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

PART 8

BD 74/00

FOUNDATIONS

SUMMARY

This Standard implements BS 8004: 1986 Code of Practice for Foundations. It gives guidance on lateral loading of piles by incorporating and superseding BD 32/88 and BA 25/88. It states the requirements for reinforcement of bored cast-in-place foundation piles.

INSTRUCTIONS FOR USE

1. Remove existing contents pages for Volume 2.

2. Insert new contents pages for Volume 2, dated May 2000.

3. Insert BD 74 into Volume 2, Section 1.

4. Archive this sheet as appropriate.

Note: A quarterly index with a full set of Volume Contents Pages is available separately from The Stationery Office Ltd.

THE HIGHWAYS AGENCY

THE SCOTTISH EXECUTIVE DEVELOPMENT DEPARTMENT

THE NATIONAL ASSEMBLY FOR WALES
CYNULLIAD CENEDLAETHOL CYMRU

THE DEPARTMENT FOR REGIONAL DEVELOPMENT*

Foundations

* A Government Department in Northern Ireland

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REGISTRATION OF AMENDMENTS

Amend No	Page No	Signature & Date of incorporation of amendments	Amend No	Page No	Signature & Date of incorporation of amendments

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

SECTION 1 SUBSTRUCTURES

PART 8

BD 74/00

FOUNDATIONS

Contents

Chapter

1. INTRODUCTION

General

1.1 The purpose of this Standard is to implement BS 8004: 1986 Code of practice for Foundations.

1.2 This Standard incorporates and supersedes BD 32/88 and BA 25/88. It gives guidance on lateral loading of piles and states the requirements for reinforcement of bored cast-in-place foundation piles. Considerable advances in computing power and program capability have taken place since BA 25/88. The usefulness of current computer programs is reviewed in publications such as Ground Engineering and the reader is directed to these.

Equivalence

1.3 The construction of foundations 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 member states of the European Economic Area, and tests undertaken in other states of the European Economic Area will be acceptable in accordance with Clauses 104 and 105 of Series 100 of that Specification. Any contract not containing these clauses must contain suitable clauses of mutual recognition having the same effect regarding which advice should be sought.

Scope

1.4 This Standard covers the use of BS 8004: 1986 Code of practice for Foundations for all permanent highway structures. This Standard gives guidance on lateral loading of piles and states the requirements for reinforcement of bored cast-in-place foundation piles. It sets out the Overseeing Organisation's particular requirements where these differ from, or are more comprehensive than, those given in the British Standard.

Implementation

1.5 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. Where contract documents are based on the Specification for Highway Works (MCHW1) use of this Standard is mandatory. For use in Northern Ireland, this Standard will be applicable to those roads designated by the Overseeing Organisation.

Mandatory Requirements

1.6 Sections of the 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. USE OF THE BRITISH STANDARD BS 8004: 1986

General

2.1 The design of foundations for all permanent highway structures which are the responsibility of the Overseeing Organisation shall be carried out in accordance with BS 8004: 1986 as amended by this Standard. Where reference is made to any British Standard, this shall be taken as reference to that Part as implemented by the Overseeing Organisation.

2.2 The assessment of existing bridge foundations should be carried out in accordance with BD 44, the Assessment of Concrete Highway Bridges and Structures (DMRB 3.4), and BA 55, the Assessment of Bridge Substructures and Foundations, Retaining Walls and Buried Structures (DMRB 3.4).

2.3 The amendments to BS 8004: 1986, which are necessary to meet the Overseeing Organisation's requirements, are given in Annex A to this Standard. The amendments are listed under the relevant clause numbers of BS 8004: 1986.

These amendments include repeated references to DMRB Standards to replace British Standards which are not implemented by the Overseeing Organisation. Should there be any conflict between the clauses in BS 8004 or the amendments in Annex A, and the appropriate clauses in DMRB Standards, the latter shall take precedence. However, examples not necessarily relevant to the design of foundations for highway structures have been retained in order to illustrate technical points.

Advice on temporary works has been retained where these may have an effect on the design of the permanent structure.

2.4 The reasons for the amendments are listed below:

i) existing clauses not relevant to permanent highway structures

ii) reference to and consistency with the DMRB Standards

iii) revisions to out of date practices and references, and the introduction of recent Health & Safety Legislation

iv) provision of additional advice

(a) "observational method"

(b) settlement considerations

(c) soil structure interaction

(d) pile testing

(e) reinforcement in piles

2.5 This Standard retains the design principles of BS 8004 with its total factor of safety on the ultimate bearing capacity to evaluate an allowable bearing pressure or load. This is different from other DMRB documents covering structural design which adopt a limit state approach with partial factors applied to both loading and materials.

Additional Requirements

2.6 The clauses in BS 8004: 1986 that are expressed in the form of recommendations using the word "should" are to be considered as mandatory.

2.7 Where reference is made to the "life" of the structure, this shall be taken to mean the "design life" which is defined in BS 5400: Part 1 as implemented by BD 15 (DMRB 1.3). The design life for these structures shall be 120 years.

2.8 Both long and short term ground and loading conditions shall be considered so that the final design satisfies the most onerous requirements encountered during both the construction period and service life of the structure.

2.9 Where reference is made to MCHW 1 (Specification for Highway Works), this should be read as also referring to MCHW 2 (Notes for Guidance on the Specification for Highway Works).

Guidance on lateral loading of piles

2.10 Guidance on lateral loading of piles is given in Annex B. This supersedes BD 32/88 and BA 25/88 and supplements information given in BS 8004: 1986.

Reinforcement of bored cast-in-place embedded foundation piles

2.11 The requirements for reinforcement of bored cast-in-place foundation piles are stated in Annex C. These supersede BS 8004:1986.

3. REFERENCES

The following documents are referred to in this Standard.

3.1. BSI publications.

BS 144: 1990 Wood preservation using coal tar creosotes.

BS 5400: Part 1: 1988 General Statement.

BS 5400: Part 3: 1982 Code of Practice for Design of Steel Bridges.

BS 5400: Part 4: 1990 Code of Practice for Design of Concrete Bridges.

BS 5628: Code of Practice for use of Masonry.

BS 7361: Cathodic Protection, Part 1: 1991 Code of Practice for Land and Marine Applications.

BS 7375: 1991 Code of Practice for Distribution of Electricity on Construction and Building Sites.

BS 8002: 1994 Code of Practice for Earth Retaining Structures.

BS 8004: 1986 Code of Practice for Foundations.

BS 8006: 1995 Code of Practice for Strengthened/ Reinforced Soils and Other Fills.

BS 8081: 1989 Code of Practice for Ground Anchorages.

BS 8102: 1990 Code of Practice for Protection of Structures against Water from the Ground.

3.2. Design Manual for Roads and Bridges. The Stationery Office

BA 25 Piled Foundations (DMRB 2.1).

BA 55 The Assessment of Bridge Substructures and Foundations, Retaining Walls and Buried Structures (DMRB 3.4.9).

BA 59 Design of Highway Bridges for Hydraulic Action (DMRB 1.3).

BA 80 Use of Rock Bolts (DMRB 2.1.7).

BD 10 Design of Highway Structures in Areas of Mining Subsidence (DMRB 1.3).

BD 13 Design of Steel Bridges. Use of BS 5400: Part 3: 1982 (DMRB 1.3).

BD 15 General Principles for the Design and Construction of Bridges. Use of BS 5400: Part 1: 1988 (DMRB 1.3).

BD 20 Bridge Bearings. Use of BS 5400: Part 9: 1983 (DMRB 2.3).

BD 24 The Design of Concrete Highway Bridges and Structures. Use of BS 5400: Part 4: 1990 (DMRB 1.3).

BD 32 Piled Foundations (DMRB 2.1).

BD 37 Loads for Highway Bridges (DMRB 1.3).

BD 41 Reinforced Clay Brickwork Retaining Walls of Pocket Type and Grouted - Cavity Type Construction (DMRB 2.1.1).

BD 42 Design of Embedded Retaining Walls and Bridge (DMRB 2.1.2).

BD 44 The Assessment of Concrete Highway Bridges and Structures (DMRB 3.4).

BD 57 Design for Durability (DMRB 1.3.7).

BD 60 Design of Highway Bridges for Vehicle Collision Loads (DMRB 1.3).

HA 34 Ground Investigation Procedure (DMRB 4.1).

HA 75 Trunk Roads and Archaelogical Mitigation (DMRB 10.6.1)

3.3 Manual of Contract Documents for Highway Works. The Stationery Office

Volume 1 Specification for Highway Works (MCHW 1)

Volume 2 Notes for Guidance on the Specification for Highway Works (MCHW 2).

4. 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
National Roads Directorate
Victoria Quay
Edinburgh EH6 6QQ

N B MACKENZIE
Director, Road Network Management and
Maintenance Division

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

J R REES
Chief Highway Engineer

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

V CRAWFORD
Director of Engineering

ANNEX A. AMENDMENTS TO BS 8004: 1986 CODE OF PRACTICE FOR FOUNDATIONS

The use of this annex is mandatory.

The following Clause titles are amended:

7.6 Integrity testing of cast-in-place piles
Delete title and replace with: **"Non-destructive testing of piles"**.
Insert the following:
7.6.1 *Integrity testing*
7.6.2 *Dynamic pile testing*

The following Tables are not implemented:

13 Curing periods for use in the absence of control cubes or steam curing
14 Suggested slump details for typical concreting situations for cast-in-place piles
16 Resistivity and redox potential values
17 Concrete exposed to sulphate attack

Section one. General
1.1 Scope
Delete Note 1 and Note 2

1.2.41 factor of safety.
Lines 2, 3 delete "or the ratio of the ultimate load to the applied load"

At the end of Section 1.2, add the following clauses:

1.2.124 nominal loads. Where adequate statistical data are available nominal loads are those appropriate to a return period of 120 years. In the absence of such data, values that are considered to approximate to a 120 year return period are given in BD 37 (DMRB 1.3).

Nominal loads shall be used as design loads.

1.2.125 dead loads. The permanent loads defined in BD 37 (DMRB 1.3), being dead loads of the structure and foundation, superimposed dead loads and loads due to filling material above the foundation.

1.2.126 live loads. The transient loads defined in BD 37 (DMRB 1.3) excluding wind loads which are considered separately.

2.1.2.2 *The foundation and the ground as an interrelated system*.
At end of last paragraph, add the following new paragraph: "Where prediction of the behaviour of the ground and foundation is particularly difficult, it may be appropriate to adopt the approach known as the "observational method" in which the design is reviewed during construction. When this approach is used, the following requirements should be met before construction commences:
(a) the limits of behaviour which are acceptable should be established;
(b) the range of possible behaviour should be assessed and it should be shown that there is an acceptable probability that the actual behaviour will be within the acceptable limits;
(c) a plan of monitoring should be devised which will reveal whether the actual behaviour lies within the acceptable limits. The monitoring should make this clear at a sufficiently early stage, and with sufficiently short intervals to allow contingency actions to be undertaken successfully. The response time of the instruments and the procedures for analysing the results should be sufficiently rapid in relation to the possible evolution of the system;
(d) a plan of contingency actions should be devised which may be adopted if the monitoring reveals behaviour outside acceptable limits.

Further information on the "observational method" may be found in CIRIA Report 185 (1998) "The Observational Method in ground engineering: principles and applications" by Nicholson D., Tse C-M. and Penny C. and in TRL Report 228 (1996) "Movement trigger limits when applying the Observational Method to embedded retaining wall construction on highway schemes" by Card G.B. and Carder D.R."

2.1.2.3.2.3 *Effect of adjacent cuttings, excavations or sloping ground*.
Line 2, after "excavations" insert: ", retaining walls"

2.1.2.3.3 *Settlement*.
Paragraph 1, after end of last sentence insert: "although these soils can also undergo creep"

2.1.2.4 *Movements independent of applied foundation load*.
(e) Line 1, after "internal erosion" insert: "due to piping or washing out of fines"
(f) Line 2, after "excavations" insert: "(including future excavations for services)"

2.1.3.1
Line 6, replace "CP 102" with: "BS 8102"

2.2.1 Ground exploration and tests
2.2.1.1 *General*.
Paragraph 2 Line 2, after "BS 5930" insert: "and appropriate Procedures, including HA 34 (DMRB4.1)."

2.2.2 Allowable bearing pressure on various types of ground
2.2.2.1 *General*.
Paragraph 1, after last sentence add: "Foundations are sized using the loading combinations given in BD 37 (DMRB 1.3) with load factors set to unity (ie using nominal loads), but the structural design of foundations utilises factored loads in accordance with BD 37 (DMRB 1.3). This can lead to differences in foundation pressure distributions, due to different factors being used on a range of load sources; for example, the structural design may need to accommodate some uplift unless the original foundation arrangement is amended."
Paragraph 4 Line 1, after "in mind"; delete remainder of sentence.

2.2.2.3.1 *Allowable bearing pressure on rocks*
2.2.2.3.1.1 *General*.
Paragraph 1 Line 3, after "weak layers" insert: "solution features, fault zones"

2.2.2.3.1.4 *Strong igneous and gneissic rocks in sound condition*.
Line 3, after end of sentence, insert: "The presumed bearing pressure may be limited by the compressive strength of the concrete foundation"

2.2.2.3.1.5 *Strong limestones and strong sandstones*.
Paragraph 1 Line 2, after "quality concrete" insert: "such that the presumed bearing pressure may be limited by the concrete strength"

2.2.2.3.2.2 *Field and laboratory observations and measurement*.
Paragraph 2 Line 4, after "Dutch cone" insert: "or cone penetrometer"

2.2.2.3.2.4 *Settlement*.
Paragraph 5 Line 2, at end of sentence insert: ", and additional time dependent settlement can also occur due to creep"
Paragraph 5 Line 7, delete: "machinery,"
Paragraph 5 Lines 8, 9 delete: "or earthquake tremors"

2.2.2.3.3.3 *Ultimate bearing capacity*.
After Paragraph 1, add new paragraph: "The ultimate bearing capacity should also be checked using long term soil parameters as changes in pore water pressure can lead to changes in shear strength of cohesive soils."

