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

PART 10

BD 82/00

DESIGN OF BURIED RIGID PIPES

SUMMARY

This Standard implements BS EN 1295-1 'Structural design of buried pipelines under various conditions of loading – General requirements' and BS EN 1610 'Construction and testing of drains and sewers'. This Standard applies to buried rigid pipes of internal diameter exceeding 0.9m for depth of cover equal to or greater than 0.6m but not exceeding 10m, measured from the finished road surface or final ground level to the external surface of the crown of the pipe. It does not cover vertical chambers.

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THE HIGHWAYS AGENCY

THE SCOTTISH EXECUTIVE DEVELOPMENT DEPARTMENT

THE NATIONAL ASSEMBLY FOR WALES
CYNULLIAD CENEDLAETHOL CYMRU

THE DEPARTMENT FOR REGIONAL DEVELOPMENT*

Design of Buried Rigid Pipes

* A Government Department in Northern Ireland

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Contents

Chapter

1. INTRODUCTION

General

1.1 This Standard provides the design and construction requirement for buried rigid pipe structures where the internal diameter of the rigid pipe exceeds 0.9m.

1.2 Those parts of the following Standards which give requirements for buried rigid pipe structures are superseded by this Standard:

BE 1/73	Reinforced concrete for highway structures (clause 2.9)
BE 1/77	Standard highway loading (1)
BD 24	Design of concrete bridges. Use of BS 5400:Part 4:1990

Note also that HA 40 'Determination of pipe and bedding combinations for drainage works' is not generally applicable to pipes exceeding 0.9m in diameter. Those parts of that document that are relevant to the larger pipe sizes are specifically mentioned in this Standard.

1.3 This Standard explains how BS EN 1295-1 'Structural design of buried pipelines under various conditions of loading – General requirements' and BS EN 1610 'Construction and testing of drains and sewers' shall be used to produce a satisfactory design and completed drainage structure.

Equivalence

1.4 The construction of buried rigid pipe structures will normally be carried out under contracts incorporating the Specification for Highway Works (MCHW 1). In such cases products conforming to equivalent standards or technical specifications of other states of the European Economic Area and tests undertaken in other states of the European Economic Area would be acceptable in accordance with the terms of the 104, 105 and 106 Clauses of MCHW 1. Any contract not containing these Clauses must contain suitable clauses of mutual recognition having the same effect regarding which advice should be sought.

Scope

1.5 The design, bedding and installation requirements given in this Standard are applicable to buried rigid pipes of internal diameter exceeding 0.9m where the depth of cover, measured from the finished road surface or final ground level to the external surface of the crown of the pipe, is equal to or greater than 0.6m but does not exceed 10m.

1.6 In the context of this Standard rigid pipes are defined as pipes manufactured of unreinforced or reinforced concrete to BS 5911:Part 100, prestressed concrete pipes to BS 5911:Part 103 and vitrified clay pipes to BS EN 295-1. This Standard covers the structural design and use of such pipes in drainage structures.

1.7 Asbestos cement pipes are not covered by this Standard. Whilst they are categorised as rigid pipes in Annex B and National Annex A of BS EN 1295-1, the manufacture and importation of products made of asbestos is not permitted in the UK for health and safety reasons.

1.8 Rigid pipes installed either by thrust boring techniques or jacking techniques or in heading or tunnel are not covered by this Standard.

1.9 While the hydraulic design of pipe systems is not dealt with in this Standard, the drainage structure must, where appropriate, be compatible with the drainage system designed in accordance with HD 33 'Surface and sub-surface drainage systems for highways'. In addition, when required, drainage structures should provide ample capacity for dealing with the runoff from larger catchment areas. As recommended in HD 33 the provision of some spare capacity is relevant to all outfall pipes which in surcharge conditions could otherwise jeopardise the safety of the highway: it might also prove useful should any necessary maintenance or repair reduce the bore of the pipe.

1.10 This Standard does not cover vertical chambers. Details of these are given in Highway Construction Details (MCHW 3).

Implementation

1.11 This Standard should be used forthwith on all schemes for the construction and improvement of trunk roads, including motorways, currently being prepared, provided that in the opinion of the Overseeing Organisation this would not result in significant additional expense or delay. Design Organisations should confirm its application to particular schemes with the Overseeing Organisation. In Northern Ireland the use of this Standard shall apply on those roads designated by the Overseeing Organisation.

