Design Manual for Roads and Bridges

Highway Structures & Bridges
Inspection & Assessment

CS 459
The assessment of bridge substructures, retaining structures and buried structures

(formerly BA 55/06)

Revision 1

Summary
The use of this document enables the safety and serviceability of bridge substructures, retaining structures and buried structures to be assessed, providing key information that is required to manage risks and maintain a safe and operational network. This document covers the assessment of existing structures affected by interaction with the ground or affected by earth pressures.

Application by Overseeing Organisations
Any specific requirements for Overseeing Organisations alternative or supplementary to those given in this document are given in National Application Annexes to this document.

Feedback and Enquiries
Users of this document are encouraged to raise any enquiries and/or provide feedback on the content and usage of this document to the dedicated Highways England team. The email address for all enquiries and feedback is: Standards_Enquiries@highwaysengland.co.uk

This is a controlled document.

Contents

Release notes

Version	Date	Details of amendments
1	Mar 2020	Revision 1 (March 2020) Update to references only. Revision 0 (May 2019) CS 459 replaces BA 55/06. This full document has been re-written to make it compliant with the new Highways England drafting rules.The key technical themes of the update are as follows:1) Some content relevant to assessment has been moved from previous documents BD21, BA16, BA42, BA87, and BA88.2) BA55 previously referred extensively to design documents, including BD30, BD31, BD42 and BD74, that have now been withdrawn and replaced by Eurocodes and Eurocode-aligned documents. There has therefore been a need to include and refer to Eurocode content in this document, including a new option to use a Eurocode-based approach for the basis of assessment. 3) Some content that is no longer needed has been removed, including models for dispersal of BD21 loads that were specific to the old loading arrangements. In the updated version the approaches for dispersal and traffic surcharge can be applied for any traffic loading model.

Foreword

Publishing information

This document is published by Highways England.

This document supersedes BA 55/06, which is withdrawn.

This document contains revision to material relevant to assessment taken from previously withdrawn documents BD 30, BD 31, BD 42 and BD 74.

Material previously covered in BD 21, BA 16, BA 42, BA 87 and BA 88 related to the assessment of substructures has also been incorporated into this revision.

Contractual and legal considerations

This document forms part of the works specification. It does not purport to include all the necessary provisions of a contract. Users are responsible for applying all appropriate documents applicable to their contract.

Introduction

Background

The use of this document enables the safety and serviceability of bridge substructures, retaining structures and buried structures to be assessed, providing key information that is required to manage risks and maintain a safe and operational network.

This document covers the assessment of existing structures affected by interaction with the ground or affected by earth pressures. The development of this document has been influenced by the changes to the standards that are used for the design of new structures, particularly the introduction of the Eurocodes, which enabled a unified limit state approach to be taken for the design of both structures and geotechnics for the first time in the UK.

Assessment of existing structures affected by interaction with the ground was previously undertaken using a combination of British Standards BS 8002 [Ref 4.N], BS 8004 [Ref 5.N], BS 8081 [Ref 2.N], ISE CP2 1951 [Ref 7.I], and DMRB documents BD 30/87, BD 31/01, BD 42/00, and BD 74/00, following the advice in BA 55/06. However, with the implementation of the Eurocodes all conflicting national standards were withdrawn, including many of the standards and documents that had been used for the assessment of geotechnical structures. British Standards BS 8002 [Ref 4.N], BS 8004 [Ref 5.N] and BS 8081 [Ref 2.N] were revised to be fully compatible with Eurocodes and limit state principles.

This document is based on an updating of BA 55/06, and includes the same phased approach of allowing a qualitative assessment to be used, with an assessment by calculation carried out following the qualitative assessment only when required.

It has been necessary in this document to allow two different approaches to be used for the assessment by calculation: one approach is based on the use of CS 454 [Ref 1.N], the second approach is based on the use of Eurocodes. This document includes an option to use Eurocodes because the standardised methods for verifying geotechnical ultimate limit states are now found in the Eurocodes and Eurocode-aligned documents. However, the verification of structural ultimate limit states can be carried out using CS 454 [Ref 1.N], which can be more convenient to apply for assessment. Conversely, as many of the partial factors in the Eurocodes are lower than in CS 454 [Ref 1.N], it can be more economic to use the Eurocode-based approach. Hence both options have been included in this document.

Assumptions made in the preparation of the document

The assumptions made in GG 101 [Ref 15.N] apply to this document.

Abbreviations

Abbreviations

Abbreviation	Definition
AIP	Approval in Principle
ALL	Assessment Live Loading
BRE	Building Research Establishment
CIRIA	Construction Industry Research and Information Association
CSBS	Corrugated Steel Buried Structure
EQU	Equilibrium ultimate limit state
GEO	Geotechnical ultimate limit state
PD	Published Document
TRL	Transport Research Laboratory
SCI	Steel Construction Institute
SLS	Serviceability Limit State
STR	Structural ultimate limit state
ULS	Ultimate Limit State
2D	Two Dimensional

Symbols

Symbols

Symbol	Definition
c_u	Undrained shear strength
DAF	Dynamic Amplification Factor as defined in CS 458 [Ref 23.N]
DAF_{red}	Reduced Dynamic Amplification Factor
d_d	Design thermal movement of the end of a bridge deck
d_k	Characteristic thermal movement of the end of a bridge deck as defined in PD 6694-1 [Ref 20.N]
F	Impact Factor as defined in CS 454 [Ref 1.N]
F_{red}	Reduced Impact Factor
H	Height difference between the application of the wheel load and the base of the wall
H_c	Depth of earth cover between ground level and the top surface of the roof of a buried structure
K_a	Coefficient of active earth pressure
$K_{\max}$	Coefficient of earth pressure applied to buried structures which takes account of pressure increases caused by expansion of the structure
$K_{\min}$	Coefficient of minimum earth pressure applied when earth pressure is favourable
K_0	Coefficient of earth pressure at rest
K_p	Coefficient of passive earth pressure
K_r	Coefficient of earth pressure resisting overturning or sliding
L_J	Length of precast segmental unit or distance between joints in a buried structure
L_L	Overall longitudinal length of a buried structure
L_T	Overall transverse length of a buried structure
p_y	Yield stress of the soil
$R1, R2$	Resistances underneath the bases of portal frame structures
X_{clear}	Clear span in a buried structure
γ_{fL}	Partial factor for load as defined in CS 454 [Ref 1.N]
γ_F	Partial factor on actions as defined in BS EN 1990 [Ref 12.N]
ϕ'	Effective angle of shearing resistance
σ'_v	Effective vertical stress

Terms and definitions

Terms

Term	Definition
Abutment	End wall or structure to which horizontal earth pressure loads are applied.
Assessment	The process of determining in terms of vehicle loading the load that an existing structure can carry with an acceptable probability without suffering serious damage that can endanger any persons on or near the structure.
Assessment actions	Actions, which can be either imposed loads or imposed displacements, which have been determined for assessment.
Assessment properties	Properties of soils, rock and other materials which have been derived for assessment.
Assessment situation	Assessment situations are sets of physical conditions representing the real conditions occurring during a certain time interval for which the assessment demonstrates that relevant limit states are not exceeded. NOTE: Assessment situations can consider the structure during normal use, in a temporary condition or during an accidental exceptional condition.
Cover	Depth of fill between ground level and the top of a structure.
Embedded retaining wall	Retaining structure, the main stability of which is provided by having a significant length of wall stem embedded in the ground. NOTE: Embedded retaining walls can be cantilevered, propped at either the top or at excavation level, doubly-propped or anchored.
Ground level	Finished carriageway level, or the temporary ground level on which traffic can run during construction.
Hard-soft piling system	A hard/soft secant pile wall consists of overlapping piles. NOTE 1: The primary piles are cast first and consist of a soft pile mix, typically cement and bentonite, or cement, bentonite and sand with a characteristic compressive strength of 1 to 3N/mm^2. NOTE 2: The soft piles are unreinforced.
Longitudinal	Perpendicular to the abutments, or in the direction of traffic.

Terms (continued)

Term	Definition
Substructure	Part of the structure that supports the superstructure, and includes: 1) abutments; 2) wing walls; 3) cantilevered wing walls; 4) skeletal abutments. Bridge sub-structures include all elements of the bridge beneath the soffit of the deck, including: 1) bearings; 2) bank seats; 3) abutments; 4) wing walls; 5) piles; 6) foundations. The sub-structure for arches includes: 1) the foundations; 1) the springings; 2) elements beneath the ground.
Superstructure	Section of the structure over which traffic can pass (i.e. the bridge deck).
Traction	Longitudinal traffic actions arising from braking and acceleration of vehicles.
Transverse	Parallel to the abutment walls, or perpendicular to the direction of traffic.

1. Scope

Aspects covered

1.1 This document shall be used for the assessment of bridge substructures (including bearings, bank seats, abutments, wing walls, piles and foundations), retaining structures and buried structures.