2.2.2.3.5 *Made ground and fill*.
Paragraph 2 Line 3, replace "Suitable" with "Acceptable"
Paragraph 2, after last sentence, add: "The acceptability of filling materials is defined in MCHW 1 Series 600."

2.3 Structural considerations
2.3.1 General
Line 7, replace "user's" with "Overseeing Organisation's"

2.3.2 Interdependence of ground, substructure and superstructure
2.3.2.1 *General*.
Line 6, after "ground settlements" insert: "in order to determine the distribution of contact pressures and internal foundation stresses. For such an exercise, loads factored in accordance with BD 37 (DMRB 1.3) should be used."

At end of clause, add new sentence: "However, soil structure interaction analyses can be undertaken using computer techniques such as finite element and finite difference methods."

2.3.2.3 *Differential settlements*.
After Paragraph 2, insert new paragraphs:
"Differential settlement caused by variability of the ground should be allowed for unless it is prevented by the stiffness of the structure and foundation. For uniformly loaded foundations within natural ground, the magnitude of differential settlement purely due to variability of the ground will usually not exceed 50% of the calculated total settlement, where the stratigraphy beneath the whole foundation is consistent.

The tilting of an eccentrically loaded foundation should be estimated by assuming a linear bearing pressure distribution and calculating the settlements at the corners of the foundation using the vertical stress distribution in the ground beneath each corner using elasticity theory and assuming a homogeneous isotropic soil properties for each stratum within the depth to be considered (see 2.1.2.3.3)."

At end of clause, add new paragraph:
"Monitoring during construction is required as part of the design process when the "observational method" is used (see 2.1.2.2). In this case, the monitoring should be carried out as planned, and additional or replacement monitoring should be undertaken if this becomes necessary. The results of the monitoring should be assessed at appropriate stages and the planned contingency actions effected if necessary."

2.3.2.4 *Foundation loads*
2.3.2.4.1 *General*.
Lines 5-7, delete sentence "However .... these loads." and replace with: "The loads and load combinations to be considered are given in BD 37 (DMRB 1.3)."
Line 8, after "unfactored" insert: "(nominal see 1.2.124)"
Line 9, replace "BS 8100" with: "BS 5400: Part 4: as implemented by BD 24 (DMRB 1.3)"

2.3.2.4.2 *Dead and live loads*.
Paragraph 1, after "Dead and live loads" delete first sentence and replace with: "The dead loads comprise the permanent loads defined in BD 37 (DMRB 1.3), being dead loads, superimposed dead loads and loads due to filling material above the foundations."
Paragraph 2, delete entirely and replace with: "Live loads are the transient loads defined in BD 37 (DMRB 1.3) excluding wind loads which are considered separately. The maximum effects of certain transient loads do not coexist with the maximum effects of certain others. The effects that can coexist are specified in BD 37 (DMRB 1.3) but nominal values should be used. Collision loads are defined in BD 60 (DMRB 1.3).

2.3.2.4.3 *Wind loading*.
Delete entirely and replace with: "Foundations should be sized so that the pressure due to combined dead (permanent), live (transient) and wind loads does not exceed the allowable bearing pressure by more than 25%."

2.3.2.4.7 *Non-vertical loading*.
Paragraph 3 Line 8, replace "the Civil Engineering Code of Practice No. 2" with: "BS 8002. Note: when using BS 8002 with other Standards, the designer shall ensure there is compatibility between design principles and values of factor of safety and partial factors."

At end of clause, add new paragraph: "Where sloping foundation bases are used to increase the lateral capacity of the foundation, the requirements of this clause should be met."

At end of clause, add new clause:
"**2.3.2.4.8** *Lateral loading*. Piles can be subjected to two types of lateral loads – those acting at pile cap level and those acting on the pile shaft through the soil mass. Both these types of lateral loads shall be taken into account in design."

2.3.2.5 *Dynamic loads*
2.3.2.5.1 *General*.
Paragraph 1 Line 4, delete last sentence.

2.3.2.5.3 *Design considerations*.
Paragraph 2 Line 2, delete "machine" and replace with: "structure, particularly foot and cycle track bridges,"
Paragraph 2 Line 4, delete "machine" and replace with: "structure"
Paragraph 2 Lines 5, 6, delete "windows, ... associated structures" and replace with: "the structure"
Paragraph 3, delete entirely and replace with: "Vibration serviceability requirements for foot and cycle track bridges are given in BD 37 (DMRB 1.3)."
Paragraph 6 (a) (1) Lines 2 and 3, delete " as is usual ...... engines",
Paragraph 6 (a) (3) delete entirely and replace with: "Anti-vibration mountings may be incorporated into the bearings beneath the bridge deck. Further information is provided in BS 5400 Part 9 as implemented by BD 20 (DMRB 2.3)."
Paragraph 6 (c), delete entirely.
Paragraph 6 (d), delete entirely.

2.3.2.6 *Distributions of contact pressure under foundations*.
Paragraph 1 Line 3, after "foundation" insert: "(see 2.2.2.1)"
Paragraph 2, after last sentence add:
"However, where concentrated forces act on a strip or raft foundation, forces and bending moments in the foundation may be derived from a subgrade reaction model of the ground, using linear elasticity. The moduli of subgrade reaction should be assessed by a settlement analysis with an appropriate estimate of the bearing pressure distribution. The moduli should be adjusted so that the computed bearing pressures do not exceed values for which linear behaviour may be assumed. More precise methods, such as finite element or finite difference analyses, should be used when ground-structure interaction has a dominant effect."

2.3.2.7 *Changes in ground conditions after construction*.
Paragraph 6 Line 7, after end of sentence, insert new sentence: "Further requirements are given in BD 10 (DMRB 1.3)."
Paragraph 7 Lines 1 and 2, replace "blasting or earthquake" with: "or blasting"

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2.3.2.8 *Mining subsidence*
NOTE Line 1; after "see" insert: "BD 10 (DMRB 1.3)"

2.3.3.2 *Shallow foundations*.
Paragraph 2 Line 3, after "special anchorages" insert: "(see BS 8081)"
Paragraph 2 Line 4, after " rock bolts" insert: "(see BA 80 (DMRB 2.1.7))"

2.3.4 Exclusion of ground moisture
Line 7, replace "CP 102" with "BS 8102"
Line 8, delete: "NOTE. Attention is drawn to current building legislation."

2.4.5 Extra cover in reinforced concrete when cast against excavated ground
Lines 2, 3, 9 and 10, replace "table 3.4 of BS 8110: Part 1: 1985" with: "BS 5400 Part 4: 1990 as implemented by BD 24 (DMRB 1.3)."

2.4.6 Retaining walls
Paragraph 1 Lines 1 and 2, replace "Civil Engineering Code of Practice No. 2" with: "BS 8002, BD 41 (DMRB 2.1.1) and BD 42 (DMRB 2.1.2).
Paragraph 2, delete entirely and replace with:
"A distinction needs to be made between the values of soil strength used in determining lateral earth pressures acting on a retaining wall (see 5.3.2), and those used in assessing the ultimate bearing capacity of the foundation. This is particularly relevant to gravity walls, and concrete or masonry walls on spread foundations.

There has been increasing use of soil reinforcement techniques for a variety of applications from vertical walls and abutments, through to reinforced slopes. Reference should be made to BS 8006 as implemented by BD 70 (DMRB 2.1.5)."

Section three. Shallow foundations
3.1 General
Paragraph 2, delete entirely.

3.2 Design considerations
3.2.1 General.
Paragraph 1 (b) Line 6, delete "and 242" and replace with: ", 242 and 298"

3.2.2 Allowable bearing pressure and settlement characteristics
At end of clause, add new paragraph:
"In addition to fulfilling the performance requirements, the design of the foundation width should take account of practical considerations related to economic excavation, setting out tolerances, working space requirements and the dimensions of the wall or column supported by the foundation."

3.2.4 Pad foundations
Paragraph 1 Lines 7, 8 replace "table 11 of Civil Engineering Code of Practice No. 2 1951" with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)."
Paragraph 1 Lines 9 and 10, delete "have been used .... Practice No. 2" and replace with: "are used, the design should be in accordance with BS 5628 and BD 41 (DMRB 2.1)"
Paragraph 3 Line 3, replace "BS 8110 or CP 114" with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)"

3.2.6 Raft foundations
3.2.6.1 *General*.
Paragraph 1 (c) Line 5, replace "2.3" with: "2.3.2.7, 2.3.2.8"

3.2.8.2 *Effects of vegetation*.
Paragraph 2 Line 5, after "BS 5837", add: "and the NHBC Standards Part 4.2"

3.2.9.1 *Frost*.
Paragraph 3, delete entirely.

4.3.3 Basement or hollow boxes
4.3.3.1 *General*.
Paragraph 1 Line 8, replace "CP 102" with: "BS 8102"

4.5.4 Allowable bearing pressure and settlement
Paragraph 3 Line 1, after "finite-element" insert: "and finite-difference"

4.5.9 Basement watertightness
Paragraph 5, at end add new sentence: "The requirements given for the utility grade are likely to be appropriate for highway structures."
Paragraph 6 Lines 7, 8 delete "Guide to .... published by CIRIA, and replace with: "CIRIA Reports 139 and 140,"

5.2.1 Quality
Line 3, after "British Standards" add: "as implemented by the DMRB Standards. The use of permanent timber is to be treated as an aspect not covered by Standards"

5.2.3 Reinforced concrete
Delete and replace with: "Concrete quality and stresses should be in accordance with BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)."

5.2.4 Steel
Line 2, replace "BS 4360" with: "MCHW 1 Series 1800"
Line 3, replace "BS 449" with: "BS 5400 Part 3 as implemented by BD 13 (DMRB 1.3)"

5.3.2 Determination of pressures
Delete first sentence "The earth pressures…. and this standard." and replace with:
"Earth pressures, including water pressures, should be calculated using the design soil strengths defined by BS 8002."

5.3.3.5.2 *Double-wall cofferdams*.
Paragraph 2 Line 2, replace "Civil Engineering Code of Practice No. 2" with: "BS 8002."

5.3.3.8.6 *Anchors*.
Paragraph 3 Line 3, replace "Civil Engineering Code of Practice No. 2" with: "BS 8002"
After last paragraph, add new paragraph:
"Further information on anchors is given in BS 8081."

5.3.4.3.3 *Workmanship and materials*.
Line 5, replace "BS 449" with: "BS 5400 Part 3 as implemented by BD 13 (DMRB 1.3)."
Line 7, after "Standards" add: "as implemented by the DMRB and relevant parts of MCHW 1"

6.3.5.2 *Removal and replacement of weak strata with strong compact material*.
Line 3, after end of sentence insert new sentence:
"Compaction of fills should be undertaken in accordance with MCHW 1 Series 600."
Line 5, at end of sentence, insert: "(see MCHW 1 Series 600)"

6.5.1.5 *Use of compressed air in conjunction with other geotechnical processes*.
Paragraph 1 Line 3, after "excavations than", insert: "by dewatering or"

6.5.3 Cast insitu diaphragm walls
6.5.3.1 *General*.
Paragraph 2 Line 2, after "excluding water", delete remainder of sentence.
After paragraph 3, insert new paragraph:
"Design and construction requirements not covered in the following sub-clauses are given in MCHW 1 Series 1600."

6.5.3.2 *Cast-in-situ diaphragm walls used as retaining walls*.
Paragraph 1 Line 10, change "1.5m" to: "1.0m"
Paragraph 1 Line 11, change "about 100mm" to: "between 25mm and 50mm"
Paragraph 1 Line 16, after "bentonite slurry" insert: "or alternative slurry"
Paragraph 1 Line 21, change "1m" to: "1.5m"
Paragraph 1 Line 25, change "1m" to: "1.5m"
Paragraph 2 Line 4; after "bentonite slurry" insert: "or alternative slurry"

6.5.3.8 *Preparation and control of bentonite and other clay slurries used in diaphragm wall construction*
6.5.3.8.1 *General*.
Paragraph 1 Line 9, replace "ICE (1978)" with "MCHW 1 Series 1600 and Specification for Piling and Embedded Retaining Walls ICE 1996"

6.5.3.8.2 *Bentonite*.
Paragraph 1 Lines 2, 3, delete "Specification ...... Materials Association" and replace with: "Drilling Fluid Material Publication 163* prepared by the Engineering Equipment and Materials Users Association"

* at bottom of page 76, replace "Oil Companies .... London WC2P ODX" with: "Engineering Equipment and Materials Users Association, 14/15 Belgrave Square, London, SW1X 8PS"

6.6.2 Shallow compaction
Paragraph 4 Line 4, after "operations" insert: "(see MCHW 1 Series 600)"

6.6.3 Deep compaction by vibration
Paragraph 1 Line 7, after "such soils", delete next sentence.
Paragraph 5 Line 16, after "permeability", delete remainder of sentence.

6.6.5 Deep compaction by heavy tamping
Paragraph 1 Line 2, at end of sentence insert: "(See MCHW 1 Series 600)"

6.6.6 Use of vertical drains
Paragraph 3 Line 6, after "wick drains," insert: "known collectively as band drains,"

6.6.7 Electro-osmosis
Line 1, delete: "(see 6.4.4.2.7)"

6.7.6.10 *Cavity grouting*.
At end of clause, add new paragraph:
"Treatment of cavities should comply with MCHW 1 Series 600."

Section seven. Pile foundations
7.1 General
At end of Paragraph 1, add new sentence: "The use of permanent timber piles is to be treated as an aspect not covered by Standards."

7.2.3 Preliminary piles
7.2.3.1 *General*.
Paragraph 1 Line 9, replace "ICE 1978" with: "MCHW 1 Series 1600"

7.3.2 Choice of type
Paragraph 8 Lines 1-2, delete "where ..... not occur" and replace with: "only when it can be demonstrated that their durability exceeds the required design life"
Paragraph 11 Line 5, replace "(see BRE Digest 250)." with: "(see BRE Digest 363). Guidance on measures to mitigate the effects of sulfate attack on concrete is contained in BRE Digest 363 "Sulfate and acid resistance of concrete in the ground." However, this has now been extended and to some extent superseded by the DETR (1999) Report of the Thaumasite Expert Group "The thaumasite form of sulfate attack." Advice should be sought from both documents."