Symbols

1.12 The symbols used in this Standard are defined as follows:

DN	Nominal size (approximately equal to internal diameter of pipe in mm)
F_m	Bedding factor
F_s	Design factor of safety for maximum crushing load
$F_{s(proof)}$	Design factor of safety for concrete pipes based on works proof load in BS 5911: - it has a value of unity
W_e	Total design external load per unit length of pipe
W_t	Crushing strength of rigid pipes (maximum load for concrete pipes) per unit length of pipe
W_p	Works proof load test.

Mandatory Requirements

1.13 Sections of this document which form mandatory requirements of the Overseeing Organisation are highlighted by being contained within boxes. The remainder of the document contains advice and enlargement which is commended to designers for their consideration.

2. DESIGN PRINCIPLES

Basis of Design

2.1 Buried drainage structures constructed from rigid pipes shall be designed in accordance with the general requirements of BS EN 1295-1 and the particular requirements of National Annex A of that document. Where appropriate BS EN 1295-1 shall be supplemented with:

(a) 'A guide to design loadings for buried rigid pipes' (2), and/or

(b) 'Simplified tables of external loads on buried pipelines' (3).

These will be referred to in this Standard as the 'Guide' and the 'Simplified tables' respectively.

The 'Guide' and 'Simplified tables' are referenced in BS EN 1295-1 Clause B1.12

Limit States

2.2 In this Standard limit state principles have been adopted for the design of rigid pipes. Both an Ultimate Limit State and a Serviceability Limit State are considered.

2.3 The Ultimate Limit State (ULS) is that represented by the collapse of the rigid pipe.

2.4 The Serviceability Limit State (SLS) is that represented by the condition beyond which a loss of utility or cause for public concern may be expected and remedial action required. In particular, crack widths are limited in structural elements. Furthermore, there shall not be excessive movement at the joints which could be capable of seriously damaging the rigid pipe or the carriageway above.

2.5 The design method described in the National Annex to BS EN 1295-1 ensures that rigid pipes designed using it do not crack in the ground so do not reach the serviceability limit state.

2.6 To reach the ultimate limit state, a pipe buried in the ground must develop at least four cracks before it can collapse. The loading required to induce the ultimate limit state exceeds that needed to cause the serviceability limit state. From a test on an unreinforced concrete pipe, Trott et al (4) reported that the collapse load required to do this was six times the design load. Tests have not been carried out on the stronger reinforced concrete pipes buried in the ground and the loading needed to induce the ultimate limit state cannot be quantified reliably. However, reinforced concrete pipes are potentially more ductile than unreinforced concrete pipes and simple analysis and finite element studies have indicated that such pipes should be capable of sustaining loads in excess of the design loads derived using this Standard.

Design Life

2.7 The design life of a rigid pipe shall be 120 years.

Design of Pipe and Bedding

2.8 The design of a pipeline using rigid pipes involves the selection of an appropriate pipe strength and bedding combination which is able to sustain the most adverse permanent and transient loads to which the pipeline will be subjected over its 120 year service life.

3. LOADING

3.1 PERMANENT LOADS

3.1.1 Dead Load of Pipe

The self-weight of the pipe is disregarded in this method of design.

3.1.2 Superimposed Dead Load

This is the load imposed on the pipe by the backfill together with any road construction materials in the overlying pavement. The rules and formulae for estimating the superimposed load on rigid pipes are briefly described in NA.4.1.1, NA.4.1.2 and NA.4.1.3 of BS EN 1295-1 and are elaborated in the 'Guide' (2). These rules and formulae are different for the different conditions of installation including the 'narrow trench' condition and the 'embankment or wide trench' condition (pipe in trench covered by embankment). The appropriate loads are tabulated in the 'Simplified tables' (3).

3.2 TRANSIENT LOADS

3.2.1 Live Loads

These are referred to as the 'concentrated surcharge load' in NA.4.1.4 of BS EN 1295-1 and those relevant to highways are shown in Figures NA.6 and NA.7 of that document: again more information is given in the 'Guide' (2). Three types of loading are applicable.

(a) Main Road Conditions (Trunk Roads and Motorways)

The live loading to be considered for Trunk Roads and Motorways is 45 units of HB loading: further details are given in Section 2.6 of the 'Guide' (2). The combined loading on pipes installed under Trunk Roads and Motorways due to superimposed dead load, HB loading and the equivalent water load (see Clause 3.2.2(a)) are listed in Table M of the 'Simplified tables' (3).

