THE HIGHWAYS AGENCY HA 70/94

THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
Y SWYDDFA GYMREIG

THE DEPARTMENT OF
THE ENVIRONMENT FOR NORTHERN IRELAND

Construction of Highway Earthworks

Summary: This advice note gives guidance on the construction of highway earthworks where the Specification for Highway Works is being implemented.

REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

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VOLUME 4 GEOTECHNICS AND DRAINAGE

SECTION 1 EARTHWORKS

PART 5

HA 70/94

CONSTRUCTION OF HIGHWAY EARTHWORKS

Contents

1. INTRODUCTION

General

1.1 The guidance given in this Advice Note has been prepared to meet the needs of the Specification for Highway Works (MCHW 1) and its Notes for Guidance (MCHW 2).

Scope

1.2 This guidance is applicable to all trunk roads and motorway projects and may also be considered as good practice for other schemes involving major earthworks. In Northern Ireland, the guidance is applicable to those roads designated by the Overseeing Organisation.

1.3 This Advice Note is focused on the constructional aspects of earthworks. Construction aspects of the widening of highway earthworks are covered in HA 43 (DMRB 4.1.2). The design and preparation of Contract documents for earthworks is covered in HA 44 (DMRB 4.1.1). Advice Note HA 44 (DMRB 4.1.1), of necessity, covers design considerations relating to the construction of earthworks and these have not been repeated here; HA 44 (DMRB 4.1.1) should be consulted when construction practices or methods may affect the design.

Definitions and Abbreviations

1.4 The Conditions of Contract (CoC) are the Institution of Civil Engineers (ICE) Conditions of Contract (Fifth Edition) for use in connection with Civil Engineering Construction works, as amended by the Manual of Contract Documents, Volume 0, Section 1: Model Contract Document for Highway Contracts.

1.5 In the engineering discipline, the definitions of, and distinctions between, the terms `soil' and `rock' are usually based on measures of particle size and either hardness, durability, inertness, or any combination of these. The accepted values for these criteria are governed by the intended use of the material. Furthermore the use of `soil' or `rock' can have implications for administering and costing projects. The result has been a number of different definitions each appropriate to a specific field of work. The SHW, appropriately, prefers to use `material' and `classes of material' to avoid any confusion of terms. Where the word `rock' is used, in Sub-Clauses 603.5, 603.6 and 604.1, it refers to insitu rock or to argillaceous rock and is defined for use in selected fills. There is no such term as `rock in excavation' in the SHW and for excavation purposes `Hard Material', as defined in the MMHW, should be assessed from the investigation drilling rate and type of recovery, insitu tests, trial pits and exposures. As far as this Advice Note is concerned, rock, soil, or material are used as general engineering terms and no contractual definition should be inferred. This reflects the differing terminology found in earthworks construction, design, assessment, and documentation.

Implementation

1.6 This Advice Note should be used forthwith for all schemes currently being prepared or under construction provided that, in the opinion of the Overseeing Organisation this would not result in significant additional expenses or delay progress. The Design Organisation should confirm its application to particular schemes with the Overseeing Organisation.

2. TESTING FOR CLASSIFICATION AND ACCEPTABILITY

Responsibility for classification

2.1 SHW Appendix 6/1 requires the compiler to state who classifies and where. It is usually recommended that the Contractor should be given responsibility for classification of site won materials based on the Designer's limits and criteria. In some circumstances, however, it may be more appropriate for the Engineer to take this responsibility.

Responsibility for testing

2.2 SA 3 `Testing in highway construction contracts' (MCHW 0.3.3) should be consulted for details on responsibilities for testing and accreditation of testing and sampling.

2.3 It is recommended that in general the Engineer conducts testing. Where the Contractor is to provide the site testing laboratory for the Engineer's use, the Contract shall include at Appendix 1/1 details of all apparatus and equipment required to equip the Engineer's laboratory.

2.4 If the Contractor is given responsibility for testing, the tests and their frequency should be given in the Contract. The Engineer shall clearly specify in SHW Appendix 1/5 (based on Table NG 1/1) the type and minimum frequency of testing to be conducted to satisfy the design together with the source reference for each test (British Standard, SHW etc). The test results should be submitted as required by the Engineer.

2.5 The Contractor has an overall responsibility to maintain the nature of acceptable material, irrespective of who is responsible for testing, so that when it is placed and compacted it remains acceptable in accordance with the Contract.

2.6 Testing should be carried out at excavation for materials found on site unless the material is likely to change between excavation and deposition, in which case further sampling and testing should be carried out at deposition.

2.7 Imported materials should be sampled and tested for compliance at deposition and preferably also at source. SHW Appendix 6/1 should state the locations of all compliance sampling and testing

2.8 SHW Sub-Clause 601.4 allows unacceptable material to be processed by mechanical, chemical or other means to render the material acceptable. This will usually be achieved by reducing the moisture content of the material. The purpose behind this Sub-Clause is to make maximum use of on-site materials.

2.9 Advice on NAMAS accredited testing is given in SA 3 (MCHW 0.3.3). In Northern Ireland, NAMAS accreditation is not yet a requirement and any testing laboratory which the Contractor proposes to use will be subject to the approval of the Engineer.

3. SLOPES, BLASTING AND EXCAVATION

Soil Slopes

3.1 The soil slopes of cuttings and embankments should be inspected on construction and subsequently at regular intervals for signs of cracking or bulging which would indicate imminent failure of the slope, or seepage which could lead to instability. Instability early in a soil slope's life is likely to be deep seated, related to some form of discontinuity such as a pre-existing shear plane, or a thin weak clay layer. The consequences are likely to be severe and may involve considerable amounts of failed material. Shallow failures, as described by Perry (1989), are relatively rare on new soil slopes when compared to slopes over, say, ten years old but they do occur more frequently on steep recently constructed rock fill slopes as a result of topsoil slippage; the failure is not of the rock fill itself. Preventative measures in soil and rock slopes will be required in cases where a geotechnical investigation shows instability to be likely (Perry, 1989; Johnson, 1985). Where failure has already begun repair methods will need to be employed (HA 48 (DMRB 4.1.2); Johnson, 1985). Both strengthening and repair works may be the subject of a Variation Order subject to the changes being agreed by the Engineer. Instability due to excavation of the toe of the slope is covered in SHW Sub-Clause 603.2. Removal of toe restraint in this way can lead to failure of the slope which, in the case of cuttings, results in material moving onto the carriageway or, in the case of embankments, can undercut the pavement leading to movement and failure of the pavement.