NOTE 1 This document does not deal with the structural aspects of bridge decks, bridge piers and arches, but it does cover assessment of their foundations.

NOTE 2 This document includes methods for the assessment of structures and structural elements where their behaviour is directly influenced by soil-structure interaction or affected by earth pressures.

NOTE 3 In general, the behaviour of substructures is more complex than that of superstructures. Actions applied to superstructures are largely unaffected by the resulting deformations and movements, whereas earth pressures at soil / structure interfaces can be influenced by the movement of the structure.

NOTE 4 This document includes specific requirements for the assessment of the following types of structure:

1) *spread and piled foundations;*
2) *gravity retaining structures and non-integral bridge abutments;*
3) *embedded retaining walls;*
4) *integral bridge abutments;*
5) *buried concrete boxes and portal frame structures;*
6) *corrugated-steel buried structures;*
7) *reinforced soil structures;*
8) *dry-stone walls;*
9) *spandrel walls.*

1.1.1 This document may be used for the assessment of associated ancillary structures.

1.2 The assessment of bridge superstructures, including arches, shall be carried out using CS 454 [Ref 1.N].

Implementation

1.3 This document shall be implemented forthwith on all schemes involving the assessment of bridge substructures, retaining structures and buried structures on the Overseeing Organisations' motorway and all-purpose trunk roads according to the implementation requirements of GG 101 [Ref 15.N].

Use of GG 101

1.4 The requirements contained in GG 101 [Ref 15.N] shall be followed in respect of activities covered by the document.

2. Assessment processes

2.1 The assessment shall be carried out according to the requirements for assessment processes given in CS 454 [Ref 1.N], supplemented by the additional requirements in this section.

NOTE The assessment processes in CS 454 [Ref 1.N] include:

1) *structural review;*
2) *inspection for assessment;*
3) *assessment;*
4) *reporting of the assessment;*
5) *management of substandard structures.*

Inspection for assessment

2.2 The inspection for assessment shall include the identification and recording of any evidence of defects or movements, including:

1) tilting and rotation, in any direction;
2) rocking;
3) cracking, splitting and spalling;
4) reinforcement corrosion;
5) internal degradation of concrete;
6) locked bearings;
7) damage due to thermal movement;
8) scour and erosion beneath the water level;
9) weathering and other material deterioration, including loss, cracking and lack of pointing for masonry and brickwork;
10) detrimental growth of vegetation, on and near the structure;
11) ineffective drainage;
12) washout and leaching of the fill;
13) settlement of the fill;
14) settlement of the structure, including global and differential movements;
15) ground slope instabilities, in front of and behind the structure;
16) evidence of vehicular impact.

NOTE 1 These requirements supplement those given in CS 454 [Ref 1.N].

NOTE 2 Principal deficiencies in the substructure can be manifested in the form of excessive movement of the structure (tilting, sliding, etc.) or of part of it (bulging, differential settlement, etc.) and problems arising from water seepage.

NOTE 3 Movement of the structure at the soil/structure interface can result from earth pressure changes in the backfill pressure due to the forward rotation of a retaining wall on its base or soil reaction pressures on an integral-bridge end support due to temperature generated expansion and contraction of the supported bridge deck.

NOTE 4 Inspection and maintenance records can sometimes provide useful information regarding hidden or inaccessible parts of the structure.

2.2.1 Inspections should include both:

1) close inspection methods;
2) inspection from a distance.

NOTE 1 Structural defects leading to excessive movement or misalignment can be overlooked during close inspection but can be apparent from a distance.

NOTE 2 Sighting along restraint systems, handrails, string courses or other features can be used to detect misalignment.

Defects and structure stability

2.3 The inspection and maintenance records shall be examined for evidence of historical and ongoing stability problems with the structure.

2.4 Signs of failure in the structure (including signs of distress, damage, deterioration or partial/localised collapse) and movement in the surrounding ground shall be investigated.

NOTE 1 Evidence of foundation deterioration or failure can be manifested as tilting, distortion or cracking of elements in other parts of a structure; for example excessive movement at joints between the deck and abutments.

NOTE 2 Differential movement of a substructure can be easier to detect than the overall movement of a whole pier or abutment.

NOTE 3 Due to the hidden or sometimes obscured location of these structures, the warning signs of failure might not be readily visible during a structural inspection.

NOTE 4 In arch bridge foundations, movement or arch spreading is generally apparent from cracks showing distress in the arch rings and spandrels; diagonal cracking of the arch can be indicative of differential settlement of the foundations.

NOTE 5 Gross deformations in culverts and buried structures can be evident from instability in the adjacent embankment or overlying highway.

2.5 Signs of damage to the structure that are due to aggressive ground conditions shall be recorded.

NOTE 1 Further guidance is found in BRE SD-1 2005 [Ref 20.I], which includes information on the assessment of the surrounding ground, backfill, groundwater and effluent carried by the structure.

NOTE 2 Argillaceous rocks such as shale and mudstone could increase earth pressures on retaining walls by swelling. They might also release sulphuric acid, putting adjacent concrete structures at serious risk, and could contribute to the blocking of drainage materials by the formation of crystalline sulphates.

2.5.1 Adjacent structures and buried services in the vicinity should be examined for signs of instability and distress where this could assist in the assessment process and understanding of the performance of the structure.

2.6 Where the movement (or the continuing movement) of a structure presents an immediate risk, the cause of the instability shall be investigated and the structure managed as an immediate risk structure in accordance with CS 470 [Ref 17.N].

2.6.1 Where a remedial solution is used to stabilise a structure, an instrumentation and monitoring regime should be implemented to monitor further movement and demonstrate the performance of the solution.

NOTE The need for instrumentation can depend on the type of remedial solution. In some cases monitoring without instrumentation can be appropriate.

2.6.2 Where an instrumentation and monitoring regime is used, the monitoring system should allow for trends in behaviour to be monitored and the results compared with well defined trigger points in a timely manner so that contingency actions can be implemented prior to a critical condition of instability and risk to safety occurring.

NOTE 1 Simple visual aids such as tell-tales can be useful to determine if the structure is moving or in a temporary equilibrium.

NOTE 2 Guidance for the geotechnical monitoring of structures is provided in BS EN 1997-1 [Ref 11.N] and CIRIA C760 [Ref 14.N].

NOTE 3 A description of available methods for the remote monitoring of highways structures for the purposes of providing information to assist the management of these structures can be found in TRL PPR 197 [Ref 10.I].

Materials, geometry and loads

2.7 Where the material types used in the construction and filling of the substructure are needed for the assessment, they shall be established through investigation.

NOTE Estimation of the material properties for assessment is covered in Section 5.

2.8 Loads due to excessive fill, previous strengthening operations and installation of services shall be identified and recorded.

2.8.1 Where practical, dimensional checks should be undertaken prior to assessment.

NOTE 1 Dimensional checks can be used to prepare sketches for analysis, estimate permanent loads and confirm the as-built information.

NOTE 2 Excavation or probing can be used to determine the depth and the extent of the sub-structure and foundations.

2.9 Excavation or probing shall not adversely affect the stability of the structure or damage any underground services.

2.9.1 Excavations and sampling should not be undertaken in the case of dry-stone walls.

2.10 Where there is a significant change in the actions on the structure or the structure is being altered, the extent of the foundation shall be determined, unless it can be demonstrated that knowledge of the exact foundation extent is not critical to the assessment.

NOTE A study of realistic ranges of foundation geometries can be used to demonstrate whether the results of the assessment are sensitive to the assumed geometry.

2.11 Where estimates and assumptions regarding the probable dimensions of the sub-structure, foundations or retaining wall are made, those estimates and assumptions shall be recorded.

Scour

2.12 Where an inspection for assessment of a structure founded in water is required, underwater inspection techniques shall be used to confirm the condition and identify defects, including scour.

NOTE 1 Flow of water can cause leaching and scour to foundations and sub-structures.

NOTE 2 Requirements for the assessment of scour and other hydraulic actions at highway structures crossing or adjacent to waterways are included in BD 97 [Ref 22.I]. Further information can be found in CIRIA R742 [Ref 16.I].

NOTE 3 The depth of scour holes which can occur during a flood are generally greater than those observed during periods of slack water. Evidence of the natural refilling of scour holes is sometimes apparent if material of a coarser or differing nature is present within the scour zone.

NOTE 4 Many arch bridges were built on shallow foundations and are vulnerable to scour.

2.13 Where information regarding the underwater parts of the structure, its foundations or the riverbed is needed for the assessment or for monitoring of deterioration, underwater photography or imaging shall be used.

NOTE Underwater photography or imaging is of particular assistance to the engineer in establishing conditions below water level. It also serves as a permanent record of the condition at the time of the inspection and can be subsequently referred to and quoted during the assessment process.

