6.8.4.8 Determination of strength of steel components in the connection and load tests

The load capacity of components in connections may be determined by load testing and statistical analysis of an adequate number of samples.

6.9 Superimposed structures and loads for walls and abutments

6.9.1 Superimposed structures such as bridge decks

Small horizontal and vertical movements of the fill and the facing should be anticipated during and after construction, see **6.5.4** and BS EN 14475:2006.

Superimposed structures should be relatively flexible and should be designed to accommodate such small movements. If the reinforced soil structure is built on poor foundation soil that is expected to experience significant settlement, the effect on the superimposed structure may be reduced by allowing sufficient time to elapse for the greater part of the total settlement to occur, and/or possibly by using a surcharge, prior to building part or whole of the superimposed structure (see Smith and Worrall [23]).

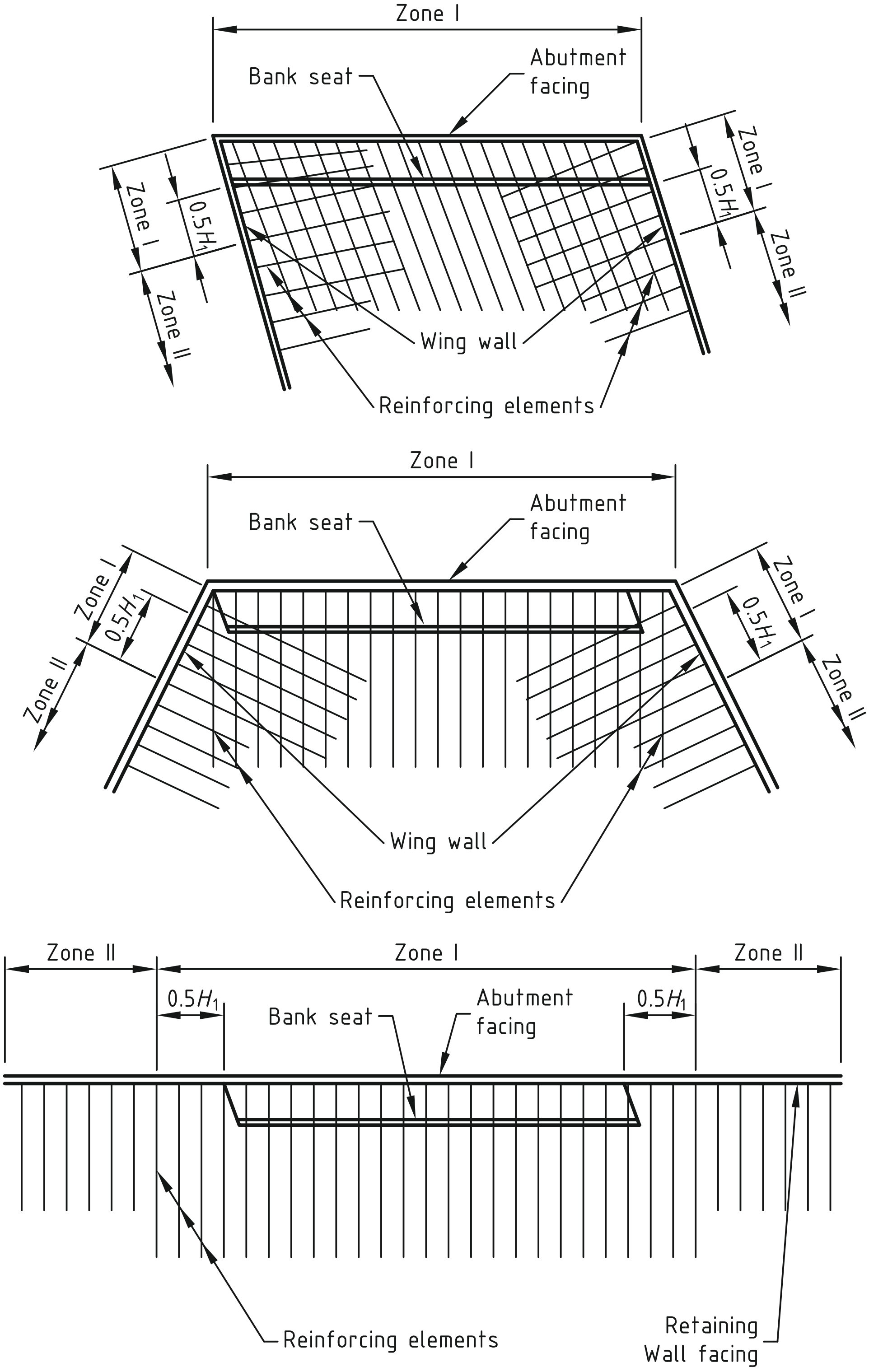
Vertical loads should be transferred directly to the reinforced fill. Base slabs of significant superimposed structures, such as bank seats for bridge decks, should not be fully or partly supported directly by the facing.

