Review of drainage behind retaining walls

Prepared for Quality Services (Civil Engineering), Highways Agency

G West

TRL Report 483

First Published 2001
ISSN 0968-4107

This report has been produced by TRL Limited, under/as part of a Contract placed by the Highways Agency. Any views expressed are not necessarily those of the Agency.

CONTENTS

Executive Summary

The Department of Transport's *Specification for Highway Works* (MCHW1) prescribes grading limits to define materials for use as drainage layers and selected backfills to different types of structure. This prescriptive approach has the advantage of simplicity but gives rise to two opposite problems. Firstly, it is presumed that these limits ensure that such materials are effectively free draining; however, experience has shown that compacting fills at the fine end of the grading limits can produce a distinctly non-free draining surface. Secondly, the requirements for drainage are not explicitly considered for each type of structure and for some types the high cost of providing good quality fills may not be justified. A new research project has been undertaken at TRL Limited with the aim of addressing these problems. It had as its objectives:

1 Determination of the permeability of currently allowed fills and filters, paying particular attention to fine fills, the effect of placing and compaction on permeability, and the development of a non-free draining layer.

2 To investigate whether fills are sufficiently free draining to prevent build up of pore water pressure behind retaining walls and to make any necessary recommendations for changes.

3 To advise on the feasibility of using permeability as an end product specification.

4 To advise on when drainage behind structures is required.

Drainage behind retaining walls was reviewed as the first stage of this research project. The review is based mainly on literature published since 1992 when the subject was last reviewed for the Department of Transport. The drainage of both granular filters and fill is considered, but that of geocomposite filters is only touched upon because these were reviewed in 1994. The drainage of highway retaining walls in the United Kingdom seems to be generally satisfactory. However, the research project has afforded an opportunity to evaluate the advantages and disadvantages of producing performance specifications for drainage. Among other detailed conclusions are that piezometric studies of the fill behind retaining walls would be worth making, that research into the cause of segregation in granular fill should be carried out with the aim of preventing it from occurring in practice, and that research into the problems of compacting fine sand fill may be needed. Attention is drawn to the susceptibility of certain fill materials to rain.

1 Introduction

The Department of Transport's *Specification for Highway Works* (MCHW1) prescribes grading limits to define materials for use as drainage layers and selected backfills to different types of structure. This prescriptive approach has the advantage of simplicity but gives rise to two opposite problems. Firstly, it is presumed that these limits ensure that such materials are effectively free draining; however, experience has shown that compacting fills at the fine end of the grading limits can produce a distinctly non-free draining surface. Secondly, the requirements for drainage are not explicitly considered for each type of structure and for some types the high cost of providing good quality fills may not be justified. The present review, which is a literature study of the drainage behind retaining walls, was the first step in a research project aimed at addressing these two problems.

1.1 Previous reviews

A review of the whole subject of highway drainage has been given by Johnson (1993) in which a few brief comments were made on the drainage of earthworks and structures. Research on highway drainage at TRL has been reviewed by Farrar (1993) who includes discussion of the drainage of retaining structures. A review specifically of the drainage of earth retaining structures for highways has been made by Bird (1992), to which the reader is referred for its comprehensive coverage of the subject. United States practice in the specialised use of geocomposite sheet drains for the drainage of retaining structures has been reviewed by the Geosynthetic Research Institute (1994). Although the present review is not concerned with the design of retaining walls, it can be noted that a very comprehensive design guide has been provided by the Geotechnical Engineering Office (1993).

Two of the previous reviews mentioned above, those by Bird (1992) and by the Geosynthetic Research Institute (1994), were made specifically for the Department of Transport's Bridges Engineering Division and Highways Agency respectively. Therefore, their contents and conclusions will not be repeated here, except to remark that they can be usefully read in conjunction with the present review.

2 General considerations

2.1 Description, definitions and terminology

A *retaining wall* is device for supporting a steep bank of soil as shown in the diagrammatic cross section through a typical structure given in Figure 1. The retaining wall is usually made of reinforced concrete, either precast concrete units placed side by side for small retaining walls, or cast-in-place concrete for large retaining walls. The base of the retaining wall is made large enough to resist overturning. Behind the retaining wall, the *fill* is placed and compacted in horizontal layers, and there are three categories of fill: *granular fill, cohesive fill and other fill*.

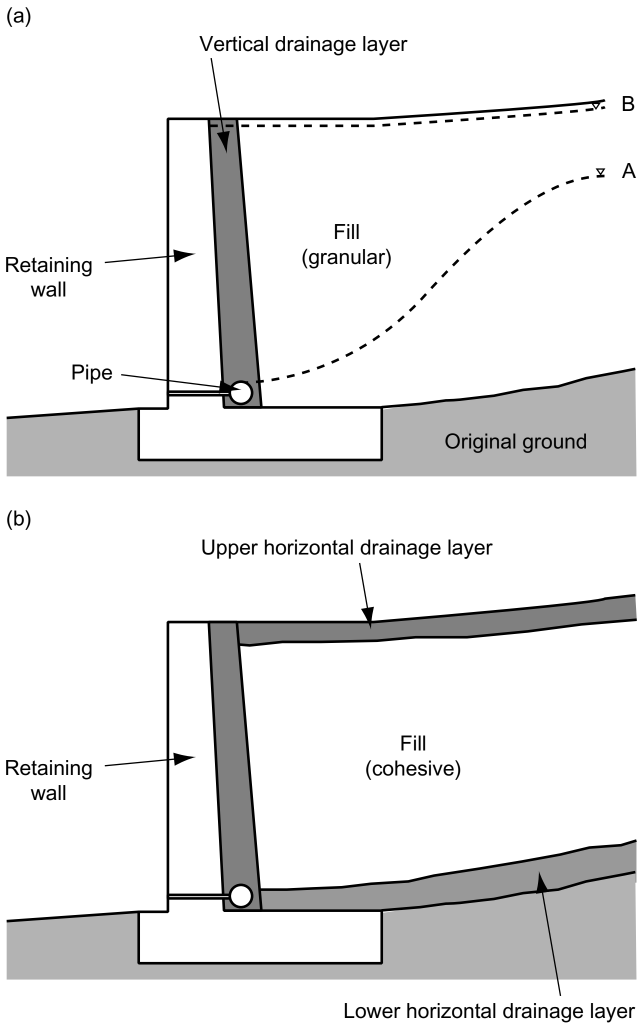


Figure 1 Cross-section of earth retaining structure (diagrammatic)