2.14 Unexpected water flows shall be investigated, to determine the cause and any resultant deterioration.

Bearings

2.15 The presence or absence of bearings shall be recorded.

2.16 Bearings shall be inspected to obtain information on the following:

1) general condition;
2) binding or jamming;
3) looseness;
4) reaching the limit of rotational or translational movement;
5) condition of seating, bedding and plinth;
6) obstacles preventing correct operation of the bearings.

NOTE Thermal movements in response to temperature changes can be assessed in accordance with CS 454 [Ref 1.N].

2.16.1 Where no bearings exist or their efficiency is impaired, the ability of a bridge to cater for thermal movements and forces should be assessed.

NOTE 1 In many early bridges, bearings were either omitted or only rudimentary forms of bearing were provided.

NOTE 2 In bridges without bearings or where the bearings have failed to function correctly, there can be local crushing or cracking of the supports, especially where they are constructed from stone or brickwork.

Assessment

2.17 The scope of the assessment, including the limit states to be assessed, shall be defined in the AIP in accordance with CG 300 [Ref 21.N].

2.18 The assessment shall verify whether or not the structure or substructure has sufficient resistance for its intended use.

2.19 The significance of defects, stability problems, the likely cause and the effect on the sub-structure resistance shall be evaluated and recorded.

2.20 The assessment shall be based on limit state verifications.

2.20.1 Limit states may include:

1) STR, for example, ULS verification of bending or shear resistance;
2) GEO, for example, ULS verification of sliding, bearing, deep-slip and rotational failures;
3) EQU, for example, ULS verification of overturning;
4) SLS, for example, settlement or crack widths.

2.20.2 The assessment should progress through successive levels of assessment, if needed to demonstrate the adequacy of the structure or parts of the structure, as follows:

1) qualitative assessment;
2) assessment by calculation;
3) assessment by calculation with updated material parameters or refined analysis models.

2.20.3 The adequacy of the structure may be demonstrated by:

1) applying the same assessment level to the entire structure;
2) applying different assessment levels to parts of the structure.

2.21 A structure, or parts of the structure, whose adequacy has not been demonstrated by a qualitative assessment or assessment by calculation shall be managed as a substandard structure in accordance with CS 470 [Ref 17.N].

2.21.1 When a superstructure is to be strengthened or replaced, the adequacy of the existing substructure and foundations may be verified based on:

1) a qualitative assessment according to this document; or
2) calculations using the standards for new design.

Qualitative assessment

2.22 The qualitative assessment shall include an assessment of the following:

1) the condition of the structure, including the extent and severity of defects;
2) the satisfactory past performance in service;
3) whether the behaviour of the structure can be readily understood;
4) anticipated changes in condition, loading or the structural form.

2.22.1 The qualitative assessment of the structure or part of the structure should be taken as satisfactory and no further assessment is necessary if all of the following apply:

1) there are no signs of significant or worsening distress, damage or deterioration;
2) there is no evidence of scour;
3) satisfactory performance has been demonstrated since construction or significant repairs or alteration, over a sufficiently long period of time to assess the performance in service;
4) the behaviour of the structure can readily be understood;
5) there are no anticipated modifications to the structure or changes in use.

NOTE Qualitatively assessing satisfactory performance of a structure or part of a structure in service relies upon the structure having experienced loading conditions that are representative of those that can be anticipated over its remaining life, which is more readily justifiable for parts of a structure that experience predominantly permanent loading than those significantly affected by traffic loading.

2.22.2 The qualitative assessment should be based on an assessment of the performance over a time period of at least five years, or a shorter period of time where it can be justified that this is sufficient to understand and assess the performance of the structure in service.

2.22.3 A qualitative assessment may be used to demonstrate the adequacy for changes in the loading where both of the following apply:

1) there is no net increase in the total action effects;
2) there is no significant reduction in permanent vertical actions that could affect the stability.

2.22.4 Results of previous inspections and assessments should be used to inform the assessment.

2.22.5 Assessment of ground movements should be based upon relevant field data and from experience of similar structures in similar ground conditions.

2.22.6 A bearing may be assessed to be satisfactory if:

1) its seating shows no sign of distress;
2) movements including rotations are free to take place;
3) there is no significant increase in loading envisaged;
4) there are no signs of significant or worsening distress, damage or deterioration in the bearing and the structure within the vicinity of the bearing.

Assessment by calculation

2.23 Assessment by calculation shall be undertaken following a qualitative assessment when:

1) the qualitative assessment has not successfully demonstrated adequacy for the structure or part of the structure at the relevant limit states; and

2) there is an established method of quantitative theoretical assessment available.

NOTE *Assessment by calculation is covered in Section 3.*

2.24 The conclusions from the assessment shall be subjected to a plausibility review, to explain differences between the results of the assessment and the observed condition or performance.

Reporting of the assessment

2.25 The assessment shall be documented in a report summarising the assumptions and methodology of the assessment, the conclusion of the assessment and recommendations for management interventions.

NOTE *Requirements for reporting assessments are provided in CS 451 [Ref 21.I].*

2.25.1 Where the assessment process has included the development of remedial works, for example where rudimentary maintenance would be sufficient to restore the structure to a state that would be no longer be substandard, the assessment report should include the details of the proposed remedial works.

Management of substandard structures

2.26 In cases where the final conclusion of the assessment process is that a structure is substandard the structure shall be managed in accordance with CS 470 [Ref 17.N].

NOTE *Movements or rotations can occur early in the life of the structure and subsequently reach a state of equilibrium that is no longer a cause for concern.*

2.26.1 The observational method may be used to monitor, control or manage movements.

NOTE *Principles and application of the observational method can be found in BS EN 1997-1 [Ref 11.N], CIRIA R185 [Ref 25.I], CIRIA C760 [Ref 14.N] and TRL Report TRL 228 [Ref 17.I].*

3. Assessment by calculation

Basis of assessment

Scope and methodology

3.1 Where an assessment by calculation is necessary, the scope and methodology for the assessment shall be agreed with the Overseeing Organisation and recorded.

3.1.1 The scope and methodology for the assessment should include the following:

1) assessment actions, comprising imposed loads and imposed displacements;
2) assessment properties of soils, rocks and other materials;
3) geometrical data;
4) analysis of the structure and the soil at the relevant limit states for assessment;
5) verifications at the relevant limit states for assessment.

3.1.2 The assessment situations and limit states to be assessed by calculation may be recorded in:

1) the AIP; or
2) the assessment certificate (for example for CAT 0 structures without an AIP).

NOTE Section 4 includes requirements for assessing specific structure types, additional to the requirements of this section.

Assessment situations and limit states

3.2 The assessment situations and limit states to be assessed by calculation shall be agreed with the Overseeing Organisation and recorded.

NOTE 1 Guidance on factors to be included in defining design situations and limit states is included in BS EN 1997-1 [Ref 11.N], which can be used in defining the assessment situations and limit states.

NOTE 2 Limit states can include STR, GEO, EQU and SLS, as covered in Section 2.

3.2.1 The assessment situations and limit states to be assessed by calculation may be recorded in:

1) the AIP; or
2) the assessment certificate (for example for CAT 0 structures without an AIP).

3.2.2 The limit states to be included in the assessment by calculation for the structure or part of the structure should be defined based on the findings of the qualitative assessment for the structure or part of the structure.

3.2.3 Verifications of limit states that have already been satisfied using qualitative assessment for the structure or the part of a structure should be omitted from the assessment by calculation for the structure or the part of the structure.

NOTE Verification at the GEO and EQU limit states can often be satisfied qualitatively and omitted from the assessment by calculation, for example where there is no evidence of settlement, tilting or sliding, and where the structure is not being modified.

3.2.4 Verifications of serviceability limit states should not be included in the assessment by calculation unless required in Section 4 or agreed with the Overseeing Organisation.

NOTE Serviceability criteria can be assessed using qualitative assessment or monitoring.

3.3 Assessment situations shall consider both short term and long term conditions.

Options for basis of assessment

3.4 The assessment by calculation for the structure or part of the structure shall be carried out using one of the two options for basis of assessment set out in Table 3.4a, depending on the limit state being assessed, as follows:

1) Option 1;
2) Option 2 (Eurocodes).