The resistance of the bank seat of a superimposed structure to horizontal loads should not be increased by attaching reinforcing elements as some movement of the bank seat is required before loads are transmitted to the reinforcing elements. Base slabs should not be attached to friction slabs or a system of ties with a ground beam or anchor blocks behind the reinforced zone, except where methods of analysis have been subject to specific study and client approval.

When a reinforced soil wall is used as a bridge abutment, then for simplicity the design of abutments may be considered in two parts, as shown in Figure 46. Zone I should be designed assuming loading includes that of the bank seat and its applied loads. Zone II should be designed as a retaining wall ignoring any loading derived from the bank seat. The load from the bank seat should be assumed to diffuse downwards at $2v{:}1h$ so that the width of Zone I increases linearly from bank seat level to be $0.5H_1$ greater in width at foundation level.

The construction sequence for the construction of a bridge abutment should be carefully considered: a bridge abutment is built in several stages, including erection of the reinforced soil mass, followed by the construction of the bankseat, and then the installation of the deck. The reinforced soil design should take account of the weight of the bankseat, the dead weight of the deck and the live loads acting on the deck. However, there might be other load cases that also have to be taken into account such as the reinforced soil mass carrying the weight of the bankseat and perhaps with the soil above the reinforced soil mass not yet up to final road level, which will not provide the same restoring overburden over the soil reinforcements for their pull-out resistance as in the final load case. The deck is likely to be installed before the road pavement layers are completed and, again, the overburden over the soil reinforcements will be less than in the final load case. The design should consider all the possible load cases and state clearly on the working drawings the arrangement and level of fill to be in place above the reinforced soil mass before construction of the bankseat and also before installation of the deck (see Figure 48). For these construction load cases, the strength of the soil reinforcement may be taken as that appropriate for the service life of temporary works as given in Table 7.

Figure 46 **Bridge abutments – Typical layout plans for strengthening elements**



6.9.2 Design of base slabs supporting vehicle parapets

The design of base slabs supporting vehicle parapets should be in accordance with Annex E unless the parapet supporting system is incorporated in a current third-party certificate [1]. A contribution to base sliding resistance may be provided by attaching reinforcing elements to the base slab but care should be taken to ensure that these are effective.

6.10 Construction and maintenance of walls and abutments

COMMENTARY ON ***6.10***
Factors affecting the performance of reinforced soil walls and abutments are detailed in Table 1.

Factors that affect the construction of reinforced soil walls and abutments include (see Moulton et al [24]):

- *foundation soils;*
- *fill material;*
- *reinforcement;*
- *facings;*
- *connections;*
- *drainage;*
- *site constraints;*
- *end use;*
- *erection rate.*

BS EN 14475:2006, Table 2 illustrates some possible aspects of design output.

6.10.1 Foundations

The foundation of the wall or abutment is the total width of the surface prepared to accept the length of the lowest layer of reinforcement.

The depth of the foundation below the finished ground level at the foot of the wall should conform to **6.4.2**.

Where the foundation is placed on natural ground it should be given several passes of a dead weight roller before the placing of any fill material. Soft spots should be removed and replaced with well graded granular fill. An additional trench excavation should normally be provided at foundation level for a mass concrete levelling pad, either precast or formed in situ, beneath hard facings in order to facilitate erection. (For segmental block walls, see **6.10.4.4**.)

