The designer should consider whether a surcharge due to traffic or similar live loads needs to be considered in settlement assessments since loading of this type is normally transient and of short duration. Traffic loads are normally local to the surface of the earthwork and usually contribute only a small proportion of the total earthwork load thus they may generally be ignored in settlement assessments unless there is a particular reason to take account of short term transient loads.

7.6.4 Selection of material properties for earthworks fill

An important activity for every earthworks project is the selection of material properties for the fill; this is considered to be a design activity regardless of whether it is undertaken by a contractor or a consultant. The material properties should be chosen to ensure that the engineering design assumptions are satisfied as well as addressing construction practicalities.

The material properties for earthworks fill should be selected to ensure that:

- the material can be trafficked, placed and compacted during construction of the earthworks;
- the earthworks will be stable during and after construction;
- excessive settlement or heave will not take place.

For the majority of fill materials the acceptable material properties should be related to limits applied to either moisture content, MCV or shear strength e.g. see Table 6/1. It is strongly recommended that only one of these properties is used for a particular acceptability limit.

For most coarse soils the upper and lower acceptability limits should be selected by reference to a particular ratio of dry density to the maximum dry density. The values are determined from dry density/moisture content relationship tests, which are illustrated in general terms in Figure 9. The most commonly adopted criteria are 95% of the maximum dry density determined from the 2.5 kg light dynamic compaction test or 90% of the maximum dry density determined from the vibrating hammer test for bulk earthworks fill. A higher value up to 100% of the maximum dry density is required for fill that will support structures where settlement is more critical. It is recommended that the air voids content at the proposed lower acceptability limit is checked to ensure that excessive air voids will not remain within the fill at the chosen compaction ratio; however, an air void content less than 10% may not be feasible with some uniformly graded coarse soils.

It is important to note that the maximum dry density and optimum moisture content are not fundamental soil properties and the values are dependent on the compactive effort imparted to the material.

For fine soils the upper acceptability limit (see Figure 10) e.g. minimum MCV, should be chosen in relation to the requirements for placement of the fill, stability of slopes, and settlement of the fill due to internal loading (see **7.6.3**). These requirements may vary for different end uses of the earthworks, which will determine the fill properties of greatest importance, e.g. permeability for a flood bund, or in-situ density for structural fill. The lower acceptability limit (minimum moisture content, maximum MCV or maximum shear strength) should be selected to reduce the air voids in the material to a value that will restrict the potential for excessive movement after compaction. A maximum of 10%

air voids for bulk earthworks fill and 5% air voids for earthworks fill that is to support structures are commonly specified values. Research at TRL led to the development of the compaction requirements of Table 6/4 of the SHW [1] which are intended to achieve these values for the relevant classes of fill provided that the moisture content of the material is appropriate. Further guidance on the degree of compaction achieved using the methods specified in Table 6/4 is provided in HA44/91.

When there are specific requirements to limit the internal settlement for large bodies of fill that will carry structures (as described at **7.6.3**) then the approach of selection of design parameters beyond that which would normally be considered under the SHW [1] approach may be developed. One methodology that may be used is proposed in BRE Digest 427 [37], whereby:

- the moisture content upper and lower acceptability limits of the fill are chosen based on OMC from both the standard Proctor (2.5 kg rammer) and the modified Proctor (4.5 kg rammer) compaction tests (i.e. relatively dry material for fine soils), see Trenter [35] for further details;
- and the method of compaction is selected to ensure heavy compaction is delivered (which is likely to be in excess of the SHW standard methods); and
- the earthworks are monitored to ensure a high in-situ density and low air voids are achieved.

It should be noted that a fine soil that is at Point A on Figure 10 will not benefit from further compaction and the strength could be reduced due to the generation of excess porewater pressure if further compactive effort is applied. Excess porewater pressures weaken the fill layers affected, which limits the effectiveness of compaction of subsequent layers of fill on fill; therefore a pause of a few days should be accommodated to allow dissipation prior to recommencing earthworks. By contrast the dry density of a soil at Point B should increase if additional compactive effort is applied.