7.3.3.3 *Axially loaded piles*.
Paragraph 1 Line 5 and Paragraph 2 Line 3, delete "BS 8110 .... BS 449" and replace with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3) and BS 5400 Part 3 as implemented by BD 13 (DMRB 1.3)"

7.3.3.4 *Laterally loaded piles*.
Line 9, delete "earthquakes".
Line 14, delete "or earthquakes".
Lines 16, 17 delete "(Civil Engineering Code of Practice No. 2)"
At end of clause, add new paragraph:
"The analysis and design of laterally loaded piles should be undertaken with all load factors equal to unity and lateral earth pressures being determined in accordance with BS 8002.

Piles can be subjected to two types of lateral loads - those acting at the pile cap level and those acting on the pile shafts through the soil mass. Both these types of lateral loads shall be taken into account in design.
a) Lateral loading at pile cap level. The following two groups of lateral loads transferred from the structure above and acting at the pile cap level shall be considered:
  (i) permanent - eg structural reactions, earth pressure
  (ii) transient - eg wind, temperature effects, longitudinal live loads.
b) Lateral loading applied through soil. When an embankment is terminated adjacent to a structure, such as a bridge abutment or pier, which is supported on a piled foundation, any underlying sub-soil stratum undergoing deformation may tend to "flow" away from under the embankment. Where it occurs, this effect results in lateral pressures that act on the pile shafts in addition to other loads carried by the foundation.

The likelihood and the effects of lateral loading due to slip circle failure of the surrounding soil and the driving of adjacent displacement piles shall also be examined.

A suggested procedure for determining the magnitude and the effects of the sub-soil generated lateral loading on piles is given in Annex B."

7.3.5.7 *Reducing movements in ground affected by mining operations*.
Before Paragraph 1, insert new paragraph:
"Piles shall only be used at sites affected by mining where the risk of subsidence is negligible, because differential vertical subsidence can withdraw end support, disrupt material within the pile group block and cause shear failure of certain pile types."

7.3.7 Pile caps
Paragraph 1 Line 15, delete "BS 8110 or CP 114" and replace with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)"

7.3.8 Factors of safety
Paragraph 1 (b) Line 4, after "safety" insert: "or load factor"

7.4.1.1.1 *Types of timber*.
After Paragraph 1, insert new paragraph:
"Timber piles should not be used unless it can be demonstrated that their durability exceeds the required design life. In any event, the use of timber in permanent works is to be treated as an aspect not covered by Standards."

7.4.1.1.3 *Preservative treatment*.
Paragraph 1 Line 10, replace "BS 913" with: "BS 144"

7.4.2 Precast reinforced concrete piles
7.4.2.1 *General*.
After Paragraph 3, insert new paragraph:
"Design and Construction requirements not covered in the following sub-clauses are given in MCHW 1 Series 1600."

7.4.2.2.1 *Concrete*.
Delete entirely and replace with:
"Materials should be in accordance with MCHW 1 Series 1700

Guidance on measures to mitigate the effects of sulfate attack on concrete is contained in BRE Digest 363 "Sulfate and acid resistance of concrete in the ground." However, this has now been extended and to some extent superseded by the DETR (1999) Report of the Thaumasite Expert Group "The thaumasite form of sulfate attack." Advice should be sought from both documents. Recommendations on special cements are given in 10.4.2."

7.4.2.2.2 *Reinforcement*.
Delete entirely and replace with:
"The reinforcement should be in accordance with MCHW 1 Series 1800."

7.4.2.3.1 *Concrete*.
Paragraph 1 Line 4, replace "BS 8110 or CP 116" with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)."
Paragraph 3 Lines 3-5, replace last sentence with: "For the different conditions of driving and exposure, guidance on minimum cement contents and strengths is given in table 12."

7.4.2.3.2 *Reinforcement*.
Paragraph 1 Line 2, replace "BS 8110 or CP 116" with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)"
Paragraph 3 Line 6, after "BS 5135" add: ", subject to the requirements of MCHW 1 Series 1700 and BS 5400 Part 3 as implemented by BD 13 (DMRB 1.3)"
Paragraph 5 Lines 2 and 3, replace from "table 3.4 .... 1985" with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3) and modified by BD 57 (DMRB 1.3.7)"

7.4.2.4.1 *Manufacture and curing*
Delete Paragraphs 5 and 6 entirely and replace with: "Protection and curing of concrete should be in accordance with MCHW 1 Series 1600 and 1700. Piles may not be moved, stressed or driven until the concrete strength is shown to be sufficient in accordance with MCHW 1 Series 1600."

Table 13 Delete table

7.4.2.5.2 *Hammer*.
Paragraph 3 Lines 5-7, delete last sentence and replace with: "Driving records should be made for every pile in accordance with MCHW 1 Series 1600."

7.4.2.5.4 *Position and alignment tolerances*.
Paragraph 1 Lines 1-5, delete first two sentences and replace with: "The piles should be installed within the tolerances given in MCHW 1 Series 1600."
Paragraph 1 Lines 8-10, delete sentence commencing "Piles should not deviate"
Paragraph 1 Line 11, delete "and for raking piles"

7.4.3 Prestressed concrete piles

7.4.3.1 *General*.
After last paragraph, add new sentence: Further details are given in MCHW 1 Series 1600."

7.4.3.2.1 *Concrete*.
Delete clause entirely and replace with:
"The materials should be in accordance with MCHW 1 Series 1600. The design should be in accordance with BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)."

7.4.3.2.2 *Prestressing steel*.
Delete clause entirely and replace with:
"*Steel*. Prestressing steel and ordinary reinforcement should be in accordance with MCHW 1 Series 1700."

7.4.3.2.3 *Reinforcement*.
Delete entirely.

7.4.3.3.1 *Concrete*.
Paragraph 1 Lines 4-6, delete "If the ratio .... CP 114: 1969"
Paragraph 1 Line 11, replace "BS 8110 and clause 322 of CP 114 : 1969" with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)"
Paragraph 2, delete entirely and replace with:
"The stresses produced during lifting and pitching or under impact should not exceed the design requirements of BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)."

7.4.3.3.2 *Prestress*.
Paragraph 4 Line 2, replace "BS 8110 .... CP 115 : 1969" with: " BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)"

7.4.3.3.3 *Prestressing wires and stirrups*.
Paragraph 2, delete entirely and replace with:
"Detailing of the prestressing wires should comply with the requirements of BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)."

7.4.3.4.1 *Manufacture*.
Paragraph 3 Lines 7, 8, replace "(see clauses ..... CP 115 : 1969)" with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)"

7.4.3.4.2 *Transfer of prestress*.
Paragraph 2 Lines 1-5, delete first sentence and replace with: "The minimum cube strength of the concrete at transfer of prestress should be in accordance with BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)."

7.4.4 Driven cast-in-place piles
7.4.4.1 *General*.
After Paragraph 2, add new paragraph:
"Construction requirements not covered in the following sub-clauses are given in MCHW 1 Series 1600."

7.4.4.2.1 *Concrete*.
Lines 7-9, replace last sentence with: "Slumps for concrete should be in accordance with MCHW 1 Series 1600, except for those piling systems requiring a dry mix."
At end of clause, add new paragraph:
"Guidance on measures to mitigate the effects of sulfate attack on concrete is contained in BRE Digest 363 "Sulfate and acid resistance of concrete in the ground." However, this has now been extended and to some extent superseded by the DETR (1999) Report of the Thaumasite Expert Group "The thaumasite form of sulfate attack." Advice should be sought from both documents."

Table 14 Delete table

7.4.4.3 *Design*
7.4.4.3.1 *Concrete*
Replace "The average" with "For piles having a permanent casing, the average"
At the end of the paragraph insert "For piles without permanent casing, the design should be carried out in accordance with Annex C."

7.4.4.3.2 *Reinforcement*
Replace "The recommendations" with "For piles having a permanent casing, the recommendations"
At the end of the paragraph insert "For piles without permanent casing, the design should be carried out in accordance with Annex C."

7.4.4.4.4 *Finishing pile heads*.
Paragraph 1 Lines 1-8, delete entirely and replace with: "Concrete should be cast to the levels specified in MCHW 1 Series 1600."

7.4.5 Bored cast-in-place piles
7.4.5.1 *General*.
After last paragraph, add new paragraph:
"Design and construction requirements not covered in the following sub-clauses are given in MCHW 1 Series 1600."

7.4.5.2.1 *Concrete*.
Paragraph 1 Line 4, replace "BS 5328" with: "MCHW 1 Series 1700"
Paragraph 1 Line 10, replace "table 14" with: "MCHW 1 Series 1600"
Paragraph 1 Line 12, delete "20N/mm^2 (200kgf/cm^2)" and replace with: "30N/mm^2"
At end of clause, add new paragraph:
"Guidance on measures to mitigate the effects of sulfate attack on concrete is contained in BRE Digest 363 "Sulfate and acid resistance of concrete in the ground." However, this has now been extended and to some extent superseded by the DETR (1999) Report of the Thaumasite Expert Group "The thaumasite form of sulfate attack." Advice should be sought from both documents."

7.4.5.3 *Design*
7.4.5.3.1 *Concrete*
Replace sentence with "The design should be carried out in accordance with Annex C."

7.4.5.3.2 *Reinforcement*
Replace "(see 7.4.4.3.2)" with "The design should be carried out in accordance with Annex C."

7.4.5.4.4 *Continuous flight augered piles*.
At end of clause, add new sentence: "Additional requirements are given in MCHW 1 Series 1600."

7.4.5.4.5 *Reinforcement*.
Line 1 replace "(see 7.4.4.3.2)" with "The design should be carried out in accordance with Annex C."
Line 3, replace "at least 1m ..... the casing" with: "at least 3m below the bottom of the casing or to the base of the pile if this is less than 3m below the bottom of the casing"

7.4.5.4.8 *Position and alignment tolerances*.
Delete Paragraph 2 entirely.

7.4.6 Steel bearing piles
7.4.6.1 *General*.
After last paragraph, add new paragraph:
"Design and construction requirements not covered in the following sub-clauses are given in MCHW 1 Series 1600 and 1800."

7.4.6.2.1 *Steel*.
Lines 2-4, delete "grades 43A .... engineer" and replace with: "MCHW 1 Series 1800"

7.4.6.2.2 *Concrete filling*.
Line 5, delete "not less than 75mm" and replace with: "as specified in MCHW 1 Series 1600"

7.4.6.3.2 *Transfer of working load to pile*.
Line 8, delete "embedded in the cap" and replace with: "down to a level 100mm above the soffit of the concrete"

7.4.6.3.3 *Protection against corrosion*.
Paragraph 1 Line 8, replace "CP 1021" with "BS 7361"

7.4.6.3.4 *Lengthening*.
Line 6, delete "taken in conjunction with BS 449" and replace with: "subject to the requirements of MCHW 1 Series 1700 and BS 5400 Part 3 as implemented by BD 13 (DMRB 1.3)"

7.5.4 Loading tests on piles
7.5.4.1 *General*.
Paragraph 1 Line 2, delete "settlement" and insert: "deformation (settlement or lateral movement)"
Paragraph 2 Line 1, delete "The" and insert: "Axial"
Paragraph 2 Line 2, after "7.5.6" insert new sentence: "Lateral load tests should be carried out in accordance with 7.5.7."

7.5.5 Pile loading using maintained loads
NOTE Line 2, replace "and ICE (1978)" with: ", ICE (1996) and MCHW 1 Series 1600"

7.5.5.2 *Method of loading*.
Paragraph 4 Lines 2 and 3, replace "at least three .... than 2m" with: "the greatest of three test or reaction pile shaft diameters from the test pile, centre to centre, or 2m"

7.5.5.3 *Measurement of settlement*.
Paragraph 1 (a) Lines 4-6, replace "A datum .... datum point" with: "At least two datum points should be established on separate permanent objects or other well-founded structures or deep datum points"
Paragraph 1 (a) Line 7, before "should" insert: "points"
Paragraph 1 (a) Lines 8-9, delete sentence "It is preferable .... demolished".
Paragraph 1 (a) Line 10, before "should" insert: "points"
Paragraph 1 (c) Lines 1-4, delete first two sentences and replace with: " Two strained high tensile wires on either side of the test pile may be used instead of the reference frame. The wires are positioned against scales fixed to the pile and the movements of the scales relative to the wires are determined."

7.5.5.4 *Procedure*.
Paragraph 1 Line 2, replace "working load" with: "design verification load and specified working load"
Paragraph 1 Lines 3-7, delete second and third sentences and replace with: "The loading and unloading shall be carried out in the stages given in MCHW 1 Series 1600.
Paragraph 3 Line 1, replace "0.25mm/h" with: "0.5% of the cumulative settlement, subject to a minimum rate of 0.05mm in 30 minutes"

7.5.6 Pile loading test at a constant rate of penetration
NOTE Line 2, replace "and Weltman (1980)" with: ", Weltman (1980) and MCHW 1 Series 1600"

7.5.6.4 *Method of testing*.
Paragraph 1 Line 7, replace "0.75mm" with: "0.6mm"
Paragraph 1 Line 9, replace "1.5mm" with: "1.2mm"

7.5.6.5 *Ultimate bearing capacity of the pile*.
At end of clause, add new clause:
"**7.5.7** Pile lateral load test

A pile lateral load test should be undertaken using maintained loads, similarly to 7.5.5, but it is normally unnecessary to continue tests to a state of failure. The magnitude and line of application of the test load should simulate the design loading of the pile.

An allowance should be made for the variability of the ground particularly over the top few metres of the pile when choosing the number of piles for testing and when determining the lateral pile capacity from the load test results.

For pile groups, the effect of interaction and head fixity should be accounted for when determining the lateral capacity from the results of load tests on individual piles.