[1] Third-party certification is accredited by UKAS (www.ukas.com) in the UK and members of the IAF (www.iaf.nu) in the rest of the world. For example, BBA and BRE are UKAS accredited.

6.10.2 Fill material

6.10.2.1 General

Reinforced soil walls and abutments are normally designed to use fill material that will allow for easy and quick erection. This fill should conform to **3.1**.

*NOTE Further guidance is given in BS EN 14475:2006, **6.2**.*

6.10.2.2 Placing and compaction of fill

The fill should be deposited, spread, levelled and compacted in horizontal layers of appropriate thickness as described in the Clause 622 within the *Specification for Highway Works* [1]

*NOTE Further guidance is given in BS EN 14475:2006, **8.5.4**.*

6.10.2.3 Quality control of fill during construction

The selection, placing and compaction of the fill should conform to the general requirements of the *Specification for Highway Works* [1] and BS EN 14475, **8.5.4**.

6.10.2.4 Restrictions on fill

*COMMENTARY ON **6.10.2.4***
Fills that might be suitable for embankment construction and reinforced slopes might not be suitable for use in reinforced soil walls e.g cohesive soils.

Frictional or cohesive frictional fills may be used in reinforced soil walls and abutments; these soils are easy to compact and are also relatively free draining avoiding the need for special drainage layers.

For land based structures the fill should conform to **3.1**. In cases where the fines content is greater than 10% the effects of pore water pressure both during construction and during the service life of the structure should be considered.

NOTE If significant pore pressures are created during compaction the soil tends to flow, and in reinforced soil this can lead to face deformations.

Very fine soils should not be used for the construction of walls in marine or river environments unless special precautions are taken and unless permanent drainage layers are provided. Construction under water using hydraulic fill may be used but in these cases the structure should incorporate special measures to allow for the settlement of the fill without compaction (see Wu and Smith [27])

6.10.2.5 Use of chalk fill

Chalk having an intact lump dry density, IDD > 1.55 Mg/m^3 (i.e. medium and/or high density chalk) and natural moisture content of up to 25% may be allowed for use as fill. Soft chalk (IDD < 1.55 Mg/m^3) should not be used as fill for permanent works. Chalk of adequate quality may be used in reinforced soil structures but a similar degree of care, as is necessary for general chalk earthworks, should be exercised.

NOTE The quality of chalk specified is that which was used in a full scale trial of walls at Paulsgrove [40].

The chalk as delivered should not contain lumps greater than 600 mm and should be deposited and compacted by bulldozer and smooth dead weight roller to ensure that no particles larger than 125 mm remain within the body of the fill. Any large lumps of chalk within 2.0 m of the face of a structure should be broken down with a power rammer or pulled back into the body of the structure and crushed. The compaction plant should be chosen to suit the grade of chalk.

The fill within 2.0 m of the face of the wall should be compacted in accordance with **6.10.2.2**. Compaction of chalk should not take place when it is in such a condition that it turns to a slurry. It is recommended that the method of working should be approved with a trial before work proceeds (see Griffiths [40]).

A 300 mm wide granular drainage and frost blanket or similar measure should be used against the back face of any facing units. Where appropriate this material should be specified as frictional fill in accordance with **3.1**. A geotextile wrapping or fin drain may also be adopted.

Although the recommended limit of IDD and moisture content is given above, special care should be taken in placing and compacting chalks that approach these limiting values. In particular it is necessary to ensure that:

a) the facing panels are not displaced by heavy compaction plant operating close to the back of the panels; and

b) the compaction plant can effectively break down large fragments to achieve the recommended compaction standard; the compaction plant necessary to achieve this objective is dependent on the properties of the chalk but the provision of a power rammer is recommended. (Further guidance is given within Clause 622 in the *Specification for Highway Works* [1].)

6.10.2.6 Use of other materials

6.10.2.6.1 General

Other fills including argillaceous materials, pulverized-fuel ash and colliery spoil may be used in accordance with **3.1**.

