PAVEMENT TRAFFICKING TRIALS

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INTRODUCTION

Considerable sums of money are invested annually in the national road network of almost every country in the world today. In addition, substantial quantities of raw materials are consumed in construction and maintenance operations. Increased knowledge of the interaction mechanisms between the materials making up a road pavement will lead to more efficient designs, reduced maintenance costs and the reduced consumption of raw materials.

Historically, pavements have been designed using empirical methods with much reliance on the experience and knowledge of the design engineer. In recent years increasingly complex design processes have been developed to great effect, but all such procedures require *real* data for both calibration and validation purposes. The preferred source of the data is obtained from monitoring the performance of in-service roads, but the data have to be gathered over many years. However, useful data can be generated much more quickly by undertaking accelerated pavement testing (APT).

ACCELERATED PAVEMENT TESTING

APT consists of the application of a large number of heavy wheel loads to one or more sections of pavement, usually constructed in a purpose made test facility. The objective of these tests is to permit the rapid assessment of the behaviour of a trial pavement that has been constructed using new techniques or materials or to undertake specific studies, e.g. to determine the optimum thickness of the different pavement layers or an investigation of the use of geosynthetic reinforcements in pavement construction. The results of these studies can be used to design, build, maintain and operate roads with greater efficiencies.

APT provides a very good simulation of the performance of in-service pavements and can be used to give a rapid indication of likely pavement performance under more severe conditions than are generally met in-service; it is one of the most important methods of investigating pavement behaviour. In most instances, because of the substantial cost of construction, continued maintenance and operating costs of the full scale testing machines, these are generally owned by national highway research centres or dedicated research institutions. But the expenditure is far outweighed by the potential economic benefits that can be accrued from improved designs and construction techniques, and a reduced need for future maintenance, COST Action 347 (2005). Harvey (2008) summarised the impacts and benefits of APT and demonstrated how a return can be made on an investment in APT programmes.

Limitations of APT

By their very definition, APTs are undertaken at a faster rate than occurs in practise, i.e. the trafficking occurs within a compressed time period. This prohibits certain real time effects from being fully represented within a test. Such effects include:

- Environmental effects (e.g. temperature, water table)
- Vehicular effects (e.g. speed, single/dual wheels, vertical loading, transversely distributed wheel path)
- Pavement effects (e.g. ageing of bound layers, cementation of aggregate particles in the unbound layers)

Attempts have been made to address some of the environmental and vehicular limitations, but these can dramatically increase the complexity of the test and the subsequent analysis of the data. Pavement ageing cannot be simulated in an accelerated pavement test, though this is not a significant limitation for tests on unbound pavements.

If the effects of these limitations are to be minimised, then the calibration of APT with the observed performance of in-service pavements must be undertaken as a priority. This will generate increased confidence in the ability of APT to predict the performance of new pavements.

APT FACILITIES

APT is intended to be closely representative of in-service conditions and therefore trials are usually undertaken on full scale sections of pavement, in specially constructed facilities at fixed locations. However, a number of mobile APT facilities have been constructed; these remarkable machines can be used to test both specially constructed and in-service pavements. Another type of APT facility is a pulse loading device, that comprises an actuator mounted on a movable chassis, which applies a series of load impulses to the pavement that simulate the passage of a single wheel. In addition to the above facilities, there are many others that test pavements, or elements of pavements, at smaller scales and which provide valuable indications of likely full scale behaviour.

Full scale APT facilities typically comprise a test pit in which a full scale trial pavement is constructed, and equipment capable of simulating in-service traffic loading. There are about 40 such facilities in the world , COST Action 347 (2005). The facilities generally operate either a linear track (such as the Road Testing Machine of DTU at Lyngby, Denmark) or a circular track (such as the Manège de Fatigue of LCPC at Nantes, France). Each track type has its own advantages, e.g.:

- circular tracks are longer than linear tracks thus allowing longer or a greater number of different trial sections to be trafficked at the same time, whereas linear facilities construct multiple parallel lanes of trial pavement.

If a section fails or access for monitoring is required on a circular track trafficking must cease, whereas for a linear system trafficking can be continued on an adjacent lane

- trafficking speed is slow on a linear track whereas normal traffic speeds are possible on a circular track
- lateral stresses are generated in the pavement of a circular track

It is interesting to note that one APT facility is unique in that it combines the advantages of both linear and circular tracks. The track of the APT facility operated by CEDEX in Madrid (Spain) has two long parallel sides connected by two semi-circular arcs; a view of the track is shown in Fig. 1.