Lateral load tests should only be undertaken on preliminary piles."

7.6 Integrity testing of cast-in-place piles
Title, delete and replace with: **"Non-destructive testing of piles."**
Before first line, insert: **"7.6.1 Integrity testing"**

NOTE Line 2, replace "and Fleming et al. (1985)" with: ", Fleming et al. (1985), Turner (1995), CIRIA Report 144 (1997) and MCHW 1 Series 1600"

At end of clause, insert new clause:
"**7.6.2 Dynamic pile testing**
Dynamic proof load testing involves monitoring the response of a pile to a heavy impact applied at the pile head. A pile-driving hammer often provides the impact and response is normally measured in terms of force and acceleration or displacement close to the pile head.

The results directly obtained relate to dynamic loading conditions. Interpretation in terms of static loading requires soil and pile dependent adjustments, and corroboration from experience may be required to correlate testing of this kind with static load tests as specified in Clause **7.5.4**.

Dynamic proof load testing should be carried out in accordance with MCHW 1 Series 1600."

8.1.1.2 *Applications*.
Line 4, after “BS 6349” add: “and BA59 (DMRB 1.3)”

8.1.2.2 *Timber*.
At end of Paragraph 1 add new sentence: “The use of timber in permanent works is to be treated as an aspect not covered by Standards.”

8.1.2.3 *Steel*.
Paragraph 1 Line 3, after “BS 5493” insert: “and MCHW 1 Series 1800 and 1900”
Paragraph 1 Lines 5 to 9, delete: “Steel also has ..... depths of water”

8.1.2.4 *Mass concrete and reinforced concrete*.
Paragraph 1 Line 5, replace “7.4.2 and section ten” with: “7.4.2, section ten and MCHW 1 Series 1700”
Paragraph 2 Lines 15-16, delete “at least 80mm of cover” and replace with: “cover as specified in BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3)”

8.1.2.5 *Bitumen and asphalt compounds*.
At end of clause, add new paragraph:
“The use of bitumen and asphaltic compounds should comply with MCHW 1 Series 2000.”

8.1.2.6 *Rock*.
Paragraph 1 Line 3, at the end of sentence insert: “and accord with MCHW 1 Series 600”

8.1.3.2 *Foreshore work*.
Line 6, replace “Civil Engineering Code of Practice No. 2” with: “BS 8002”

8.2.2.5 *Use of reinforcement.*
Paragraph 3, delete and replace with: “Cover should be as specified in BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3), but greater cover than the minimum specified is advisable.”

9.1.2 Archaeological finds on construction sites*
*at bottom of page 115, Line 1: replace “the Inspectorate of Ancient Monuments .... Fortress House” with: “English Heritage (Historic Buildings and Monuments Commission), Historic Scotland, Longmore House, Salisbury Place Edinburgh or Wales, Cadw: Welsh Historic Monuments”
*at bottom of page 115, Lines 2, 3: replace “112 Kennington Road, London, SE11” with: “Bowes Morrell House, 111 Walmgate, York, YL1 2VA. See HA 75 Trunk Roads and Archaeological Mitigation (DMRB 10.6.1) for further advice.”

9.2 Design of foundations
At end of clause, add new paragraph:
“The design should be formulated to avoid, reduce or control risks to health and safety as far as is reasonably practicable so that the foundations can be constructed and maintained safely. The designer should comply with the Construction (Design and Management) Regulations 1994 where these are applicable (see Section 11.1.1).”

9.8.7 Current developments
NOTE Lines 1 and 2, delete “a Building .... in preparation” and insert: “BRE Digests 313 and 352”

10.2 Timber
10.2.1 General
At end of clause, add new paragraph:
“The use of timber in permanent works is to be treated as an aspect not covered by Standards.”

10.2.6.3 *Preservative treated timber*.
Paragraph 2 Line 2, replace “BS 913” with: “BS 144”

10.2.8 Advisory bodies
Line 2, replace “the Timber Research and Development Association” with: “TRADA Technology Ltd”
Lines 4-6, replace “Princes Risborough ... Bucks HP17 9PX” with: “Building Research Establishment, Building Research Station, Garston, Watford, Herts WD2 7JR”

10.3 Metals
10.3.1 General
After Paragraph 2, insert new paragraph:
“Protection of metals against corrosion should comply with MCHW 1 Series 1900 and BD 42 (DMRB 2.1).”

Table 16 Delete table.

10.3.5 Corrosion of mild steel
After Paragraph 1 Line 7, delete remainder of clause including Table 16 and replace with:
“The corrosivity of the ground, water and atmosphere and resulting protection requirements for steel should be determined in accordance with BD 42 (DMRB 2.1). Further information may be obtained from Booth et al. (1967), Morley 1978, and Romanoff (1957).

Ground anchors are often used in foundation engineering and reference should be made to BS 8081.

Special consideration should be given where abrasion damage from shingle, sand and silt laden waters is possible or where floating fendering systems may abrade piling and the action of ship propellers in shallow waters may disturb harbour bed material causing abrasion damage and loss of steel thickness. Contact of steel with wood used, for example, as rubbing strips on jetty structures, can cause higher than normal corrosion rates because of crevice corrosion effects between the wood and steel interfaces."

10.4 Concrete
10.4.1 General
Paragraph 2 Line 2, replace "BS 8110" with: "MCHW 1 Series 1700, and BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3) and modified by BD 57 (DMRB 1.3.7)"

10.4.2 Sulfate attack
Paragraph 1 Line 12, replace "Digest 250" with: "Digest 363, subject to the requirements of MCHW 1 Series 1700"
Paragraph 1 Lines 16, 17, delete "table 17 .... Digest 250" and replace with: "BRE Digest 363, subject to the requirements of MCHW 1 Series 1700"
Paragraph 1 Lines 17-20, delete whole sentence.
Paragraph 1 Line 21, replace "table 17" with: "BRE Digest 363"
At end of clause, add new paragraphs:
"For further information, see BS 6699 regarding the use of ground granulated blastfurnace slag, BS 3892 regarding the use of pulverised fuel ash, BRE Current Paper 2/79 for methods of analysis of sulphate content, and BRE Digests 275 and 276 for interpretation in relation to fill and hardcore.

Guidance on measures to mitigate the effects of sulfate attack on concrete is contained in BRE Digest 363 "Sulfate and acid resistance of concrete in the ground." However, this has now been extended and to some extent superseded by the DETR (1999) Report of the Thaumasite Expert Group "The thaumasite form of sulfate attack." Advice should be sought from both documents."

Table 17 Delete table.

10.4.4 Chloride content
Paragraph 2 Line 6, replace "BS 8110" with: "MCHW 1 Series 1700"

10.4.6 Frost attack
Line 5, change "5%" to: "5.5%"
Line 8, replace "BS 8110" with: "MCHW 1 Series 1700"

10.4.7 Corrosion of reinforcement
Line 12, replace "BS 8110" with: "BS 5400 Part 4 as implemented by BD 24 (DMRB 1.3) and modified by BD 57 (DMRB 1.3.7)"

10.4.8 Unsuitable aggregates
Paragraph 1 Line 11, replace "237 and 258" with: "325 and 330"
Paragraph 2 Line 3, replace "35" with "357"

11.1.1 Statutory requirements
At end of clause, add new paragraph:
"It is also necessary to comply with other more recent statutory regulations which are listed in Appendix D. These include the Construction (Design and Management) Regulations 1994 which impose additional responsibilities on the Client, Designer, Planning Supervisor and Principal Contractor. These are intended to ensure that health and safety is taken into account and co-ordinated and managed effectively throughout all stages of a project from conception, design and planning through to construction and subsequent maintenance and repair. In Northern Ireland, the Construction (Design and Management) Regulations (Northern Ireland) 1995 apply."

11.2.5 Electricity
Paragraph 2 Line 3, replace "CP 1017" with: "BS 7375"

11.7.2 Use of explosives
Paragraph 1 Line 2, at end of sentence insert: "and MCHW 1 Series 600"
Paragraph 3, delete entirely.

APPENDIX B. Bibliography

The following references have been revised:

BRE Digest 35; withdrawn and replaced by:
BRE Digest 357. 1991. Shrinkage of natural aggregates in concrete.

BRE Digest 237; withdrawn and replaced by:
BRE Digest 325. 1987. Concrete Part 1 : materials.

BRE Digest 250; withdrawn and replaced by:
BRE Digest 363. 1991. Sulfate and acid resistance of concrete in the ground.

BRE Digest 258; withdrawn and replaced by:
BRE Digest 330. 1988. Alkali aggregate reactions in concrete.

CIRIA Underwater Report 23 1970: reprinted 1984.

CIRIA Report 44 1982: reprinted with amendments 1992.

DAVIS, Sir R.H. 1951; 6th edition, 1955.

FLEMING, W.G.K. and SLIWINSKI, Z.J. 1977; replaced by : The use and influence of bentonite in bored pile construction. CIRIA PG3, reprinted 1991.

HOBBS, N.B. and HEALY, P. 1979; reprinted 1991.

HEALEY, P.R. and HEAD, J.M; replaced by : Building over abandoned mineworkings CIRIA Report SP32, 1984.

ICE 1963; change 1963 to 1936 and add: reprinted 1949.

ICE 1978. *Piling* – Model procedures and specification. Instn. Civ.Engrs. replaced by:
ICE 1996 Specification for Piling and Embedded Retaining Walls Thomas Telford.

SHREIR, L.L. 1976; 3rd edition, 1994.

THORBURN, S. and THORBURN, J.Q. 1977; reprinted with amendments 1985.

The following references are to be inserted.

After BRE Digest 296;
BRE Digest 298. 1987. The influence of trees on house foundations in clay soils. HMSO.
BRE Digest 313. 1986. Mini-piling for low-rise buildings. HMSO.
BRE Digest 352. 1993. Underpinning. HMSO.

After Butterfield,R and Bannerjee, P.K;

Card G.B. and Carder D.R. "Movement trigger limits when applying the Observational Method to embedded retaining wall construction on highway schemes". TRL Report 228, Transport Research Laboratory, Crowthorne, 1996.

After CIRIA Report 44;
CIRIA Report 139 1995. Water-resisting basements (full report).
CIRIA Report 140 1995. Water-resisting basements (summary report).
CIRIA Report 144 1997. Integrity testing in piling practice by M J Turner.
CIRIA Report 185 1998. The Observational Method in ground engineering: principles and applications by Nicholson D., Tse C-M. and Penny C.

After de RUITER, J. 1982;

DETR (1999) The thaumasite form of sulfate attack: Risks, diagnosis, remedial works and guidance on new construction. Report of the Thaumasite Expert Group. January 1999. The Stationery Office.

After NCB 1965;

NHBC Standard Part 4.2 as amended by updates 1 to 11, 1995.

After TRRL Report No. LR90;

TURNER, M.J. 1995. Advice on integrity testing of piles TRL Report PR113.

The following references are to be deleted:

MAISHMAN, D. 1975. Ground freezing in methods of treatment of unstable ground (ed. F.G. Bell) Newnes-Butterworth, London 151-159.

STEFFENS, R.J. 1952. The assessment of vibration intensity and its application to the study of building vibrations. National Building Studies Sp. Rep. No. 19 HMSO.

APPENDIX C. Further reading

C.1. Books

The following books have been revised:

FLEMING, W.G.K., WELTMAN, A.J., RANDOLPH, M.F. and ELSON, W.K. 1985; 2nd edition, 1992.

LEGGETT, R.F. 1962; 2nd edition, 1988.

SHREIR, L.L. 1976; 3rd edition, 1994.

TOMLINSON, M.J. 1977; 4th edition, 1994.

TOMLINSON, M.J. 1980; 6th edition, 1995.

APPENDIX D. Recommendations and statutory requirements affecting the safety, welfare and health of persons at work

The following amendments should be made:

Statutory Instrument 1966 No. 95; after title, insert: "as amended by SI 1974 No. 209"

The Protection of Eyes Regulations 1974; add: "(Statutory Instrument No. 1681)"

The Abrasive Wheels Regulations 1970; add: "Statutory Instrument No. 535)"

The following should be added to the list:

After “Statutory Instrument 1960 No. 688” add:
“Statutory Instrument 1981 No. 399 Diving Operations at Work Regulations 1981”

After “The Abrasive Wheels Regulation 1970” add:
“Electricity at Work Regulations 1989
Manual Handling Operations Regulations 1992
Workplace (Health, Safety and Welfare) Regulations 1992
Management of Health and Safety at Work Regulations 1992
Provision and Use of Work Equipment Regulations 1992
Personnel Protective Equipment at Work (PPE) Regulations 1992
Construction (Design and Management) Regulations 1994
The Control of Substances Hazardous to Health Regulations 1994 (SI 1994 No. 3246).

NOTE: In Northern Ireland, the equivalent Northern Ireland Health and Safety Legislation applies.

The following publications referred to are to be deleted:

BS 449 The use of structural steel in building.

BS 4360 Specification for weldable structural steels.

BS 4449 Specification for hot rolled steel bars for the reinforcement of concrete.

BS 4461 Specification for cold worked steel bars for the reinforcement of concrete.

BS 5328 Methods of specifying concrete including ready mixed concrete.

BS 8110 Structural use of concrete.
Part 1 Code of Practice for design and construction.

CP 101 Foundations and substructures for non industrial buildings of not more than four storeys.

CP 102 Protection of buildings against water from the ground.

CP 114 Structural use of reinforced concrete in buildings.

CP 115 Structural use of prestressed concrete in buildings.

CP 116 The structural use of precast concrete.

DD81 Recommendations for ground anchorages.

Civil Engineering Code of Practice No. 2 Earth Retaining Structures.

ANNEX B. GUIDANCE ON LATERAL LOADING OF PILES.

B.1. INTRODUCTION

B.1.1 This Annex gives guidance on the requirements concerning the lateral loading of piles.