Table 3.4a Options for basis of assessment

	Option 1	**Option 2 (Eurocodes)**
Possible limit states	STR, SLS	STR, GEO, EQU, SLS
Actions	As defined in CS 454 [Ref 1.N]	See Table 3.4b
Combinations of actions	As defined in CS 454 [Ref 1.N]	As defined in BS EN 1990 [Ref 12.N]
Partial factors on actions	As defined in CS 454 [Ref 1.N]	See Table 3.4b
Partial factors on geotechnical material parameters	1.0	As defined in BS EN 1997-1 [Ref 11.N] for the limit state[1]
Resistance	As defined in CS 454 [Ref 1.N]and the related assessment documents.	As defined in BS EN 1997-1 [Ref 11.N], BS EN 1990 [Ref 12.N] and PD 6694-1 [Ref 20.N] for GEO, EQU, SLS. As defined in CS 454 [Ref 1.N] and the related assessment documents, or using the relevant Eurocode documents for STR.
Application of γ_{f3}	As defined in CS 454 [Ref 1.N]	$\gamma_{f3} = 1.0$ [2]
Note 1: In BS EN 1997-1 [Ref 11.N] Design Approach 1, partial factors are applied to actions and to ground strength parameters in two combinations, denoted Combination 1 and Combination 2, which are used for STR and GEO limit states. Combination 2 has lower partial factors on actions, but applies partial factors to geotechnical parameters that can result in higher effects of geotechnical actions. Further guidance is provided in PD 6694-1 [Ref 20.N] Note 2: When using Option 2 (Eurocodes) there is no γ_{f3} applied to the effects of actions (and the effect of γ_{f3} has already been included in the calibration of the partial factors on actions as set out in Table 3.4b). However, if CS 456 [Ref 24.N] is used to assess resistance using Option 2 (Eurocodes) then γ_{f3} does appear in the formulae for resistance, and setting γ_{f3} to unity avoids the effect of γ_{f3} being double-counted.		

Table 3.4b Partial factors on actions for Option 2 (Eurocodes)

Actions	Load model	Limit states			
		STR,GEO		EQU	SLS
		Design Approach 1[1] Combination 1	Design Approach 1[1] Combination 2		
Normal and restricted traffic (including traffic surcharge effects)	As defined in CS 454 [Ref 1.N]	1.65	1.41	1.65	1.2
Abnormal traffic and accompanying normal traffic (including traffic surcharge effects)	As defined in CS 458 [Ref 23.N] but without the overload factor applied[2]	1.35	1.15	1.35	1.0
Other actions	As defined in the relevant parts of BS EN 1991 [Ref 13.N]	As defined in BS EN 1990 [Ref 12.N][3]	As defined in BS EN 1990 [Ref 12.N][3]	As defined in BS EN 1990 [Ref 12.N] [4]	1.0

Note 1: In BS EN 1997-1 [Ref 11.N] Design Approach 1, partial factors are applied to actions and to ground strength parameters in two combinations, denoted Combination 1 and Combination 2. Combination 1 and Combination 2 can be critical for different aspects of the same assessment.
Note 2: The effect of the overload factor is already accounted for in the values of the partial factors.
Note 3: The set of partial factors to be used from BS EN 1990 [Ref 12.N] for Combination 1 or Combination 2 is defined in BS EN 1997-1 [Ref 11.N] Design Approach 1. Further guidance is provided in PD 6694-1 [Ref 20.N].
Note 4: The set of partial factors to be used for the EQU limit state is defined in BS EN 1990 [Ref 12.N].

NOTE *The use of Eurocodes for the design of highway structures is covered in CD 350 [Ref 23.I] which also includes requirements and advice regarding the use of Eurocodes for assessment.*

3.4.1 Either Option 1 or Option 2 in Table 3.4a may be used for the assessment of the STR limit state.

NOTE 1 *It can be more convenient to apply Option 1, for example, when assessing abutments or wing walls of a bridge that is being assessed using CS 454 [Ref 1.N].*

NOTE 2 *It can be more economic to apply Option 2, for example, to benefit from lower values of partial factors.*

NOTE 3 *In CS 454 [Ref 1.N], STR is referred to as ULS.*

3.4.2 Either Option 1 or Option 2 may be used for the assessment of structural SLS verifications.

3.5 Option 1 shall not be used for any of the following:

1) assessments of embedded walls;
2) assessments at the GEO limit state;
3) assessments at the EQU limit state;
4) assessments of geotechnical SLS verifications.

3.6 Where the assessment is based on the partial factors for earth pressures in CS 454 [Ref 1.N], the additional model factor on earth pressure coefficients described in PD 6694-1 [Ref 20.N] shall not be applied.

NOTE The partial factor for horizontal earth pressure in CS 454 [Ref 1.N] is higher than the partial factor for vertical earth pressures in CS 454 [Ref 1.N]. This already accounts for the effect included in the additional model factor described in PD 6694-1 [Ref 20.N].

Ground properties and geotechnical parameters

3.7 The assessment shall be carried out based on geotechnical parameters that:

1) have been interpreted for the limit state being assessed, and
2) take account of the possible differences between the ground properties and geotechnical parameters obtained from test results and those governing the behaviour of the structure.

3.7.1 Assessment may be carried out using geotechnical parameters established or estimated from available site information or default values taken from published literature.

NOTE 1 Parameters established or estimated from available site information is likely to be more reliable and accurate than default values taken from published literature.

NOTE 2 Further information on ground properties and geotechnical parameters for assessment can be found in Section 5.

Actions

3.8 Actions for assessment shall be applied in accordance with Table 3.4a.

NOTE The traffic actions contained in CS 454 [Ref 1.N] includes the rules for the application of impact factors, transverse separation of vehicles between lanes, traffic flow factors and notional lane factors.

Analysis

3.9 The analysis model shall represent the behaviour of the structure and the ground at the relevant limit state.

NOTE The ability of structures to redistribute load can be particularly relevant in assessment. A structure that is showing local signs of movement or cracking has not necessarily exceeded an ultimate limit state, particularly for ductile structures.

3.10 The horizontal effects of traffic surcharge actions through the fill shall be based on representative analyses of the stresses in the soil.

3.10.1 When a more detailed analysis model is not used, the simplified methods in PD 6694-1 [Ref 20.N] may be used to model the horizontal effects of traffic surcharge actions on structures.

NOTE The model for traffic surcharge on wingwalls in PD 6694-1 [Ref 20.N] can be used for any wheel load arrangement and magnitude for assessment according to CS 454 [Ref 1.N] or CS 458 [Ref 23.N]. In contrast, the model in PD 6694-1 [Ref 20.N] for traffic surcharge on abutments is specific to Eurocode design load models and can result in excessive earth pressures for assessment purposes.

3.10.2 The model for traffic surcharge on wingwalls in PD 6694-1 [Ref 20.N] may be used for assessing the horizontal effects of traffic on any retaining structure, including abutments, and applied as follows:

1) draw the arrangement of wheel loads and their positions relative to the structure for the traffic load case being assessed;
2) omit wheel loads further away than $1.5H$ from the structure, where H is the height difference between the application of the wheel load and the base of the wall;
3) to simplify the calculation, group closely spaced wheels into a combined patch load, extending to the edges of the wheel group, where each patch does not exceed 2.5 m in any direction;
4) calculate the distribution of earth pressures on the wall for each patch using the model for traffic surcharge on wing walls in PD 6694-1 [Ref 20.N];
5) superpose the effects of the patches to calculate a total surcharge pressure distribution;

6) analyse the wall for the effects of the traffic surcharge.

3.10.3 The assumed width of the patch and transverse distribution of traffic surcharge through the fill for segmental structures should consider the segmentation of the structure when determining horizontal effects of traffic where there is little or no transverse strength.

Structural resistance

3.11 The assessment resistance of structural elements shall be calculated in accordance with the relevant structural assessment documents, as described in Table 3.4a.

4. Additional structure-specific assessment requirements

General

4.1 The structure-specific requirements of this section are supplementary to the general requirements and shall be applied in addition to the requirements elsewhere in this document.

NOTE *This section includes additional requirements for aspects of the assessment of specific structure types.*

4.2 Where a structure is supported on a number of individual foundations, the individual foundations shall be assessed.

4.3 Retaining structures shall be assessed for the effects of an additional minimum surcharge which is:

1) applied to the ground surface on the retained side of the structure;
2) calculated in accordance with BS 8002 [Ref 4.N];
3) not combined with traffic loading; and
4) not applied if it has a relieving effect.

Spread and piled foundations

4.4 Lateral loading of piled foundations shall be assessed where there is a likelihood of soil-induced horizontal loading being developed.

NOTE 1 *Further information of piles subject to horizontal loading is contained in PD 6694-1 [Ref 20.N].*

NOTE 2 *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 horizontal loading is high.*

NOTE 3 *Studies into the effect of lateral loading of piled foundations supporting highway structures have been carried out for Highways England, the results of which are contained in TRL Project Reports TRL PR 98 [Ref 2.I] and TRL PR 112 [Ref 12.I], and TRL Report TRL 246 [Ref 13.I].*

Assessment by calculation of spread and piled foundations

4.5 Where an assessment of spread and piled foundations is carried out by calculation, the assessment shall be based on representative models suitable for assessment of the relevant limit states and assessment situations.

4.5.1 The models, methods and recommendations contained in BS 8004 [Ref 5.N] and PD 6694-1 [Ref 20.N] should be used for the assessment of spread and piled foundations by calculation.

