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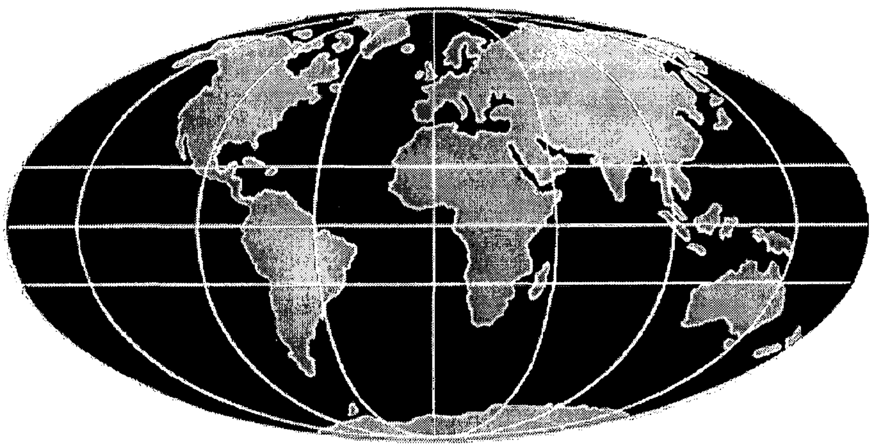
TITLE: **Compaction for Earth and Gravel Access Roads and Tracks**

by: P A K Greening and T Toole



Transport Research Laboratory
Crowthorne
Berkshire RG45 6AU
United Kingdom

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COMPACTION FOR EARTH and GRAVEL ACCESS ROADS and TRACKS

by
Tony Greening and Tyrone Toole
Transport Research Laboratory

1. INTRODUCTION

The main aim of this paper is to heighten awareness of the need for appropriate standards and quality control in the construction of low-volume earth and gravel roads and tracks (with particular emphasis on the role of compaction) which are often built by labour-based methods.

Because the provision of labour-based roads can often be justified in economic terms by the social benefits alone, there has sometimes appeared to have been a reluctance to set and adhere to standards in the way that is required for the plant-based operations used in the construction of more highly trafficked roads. The provision or improvement of a track or road of any standard can often have a major impact on the economy of a village or even a region and this was seen as sufficient justification in itself without the need for adherence to engineering standards. An example of this is in the wide range of the techniques used for compaction which can range from compaction by traffic to full plant-based compaction. Thus the level of compaction achieved will often depend on the equipment available and other factors such as whether water is available or if there is a conscious effort to achieve a standard related to laboratory tests on the construction materials. Inevitably, this has resulted in a large variation in the level of compaction achieved on labour-based roads. In the past, this diverse approach by labour-based practitioners has led to a division of opinion on the value of labour-based schemes between the established engineering fraternity and those involved in labour-based projects.

Furthermore, as expertise in the construction of labour-based operations increased, these techniques have been used to construct roads of a higher geometric standard and carrying relatively high levels of traffic. This has led to a wide range in construction standards which, in some cases, has resulted in problems in the maintenance of these roads. Whilst basic standards may be appropriate for tracks providing basic access, the additional investment in more highly trafficked roads (or other roads which require the importation of gravel) requires additional attention to be given to design and construction standard. Compliance with appropriate compaction standards is needed. Otherwise there is a risk of accelerated deterioration of these roads by climatic influences and traffic with the obvious consequences for maintenance whether by labour or other methods.

An additional factor which has highlighted the need for setting appropriate compaction standards for these roads is in the training of local contractors in the construction of low-volume roads with emphasis on the use of labour-based methods.

Thus, the importance of compaction needs to be recognised even in very low-volume access roads and tracks. This is already acknowledged for more heavily trafficked roads to the extent that compaction is likely to be a highly significant parameter in the new models being developed for HDM4. Its importance in the performance of very low-volume roads needs to be recognised at least qualitatively in the absence of authoritative guidelines which are clearly urgently required.