NOTE Fills with a significant proportion of coarse particles represent a problem for determination of acceptability criteria, as these soils often prove inappropriate for either laboratory testing or in-situ density testing. BS 1377-4:1990 sets an upper limit of 10% of particles coarser than 37.5 mm and 30% coarser than 20 mm above which standard laboratory compaction tests are not applicable since the fill is classified as being "Grading Zone X". However, if the Zone X criteria are strictly applied, then many UK materials used as fill are classified as untestable by virtue of a relatively low granular content (e.g. well-graded glacial till). This is actually detrimental to the management of the earthworks project. Trenter [35] provides methods for adjustment of the results to allow for the influence of coarse fraction.

An experience based approach is recommended for these coarse soils to determine the most appropriate method for testing and management of the fill. For gap graded or well graded fills (granular or cohesive) the earthworks engineer may judge that there is a matrix of testable material that will strongly influence the performance of the fill. In many cases it may be appropriate to remove coarse particles to facilitate laboratory testing and base the acceptability criteria on the finer fraction of material.

Acceptability criteria based on moisture content may be used for very coarse granular fills, such as Class 1C and Class 6B of the SHW [1]. Compaction using Method 5 of SHW Table 6/4 may provide a general approach but performance should be reviewed on site. The construction and analysis of trial embankments should be used to provide definitive site and source specific guidance for compaction of very coarse fills.

The above is a limited summary only; designers of earthworks should have an awareness of the various issues that might influence the fill material that they will utilize.

*COMMENTARY ON **7.6.4***
It is useful for the earthworks engineer to have an understanding of both the underlying principles of fill material behaviour and the development history of earthwork engineering. The latter is important since earthworks is not a well defined science, and to resolve certain practical difficulties the standard approaches draw upon previous work. Of particular importance in the development of the subject is the testing undertaken by the Transport Research Laboratory to develop the method specification that is included with the SHW [1], details of the TRL research were recorded by Parsons [38]. Field trials by the Building Research Establishment showed the importance of control of air voids content of fill materials incorporated in earthworks for future building development (e.g. BRE Digest 427 [37], Charles et al [39]).

Informative descriptions of the history and principles that underlie earthworks are included in a number of published documents including:

- *HA44/91 [17] and HA70/94 [18];*
- *Trenter and Charles [40] re building on earthworks;*
- *Reeves et al [41];*
- *Trenter [35].*

These documents provide guidance on the selection of appropriate parameters for earthworks materials (and limited comment on the selection of suitable tests for the practical control of the construction of earthworks).

Fine soils and weak argillaceous rocks that are placed dry in a relatively loose condition are prone to collapse on subsequent wetting (Charles and Watts [42]). It is particularly important that the air voids content of these materials is restricted to prevent collapse settlement. Where possible it is advisable to avoid use of such fills in situations where inundation by floodwater or groundwater is likely.