Figure 1. CEDEX APT facility in Madrid (Spain).

When undertaking any experimental or development work, the importance of planning, attention to experimental detail and accurately recording information cannot be over emphasised. Researchers planning and carrying out APT are advised to follow established guidelines as this can save much time and effort, while at the same time increasing the probability of obtaining high quality data. A *Common Code of Good Practice* for APT was prepared by COST Action 347 (2005). The code is universally applicable and provides guidance on all aspects of APT from planning of the experiment to pavement condition evaluation; it also includes recommendations for achieving effectiveness and economy of operation. The implementation of the code will not only facilitate the achievement of consistently high quality data, but will encourage a common method of reporting which would greatly facilitate the comparison of data from different sources thereby leading to a more effective use of APT worldwide.

PAVEMENT REINFORCEMENT

The concept and practice of using materials as reinforcements in engineering applications is not new. Probably the first documented application of reinforcement in highway construction, in a form comparable with techniques used today, was in trials carried out by the South Carolina Highways Department in the United States of America and reported by Beckham and Mills (1935). In the trials a woven cotton fabric was used in a series of road construction field tests which lasted for about nine years. The test results were encouraging but the durability of the cotton fabric was low and they never came into general use.

It was not until the 1980s, after the development of geosynthetics, that researchers and engineers realised the potential of reinforcement in highway construction. For example, studies by TRRL (now TRL) of unpaved roads on a clay subgrade, undertaken by Potter and Currer (1981) and Ruddock et al (1982) demonstrated that the performance of a road under trafficking could be improved by the installation of a strong fabric separator at the sub-base/subgrade interface. A study by Chaddock (1988) used the concept of APT to investigate the benefit of introducing a geogrid at the sub-base/subgrade interface. The sub-base thickness was varied up to 200mm; trials were undertaken with three different subgrade strengths with CBR values of 0.4%, 1.4% and 4.9%. This work was conducted in a concrete pit. Traffic loading was provided by a lorry, with the rear axle loaded to 80kN (one standard axle), traversing the pavement. The study demonstrated that a geogrid installed between the sub-base and subgrade allowed about 3.5 times more traffic to be carried than was possible with the unreinforced pavement for the same level of deformation. Alternatively the same performance of the pavements under traffic loading would be obtained if the reinforced pavement sub-base was 50mm thinner than the corresponding unreinforced structure. The study also found that geogrids placed on very weak subgrade material may be prevented from developing good interlock with the sub-base due to the clay pushing through the apertures, and suggested that the use of reinforcement in such conditions required further investigation.

During the last twenty five years much investigation into the use of geosynthetic reinforcements in both unbound and bound pavement layers, and geotechnical applications has been completed. McGown and Brown (2008) undertook a review of *Applications of reinforced soil for transport infrastructure*. The review acknowledges that many great successes have been achieved, while noting that current design procedures continue to utilise empiricism and adopt a conservative approach. They suggest that new fundamental research is needed to move forward and generate safer and more economic designs for the future. Several aspects require further research, but the principal objective must be the development of a model that fully reflects the true interaction mechanism between the reinforcement and the soil/aggregate. This will inevitably require the use of numerical computational techniques and thorough validation with data from APT at full scale and data from a methodical study of real roads.

AN EXAMPLE OF THE USE OF AN APT FACILITY

The APT facility at TRL, commissioned in 1986, is pictured in Fig. 2. It comprises a concrete lined pit, 10m wide by 25m long and 3m deep, containing a clay subgrade on which experimental pavements are constructed. A gantry spanning the pit supports a road wheel that trafficks forwards and or backwards across the full width of the trial pavement. The configuration of the road wheel(s) and the applied vertical loading can be varied. The facility has been used to investigate many different aspects of pavement design, construction and maintenance treatments.

During the past nine years TRL has undertaken a sequence of seven trials to investigate the performance of geosynthetic reinforcements in a road pavement. These trials were undertaken to generate an improved understanding of the reinforcing mechanism, and to investigate the benefit of reinforcement and different reinforcement types.

The experimental pavement comprised a compacted sub-base overlying a conditioned subgrade. A range of reinforcements were tested. The reinforcements were installed directly on the surface of the subgrade. Importantly, as well as reinforced sections, each the trial also contained un-reinforced control sections. The same general arrangement and test methodology was used for each trial. A description of the trial procedure, with an overview of typical results, is presented.