Between the fill and the retaining wall is placed a thin layer (≈ 350 mm) of free draining material called the *vertical drainage layer*. At the bottom of the vertical drainage layer a *porous or perforated pipe* is positioned. The pipe runs along the full length of the wall and connects at intervals with short *weep pipes* which run through the wall from the back to the front. Where cohesive and other fill is used, *horizontal drainage layers* are placed both above and below the fill (Figure 1b), but these are omitted if the fill is granular (Figure 1a). The whole installation (wall, fill, drainage layers, pipes, etc) is referred to as an *earth retaining structure* and the stratum upon which it rests is referred to as the *original ground*.

2.2 Drainage

The purpose of the vertical drainage layer is to receive water seeping out of the fill horizontally and convey it to the pipe at the bottom. The vertical drainage layer also has to filter out any fines from the seepage water to prevent them from otherwise clogging the pipe: it is this function which has resulted in the vertical drainage layer sometimes being referred to as the *filter*.

The upper and lower horizontal drainage layers are intended to keep water out of the fill. The principal purpose of the lower horizontal drainage layer is to intercept any groundwater seeping up out of the original ground and convey it to the pipe, having filtered out any fines. Likewise, the purpose of the upper drainage layer is to intercept rainwater and surface water and convey it to the vertical drainage layer. Therefore, to function effectively, both these layers should be constructed with a fall towards the wall.

The purpose of the porous pipe is to collect the water from the drainage layers and conduct it to the weep pipes which then convey the water to the front of the wall from whence it can be discharged to a nearby watercourse or soakaway. Therefore, the porous pipe must be laid with a fall along the length of the wall. The porous pipe is provided at intervals with *rodding eyes* so that any sediment that does accumulate in it can be cleaned out periodically.

If all the drainage elements of the structure perform according to their designed purpose, the water table in the fill will be drawn down to the pipe as shown by line *A* in Figure 1a, in which case the retaining wall will not be required to withstand any water pressure. But if the drainage elements are deficient in function, there is the danger that the water table will rise to the surface as shown by line *B* in Figure 1a, in which case the retaining wall will be required to withstand the full hydrostatic pressure of water in the fill.

Theoretically, the drainage and the filtration requirements of the vertical drainage layer are incompatible in the long run, because if the material works efficiently as a filter it will eventually become blocked with fines and be unable to act as a drain. The vertical drainage layer, therefore, will tend to become less effective with time. The same considerations apply to the horizontal drainage layers. In practice, the aim of good specification is to provide filters which will perform effectively over the lifetime of the structure. This is done by choosing their grading to match the grading of the fill, as discussed in Section 2.4. In the United Kingdom, retaining walls have a conventional design life of 120 years.

Some old masonry and concrete retaining walls do not have the drainage arrangements described above, but have instead an array of more or less closely spaced *weep holes* in the wall itself. The water discharging from these is allowed to run down the front of the wall and is sometimes collected in a drainage channel at the bottom. Provided the weep holes do not become blocked they will be effective in preventing build up of hydrostatic pressure behind the wall; but the flow of water from the weep holes down the face of the retaining wall together with the associated discoloration or staining would be regarded as unacceptable for a public service structure today.

2.3 Materials

The properties of the various materials to be used in earth retaining structures are defined in the *Specification for Highway Works* (MCHW1) which should be referred to for the full details of all the requirements. The following notes are a simplified summary.

Vertical drainage layer

There are a number of materials from which the vertical drainage layer may be formed and they are:

1 Graded granular material, either gravel and sand or crushed rock aggregate.

2 Hollow concrete blocks.

3 No-fines concrete.

4 Graded granular material plus a geotextile filter between the vertical drainage layer and the fill. This has the advantage during construction of separating the vertical drainage layer from the fill and preventing it from contamination. In service, the geotextile may assist in the filtering function.

5 Geocomposite sheet drains (sometimes called fin drains). These are geotextile composites consisting of a more-or-less hollow polymer core which permits the free flow of water, with a geotextile filter attached to it on either side.

Options 1, 2 and 3 are allowed in the *Specification for Highway Works* (MCHW1), but options 4 and 5 have been used for retaining structures for roads other than those on the trunk road network.

Horizontal drainage layers

These are of graded granular material, usually gravel and sand.

Fill

The fill can be either (1) a granular material or (2) a cohesive material or (3) other material.

1 Granular materials can be well graded or uniformly graded sands and gravels. They are specified because of their permeability and ease of compaction.

2 Cohesive materials are clays and silts and combinations of these.

3 Other materials are pulverised-fuel ash, blastfurnace slag, burnt colliery shale and chalk. Pulverised-fuel ash is often treated as a cohesive material, blastfurnace slag and burnt colliery shale as granular materials, and chalk as a cohesive material but one requiring special consideration.

If suitable, soil from a nearby excavation will usually be the source of the fill, but if the spoil arising on site is unsuitable, the fill material will have to be imported.

2.4 Grading of granular filter

2.4.1 Principle

In order to specify the grading of a filter material in contact with soil of a given grading, certain criteria have been formulated to ensure that both the drainage and the filtration functions of the filter will be effective. These are based on the original ideas of K Terzaghi formulated in 1921. They have been extensively reviewed by Spalding (1970). Two criteria have to be satisfied: a filtration criterion and a drainage or permeability criterion.