3.2 Proposals for tree planting need careful consideration in terms of their effect on slope stability, particularly on clay slopes, as well as to ensure successful growth. Tree pits can pond water and concentrate flows of water into the slope which can lead to instability. It is necessary, therefore, to ensure the positions of pits are such that they do not form a path for the development of cracking and that water is prevented from ponding within them.

Rock Slopes

3.3 The exposed faces of rock cuttings should be inspected for discontinuities especially those orientated in such a manner as to lead to instability (Matheson, 1983; Hudson, 1989; Hoek and Bray, 1981). The face should also be examined for signs of excessive weathering after a period of exposure, preferably through the winter season. If left unchecked, excessive weathering could lead to instability and future high maintenance costs, incurred as a result of frequent removal of large amounts of debris from the base of the face. The inspections should be undertaken by an experienced geotechnical engineer and a report submitted on the stability of the face and whether remedial action is needed. Proposals for remedial action need to be agreed by the Overseeing Organisation. Further details can be found in HA 48 (DMRB 4.1.2) Earthworks: Maintenance of highway earthworks and drainage. Possible remedial measures are outlined in SHW Sub-Clause 603.6.

Blasting

3.4 Whenever blasting is anticipated, good public relations and a public information and education programme by Contractors are essential, both when blasting commences and during the following construction period. There needs to be full consultation with Local Authorities and the police regarding traffic management measures and publicity. The requirements for traffic management measures should include warning signal procedures.

3.5 Safety matters should always be considered. The blasting Contractor must be familiar with the appropriate codes of practice for safety, such as BS 5607 (1988) or equivalent in other states of the European Economic Area. SHW Clause 607 states that the Contractor shall only permit explosives to be used or handled by or under the immediate control of a competent person in accordance with Construction (General Provisions) Regulations 1961 (Regulation 19) and subsequent amending Regulations. Advice Note HA 44 (DMRB 4.1.1) gives details of acceptable vibration levels. The use of explosives in Northern Ireland is governed by the Explosives Regulations (NI) 1970.

3.6 SHW Appendix 6/3 includes requirements for blasting and the Engineer's arrangements for the Contractor's monitoring of property off-site. The nature and condition of property should be taken into account. An assessment of the sensitivity of the situation, having regard to the occupiers of such property, will need to be made if complaints are received.

4. COMPACTION OF EARTHWORKS MATERIALS USING THE METHOD SPECIFICATION

General

4.1 The SHW method specification defines how compaction should be conducted in terms of the types of compaction plant, method of operation of the plant, number of passes of the plant required and the final thickness of the compacted layer. Measurements of the final state of compaction, that is the in-situ dry density or air voids (defined in Appendix A) are not normally required.

4.2 The information given in SHW Table 6/4 has been determined from research using full scale testing of the plant described (Parsons, 1992). These trials ignored the effects of any compaction from earthmoving machinery, so that the figures are, to that extent, conservative. The values given are for satisfactory compaction of the more difficult conditions of materials in each group, so that in many instances the compaction may be more than adequate. The compactive effort stipulated in SHW Table 6/4 is designed to produce an adequate state of compaction (usually 10% air voids or less) at a conservative (low) moisture content for the particular class of soil (see SHW NG 612 for more details).

Ensuring compliance with the method specification

4.3 The flow chart in Figure 4.1 illustrates how compliance with the method specification can be achieved and forms the framework for the following paragraphs. SHW Sub-Clause 602.2 requires that the haulage of material to embankments or other areas of fill shall proceed only when sufficient spreading and compaction plant is operating at the place of deposition to ensure compliance with Clause 612 (Compaction of fills).

4.4 SHW Table 6/1 identifies different Classes of materials and prescribes different methods for compaction. When the method specification is required and more than one Class of material is being used, it may not be practicable to define the area where each Class of material occurs in order to apply the appropriate method of compaction. In these cases the method for the material requiring the greatest compactive effort shall be used (SHW Sub-Clause 612.8).

4.5 The majority of available compaction plant is included in SHW Table 6/4. It will be necessary to identify and classify these machines in order to determine the thickness of compacted layer and number of passes to be applied. The general type of machine (smooth-wheeled roller, vibrating roller, vibrating-plate compactor, etc), total mass and distribution of mass between rolls, must be determined and, in most instances, either width of roll, number of wheels, or area of plate. Direct weighing and measurements are preferable, although the machine specifications may be resorted to; it is essential that the correct parameters are used. Placing of fill materials must never commence until compaction plant is available. In approving the simultaneous usage of items of compaction plant of different types, the least thickness of layer and number of passes should be in accordance with SHW Sub-Clause 612.10 (xiv).

4.6 SHW Table 6/4 and SHW Sub-Clause 612.10 define, stipulate and classify the type of compaction plant to be used with the method specification. The list of compaction plant is comprehensive. If, however, the Contractor wishes to use a piece of construction plant not given in the SHW Table 6/4, the proposed alternative method must achieve the same state of compaction in a site trial as would be achieved using the specified method (SHW Sub-Clause 612.6, and Appendix C of this Advice Note).

4.7 Great reliance will have to be placed on earthworks inspectors to ensure compliance of compaction undertaken using the method specification. Difficulties will be minimized by ensuring that the continuous operation of the compaction machinery which the Contractor proposes to use is commensurate with the rate of fill to be expected from the excavating and spreading machinery in use. This is achieved by comparing the estimated output of the compaction plant with the estimated rate of input of earthwork material and as a result removes the need, under normal working conditions, for inspectors to count the number of passes of compaction plant. Particular attention must be given to ensure that the vibrating mechanism is in operation at all times during compaction.