Figure 2. Accelerated Pavement Testing at TRL

Materials

Subgrade

The subgrade was grey silty London clay, of very high plasticity, described by Casagrande's extended soil classification system as Type CH. Prior to the start of the trials tests were undertaken to determine the relations between the CBR value and the both moisture content and Moisture Condition Value (MCV), moisture content and the Cone Index value measured with a penetrometer, and the optimum moisture content for compaction. These relations were used when conditioning the clay to achieve the target in situ CBR value of about 2%, and to assess the in situ strength. The top 500mm of the subgrade was excavated and carefully conditioned by a cycle of wetting and rotavating to provide a homogeneous material. The conditioned clay was then placed and compacted into the pit in layers in accordance with the Series 600 of the Specification for Highway Works (SHW) (MCHW 1). After placement the vertical level of the subgrade surface at a matrix of points, relative to a fixed datum point, was determined by survey.

Sub-base

The sub-base material was derived from a crushed granite aggregate that conformed to the requirements of the 800 Series of the SHW (MCHW 1). The material was placed and compacted in accordance with the 600 Series of the SHW (MCHW 1). After placement the vertical level of the subgrade surface at a matrix of points, relative to a fixed datum point, was determined by survey.

For each trial and section, the target thickness of the sub-base layer was 0.30m. The actual thickness of the sub-base was calculated from the known vertical position of the surfaces of the sub-base and subgrade.

Geosynthetic reinforcements

The geosynthetic reinforcements included three different types of geogrid, one geotextile, and a composite geosynthetic.

General arrangement

A typical test arrangement comprising four trafficking lanes, each divided into three test sections (2.4m wide by 2.7m long), is shown in Fig. 3; ten sections were reinforced and two sections were un-reinforced control sections.

		Lane				
		1	2	3	4	<<< Direction of trafficking >>>
Section	a	Reinf. 1	Reinf. 4	Reinf. 2	Un-reinforced control	
	b	Reinf. 2	Reinf. 5	Reinf. 3	Reinf. 4	
	c	Reinf. 3	Un-reinforced control	Reinf. 4	Reinf. 3	

Figure 3. General arrangement for trafficking

Monitoring the test pavement

Subgrade stiffness

The stiffness of the in situ subgrade was determined using the cone penetrometer before placing the sub-base material and after the completion of trafficking.

Stiffness of the pavement

The stiffness of the pavement was measured before trafficking commenced and during the tests, using a Falling Weight Deflectometer (FWD), as described by Sorensen and Hayven (1982). For all tests, the FWD was fitted with a 300mm diameter segmental loading plate, and the weight fell from a predetermined height to produce a stress of 150kPa on the surface of the sub-base. The pavement stiffness (*E*) was calculated from the following equation:

$$E = \frac{2qa(1-\nu^2)}{d}$$

where: q is the stress under the plate, a is the radius of the plate, ν is Poisson's ratio of the sub-base (taken as 0.45), and d is the maximum deflection at the centre of the plate.

Deformation

Vertical deformation of the pavement surface was determined from the change in level relative to that at the commencement of the trial, measured with respect to the fixed datum. Surface profiles, transverse to and parallel to the wheel path were determined at intervals over each test section. The rut depth in the wheel path was also recorded.

The deformation of the pavement surface was determined at intervals (of pre-set numbers of passes) and on completion of trafficking. The frequency of measurement decreased with increased numbers of passes.

Exhumation of the reinforcements

After trafficking the sub-base was removed to permit the inspection of the reinforcements in situ and the recovery of the whole or a part of the reinforcement for further inspection. An excavator was used to remove the sub-base to within about 0.05m of the reinforcements. The final thin layer of aggregate was removed carefully using hand tools to avoid damaging the reinforcements. Removal of the sub-base also permitted the surface of the subgrade to be surveyed and the CBR value of the clay to be re-measured using the penetrometer.

Arrangement for trafficking

The APT facility may be operated with a twin or single road wheel, and axle loadings from 23kN to 100kN. For all trials a dual wheel pair was used with an axle loading of 40kN, i.e. about half of a standard axle. The wheel passes were bi-directional and canalised along the centreline of each trafficking lane, on the sub-base surface, at a speed of 15kph.

Results

Subgrade stiffness

Results comparing the CBR value of the subgrade, for each lane before and after trafficking the pavement, are presented in Fig. 4. The stiffness of the subgrade clearly increased throughout each test, resulting from the consolidation of the clay during the test period.

Pavement stiffness

Pavement stiffness measurements with the FWD, in the centre of each section, prior to trafficking could not differentiate between reinforced and un-reinforced sections. Tests were not undertaken after the completion of trafficking due to the disturbed surface of the pavement. These measurements will form a part of a database for future research.