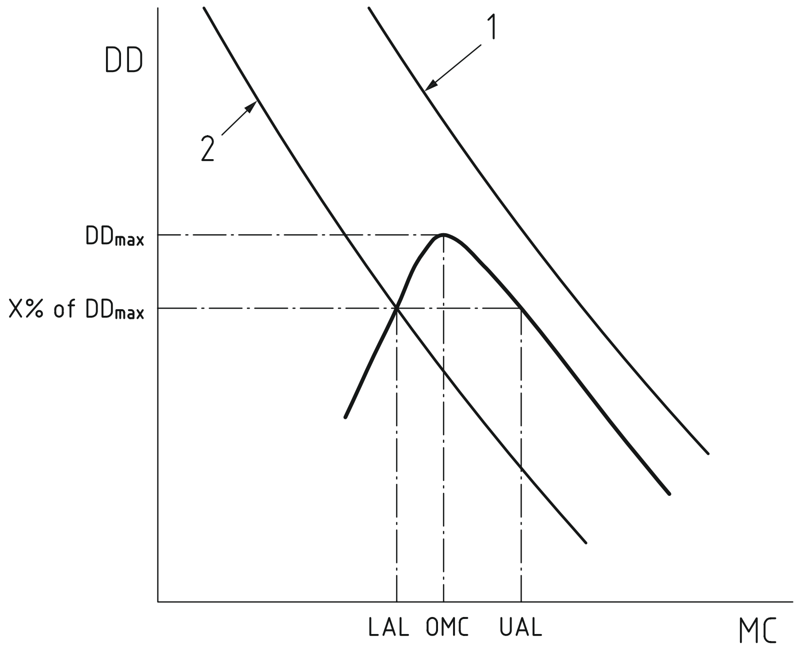
7.6.5 Compliance testing

The Designer should select the appropriate form of compliance testing for the earthworks. The selection of material properties should consider the feasibility of performing compliance testing relative to the selected acceptability criteria and the constraints imposed by the contract and construction operations.

Relationship testing should be used to determine the correlation between compliance tests that will be used to control the earthworks (such as MCV) and the fundamental soil properties upon which the earthworks design is based (such as undrained shear strength). An illustration of the relationship test concept is provided at Figure 11. The relationship testing should be used to determine the acceptability limits for the chosen compliance tests. The correlation testing should be carried out during the ground investigation phase but may also be required during the construction phase to address natural variation of materials encountered.

Designers should maintain awareness of developing technologies for in-situ and laboratory testing.

Figure 9 **Determination of acceptability limits for coarse soils using relationship testing data**

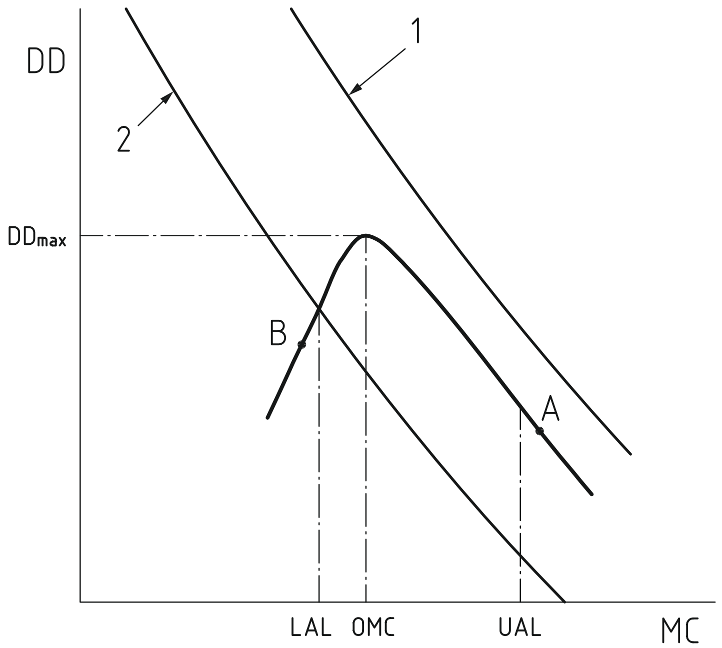


Key

1	Saturation line (0% air voids)
2	X% air voids
MC	Moisture content (%)
DD	Dry density (kg/m^3)
OMC	Optimum moisture content
LAL	Lower acceptability limit
UAL	Upper acceptability limit

NOTE The indicated UAL and LAL will generally allow compaction to achieve at least the indicated percentage of maximum dry density.