It should be noted that the suitability of these materials depends upon their frictional strength and on their aggressiveness to the intended reinforcement, facing and connections.

Their suitability should be determined beforehand by tests on a representative number of samples. To ensure quality during construction frequent site checks on both strength and the chemical properties should be carried out.

6.10.2.6.2 Argillaceous materials

Argillaceous material (e.g. shales, mudstones) used in reinforced soil applications should be carefully selected Rainbow [15]). Particular care should be taken in assessing the chemical characteristics of these materials, and their variability, to ensure compatibility with the reinforcement (see **3.1.2**). Many argillaceous materials can be friable in nature and in such circumstances they should not be used (see **3.1.3.5**).

6.10.2.6.3 Pulverized-fuel ash

Pulverized-fuel ash, used as fill in reinforced soil in accordance with **3.1.3.3** is the resultant ash from pulverized coal burnt in power stations. The material used as fill in any structure should be obtained from one source and should have a maximum particle size of 3 mm.

Pulverized-fuel ash should be compacted by vibrating rollers at a moisture content not exceeding optimum.

NOTE Some pulverized-fuel ash fills might not conform to the electrochemical limits of fill in respect of metallic reinforcement.

Only non-metallic reinforcing elements, e.g. polymeric reinforcement, should be used with pulverized-fuel ash fill.

A layer of frictional fill not less than 500 mm thick should be placed on top of the PFA and below the road formation level. This layer should connect with the vertical drainage layer described in **6.10.5.2**.

A 300 mm wide granular drainage blanket complying with SHW [1] Clause 622.5 (ii) should be used against the facing units. Reinforcement connections buried within the drainage blanket should be considered in accordance with **3.2.1** and Table 3.

6.10.2.6.4 Colliery spoil

Generally material from a spoil heap should be preferred as this will have undergone a degree of physical and chemical weathering both during placing and whilst in place on the tip. Material taken direct from a mine or coal preparation plant may be used but as the material may vary a high level of quality control should be undertaken to ensure the materials characteristics remain consistent during use (see **3.1.1**).

Minestone within a spoil heap is generally well graded and at optimum moisture content for compaction and selected as-dug material may be used as fill. Compaction should be achieved using vibrating smooth wheeled rollers.

6.10.3 Reinforcement elements

Metallic reinforcement should be prefabricated and delivered to site ready for installation into the structure. Stiff polymeric reinforcement should be prefabricated and delivered to site ready for installation into the structure. Flexible reinforcement including geotextile sheets, meshes, grids and strips should be prefabricated and delivered to site in secure rolls, if appropriate.

*NOTE Further guidance is given in BS EN 14475:2006, **6.3**.*

6.10.4 Facing

6.10.4.1 General

Only hard or flexible/deformable units should be used for walls.

*COMMENTARY ON **6.10.4.1***
The visual appearance of a structure is affected by the final shape of the facing. The surface can vary from the theoretical plane due to several causes including the following.

a) Poor workmanship. *The effect of poor workmanship will be evident as construction proceeds and may be noticed by the erratic inclination of the facing. Face construction should be supervised and checked for alignment as work progresses.*

b) Extension of the reinforcements during and immediately after construction. *Extension of the reinforcements under load can give* *rise to wall face deformation, the amount of which will be dependent upon the axial stiffness of the reinforcement and the extent of the restraint mobilized in the soil as the composite soil/reinforcement system is put under the load.*

c) Creep in reinforcement. *These are limited to the serviceability limits specified in **6.5.5.2** and Table 19.*

d) Creep in fine grained soils. *This can occur due to high moisture content (see **6.5.5.1**).*

*Further guidance is given in BS EN 14475:2006 **6.4** and Annex B.*

6.10.4.2 Hard facing

*COMMENTARY ON **6.10.4.2***
Hard facing units are usually produced in precast concrete. They can be full height panels, partial height panels, sloping panels, planter units or segmental blocks.

Examples are shown in Figure 16a), Figure 16b) and Figure 16d).

Full height panels should be propped during the filling operation and until the connected reinforcements support the facing. The toe of the wall facing should be restrained to prevent forward movement before the bottom layer of reinforcement is able to act; an estimate of prop force is needed in order to size up the prop and its foundation.