(b) Field Conditions (Lightly trafficked areas)

Field loading applies to fields, gardens, lightly trafficked access tracks and the like. It may also be considered adequate to cater for random heaps or stacks of materials on the ground: where large heaps or stacks are likely which could impose a heavier loading, these more adverse conditions should be specially designed for as described in the 'Guide' (2). The combined loading on pipes installed in fields due to superimposed dead load, two 3 tonne wheel loads enhanced by an impact factor of 2 (i.e. total load 2 x 60 kN) and equivalent water load (see Clause 3.2.2(a)) are listed in Table F of the 'Simplified tables' (3).

(c) Construction Loads

Construction loads may occur on any highway construction site where heavy construction plant is used and they will often exceed the loads imposed by main road traffic. In addition the depth of fill or cover over the pipes may be less than in the completed installation and for which the pipes would normally be designed. To allow for the effects of this construction phase, pipes should be designed to carry the heaviest plant likely to be used on site at the minimum likely cover. In the 'Simplified tables' (3) the additional effect of a 30 tonne wheel load enhanced by an impact factor of 2.0 is listed in Table C. To obtain the total loading on the pipe the value given in this table must be added to the corresponding loads in Table M. Although a 30 tonne wheel load is likely to represent the most adverse loading on the majority of sites, this assumption needs to be confirmed prior to the initiation of the construction phase and measures taken to remedy any deficiency in the design.

At some sites it may be advantageous to limit plant crossings to various points along a pipeline, and at these points to incorporate, for example, a permanent or temporary overlying reinforced concrete slab which would better distribute the loads imposed by construction traffic. Details of such slabs are given in BD 12 (DMRB 2.2.6).

3.2.2 Equivalent Water Load

(a) The equivalent water load in pipe is considered in NA.4.1.5 of BS EN 1295-1.

(b) Where pipes are used for purposes other than drainage, the equivalent water load considered in Clause 3.2.2(a) may be ignored unless such structures are prone to flooding.

3.2.3 Traction Loads and Temperature Effects

Traction and temperature effects shall be ignored.

3.3 TOTAL EXTERNAL DESIGN LOAD W_e

3.3.1 The superimposed dead load, appropriate live load and equivalent water load are added to determine the total external design load W_e (kN/m) given in Tables M and F in the 'Simplified tables' (3).

3.3.2 There has been some confusion at the differences between the values of W_e given in the 1970 and 1986 versions of the 'Simplified tables' which were produced by the BRS (now BRE) and the TRRL (now TRL) respectively. The reasons for any discrepancies at shallow depths of cover have been explained in Section 2.6.1.4 of the 'Guide' (2). The other apparent difference concerns Table 4 of the 1970 version where the heading 'Total design load W_e —.' is used although it will be clear by cross-checking with Table 1, 2 and 3 of the same publication that the values in Table 4 do not include the equivalent water load.

4. DESIGN PROCEDURE

General

4.1 The National Annex 'Calculation procedure for the UK established method' of BS EN 1295-1 provides details of the design method for rigid pipes, but a more comprehensive treatment is given in the 'Guide' (2). The 'Guide' and the 'Simplified tables' (3) are regarded as two of the 'primary sources' of information for the standard UK procedures (see BS EN 1295-1, Clause B.12).

4.2 The 'Guide' (2) gives more comprehensive design procedures than the 'Simplified tables' (3). Because of this, worthwhile economies may well be possible in the larger pipe diameters and on major highway projects by applying the 'Guide' procedures.

Pipe Strength

4.3 The crushing strength, W_t, of a rigid pipe is determined by subjecting the pipe to an approximation of a longitudinal line loading across a diameter. The load at which failure occurs is expressed in kN per metre length of pipe. This strength is then multiplied by a bedding factor, F_m, which reflects the load-and-reaction spreading properties of the bedding materials supporting and/or encapsulating the pipe to provide a value for the supporting strength (W_t x F_m) of the rigid pipe in the ground.

Bedding Factors

4.4 The bedding factors to be used in the design of buried drainage structures constructed from rigid pipes are given in Table 4.1.