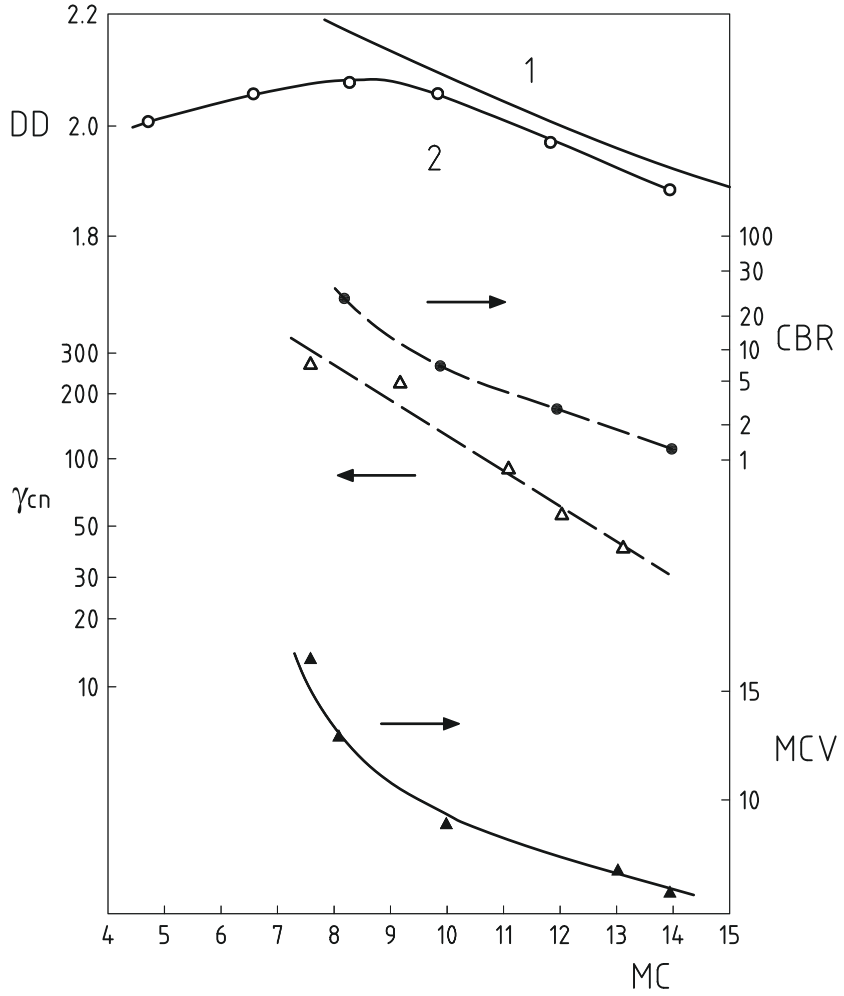
Figure 10 **Determination of acceptability limits for fine soils using relationship testing data**



Key

1	Saturation line (0% air voids)
2	X% air voids
MC	Moisture content (%)
DD	Dry density (kg/m^3)
OMC	Optimum moisture content
LAL	Lower acceptability limit
UAL	Upper acceptability limit

Figure 11 **Example of relationship testing**



Key

MC	Moisture content (%)	MCV	Moisture condition value
DD	Dry density (kg/m^3)	1	Zero air voids (particle density = 2.64 Mg/m^3)
γ_{cn}	Undrained shear strength (kN/m^2)	2	2.5 kg rammer compaction test
CBR	California bearing ratio		

Based on Reeves et al [41].

*COMMENTARY ON **7.6.5***
On most civil engineering projects, the rate of earthworks construction is usually a critical activity. Related to this is the need for rapid turnaround of the results from compliance testing linked to the contract specification. Delays in this process increase the volume of material placed and compacted for which compliance is unproven. When assessing the appropriate form of compliance testing for an earthworks project the designer should be aware of these testing limitations.

Material failing to conform to the specification might require remedial treatment. In the worst case, this can entail excavation of the non-conforming material and its disposal off site. This is wasteful of material and site resources, including plant, fuel, labour and time. The site control and testing procedures should be devised to minimize this risk.

Tests such as the undrained triaxial test, optimum moisture content and Atterberg Limits are not generally appropriate for routine earthworks control, either in the equipment required by a site laboratory or in the time/personnel resource required.

