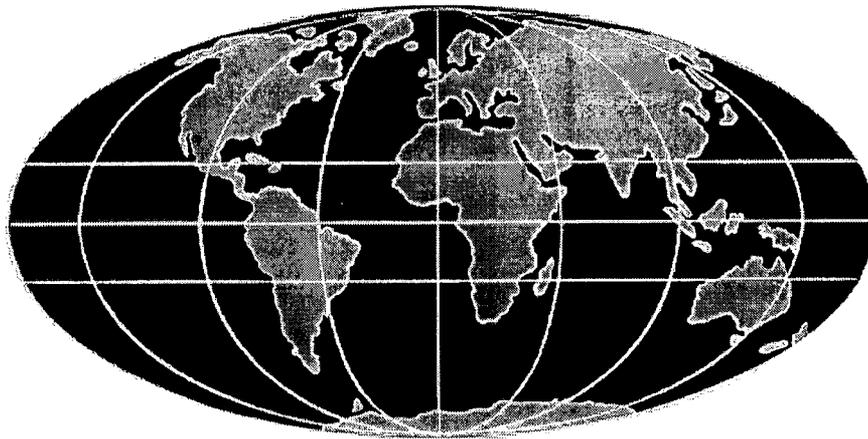


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by: D Newill and M J O'Connell



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TRL RESEARCH ON ROAD CONSTRUCTION IN ARID AREAS

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ABSTRACT This paper outlines work being undertaken by the Transport Research Laboratory on road construction in arid areas in the tropics. Full-scale road trials are in progress to assess the compaction of soils at their naturally occurring moisture contents instead of at the normally specified optimum moisture content. The savings in water using these techniques can amount to twenty per cent of total construction costs. The road trials also include the use of expansive clays in road embankments where different design methods, some employing geosynthetic materials, are being compared to control and prevent ingress of water. Site instrumentation, which includes a new TRL soil suction probe, is also briefly described.

INTRODUCTION

A major problem encountered in road construction in arid areas is the provision of water for soil compaction. This is because specifications normally require soils to be compacted at or close to the optimum moisture content, in order to achieve maximum density (see Fig 1). In these areas estimates have shown that up to 2,800 m³ of water could be needed to construct 1 km of road. Depending on the source of the water this could amount to as much as 20% of total construction costs. This is far in excess of costs in temperate zones or wetter areas where the natural moisture content is usually close to the optimum and relatively small adjustments of water content are necessary. Even after compaction at the optimum moisture content, large evaporation losses will result in the equilibrium condition in the road structure reverting to a value close to the original natural moisture content.

With increasing development linked to road construction in hot, dry areas in many developing countries, the Transport Research Laboratory has in recent years focused part of its research effort on the associated road building problems. This has concentrated on investigating dry compaction as a means of saving water for a wide range of soil types as well as examining the behaviour of problem soils where the emphasis has been on expansive clays, commonly known as black cotton soils.

COMPACTION AT LOW MOISTURE CONTENT

As part of the work on dry compaction, laboratory compaction tests were carried out on different soils where the moisture content range was extended to include the dry condition. Generally a relation between dry density and moisture content was obtained similar to that

shown in Figure 2. The increasing density in the dry state was believed to be the result of reduced surface tension. Figure 3. shows specific relations for three different levels of laboratory compaction for a gravel-sand-clay that was used for the road base in a full-scale road experiment built in northern Kenya (O'Connell, 1987). Also included in the graph is the relation obtained for the same soil from a field compaction trial using six passes of a vibrating roller with a mass of 3.4 Mg/m width. The implication from the laboratory tests and the field compaction trial was that specified densities for normal contractual requirements could be achieved by compaction at low moisture contents. This was borne out subsequently by the results obtained in the full-scale experiment referred to above. Figure 4. shows the layout of the experiment which comprised three sections each using the same material. The only difference between them was the moisture content at which the gravel-sand-clay road base was compacted. Section A was at the optimum moisture content obtained in the BS 4.5 kg rammer test (equivalent to the modified AASHTO compaction test). Section B was at an intermediate moisture content and Section C was at the same dry natural moisture content as occurred in the borrow pit. The mean values of the dry densities and moisture contents achieved in the experiment are designated by the letters A, B and C superimposed on the compaction curves in Figure 3. All three sections achieved the specified density (95% relative compaction) but clearly the highest was obtained for the dry section, Section C (equal to 100% relative compaction).