B.2. DESIGN PRINCIPLES

B.2.1 In addition to the general design principles already covered in this Standard, CIRIA Report 103, Design of Laterally Loaded Piles (reference B.5.1) provides additional guidance. Modern analytical methods and their suitability for design are discussed in detail in Pile Foundation Analysis and Design by H G Poulos and E H Davis (reference B.5.2).

B.2.2 More recent developments in the analysis and design of laterally loaded piles are described in TRL CR196 (Springman and Bolton, 1990) (reference B.5.3) and TRL PR 71 (Seaman, 1993) (reference B.5.4).

B.3. LATERAL LOADING

B.3.1 In recent times there have been cases of excessive movement of piled foundations supporting abutments that retain adjacent embankments. The cost of remedial work has in some instances been exceedingly high. These movements have been attributed to lateral pressures in the underlying ground caused by the imposed loading of the embankment. In every case the piling was carried out before all the movement caused by the construction of the embankment had taken place. Where lateral pressure may be developed due to this cause it should be taken into account in the design in addition to the usual loading which has to be resisted at pile cap level. In the case of a full height piled bridge abutment, it is also possible that additional interaction between the fill and underlying material and the abutment structure may result in increased lateral loading on the structure and foundation.

B.3.2 This Annex highlights the problems involved, gives advice on preventive design and construction practices and points out the inter-dependence between the design of the embankment and the design of the structure.

B.3.3 A study into lateral loading of piled foundations has been carried out for the Highways Agency. As well as references B.5.3 and B.5.4, the following additional publications contain the results of this work: TRL Project Report 112 “Lateral loading of piled foundations at Dartford Creek Bridge” (Carder, Gent and Darley, 1994) (reference B.5.5), TRL Project Report 98 “Centrifuge and analytical studies of full height bridge abutment on piled foundation subjected to lateral loading” (Springman, Ng and Ellis, 1994) (reference B.5.6) and TRL Report 246 “Lateral loading of piled foundations at Wiggenhall Road overbridge (A47)” (Darley, Carder and Ryley, 1997) (reference B.5.7).

B.4. DESIGN FOR LATERAL LOADING

B.4.1 When there is a likelihood of any soil-induced lateral loading being developed during or after the construction of a pile, efforts should be made firstly to identify the extent of the problem, and then to determine the most economical solution. This could be either to take measures at the construction stage to reduce the magnitude of the effects, as described below, or to design the piles to withstand the predicted lateral loading, or a combination of both. Detailed consideration of the design methodology for laterally loaded piles is presented in TRL PR 71 (Seaman, 1993) (reference B.5.4).

B.4.2 Ground Investigation. Where piled foundations are required adjacent to an embankment, for example a bridge abutment, special attention should be given at the ground investigation stage to the need to obtain sufficient and reliable data for the assessment of the risk and significance of lateral loading. Advice Note HA 34 (DMRB 4.1) Ground Investigation Procedure (reference B.5.8), gives guidance on the preparation of ground investigation contracts.

B.4.3 Initial Design Considerations. In certain types of locations such as river valleys, the material overlying the founding stratum for the piles often consists of soft clays, silts, loose sands and gravels and, occasionally, peat. When piled foundations are used in such ground conditions the possibility of soil induced lateral loading is high and should be investigated; the necessary measures should be taken as described in the following sections.

B.4.4 Design Measures. The structural configuration may be modified in one of the following ways in order to minimise the lateral loading due to movements of soft strata, or eliminate the need for piling altogether:-

(a) Use of skeletal (spill-through) abutments. This may obviate the need for piled foundations or at least avoid high earth-retaining forces from being applied to the tops of the piles. However, it should be noted that good compaction of the fill material within a skeletal abutment is difficult to achieve, and it may be necessary to lengthen the superstructure. Advice on the appropriate forces to be considered when skeletal abutments are used can be found in “Bridge Foundations and Substructures” (reference B.5.9)

(b) Use of bank-seat abutments. The benefits of this are similar to those of skeletal abutments but the designer usually has more freedom with the geometry. For instance, the slope of the embankment may be varied to reduce the magnitude of lateral forces on piles. The use of bank-seats normally makes it necessary to lengthen the superstructure. If piling cannot be eliminated, there may be problems of driving piles through the embankment material.

(c) Extend the length of the structure if this will reduce the height of the embankment at the abutment location.

B.4.5 Constructional Measures. One or more of the following measures may be considered at the design stage in order to minimise the lateral loading due to movements of soft strata, or eliminate the need for piling altogether:

(a) Construct the embankment allowing sufficient time, by monitoring with inclinometers if necessary, for movement of the soft strata to occur before piling. The movement of the soft strata may be accelerated, and a stable state achieved reasonably quickly, by using ground improvement techniques such as vertical sand drains, dynamic consolidation of the soft strata or by surcharging the embankment.

(b) Excavate the soft strata in the foundation/ embankment area and backfill with a suitable filling material with thorough compaction. This is likely to be more expensive than other measures although it may give greater assurance.

(c) Use lightweight fill for all or part of the embankment.

(d) Reduce the amount of deformation of the soft strata under the embankment by using ground improvement techniques such as settlement reducing piles and lime or stone columns.

As each of the above measures can be relatively expensive it is important that the economics of the situation are fully investigated before the final design is adopted. A significant factor will clearly be the depth, thickness and nature of the underlying soft strata.

B.4.6 Pile Design. When piles are to be designed for soil-induced lateral loading, in addition to the normal requirements, the following procedure is recommended for use:

(a) Analyse the behaviour of the soil cross-section omitting the piles and the pile loads transferred from the structure, to obtain the soil displacements perpendicular to the pile shafts calculated at the position of the piles, over the whole length of the pile. Any suitable finite element based computer program capable of analysing elastoplastic soil behaviour may be used for this purpose.

(b) Apply the above soil displacements to the individual piles as lateral deflections with due regard to their end fixities. Only differential deflections, ie deflections with respect to one end of the pile, should be used as the applied deflections. Each pile should be considered as a free standing frame element without the surrounding soil.

Any suitable continuous beam or frame analysis computer program can be used for this. The soil deflections should be input as imposed deflections, either directly if this facility exists, or as “support settlements”. The points at which the deflections are applied must correspond with the soil deformation output points. About 10 regularly spaced deflection points along each pile should be sufficient. The reactions output by the program represent the point loads required to produce the calculated displacement profile.

(c) Obtain the lateral pressures developed along each pile which would generate the above deflections by dividing any point load or reaction by the corresponding length of pile multiplied by the diameter or the width of the pile. If in any part of the pile this pressure exceeds the yield stress P_y of the soil, the excess pressure should be redistributed uniformly along the remainder of the pile. Each pile is then to be analysed using the redistributed total pressure as the applied pressure. The yield stress P_y is to be taken as the greater of the following:

$P_y = 3 K_p \sigma_v'$
$P_y = 9C_u$
where K_p = coefficient of passive earth pressure
σ_v' = effective overburden pressure
C_u = undrained cohesion

(d) Forces, moments and any other load effects developed in the piles at the end of step (c) should finally be added to the total load effects for both the serviceability and the ultimate limit states (ie γ_{fL} = 1.0 for both limit states).

The above procedure is a simplistic but conservative method to calculate lateral forces and moments induced into a single pile. This is because:

(i) it makes the assumption that the presence of the pile does not influence the ground movement;

(ii) it does not allow for soil yield and flow around the pile;

(iii) no allowance is made for increase in strength as the soil consolidates under the embankment surcharge.

The method can be refined by using "link elements" which model interaction between the soil and the pile (eg Stewart, 1994) (reference B.5.10).

Appendix A of TRL PR 71 (Seaman, 1993) (reference B.5.4) describes various design approaches and their advantages and limitations.

B.5. REFERENCES

B.5.1. CIRIA Report 103, Design of laterally-loaded piles, 1984.

B.5.2. H G Poulos and E H Davis, Pile Foundation Analysis and Design, John Wiley and Sons, 1980.

B.5.3. Springman S M and Bolton M D (1990). The effect of surcharge loading adjacent to piles. Transport Research Laboratory Contractor Report 196.

B.5.4. Seaman J W (1993). A guide to accommodating or avoiding soil-induced lateral loading of piled foundations for highway bridges. Transport Research Laboratory Project Report 71.

B.5.5. Carder, Gent and Darley,(1994). Lateral loading of piled foundations at Dartford Creek Bridge. Transport Research Laboratory Project Report 112

B.5.6. Springman, Ng and Ellis,(1994). Centrifuge and analytical studies of full height bridge abutment on piled foundation subjected to lateral loading. Transport Research Laboratory Project Report 98.

B.5.7. Darley P, D R Carder and M D Ryley (1997). Lateral loading of piled foundations at Wiggenhall Road overbridge (A47). Transport Research Laboratory Report 246.

B.5.8. HA 34 Ground Investigation Procedure (DMRB 4.1) TSO.

B.5.9. Bridge foundations and substructures: Building Research Establishment Report, HMSO, 1979.

B.5.10. Stewart, D.P., Jewell R.J and Randolph M.F (1994) Design of piled bridge abutments on soft clays for loading from lateral movements. Geotechnique 44 (2), 277 – 296.

ANNEX C. THE REINFORCEMENT OF BORED CAST-IN-PLACE EMBEDDED FOUNDATION PILES

Contents

Figures

C1 Introduction

C1.1 This Annex states the requirements for the reinforcement of bored cast-in-place embedded foundation piles. It has been prepared as a stand-alone document.

For the purposes of this Annex an embedded pile is defined as a foundation pile that is surrounded by ground capable of providing some degree of lateral support to the pile, throughout its entire length.

For guidance on the reinforcement of free standing cast in place piles refer to Clause 7.3.3.3.

For guidance on the reinforcement of embedded pile retaining walls refer to BD 42 (DMRB 2.1.2).

C1.2 Reinforcement for bored cast-in-place embedded foundation is based on the requirements of BS5400: Part 4:1990, as implemented by BD24 (DMRB 1.7.1), and as further modified by the recommendations of TRL Report 144 (1995).

Units and symbols in this Annex are as used in BS 5400: Part 4: 1990 as implemented by BD24 (DMRB 1.3.1).

Typical applications for cast in place embedded foundation pile types described above are shown in Figure C1.

C1.3 A flow diagram, figure C2, demonstrates the use of Annex C.

