objective of the crack and seat technique is to induce fine cracks into the existing cement-bound base, before overlaying with new or recycled asphalt. This encourages seasonal thermal movement in the concrete layer to also occur at the induced cracks. These are at a closer spacing than the existing shrinkage cracks, thus the thermal movements at

individual cracks are much smaller and the occurrence of transverse reflection cracks in the asphalt overlay is minimised.

The technique first requires the CBM to be exposed by planing off the asphalt. The CBM slab is then broken into smaller lengths using specialist equipment: typically a self propelled five tonne guillotine (Figure 3). The force required by the guillotine to break the CBM with a neat single crack depends upon many factors including the CBM strength and thickness, as well as the underlying support. The drop height needs to be controlled and continually reviewed to ensure that the pavement is not being over-cracked or under-cracked. As a result of the cracking operation, the strains resulting from thermal movements are reduced and distributed more evenly. It is extremely important that the cracks created are fine, transverse and vertical to maintain good load transfer between CBM sections. The technique tackles the root cause of reflection cracking: that is, the thermal movements at individual cracks are much smaller and the occurrence of transverse reflection cracks in a new asphalt overlay are minimised. After the cracking treatment, the CBM surface is rolled with a minimum of six passes of a 20 tonne Pneumatic Tyred Roller (PTR). This seating operation is carried out to assist the full-depth propagation of induced cracks and to minimise the rocking of concrete at the location of any voids that may be present under the CBM prior to overlaying with a minimum of 150mm of asphalt.



Fig. 3. Use of guillotine to induce fine vertical cracks in existing CBM

CSO trials

The first Scottish trial of CSO was undertaken near Dalnaspidal on the A9, Perth and Kinross in September 2006. The original maintenance scheme had required the pavement to be replaced by full depth reconstruction in asphalt. As a result of a preliminary costing exercise, it was found that by adopting the CSO option the original scheme length could be doubled for the same level of funding. In addition to cost savings, substantial reductions in CO₂ equivalent emissions or ‘Carbon Footprint’ have been estimated using the CSO process. Compared to a total bound layer construction, the CSO process saved approximately 484t of CO₂ on one comparable UK scheme [Hewitt *et al*, 2008]. However, when the new hot mix asphalt base was replaced with a cold recycled base (Viafoam) it was estimated to result in an overall reduction in CO₂ emissions of 840t. The CO₂ Emissions Estimator Tool used on the project was developed by TRL for the Waste and Resources Programme [WRAP, 2006a] and is available at <<http://www.aggregain.org.uk>>.

Rubblisation

Rubblisation is a technique that may be considered for flexible composite pavements nearing the end of their serviceable lives and are showing evidence of major structural problems. The technique is considered to be a more sustainable alternative to full depth reconstruction

providing the existing finished road level can be easily raised. The existing asphalt is removed and the underlying CBM is pulverised to effectively create a sub-base layer for a new fully-flexible pavement construction consisting of a thick layer of asphalt. Care needs to be exercised when rubblising the CBM due to the likely presence of soft spots in the unbound foundation and also to minimise damage to the existing foundation.

At present there are no published specifications that address rubblisation as a process of pavement rehabilitation within the United Kingdom. However, there is considerable amount of work being undertaken in the USA. Since the early 1990s, over 26 states have adopted this technique to successfully treat many hundreds of miles of concrete carriageway.

Scottish rubblisation trial

Acting on behalf of Transport Scotland, Scotland Transerv evaluated the rubblisation of a flexible composite pavement at Kinraig on the A9 in early 2008. Requirements for the rubblisation process were based on an amalgamation of four specifications: two documents from Wisconsin State Department of Transportation [State of Wisconsin 2004]; one from Illinois State Department of Transportation [State of Illinois 2001]; and MCHW Specification for Highway Works Series 700.

The ultimate objective of rubblisation is to produce a structurally sound base which prevents reflective cracks. This is achieved by pulverising the existing pavement to create an assemblage of concrete segments that form a tightly keyed, interlocked, high-density material layer. It is not a typical granular material and is not an engineered material like sub-base. The machine used was a multi head breaker (Figure 4). It consists of 8 pairs of drop hammers, each weighing approximately 500 – 600kg each. They are diagonally offset in two rows, four at the front and four at the rear and capable of breaking a 4m width of carriageway in one pass. Each pair of hammers is independently lifted and controlled by a hydraulic cylinder developing between 2,700 – 16,300 Nm of energy depending on the drop height set. This can be adjusted during the works to achieve the desired fracture pattern.