Briefly, the essential rules are as follows. For a granular filter material in contact with soil of a given grading, the *filtration criterion* is:

$$D15F \leq N \times D85S \quad (1)$$

where *D15F* is the filter particle size for which 15% by mass is finer, and *D85S* is the soil particle size for which 85% by mass is finer, and *N* is 6 for soils with a coefficient of uniformity[1] of less than 1.5, but is 5 for all other soils. The *permeability criterion* is:

$$D15F \geq N \times D15S \quad (2)$$

where *D15S* is the soil particle size for which 15% by mass is finer. Equations 1 and 2, therefore, define the grading limits of an effective filter for any particular soil.

Consider, for example, that we are going to use a particular Mercia Mudstone soil as the fill for an earth retaining structure and we want to determine the grading of a granular filter to use with it. From the grading curve of the soil (Figure 2), D*85S* is 0.07 mm (point *A*), and the values of *D60* and *D10* are 0.02 mm and 0.002 mm respectively. The coefficient of uniformity is 10, therefore *N* is 5. Substituting these values in Equation 1 gives us a value for *D15F* of ≤ 0.35 mm (point *B*).

From the grading curve of the soil the value of *D15S* is 0.0023 mm (point *C*) and substituting this value in Equation 2 gives us a value for *D15F* of ≥ 0.011 mm (point *D*).

The granular filter must, therefore, have a *D15F* value which lies between 0.011 mm and 0.35 mm, i.e. its grading curve must pass between points *D* and *B* in Figure 2. A sand would satisfy this requirement and the grading curve of a suitable filter is shown in Figure 2.

[1] *The coefficient of uniformity of a soil is D60 divided by D10. The smaller the value, the more uniform the soil. Uniform soils have a coefficient of uniformity of less than 3.*

2.4.2 Practice

In practice, for Highways Agency schemes the *Specification for Highway Works* (MCHW1) specifies the grading limits for the granular filters to be used with given fills in an earth retaining structure. Briefly, for use in conjunction with granular fill, the grading of the granular filter is specified by:

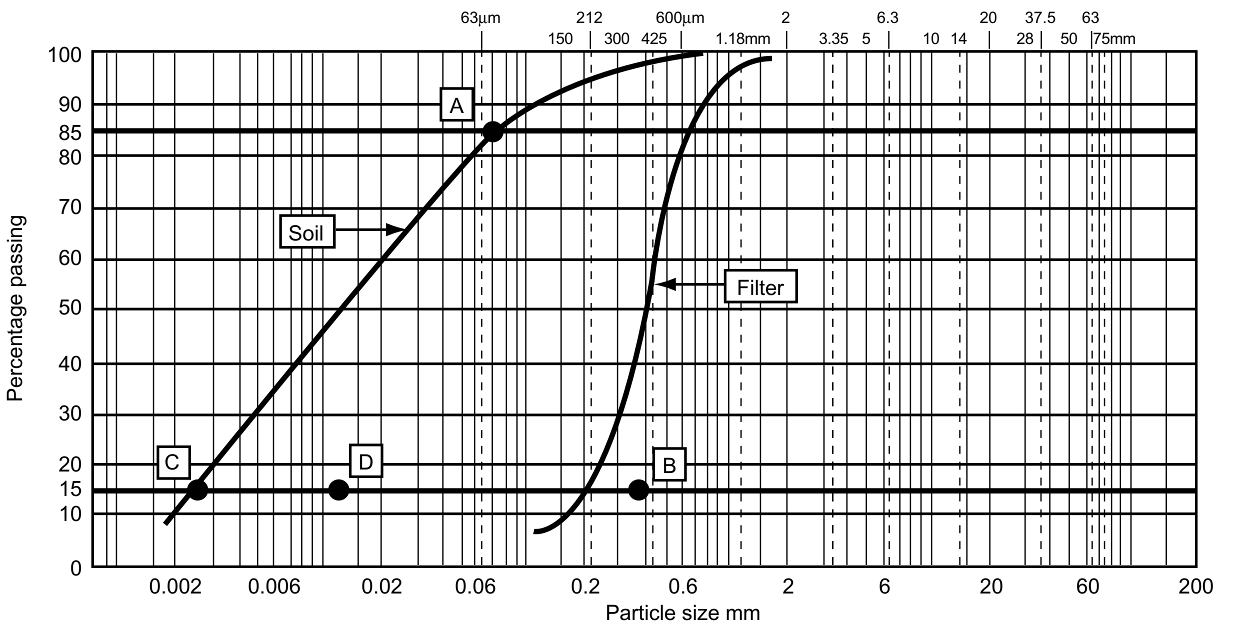
$$D15F \div D85S < 5 \quad (3)$$

$$D15F \div D15S > 5 \quad (4)$$

It can be seen that Equations 3 and 4 are almost the same as Equations 1 and 2 except that *N* has the fixed value of 5. For use in conjunction with cohesive fill, pulverised-fuel ash or chalk, the granular filter is specified as concreting sand.

2.5 Burst water main contingency

Although the principal purpose of providing drainage for an earth retaining structure is to ensure that the retaining wall does not have to sustain the full hydrostatic pressure of a water table at the top of the retaining wall, designers often assume a water table at full wall height (case *B* in Figure 1a) to cope with abnormal events such as a burst water main behind the wall, or completely blocked drains. This would appear to be a somewhat paradoxical situation, but it is one likely to be perpetuated because a water table at full wall height has been adopted as the limit state in *Eurocode 7* (British Standards Institution, 1995) at least for fills of medium or low permeability (silts and clays).



Clay	Fine	Medium	Coarse	Fine	Medium	Coarse	Fine	Medium	Coarse	Cobbles	Boulders
	Silt			Sand			Gravel				

Figure 2 Selection of filter for soil

In this context, it can be noted that Card and Darley (1995), in an examination of over-conservatism in design of seven retaining walls, did not assume a water table at full wall height as their ultimate limit state for no drainage. Instead, they assumed the water table was at some intermediate height between the level of the weep pipes and the top of the wall. The reason for this was because they took the highest water level in the fill to be equivalent to the lowest crest level of the overall structure which was not necessarily the same as the level of the top of the wall. Therefore, their assumptions are probably not the same as those of the designers of the retaining walls. Furthermore, it is not known whether this assumption of an intermediate water table level in the fill behind the wall is a valid one to make, or whether there is any site observational evidence to support it.