2. ROLE OF COMPACTION

The role of compaction is the process whereby the material particles are constrained to pack more closely through a reduction of the air voids in the mass of the material. This reduces the permeability of the material to water and increases its shear strength, bearing capacity and resistance to further settlement and deformation. Thus the material, when used in road construction, is better able to withstand traffic loads and any negative influences of climate.

The role of compaction in the context of road construction has been investigated by a number of institutions including the Transport Research Laboratory (TRL) in the UK. Most of the TRL work has been carried out on road construction materials found in the UK, but some studies have also involved materials found in developing countries. This work illustrated that a methodological approach based on quantitative experience with a wide variety of equipment can form the basis of local guidelines irrespective of location.

There is little doubt that there is general agreement that some degree of compaction is required if a road or track is to do the job expected of it. Even in situations where no specialised compaction plant is available, vehicles are often used to achieve some degree of compaction although the level of compaction achieved is variable.

Climate, particularly the effects of water ingress and rainfall run-off, can significantly affect the performance of unpaved roads. Unfortunately, there is little quantitative evidence on the interaction between the level of compaction (density), materials properties and climate on deterioration rates for very low-volume earth and gravel roads, although the additional resistance of the material to the effects of both climate and traffic with increasing compaction is accepted.

Some evidence is available on the effects of traffic on poorly compacted gravel roads and this is discussed in Section 4.

3. ROLE OF WATER

The important role of water in the construction of unpaved roads should not be underestimated. The amount of water used during construction will have a highly significant effect on the durability of the materials used in the road structure whether earth or gravel.

The role of water in the compaction process can be thought of as a lubricant with increasing lubrication resulting in increased compaction and increasing levels of dry density. This process continues until additional water displaces the solid particles and produces a decrease in density. A typical relation between dry density and moisture content is given in Figure 1 for a given level of energy input.

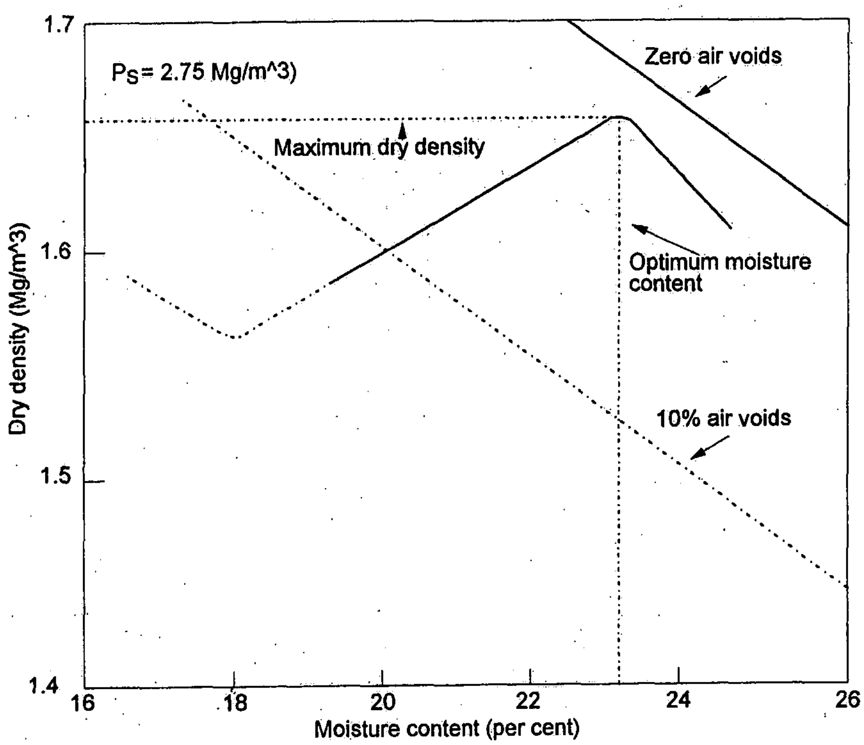


Figure 1: Typical Moisture Content – Dry Density Relationship under Compaction

At moisture contents below the optimum value, much more effort will normally be required to achieve a similar level of density. (The one exception being the specific "dry compaction" moisture condition which also enables a relatively high density to be achieved). With the compaction equipment available on many labour-based projects the practical consequences of using too little water is that the achieved densities could be much lower than the target density.