NOTE 1 *The revised and updated information previously contained in BD 74 is now contained in PD 6694-1 [Ref 20.N].*

NOTE 2 *Guidance on the determination of horizontal effects on piled foundations can be found in the following documents.*

1) CIRIA R103 [Ref 4.I];
2) Pile Foundation Analysis and Design PFAD [Ref 19.I];
3) TRL Contractor Report TRL CR196 [Ref 24.I]; and
4) TRL Project Report TRL PR 71 [Ref 1.I].

NOTE 3 *A procedure for the calculation of horizontal effects on piled foundations can be found in Appendix A.*

4.6 When horizontal actions due to traction and braking forces or skew effects are included in the assessment, the assessment shall include a verification of sliding of the foundation as a whole.

NOTE *Sliding can include translation and rotation. Rotational sliding can occur with skewed in-situ structures and also with eccentric traction.*

Gravity retaining structures and non-integral bridge abutments

Assessment by calculation for gravity retaining structures and non-integral bridge abutments

4.7 Where an assessment of a gravity retaining structure or a non-integral bridge abutment is carried out by calculation, the assessment shall be based on representative models, including earth pressure coefficients, suitable for assessment of the relevant limit states and assessment situations.

4.7.1 The models contained in BS 8002 [Ref 4.N] and PD 6694-1 [Ref 20.N] should be used for the assessment of gravity-retaining structures and non-integral bridge abutments by calculation.

NOTE The revised and updated information previously contained in BD 30/87 is now contained in PD 6694-1 [Ref 20.N].

Embedded retaining walls

Inspection for assessment for embedded retaining walls

4.8 Where a piling system for an embedded retaining wall includes the use of cement-bentonite piles, the inspection for assessment shall check for evidence of deterioration or failure, including seepage through the soft piles.

NOTE 1 Soft cement-bentonite piles can exhibit poor durability.

NOTE 2 Sprayed concrete facings have been used over the exposed sections of soft piles where there has been a need to enhance durability. Further details can be found in TRL Report TRL 438 [Ref 18.I]

4.9 The inspection for assessment shall include a visual check for signs of movement and distress in the following elements:

1) the prop slab (or the carriageway over it);
2) the tunnel roof and the lower prop slab (or the carriageway over it) for doubly-propped structures, such as cut-and-cover tunnels; and
3) the carriageway over the base for structures with a stabilising base.

NOTE Where there is movement, cracking can develop above the end of the base remote from the wall.

4.10 Where lateral support is provided by ground anchors, the externally accessible elements of the anchors shall be inspected.

NOTE Anchor head caps can be provided as part of the structural protection and would need to be removed to facilitate the inspection of the anchor elements.

4.10.1 Where lateral support is provided by ground anchors, testing may be used to verify the performance or the load in the ground anchors.

NOTE 1 Lift-off checks can provide an estimate of the load in ground anchors.

NOTE 2 Ground anchors can also be referred to as grouted anchors.

NOTE 3 Guidance on the testing and monitoring the service behaviour of grouted anchors is obtained in BS 8081 [Ref 2.N].

Assessment by calculation for embedded retaining walls

4.11 The assessment of embedded retaining walls by calculation shall include the assessment of the in-situ stress state, the value of the at-rest earth pressure coefficient, K_0 , and the material type, strength and stiffness.

NOTE 1 The value of K_0 can be influenced by the construction process, the flexibility of the retaining wall system, the in-service period and the depositional and erosional history of the ground.

NOTE 2 Embedded walls that are integral bridge abutments can experience higher earth pressures than K_0. The assessment of integral bridge abutments is covered within Section 4 of this document.

4.11.1 The models, methods and recommendations contained in BS 8002 [Ref 4.N] and CIRIA C760 [Ref 14.N] should be used for the assessment by calculation of embedded retaining walls.

NOTE 1 Guidance on the use of steel sheet piles or H-piles that resist vertical effects is included in SCI P335 [Ref 9.I].

NOTE 2 Guidance on the use of steel sheet piles as bridge abutments can be found in SCI P187 [Ref 3.I] although aspects of this guide are not aligned to the requirements of the Eurocodes.

4.12 The effects of over-consolidation of soil shall be included in the assessment by calculation of embedded retaining walls.

4.12.1 Assessment by calculation of embedded retaining walls in over-consolidated soils should include assessment at the serviceability limit state.

NOTE The serviceability limit state can be more onerous than the ultimate limit state for walls embedded in over-consolidated soils.

4.13 The assessment by calculation shall include an assessment of the global and local movements which have occurred following construction.

4.14 Lateral earth pressure effects due to the effects of backfill compaction and swelling in compacted cohesive materials shall be taken into account in the assessment.

NOTE Clayton et. al. Clayton, Hiedra-Cobo & Symons [Ref 14.I] and Clayton, Symons & Hiedra-Cobo [Ref 26.I], TRL Project Report TRL PR 72 [Ref 27.I] and TRL Report TRL 152 [Ref 6.I] provide guidance on the effects of swelling on earth pressures in compacted cohesive materials.

Integral bridge abutments

Inspection for assessment for integral bridge abutments

4.15 The abutments of integral bridges shall be examined for signs of cracking caused by movements resulting from the thermal expansion and contraction of the bridge deck.

NOTE 1 Bridge decks with integral abutments experience repeated movements of the abutments in and out of the backfill as the bridge superstructure expands and contracts with diurnal and seasonal temperature changes.

NOTE 2 Over a period of time cyclic movements of integral bridge abutments can cause an increase in the backfill soil stiffness and enhanced earth pressures.

Assessment by calculation for integral bridge abutments

4.16 The assessment of integral bridges shall include an assessment by calculation at the STR limit state, including assessment of enhanced earth pressures caused by cyclic thermal movements.

NOTE The enhanced earth pressures on integral bridge abutments can have a significant effect on the whole structure including the deck.

4.17 The assessment by calculation of integral bridge abutments shall be based on representative models, suitable for assessment of the relevant limit states and assessment situations, including the assessment of enhanced earth pressures caused by cyclic thermal movements.

4.17.1 The assessment of earth pressures on integral bridge abutments should be carried out in accordance with PD 6694-1 [Ref 20.N] except where modified within this Section 4 of this document.

NOTE The revised and updated information previously contained in BA 42/96 is now contained in PD 6694-1 [Ref 20.N].

4.17.2 The assessment by calculation of earth pressures on integral bridge abutments should be based on a range of values of the triaxial effective angle of shearing resistance of the backfill, from the inferior characteristic value to the superior characteristic value.

NOTE 1 *Guidance on evaluating the characteristic values of the triaxial effective angle of shearing resistance of the backfill using peak and constant volume effective angles of shearing resistance is contained in PD 6694-1 [Ref 20.N].*

NOTE 2 *An underestimation of ϕ' can underestimate earth pressures during thermal expansion. An overestimation of ϕ' can overestimate the abutment's resistance to longitudinal braking forces.*

NOTE 3 *In general granular materials comprising compacted rounded particles of uniform grading can have a peak angle of internal friction, ϕ' , as low as 35 degrees, and can accommodate thermal expansion without high earth pressures. However, they are somewhat vulnerable to settlement. Fill of compacted, well-graded, hard angular particles can have a peak angle of internal friction as high as 55 degrees with very high resistance to thermal expansion and are less vulnerable to settlement.*

4.17.3 Where assessment actions and partial factors are assessed using CS 454 [Ref 1.N], the enhanced earth pressures due to strain ratcheting should be calculated using the procedures contained in PD 6694-1 [Ref 20.N] but with the design value of the movement d_d calculated using Equation 4.17.3.

Equation 4.17.3 Value of the movement where BD21 is used

$$d_d = \frac{1}{2} d_k (1 + \gamma_{fL})$$

where:

d_k	is the characteristic value of thermal movement calculated in accordance with PD 6694-1 [Ref 20.N], but using the thermal actions given in CS 454 [Ref 1.N].
γ_{fL}	is the partial factor for thermal actions (restrained movement) taken from CS 454 [Ref 1.N].

4.18 Enhanced earth pressures shall be applied as a permanent action.

Buried concrete box and portal frame structures

Inspection for assessment for buried concrete box and portal frame structures

4.19 The inspection for assessment of buried concrete box and portal frame structures shall include the identification of the following:

1) shrinkage cracks on cast in-situ structures;
2) differential settlement;
3) failure in the joints between structural units;
4) deterioration of structural waterproofing and evidence of water ingress;
5) localised deterioration due to detailing faults and poor workmanship during construction;
6) scour and undercutting of the end elevations;
7) subsidence resulting in ground movements in the vicinity of the structure;
8) degradation and deterioration of the reinforced concrete;
9) cracking through excessive loading.