2.6 Compaction of fill

The fill material is compacted in horizontal layers in the fill area behind the retaining wall. The process of compaction produces a density gradient within each layer with the highest density at the top and the lowest density at the bottom. Because permeability varies inversely with density, a permeability gradient is therefore produced in each layer with the lowest permeability at the top and the highest permeability at the bottom. Overall, the vertical permeability through the fill will be governed by the low permeability at the top of the layers, while the horizontal permeability through the fill will be governed by the high permeability at the bottom of the layers. The result is a permeability anisotropy in the fill, with the horizontal permeability tending to be higher than the vertical permeability.

Experience has shown that it may be difficult to compact cohesive fill close to a granular vertical drainage layer without distorting or displacing the filter material. To overcome this difficulty, there is a trend to use hollow concrete blocks instead of granular material as the drainage filter, because, being rigid, the blocks resist deformation by the compaction process.

2.7 Location of road

Depending upon the purpose of the retaining wall, the road may be located either below the retaining wall on the original ground or above it on the fill; or in the case of grade-separated carriageways, there will be roadways both below and above the wall. The Department of Transport's *Design Manual for Roads and Bridges* requires drainage to be provided to drain surface water away from the retaining wall and backfill. When the road is located above the wall on the fill, it is mandatory to provide a completely separate, positive drainage system to carry runoff away from the fill or the retaining wall drainage layers.

3 Performance of fills

In this section the performance of fills will be reviewed, and in the next section the performance of filters. However, the reader should bear in mind that this division is somewhat arbitrary because the performance of one depends to a greater or lesser extent on the performance of the other.

Two studies have been made of the causes of retaining wall failures (US Army Corps of Engineers, 1994). The first reported that in 51% of failures the fill was clay, and the second reported that the cause of failure of 33% was missing or inadequate drainage systems. These figures highlight the importance of ensuring suitable fill is used and effective drainage is provided when a retaining wall is constructed.

3.1 Indian retaining wall

The following interesting case history has been reported by Natarajan and Jagannatha Rao (1988). A retaining wall 3-5 m high was built near the sea shore on a gently sloping hillside, and the area behind the wall was backfilled to provide a large level area for development. Shortly after the fill had reached full height, there was heavy and sustained rain over 3-4 days. During this period the wall was observed to be moving, and the total movement experienced by the wall was 1.6 m horizontally outward and 1.5 m vertically downward. The displacements were of the rigid body kind and the wall suffered no structural damage, remaining vertical with no tilt in the displaced position.

Geotechnical investigation showed that the natural slope on which the retaining structure rested had experienced a slip failure initiated by overloading at the head of the slide by the fully saturated mass of the fill material. It was concluded that the fill material had become saturated, with consequent high pore water pressure, because of inadequate drainage of the structure. As the soil mass moved, the retaining wall was carried along with it, thereby giving rise to the kind of displacement observed above.

Remedial measures were of three kinds. Firstly, replacing some of the soil in the fill area with lightweight fill - in this case sawdust which was available from local timber mills. The sawdust was enclosed in an impervious geomembrane to keep it dry. Secondly, a horizontal drainage layer was installed below the sawdust with a fall towards the wall, and a vertical drainage layer was installed between the wall and the fill for the full depth of the wall. The filter material used was clean well graded gravel. A permeable geotextile was placed between the vertical drainage layer and the fill to act as a separation barrier. Thirdly, a porous drain pipe, running the full length of the wall, was provided to collect the water from the gravel drains and discharge it to a natural outlet. The fact that these drainage works are described as remedial measures implies that there were no such drains in the structure as originally built.

Although retaining structures for highways in the UK are unlikely to be built without drainage, this case history does serve to emphasise, in a rather dramatic way, the importance of providing proper drainage for an earth retaining structure. Another lesson for the designer is that it is essential to consider whether the stability of the original ground will be affected by the construction on it of the earth retaining structure.

Although not specifically stated, the retaining wall case history reported by Kamdar and Natarajan (1987) appears to be the same one as that described above.

3.2 Segregation in granular fill

During the course of laboratory oedometer tests on a well-graded, crushed limestone aggregate used as granular fill material, Brady and Kirk (1990) observed that after the vibratory compaction of specimens of high moisture content, segregation of material had taken place, finer particles having migrated to the top of the layer leaving coarser particles at the bottom. This would have the effect of producing permeability anisotropy in the layer, with lower permeability at the top and higher permeability at the bottom. Note that this is an effect quite separate from that due to density discussed in Section 2.6.

If segregation occurred during construction on site, it might account for the production of a non-free draining surface at the top of layers of granular fill during vibratory compaction, and, therefore, it might be the explanation of one of the problems mentioned in the Introduction. Research could well be carried out to establish the conditions that lead to segregation in granular fills with a view to preventing this occurring in practice.

For the present, three assumptions can be made. Firstly, that segregation in the granular fill accounts for the impermeable surface; secondly, that the segregation is caused by vibratory compaction at too high a moisture content; and thirdly, that the fill is at the correct moisture content when delivered. The most likely reason for too high a moisture content in a fill on a construction site is rain falling on the fill material before, or during, spreading and compaction. Therefore, the desirability of not placing fill during heavy rain should be advised, although it is recognised that sometimes it may be difficult to follow this advice in practice. Indeed, economic benefits may accrue from devising methods of allowing wet weather working to take place with moisture susceptible materials.

3.3 Fills for retaining walls in southeast England

It will be recalled from the Introduction that one of the perceived problems is the high cost of providing good quality fills for retaining walls. This problem was studied by Naish (1988), although more generally and not in the context of drainage specifically. Naish examined the cost of the fill for thirty bridge abutments and retaining walls in southeast England and made calculations to find the savings if relaxations in the specification of the physical properties of the fill had been made. All the structures were constructed between 1975 and 1987.