Different soils will achieve different levels of density for any given compaction effort and typical curves for a range of soil types are given in Figure 2.

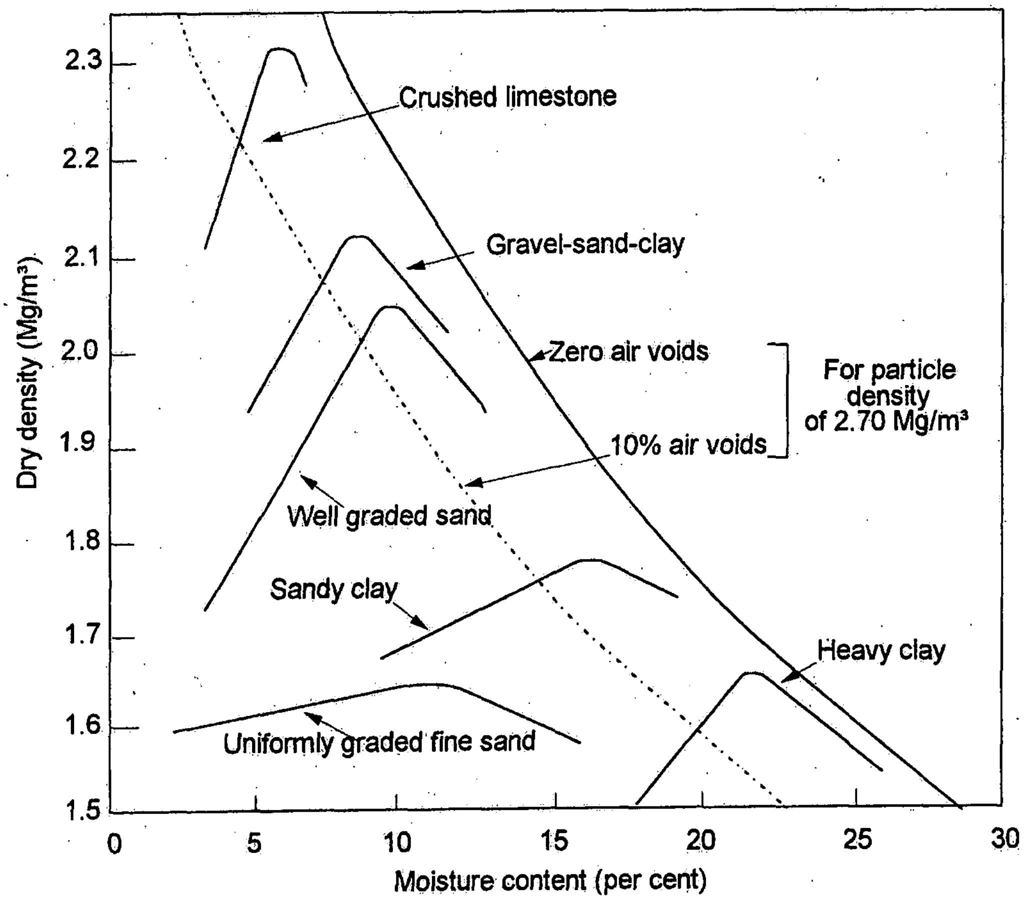


Figure 2: Effect of Soil Type on Density under Compaction

In unpaved roads, the water used for compaction has an additional role. The clay component present in most materials used in the construction of unpaved roads acts as a binding agent when activated by moisture. Thus the addition of water mobilises the cohesive properties of the soil which increases its resistance to ravelling and erosion. This reduces the rate of deterioration by reducing the rate of the progression of roughness and loss of shape. It also reduces the rate of loss of material, surface erosion and dust emission.

4. ROAD PERFORMANCE AND COMPACTION

Quantitative information on the performance of gravel roads is relatively scarce. Some work has been carried out by TRL and CSIR which has resulted in models being developed to describe the likely rate of deterioration of unpaved roads in terms of gravel loss and roughness progression.