NOTE 1 *Management of buried concrete box structures is covered in CM 432 [Ref 15.I]and CS 432 [Ref 11.I].*

NOTE 2 *Degradation and deterioration of reinforced concrete can occur due to aggressive ground and groundwater, environmental effects, the aggregate properties and internal composition of the concrete, reinforcement corrosion and chemical attack.*

4.20 Where clearance of silt, debris or vegetation is carried out during an inspection for assessment, the clearance shall be carried out without damaging the structure.

NOTE 1 *Clearance of silt, debris and other vegetation can be necessary in order to inspect the invert of the structure.*

NOTE 2 *Silting of an invert commonly occurs with culverts built on waterlogged ground or where flow rates are low.*

Assessment by calculation for buried concrete box and portal frame structures

4.21 The assessment of buried concrete box and portal frame structures shall include an assessment by calculation at the STR limit state.

4.22 The assessment by calculation for buried concrete box and portal frame structures shall be based on representative models, suitable for assessment of the relevant limit states and assessment situations, including the assessment of earth pressures acting on the faces of the structure.

4.22.1 The assessment by calculation of buried concrete box and portal frame structures for which the overall longitudinal length L_L does not exceed 15 m in length and the depth of earth cover H_C does not exceed 11 m should be undertaken based on PD 6694-1 [Ref 20.N] as modified by Section 4 and Appendix B of this document.

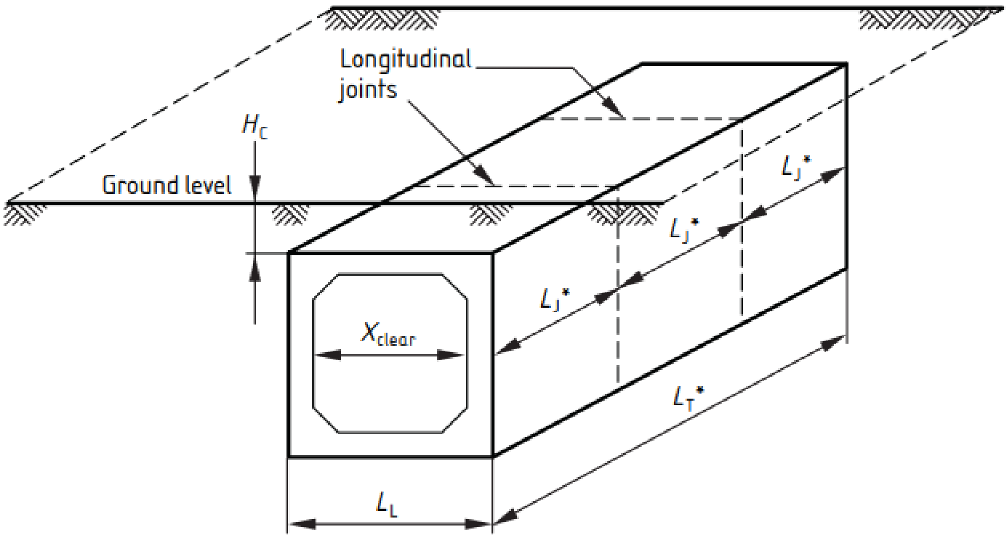
4.22.2 The assessment by calculation of buried concrete box and portal frame structures for which the overall longitudinal length L_L exceeds 15 m in length may:

1) conservatively be assessed as an integral bridge; or
2) be assessed assuming that the earth pressure at any depth varies linearly between the values for a buried structure of 15 m overall length to the values for an integral bridge with a 10 m expansion length.

NOTE 1 *Revised and updated design information previously contained in BD 31/01 is now contained in PD 6694-1 [Ref 20.N].*

NOTE 2 *Figure 4.21.2N2 illustrates the format for the symbols defining the geometry of buried boxes.*

Figure 4.22.2N2 Symbols for typical buried box structure



4.23 Assessment of the foundations at the GEO limit state shall be assessed if there is evidence of settlement, tilting or sliding.

NOTE 1 *Tilting of a buried concrete box structure is an extremely unlikely event and can be observed due to the passage of traffic loading or from the washout of the fill material.*

NOTE 2 *Tilting and cracking adjacent to the junction of the walls and roof could be indicative of issues arising from the effects of traction, braking or unbalanced traffic surcharge actions.*

NOTE 3 *The likelihood of any buried concrete box structure failing by sliding on its base or overturning about one of its bottom edges is remote.*

4.24 Assessment at the STR and GEO limit states for longitudinal traffic actions shall be assessed if there are signs of tilting or cracking adjacent to the junction of the walls and roof.

NOTE *Signs of tilting, or cracking adjacent to the junction of the walls and roof can be the result of longitudinal or unbalanced traffic surcharge actions.*

4.25 The traffic actions acting on a buried concrete box or portal structure shall be based on the relevant traffic actions from CS 454 [Ref 1.N] or CS 458 [Ref 23.N], dispersed and applied to the structure in accordance with this document.

4.26 The dispersal of traffic actions and traffic surcharge actions through the fill shall be based on representative analyses of the stresses in the soil.

4.26.1 Where a more detailed analysis model is not used, the simplified methods in PD 6694-1 [Ref 20.N] may be used to model the dispersed vertical effects of traffic actions on structures.

NOTE *The horizontal effects of traffic surcharge loading are covered in Section 3.*

4.26.2 The dynamic effects of vehicle loading may be reduced accounting for the damping effect of the depth of cover.

4.26.3 For normal and restricted traffic modelled using ALL model 1 in CS 454 [Ref 1.N], the impact factor may be reduced according to Equation 4.26.3.

Equation 4.26.3 Reduced impact factor for normal and restricted traffic

$$F_{red} = \max \begin{cases} 1 + (F-1)(1-0.5H_c) \\ 1.2 \end{cases}$$

where:

F_{red}	is the reduced impact factor
H_c	is the depth of cover in metres
F	is the impact factor taken from CS 454 [Ref 1.N]

4.26.4 For abnormal traffic modelled using CS 458 [Ref 23.N], the dynamic amplification factor may be reduced according to Equation 4.26.4.

Equation 4.26.4 Reduced impact factor for abnormal traffic

$$DAF_{red} = \max \begin{cases} 1 + (DAF-1)(1-0.5H_c) \\ 1 + 0.25(DAF-1) \end{cases}$$

where:

DAF_{red}	is the reduced dynamic amplification factor
H_c	is the depth of cover in metres
DAF	is the dynamic amplification factor taken from CS 458 [Ref 23.N]

4.27 The permanent action due to the weight of soil acting on the roof of buried box structures and portal structures shall be assessed based on the weight of the soil and accounting for adverse arching effects (negative arching).

4.27.1 The supplementary model factor in PD 6694-1 [Ref 20.N] accounting for negative arching may be omitted from the maximum value of the vertical permanent load where there is no evidence that consolidation or settlement of the fill has occurred.

4.28 The structure shall be analysed as a continuous frame, with pin joints where the walls are not continuous or fully integral with the roof slab or base.

4.28.1 The stiffness of any corner fillets may be included in the calculations.

4.28.2 Portal frames should be checked to ensure that they are structurally capable of carrying the applied loads in conjunction with the frictional resistance forces.

4.29 The horizontal earth pressures acting on the walls of buried concrete box structures and portal frame structures shall be assessed accounting for the effects of strain ratcheting, wall friction and thermal expansion and contraction.

4.29.1 The earth pressure coefficients may be assessed using one of the following methods:

1) using directly determined values;
2) by calculation.

4.29.2 When the method of assessment adopts the use of directly determined values, the earth pressures coefficients should be taken from:

1) Appendix B where the assessment is undertaken to CS 454 [Ref 1.N];
2) PD 6694-1 [Ref 20.N] where the assessment is undertaken to BS EN 1997-1 [Ref 11.N] and BS EN 1990 [Ref 12.N].

NOTE The directly determined earth pressure coefficients in Appendix B and PD 6694-1 [Ref 20.N] include the effects of strain ratcheting, wall friction and thermal expansion and contraction.

4.29.3 Where the earth pressure coefficients are assessed by calculation, earth pressure coefficients should be based on geotechnical parameters derived from the results of a geotechnical investigation.

NOTE Further guidance is provided in PD 6694-1 [Ref 20.N] and BS EN 1997-1 [Ref 11.N].

4.29.4 Where the earth pressure coefficients are assessed by calculation, the enhanced earth pressures due to strain ratcheting (including K_{min} and K_{max}) should be calculated using the requirements for integral bridge abutments in this document.

Corrugated steel buried structures

Inspection for assessment for CSBS

4.30 The distortion of the CSBS shall be measured.

NOTE Management of CSBS is covered in CS 460 [Ref 16.N].

4.31 Where the bolts on a CSBS are badly corroded the extent of corrosion shall be measured and accounted for in the resistance verification.

NOTE Visual inspection of a core, including a bolt and the surrounding section of the plates that form the seam can enable measurements to be made on the extent of corrosion.