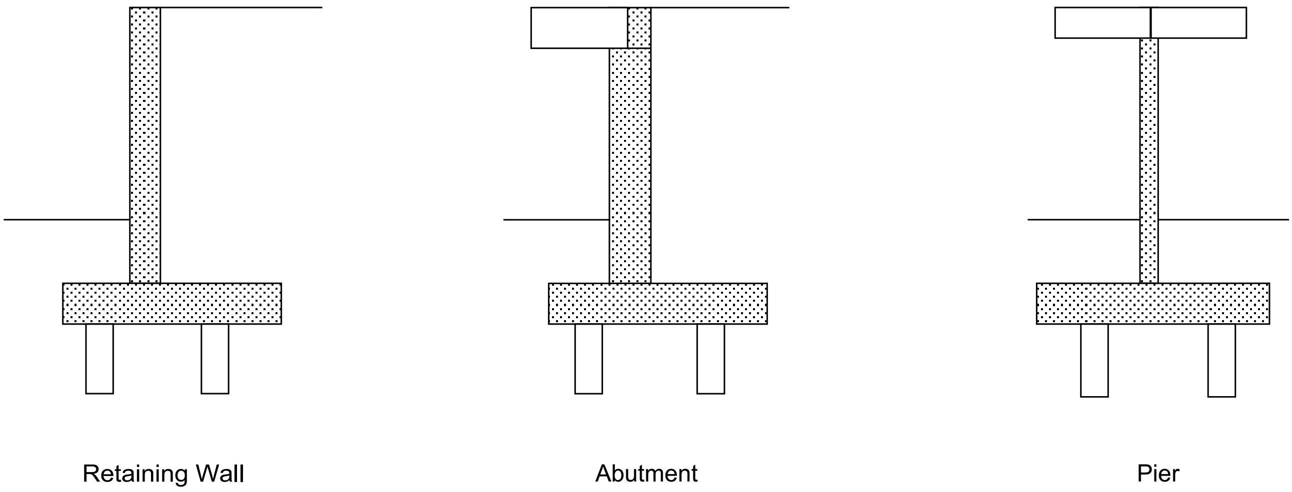

Figure C1: Typical Applications for Cast-in-Place Embedded Piles

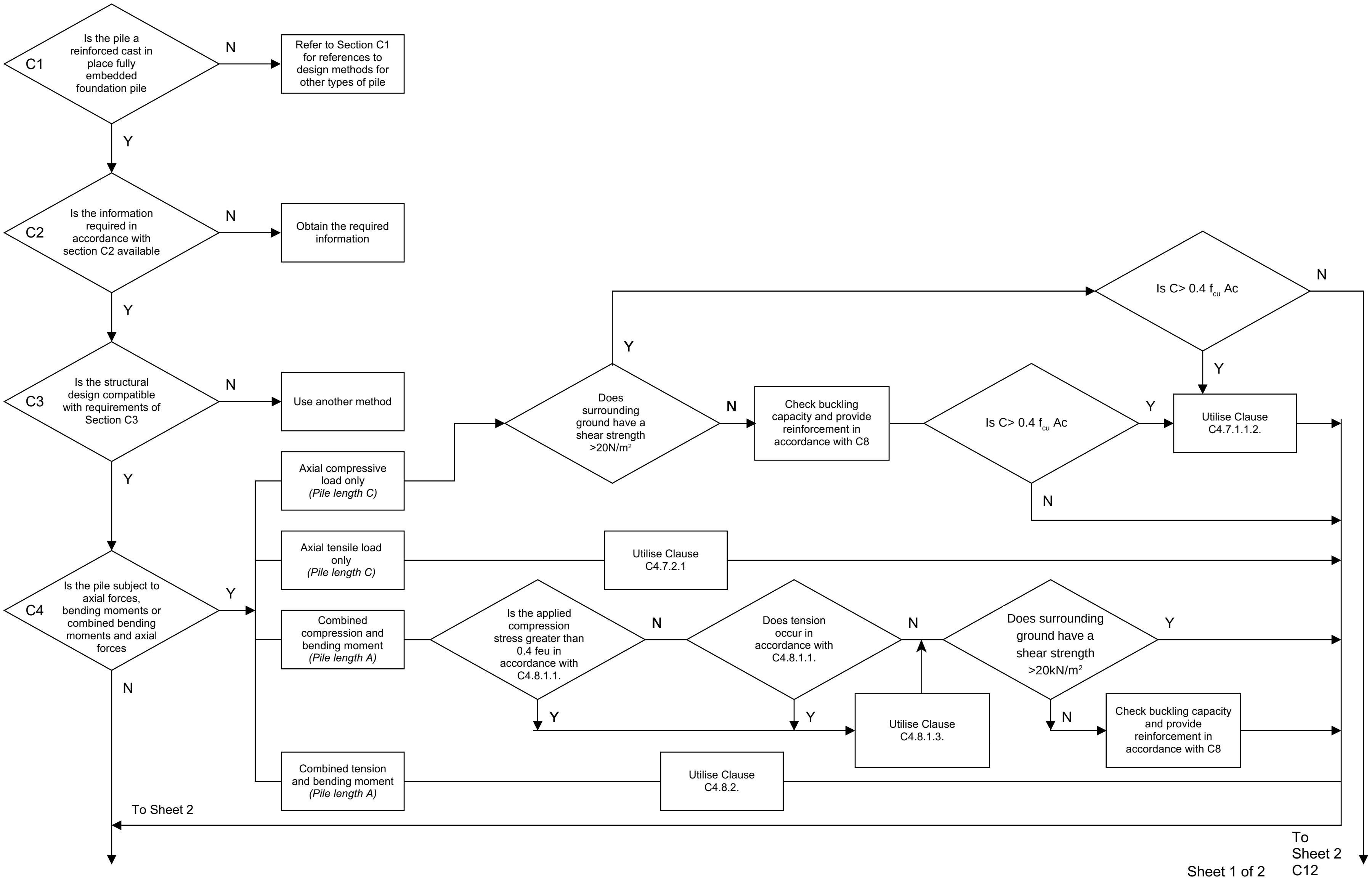

Figure C2: Use of Annex C - Flow Diagram

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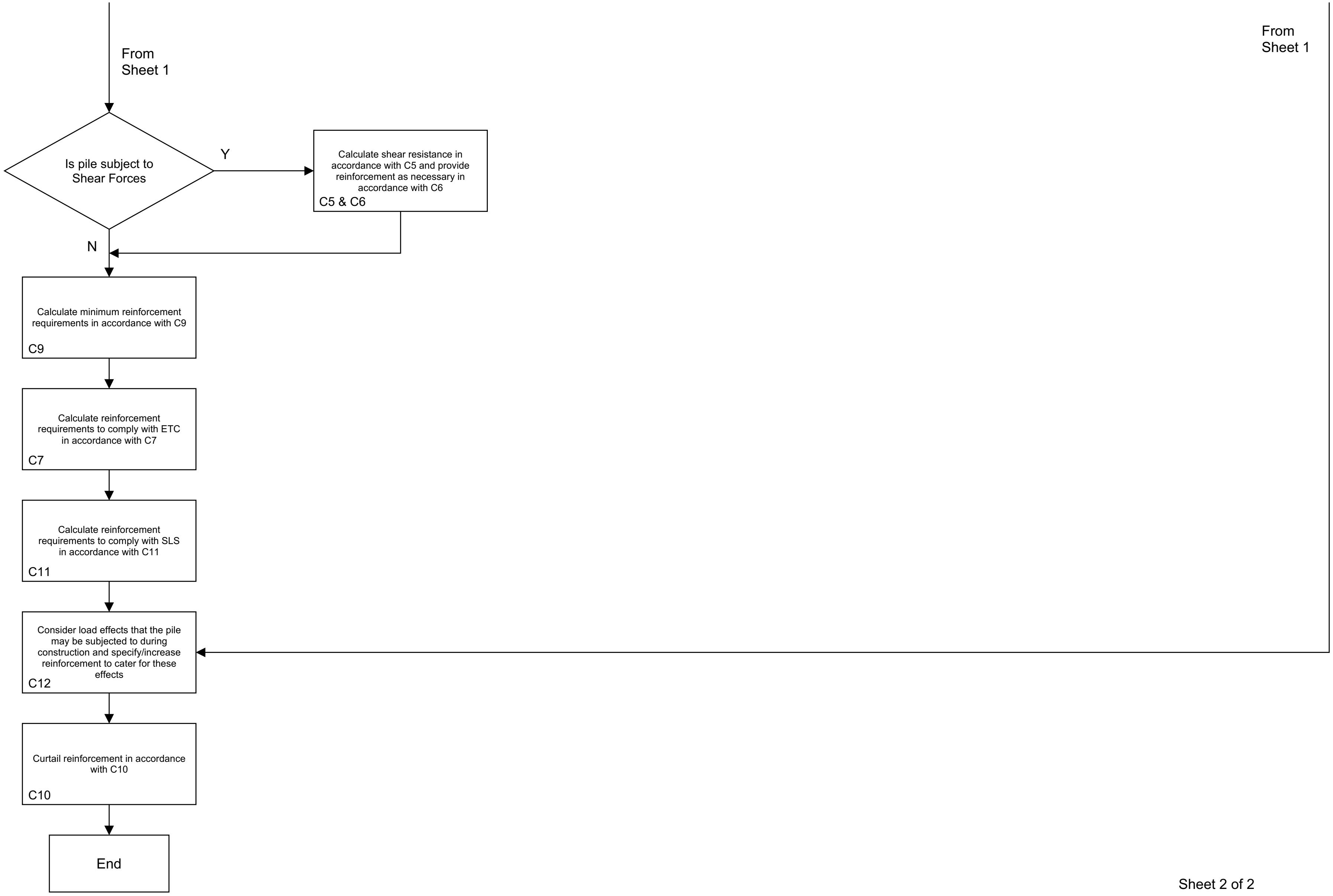


Figure C2: Use of Annex C - Flow Diagram (continued)

C2 Load Effects and Design Considerations

C2.1 At this stage in the design process the pile size and its overall length will have been determined using nominal loads and net bearing pressures and frictional resistances as appropriate.

C2.2 It should be appreciated that the length of pile necessary to resist applied bending moments and horizontal load effects (designated pile length A), to satisfy ultimate limit state and serviceability limit state requirements for soil-structure interaction, may be less than the length of pile necessary to resist axial load effects (designated pile length B). The additional length of pile required to resist axial loading is designated pile length C, as shown in Figure C3.

C2.3 There will be no structural design requirement for the pile below pile length A to carry bending moment or shear load effects. Instead this section of pile (pile length C) must be structurally capable of carrying the design axial load effects only. In such cases, for compression piles, no reinforcement will be required within pile length C, providing the plain concrete can carry the design axial load effect in accordance with the requirements of this Annex, and providing that the buckling resistance of the pile as described in Section C8, need not be considered.

C2.4 Before using Annex C, design information should be available upon the minimum length of pile required purely to withstand any externally applied moment and horizontal load effects (pile length A) and the length of pile required to resist axial load effects (pile length B). Moments will be applied to a pile in various instances, including where axial load is applied eccentrically by virtue of construction tolerances in installing the pile.

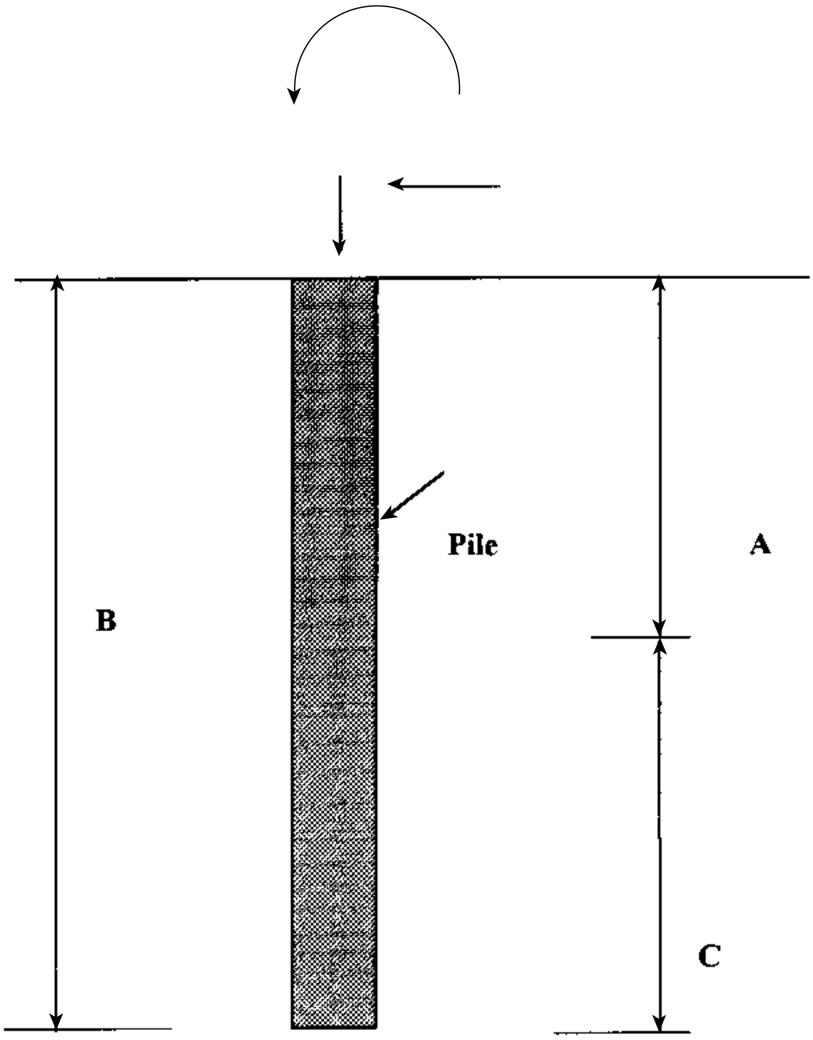
C2.5 The design of the structural elements of the pile requires a limit state approach based on factored load effects. It is important that the structural engineer responsible for design of the structural elements of the pile in accordance with this Annex communicates with the geotechnical engineer to ensure there is a mutual understanding of each party's requirements. The geotechnical engineer must be aware of any performance requirements, for example, in terms of horizontal and vertical deflection limits.

C2.6 If the geotechnical engineer is responsible for supplying the structural engineer with design load effects acting on a pile, they must represent the most onerous load effects upon that element for the likely range and combination of soil properties and stiffnesses which will operate on the structure. For example, down drag effects on a pile can give rise to tension in a pile either due purely to that effect, or as a result of combination with other effects such as bending or uplift forces resulting from lateral loading.

C2.7 Load effects shall be provided for both the serviceability limit state (SLS) and the ultimate limit state (ULS) conditions using the partial load factors in BD 37 (DMRB 1.3) and the partial safety factor, γ_{f3} in BS 5400: Part 4: 1990 as implemented by BD 24 (DMRB 1.3.1).

C2.8 Envelope diagrams for axial force, shear force and bending moments at SLS and ULS shall be made available including details of how the various effects interact to form the basis of the structural design.

C2.9 When applying the structural design rules in this Annex to co-existent load effects, care must be taken to apply the correct (reduced) partial load factors to load effects which have a relieving effect.



Key To Pile Lengths

A : Length of pile subjected to axial forces, shear forces and bending moments

B : Overall length of pile

C : Length of pile subjected to axial forces only

Figure C3: Pile Lengths as Defined in Section C.2

C3 Pile Strength and Stiffness

C3.1 General

C3.1.1 Pile strength and stiffness is related to the size of pile and the strength of concrete used to construct the pile. An increase in concrete strength will result in an increase in concrete stiffness, and therefore the strength of concrete used in design has an effect on both pile capacity and the forces attracted to the pile.

C3.1.2 For laterally loaded piles an increase in concrete strength results in an increase in the relative differences between soil and pile stiffnesses. This has the effect of increasing the magnitude of shear forces and bending moments acting on a pile.

C3.1.3 For axially loaded piles concrete strength is a governing factor for pile load carrying capacity and an increase in concrete strength will directly reduce any requirement for compression reinforcement.

C3.1.4 Increased concrete strength, although allowing greater axial and lateral loads to be carried, has the disadvantage of producing a greater tendency for thermal cracking to occur. The specification of concrete mixes for use in piles therefore needs to be carefully selected to provide the optimum design solution.

C3.2 Concrete

Concrete shall be in accordance with MCHW 1 Series 1700 and have a minimum characteristic strength at 28 days of 30N/mm².

C3.3 Reinforcement

Reinforcement shall be in accordance with MCHW 1 Series 1800.

C3.4 Cover to Reinforcement

Cover to reinforcement shall be in accordance with BS 5400: Part 4: 1990 Table 13 as implemented by BD 24 (DMRB 1.3.1) **plus** the additional requirements of BS 8004 Clause 2.4.5. The requirements of BD 57 (DMRB 1.3.7) shall be deemed to be satisfied.

C4 Piles Subject to Axial Forces and Bending Moments (ULS)

C4.1 Applied load effects calculated in accordance with Section C2 give rise to axial forces, shear forces and bending moments acting singly or in combination within the pile.

C4.2 The magnitude and distribution of load effects generated in a pile are affected by the interaction of the structure and soil.

C4.3 The magnitude of load effects in the pile will depend on the strength and stiffness of the surrounding ground and the stiffness of the pile. Stiff soils mobilise greater resistance against the pile resulting in less deflection of the pile but in certain configurations may induce greater load effects for a given load than for the same pile surrounded by soft soil.

C4.4 The method of determining load effects should take into account the size and complexity of structure to be supported. For simple structures, a design based on the piles acting as free in air columns down to a calculated depth to fixity may be appropriate. For more complex structures the determination of load effects on a pile should take account of soil/structure interaction effects. Further details regarding appropriate techniques for such analyses are contained in Annex B.