Typical results of a TRL study in Botswana on a road constructed with nodular calcrete are shown Figure 3. The roughness of the road compacted at a half the optimum moisture content (0.5 x OMC) attained a peak value of 16 IRI (International Roughness Index). At this level of roughness drivers chose to drive along the old sand track (or even in the bush when this was possible) rather than use the road. In effect, the road became almost impassable to motorised traffic. In comparison, a similar road compacted at OMC could be expected to have a roughness level of less than 10 IRI even after 60 000 vehicle passes. In this example, the results also showed that a road constructed at half OMC may be expected to deteriorate four times faster than a similar road constructed at OMC.

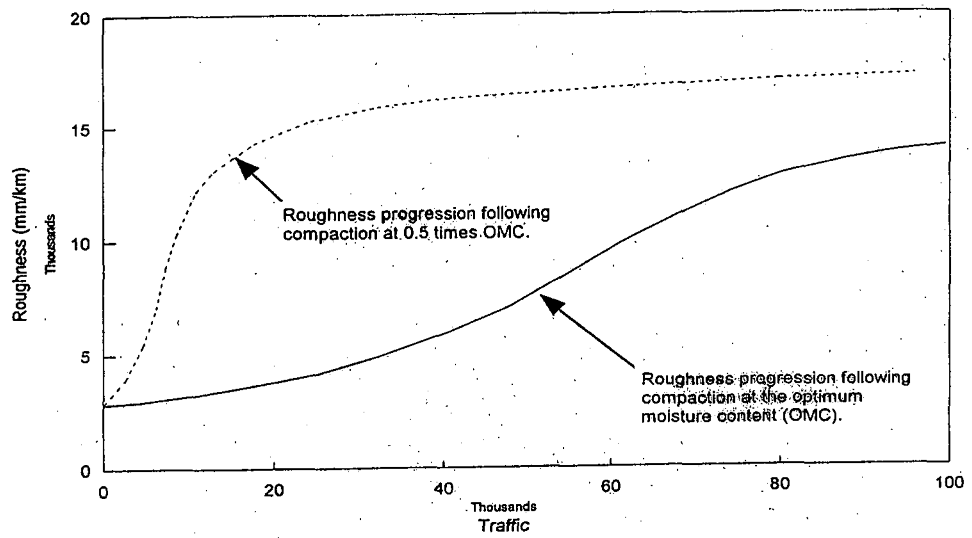
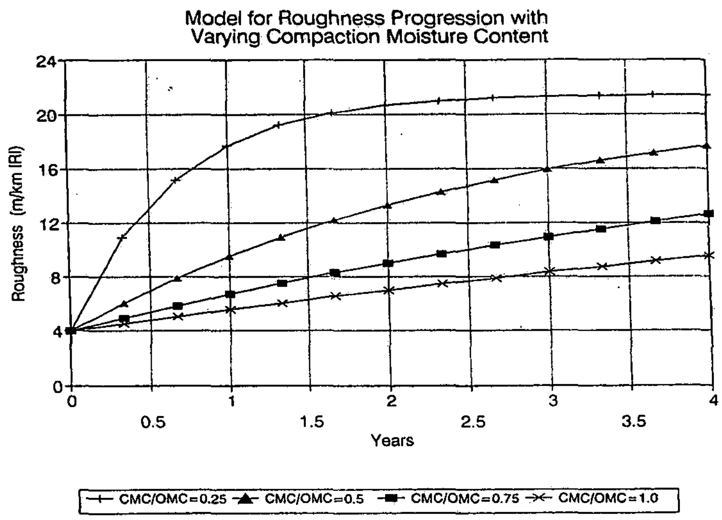


Figure 3: Roughness Progression of Nodular Calcrete Compacted at Different Moisture Contents

These and other results have been used to compile the models for roughness progression which, in time, will be incorporated into HDM. The model for roughness progression with varying moisture content is shown in Figure 4. This example is only illustrative and the maximum roughness and rate of progression are controlled by material properties, climate, traffic and other factors.

