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THE SCOTTISH OFFICE DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
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THE DEPARTMENT OF THE ENVIRONMENT
FOR NORTHERN IRELAND

Backfilled Retaining Walls and Bridge Abutments

Summary: This Departmental Standard sets out the design and construction requirements for backfilled walls and bridge abutments.

VOLUME 2	HIGHWAY STRUCTURES: DESIGN (SUBSTRUCTURES AND SPECIAL STRUCTURES), MATERIALS
SECTION 1	SUBSTRUCTURES

BD30/87

BACKFILLED RETAINING WALLS AND BRIDGE ABUTMENTS

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SYMBOLS

c_u Undrained shear strength

c' Effective cohesion

ϒd Dry density in Mg/m3

ϒ Bulk density

ϒfL Partial Load factor

Φ' Effective angle of internal friction

1. INTRODUCTION

1.1 This Departmental Standard gives recommendations on the selection of materials for backfilling to structures. It also specifies design and construction requirements for backfilled retaining walls and bridge abutments. It complements the Department of Transport Specification for Highway Works[1] (6th Edition, 1986), which is hereafter referred to as the Specification.

1.2 This Departmental Standard supersedes Interim Memorandum[2] (Bridges) IM4 - Pulverised Fuel Ash - Backfilling to Structures.

2. SCOPE

2.1 Recommendations given in this Departmental Standard are applicable to backfilled retaining walls, bridge abutments and wing walls. Reinforced and anchored earth retaining walls are covered by Technical Memorandum BE 3/78 and the backfilling requirements for buried corrugated steel structures are given in the Departmental Standard BD 12/82. This Departmental Standard is not applicable to structures retaining natural ground as in deep cuttings or for cut and cover tunnels.

2.2 Guidance is given on the selection of materials - the various types permitted and the considerations of economy and structural safety. Methods for calculating design forces generated by the backfill are also given.

2.3 This Departmental Standard also contains recommendations on construction details such as drainage requirements and compaction.

3. ECONOMIC CONSIDERATIONS

3.1 The wedge of backfilling should be considered to form part of the structure and an economic assessment of all available material should be made in every case to test whether savings in wall, abutment and foundation design would outweigh the cost of importing fill.

3.2 The rate for imported backfilling such as rock fill or other granular materials can be many times the cost of acceptable material arising on site. Such high costs, which may be equivalent to between 10 and 30 per cent of the total bridge cost, can seldom be justified by savings in the design resulting from reduced earth pressures.

3.3 The normal intention should therefore be to use materials acceptable for backfilling which are available on site. From a study of the properties identified by the ground investigation the Engineer should be able to determine the least favourable material he is prepared to accept, and design the structure for this.

3.4 In general imported fill should only be specified in circumstances such as when

(a) acceptable material is not available on site, or

(b) a small amount of backfilling is required in a very restricted space, or

(c) it is justified by specific design requirements such as the need to use low density fill to reduce settlement problems, or

(d) it is cost effective.

4. BACKFILLING MATERIALS

4.1 The following classes of material which are fully described in the 600 Series of the Specification are acceptable for backfilling to retaining walls and abutments:

(a) Class 6N - Selected well graded granular material.

(b) Class 6P - Selected uniformly graded granular material (Note: this includes chalk).

(c) Class 7A - Selected cohesive material.

(d) Class 7B - Selected conditioned pulverised fuel ash (PFA).

4.2 Selected well graded granular material can consist of natural gravel, natural sand, crushed gravel, crushed rock etc. This is a mainly frictional material with less than 15 per cent passing the 63 micron sieve and with a minimum acceptable uniformity coefficient of 10.

4.3 Selected uniformly graded material is as Class 6N material except that a minimum uniformity coefficient of 5 is acceptable. Additionally, chalk with a saturation moisture content of 20 per cent or less shall be acceptable. The saturation moisture content of chalk shall be evaluated from its dry density, determined in accordance with Test 15E of BS 1377, using the following expression:

$$\text{Saturation moisture content} = \left(\frac{1}{\Upsilon d} - \frac{1}{2.7} \right) \times 100 \text{ per cent}$$

where ϒd = dry density Mg/m3

Information on the determination of saturation moisture content of chalk may be obtained from TRRL Report LR 8063.