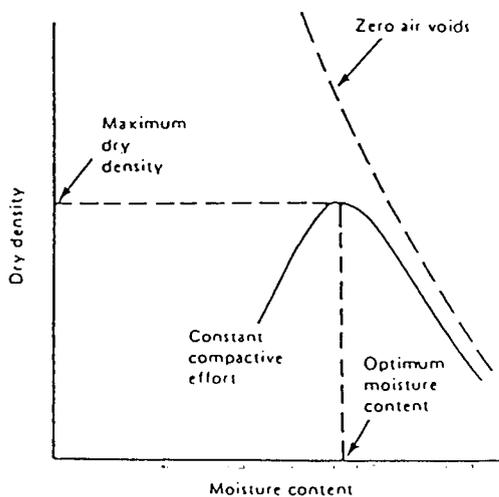


Fig. 1 Conventional compaction curve

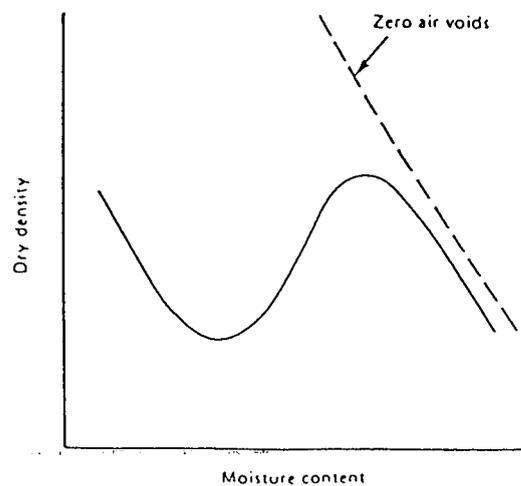


Fig. 2 Extended compaction curve for low moisture contents

Despite the high density achieved by dry compaction there is an element of risk because of the high air void content in this condition (see Figure 3). Any increase in moisture content from wetting up would be expected to have a detrimental effect on strength especially if there is a clay component in the soil. In arid areas

where water tables are generally very deep there is unlikely to be any increase in moisture content by capillary rise from below. However, increases can occur at the edges of the paved surface from run-off water from the sealed pavement or from the lateral movement of water that may collect in roadside drains. In such cases the cumulative quantity of water would be greater than that simply from annual precipitation.