4.8 In order to estimate the potential output of compaction plant, the Engineer's inspectors need to note the speed of travel of the compactor when it is operating normally. This can be achieved by timing the compactor over a measured distance. If the measured speed exceeds any maximum stipulated, or if a higher gear than that stipulated is used (eg with vibrating rollers), the speed should be reduced or the number of passes to be applied should be increased in proportion to the increase in speed beyond the maximum specified. It is not a requirement of the SHW that a speed restriction be applied to compactors other than vibrating rollers or vibrating-plate compactors, however it must be measured in order to determine potential output, and hence compliance. The potential output of the compactor or a team of compactors can be determined from the following:

$$P = \frac{(W \times V \times D)}{N}$$

Where	P	=	output of a machine (m^3/hr)
	W	=	effective width (90% of width of rolls to allow for overlap) (m)
	V	=	speed of travel (km/hr)
	D	=	depth of layer required in the specification (mm)
	N	=	number of passes required in the specification.

When P has been calculated it should be multiplied by a factor of 0.85 to allow for turning, minor stoppages, etc. on straightforward sites: on irregular shaped sites the time lost through these activities may be greater.

4.9 The rate of input of earthwork material to a given area of fill should be assessed from the number of loads per hour and the approximate capacity of the earthmoving machines. The rate of input in terms of compacted volume in m^3/hr must not exceed the potential output of the compactor or compaction team.

4.10 The depth of layer should be checked regularly, using a probe in the loose material or by small excavations in the compacted material. The relation between loose and compacted thickness will quickly become apparent and probing of the loose layer can take precedence. The uniform coverage of the area to be compacted and the continuous operation of the compaction plant should be ensured by general supervision of the fill area.

4.11 It is also necessary to check regularly the frequency of vibration of vibrating rollers and vibrating-plate compactors, to ensure that it is as stated in the manufacturer's specification. The SHW, in Sub-Clause 612.10, requires vibrating rollers to be equipped or provided with devices indicating the frequency of vibration of the mechanism which can easily be read by inspectors, together with the speed of travel. Vibrating-plate compactors are not required to have devices provided or be equipped, but the frequency of vibration must still be measured to ensure that they are operating at the frequency of vibration recommended by the manufacturers. One way of achieving this is to use a vibrating wand frequency measuring device, held against an appropriate part of the machine.

4.12 In summary, it is necessary to ensure the correct layer thickness of deposited material, that the spreading and compaction machinery are operating continuously, systematically and efficiently, and the rate of input of material for compaction does not exceed the output of the compaction plant.

Over-compaction of materials

4.13 When the moisture content of a soil exceeds the optimum moisture content for the compactive effort being applied, the compaction specified may produce over-compaction of some soils. Over-compaction is compaction of the whole layer to a point of saturation, within the acceptability limits of the Specification. Over-compaction will manifest itself as remoulding of the surface of the compacted soil or severe permanent deformation upon passage of the compactor. This is the result of a reduction in air-voids to a low level with the generation of excess pore water pressures. Note that elastic deformation (the `rubber mattress' effect) is not necessarily indicative of over-compaction in the surface layer but indicates the generation of excess pore water pressures in one or more of the underlying layers.

Although these conditions will dissipate with time, this may be long with cohesive soils. If remoulding of the surface or severe permanent deformation develops with cohesive soils first check that the moisture content of the material is below the acceptable upper limit. If so consider one or more of the following corrective measures:

(a) reduce the number of passes;

(b) increase the depth of compacted layer;

(c) temporarily cease compaction;

(d) change the method of excavating and hauling the material, and size of plant used;

(e) dry the material by rotavation or the like.

NOTE: The use of lighter compaction equipment with their own particular layer thicknesses and passes will not necessarily improve matters.

The measure applied should be related to the cause of the condition of the material and the economic consequences, and must be agreed by the Engineer.

4.14 Before concluding that over-compaction is taking place, a few trial holes should be excavated to the bottom of the layer to ensure that full compaction (near saturation conditions) occurs throughout the total depth of layer. If the bottom of the layer is not in a saturated condition then over compaction has not taken place and the compactive effort should be maintained at its original level in order to ensure the lower part of the layer achieves the correct dry density. Over-compaction is not a serious problem with most soil types encountered. (With chalk, however, over-compaction can lead to problems of instability and associated construction delays and a reduction in compactive effort is advisable.) When the compactive effort is reduced it should be deemed to be a temporary measure and the specified compactive effort should be reverted to from day-to-day to check whether soil conditions still require the modified treatment. If acceptability of the material is controlled by MCV, then material at MCV less than about 10 may be prone to over-compaction when using Methods 1 and 2 of SHW Table 6/4. The earthworks design should take over-compaction into account when setting acceptability

limits, for example by using these materials which may be susceptible to over compaction in the core of the embankment.

Poorly compacted materials

4.15 Poor compaction of a material is difficult to identify as the surface of the poorly compacted layer will often appear to be well compacted. Unlike an over-compacted material which has a moisture content in excess of the optimum moisture content for the applied compactive effort, poorly compacted materials are well dry of the optimum moisture content for the applied compactive effort. Consequently, the poorly compacted layer is also initially strong and does not deform under traffic. However low densities will be present deeper in the layer and large voids can occur near the bottom of a layer. In the longer term, the material will be able to take up any available water causing the material to weaken with resulting settlement at the surface. The only way to check for voids is by digging small trial holes and inspecting the condition of the material in the lower part of the layer. In general, materials placed at MCV in excess of about 14 may be poorly compacted when the method specification for compaction of earthworks is applied strictly. In order to remedy the situation, the thickness of layer should be reduced; reducing the depth of layer will generally produce better results than increasing the number of passes.

4.16 Designers should be aware of the acceptability limits which may lead to over-compaction or poor compaction. In order to make maximum use of materials the engineer should consider at the design phase of earthworks where and how these materials can be used.

Testing within the method specification (during main works compaction)

4.17 For method specification applications, provision has been made in SHW Sub-Clause 612.9 for the Engineer to carry out field density tests on compacted materials. The tests should be made only in the following circumstances.

(a) As a basis of settlement when compliance with the specified compaction requirements is in dispute.

(b) When it is suspected that despite compliance with the Specification the state of compaction achieved is inadequate to ensure stability of the fill. If the tests indicate inadequate compaction a Variation Order should be issued to cover the necessary remedial works.

(c) If alternative plant or techniques for compaction are proposed which are not included in SHW Table 6/4.

4.18 The results of such trials using one Class of material stated in SHW Table 6/1 should not be applied to the other Classes of material without further trials being undertaken.