Bedding Class	Description	Bedding Factors for Narrow & Wide Trench Conditions (F_m)
N	Granular or Sand Bed	1.1
F	Granular Bed	1.5
B	Granular Bed & Haunch	1.9
S	Granular Surround	2.2
A unreinforced	Concrete Bed	2.6
A reinforced	Concrete Bed	3.4

Table 4.1 Bedding factors

Further details of various bedding constructions can be found in BS EN 1295-1, BS EN 1610, the 'Guide', and the 'Simplified tables', Highway Construction Details (MCHW 3) and also in Appendix B of HA 40. Bedding materials shall be as described in Clause 2506 of MCHW 1. Note that although bedding factors are given for embankments in the two BS EN's and the 'Guide' (2) they are not applicable to pipes laid in accordance with sub-Clause 2506.3 MCHW 1. Occasionally pipes are laid as described in sub-Clause 608.8 MCHW 1 and in such situations the bedding factors for embankments in the publications mentioned above would be applicable.

External Loads, Pipe Strength and Bedding Combination

4.5 In design the maximum total external load on the pipeline, W_e, must not exceed the minimum value of the pipe strength, W_t, multiplied by the appropriate value of the bedding factor, F_m, given in Clause 4.4 and divided by an appropriate factor of safety, F_s.

Thus $W_e < W_t \times F_m/F_s$

The value of F_s, in the above equation shall be 1.25 (see BS EN 1295-1 sub-Clause B2.12.1.7) for unreinforced and reinforced concrete pipes to BS 5911:Part 100 and vitrified clay pipes to BS EN 295-1, whilst for prestressed concrete pipes to BS 5911:Part 103 the value of F_s shall be 1.40, unless otherwise agreed with the Overseeing Organisation.

In the case of unreinforced and reinforced concrete pipes to BS 5911:Part 100 the proof load, $W_p = W_t/1.25$, while for prestressed concrete pipes to BS 5911:Part 103 the proof load, $W_p = W_t/1.4$. Thus if W_p is substituted for W_t and these recommended factors are applied, the above equation reduces to:

$W_e < W_p \times F_m$

since the appropriate factor of safety, $F_{s(proof)}$, for designs based on the results of proof tests is unity.

Proof Strength

4.6 Proof tests can be undertaken to unreinforced, reinforced and prestressed concrete pipes. The acceptance criteria are given in BS 5911:Part 100 (Clause 20.4.2) for unreinforced and reinforced concrete pipes and Part 103 (Clause 5.2.2.2) for prestressed concrete pipes.

Notes

4.7 The present edition of the 'Simplified tables' (3) was published in 1986 and not all entries in the Tables will be relevant to the design of pipe installations carried out today. The following points shall be noted:

(i) Pipe type (a) in Tables M and F - Asbestos cement pipes shall no longer be used on highway works.

(ii) Pipe type (b) in Tables M and F - Currently vitrified clay pipes are generally manufactured to BS EN 295-1 and the minimum crushing strength values are given in Clause 2.9 Table 5 of that document. As a consequence the vitrified clay pipes now available differ from those covered in Tables M and F and the range of sizes covered has been increased to 1200DN. Because of this pipe designers must ignore the values of safe supporting strengths in the ground given in Tables M and F for this type of pipe.

(iii) Minimum trench widths, related to the nominal pipe size (DN), are now specified in Table 1 of BS EN 1610. These widths are invariably greater than the lower values of trench width given in Tables M and F and indeed are at times quite close to the maximum values used in the preparation of those tables. Modest extrapolation of the external loads, W_e, to greater trench widths may, therefore, be required in some such circumstances; the number of situations where the wide trench loading is the appropriate design load will increase as a result.

Differential Settlement

4.8 The rigid pipeline design shall be checked to ensure it is able to accommodate all differential settlements by articulation of the rigid pipe joints.

4.9 The pipeline shall be checked to ensure that differential settlement does not result in silting of the invert or reduced hydraulic capacity.

5. DURABILITY REQUIREMENTS

5.1 Concrete in the ground is liable to attack by chemicals, including acids and sulfates, present in effluent carried by the pipe, and in groundwater and soil surrounding the pipe. Concrete pipes, manufactured in accordance with BS 5911: Part 100, used in such conditions, shall comply with the recommendations given in BRE Digest 363 ‘Sulphate and acid resistance of concrete in the ground’ (5).