6.10.4.3 Flexible facing

*COMMENTARY ON **6.10.4.3***
Flexible or deformable facings are as shown in Figure 16c).

They are formed of metal or polymeric material such as steel welded wire mesh, gabion baskets or tyres, or wrap-around polymeric construction.

In all reinforced soil applications there is a small compression of the fill during erection. In the case of discrete panels, the movement is accommodated by the use of compressible joints, with flexible metal facing the curved cross section of the facing unit flexes and with soft facings the face distorts.

In the case of full height facing panels of any significant height any relative displacement between fill (and the embedded reinforcing element) and facing may be accommodated by permitting the reinforcements to slide or move relative to the facing; various methods have been used including the use of grooves, slots, vertical poles, lugs or bolts. A sliding connection will permit the reinforcement to transmit horizontal load and yet slide downwards as filling progresses without loss or gain in load. In the case of relatively short full height panels, reinforcements such as geotextiles may be fixed into the facing panel. With this arrangement, deformation in the region of the face connections can occur. An assessment of the additional load imposed by this deformation may be included in the design load to be carried.

6.10.4.4 Segmental block wall facing

To aid alignment of the facing, the blocks should be laid on a leveling pad, which is usually concrete, although granular fill may also be used; the leveling pad is not a foundation but a means of providing a flat level surface for the first course of blocks.

If concrete is used it is usually mass concrete of low strength and about 150 mm thick and extending beyond the front and rear faces of the blocks; the blocks may be laid on a mortar bed on the concrete leveling pad.

A vertical layer of granular drainage fill, typically class 6H, with a width of 300 mm should be used behind the block facings. This layer may prevent the loss of fines from the structural fill through the joints between the blocks and also reduces the risk of block displacement during compaction of the fill. The drain may also channel any water seepage to the toe of the wall where it may exit through the normal dry joints between the blocks to the front of the wall where a longitudinal drain may be laid, see **6.10.5.3**.

Traditional earth retaining walls in reinforced concrete or masonry should be built with a slight batter to off-set the slight forward rotation as backfill is placed against their stem and causing the stem to move towards vertical; if such a wall was built with a vertical stem its face would move forward of vertical and look over-hanging and have a disturbing visual effect.

The discrete panel face units of reinforced soil walls, having facings which are designed to be vertical upon completion of construction, should be placed in position in the wall and inclined inwards slightly and allowed to rotate out to vertical as the backfill is placed against them, as the load is taken up by the soil reinforcement.

It should be noted that segmental blockwalls are similar to traditional masonry walls and so their faces are usually battered back by one degree or more by either the front face of the block being battered or by setting the front of a block slightly inwards compared with the course below – the amount is called the set-back. It is common for nibs and lips formed on the upper and lower faces of the blocks to automatically form the set-back.

6.10.5 Drainage

*COMMENTARY ON **6.10.5***
In reinforced soil structures drainage is an important consideration. If the structure is allowed to become waterlogged the tensile forces in the reinforcing elements increase and the properties of the fill and retained ground can change. The force on the wall can increase and any pore water pressures can reduce the effective overburden pressure on the reinforcements thus reducing pull-out capacity.

Water can enter a structure in two ways.

Water can percolate from the upper surface unless effective sealing details are provided.

Ground water can flow into the structure from the retained ground. This is usually only significant in cases of structures supporting roads or railways on side-long ground where water can emerge from the cutting at the uphill side.

Consideration has to be given to drainage during construction.