Available rapid methods for determining suitability of cohesive materials include the hand shear vane and the moisture condition value (MCV) test. Both can be carried out in situ and provide immediate results. If in-situ density is required as a control mechanism, the nuclear density gauge is proven technology that may be used.

Additionally, there are several techniques which provide a quick assessment of CBR values; these include the Dynamic Cone Penetrometer and the MEXE cone penetrometer.

7.6.6 Use of potentially contaminated, site-won fill

The earthworks designer should carefully consider the implications of potential contamination in site-won fill. Expert advice should be sought in relation to potentially contaminative previous land uses, regulatory requirements and testing regimes. See also SHW [1] Clause 601.

The earthworks designer should refer to EA guidelines that are current at the time of the design in order to remain aware of current legislation. It is advisable to discuss proposals for use of these fills with the EA (and HSE if an occupational health problem is suspected) at as early a stage as possible. The earthworks designer should avoid the temptation to overspecify the requirements; in general terms if the fill meets the contract terms and is acceptable to the EA then the contractor should consider using it. It may often be appropriate to obtain input by a waste management/human health risk assessment specialist to assess the suitability of the material for reuse.

A sampling and testing plan, comprehensive in both location of sample points and determinands analysed should be prepared to assess the source of material. Recommendations have been published (e.g. BS EN 14899) and have been incorporated by EA in their guidance; it is, however, strongly recommended to seek the advice and assistance of a contaminated land specialist in this.

NOTE Alongside the chemical nature of the material, the earthworks designer will commonly need to consider physical re-processing methods that will be necessary in order to ensure that fill materials will meet the physical requirements of suitable fill (e.g. screening to remove oversize particles).

Designers should be aware that the chemical characteristics of some materials might limit the applications for use.

7.6.7 Stabilized and modified materials

Designers should consider the use of stabilized or modified materials to maximize the use of site-won materials, and should make use of published guidance such as HA 74/07 [43].

*COMMENTARY ON **7.6.7***
The use of lime for treating cohesive materials and enabling them to be used on site has been established within the UK for a considerable time as has the use of cement to treat granular materials. More recently a two stage process of using lime followed by cement on cohesive materials has been developed – details are provided in the SHW [1].

The two main applications within cohesive soils are:

- *modification/improvement which is a process to render unacceptable bulk fills acceptable and simply uses lime;*
- *stabilization which is used for higher quality uses such as capping/subbase material or for slope repairs and uses lime together with additional binders such as cement, ggbs, pfa etc. in order to prevent potential swelling effects owing to high sulfur contents.*

There is an extensive suite of European standards which have been developed over the past few years [see BS EN 13286 (all parts) and BS EN 14227 (all parts)].

Britpave (http://www.britpave.org.uk/) provide extensive guidance on procedures and considerations that can be undertaken if the option for stabilization is considered. Additional information on the performance, materials, mixture design, construction and control testing of hydraulically bound mixtures for pavements is available from the Concrete Centre [www.concretecentre.com/publications].

7.6.8 Use of secondary aggregates and recycled materials

Published guidance (see commentary) should be followed on the use of secondary aggregates and recycled material. Data on compaction, durability and environmental aspects, such as leaching, should be sought from potential suppliers before confirming use in design. The designer should seek to minimize overall environmental and economic impact. However, there can be instances where primary aggregates carry the least cost, both in environmental impact and commercial economy.

COMMENTARY ON ***7.6.8***
Government policy encourages the use of these materials; this is captured in SHW [1], where recycled aggregate is specifically permitted in Table 6/1 for many Class 6 materials.

Although, in general use, the term "recycled aggregate" is used to cover all non-primary material, there are differences between recycled and secondary aggregates. The former have been recovered from previously used material (e.g. crushed concrete and masonry), the latter are by-products of an industrial process (e.g. PFA, china clay stent). Whilst different in origin, both types are covered by legislation to control the process of recovery (and licensing of this by EA) and taxation.