Figure 4: Modelled Roughness Progression with Varying Compaction Moisture Content



It is not always appreciated that mechanical compaction has considerable impact on the performance of unpaved roads. Roughness progression on a road constructed carrying 50 vehicles per day with and without mechanical compaction is shown in Figure 5.

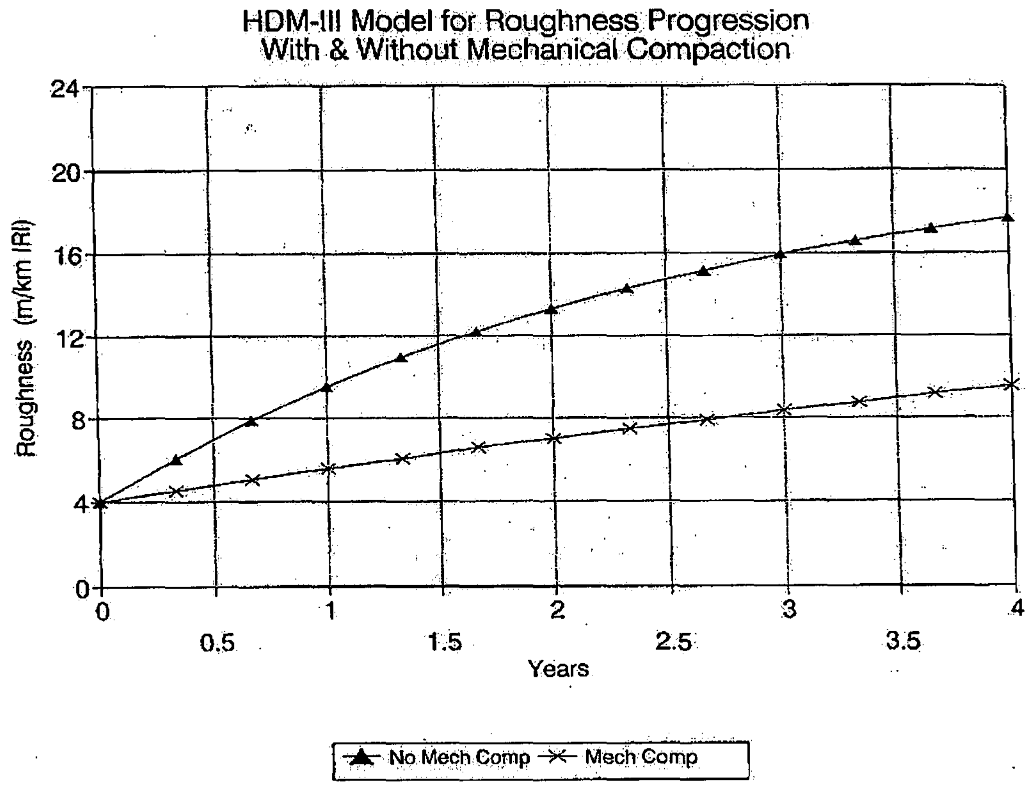


Figure 5: Modelled Roughness Progression with and without Mechanical Compaction

Although the above examples relate to traffic-induced deterioration, they illustrate the reduction in durability that can be expected if a road is compacted at moisture level below the optimum moisture content or at a low compactive effort.

5. COMPARISON OF COMPACTION PLANT

5.1 Key Factors

The normal guiding principle in the selection of compaction plant is that the equipment should be capable of achieving the desired state of compaction at the moisture condition of the soil. However, there may be constraints on the choice of plant particularly in low-volume roadworks where manouverability, maintainability and mode of traction may influence the selection. Availability of certain types of plant is, of course, fundamental.

The key factors which influence the compaction process are material properties, moisture content and the available compaction equipment. The effect of moisture has been discussed in Section 3 and the materials properties are usually fixed by the available construction materials in labour based projects. Although the choice of equipment is also often limited on labour-based projects, it is important to have some estimate of the effectiveness and productivity that can be expected from the different types of equipment available. An example of the increase in density with the number of roller passes for a particular material compacted at OMC is shown in Figure 6.