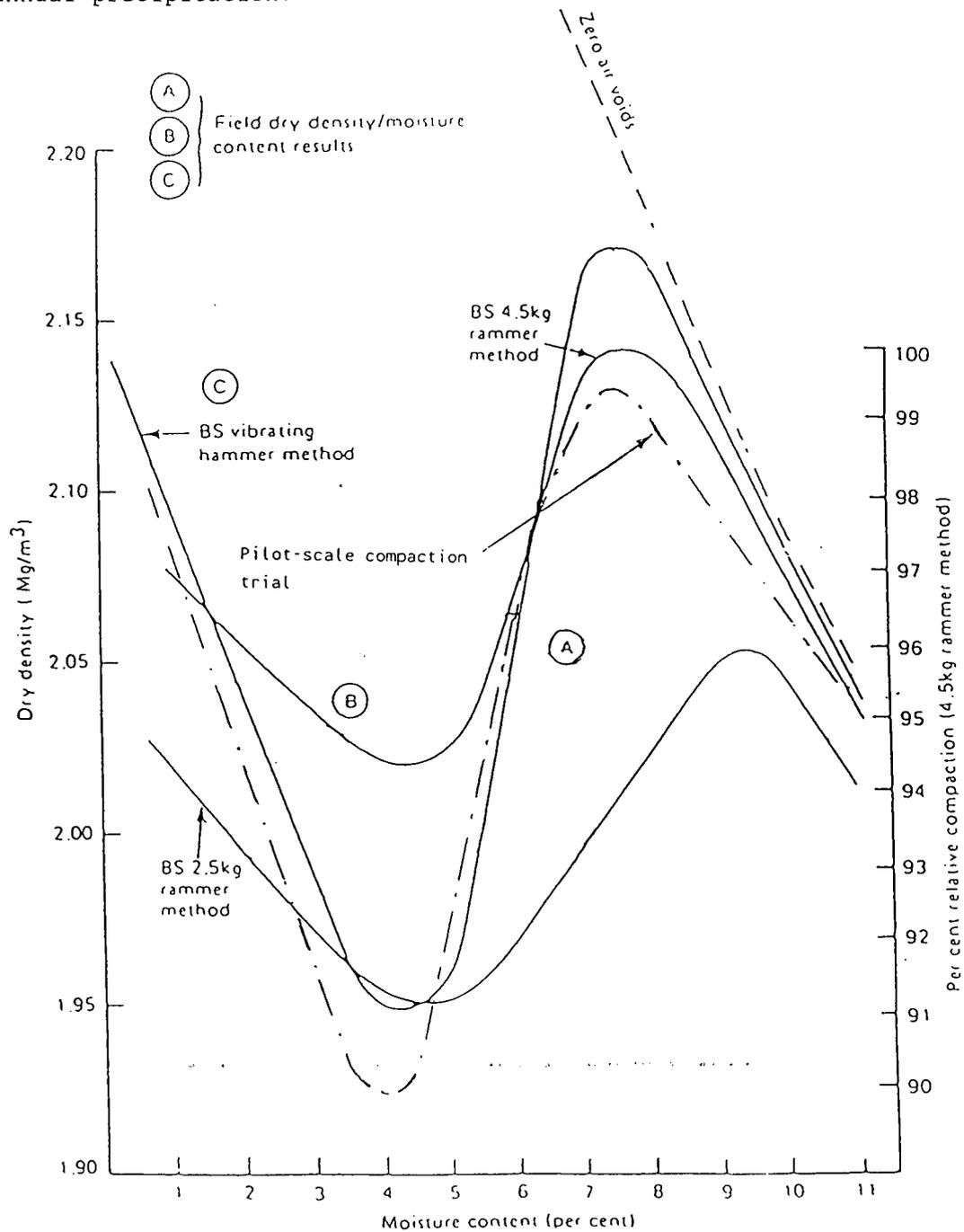
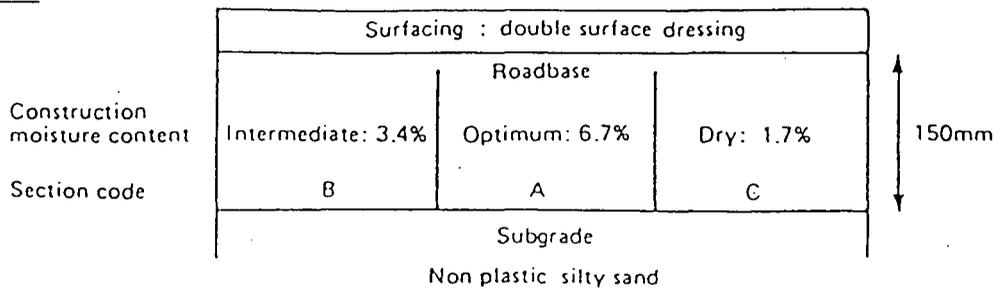


Fig 3. Laboratory CBR/dry density/moisture content relationship for road base gravel (full scale trial) with field results