WRAP (Waste and Resources Action Programme) provide information on recycling on their webpages (http://www.wrap.org.uk/), which includes Aggregain (http://www.aggregain.org.uk), specifically for recycled aggregate in construction. This includes a directory of suppliers with distance from a defined location.

NISP (National Industrial Symbiosis Programme) http://www.nisp.org.uk/ exists to create symbiotic links between businesses to reduce waste by keeping material in the chain of utility.

Examples of practical research initiatives that have resulted in guidance notes for designers in order to promote certain recycled materials (e.g. Winter et al [15]), or options in particular settings (e.g. Brampton et al [44]).

In addition, there are a number of materials exchange initiatives, business and publicly funded, with a presence on the internet. As this is a fluid marketplace, the designer is encouraged to search for themselves.

7.6.9 Filling into water

7.6.9.1 Standing water

NOTE Standing water is the term applied to ponds, lakes, canals and water-filled mineral workings.

Where it is impracticable or uneconomical to drain standing water, particular attention in the design of the embankment should be given to the maximum and minimum water levels and to the characteristics of the soil underlying the water. Where practicable, any soft silt, clay or peat should be removed before placing fill, as it is difficult to compact the fill material under water. Fill should be selected from material which remains stable when inundated or when within the zone of a fluctuating water table, particularly in saline tidal water. Broken concrete, broken brick or granular material should be used to reduce settlement and maintain stability. Where it is impracticable or uneconomical to remove soft materials displacement by end tipping of bulk fill may be adopted. Measures should be taken to equalize water levels on each side of the embankment by means of pipes or pervious blanket drains.

For large areas of standing water, it may be practicable and economical to adopt hydraulic filling using a suitable type of granular material.

The slopes of an embankment in standing water should be flatter than those required above water level and they should be protected against wash or wave action.

7.6.9.2 Tidal, river and flood waters

In tidal and flood waters the effects of the rise and fall of the water level and of wave action on the embankment should be given special consideration and techniques such as are necessary in the design of maritime structures should be considered. Where a sudden rise or fall in the level of the water can occur, precautions should be taken to avoid external erosion and to mitigate the effects of sudden drawdown.

NOTE 1 This condition can occur where an embankment crosses the flood plain of a river where the embankment is, for most of the time, on dry ground but where, under flood conditions, erosion of the slopes of the embankment in the vicinity of a bridge or culvert is possible owing to the increase in velocity of the flood water passing through the opening.

Where flowing water against the earthworks face can be expected then measures should be include to prevent erosion of the earthworks. The earthworks engineer will need to consider the risk of erosion and options available for protection, but is likely to require input from a specialist with experience of design of erosion protection to ensure that site conditions are properly understood and that design, installation and maintenance factors are properly allowed for.

NOTE 2 When the risk of erosion in port, coastal and river engineering is judged as sufficient to require the use of rock fill for erosion protection then reference can be made to CIRIA C683 [45]. References are available for river engineering, such as Escaramia and Wallingford [46] and Hemphill and Bramley [47]. For less severe erosion cases then options of green engineering can prove very effective to protect the face of the embankment, examples are given by River Restoration Centre [48].

7.6.10 Filling adjacent to structures

Earthworks operations adjacent to structures are frequently carried out separately from the main earthworks operations and may be considered in the following categories:

a) filling over large pipes and culverts; in these cases it is important that fill is brought up equally on each side of the structure to prevent unbalanced loading and that great care is taken with the first layers of fill over the top of the structure;

b) against abutment and wing walls of bridges and retaining walls of all kinds;

c) around and between skeleton abutments, buried piers and bank seats.

Because satisfactory compaction of fill adjacent to structures is often more difficult to achieve owing to the restricted nature of the operation, it is usual practice to specify particular types of fill, such as selected granular materials (including specialist fill such as pulverized fuel ash), in the immediate area of the structure. Satisfactory compaction to reduce to a minimum differential settlement between backfill and structure is important enough to warrant the use of more expensive materials. Both the type of compaction plant and the method of compaction may be modified from those used in general embankment construction to prevent the development of excessive horizontal forces on foundations, retaining walls or piles.