Deformation

The range of measured deformation in the wheel path, for both reinforced and unreinforced sections, is shown in Fig. 5.

Deformation of the subgrade surface follows the shape of the deformation at the surface of the sub-base, but is of a smaller magnitude; this phenomenon was exhibited by all reinforced sections. An example of the relative position of the sub-base and subgrade surfaces before and after completion of trafficking is shown in Fig. 6. Equivalent data for an un-reinforced section could not be measured, due to the substantial deformation of the un-reinforced control sections during trafficking, which necessitated the placement of additional sub-base material on these sections to prevent the deformation propagating to adjacent sections, and to prevent the trafficking wheel exceeding its limit for vertical movement.

A photograph depicting the measurement of rut depth, on a control section, is shown in Fig. 7.

Inspection of the reinforcements

The reinforcements were inspected in situ, after the removal of the sub-base, and after being recovered from the pit. The condition of the exhumed reinforcements was generally very good with little or no sign of damage except that inflicted during recovery.

A qualitative indication of the effectiveness of the aggregate interlock with the apertures of the different grid reinforcements was observed and demonstrated by the amount of effort required to exhume the reinforcement. However, no tests were undertaken to quantify this phenomenon which is worthy of further study.

In most tests clay was observed to have extruded through the apertures of grid reinforcements. As a consequence of this it is probable that maximum potential interlock was not achieved.

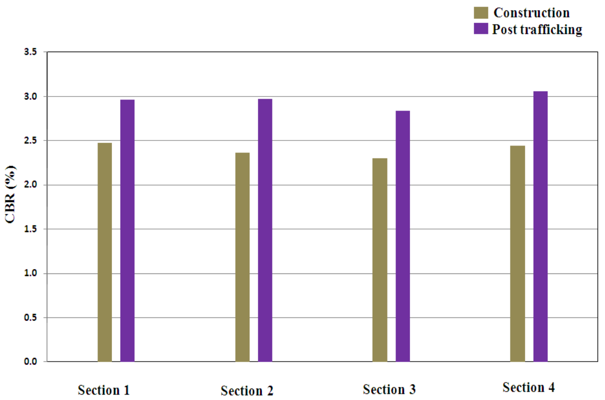

Figure 4. Change in stiffness of the subgrade

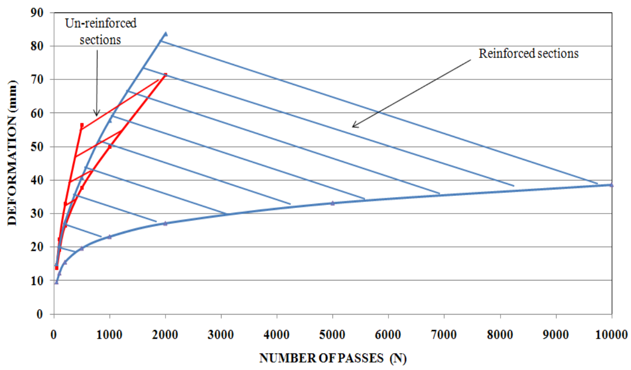

Figure 5. Range of deformations in the wheel path

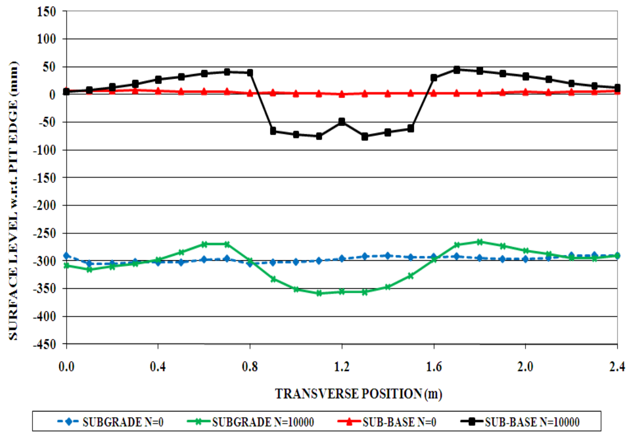

Figure 6. Deformation of the sub-base and subgrade

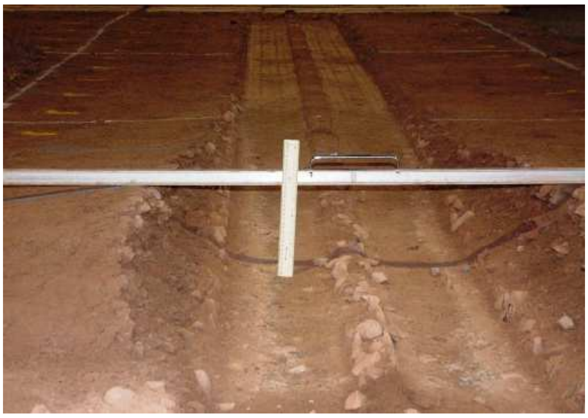

Figure 7. Measurement of rut depth

Conclusions from studies at TRL

The following general conclusions can be drawn, based on the programme of research studies at TRL described in this paper.