4.4 Selected cohesive material. This material is intended to include acceptable material available on site. It can consist of sand, silt and clay with 15 to 100 per cent passing the 63 micron sieve. At the finest end over-consolidated clay will be acceptable, subject to other requirements as described in the Specification, such as the maximum acceptable Liquid Limit of 45 and Plasticity Index of 25.

4.5 For consistent properties only conditioned PFA from any single source shall be used for each structure.

4.6 Argillaceous rocks such as shale and mudstone can increase earth pressures on retaining walls by swelling; they may also release sulphuric acid, putting adjacent concrete structures at serious risk and may contribute to the blocking of drainage materials by the formation of crystalline sulphates. Such rocks, in any form, must not be used within 5m of a structure. If the structure is piled, such material must not be used within 10m of the structure or its foundation.

4.7 The Engineer shall specify the properties of the fill material on which the design of the structure is based and record those in the contract documents. Any departure from the specification will require a reassessment of the design.

5. DESIGN

5.1 The following design principles apply to backfilled cantilever retaining walls with spread footing or pile foundation. Design of the embedded (or diaphragm) type of retaining walls should continue to be based on currently used design methods such as those given in CIRIA Report 104[4].

5.2 Limit States

5.2.1 The structure and the surrounding soil must be designed to perform satisfactorily for both the ultimate and the serviceability limit states. The four limit states which are to be considered in the design are described below.

5.2.2 Ultimate Limit State of the Structural Elements. This limit state corresponds with the failure of the stem or the base of a retaining wall and is as defined in BS 5400: Part 4, as implemented by BD 24/84, for concrete walls. The structural design and detailing shall be in accordance with that code.

5.2.3 Serviceability Limit State of the Structural Elements. This limit state corresponds with acceptable limits of cracking as described in BS 5400 Part 4, as implemented by BD 24/84, for concrete walls. The structural design and detailing shall be in accordance with that code.

5.2.4 Ultimate Limit State of Soil.

5.2.4.1 This limit state corresponds with the following failure modes of the surrounding soil and the soil-structure interface:

Sliding
Overturning
Failure of the foundation soil
Slip failure of the surrounding soil

5.2.4.2 Design for this limit state shall be based on the design procedures and the overall factors of safety given in CP2 and BSCP 2004. Nominal values of dead and highway live loads as given in BS 5400: Part 2, as implemented by BD 14/82, shall be used in the calculations where necessary.

Note: The overturning design criterion given in BS 5400: Part 2 is not applicable to this limit state.

5.2.5 Serviceability Limit State of Soil.

5.2.5.1 The adoption of recommended safe bearing capacities for the foundation design should avoid undesirable settlements and tilting of the structure. Nevertheless a separate assessment of the differential settlements and tilting of the structure is necessary for the design of associated superstructures. Such movements can be calculated from a displacement or consolidation analysis. The predicted movements shall be taken into account in the overall design of the structure.

5.2.5.2 The factor of safety for this limit state shall be taken as 1. Nominal values of dead and highway live loading as given in BS 5400: Part 2, as implemented by BD 14/82, shall be used in the calculations where necessary.

5.3 Earth Pressures

5.3.1 In all limit states of design, earth pressures generating from the retained fill will need to be considered. Methods for calculating these earth pressures and the corresponding partial load factors applicable to them are given below. For low permeability backfill such as the selected cohesive material it is necessary in design to assess separately the earth pressures acting in the short term and those acting in the long term when full porewater pressure equilibrium has occurred. In clay fills the short term earth pressures are determined using the undrained shear strength (c_u) whereas for the long term earth pressures the effective stress strength parameters (c', Φ') are used.

5.3.2 For the ultimate limit state of the structural elements ‘at rest’ earth pressure shall be used in the design. The partial load factor ΥfL for earth pressure generated by the backfill itself shall be taken as 1.5 (1.0 for relieving effects).

5.3.3 For the serviceability limit state of the structural elements ‘at rest’ earth pressure shall be used in the design. The partial load factor ΥfL for earth pressure generated by the backfill itself shall be taken as 1.0.