NOTE Transition zones are commonly utilized to manage the settlement difference between embankments and structures, good practice guidance is provided with UIC 719 [49]. The problem of design of remedial works due to inadequate transition zones at existing structures is a complex issue upon which there is little standard guidance.

7.6.11 Filling over compressible ground

There are various circumstances where earthworks will be required over soils liable to significant settlement, such as soft ground (e.g. alluvium), compressible (e.g. loose Made Ground), collapsing ground (e.g. loess and karst geology), and unstable areas (e.g. land prone to mining subsidence); the designer should assess the magnitude of the risk and give consideration to the acceptable level of deformation for the proposed earthwork and determine an appropriate design logic to suit the site conditions. Guidance is provided in various references, e.g. CIRIA SP32 [50] (currently under revision) and Charles and Watts [42].

NOTE Methods of constructing an embankment over compressible ground include:

- *excavation and replacement of the poor material;*
- *grouting;*
- *consolidation of the soft material by surcharge;*
- *staged construction or controlled rate of filling;*
- *improvement of the engineering properties of the soft material by ground improvement techniques;*
- *modification of the engineering properties of the soft material by the use of additives such as lime or cement;*
- *use of lightweight fill;*
- *drainage of the soft material by the installation of horizontal or vertical drains;*

- *reduction in the gradient of the side slopes and / or the provision of berms;*
- *use of synthetic reinforcement; and*
- *use of piles.*

The selection of the method of construction proposed should give particular attention to the potential implications on the environment or adjacent structures and earthworks.

7.6.12 Embankments on sloping ground

The inherent stability of the natural ground forming a slope should be investigated carefully, particularly in regions known to be prone to landslips; in some cases evidence of existing instability can be seen on the site in the form of undulations, hummocks, lobes and water seepages. Investigations should be made of the geological stability of the slope, including long-term monitoring, and the likely re-activation of the existing slips under the loading conditions arising from the embankment construction.

Where an embankment is to be constructed on sloping ground and there may be a danger of a slip developing at the interface, benches or steps should be cut into the existing ground surface to key-in the new construction. Preferably, the bottom of the bench should be graded away from the surface of the slope, with provision for positive drainage measures to deal with any subsoil water which might collect at low points of the benching.

In order to deal with instability problems connected with the existing ground, the cross sections of the embankment may be designed to ensure a safe distribution of loading on the ground. The method of building up the embankment may also be specified to prevent unbalanced loading. Drainage of the interface between the slope and the embankment and of any potential slip planes is most important and adequate cut-off and subsoil drains should be provided.

7.7 Stability of temporary cuttings and open excavations

The overall stability of slopes for temporary cuttings and open excavations should be determined in accordance with the principles of **11.5.1** of BS EN 1997-1:2004 and the guidance given in **7.3**.

The designer should select appropriate soil parameters for use in the design of temporary slopes. In some cases it may be reasonable to rely on the short term (undrained) parameters where the designer is satisfied that insufficient time is available for a significant rise in porewater pressure to take place. However, this decision must be carefully considered as the transition to partially drained conditions occurs relatively quickly in some fine grained soils in the UK.

NOTE The overall effect of excavation for a cutting is to temporarily increase the stability of the slope due to reduced porewater pressures. With time the reduced porewater pressures rise towards higher equilibrium values with a consequent reduction in the shearing resistance of the soil mass. Thus the most critical conditions for temporary slopes to cuttings and open excavations occur some time after the formation of the slope (see Figure 6). The rate at which the porewater pressures rise towards equilibrium depends primarily on the soil type; for low permeability soils the process of reaching equilibrium porewater pressures may take decades whereas the porewater pressures in a highly permeable soil can reach equilibrium immediately following excavation.