Incorporating geosynthetic reinforcement into the construction of an unpaved road can considerably improve the performance of the road in-service. Different reinforcements provide different levels of improvement.

The change in stiffness of the clay subgrade noted in the APT suggests that trial pavements should be allowed to 'rest' prior to the start of trafficking, to make the trial more representative of in-service performance.

The measurement of surface deformation can be used to provide a good indication of the performance of a reinforced pavement, provided that baseline or bench marked data is available.

The trials provided a good example of the use of APT. The sequence of trials provided an improved knowledge of how reinforcements perform and demonstrated the relative effectiveness of different forms of reinforcement. Such information may be used to select a reinforcement for given site conditions thereby providing confidence that the product is fit for purpose.

SUMMARY

This paper has summarised the key factors relating to the use of APT in highway engineering, and has presented an example of how APT can be used to improve our understanding of the performance of highway pavements. The example described how APT was used to gain greater knowledge and understanding of the performance of geosynthetic reinforcement in unbound materials.

The prime advantage of APT is that it can be used to study the performance of a road pavement at full scale under controlled conditions. Areas where APT can facilitate research investigations include: pavement deterioration mechanisms, the relative assessment of alternative construction techniques, the use of recycled materials and other sustainability issues. However, there are limitations on the ability of APT to fully simulate in-service pavements, and comparative studies on pavements are required to bridge this gap.

APT should be regarded as a single step in a developing sequence of events, e.g. concept, desk study, laboratory tests, numerical modelling, APT and monitoring of in-service pavements in real time. When used together these techniques will help ensure that a pavement is fit for purpose.

The benefit of incorporating reinforcements in highway pavement construction has been clearly demonstrated by APT at TRL and other facilities.

FUTURE RESEARCH

Currently, there are no mathematical models that accurately predict the performance of reinforcements installed in the ground; this is the biggest stumbling block to advances in the use of geosynthetic reinforcements in both geotechnical and highway engineering. A step towards achieving this target would be the development of a mechanistic/empirical model, possibly derived from the results of APT, which would enable more efficient and economic pavements to be designed.

The opportunity to obtain performance data from real life events should never be overlooked. It is only by having such data available that we can calibrate and validate our designs, and confidently predict future performance. However, it is essential that any such data include a baseline, e.g. the profile of the pavement before it enters service, against which future changes can be quantified.

REFERENCES

Beckham, W.K. & Mills, W.H. 1935. Cotton fabric reinforced roads. Engineering News Record. McGraw-Hill, New York. 115, 14, 453-455.

Chaddock, B. C. J. 1988. Deformation of road foundations with geogrid reinforcement. Transport and Road Research Laboratory, Research Report RR 140. TRL, Wokingham.

COST Action 347, 2005. Improvements in pavement research with accelerate load testing. Final Report COST Action 347. European Commission, Brussels.

Harvey J. T. 2008. Impacts and benefits of APT: An operator's perspective. Proc. of 3rd Int. Conf. on accelerated pavement testing. CEDEX, Madrid, October 2008. APT 2008.

Manual of Contract Documents for Highway Works (MCHW). The Stationery Office, Norwich. Volume 1: Specification of Highway Works (MCHW 1).

McGown A. & Brown S. F. 2008. Applications of reinforced soil for transport infrastructure. Proc. of 1st Int. Conf. on Transportation Geotechnics, Nottingham. CRC Press. 27-36.

Potter J. F. & Currer E. W. H. 1981. The effect of a fabric membrane on the structural behaviour of a granular road pavement. Transport and Road Research Laboratory, Laboratory Report LR 996. TRL, Wokingham.

Ruddock, E. C. Potter, J. F. & McAvoy, A. R. 1982. A full scale experiment on granular and bituminous road pavements laid on fabrics. Proc. of 2nd Int. Conf. on geotextiles, Las Vegas. IFAI, Mn. 365-370

Sorensen & Hayven: 1982. The Dynatest 8000 Falling Weight Deflectometer Test System. Proceedings of the International Symposium on Bearing Capacity of Road and Airfields. Trondheim. 464-470