Naish made two calculations: firstly, to see what saving would have been made if *acceptable fill* had been used instead of *granular fill*; and secondly, what additional saving would have been made if *general fill* had been used[2]. His findings are summarised in Table 1. The units in the table are the maximum savings expressed as a percentage of (a) the total structure cost, and (b) the total substructure cost; they are called maximum savings because they do not take into account the offsetting cost of design changes to the structure that may have been necessary had a lower quality fill been used.

Table 1 Maximum savings from using lower quality fill

	Saving if acceptable fill had been used instead of granular fill (%)	*Additional saving if general fill had been used instead of acceptable fill (%)*
a Of total structure	5.0 to 9.0	3.0 to 5.0
b Of total substructure	8.7 to 15.7	5.2 to 8.7

Table 1 shows that worthwhile, albeit modest, savings can be made by using lower quality material as the fill in retaining structures. However, cost is not the only consideration, and the wet-weather susceptibility of some low quality materials may preclude or restrict their use as fills.

The fill used on several of these projects was Thanet Sand, which was typically 90% fine sand, or variable clayey or silty fine sand. There is hearsay evidence that sometimes Thanet Sand has proved difficult to compact when used as fill, which may be the origin of the other perceived problem mentioned in the Introduction. Research on this subject would be useful, to establish the precise nature of such anecdotal evidence.

Drainage

Naish made only brief comments on the drainage arrangements of the structures in the projects studied. However, he remarked that on some contracts fewer than the three standard options for the vertical drainage layer were allowed. On other contracts a combination of porous concrete blocks and no-fines concrete was specified. It would be interesting to know why these restrictions were imposed, and whether they persist.

3.4 Rock fill for embankment dams

Although they are not retaining walls, two case histories of the use of rock fill for embankment dams will be discussed because of the experience they provide in the compaction of fill. By coincidence, although in different parts of the country, both dams were constructed using the same kind of rock fill which consisted of Carboniferous mudstones, siltstones and sandstones.

Roadford Dam, Devon

The rock fill was extracted from the borrow area by rippers and face shovel loaders, and the method of working had the effect of roughly blending the mudstone and sandstone in about equal proportions. The fill material so produced had a slight excess of fines. The rock fill was spread by bulldozer and it was noted that the tracks of the machines caused additional breakdown of rock which further increased the fines content. A compaction trial was carried out and one of the observations made was that a surface

[2] *Definitions of these three types of fill are given in the Department of Transport's Specification for Road and Bridge Works (5th edition, 1976) and Specification for Highway Works (6th edition, 1986).*

crust of fine material formed after compaction of each layer of fill, and on getting wet this surface crust became slurried, being particularly sticky after trafficking by construction plant. Before placing the next layer, the surface was scarified with a multi-tine ripper in order to break up the surface crust formed by the rolling (Wilson and Evans, 1990).

Reconstructed Carsington Dam, Derbyshire

To minimise breakdown of the rock, the rock fill was excavated by backacters and transported and placed by dump trucks. In addition, trafficking of prepared areas of fill before placement of the next layer was not allowed. A compaction trial was made and showed that the top of the fill surface became polished under the action of tyres and rollers. Therefore, immediately before the next layer was placed, the previously compacted surface was scarified - this was done at first with a towed, multi-tine agricultural harrow, but later using dozer tracks with good grousers (Chalmers, Vaughan and Coats, 1993; Macdonald, Dawson and Coleshill, 1993).

The cause of the fines-rich crust on the surface of compacted layers of rock fill in the embankment dams is breakdown of the mudstone during compaction. It is, therefore, different in origin from the accumulation of fines at the surface produced by segregation discussed in Section 3.2. The surface crust will be of lower permeability than the rest of the layer and, unless removed, will have the effect of reducing the vertical permeability of the fill.

3.5 Retaining wall in Kent

Retaining wall R5 (northeast) is one of four reinforced earth retaining walls built as part of the grade-separated A229/M20 rotary interchange, Junction 6, on the M20 motorway in Kent. The four walls are each 100-170 m long with a maximum height of 9 m tapering to 2-3 m at their ends, and were constructed to allow the A229 to pass below the motorway in a 10 m deep retained box-cut. The fill used was an orange-yellow, slightly silty, fine to medium sand and an orange-brown, silty or slightly silty, fine to medium sand, obtained from specially identified horizons in a local sand pit in the Folkestone Beds. The fill complied with the grading limits for Class 6X material; however, both sands were close to, but nevertheless within, the lower grading limit of the specification. The brown sand was siltier and more cohesive than the yellow sand. The fill was compacted by a self-propelled, tandem vibratory roller in 150 mm thick layers, except against the panels where a vibrating plate compactor was used. Most deliveries of fill to the site were rolled on the dry side of optimum moisture content, in spite of which high densities were achieved. The original ground on the site was Gault Clay.

Both during and after construction of retaining wall R5 (northeast) vertical misalignment of certain elements was noted, and shortly after construction had finished the misalignment was considered to be so severe (spalling of the concrete panels had occurred as a result) that it was decided to dismantle and reconstruct the affected part of the wall. An investigation was carried out during the dismantling (Travers Morgan, 1993), and four observations that relate to the drainage of the structure were made. These were:

1. During the original construction of the retaining wall there were several extended pauses, leaving backfill exposed to rain, one such being the three week Christmas and New Year holiday 1992-93. It was usual practice to remove any saturated fill but there was some doubt if this was done thoroughly after the Christmas break. Nevertheless, no water seepage or loss of sand from the structure were recorded as having occurred.
2. During dismantling of the retaining wall seepages of water were noted along the temporary works profile of the Gault Clay behind the wall. The source of this water was thought to be natural surface runoff from a hill near the interchange. To prevent this entry of water into the fill in the future, a vertical cut-off situated upslope of the retaining wall was proposed.
3. It was recommended that a toe filter drain should be installed immediately after filling behind the bottom row of wall panels in the reconstructed section.
4. Although not required by the specification, laboratory constant-head permeability measurements were made on samples of the fill taken during the dismantling of the retaining wall. The results are given here because of their relevance to the matters discussed in this section.
5. The permeabilities were:

   Yellow sand: 9.5×10^{-6} m/s

   Brown sand: 2.1 and 3.9×10^{-7} m/s

The brown sand, which was more silty than the yellow sand, has a lower permeability.