Fig. 4. Multi Head Breaker

Following rubblisation, two forms of compaction are used: Z grid roller and PTR. The former comprises a vibratory, 20 tonne, single drummed roller with a Z pattern on the main drum (Figure 5). This is used to further pulverise the surface of the rubblised concrete, breaking down the larger fragments and compacting and seating the fractured layer. Further compaction and consolidation of the layer is then carried out using the PTR. The action of the rubber wheels is to reduce the embossed pattern caused by the z grid roller and to smooth and further compact the layer.

Using the CO₂ Emissions Estimator Tool mentioned above, rubblisation was compared to full reconstruction. Results showed a significant calculated reduction with over 80% less CO₂ released by the individual processes and an overall saving in the region of 30% for the whole

Kincraig project. Replacing all of the CBM with new granular sub-base would have cost in the region of £170k. This together with removal to tip of existing material, extraction of new aggregate from quarry and transport to site would have raised costs to £270k - £300k whereas the cost for the rubblisation was approximately £120k.



Fig. 5. Z pattern roller

CURRENT DESIGN

The current procedure for determining the overlay thickness for a cracked and seated concrete pavement is based on an analytical design procedure, described in Chapter 4 of HD26/06 [DMRB 7.2.3]. At present, there are two main requirements in designing overlays for cracked and seated concrete pavements: to inhibit reflection cracking and to ensure the treated pavement can carry the anticipated future traffic loading.

Research, based on the performance of UK crack and seat trials monitored since the early 1990s, has shown that 150mm total overlay (surface plus binder/base course) is usually sufficient to inhibit reflection cracking and this is the current recommended minimum thickness of overlay for a cracked and seated concrete pavement. It is also particularly important that the overlay design ensures that the treated pavement can carry the anticipated future traffic loading. The crack and seat process has a weakening effect on the concrete pavement and the required overlay thickness needs to take this into account.

The current structural design guidance is based on the method reported in TRL's report LR1132 [Powell et al, 1984]. This classic pavement design method uses a simplified multi-layer, linear-elastic model analysis to determine the two standard modes of failure caused by repeated loading of a standard 40kN wheel load (with radius 0.151m). The two modes of failure are fatigue cracking at the bottom of the asphalt overlay (tensile strain) and overstressing of the subgrade (vertical strain), resulting in permanent deformation.

There are four main variables in the design method:

1. Existing pavement construction details (material and layer thicknesses, including subgrade CBR)
2. Design traffic
3. Asphalt overlay material and thickness
4. Stiffness of the cracked and seated concrete

The first two variables are known for each scheme and are determined from in situ pavement testing and the use of existing equations to calculate stiffness values, past traffic data and predicted traffic growth. The third and fourth variables are the main outputs required from the design process. The fourth variable is important from a structural viewpoint as the required thickness of the overlay will depend on the load-spreading ability of the existing pavement structure after the crack and seat treatment. At the design stage, the stiffness modulus of the

pavement after it is cracked and seated is not known as it depends on many factors including sub-base type, concrete strength, and crack spacing.

Analysis

The overlay design process requires an analysis program that uses a simplified multi-layer linear elastic model, e.g. BISAR [Shell 1998], PADAL [Tam and Brown, 1989] or WESLEA [Van Cauwelaert *et al*, 1989]. Each overlay thickness and material type requires a separate run of the analysis program which will calculate the critical stresses and strains in the pavement as the cumulative traffic loading increases. Each run will provide a value for the expected life (in msa) of the pavement model.

To facilitate the above process, typical values for the stiffness modulus of a cracked and seated concrete pavement (for various pavement types) have been determined from a TRL database of previous CSO schemes. These 'seed values' are the 5th percentile modulus values, which means that 95% of values have been above this seed value hence, for typical pavements, they should represent a 5% failure threshold.