C4.5 Whatever method of analysis is adopted for soil-structure interaction the requirements of C2 shall be adopted.

C4.6 The pile adequacy shall also be considered at Serviceability Limit State in accordance with Section C11.

C4.7 Piles Subject to Axial Forces (Pile Length C)

C4.7.1 Compressive Axial Forces

C4.7.1.1 The resistance of pile lengths subject to compressive axial forces, where the ground surrounding the pile has a shear strength $\geq 20kN/m^2$, shall be calculated using the following formulae:

C4.7.1.1.1 For an applied axial force $N < 0.4\, f_{cu}\, A_c$ no reinforcement is required, subject to the requirements of C12.

C4.7.1.1.2 For an applied axial force $N \geq 0.4\, f_{cu}\, A_c$ provide reinforcement in accordance with Clauses 5.5.3.2 and 5.5.4 of BS 5400: Part 4: 1990 implemented by BD 24 (DMRB 1.3.1). The requirements of Sections C9 and C12 shall also apply.

C4.7.1.1.3 Reinforcement provided for an applied axial force $N \geq 0.4 f_{cu}\, A_c$ shall be at least equal to the minimum reinforcement requirements stated in Section C9. The requirements of Section C12 shall also be considered.

In the above formulae:

f_{cu} is the characteristic compressive strength of the concrete.

A_c is the gross cross sectional area of the pile at the section considered.

C4.7.1.2 Where the ground surrounding the pile has a shear strength $< 20kN/m^2$ the effects of buckling of the pile shall be considered in accordance with the requirements of Section C8.

The value of P_{CR} calculated in accordance with Section C8 shall not exceed the applied compressive axial force.

Minimum reinforcement in accordance with the requirements of C9 shall be specified.

C4.7.2 Tension

C4.7.2.1 The resistance of piles subject to tensile axial forces shall be calculated using the following formula:

$$A_{st} = \frac{T}{0.87 f_y}$$

where A_{st} is the area of longitudinal reinforcement (which shall not be less than the minimum area of reinforcement stated in Section C9).

T is the applied tensile axial load.

f_y is the characteristic tensile strength of the reinforcement.

C4.7.2.2 The requirements of Sections 7, 9, 11 and 12 shall be applied.

C4.8 Piles Subject to Axial Forces Combined with Bending Moments (Pile Length A)

C4.8.1 Compressive Axial Forces and Bending Moments

C4.8.1.1 Bending moments in combination with compressive axial forces will, depending on their respective magnitudes, result in a pile at any particular cross section remaining wholly in compression or partly in compression and partly in tension. In certain instances there will be no requirement to provide longitudinal reinforcement. This condition occurs where:

i) the ground surrounding the pile has a shear strength ≥ 20kN/m²

ii) there is no net tension in the pile at the section under consideration

iii) the maximum compression stress is less than 0.4 f_{cu}

For the purposes of these calculations extreme fibre stresses shall be calculated using normal elastic theory.

C4.8.1.2 If the requirements of C4.8.1.1 indicate there is no requirement for reinforcement the further provisions of Sections C5, C6 and C12 shall be applied.

C4.8.1.3 In all other instances the design shall be in accordance with the requirements of Clauses 5.5.3.2 and 5.5.4 of BS 5400: Part 4: 1990 as implemented by BD 24 (DMRB 1.3.1). The further provisions of Sections C5, C6, C11 and C12 shall also be applied. Minimum reinforcement requirements shall be in accordance with Section C9.

C4.8.1.4 When the shear strength of the surrounding ground ≤ 20kN/m² the effects of buckling need to be considered in accordance with the requirements of Section C8.

C4.8.1.5 Where an axial compressive force acting on a pile provides a beneficial effect, the value of this force must be carefully evaluated, both in terms of the likely variation of its magnitude along the length of the pile and the partial load factor employed, to ensure an appropriate value is utilised.

C4.8.1.6 Unless accurate positioning of the reinforcement within the pile can be ensured, the analysis should take into account the most onerous orientation to ensure that the required value of bending resistance is achieved.

C4.8.2 Tensile Axial Forces and Bending Moments

C4.8.2.1 Bending moments acting in conjunction with tensile axial forces will, depending on their respective magnitudes, result in a pile at any particular cross section remaining wholly in tension or partly in tension and part compression.

C4.8.2.2 Design shall be carried out in accordance with Clauses 5.5.3.2 and 5.5.4 of BS 5400: Part 4: 1990 as implemented by BD 24 (DMRB 1.3.1). The further provisions of Sections C5, C6, C11 and C12 shall also be applied. Minimum reinforcement requirements shall be in accordance with Section C9.

C4.8.2.3 Unless accurate positioning of the reinforcement within the pile can be ensured, the analysis should take into account the most onerous orientation to ensure that the required value of bending resistance is achieved.

C5 Piles Subject to Shear Forces (ULS)

C5.1 Lateral forces calculated in accordance with C2 set up shear forces within the pile.

The shear stress, v, at any cross section shall be calculated from

$$v = \frac{V}{bd}$$

where V is the shear force due to ultimate loads

b is the pile diameter

d is the distance from the extreme fibre with maximum compression to the centroid of the reinforcement in the half of the pile opposite the extreme compression fibre

To prevent crushing of concrete v shall not exceed $0.75\sqrt{f_{cu}}$ or 4.75N/mm² whichever is the lesser, whatever shear reinforcement is required.

C5.2 For design of reinforcement refer to Section C6.

C6 Shear Reinforcement

C6.1 Shear link reinforcement shall be provided where required in accordance with the following criteria:

$v \leq \frac{\xi_s v_c}{2}*$	No shear reinforcement required (refer to Section C9)
$\frac{\xi_s v_c}{2} \leq v \leq \xi_s v_c *$	Minimum reinforcement (refer to Section C9).
$v > \xi_s v_c *$	The greater of $A_{sv} = \frac{s_v\ b(v - \xi_s v_c)}{\frac{f_{yv}}{\gamma_{ms}}}$ or minimum reinforcement requirements in accordance with Section C9.

where A_{sv} is the cross sectional area of all legs of the links at a particular cross section

v is the applied shear stress

v_c is the ultimate shear stress in concrete calculated in accordance with Table 8 of BS 5400: Part 4: 1990 where the area of longitudinal reinforcement A_s to be used to calculate v_c shall be taken as the area of reinforcement which is in the half of the column opposite the extreme compression fibre. The effective depth shall be taken as the distance from the extreme fibre with maximum compression to the centroid of this reinforcement. The web width shall be taken as the column diameter.

ξ_s is the depth factor (refer to Table 9 of BS 5400: Part 4: 1990)

s_v is the spacing of the links along the member

b is the pile diameter

f_{yv} is the characteristic strength of link reinforcement but not greater than 460N/mm²

γ_{ms} is the partial safety factor for steel reinforcement

* $\xi_s v_c$ shall be multiplied by $1 + \frac{0.05N}{A_c}$ in these instances.

where N is the ultimate axial load (in newtons). Refer also to C4.8.1.5

A_c is the area of the entire concrete section (in mm²).

C6.2 The spacing of the legs of links in the direction of the span and at right-angles to it shall not exceed 0.75d.

C6.3 At any cross section additional longitudinal reinforcement is required in the tensile zone (in excess of that required to resist bending) such that

$$A_{sa} \geq \frac{V}{2(0.87f_y)}$$

where

A_{sa} is the area of effectively anchored additional longitudinal tensile reinforcement

f_y is the characteristic strength of the longitudinal reinforcement

V is the shear force due to ultimate loads

Note: For symmetrical arrangements of reinforcement this will result in a total required area of reinforcement equal to 2 x A_{sa} spaced evenly round the perimeter of the pile.

C6.4 Enhanced Shear Strength of Sections Close to Supports

Refer to BS 5400: Part 4: 1990 Clause 5.3.3.3 as implemented by BD 24 (DMRB 1.3.1)

C6.5 The minimum reinforcement requirements in Section C9 shall be provided.

C7 Early Thermal Cracking

C7.1 General

C7.1.1 Fully embedded piles restrained along their outer surfaces by the surrounding ground can suffer from the effects of both externally and internally restrained early thermal cracking. Due to the insulating properties of the surrounding ground externally restrained cracking is usually the dominant factor. This type of cracking can penetrate through the entire concrete section and is generally horizontal except at positions close to the pile head where restraint from the pile cap may cause vertical cracking. Checks shall be carried out to ensure that the longitudinal steel does not yield and that the cracked pile section shall be capable of resisting applied shear forces.

C7.1.2 Sections 7.2 and 7.3 need only be implemented if reinforcement is required to comply with other sections of this Annex.

C7.2 Control of Thermal Cracking

To ensure the reinforcement in the pile will not yield before the tensile strength of the immature concrete is exceeded the following equation shall be satisfied:

$$A_s = \frac{f_{ct}*}{f_y} \quad A_c$$

where

A_s is the total cross sectional area of effectively anchored longitudinal reinforcement distributed evenly around the perimeter of the pile.

A_c is the effective concrete area of the pile which is equal to the gross cross sectional area for sections up to 500mm thick (diameter). For sections with a diameter greater than 500mm dia it shall be taken as that area of concrete which lies within 250mm of the surface.

f_y is the characteristic tensile strength of the reinforcement

$f_{ct}*$ is the tensile strength of immature concrete which may be taken as $0.37\sqrt{(f_{cu})}$

f_{cu} is the characteristic cube strength of concrete

C7.3 Shear Resistance of Sections at Ultimate Limit State Subject to Early Thermal Cracking

C7.3.1 Piles shall be designed to withstand applied shear forces in conjunction with the effects of early thermal cracking. The shear resistance of piles subject to early thermal cracking should be calculated using the following method:

Longitudinal reinforcement shall be provided in accordance with the following equation:

$$A_s \geq \frac{V}{0.73f_y} + \frac{1.15T}{f_y}$$

where

V is the shear force due to ultimate loads

T is the tensile axial force due to ultimate loads

A_s is the total cross sectional area of effectively anchored longitudinal reinforcement crossing a cracked section

f_y is the characteristic strength of effectively anchored reinforcement crossing a cracked section

Notes

i) The first term of this equation is derived from equation reference 61 in BS 8110: Part 1, “Structural Use of Concrete” with tan α taken as 1.4. The constant 0.73 is the product of 0.6 (constant stated in equation reference 61), 1.4 (value of tan α) and 0.87 ($1/\gamma_m$)

C7.4 Requirements for Longitudinal Reinforcement

C7.4.1 The area of longitudinal reinforcement calculated in accordance with Sections C7.2 and C7.3 shall be compared to the summed longitudinal reinforcement requirements, calculated in accordance with Sections C4 and C6. The greatest area calculated in accordance with Section C7.2, C7.3 and the summed requirements of Section C4 and C6 shall be specified.

C8 Buckling

C8.1 The effects of buckling shall be considered when the ground surrounding a compression pile has a shear strength less than 20kN/m².

C8.2 In such cases minimum reinforcement shall be provided in accordance with Section C9 for the length of pile over which buckling needs to be considered. Reinforcement continuity above and below the pile length affected by buckling shall be considered.

C8.3 When considering buckling loads on piles the effect of any lateral displacement of the pile due to horizontal loading shall be taken into account.

C8.4 The buckling resistance of a pile where the surrounding ground has a shear strength less than 20kN/m² may be calculated using the methods of Francis et al (1962) or Poulos and Davis(1980). The following example shows how buckling resistance of a pile can be calculated and compared with applied compressive axial forces as described in Section C4.

C8.5 Buckling load of a pile, P_{cr} , can be found from:

$$P_{cr} / P_E = (n^2 + \beta / n^2) \qquad (C8.5.1)$$

where n = number of half sine waves caused by buckling load in pile (see figure C4)

P_E = buckling load of a pin-ended strut in air = $\pi^2 EI / L^2$

$\beta = (L / L')^4$

L = length of pile

L′ = length of half sine wave

If L_e is the effective length of the pile considered as a pin-ended strut ie $P_{cr} = \pi^2 EI / L_e^2$

Then $$1/(L_e / L')^2 = 1/ (L/ n.L')^2 + (L/ n.L')^2 \qquad (C8.5.2)$$

and equation C8.5.2 is plotted as figure C5.

From figure C5 it is found that:

For $L/ L' < (1 / \sqrt{2})$, ie $L < 0.71.L'$, it can be assumed that the soil offers no support and $L_e = L$

For $L/ L' > (1 / \sqrt{2})$, ie $L > 0.71.L'$, it can be assumed that $L_e = L' / (\sqrt{2})$ and P_{cr} is twice the buckling load of a pin-ended column in air so $P_{cr} = 2\sqrt{(EIk)}$.

L′ is governed by the soil properties and may be given by:

$L' = (\pi^4.EI/k)^{1/4}$ for a uniform soil or

$L' = (2\pi^4.EI/k_o)^{1/5}$ where soil stiffness is proportional to depth ie k_o is the rate of increase in k with depth

Where k = coefficient of lateral displacement of soil and may be taken as

$$k = \frac{8\pi E_s (1-\mu)}{1.13(3-4\mu)(1+\mu)(2(\log_e(2L/b)) - 0.443)}$$

where L = length, b = breadth of pile and E_s = modulus of soil. (reference Glick (1948))

C8.6 Example.

C8.6.1 For a typical uniform soft soil of undrained shear strength Cu = 10 kN/m², the modulus of elasticity of the soil E_s = 500 Cu = 5000 kN/m² and μ = 0.4 . For a 15m long, 0.5 m diameter pile:

$$k = \frac{8\pi 5000(1-0.4)}{1.13(3-4\times 0.4)(1+0.4)(2\log_e(2\times 15/0.5) - 0.443)} = 4395 kN/m^3$$

$L' = (\pi^4.EI/4395)^{1/4}$ = 6.4m (E = 25 x 10^6 kN/m² and I = $\pi.b^4 /64$)

L > 0.71 . L′ therefore $P_{cr} = 2\sqrt{(EIk)}$ = 37MN.

which is equivalent to an applied stress of 188 MN/m², well in excess of the 28 day characteristic concrete strength of say 40 MN/m².