The lessons of this case history are that silty, fine sand fill is likely to be susceptible to rain; and that the water regime of the original ground on the site and its surroundings needs to be studied to prevent water entering the fill from this source.

4 Performance of filters

4.1 Bridge approaches in the United States

The abutments and wingwalls of bridges are a special case of retaining walls, and the design and construction practices for these in the United States, with special emphasis on the drainage provisions have been reported by Chini, Wolde-Tinsae and Aggour (1993). They found that usual practice was to provide a vertical drainage layer behind the abutment and wingwalls together with a system of drainage pipes that carried the water to a collection point outside the abutment. In many cases a lateral drainage layer was also provided to collect infiltrated water. They also reported that new geocomposite drains were coming into use which consist of a prefabricated geocomposite drain attached to the abutment and wingwalls, having at its bottom a slotted plastic pipe encapsulated with a treated permeable material. They recommended that bridge deck and roadway surface drainage should be isolated completely from the retaining wall drainage, and that the surface drainage should be channelled away separately and not allowed to discharge into the abutment backfill or down the slopes of the approach embankment.

Commenting on the new geocomposite filters, they said that there were three main properties that needed consideration, and these were:

1 *Flow rate*. The permeability of the geocomposite must be greater than that of the soil backfilled against it so that water can flow from the fill to the filter. In this context, a worked example showing how to calculate the flow net for a geocomposite vertical drainage layer behind a retaining wall is given by Koerner and Bove (1987).

2 *Pore size*. The pores in the geotextile sheet forming the skin of the filter must be small enough to retain erodible soil particles in the fill. The opening size is usually quoted by the supplier in a geotextile specification sheet (e.g. Drainage Products Inc, 1993).

3 *Strength.* The geocomposite must be able to support the backfill soil without the polymer core collapsing. In this context, the problem of compacting cohesive fill adjacent to the filter (see Section 2.6) is clearly of great relevance.

Apart from the incoming use of geocomposite drains there is nothing new here. The drainage arrangements follow conventional retaining wall practice, and the separation of road surface drainage and ground water drainage in situations of this kind is already good practice in the UK (Johnson, 1993).

In the United States it is sometimes the practice to finish off the fill behind a retaining wall with a layer of impermeable material on top, the purpose of which is to reduce infiltration of rainwater into the main mass of the fill (US Army Corps of Engineers, 1994). This impermeable capping is laid with a fall towards a surface-water drainage channel that conveys the runoff away from the retaining structure to some suitable disposal point. This idea might be worthy of consideration for use in the wet UK climate, perhaps to be used in conjunction with an impervious geomembrane.

4.2 Hong Kong retaining walls

This case history concerns weep holes rather than filters but is included here because of its relevance to retaining wall drainage. Hong Kong is an area of intensive development, much of it on steeply sloping ground, and retaining walls have been much used to support building platforms, roads and slopes. Most of the retaining walls are drained by closely spaced weep holes, 75-100 mm in diameter, and spaced at 1.5-2.0 m centres throughout the full height and width of the wall. The weep holes allow water, which might otherwise accumulate behind the wall, to drain away, thus improving the stability of the wall. Au and Pang (1993) have observed that a lack of pattern is commonly observed in the flow from the weep holes, one weep hole flowing copiously while adjacent ones have no flow.

They investigated a particular retaining wall showing this effect and established that weep hole seepage falls into three types depending on the source of the water: firstly, surface water ingress; secondly, leakage of water-bearing utilities; and thirdly, rise in the ground water table. They concluded that a strongly flowing weep hole amid dry ones indicates either a localised surface water ingress or a leaking water utility. If the flow occurs continuously and not only after rain, a leaking water utility is the more likely of the two causes. They further observed that localised surface water ingress was common in the soil mass behind retaining walls because of voids in the fill due to areas of poor compaction, loosely backfilled trenches for buried services, etc.

The lesson from this case history is that in retaining walls drained by weep holes, any single weep hole that has an abnormally high flow compared with the others should be investigated to find the cause, which may be a leaking water utility in the fill area behind the wall.

4.3 Polish dam

The present review has not found any recent case histories of the performance of filters in retaining walls. However, one example from an earth dam in Poland was found. The fill for the dam consisted of fine and medium sands, and the drainage was provided by horizontal drain pipes surrounded by gravel which in turn was enveloped in a non-woven needle-punched geotextile sheet. The apparent opening size (AOS) of the geotextile was selected using the expression:

$$2 \text{ x } D15S < \text{AOS} < 2 \times D85S \qquad (5)$$

After eight years of service one of the drains was excavated and samples of the geotextile carefully removed for testing in the laboratory. It was noticed that the geotextile had promoted the formation of natural soil filter at the contact with the fill, but that there was little mechanical or biological clogging of the geotextile, although some micro-organism attack (iron bacteria) and plant-root penetration was noted. Laboratory permeability tests on the recovered geotextile showed that the permeability was about half that of the same material when new, but was still ten times higher than that of the fill (Mlynarek, Lafleur and Lewandowski, 1990).

This case history shows that in service a permeable geotextile can be effective in preventing fines from passing from the fill into the gravel of a filter drain, but that, as well, its permeability can be considerably reduced. Other than this, the experience of the dam filter drain should not be applied to retaining wall filters.

5 Specifying filters by permeability

It will be recalled that the specification for granular material for the vertical drainage layer to be used in conjunction with granular fill for a retaining wall is based on the particle size distribution (Section 2.4). The aim is to provide a filter having greater permeability than the fill. It has been suggested recently that instead of specifying the grading of the filter, its permeability could be specified instead. This, of course, implies measuring the permeability of the fill, and knowing how much more permeable than the fill it is desired to have the permeability of the filter.