Longitudinal section



Cross section

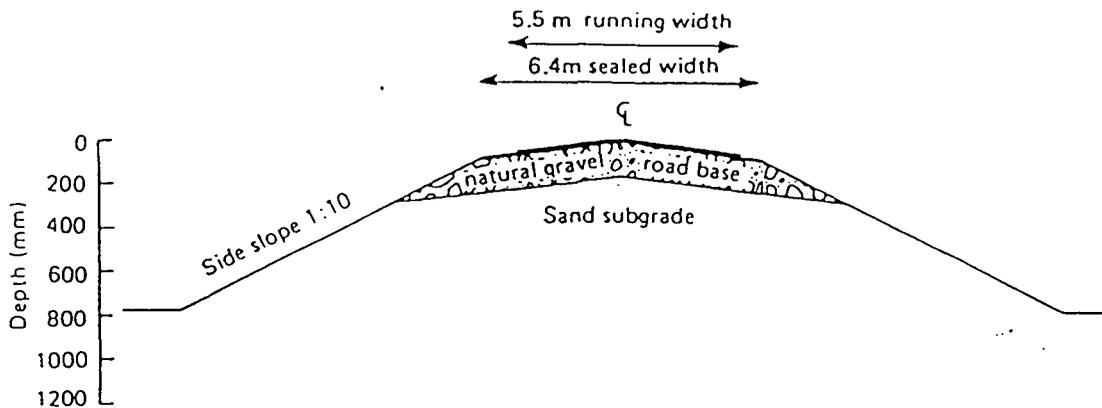


Fig 4. Layout of full scale trial in northern Kenya

The problem can be exacerbated by rainfall occurring in concentrated short periods. The potential build-up of water at the edge of the road pavement leads to the recommendation for sealed shoulders to ensure that any wetting up under the road is kept away from the position of the wheel-tracks, where traffic loading occurs. This is a policy which has been adopted recently for new roads being built in the Kalahari Desert region of Botswana. In the case of the full-scale experiment in northern Kenya, however, where sealed shoulders were not incorporated into the design, there has been no marked increase in moisture in any part of the road structure and seven years after construction all three sections are performing equally well with no signs of deterioration. The difference in behaviour between the cases in the two countries is probably because rainfall in northern Kenya is lower than in Botswana. As a result the ratio evaporation to precipitation will be higher and it is unlikely that water will accumulate.

EXPANSIVE CLAYS

Expansive clays, known locally as black cotton soils, occur extensively in tropical climates. When encountered in road building, specifications normally do not permit their use in embankments, moreover excavation below the embankment and

replacement of the expansive soil by better quality materials may also be required. This is because of the large volume changes that can occur as a result of wetting and drying with seasonal changes of climate. Earlier work by TRL in Sudan (Ellis, 1981), where large deposits of black cotton soil occur in the region of the Nile valley, showed from road trials that these soils can be used effectively in road embankments provided that they can be retained at their dry natural condition. If ingress of water can be prevented the higher strength of the dry soil can also lead to benefits in reduced pavement thickness. No preventative measures were taken in the road trials in Sudan and the road shoulders were not sealed. The results showed that with a deep water table there was no capillary rise of water into the embankment but sideways movement did take place from seasonal rainfall and irrigation water that collected in the roadside drains for a period each year. This led to the progressive development of longitudinal cracks along the embankment and unsealed shoulder which, after five years, reached a position 1 metre in from the edge of the sealed pavement in the line of the outer wheel-path. Such cracks are characteristic of roads built on black cotton soil and clearly the entry of water into the pavement will lead to structural failure.

To examine methods of preventing entry of water into black cotton soil embankments a new full-scale experiment has been constructed in Kenya as part of a joint research programme between TRL and the Ministry of Public Works. The experiment is located on a 125 km road currently being built on part of the A3 from Thika to Garissa where annual rainfall is about 300mm. It comprises 20 different sections within a length of 1.5 km and includes the following main features:-

- (i) Compaction of the embankment soil at the natural moisture content which was much lower than the optimum moisture content. For comparison one section was compacted at optimum moisture content. The design thickness of the base and sub-base was determined from the dry strength of the embankment (subgrade) soil.
- (ii) Different road shoulder widths to limit the potential for water to penetrate to the wheel paths.
- (iii) The use of a range of geosynthetic materials in different positions within the road e.g. across the full width of the road at the bottom of the embankment, between the permeable base and sub-base (see photo) and between the top of the expansive clay embankment (subgrade) and the sub-base. In the latter two cases the materials were laid in either 1.5m or 3m widths sufficient to cover the outer parts of the road structure. Four types of geosynthetic material were used to create either impermeable membranes, drainage layers or subgrade support.
- (iv) Different side slopes of the embankment to control erosion.

- (v) For control purposes one section was designed according to the specification of the Kenya road design manual. Here, the upper 450 mm of the embankment was constructed with higher quality material instead of the expansive clay.

The height of the embankment (not including base and sub-base) was constant throughout the experiment at 1.3m.