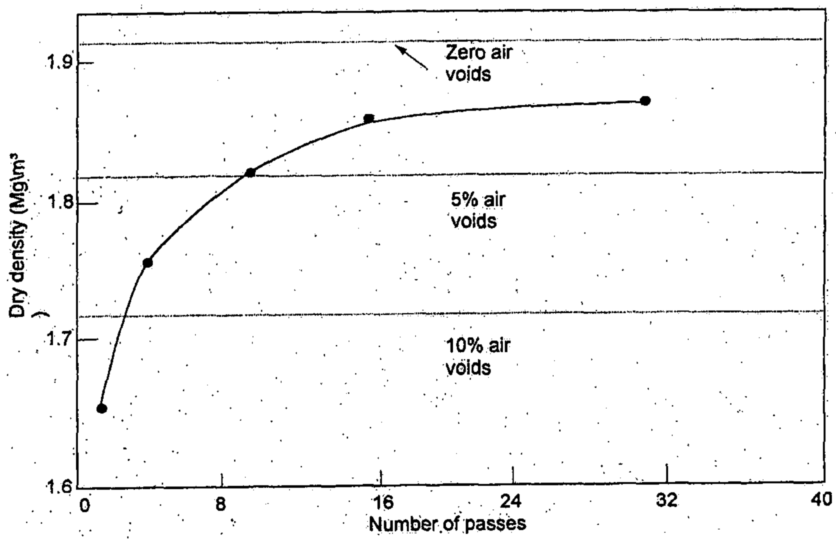


Figure 6: Relationship between Density and number of Compaction Passes

5.2 Types of Compaction Equipment

The following types of compaction equipment are commonly employed in roadworks:

Smooth wheeled roller (deadweight or vibratory without vibration)
Grid roller
Tamping roller
Pneumatic tyred roller
Vibrating roller
Vibro tamper
Power rammer
Dropping weight compactor

For conventional roadworks, smooth deadweight, pneumatic tyred and vibrating rollers are amongst the most commonly used.

For labour intensive works, deadweight rollers, towed by a variety of prime movers, and hand propelled vibrating rollers are widely used.

The following sections document the performance of both conventional and intermediate compaction plant.

5.2.1 Performance of Conventional Compaction Plant

The results of compaction trials shown in Table 1 assume a target density of 95 per cent of the laboratory Proctor (2.5Kg Rammer) Maximum Dry Density (MDD) level of compaction which is a standard often applied to earth roads. In these examples, the performance of three heavy rollers typical of those used in capital intensive projects were compared in experimental trials conducted by TRL. The table shows the results for three soil types compacted at the optimum moisture content and in a dry condition. Cohesive soils comprise materials with more than 80% passing the 2mm sieve and more than 15% passing 0.075mm. Light cohesive soils have a liquid limit less than 50. The dry moisture condition in the trials correspond with 5%, 6% and 10% less than OMC for the granular, light cohesive and heavy cohesive soils respectively.

Table 1
Comparison of Typical Compaction Plant
(Parsons, 1992)

Roller Type	Load (drum)	Light Cohesive Soil		Heavy Cohesive Soil		Well Graded Granular Material	
		Opt	Dry	Opt	Dry	Opt	Dry
9 tonne Smooth Deadweight Roller	3.5 T/m	6 (105)	NS	3 (210)	6 (105)	2 (210)	8 (52)
9.3 tonne Smooth Vibrating Roller	2.4 T/m	4 (170)	8 (85)	4 (170)	6 (57)	4 (165)	16 (42)
20 tonne Self Propelled Roller	2.5 T/wheel	4 (253)	NS	4 (259)	8 (65)	4 (260)	16 (43)

Notes: 1.Number of passes for 95% Proctor Density for a 150 mm layer. 2.Output (m3) per hour. 3.NS - not suitable (>16 passes required or ground too soft).

With the exception of the deadweight roller, the rollers were generally heavier than those normally employed in labour-based projects, but the comparisons give useful examples of the relative performance that can be expected at different moisture contents and different soils. (In the UK, the Department of Transport specifications give estimates of the number of passes required for a large range of compaction plant and materials).