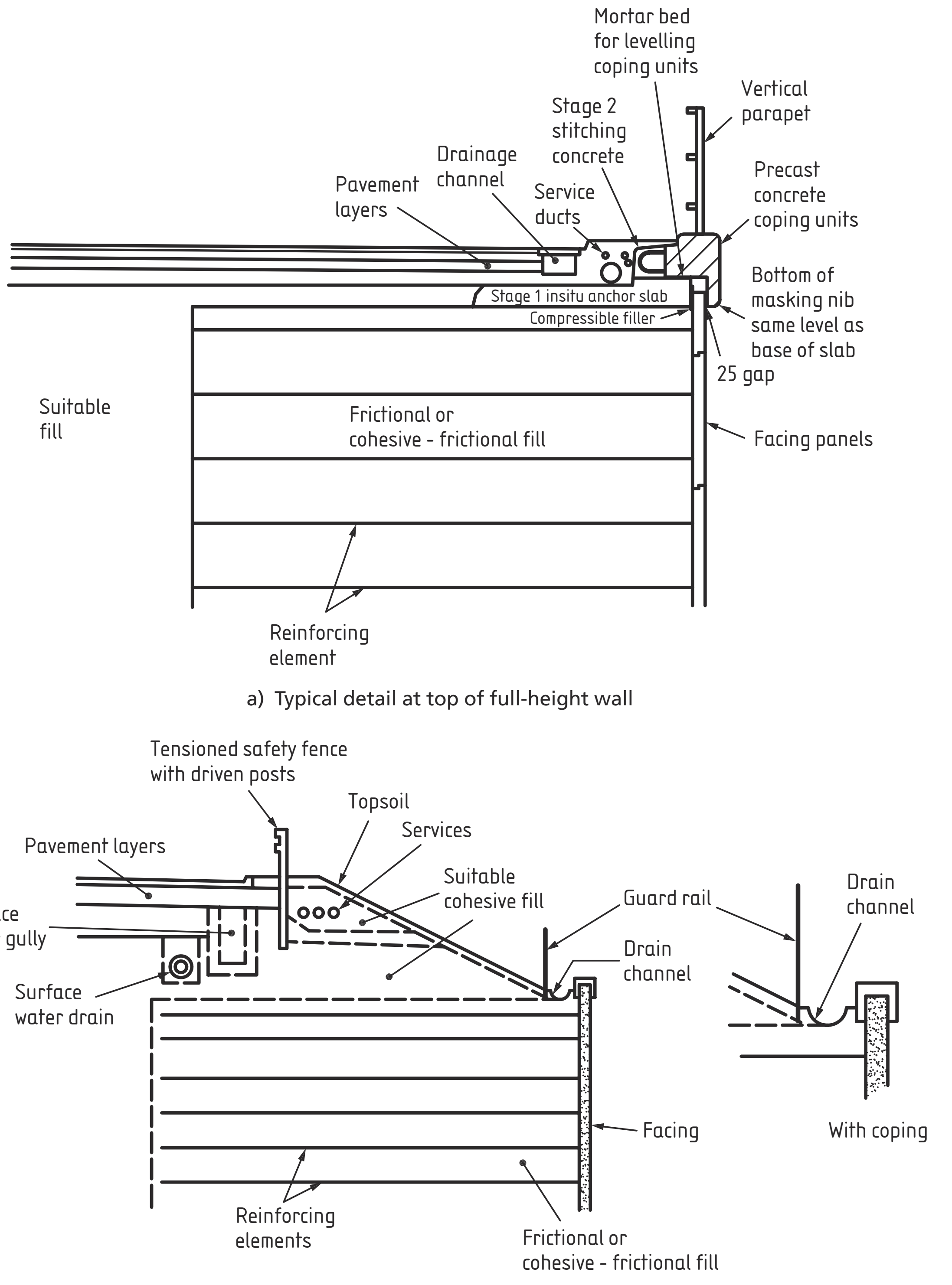
*Further guidance is given in BS EN 14475:2006, **8.4**.*

6.10.5.1 Drainage at the top of a wall

For walls supporting roads, the use of a sealed kerb and drainage channel at the back of the hard shoulder should normally be sufficient. Where there is no hard shoulder, a channel with flexibly sealed joints should be provided at the back of the hard strip/edge of carriageway [see Figure 47a)]. In addition, for part-height walls a drainage system should be provided at the top of the facing behind the panel top or coping, if used, in order to remove water running off the side slope [see Figure 47b)]. This may consist of a simple drain channel leading surface water along the wall top to discharge beyond the end of the wall.