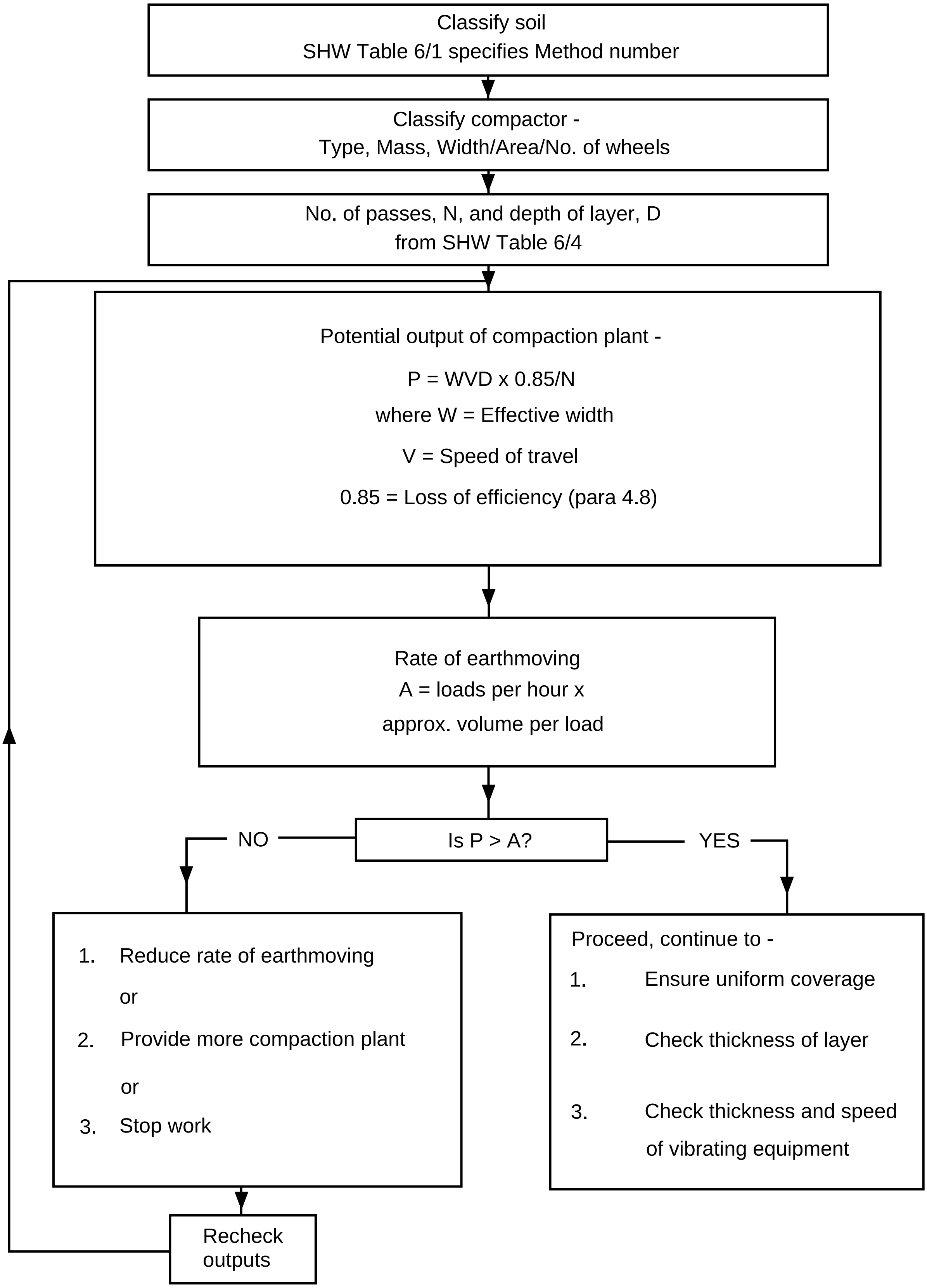

Fig. 4.1 Flow Chart for the control of method specification for the compaction of earthworks (after Parsons, 1992).

5. COMPACTION OF EARTHWORKS MATERIALS USING THE END-PRODUCT SPECIFICATION

General

5.1 To apply the end-product specification, density testing will be needed to ensure adequate compaction is achieved, ie that the percentage dry density given in SHW Table 6/1 has been achieved or bettered. Appendix A explains how to calculate dry density. The thickness of loose material prior to compaction is limited to 250mm (SHW Sub-Clause 608.1 (iii)) so that effective control can be maintained. In-situ bulk density and moisture content determinations are required to ascertain the in-situ dry density using the formula in Appendix A. In addition, laboratory testing is required to determine whether the dry density achieved on site meets the percentage of the specified laboratory compaction test given in SHW Table 6/1.

Classes of material are given in Table 6/1 of SHW and materials which require an end-product specification are as follows:

(a) Class 2E reclaimed pulverized fuel ash cohesive materials as general fill. Compaction requirement: 95% of maximum dry density of BS 1377:Part 4 (2.5kg rammer method);

(b) Class 6K and 6M materials surrounding corrugated steel buried structures. (The upper bedding, Class 6L, requires no compaction). Compaction requirement: 90% of maximum dry density of BS 1377:Part 4 (vibrating hammer method). Class 6M can have other compaction requirements if stated in Appendix 6/1;

(c) Classes 6N, and 6P fill to structures. Compaction requirement: 95% of maximum dry density of BS 1377:Part 4 (vibrating hammer method).

(d) Class 7A fill to structures. Compaction requirement: 100% of maximum dry density of BS 1377:Part 4 (2.5kg rammer method) or a dry density corresponding to 5% air voids at the field moisture content whichever is the lower;

(e) Class 7B fill to structures and reinforced earth. Compaction requirement: 95% of maximum dry density of BS 1377:Part 4 (2.5kg rammer method);

(f) Class 9C cement stabilized pulverised fuel ash cohesive material. Compaction requirement: 95% of maximum dry density of BS 1924:Part 2 (2.5kg rammer method);

Types of in-situ bulk density test (SHW Sub-Clause 612.15)

5.2 The sand-replacement test is fully described in BS 1377: Part 9 (1990) and is the preferred method in the UK for the determination of in-situ bulk density. It is, however, laborious, time consuming and prone to error in wet non-cohesive soils where slumping of the excavated hole can occur and in dry and fissured soils. It may be used on fine, medium and coarse grained compacted soils.