5.2 Concrete pipes in the ground may also be susceptible to the thaumasite form of sulfate attack. Concrete pipes, manufactured in accordance with BS 5911:Part 100, used in such conditions, shall comply with the recommendations of the Thaumasite Expert Group Report (6).

5.3 Steel reinforcement in reinforced concrete pipes is also liable to corrosion and it is difficult to be certain that precast reinforced and prestressed concrete pipes manufactured to current standards and specifications will not suffer some degree of deterioration over a 120 year service life. The limited and fragmentary evidence from the field both in the UK and abroad does, however, suggests that there is no cause for alarm. If deterioration does occur, there are a number of renovation techniques available (7) for man-entry pipes to ensure that the pipe fabric is maintained for the design life see also BS 8005:Part 5 Sewerage – Guide to rehabilitation of sewers.

5.4 Vitrified clay pipes manufactured in accordance with BS EN 295-1 are more resistant to chemical attack than concrete pipes. Guidance on the use of such pipes is given in Table 3 of BS 8301.

5.5 In some circumstances there may be chemical residues which may attack the materials from which rigid pipe joints and seals are made and specialist advice should be sought from the pipe or joint manufacturer. Such a situation may arise for example when pipes have to be laid in ground contaminated by previous industrial activities.

5.6 Both precast concrete pipes to BS 5911:Part 100 and Part 103 and vitrified clay pipes to BS EN 295-1 are considered to provide a 120 year life in normal conditions.

6. MATERIALS

6.1 The Overseeing Organisation's requirements for buried rigid pipes subject to highway loading are contained in the Clause 2505 of MCHW 1 and in particular in Table 25/1.

6.2 The Overseeing Organisation's requirements for the joints in buried rigid pipes are contained in the Clause 2506 of MCHW 1. Where applicable, they shall be designed to accommodate thermal movement and differential settlement and shall be resistant to any chemicals present in the ground.

6.3 The Overseeing Organisation's requirements for bedding and backfill material to buried rigid pipes are contained in the Clause 2506 and Series 600 respectively of MCHW 1.

6.4 Where conditions are acidic, reactions between the acid and limestone and other aggregates containing carbonates results in the formation of carbon dioxide gas which may pose problems for operatives carrying out maintenance. In these situations consideration must be given to prohibiting the use of such aggregates in beddings and pipes. Furthermore it has been suggested that the thaumasite form of sulfate attack can result from contact with water containing dissolved carbon dioxide (6).

7. CONSTRUCTION

> 7.1 The Overseeing Organisation's requirements for the construction of drainage structures of buried rigid pipes are contained in the Clause 2506 of MCHW 1.

7.2 It is recommended that rigid pipe drains should not be laid with depth of cover less that 1.2m to avoid interference with other services. Where pipes must be laid at shallower depths, protective measures may be required to reduce the risk of damage.

> 7.3 Where pipe loading is based on 'narrow trench' conditions, precautions must be taken to ensure that the trench width never exceeds that required to resist the superimposed dead load on the pipes (see Clause 3.1.2).

7.4 There is a tendency for water to flow along the granular beddings that surround rigid pipes and as this may induce stability problems by causing erosion and migration of fine soil; such flows should be minimised. Where manholes are being installed this may be achieved by compacting wet cohesive fill (Table 6/1 Class 2A, MCHW 1) having a minimum LL and PL of 35% and 15% respectively and with more than 50% finer than 0.06mm, to the sides of the manhole to form a water stop. In the absence of manholes, water stops (also known as stanks) of similar cohesive material should be formed through the bedding and side fill at intervals along the pipeline. Where pipe ends protrude from the sides of an embankment this objective can more readily be achieved by placing and compacting wet cohesive material, as above at these locations; precautions may need to be taken to prevent erosion or drawdown effects at these points. Water stops may also be formed of geosynthetics.

7.5 On steep slopes and at bends, concrete thrust blocks may need to be provided.

> 7.6 Drainage structures shall be visually examined before backfilling is commenced and after the backfilling is complete. Where such installations have subsequently been subjected to heavy construction plant they must be inspected again when construction work has finished and before handover of the completed works.

8. CONTRACTUAL ARRANGEMENTS

8.1 The Overseeing Organisation's technical approval procedures shall be followed when buried precast concrete and vitrified clay pipes to BS 5911: Parts 100 and 103 and BS EN 295-1 are specified. These are non-proprietary products and the Design Organisation carries out the complete design of the structure.