5.3.4 For the ultimate and serviceability limit states of the soil ‘active’ earth pressure shall be used in the design. Partial load factors are not required for these limit states since the CP2 and BS CP 2004 design methods are based on overall factors of safety.

5.4 General Design Considerations

5.4.1 Where the design uses assumed soil parameters, such as soil density ϒ, effective cohesion c' and the effective angle of shearing resistance Φ', the Engineer shall check and confirm that the properties of the fill material to be used in the actual construction are not inferior to those used in the design.

5.4.2 All combinations of design situations such as the presence of hydrostatic pressure etc shall be considered when applicable. The possibility of burst water mains in the vicinity of the structure shall be taken into account.

5.4.3 When PFA is used, the value of the effective angle of internal friction Φ' for PFA can be taken as 30°, but must be confirmed by tests for final design. The value of c' for PFA should be established by test but must not be taken to be greater than 5 kN/m^2 for design purposes. The properties of PFA can vary considerably from one source of supply to another.

5.4.4 Cohesive fill materials other than PFA should be placed at moisture conditions close to their long term equilibrium states which shall be specified in the Contract. Otherwise problems associated with volume change, such as increased wall pressure, can arise afterwards.

6. CONSTRUCTION DETAILS

6.1 Extent of Backfilling

The extent of the backfilling wedge to be treated separately from the main earthworks should be indicated on the contract drawings. It is essential to provide adequate space for the compacting plant to operate efficiently. Normally the wedge will have a benched back slope of 1.5 horizontal to 1 vertical. Whether the minimum width of the wedge is at the top or the bottom of the backfill will depend upon whether a bridge and its abutments are to be constructed in advance of the approach embankment or vice versa. The minimum width will be determined by the requirements for good compaction as well as by the need to satisfy the principles used in the calculation of earth pressure.

6.2 Compaction

6.2.1 Compaction of the backfill shall be in accordance with the Specification.

6.2.2 Moisture content requirements must be complied with during compaction since unduly wet or very dry material is not only difficult to compact, but may also result in lower than the designed strength of the backfill and consequently higher pressures. This is specially true for PFA and cohesive materials. In order to achieve the required compaction PFA should be placed at a moisture content of 0.8 to 1.0 of the optimum moisture content determined in accordance with Test 12 of BS 1377.

6.2.3 Chalk undergoes physical degradation during handling, mainly in the excavation, spreading and compaction stages. The objective must be to retain the maximum possible amount of intact chalk rock at all stages whilst still complying with the compaction requirements of the Specification.

6.3 Drainage

6.3.1 Surface drainage must be provided to drain surface water away from an earth retaining structure or the backfill.

6.3.2 Sub-surface drainage is important for an earth retaining structure and must be shown in detail on the contract drawings.

6.3.3 In order to collect and dispose of any water percolating through the fill a continuous system of porous or perforated drainpipes not less than 150mm diameter shall be provided adjacent to, and at the rear of the vertical stem of the wall at the level of the top of the footing. For ease of maintenance, facilities should be included for rodding the whole length of the system from inspection manholes positioned at the foot of the wall. Weep holes located just above ground level can provide a useful visual check that the system is functioning correctly, and will limit the rise in water level in the event of a drainage failure.

6.3.4 For selected granular backfill a vertical permeable layer shall be provided at the back of the wall consisting of the following materials as described in the Specification:

(a) Precast hollow concrete blocks.

(b) Cast in-situ porous no fines concrete.

(c) Granular drainage layer.

6.3.5 When drainage materials of the types (a) and (b) above are used, they shall be capable of withstanding any horizontal pressure likely to be exerted through the backfill. These drainage materials are not recommended when the backfill contains materials susceptible to piping such as silt, chalk or PFA.

6.3.6 When drainage material type (c) is used, it must satisfy the following criteria, which shall be included in the

Contract as additional requirements pending revision of the Specification:

Piping ratio, defined as

$$\frac{15 \text{ per cent size of the drainage material}}{85 \text{ per cent size of the backfill material}} < 5$$

Permeability ratio, defined as

$$\frac{15 \text{ per cent size of the drainage material}}{15 \text{ per cent size of the backfill material}} > 5$$

The per cent size of a material is the size of particle corresponding to the given per cent ordinate of the particle size distribution chart.