5.3 Nuclear methods for determining density and moisture content are popular because of their speed of measurement and the greater reliability of currently available instruments compared with the earlier models. They may be used when required in SHW Appendix 6/3 or when permitted by the Engineer and as an adjunct to sand replacement testing (see Appendix D). Where the two methods are to be used, they should be used in the early stages of the Contract to calibrate nuclear methods on site for each class of material (see Paragraph D3).

Tests in Pulverised Fuel Ash (PFA)

5.4 After PFA has been compacted, loose materials can be present on the surface of the layer, even though the rest of the layer below meets the end-product specification. This loose material will, however, become compacted when the next layer above is placed and compacted. Field density measurements will be required to ensure compaction has met the end-product specification. Any loose material on the surface of the layer at the testing location should be removed before testing as this will become compacted by the next layer.

The depth tested below the removed material should be sufficient to include the previously loose material on the surface of the underlying layer. Usually the depth of overstressed material is about 100mm but depends on the nature of the PFA and the size and type of compaction plant. Due to the variability of PFA and the effect this can have on compaction, SHW Sub-Clause 601.17 enables the Engineer to keep a record of the sources, and places the onus on the Contractor to provide the requisite data including moisture content on delivery, and the optimum moisture content and maximum dry density of each consignment. For PFA in general fill applications, Class 2E, the end-product specification relies on achieving 95% maximum laboratory dry density. If the weight of the embankment is critical to the design, then the bulk density of the PFA must fall within the limits given in the design. The bulk density limits are based on consideration of the settlement of the soil beneath the embankment expected in the design, while the purpose of the dry density requirement is to achieve adequate compaction within the fill.

6. LANDSCAPE AREAS

On-site landscape areas

6.1. On-site landscape areas can be excellent locations for use as temporary holding areas for acceptable fill where there is the possibility that the Contractor may need more fill in a particular area, or for placing surplus material without needing to find additional off-site tips.

6.2 The reduced compaction requirement in landscape areas means that materials with wider acceptability criteria may be used thus leaving the better engineering materials for fill areas.

6.3 Areas of special interest, eg trees, require protective fencing and careful monitoring. These areas should be treated in a similar way to areas of earthworks instrumentation which also need to be carefully protected.

6.4 Any special requirements for topsoil should be carefully monitored and controlled where necessary.

6.5 All on-site landscape areas should be subjected to the Geotechnical Certification process. Other landscape operations, such as to strip topsoil, or other earthwork operations to produce ecologically different conditions should also be subject to Geotechnical Certification. Procedure for Geotechnical Certification is covered in HD22 (DMRB 4.1.2).

7. INFORMATION ON SOME SPECIFIC MATERIALS

General

7.1 Some general information is given below on some specific materials which complements the information in HA 44 (DMRB 4.1.1). HA 44 (DMRB 4.1.1) covers a wider range of materials in more detail and should be consulted if more information is required.

Chalk

7.2 Chalk is sensitive to disturbance at excavation, during transportation, placing and compaction and should be handled with care. HA 44 (DMRB 4.1.1) includes information on classification of chalk and the appropriate method of compaction.

7.3 If small pockets of soft chalk are encountered during construction in hard chalk areas, it may be better to leave the compaction method, as required for the harder chalk, unchanged and either remove occasional unstable material as it is found or alternatively allow delays for the softer material to recover stability. Reducing the compactive effort to suit the soft chalk will risk long-term settlement in the under-compacted hard chalk.

7.4 If it is found that the compaction requirement consistently causes instability on site, the Engineer may reduce this requirement.

Minestone

7.5 Minestone is the generic name for unburnt colliery shale which consists mainly of shales, mudstone and siltstones. Minestone is extremely variable and the properties of material coming from a tip may change significantly as excavation progresses. There should therefore be frequent sampling and testing at the source.

7.6 The argillaceous materials in Minestone are moisture susceptible and are likely to soften and swell when weathered. Large amounts of weathering occur in older tips as they tend not to have been compacted when tipped and have been exposed to the elements for longer. On the other hand, newer tips will contain amounts of unweathered pyrites. It will therefore be necessary to consider the properties of the minestone and the use to which it is to be put. Older weathered material, timber (pit props etc) and large lumps should not be used.

7.7 Minestone can be chemically reactive and it is important that as much emphasis is placed on chemical tests as is placed on physical ones. There are limitations on its use in the vicinity of concrete structures as a permitted constituent in Table 6/1.

7.8 One source of information is British Coal Property, Unit 21, Philadelphia Business Park, Houghton-le-Spring, Tyne and Wear DH4 4TG.

Pulverised Fuel Ash (PFA)

7.9 Details on the properties of PFA are given in HA 44 (DMRB 4.1.1). Slopes of PFA are particularly susceptible to erosion if not protected. Care should be taken to ensure that the PFA is covered as soon as possible after forming the slope and that the topsoil used remains stable. It is the Contractor's responsibility to ensure that the site is adequately drained during construction.

7.10 Further information on the use of PFA can be found in Dhir and Jones (1992).

7.11 PFA and Minestone are industrial by-products and their use has environmental benefits. The benefits include the reduction in the size and number of spoil tips and the saving of natural resources such as gravel beds. By conserving natural resources, the amount of disturbance of green field sites is reduced and the productive life of resources is extended.

Geotextiles

7.12 SHW Clause 609 and HA 44 (DMRB 4.1.1) provide details on the use and handling of geotextiles during construction.

7.13 It is important that geotextiles do not suffer physical or chemical damage during construction as this can lead to a reduced life and the risk of instability. SHW Clause 609 specifies the requirements to prevent damage and hence ensure that the design life requirements are met. Damage can be caused by mechanical effects, such as:

(a) puncturing by sharp projections;

(b) tearing during placement or by construction plant running over the geotextile once laid.

The main cause of chemical damage is the embrittling effect that ultra-violet light has on the geotextile. The inclusion of Carbon within the polymers used to make the geotextiles reduces this effect.