For all structures, details should be used to avoid significant water penetration from the upper surface and means of collecting and leading away rain water should be provided. Abutment bank seats should include means of collecting any seepage from a faulty joint between the curtain wall and the deck (see Figure 48).

[A1⟩ Figure 47 **Reinforced soil retaining walls**



a) Typical detail at top of full-height wall

b) Typical detail at the top of a part-height wall

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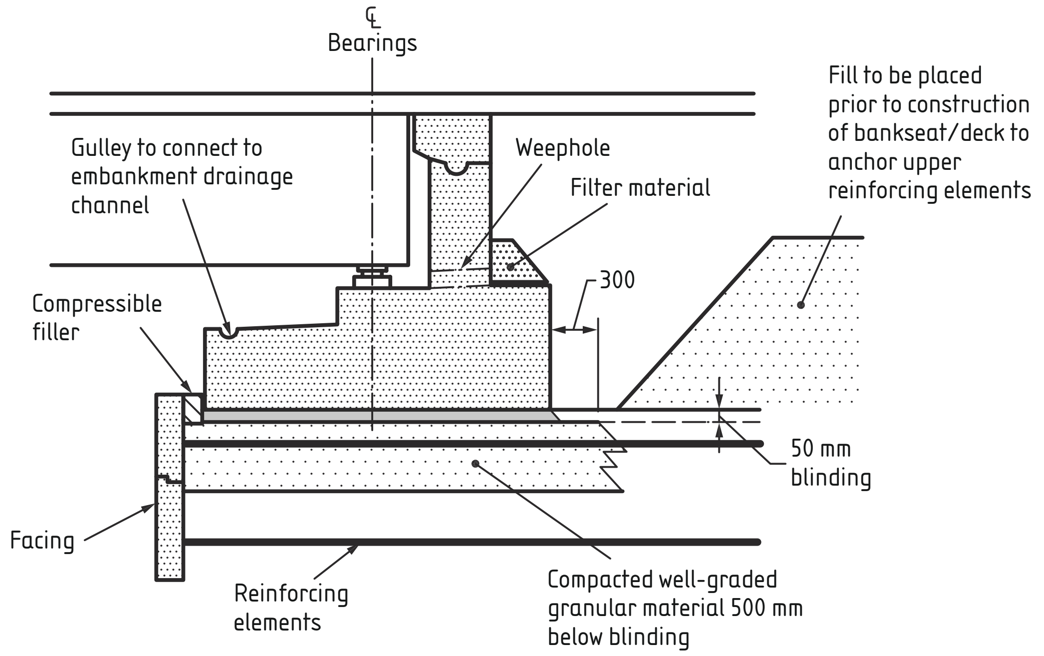
Figure 48 **Typical drainage detail for abutment bankseat**



6.10.5.2 Drainage of the wall

*COMMENTARY ON **6.10.5.2***
The normal considerations of drainage of conventional structures apply equally to reinforced soils. However due to the design considerations requiring the reinforced fill to have frictional properties means that it is also relatively permeable compared to fill retained behind conventional structures. Even where the reinforced fill is at the fine end of the specified range it will be relatively permeable and will have a large width (usually at least 0.7H).

In many circumstances this reinforced mass is effective as a drain without the use of other means, see Figure 49.

If the structure is located on a permeable foundation soil above the water table any small water seepage will pass into the foundation soils and a drain layer/pipe should not be necessary.

In other situations a longitudinal porous or open jointed pipe of not less than 150 mm diameter should be used at the front toe of the structure to collect water and bring it into the site drainage system. This pipe should be laid in front of the face panel where it will be accessible for future maintenance. To enable any seepage to pass through a hard facing, weep holes may be located in selected panels. For discrete facings the drain path may be more easily provided by omission of the vertical joint filler between all panels at the foot of the wall in the embedded depth, see Figure 50.

NOTE A pipe located in front of the facing allows reinforced soil construction to commence without the interruption of drain laying amongst the reinforcements. If the pipe is laid behind the panels there can be difficulty providing adequate falls due to the adjacent reinforcements. Access is also more difficult and substantial facilities for rodding the pipe are necessary.