8.2 Where proprietary drainage products such as corrugated steel structures designed to BD 12 (DMRB 2.2.6), precast concrete box type structures designed to BD 31 (DMRB 2.2), elliptical concrete pipes or the like can be satisfactory alternatives, the procedures set-out in SD 4 (MCHW 0.2.4) shall be followed.

9. REFERENCES

9.1 Design Manual for Roads and Bridges

BD 12 - Design of corrugated steel buried structures with spans not exceeding 8m (including circular arches) (DMRB 2.2.6).

BD 24 - Design of concrete bridges. Use of BS 5400: Part 4:1990 (DMRB 1.3.1).

BD 31 - Buried concrete box type structures (DMRB 2.2).

BE 1/73 - Reinforced concrete for highway structures (DMRB 2.3).

HA 40 - Determination of pipe and bedding combinations for drainage works (DMRB 4.2).

HD 33 - Surface and sub-surface drainage systems for highways (DMRB 4.2.3).

9.2 Manual of Contract Documents for Highway Works

Volume 0: Section 2 Implementing Standards.

SD 4 Procedures for adoption of proprietary manufactured structures (MCHW 0.2.4).

Volume 1: Specification for Highway Works (MCHW 1).

Volume 3: Highway Construction Details (MCHW 3).

9.3 British Standards

BS 5911: Part 100. Precast concrete pipes, fittings and ancillary products - Specification for unreinforced and reinforced pipes and fittings with flexible joints.

BS 5911: Part 103. Precast concrete pipes, fittings and ancillary products - Specification for prestressed non-pressure pipes and fittings with flexible joints.

BS 8005: Part 5. Sewerage - Guide to rehabilitation of sewers.

BS 8301. Building drainage.

BS EN 295-1. Vitrified clay pipes and fittings and pipe joints for drains and sewers - Requirements.

BS EN 1295-1. Structural design of buried pipelines under various conditions of loading - General requirements.

BS EN 1610. Construction and testing of drains and sewers.

9.4 Other Documents

1. BE 1/77. Standard highway loading. Technical Memorandum (Bridges) Department of Transport (1977). HMSO, London.

2. Young O C and O’Reilly M P (1983). A guide to design loadings for buried rigid pipes. Transport and Road Research Laboratory. HMSO, London.

3. Young O C, Brennan G and O’Reilly M P (1986). Simplified tables of external loads on buried pipelines. Transport and Road Research Laboratory. HMSO, London.

4. Trott J J, Nath P and O’Reilly M P (1981). Longitudinally cracked pipes and their structural capacity. Repair of sewerage systems. Institution of Civil Engineers, London.

5. Building Research Establishment (1991). Sulphate and acid resistance of concrete in the ground. BRE Digest 363. Building Research Establishment, Garston.

6. Thaumasite Expert Group (1999). The thaumasite form of sulfate attack: risks, diagnosis, remedial works and guidance on new construction. Department of the Environment, Transport and the Regions, London.

7. Water Research Centre (1994). Water Research Centre sewerage rehabilitation manual, Third edition. Vol 111. Water Research Centre, Swindon.

9.5 Bibliography

Foundation for Water Research (1993). Materials selection manual for sewers, pumping mains and manholes. Water Research Centre, Swindon.

UKWIR (1999). Civil engineering specification for the water industry, Fifth edition. UKWIR Ltd, London.

9.6 Trade Associations

Concrete Pipe Association, 60 Charles Street, Leicester, LE1 1FB.

Clay Pipe Development Association, Copsham House, 53 Broad Street, Chesham, Bucks, HP5 3EA.

10. ENQUIRIES

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

Quality Services Director
The Highways Agency
St Christopher House
Southwark Street
London SE1 0TE

J KERMAN
Quality Services Director

Director, Road Network Management and
Maintenance Division
The Scottish Executive Development Department
Victoria Quay
Edinburgh EH6 6QQ

N B MACKENZIE
Director, Road Network Management and
Maintenance Division

Transport Directorate
The Chief Highway Engineer
The National Assembly for Wales
Cynulliad Cenedlaethol Cymru
Crown Buildings
Cathays Park
Cardiff CF1 3NQ

J R REES
Chief Highway Engineer

Director of Engineering
Department for Regional Development
Roads Service
Clarence Court
10-18 Adelaide Street
Belfast BT2 8GB

V CRAWFORD
Director of Engineering