Assessment by calculation for CSBS

4.32 Corrugated steel buried structures shall be assessed by calculation when any of the following apply:

1) there is evidence of corrosion or deterioration of the corrugated steel exceeding 10% of the thickness over a substantial area of the structure;
2) there is movement of the structure's profile outside the CS 460 [Ref 16.N] limits for cross section deviation;
3) the structure exhibits longitudinal distortion.

NOTE Signs of deterioration in CSBS can include cracking around the boltholes, separation at seams, local buckling or signs of reverse curvature.

4.33 Assessment by calculation for CSBS, including checks on wall stress, seam strength and buckling, shall be undertaken in accordance with the methods and models in CD 375 [Ref 7.N].

NOTE 1 The seams in bolted structures are designed to fail in compression through distortion and tearing of the plates around the bolts, but not through failure of the bolts.

NOTE 2 Bolt failure is one of the potentially catastrophic failure modes because the failure of a single bolt could lead to load shedding and subsequent overloading of adjacent bolts.

NOTE 3 Determination of material properties suitable for assessment is covered in Section 5.

4.33.1 No deductions should be made for future corrosion of the CSBS in the assessment.

4.33.2 The method contained in CD 375 [Ref 7.N] may be used to predict the future remaining life of the structure.

4.33.3 Where further information is needed for the assessment of a CSBS, guidance should be sought from the manufacturers or other specialists to assist in the assessment of CSBS.

NOTE Corrugated steel buried structures are proprietary manufactured structures and the design could have been undertaken by the manufacturer or other specialist as part of the structure procurement.

4.34 The assessment of CSBS outside the scope of CD 375 [Ref 7.N] shall be agreed with the Overseeing Organisation.

4.35 The assessment of a CSBS whose shape is outside the deviation limits for cross section, or exhibits longitudinal distortion, shall be based on an analysis method that accounts for the effect of the distortion.

NOTE 1 In most cases, the greater the deviation from the nominal cross section the greater the loss in capacity; and the larger the span, the greater the sensitivity to deformation.

NOTE 2 Assessment of a structure that has suffered longitudinal distortion can require specialised analysis.

NOTE 3 Longitudinal distortion can be caused by differential settlement or by mining subsidence.

4.35.1 Where longitudinal distortion has occurred, the calculation of the area of section and the second moment of area should include the effects of hogging strains in the longitudinal direction.

NOTE Hogging strains can reduce the area and second moment of area of corrugated sections.

Reinforced soil structures

Assessment by calculation for reinforced soil structures

4.36 Reinforced soil structures shall be assessed by calculation where there is reliable as-built information on the fill and the reinforcement properties and layout, and:

1) there are signs of movement or cracking; or
2) there is evidence of corrosion or some other form of deterioration of the reinforcement exceeding that allowed for in the design.

NOTE 1 There are two resistance elements providing global stability in reinforced soil structures (the soil and the reinforcement). It is unlikely that there will be signs of movement or cracking at the facing unless there is loss of strength in the soil or the reinforcement.

NOTE 2 Reinforced soil structures can suffer local failure of the facing, without danger of global failure, where the reinforcement attached to the rear of the facing fails due to local corrosion or some other form of deterioration in non-metallic elements.

NOTE 3 For anchored earth structures, the facing panels can play a major role in providing global stability.

4.36.1 Assessment by calculation of reinforced soil structures and soil nail structures should be undertaken in accordance with BS 8006-1 [Ref 3.N] and BS 8006-2 [Ref 6.N].

NOTE 1 *For complex structures involving reinforced soil and soil nails, both BS 8006-1 [Ref 3.N] and BS 8006-2 [Ref 6.N] can be needed.*

NOTE 2 *Strengthened and reinforced soil structures is not covered in BS EN 1997-1 [Ref 11.N].*

4.36.2 Where further information is needed for the assessment of a reinforced soil structure, guidance may be sought from the manufacturers or other specialists.

NOTE *Reinforced soil structures, or components of, are proprietary manufactured structures and the design could have been undertaken by the manufacturer or other specialist as part of the structure procurement.*

Dry-stone walls

4.37 Dry-stone walls shall be assessed qualitatively.

4.37.1 The assessment of dry-stone walls should be based upon the results of visual inspections and surveys.

4.38 The inspection for assessment of dry-stone walls shall include the identification of the following:

1) the type, size and shape of stone(s);
2) the age of the wall;
3) the skill with which the stones have been laid or replaced;
4) signs of bulging or loss of profile;
5) stone loss, particularly at the top of the wall;
6) the likely nature of the retained material supporting the wall foundations;
7) the existing loads carried by the wall(s) in terms of traffic volume;
8) the presence (in and around the wall) of vegetation; and
9) influence of trees and vegetation on the wall stability.

NOTE 1 *Qualitative judgements are difficult since conditions will vary greatly with the quality of stone used, age, subsoil conditions, geometry, weathering factors and local expectations.*

NOTE 2 *Advice on the interpretation of the observations from the visual inspection, the seriousness of the various defects which can occur and the application to the assessment for dry-stone walls is contained in Appendix D.*

4.39 Assessment of dry-stone walls shall include a comparison with the performance of adjacent structures.

4.39.1 Local experience of the behaviour and comparison with past performance of the structure should be used to inform the assessment when available.

Masonry spandrel walls

4.40 Masonry spandrel walls shall be assessed qualitatively.

4.40.1 The assessment of masonry spandrel walls should be based upon the results of visual inspections and surveys.

NOTE *Advice on the interpretation of the observations from the visual inspection, the serious of the various defects which can occur and the application to the assessment for masonry spandrel walls is contained in Appendix E.*

4.41 Masonry spandrel walls shall be assessed separately from the arch barrel.

5. Properties of materials and drainage

Geotechnical information

5.1 Geotechnical information and data obtained for the assessment process shall identify the properties of the geotechnical materials so that any risks can be identified and the structure managed.

5.1.1 Geotechnical information should be obtained from desk studies and/or geotechnical investigations.

NOTE Geotechnical information can be established from existing or newly obtained geotechnical data.

5.1.2 Where geotechnical information exists, the information may be reassessed by carrying out further studies and investigation to refine the understanding, obtain more reliable values and extend the knowledge of the ground for the purpose of the assessment.

5.2 Geotechnical investigation shall be undertaken when it is required for the assessment.

5.2.1 Geotechnical investigations should be carried out if the information obtained can improve the reliability of the assessment.

NOTE 1 Desk studies are normally sufficient for the purpose of a qualitative assessment.

NOTE 2 Geotechnical investigations are unlikely to be required unless there is a requirement for an assessment by calculation.

5.2.2 The geotechnical investigation should gather relevant knowledge about the site required for the assessment including:

1) establishment of the geotechnical material and groundwater conditions;
2) determination of the properties of the geotechnical materials; and
3) the pore pressure distributions.

5.2.3 The planning and reporting of ground investigations, interpretation and evaluation of test results, and the derivation of values of geotechnical parameters and coefficients should be carried out in accordance with BS EN 1997-2 [Ref 8.I].

5.3 Where geotechnical information is required for the assessment, the geotechnical activities shall be certified in accordance with CD 622 [Ref 18.N].

Structural materials

5.4 Properties of structural materials and cross sections, including the effects of deterioration and damage, shall be determined in accordance with:

1) CS 454 [Ref 1.N] when assessment by calculation is undertaken to Option 1;
2) BS EN 1990 [Ref 12.N] and BS EN 1997-1 [Ref 11.N] when assessment by calculation is undertaken to Option 2 (Eurocode); and
3) the relevant material standards.

NOTE 1 CS 454 [Ref 1.N], CS 455 [Ref 22.N] and CS 456 [Ref 24.N] provide requirements for structural material properties, including the effects of deterioration and damage, for assessment by calculation to Option 1.

NOTE 2 BS EN 1990 [Ref 12.N], BS EN 1992-2 [Ref 8.N], BS EN 1993-2 [Ref 9.N], BS EN 1994-2 [Ref 10.N] and BS EN 1997-1 [Ref 11.N] provide requirements for structural and geotechnical material properties, including the effects of deterioration and damage, for assessment by calculation to Option 2 (Eurocode).

NOTE 3 Where measurement of the present cross section is not feasible, such as for buried elements, estimates of the loss in section can be made with reference to published literature taking into account the age of the structure.

5.5 Where estimates of the cross-sectional loss are made, the method of estimation and the assumed loss shall be recorded.

5.6 The estimated degradation of exposed components and surfaces shall include an assessment of the effects of the following:

1) aggressivity of the ground;
2) groundwater (where present);
3) corrosivity of the atmosphere.

NOTE With water, oxygen, organic matter and salt all likely to be in regular contact the conditions prevailing at the exposed component and surfaces of structures can be more onerous then those applicable to buried components.

Drainage

5.7 The assessment shall include a review of the effectiveness of the surface and sub-surface drainage provisions to the structure, including drainage provided to intercept and convey surface water away from an earth retaining structure or the backfill.