8. EFFECTS OF CONSTRUCTION PLANT OPERATIONS

General

8.1 At higher moisture contents the range of types of plant which can be used will be restricted. However, this should not inhibit the use of wetter cohesive materials. Providing the site investigation is adequate and gives information on the moisture conditions of soil in-situ then it is the Contractor's responsibility to select and use plant which can operate effectively in the particular conditions and not to assume that the largest available machines can be used. The Contractor has a responsibility under SHW Sub-Clause 602.1 to maintain the acceptability of materials and so plant which will reduce the strength of material either remaining in-situ, being transported and placed or in its final compacted state should not be used.

Minimizing the effects of construction plant operations

8.2 SHW Sub-Clauses 617.1 and 617.2 require that sub-formation and formation be protected from construction plant not involved in the construction of capping and sub-base. If necessary protection should be in addition to any weather protection already provided. Also in SHW Sub-Clause 617.3, the sub-formation and formation must be protected from construction plant if they are within 300mm of existing ground level, after topsoil has been stripped.

8.3 During lime stabilization processes where powdered lime is being used, lime spreading and rotavation plant should be operated in such a manner so as to keep the amount of lime dust to a minimum. The amount of lime dust in the air can be reduced by ensuring the lime discharging outlet of the spreading plant and the hood of the rotovating plant are efficiently curtained. Although this will prevent most dust from escaping, consideration may need to be given to the surrounding areas outside the highway boundary to ensure there is no hazard to health or property. The Lime Stabilization Manual (1990) contains information on safety aspects.

8.4 When working in urban areas it is important that the Resident Engineer is alert to the problems which could arise when earthmoving construction plant and vibratory compaction plant are operating. It is important that any restrictions on working hours, noise levels and vibration levels specified in the Contract are strictly adhered to in order to keep noise, vibration and visual impact to a minimum. New (1986) provides guidelines on acceptable vibration levels and BS 7385 provides guidance on the Evaluation and Measurement for vibration in buildings.

9. PREVENTING THE SPREAD OF PLANT AND ANIMAL DISEASES

9.1 The Engineer should make contact with the Ministry of Agriculture, Fisheries and Food Divisional Veterinary Officer (DVO) and, in England and Wales, the Senior Plant Health and Seeds Inspector (SPHSI); or in Scotland, the Principal Agricultural Officer (PAO) for the area concerned; or in Northern Ireland, the Department of Agriculture, Animal Health Division or Agricultural and Food Science Division, to enquire if:

(a) any statutory restrictions currently apply to the site or in the immediate locality, and if there is any need for special precautions to be taken;

(b) they know of the presence of any soil-borne diseases in or near where the Contractor will be working.

The Engineer should be aware of these requirements and have made comment in the `Special Requirements' or within SHW Appendix 6/2.

9.2 If the site involves removing trees, then it is recommended that the Engineer consults the Forestry Commission Plant Health Inspector for the area for advice on how to avoid spreading tree diseases. In Northern Ireland, consultation should be with the Forestry Services Officer of the Department of Agriculture.

9.3 Further advice on precautions to be taken is given in Ministry of Agriculture, Fisheries and Food publication "Preventing the Spread of Plant and Animal Diseases - A Practical Guide" (1991).

10. INSTRUMENTATION AND MONITORING

10.1 The installation of instrumentation is specifically included in a Contract for collecting information important to the successful completion and design life of the construction. The construction and longer term performance of the Works will depend on the information recorded.

10.2 The instrumentation should be installed, monitored and maintained as conscientiously as any other aspect of the Works.

10.3 It may be necessary to control site operations in order to avoid damage to the instruments, to analyze the results obtained and to have a defined set of criteria to compare the observed results against. Investigatory and action levels should be known.

11. FEEDBACK

11.1 This is an important aspect of construction. Whether the Works have been a success or a problem, will add useful information for future designs and construction techniques.

11.2 Under Geotechnical Certification procedure HD22 (DMRB 4.1.2), the Engineer's Representative is required to produce a Geotechnical Feedback report detailing the location and nature of materials encountered, particularly geotechnical problems and their solutions. The format of the Geotechnical Feedback report is given in Appendix H of HD22.

12. REFERENCES

1. **Design Manual for Roads and Bridges (DMRB).**

HA 43 - Geotechnical considerations and techniques for widening highway earthworks (DMRB 4.1.2).

HA 44 - Earthworks: design and preparation of contract documents (DMRB 4.1.1).

HA 48 - Earthworks: maintenance of highway earthworks and drainage (DMRB 4.1.2).

HD 22 - Ground Investigation and Earthworks: Procedure for Geotechnical Certification (DMRB 4.1.2).

2. **Manual of Contract Documents for Highway Works (MCHW).**

Volume 0: Model contract document for major works and implementation requirements:

SD5 - Model contract document for Highway Works (MCHW 0.1.1)

SA 3 - Testing in Highway Construction Contracts (MCHW 0.3.3)

Volume 1: Specification for highway works (December 1991): HMSO (MCHW 1).

Volume 2: Notes for guidance on the specification for highway works (December 1991): HMSO (MCHW 2).

Volume 4: Bills of quantities for highway works (December 1991): HMSO (MCHW 4).

Section 1: Method of Measurement for Highway Works.

3. **British Standards Institution**

BS 5607 Code of practice for safe use of explosives in the construction industry. BSI London.

BS 1377 Methods of test for soils for civil engineering purposes. BSI London.

BS 1924 Stabilized materials for civil engineering purposes. BSI London.

BS 7385 Evaluation and measurement for vibration in buildings.

4. BRITISH LIME ASSOCIATION (1990). Lime stabilization manual. 2nd Edition.

5. DHIR R K and JONES M R (1992). The use of PFA in construction. Proceedings of the national seminar held at the University of Dundee on 25-27 February 1992.

6. HOEK E and BRAY J W (1981). Rock slope engineering. 3rd Edition Institution of Mining and Metallurgy.

7. HUDSON J A (1989). Rock mechanics principles in engineering practice. CIRIA.

8. JOHNSON P E (1985). Maintenance and repair of highway embankments: studies of seven methods of treatment. Department of Transport, TRRL Research Report RR 30, Transport and Road Research Laboratory, Crowthorne.

9. MATHESON G D (1983). Rock stability assessment in preliminary site investigations - graphical methods. Department of Transport, TRRL Laboratory Report 1039, Transport and Road Research Laboratory, Crowthorne.