If specification by permeability were to replace specification by grading completely, for filters it would be necessary to specify *two* values of permeability to cover the filtration criterion as well as the permeability criterion (see Section 2.4.1). Alternatively, a mixed system could be used in which the permeability criterion of the filter was specified by permeability, and the filtration criterion was specified by grading.

5.1 Measurement of permeability

The measurement of permeability of fine granular filter material, fine granular fill material and cohesive fill material could be done in standard, soil mechanics, laboratory permeameters (Head, 1994) but for coarse granular material a large permeameter similar to that used to test the horizontal permeability of embankment drainage layers, capping materials and sub-bases would have to be used (DMRB4). The comparability and precision of these methods would need to be considered. Other difficulties include deciding on the method of compaction, and the moisture content and density of the specimens. For the vertical drainage layer, the vertical permeability would have to be measured; for the horizontal drainage layers, the horizontal permeability would have to be measured; and for the fill, both vertical and horizontal permeabilities. All these matters pose problems.

5.2 Estimation of permeability

An alternative approach, instead of measuring permeability, would be to estimate it from the grading. Two empirical expressions are available for doing this:

$$k = 0.01 \times (D10)^2 \text{ m/s} \qquad (6)$$

$$k = 0.0035 \times (D15)^2 \text{ m/s} \qquad (7)$$

where k is the coefficient of permeability (Smith and Collis, 1993). To illustrate the estimation of permeability from grading we will use the two grading curves in Figure 2 as examples. From Figure 2 we have:

$D10S$ = 0.002 mm and $D15S$ = 0.0023 mm

$D10F$ = 0.15 mm and $D15F$ = 0.2 mm

Substituting these values in Equations 6 and 7 we get the values for the coefficient of permeability, k (m/s), shown in Table 2.

Table 2 Estimated permeabilities of soil and filter (*k*, m/s)

	Soil	*Filter*
Equation 6	4.00×10^{-8}	2.25×10^{-4}
Equation 7	1.85×10^{-8}	1.40×10^{-4}

It can be seen that Equations 6 and 7 do not give identical results, but they do give values that are of the same order of magnitude.

Although this method is much easier to carry out than directly measuring the permeability, we still have to decide how much greater than the permeability of the soil we want the permeability of the filter to be.

5.3 The current position

The present method of specifying granular filters has the advantages that grading is a simple test to carry out and does not depend on method of compaction, density and moisture conditions; there is long experience of its use, its precision is known and it gives satisfactory results. Therefore, moving to a different method of specification would only be justified if a need to do so was established. From this review, there does not seem to be any case where the present method has not been satisfactory. This conclusion is supported by the previous review (Bird, 1992), which did not report any difficulties with specifying filters by grading at that time.

However, this does not fit in with the current move to performance specifications throughout Europe. Thus, rather than pre-empting the outcome of all the aspects of this and other research projects, it is considered prudent to see if a case can be made for changing to specification by permeability. If it can, it is likely to be based on allowing a wider range of materials to be used, thus reducing costs.

6 Conclusions

The scarcity of case histories reporting problems with the drainage of retaining walls for highways in the UK indicates that current methods of providing drainage are generally satisfactory. However, the following points of detail have emerged from the present review:

General

1. It would be worth while carrying out piezometric studies of the fill behind properly drained retaining walls to see if the expected drawdown of the water table shown in Figure 1a occurs in practice. Both granular and cohesive fills should be studied.
2. The results of the piezometric studies will need to be interpreted in the light of the assumptions made in design. In turn, these should be reviewed to assess whether they are realistic or overly conservative.
3. If an earth retaining structure is to be sited on sloping ground, consideration must be given as to whether the structure may induce slope instability in the original ground.
4. The water regime of the original ground on the site and the surrounding area should be studied with the aim of ensuring water does not enter the retaining structure from this source.

Fills

5. Research is needed to determine the cause of segregation in granular fill material during vibratory compaction, with the aim of preventing segregation from occurring in practice.

6 In the meantime, placing of fill, which is likely to be particularly moisture sensitive, should not take place during heavy rain.

7 Modest savings are possible by using lower quality materials as the fill in retaining structures.

8 Research may be needed into the problems of compacting fine sand fill, and on the susceptibility to rain of silty fine sand fill.

9 If mudstone, as rock fill, is used as a fill for retaining walls there may be problems from the production of fines caused by the breakdown of the mudstone.

10 Consideration could be given to using an impermeable capping to protect fill from rain water infiltration.

Filters

11 If geocomposite filters are to come into use for the vertical drainage layer of retaining walls for highways in the UK, a trial should first be made to see if cohesive fill can be compacted against the filter without damaging or distorting it.

12 In retaining walls drained by weep holes, any single weep hole with a high flow should be investigated to find the cause, which may be a leaking water utility.

13 A permeable geotextile can be effective in preventing soil from entering the filter from the fill, but may suffer some loss of permeability with time.

14 The present method of specifying filters by grading seems to be satisfactory. However, research should be used to assess whether there is advantage in moving to a performance specification for filters, or retaining the current recipe specification.

7 Acknowledgements

The work described in this study is part of the research programme of the Structures Department of TRL Limited and was funded by Quality Services (Civil Engineering), Highways Agency. The TRL Project Manager is Mr A J Todd and the HA Project Manager is Mr P E Wilson. Mr P Darley, Mr P E Johnson and Dr J Temporal are thanked for assistance.

8 References

Au S W C and Pang K K (1993). *A note on seepage from retaining walls*. Quarterly Journal of Engineering Geology, 26, (1), pp 19-24.

Bird R W (1992). *Review of drainage to earth retaining structures for highways*. Contractor Report CR324. Crowthorne: TRL Limited.

Brady K C and Kirk G (1990). *The compressibility of a crushed limestone backfill*. Research Report RR251. Crowthorne: TRL Limited.