6.3.7 The vertical drainage layer should connect with the drainage pipes.

6.3.8 In highly permeable backfill a vertical drainage layer may be omitted.

6.3.9 When selected cohesive material, PFA or chalk are used as backfill, the following provisions shall be made:

(a) A layer of granular fill not less than 500mm thick shall be placed on top of the fill and below the road foundation level. This layer shall connect with the vertical drainage layer described below.

(b) A vertical drainage layer of thickness not less than 300mm of fine aggregate of grading C or M complying with BS 882: Table 5 shall be provided behind the wall. The layer shall connect with the drainage system at the base of the structure.

(c) A horizontal drainage layer 450mm thick shall be placed beneath the fill. The top 200mm of this layer will be of fine aggregate of grading C or M complying with BS 882: Table 5, the remaining 250mm will be of Type B filter material complying with Clause 505 of the Specification. This layer shall connect with the drainage system at the base of the structure. This layer can be omitted if the underlying soil is highly permeable.

(d) When PFA is used as the fill material the components of the drainage system at the base of the structure shall be resistant to the effect of sulphates.

6.3.10 Proprietary drainage materials can be used as permeable backing provided they have a British Board of Agrement Roads and Bridges Certificate registered with the Department of Transport.

6.3.11 When PFA is used as the backfilling material, there is a danger that it may turn into a slurry as a result of accidental flooding forming voids in the mass of the backfill. This can happen during construction as well as afterwards. Due precaution should therefore be taken at the design stage to reduce the likelihood of water leakage in the vicinity of the PFA fill by specifying leak-proof joints in any drains and if necessary rerouteing any water mains.

6.4 Protection of Structural Materials

Some protection of concrete and steel in the retaining structure against injurious leachates originating from the mass of the fill material is achieved by the provision of adequate drainage as specified in 6.3. As an additional precaution, those parts of the retaining structure which will be in contact with soil shall be coated prior to backfilling with at least two coats of a material approved for waterproofing below-ground concrete surfaces and complying with Clause 2004 of the Specification.

6.5 Frost Protection

PFA, selected cohesive material and chalk are susceptible to frost damage. When such materials are used for backfilling all exposed surfaces of earthwork must consist of a 450mm thick layer of other acceptable fill material.

7. REFERENCES

1. Specification for Highway Works - 6th Edition, Department of Transport, HMSO 1986.

2. IM4 Pulverised Fuel Ash - Backfilling to Structures, Department of Transport, 1969.

3. H C Ingoldby and A W Parsons "The Classification of Chalk for Use as a Fill Material", LR 806, TRRL, 1977.

4. C J Padfield and R J Mair "Design of Retaining Walls Embedded in Stiff Clay", Report 104, CIRIA, 1984.

The following is a list of British Standards and DTp Departmental Standards to which reference is made in this Standard.

BS 882: 1983 Specification for aggregates from natural sources for concrete.

BS 1377: 1975 Method of tests for soils for civil engineering purposes.

BS CP 2004: 1972 Foundations.

BS 5400 Steel, concrete and composite bridges.

Part 2: 1978 Specification for loads.

Part 4: 1984 Code of practice for design of concrete bridges.

CP 2: 1951 Earth retaining structures.

IM4 Pulverised Fuel Ash - Backfilling to Structures.

BD 12/82 Corrugated Steel Buried Structures.

BD 14/82 Loads for Highways Bridges: Use of BS 5400: Part 2: 1978.

BD 24/84 Design of Concrete Bridges: Use of BS 5400: Part 4: 1984.

BE 3/78 (Revised 1987) Reinforced and Anchored Earth Retaining Walls and Bridge Abutments for Embankments.

8. ENQUIRIES

Technical enquiries arising from the application of this Departmental Standard to a particular design should be addressed to the Technical Approval Authority for that Scheme.

All other enquiries or comments about this Departmental Standard should be sent in writing to:

Head of Division
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