10. MINISTRY OF AGRICULTURE, FISHERIES AND FOOD (1991). Preventing the spread of plant and animal diseases: a practical guide. MAFF Publications, London SE99 7TP.

11. NEW B (1986). Ground vibrations caused by civil engineering works. Department of Transport, TRRL Research Report RR 53, Transport and Road Research Laboratory, Crowthorne.

12. PARSONS A W (1992). Compaction of soils and granular materials: a review of research performed at the Transport Research Laboratory. HMSO.

13. PERRY J (1989). A survey of slope condition on motorway earthworks in England and Wales. Department of Transport, TRRL Research Report RR 199, Transport and Road Research Laboratory, Crowthorne.

13. ENQUIRIES

All technical enquiries or comments on this Standard should be sent in writing as appropriate to:

Head of Road Engineering and Environmental Division The Highways Agency St Christopher House Southwark Street London SE1 0TE	N S ORGAN Head of Road Engineering and Environmental Division

The Deputy Chief Engineer Roads Directorate The Scottish Office Industry Department New St Andrews House Edinburgh EH1 3TG	J INNES Deputy Chief Engineer

Heads of Roads Engineering (Construction) Division Welsh Office Y Swyddfa Gymreig Government Buildings Ty Glas Road Llanishen Cardiff	B H HAWKER Head of Roads Engineering (Construction) Division

Assistant Chief Engineer (Works) Department of the Environment for Northern Ireland Roads Service Headquarters Clarence Court 10-18 Adelaide Street Belfast BT2 8GB	W J O'HAGAN Assistant Chief Engineer - (Works)

A. CALCULATION OF DRY DENSITY AND AIR VOIDS

A.1 Dry density (ρ_d) is the mass of the dry soil contained in unit volume of undried material:

$$\rho_d = \frac{100\rho}{100 + w}$$

where ρ = bulk density; the mass of material (including solid particles and any contained water) per unit volume including voids.

w = moisture content; the mass of water which can be removed from the soil, usually by heating at 105°C, expressed as a percentage of the dry mass.

A.2 Air voids (V_a) is the volume of air voids in the soil expressed as a percentage of the total volume of the soil and is usually calculated by:

$$V_a = \left[1 - \frac{\rho_d}{\rho_w}\left(\frac{\rho_w}{\rho_s} + \frac{w}{100}\right)\right] 100(\%)$$

where ρ_d = the dry density of the soil (Mg/m^3)

ρ_w = the density of water (Mg/m^3) (1.0 Mg/m^3 is normally used, which is the density at 20°C)

ρ_s = particle density (Mg/m^3)

w = moisture content; the mass of water which can be removed from the soil, usually by heating at 105°C, expressed as a percentage of the dry mass.

B. TESTING WITHIN THE SHW METHOD SPECIFICATION (DURING MAIN WORKS COMPACTION)

B.1 To compare the difference in the state of compaction of suspect and approved areas, tests should be carried out on areas in which materials are of the same classification, having similar characteristics and within the Specification requirements for acceptability. It is for the Engineer to demonstrate that the Contractor's compaction is inadequate beyond reasonable doubt. When measurements of the state of compaction of an area are carried out, due allowance should be made for the variability of the test results, and the appropriate number of tests within an area should be related to the accuracy required and the standard deviation of the results obtained. It is recommended that initially a minimum of five tests be carried out in each area. Air void measurements are used to minimise the effects of variations of materials. From these results the mean and standard deviation of the air voids for each area can be calculated from;

$$\textit{mean air voids} = \frac{\sum V_a}{n}$$

$$\begin{matrix}\textit{standard deviation (sd)} \\ \textit{of air voids}\end{matrix} = \sqrt{\frac{\sum V_a^2 - \frac{[\sum V_a]^2}{n}}{n-1}}$$

where V_a = air voids (as defined in Appendix A)
n = number of samples

Subsequently an additional number of tests may be carried out sufficient for the accuracy required using Table 1 with the standard deviation obtained for that area. Usually the values of standard deviation lie between $\pm$3% and $\pm$5% air voids. Having conducted sufficient testing, the Engineer should require remedial measures to be taken in a suspect area <u>only when the state of compaction is shown to be lower</u> than that of the approved area with which comparison is being made, by a difference which is statistically significant (with a 90% probability).

B.2 To illustrate this approach, consider the following results for an approved and a suspect area.

Approved Area -

sd of first five readings = $\pm$3.5%. Using Table 1 for an accuracy of mean air voids of $\pm$2%, a further 5 tests, giving a total of 10, were conducted. The 10 results from these tests gave a mean air voids of 5.0%, a similar standard deviation and hence a confidence interval of 3%-7%.

Suspect Area -

sd of first five readings = $\pm$3.0%. Using Table 1 for an accuracy of mean air voids of $\pm$2%, a further 3 tests, giving a total of 8, were conducted. The 8 results from these tests gave a mean air voids of 5.5%, a similar standard deviation and hence a confidence interval of 3.5% - 7.5%.It can be seen that the ranges of the means in the suspect and approved areas overlap and so it can be concluded that there is no significant difference, with a 90% probability, between the mean air voids in both areas, and that the suspect area achieves adequate compaction.

B.3 If the standard deviation had changed with the addition of further tests then a new accuracy would be obtained from Table 1 which, if it were not acceptable, would lead to further testing.

TABLE 1

Numbers of tests required to produce results having mean values of air voids within various limits of error with a probability of 90%

Value of standard deviation of air voids %	Number of tests for limit of error of:				
	±1% air voids	±2% air voids	±3% air voids	±4% air voids	±5% air voids
±1	5	3	3	3	2
±1.5	8	4	3	3	3
±2	13	5	4	3	3
±2.5	19	7	4	4	3
±3	26	8	5	4	4
±3.5	35	10	6	5	4
±4	45	13	7	5	4
±4.5	57	16	8	6	5
±5	70	19	10	7	5
±5.5	84	23	11	8	6
±6	99	27	13	8	6
±6.5	116	31	15	9	7
±7	135	35	17	11	8

C. TRIALS TO ENSURE THAT PROPOSED NEW METHODS ACHIEVE ADEQUATE COMPACTION

C.1 SHW Sub-Clause 612.6 has been included to facilitate the development of new plant or techniques for soil compaction. Where the Contractor proposes to use a type of plant or method other than those given in SHW Table 6/4, it is recommended that the proving trials be carried out in the following manner.