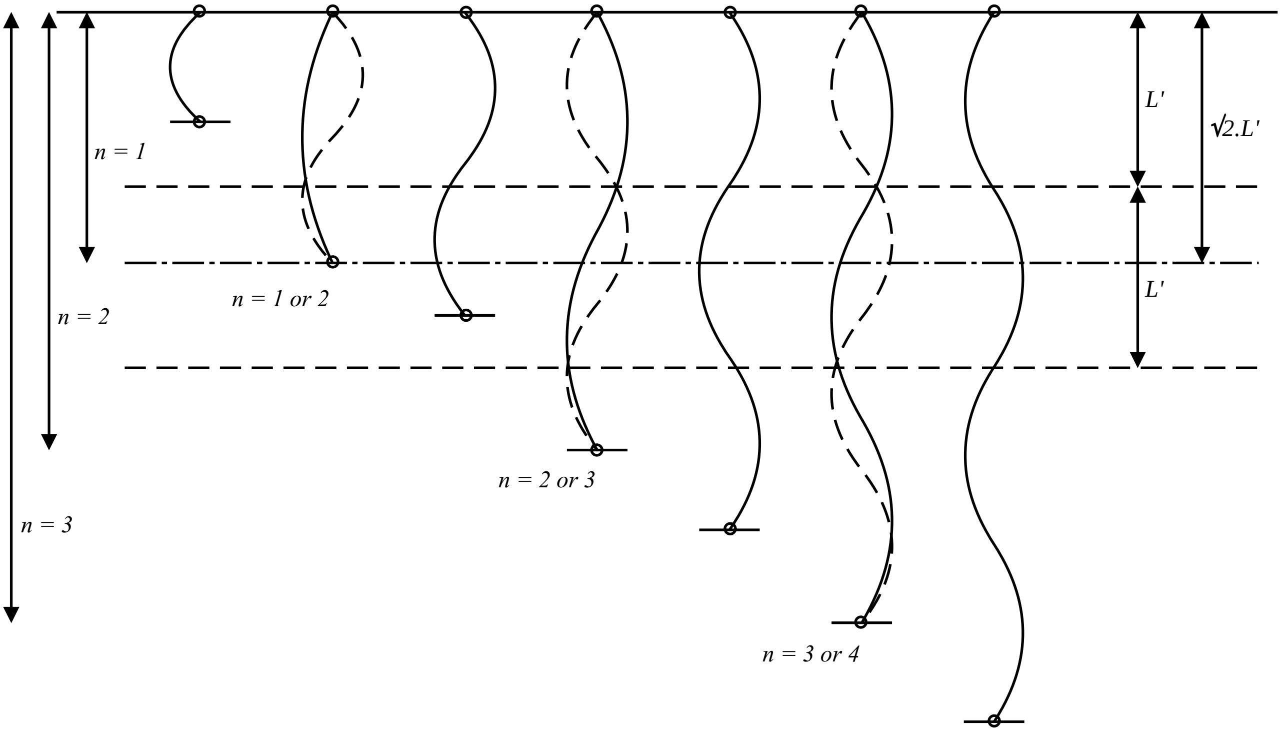


Figure C4: Buckled Form of Piles of Various Depths in a Uniform Medium (after Francis et al 1962)

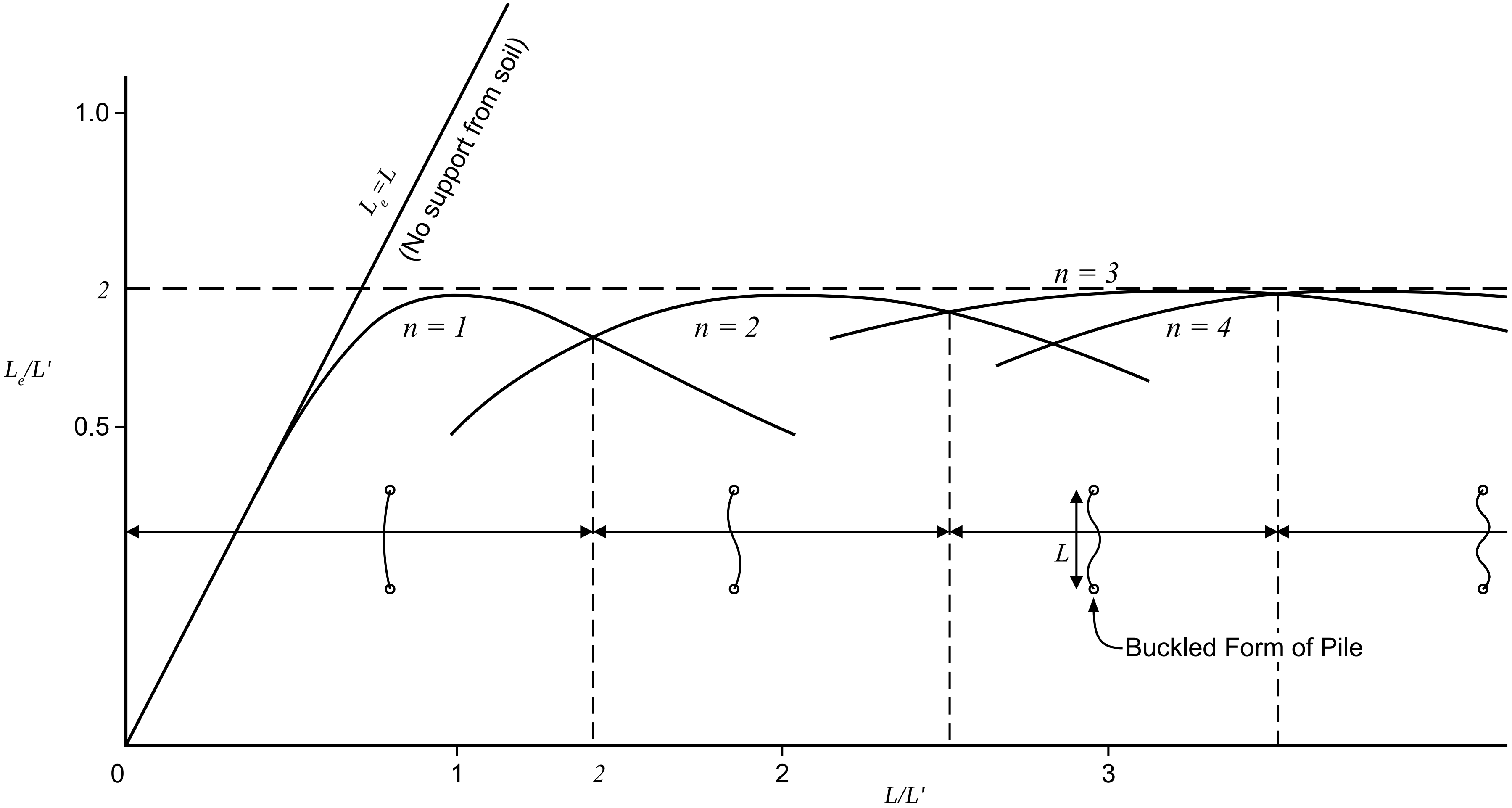


Figure C5: Graph of L_e / L′ and L/ L′ for Pin-Ended Pile in Uniform Soil (after Francis et al 1962)

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C9 Minimum Reinforcement Requirements

C9.1 Where the application of this Annex, including Section C12, does not lead to a requirement for pile reinforcement, there is no need to comply with the minimum reinforcements requirement in this Section. Where reinforcement is required to comply with Sections C4, C6, C7 and C8 it shall not be less than the minimum areas stated below, or less than the reinforcement areas that might be required to comply with Section C12.

C9.2 Longitudinal Reinforcement

C9.2.1 Where reinforcement is required to resist bending or axial tension forces, the area of reinforcement spaced evenly around the perimeter of the pile shall be not less than 0.3% of the cross sectioned area of the pile, $\pi b^2/4$

where b is the pile diameter

C9.2.2 Where reinforcement is required to resist axial compression forces or where the effects of buckling need to be considered the greater of the following areas of reinforcement shall be provided:

i) Minimum of 0.3% of the cross sectional area of the pile

ii) Minimum of 6 No bars spaced evenly around the perimeter subject to a maximum spacing of 300mm.

Minimum bar size, shall be 12mm diameter.

iii) Not less than $0.15N/f_y$, where N is the ultimate axial load acting on the pile and f_y is the characteristic strength of the longitudinal reinforcement.

C9.3 Transverse Reinforcement (Links)

The provision of nominal transverse reinforcement is required to resist buckling, to comply with shear requirements as stated in Section C6.1 or to ensure a rigid reinforcement cage for handling and installation purposes.

C9.3.1 Where reinforcement is required to resist axial compression forces or where the effects of buckling need to be considered the following minimum area of transverse (link) reinforcement shall be provided.

Links shall be at least one-quarter the size of the largest longitudinal bar at the section under consideration.

Spacing of links shall be no greater than 12 times the size of the smallest longitudinal bar at the section under consideration.

C9.3.2 Where reinforcement is required to resist shear forces the area of reinforcement shall satisfy the following equation:

$$A_{sv} \geq \frac{0.4bS_v}{0.87f_{yv}}$$

where:

A_{sv} is the cross sectioned area of all the legs of the links at a particular cross section.

b is the pile diameter

S_v is the link spacing

f_{yv} is the characteristic strength of link reinforcement

C9.3.3 For handling and installation purposes only, in order to contain longitudinal reinforcement, the requirements of Clause 9.3.1 may be relaxed provided that the transverse reinforcement specified is of a suitable size and spacing to ensure the cage remains rigid during handling and installation.

C10 Curtailment of Reinforcement

C10.1 Longitudinal Reinforcement

Longitudinal reinforcement may be curtailed to suit the applied bending moments, axial and shear forces acting on the pile.

Gradual curtailment of reinforcement is to be considered to discourage horizontal cracking at the point of sudden curtailment of all longitudinal steel. For gradual curtailment the following aspects should be considered:

- Depending on the way in which reinforcement is curtailed, the orientation of the cage may be significant;

- In the case of piles where reinforcement is pushed into the pile after placing the concrete, the rigidity of the curtailed steel cage shall be designed to ensure that handling and installation is not affected. (See Section C12)

Sudden curtailment of reinforcement can be accepted provided that the pile is checked at the point of curtailment to ensure it is adequate in its cracked state.

C10.2 Transverse Reinforcement

Transverse reinforcement (links) may be curtailed to suit the applied shear forces acting on the pile, in accordance with the requirements of Section C6 and C12.

C11 Corrosion and Durability/Control of Crack Widths (SLS)

C11.1 For the general case of a fully embedded pile in non aggressive ground as defined in BD42 (DMRB 2.1.2), ready access to oxygen is restricted to a distance of one metre below the surface of the naturally occurring ground surrounding the pile. Corrosion action on reinforcement within the pile below this point is likely to be initially slow and, once started, quickly stopped by the deposition of solids. However, if the natural ground at depth below 1 metre is loose granular material with brakish or saline groundwater, the requirements for the first metre shall be applied over this type of ground.

C11.2 Protection of reinforcement in piles from corrosion under all conditions is best achieved by good initial site investigation and the provision of dense durable concrete in accordance with Sections C2 and C3.

C11.3 Control of crack widths has little effect on the corrosion of reinforcement. The control of crack widths in accordance with the requirements of Clause 5.8.8.2 of BS 5400: Part 4: 1990 as implemented by BD 24 (DMRB 1.3.1) shall be restricted to any section of a pile that is within 1 metre of the naturally occurring ground surface. The cover for the purposes of this calculation shall be as stated in Section C3 ignoring the additional requirements of BS 8004.

C11.4 Heavy corrosion can occur when one or more of the following is present:

- rapid flow of oxygen or carbon dioxide rich groundwater
- highly acidic groundwater
- heavy carbonation of the concrete

Where aggressive environments are identified crack widths shall be controlled in accordance with the requirements of Clause 5.8.8.2 of BS5400:Part 4:1990 as implemented by BD24 (DRMB 1.3.1) over the length of pile surrounded by ground classified as aggressive or very aggressive in accordance with BD42 (DMRB 2.1.2). In addition to the specification of concrete resistant to carbonation attack, a protective cover to the reinforcement or protection with a sleeve of a non corrosive or sacrificial material may be considered.

C11.5 The effects of sulphate resisting cement and Thaumasite action should be considered by reference to the following documents:

BRE Digest 363: 1991: Sulfate and acid resistance in the ground.

DETR (1999) The thaumasite form of sulphate attack: Risks, diagnosis, remedial works and guidance on new construction. Report of the Thaumasite Expert Group. January 1999. The Stationery Office.

C12 Construction Considerations Affecting Design

C12.1 Whatever design requirement there may be for reinforcement it shall be increased if necessary to ensure a rigid cage for handling and installation purposes to suit the proposed method of construction.

C12.2 Consideration shall be given to events that may arise on site during installation of the piles, and all subsequent construction operations that could result in the piles being subjected to load effects that are more onerous than design load effects already considered in the foregoing sections. This is of particular importance where no reinforcement is required to meet the other requirements of this Annex. The following list, which is not intended to be exhaustive, details considerations that could result in a decision to specify or to increase the quantity of reinforcement required to ensure the piles remain serviceable.

- Piles subject to accidental impact from construction equipment.
- Piles subject to construction operations, for example breaking down of pile heads.
- Piles subject to load testing, static or dynamic.
- Piles subject to lateral loading from:

  i) differences in ground levels due to excavation/surcharging of adjacent areas before propping is effective.

  ii) passage of construction traffic within influencing distance of the piles.

  iii) variance between the construction sequence implemented and that assumed.

C13. References

Glick G W (1948) "Influence of soft ground on the design of long piles." Proc 2nd Int Conf Soil Mechanics, Rotterdam, Vol 4 pp84 – 88.

TRL Report 144 (1995) "Design of reinforcement in piles" J P Tyson, Transport Research Laboratory, Crowthorne, Berkshire.