The results of the trials show that dry materials require between 50% and 400% more passes than materials at OMC and plant output on materials compacted at optimum is up to five or six times greater than in the dry condition. In overall terms the vibrating roller was the most versatile but the deadweight roller also performed well in most circumstances.

5.2.2 Performance of Intermediate Compaction Plant

There are remarkably few results available from controlled field trials on the performance of intermediate compaction plant. Some field results (mainly from Kenya) are given in Table 2. The soil types are not clearly defined and the moisture contents are not known but is assumed that the target moisture condition was OMC. For comparison purposes, the estimated expected performance for similar types rollers from TRL pilot-scale trials are shown in the last two columns of Table 2. The hand-drawn or animal drawn roller was below the minimum weight of the non-vibratory rollers tested in the TRL trials. In all cases, the number of passes required in the field were greater than the expected range in the pilot trials, although in all cases they were of an acceptable order. There could be a number of reasons for this, and the results highlight the need for on-site field compaction trials. Another important result from the TRL trials is that the productivity of the tractor-towed equipment is between 3.5 and 9 more than the pedestrian vibratory equipment for granular soils and 3 times greater for cohesive soils.

Table 2
Performance of Intermediate Compaction Equipment

Roller	Load	Measured No. of Passes for 95% Proctor MDD at OMC	Estimated No. of Passes for 95% Proctor MDD (output (m3) per hour)	
			Cohesive	Granular
Hand or Animal Drawn Roller (Kenya)	Empty - 0.6 T/m Loaded - 1.4 T/m	8 - 12	Not tested	Not tested
Tractor Towed Smooth Wheeled Roller (Kenya)	Empty - 3.1 T/m Loaded - 3.7 T/m	8 - 12	6 (120)	2 (480)
Tractor Towed Ribbed Roller (Kenya)	Empty - 3.2 T/m Loaded - 3.8 T/m	8 - 12	6 (120)	2 (480)
Twin Drum Pedestrian Operated Vibrating Roller	0.4 T/m	6 - 8	NS ?	3 (50)
Twin Drum Pedestrian Operated Vibrating Roller	0.7 T/m	6 - 8 ??	NS ?	2 (135)

6. COMPACTION STANDARDS FOR LABOUR-BASED ROADS

6.1 Compaction Standards

The standard of compaction achieved on labour-based road projects is extremely variable, depending on the equipment available for compaction, whether adequate water is available and the type of soil being compacted. Design standards also vary but typical target densities might be 90 per cent of the mod AASHTO laboratory density for earth roads constructed with the available formation soils and 95 per cent of mod AASHTO for gravel wearing courses. However, these densities are frequently just nominal targets as there is often little on-site sampling and testing or access to laboratory facilities either to determine the target densities or to carry out control testing during construction. In these circumstances, it is hardly surprising that there is such a wide variation in the standard of construction achieved on these roads.

It is often assumed that compaction is less important on earth roads and tracks with low traffic volumes and providing basic access. However, some formation soils are particularly susceptible to erosion and inadequate compaction will result in accelerated deterioration due to climatic affects regardless of traffic levels.

A gravel wearing course is usually provided to provide additional bearing capacity or reduce the erodibility of poor soils or to increase the durability of the road to the effects of traffic and climate. Typically, the provision of this layer increases costs by around 40-50 per cent. Therefore, it is important to protect this additional investment by ensuring that this layer is adequately compacted and that sufficient water is added at compaction so that the maximum density is achieved with the compaction equipment available.

6.2 Standards and Contractor Development

Most of the early labour-based roads were constructed as part of the force account operations under the auspices of Road Authorities, District Councils or other quasi-Government organisations. More recently, there has been a move to towards increasing private sector involvement in the construction of labour-based roads and many rural development programmes which involve labour-based road construction projects now also have an element of contractor training. This move has highlighted the need for setting standards and methods of monitoring quality control. Contractors construct roads as a business and as with any business, reducing costs increases profits. One way of reducing costs is to cut compaction costs either through using less water (which can be an expensive resource in the dry season) or reducing the number of plant passes. Either of these measures will reduce durability and increase maintenance costs.