(a) The trial area should be located on material compacted in accordance with SHW Clause 612 to a depth of at least 1 metre. The materials in the trial area must have the same classification, similar characteristics and be within the Specification requirements for acceptability as those on site. The length of the trial area should be about 15 to 20 metres and the width at least four times the overall width of the largest item of plant to be used.

(b) The trial area should be divided into two equal widths and acceptable materials, as defined in SHW Clause 601 and the Classes in SHW Table 6/1 upon which the Contractor intends to use the proposed alternative plant or method, deposited evenly over each half. The depth of the material in the first half should be such as will produce the appropriate depth of compacted layer as required in SHW Table 6/4 for the approved plant to be used in the trial, and in the second half, the depth proposed by the Contractor for the alternative plant or method. Care should be taken to ensure that uniform soil conditions are achieved over the whole trial area.

(c) The trial area should then be compacted; the first half by using the approved plant according to the requirements of SHW Table 6/4 and the second half according to the Contractor's proposals.

(d) After compaction, determinations of the state of compaction, in accordance with the sand-replacement method or by nuclear gauge methods as described in BS 1377: Part 9 (1990) should be made in each half of the compacted area. For each half the air voids so obtained should be the average for the total depth of the compacted layer, except where the surface material has been loosened, in which case the loose material should be removed prior to testing. Sufficient tests should be carried out in each half of the compacted area to yield results on which decisions can be made on a sound statistical basis. That is, the number of tests in each half of the compacted area should be progressively increased until, by satisfactory analysis, it is shown that any difference between the mean air voids of the two halves is statistically significant (with a 90% probability) (see Table 1) or until the limits of error of each mean has been reduced to ±1% of air voids (see Table 1). In order to show there is a significant difference between the means, the confidence ranges, as deduced in a similar way to the example given in Appendix B, should not overlap.

(e) Having conducted sufficient tests and either shown a significant difference between the means or shown a high degree of confidence in the value of each mean, the Contractor's proposed method should be approved if the mean of its air void determinations is less than or equal to the mean air voids obtained from the approved method. This is a more rigorous approach compared to that in Appendix B as the new approved method is likely to be used throughout the earthwork's construction.

(f) If the Contractor cannot achieve adequate compaction using an initial suggested method, then increasing the compactive effort may be considered.

D. NUCLEAR METHODS

D.1 Nuclear methods are suitable for use on fine, medium and coarse grained compacted soils. SHW Sub-Clause 612.15 states that the nuclear gauges used shall be calibrated in accordance with BS 1377: Part 9, and their use shall comply with the safety requirements of SHW Clause 123. Nuclear gauges operate in two different modes for the determination of bulk density.

(a) The direct transmission method is the recommended method for measuring bulk density. It involves inserting a probe containing a source of gamma radiation down a preformed hole in the soil and placing a gamma detector at the surface of the soil. This technique measures the amount of attenuation of the gamma particles reaching the detector which is a function of the average bulk density over the depth to which the source is inserted.

(b) The backscatter method uses both a gamma source and detector at the surface of the soil, and as a consequence tests only a thin upper layer of soil. This method should only be used for bulk density determinations when the probe of the direct transmission method cannot be inserted into the soil.

The determination of moisture density relies on the reduction in the speed of neutrons, from a fast neutron source, as they collide with hydrogen nuclei in the soil. The source and detector are placed on the surface of the soil but the technique can be used with either direct transmission or backscatter modes when determining bulk density. The dry density of the soil is the difference between the bulk density and the moisture density, and the moisture content is calculated by the percentage of moisture density to dry density. These values are usually calculated by a micro-processor on the gauge. It is essential that the calibrations prepared by the manufacturers of the instruments are checked for each soil type and, when using the backscatter method, after any significant change in method of compaction. In checking calibrations, it is important to compare values of bulk density and moisture density for the gamma radiation and neutron radiation techniques respectively (see Paragraph D4). For the backscatter method, it is recommended that the nuclear gauge be calibrated insitu.

D.2 The principal sources of variation in calibration and in measurement are:

(a) the effects of the chemical constituents of the soil on:

(i) the absorption of gamma radiation (for example by iron in blast furnace slag) which affects the calibration for the measurement of bulk density;

(ii) the presence of hydrogen which is not removed during the drying process; for example soils containing organic matter, or minerals, such as gypsum, with high amounts of chemically bound water which cannot be distinguished from free water by the nuclear gauge. Some elements such as cadmium, boron and chlorine can also have an effect on moisture density measurements.

(b) for the direct transmission method, the effects of variations in particle size on the degree of disturbance created by inserting the probe;

(c) for the backscatter method the effects of density gradients within the layer; the density of the near surface material sampled by the gauge bears little or no relation to the overall average density of the layer;

(d) for both measurements of bulk density and moisture density, heterogeneity within the layer can lead to unrepresentative results.

(e) lack of contact between the gauge and soil surface can affect results for all modes of operation.

D.3 Ideally the calibration of nuclear gauges should be checked by performing both sand replacement and nuclear testing in the early stages of a scheme. As confidence increases in the relation between the nuclear results and sand replacement results on a particular site, the intensity of sand replacement testing may be reduced.

D.4 The basic calibrations for a nuclear gauge are in terms of relations between intensity of detected gamma radiation at the detector and bulk density, and between neutron intensity at the detector, which is related to the rate of arrival of the slow neutrons, and moisture density. It is important that the correct parameters are compared and subjected to correction, ie bulk density (nuclear) with bulk density (sand replacement), and moisture density (nuclear) with moisture density (sand replacement and oven drying). Note that moisture density = bulk density - dry density. Typical results under controlled conditions are given below, for a well graded sand, illustrating how such comparisons would allow subsequent corrections to be applied to the nuclear gauge readings for that soil.

$$D_{SR} = 1.297\,D_{NG} - 0.532$$
$$M_{SR} = 0.856\,M_{NG} + 0.026$$

where D_{SR} = bulk density by sand replacement (Mg/m^3)
D_{NG} = bulk density by nuclear gauge (Mg/m^3)
M_{SR} = moisture density by sand replacement (Mg/m^3)
M_{NG} = moisture density by nuclear gauge (Mg/m^3)