British Standards Institution (1995). *Eurocode 7: Geotechnical design. Part 1: General rules. Draft for Development DD ENV 1997-1: 1995*. London: British Standards Institution.

Card G B and Darley P (1995). *Assessment of substructures and over-conservatism in design*. Project Report PR120. Crowthorne: TRL Limited.

Chalmers R W, Vaughan P R and Coats D J (1993). *Reconstructed Carsington Dam: design and performance*. Proceedings Institution Civil Engineers: Water, Maritime and Energy, 101, (March), pp 1-16.

Chini S A, Wolde-Tinsae A M and Aggour M S (1993). *Drainage and backfill provisions for approaches to bridges*. Transportation Research Record 1425. Washington DC: Transportation Research Board.

Design Manual for Roads and Bridges. London: The Stationery Office,

Volume 2 Highway structures: design (DMRB2).
BD 30: Backfilled retaining walls and bridge abutments.

Volume 4 Geotechnics and drainage (DMRB4).
HA 41: A permeameter for road drainage layers.

Drainage Products Inc. (1993). *Drain away: no aggregate drainage systems*. Drainage Products Inc, Connecticut: Windsor Locks.

Farrar D M (1993). *TRL research on highway drainage*. Project Report PR/GE/21/93. Crowthorne: TRL Limited. *(Unpublished report available on direct personal application only)*

Geosynthetic Research Institute (1994). *Drainage to retaining structures using geocomposite sheet drains: the state-of-the-art practice in the USA*. Report to the Highways Agency. Philadelphia: Drexel University.

Geotechnical Engineering Office (1993). *Guide to retaining wall design. Geoguide 1. Second Edition*. Hong Kong: Civil Engineering Department.

Head K H (1994). *Manual of soil laboratory testing. Volume 2. Second Edition*. New York: John Wiley and Sons. Chapter 10.

Johnson P E (1993). *Highway drainage*. Project Report PR/GE/24/93. Crowthorne: TRL Limited. *(Unpublished report available on direct personal application only)*

Kamdar V P and Natarajan T K (1987). *Question 1: Earthworks, drainage, subgrade. Indian National Report*. Brussels: Proceedings 18th PIARC World Road Congress, pp 54-55.

Koerner R M and Bove J A (1987). *Lateral drainage designs using geotextiles and geocomposites*. In: Fluet J E (Editor) Geotextile testing and the design engineer. ASTM STP 952. Philadelphia: American Society for Testing and Materials, pp 33-44.

Macdonald A, Dawson G M and Coleshill D C (1993). *Reconstructed Carsington Dam: construction*. Proceedings Institution Civil Engineers: Water, Maritime and Energy, 101, (March), pp 17-30.

Manual of Contract Documents for Highway Works. London: The Stationery Office.

Volume 1 Specification for Highway Works (MCHW1).
Series 500 Drainage and service ducts.
Series 600 Earthworks.

Mlynarek J, Lafleur J and Lewandowski J B (1990). *Field study on long term geotextile filter performance*. Balkema, Rotterdam: Proceedings Fourth International Conference on Geotextiles, Geomembranes and Related Products, Volume 1, pp 259-262.

Naish M G (1988). *A cost survey of backfill around bridge abutments and retaining walls in southeast England*. Contractor Report CR112. Crowthorne: TRL Limited.

Natarajan T K and Jagannatha Rao P (1988). *Restoration of the stability of retaining wall*. Proceedings Second International Conference on Case Histories in Geotechnical Engineering, pp 365-368. Rolla, Missouri: University of Missouri-Rolla.

Smith M R and Collis L, *Editors* (1993). *Aggregates: sand, gravel and crushed rock aggregates for construction purposes. Second edition*. Geological Society Engineering Geology Special Publication No 9. London: Geological Society, Chapter 10.

Spalding R (1970). *Selection of materials for sub-surface drains*. Laboratory Report LR346. Crowthorne: TRL Limited.

Travers Morgan (1993). *Report on dismantling reinforced earth retaining wall R5 (northeast), M20 improvement, Junctions 5-8*. Report to Department of Transport South East Regional Office. East Grinstead: Travers Morgan. *(Unpublished).*

US Army Corps of Engineers (1994). *Retaining and flood walls*. New York: American Society of Civil Engineers Press, pp 97 and 104-105.

Wilson A C and Evans J D (1990). *The use of low grade rock fill at Roadford Dam*. In: The Embankment Dam: Proceedings Sixth Conference of the British Dam Society, Paper 3, pp 15-21.

Abstract

Drainage behind retaining walls was reviewed as the first stage of a research project carried out at TRL. The review is based mainly on literature published since 1992 when the subject was last reviewed for the Department of Transport. The drainage of both granular filters and fill is considered, but that of geocomposite filters is only touched upon because these were reviewed in 1994. The drainage of highway retaining walls in the UK seems to be generally satisfactory. However, the research project has afforded an opportunity to evaluate the advantages and disadvantages of producing performance specifications for drainage. Among other detailed conclusions are that piezometric studies of the fill behind retaining walls would be worth making, that research into the cause of segregation in granular fill should be carried out with the aim of preventing it from occurring in practice, and that research into the problems of compacting fine sand fill may be needed. Attention is drawn to the susceptibility of certain fill materials to rain.

Related publications

PR120 *Assessment of substructures and over-conservatism in design* by G B Card and P Darley. 1995 (price £50, code N)

CR324 *Review of drainage to earth retaining structures: methods of numerical modelling* by D I Harris. 1992 (price £50, code L)

RR251 *The compressibility of a crushed limestone backfill* by K C Brady and G Kirk. 1990 (price £20, code C)

CR112 *A cost survey of backfill around bridge abutments and retaining walls in southeast England* by M G Naish. 1989 (price £20, code C)

LR346 *Selection of materials for sub-surface drains* by R Spalding. 1970 (price £20)

Prices current at January 2001

For further details of these and all other TRL publications, telephone Publication Sales on 01344 770783 or 770784, or visit TRL on the Internet at www.trl.co.uk.