Once an overlay design is selected, the above process is repeated (using the same model) to determine a minimum effective stiffness threshold that needs to be achieved by the cracked and seated concrete in order to achieve the required design life. The pavement construction data is input along with the design overlay thickness, the stiffness value for the chosen overlay base material, and at least three values for the cracked and seated concrete stiffness modulus. Each concrete stiffness value requires a separate run of the analysis program and the output will then determine the minimum expected pavement life for each of these designs.

Validation

During subsequent construction of a CSO scheme there is a design validation stage where detailed FWD testing and back-analysis is used on site to identify locations where the cracked concrete does not meet the effective stiffness threshold. Any such areas are then inspected, and retested if required. If the areas of low effective stiffness are also seen to be visually defective, they are normally excavated and replaced in asphalt.

WEAKNESSES OF PRESENT METHOD

The present linear elastic analytical design phase is built upon an approach which is highly site specific and is consequently onerous for simple designs with few variables. The existing design methodology is heavily dependent on accurate knowledge of the thicknesses and elastic stiffnesses of the underlying unbound foundation materials. Robust values for these parameters are very hard to determine from the limited amount of data usually available from pavement investigations, and there is a sizeable risk that designs may be unreliable where there is variability in foundation condition/construction. The current design method does not make use of data regarding the foundation derived from FWD measurements on the in-service pavement.

The on-site design validation stage uses back-analysis of FWD data to determine the stiffness of the cracked and seated concrete. The theory behind this approach assumes that the material tested is homogeneous. While the derived parameter is therefore termed an

“effective” stiffness, the presence of the induced cracks introduces considerable uncertainty into the results. Rubblisation design is not included.

SIMPLIFIED METHOD

A partnering approach between Transport Scotland, Scotland Transerv and TRL is being used to develop a simplified design methodology. It is considered that sufficient information has been gained from previous CSO schemes to allow a more general, streamlined approach to be developed. It is proposed to adopt a semi-empirical approach whereby the overlay thickness will be standardized and an estimate of the surface modulus of a crack and seated pavement will be based on foundation strength assessment and historical data from previous CSO schemes.

Overlay thickness

Research, based on observations from the crack and seat trials, has shown that a total overlay thickness of 150mm is sufficient to inhibit reflection cracking and this is the current recommended minimum thickness of overlay for a CSO design. It is proposed that the overlay thickness be standardised to 170mm and schemes be designed for 40 years; historically CSO schemes have been designed for 20 years. It is likely that this change will necessitate finished road levels to be raised or alternatively, to allow an increase in the asphalt thickness requiring the removal of some of the existing concrete depth by planing.

Surface modulus

It is proposed to adopt an approach similar to that of foundation classes used in HD26/06. The use of foundation classes, in which the foundation layers are represented by a surface modulus, makes the subgrade strain criterion (currently used) redundant if the crack and seated layer is incorporated into the design and possesses a minimum surface modulus. The approach will rely on a single criterion that limits the flexural strain at the underside of the asphalt overlay.

Work is underway to review surface moduli data collected with the FWD that has been collected on pavements prior to and following the crack and seat of the CBM base. The information will be used to determine whether the foundation stiffness is suitable for CSO and provide a range of surface moduli measured on the top of crack and seated CBM. Estimates of surface moduli for a range of foundations and cracked CBM in varying conditions will be used to produce design graphs. It is intended that the new methodology will be validated against the existing method for the design of a range of future CSO schemes on the Scottish trunk road network.

SUMMARY

Trials of sustainable maintenance techniques such as CSO and rubblisation have demonstrated that the methods are quick and cost-effective when compared to conventional processes. Both processes show a substantial a reduction in ‘Carbon Footprint’ when compared to full depth reconstruction.

The current design employs an approach which is highly site specific and is consequently onerous for simple designs with few variables. A simplified approach is outlined which proposes to use surface moduli data collected on pavements prior to and following the crack and seat of the CBM base. It is intended that the model will make better use of FWD and other technical data used in the design and validation of previous schemes. It is anticipated that the new method will be more flexible and versatile allowing variation in thicknesses, materials and traffic to be easily accommodated. The method will use FWD measurements taken before and after construction, and consider recent design developments regarding foundation classes and pre-cracked hydraulically bound materials.

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