6.3 Quality control

Labour-based roads projects are often located in remote areas where the aim is to alleviate rural poverty by promoting economic activity and providing opportunities for employment. In these situations, there is often no access available to laboratory testing facilities and even where a laboratory is available, labour-based projects often get low priority and test results arrive too late to be used effectively. Therefore, conventional methods of quality control such as in-situ density measurements may be inappropriate for many labour-based projects. It has been suggested that instruments such as the Dynamic Cone Penetrometer (DCP), Clegg Hammer can be used or modified to measure in-situ density. Most of these instruments have been developed to give proxy measurements of strength. Although strength measurements can be used to determine density, strength is also affected by moisture. Therefore, if there is any delay in conducting these measurements it is quite feasible that an acceptable strength result may be obtained even if the material has been compacted at a lower (unacceptable) density. Therefore, extreme caution must be exercised when using strength determinations as a proxy for the quality control of density.

In the absence of specialised equipment and access to laboratory facilities, one alternative method of ensuring adequate quality is to control compaction through moisture measurements. The optimum moisture condition of the soil/gravel can usually be determined to quite close tolerances by experienced technicians by the hand squeeze method. This moisture content can then be simply determined with the use of a field balance and drying over an open fire. The number of passes to achieve the optimum level of compaction (no further significant settlement) can also be determined by a simple compaction trial. Quality control of the compaction process can then be carried out by counting the number of passes and spot checks on moisture content.

6.4 Compaction standards and deterioration

One of the main factors which affect the performance of all types of road is the standard to which it has been designed and constructed. For more highly trafficked paved and gravel roads, deterioration relationships have been derived from research and the relationships incorporated into investment appraisal models such as HDM. Some examples relating roughness to compaction were given in Section 4. These models assist in predicting the rates of deterioration for different types of road and help to ensure that roads are designed and built to appropriate specified standards and total life-cycle costs optimised.

Far less is known about the engineering performance and modes of deterioration of low-volume earth and gravel roads which are often constructed by labour-based methods, by different techniques or with quite different equipment than is used on projects constructed by conventional methods. Deterioration due to environmental and climatic effects on these roads can be greater than the effects of traffic and this is the important difference between these and more highly trafficked roads. Without deterioration relationships for these roads, it is difficult to set appropriate standards or to know the effect of different standards on performance. This means that the level of maintenance required is also uncertain and whole-life costs and benefits almost impossible to determine.

Therefore there is a need for quantitative information on the modes of deterioration for different types of very low-volume roads so that appropriate engineering standards can be set, methods to monitor compliance determined, deterioration relationships derived and total life-cycle costs calculated.

7. CONCLUSIONS

The important role of compaction on the durability of low-cost and labour-based roads needs to be recognised. Although quantitative evidence is sparse for very low volume roads there is evidence available from more highly trafficked roads on the accelerated deterioration rates likely to occur as a result of inadequate compaction.

Water plays an important role not only as an enabling agent for compaction but in mobilising the cohesion properties necessary to reduce the deterioration processes in unpaved roads.

There is relatively little reliable evidence available from field studies on the relative performance of compaction plant but TRL trials indicate that between 50% and 400% more passes are required if materials are compacted at moisture contents below optimum and output can be reduced by up to approximately 80 per cent.

Private sector involvement and contractor training programmes have highlighted the need for guidelines on appropriate compaction standards and methods of quality control in the construction of labour-based roads.

In order to set standards, quantitative information is required on the performance of these roads. Deterioration rates and the effects on maintenance need to be determined for different types of low-volume roads so that costs can be calculated from this information which, together with socio-economic data will enable total life cycle costs to be optimised in the planning of future projects.

8. REFERENCES

Parsons, 1992. Compaction of Soils and Granular Materials: A Review of Research Performed at the Transport Research Laboratory. London, HMSO. 1992

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