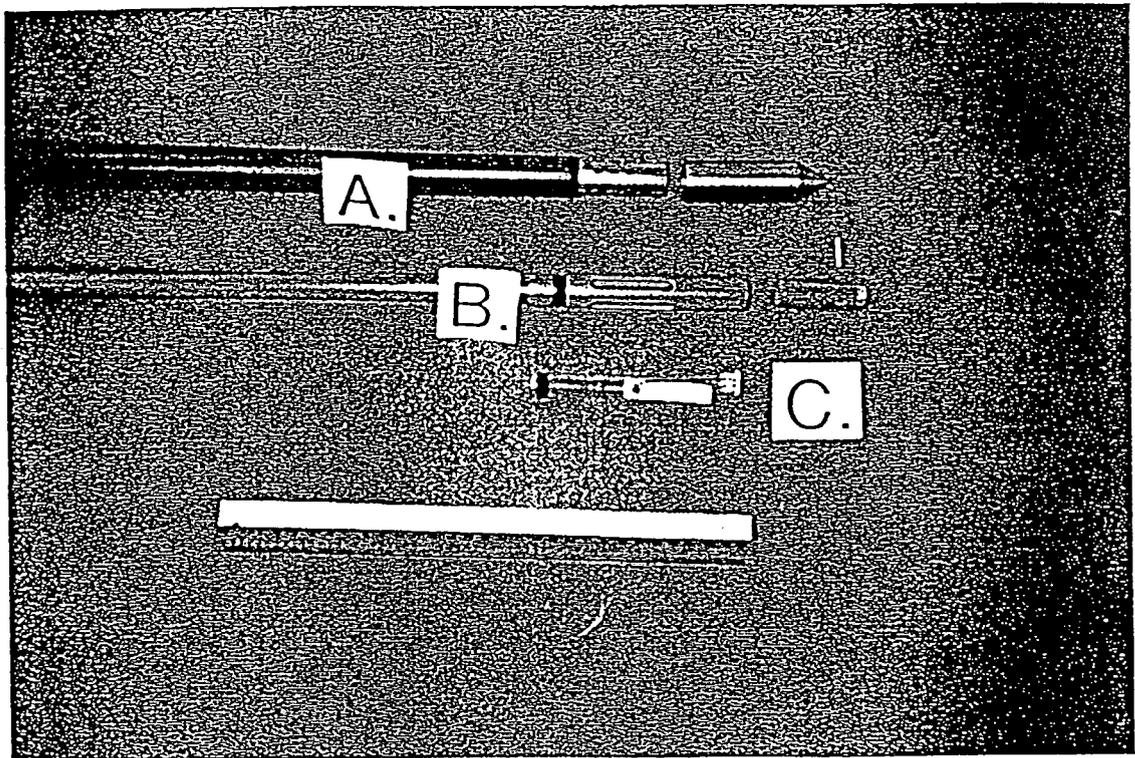


Geosynthetic material being laid as a drainage layer between sub-base and road base.

After construction, the experimental sections were fully instrumented to enable future performance to be monitored. Key parameters being measured regularly are soil moisture, density and strength as well as any expansion or shrinkage expressed as ground movements. The effect of climate on the road structure is being closely monitored. Special attention has been paid to the design of instrumentation so that measurements can be made rapidly throughout the body of the experiment without any sub-surface disturbance. More than 200 aluminium tubes have been installed to depths of 2 metres to enable a nuclear gauge depth probe to be used to measure soil moisture and density at any chosen depth. The tubes have been arranged in groups of ten to give cross-sectional coverage of any changes that may occur.

In a number of the sections at positions close to the aluminium tubes suction probes have been installed to measure soil moisture suction, a parameter strongly related to the affinity of soil to attract water. Changes in soil suction can have dramatic effects on the strength and volume change characteristics of expansive soils. The suction probes were designed at TRL (Schreiner, 1991), (see photo), and use the TRL dynamic cone penetrometer (DCP) for installation. This has the advantage of providing additional information on soil strength from the DCP-CBR (California Bearing Ratio) relation. Suction is determined using the equilibrium moisture content of a filter paper suspended within the probe which lies close to the embankment soil. Data collected so far have proved the reliability of the new system. The ease and speed of installation and monitoring have also shown it to be an appropriate technique for use in developing countries.

Information related to the pavement design aspects of the experiment will be obtained from measurements of rut depth and deformation across the road and from deflection surveys using a Benkleman beam. These will be related to results of traffic surveys and axle-load measurements.



TRL Suction Probe

A - outer casing driven by DCP

B - removable inner sleeve

C - filter paper

(In operation C fits inside B and B fits inside A)

Linked to the field trials on expansive clays described here, was a

laboratory investigation undertaken by Imperial College, London. The aim is to determine the extent of changes in volume and soil strength that occur in the compacted soils under arid climate conditions.

The success of earlier work in Sudan and Kenya and the research currently in progress should lead to clearer guidelines for road construction in arid areas.

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