NOTE 1 As-built drawings can indicate the drainage provisions that were originally intended.

NOTE 2 Facilities can be present for rodding the drainage system from inspection manholes, which can be positioned at the foot of a wall.

NOTE 3 Weep holes located just above ground level can provide a visual check that the system is functioning correctly, and can limit the rise in water level in the event of a drainage failure.

5.7.1 Where the drainage system is not functioning effectively, the consequences of malfunction of the drainage system should be reviewed and included in the assessment.

5.7.2 The following features should be noted, with respect to changing groundwater levels:

1) the possibility of rise in pore water pressures caused by malfunction of the drainage system or resulting from fracture of water mains located in the vicinity;
2) rising groundwater levels, particularly in urban environments, and their effect on the long-term magnitude and distribution of water pressures;
3) damage to adjacent structures due to depression of the water table.

5.7.3 The following features should also be noted:

1) whether the vertical drainage layer (where present) has a direct connection with the drainage pipes;
2) whether suitable exits with positive outfall are provided for any drainage system;
3) whether drains are oversized to allow for blockage during working life to enable better access for rodding.

NOTE In highly permeable backfill a vertical drainage layer can be absent.

6. Normative references

The following documents, in whole or in part, are normative references for this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

Ref 1.N	Highways England. CS 454, 'Assessment of highway bridges and structures'
Ref 2.N	BSI. BS 8081, 'Code of practice for grouted anchors'
Ref 3.N	BSI. BS 8006-1, 'Code of practice for strengthened / reinforced soils and other fills'
Ref 4.N	BSI. BS 8002, 'Code of practice for earth retaining structures'
Ref 5.N	BSI. BS 8004, 'Code of practice for foundations'
Ref 6.N	BSI. BS 8006-2, 'Code of practice for strengthened / reinforced soils Part 2: Soil nail design'
Ref 7.N	Highways England. CD 375, 'Design of corrugated steel buried structures'
Ref 8.N	BSI. BS EN 1992-2, 'Eurocode 2. Design of concrete structures. Part 2: Concrete bridges. Design and detailing rules'
Ref 9.N	BSI. BS EN 1993-2, 'Eurocode 3. Design of steel structures Part 2: Steel bridges'
Ref 10.N	BSI. BS EN 1994-2, 'Eurocode 4. Design of composite steel and concrete structures. Part 2: General rules and rules for bridges'
Ref 11.N	BSI. BS EN 1997-1, 'Eurocode 7: Geotechnical design - Part 1: General rules'
Ref 12.N	BSI. BS EN 1990, 'Eurocode: Basis of structural design'
Ref 13.N	BSI. BS EN 1991, 'Eurocode 1: Actions on structures'
Ref 14.N	CIRIA. Gaba, A., Hardy, S., Doughty, L., Powrie, W. and Selemetas, D.. CIRIA C760, 'Guidance on embedded retaining wall design'
Ref 15.N	Highways England. GG 101, 'Introduction to the Design Manual for Roads and Bridges'
Ref 16.N	Highways England. CS 460, 'Management of corrugated steel buried structures'
Ref 17.N	Highways England. CS 470, 'Management of sub-standard highway structures'
Ref 18.N	Highways England. CD 622, 'Managing geotechnical risk'
Ref 19.N	Highways England. MCHW, 'Manual of Contract Documents for Highway Works'
Ref 20.N	BSI. PD 6694-1, 'Recommendations for the design of structures subject to traffic loading to BS EN 1997-1:2004'
Ref 21.N	Highways England. CG 300, 'Technical approval of highway structures'
Ref 22.N	Highways England. CS 455, 'The assessment of concrete highway bridges and structures'
Ref 23.N	Highways England. CS 458, 'The assessment of highway bridges and structures for the effects of special type general order (STGO) and special order (SO) vehicles '
Ref 24.N	Highways England. CS 456, 'The assessment of steel highway bridges and structures'

7. Informative references

The following documents are informative references for this document and provide supporting information.

Ref 1.I	Transport Research Laboratory. Seaman, J.W.. TRL PR 71, 'A guide to accommodating or avoiding soil-induced lateral loading of piled foundations for highway bridges'
Ref 2.I	Transport Research Laboratory. Springman, S.M., Ng, C.W.W., Ellis, E.A.. TRL PR 98, 'Centrifuge and analytical studies of full height bridge abutment on piled foundation subjected to lateral loading'
Ref 3.I	SCI. Yandzio, E.. SCI P187, 'Design Guide for Steel Sheet Pile Bridge Abutments'
Ref 4.I	CIRIA. Elson, W.K. CIRIA R103, 'Design of laterally-loaded piles'
Ref 5.I	ICE Publishing. Stewart, D.P., Jewell R.J., and Randolph M.F.. Geotechnique Vol. 44, 2, p277, 'Design of piled bridge abutments on soft clay for loading from lateral soil movements'
Ref 6.I	TRL. Brookes, A.H.,Carder, D.R., Darley, P.. TRL 152, 'Earth pressures against an experimental retaining wall backfilled with Lias Clay'
Ref 7.I	Institution of Structural Engineers. ISE CP2, 'Earth retaining structures' , 1951
Ref 8.I	BSI. BS EN 1997-2, 'Eurocode 7 - Geotechnical design - Part 2: Ground investigation and testing'
Ref 9.I	SCI. Biddle, A.R.. SCI P335, 'H-Pile Design Guide'
Ref 10.I	TRL Limited. Daly, AF, and Watts, Guy RA. TRL PPR 197, 'High-Tech Remote Monitoring for the Management of Highway Structures'
Ref 11.I	Highways England. CS 432, 'Inspection of buried concrete box structures'
Ref 12.I	Transport Research Laboratory. Carder, D.R.,Gent, A.J.C., Darley, P.. TRL PR 112, 'Lateral loading of piled foundations at Dartford Creek bridge'
Ref 13.I	TRL. Darley, P., Carder, D.R., Ryley, M.D.. TRL 246, 'Lateral loading of piled foundations at Wiggenhall Road overbridge (A47)'
Ref 14.I	VIII CPMSIF - PCSMFE. Cartagena, Columbia, Vol 2, 473 - 483. Clayton C.R.I., Hiedra-Cobo J.C. and Symons I.F.. Clayton, Hiedra-Cobo & Symons, 'Lateral pressures induced by compaction of clay backfill'
Ref 15.I	Highways England. CM 432, 'Maintenance of buried concrete box structures'
Ref 16.I	Department for Transport. Kirby, Roca, Kitchen, etal. CIRIA R742, 'Manual on scour at bridges and other hydraulic structures'
Ref 17.I	Transport Research Laboratory. Card, G.B., Carder, D.R.. TRL 228, 'Movement trigger limits when applying the Observational Method to embedded retaining wall construction on highway schemes'
Ref 18.I	Transport Research Laboratory. Carder, D.R.,Steele, D.P.. TRL 438, 'Performance of the hard-soft piling system at A12 Hackney to M11 Link Road'
Ref 19.I	John Wiley and Sons. Poulos, H.G. and Davis, E.H.. PFAD, 'Pile Foundation Analysis and Design'
Ref 20.I	BRE. BRE SD-1 2005, 'Special Digest 1:2005, Third edition, Concrete in aggressive ground.'
Ref 21.I	Highways England. CS 451, 'Structural review and assessment of highway structures'

Ref 22.I	Highways England. BD 97, 'The Assessment of Scour and Other Hydraulic Actions at Highway Structures'
Ref 23.I	Highways England. CD 350, 'The design of highway structures'
Ref 24.I	TRL. Springman, S.M., Bolton, M.D.. TRL CR196, 'The effect of surcharge loading adjacent to piles'
Ref 25.I	CIRIA. Nicholson, DP, Tse, C and Penny, C. CIRIA R185, 'The Observational Method in ground engineering – principles and applications'
Ref 26.I	Canadian Geotechnical Journal, Vol 28, 282 - 297.. Clayton C.R.I., Symons I.F. and Hiedra-Cobo J.C.. Clayton, Symons & Hiedra-Cobo, 'The pressure of clay backfill against retaining structures'
Ref 27.I	Transport Research Laboratory. O'Connor, K.,Taylor, R.N.. TRL PR 72, 'The swelling pressure of compacted clayey fill'

Appendix A. Lateral loading of piles

A1 General

The following procedure can be used for the determination of soil-induced lateral loading effects on piles for assessment.

A1.1 Step 1

Analyse the behaviour of the soil cross-section to obtain the soil displacements over the length of the piles but omitting the pile structural elements and the pile actions transferred from the structure.

Any numerical method capable of analysing non-linear soil behaviour may be used for this purpose.

Soil displacements should be calculated at the position of the piles perpendicular to the pile shaft along the length of the piles.

About 10 regularly spaced deflection points along each pile should be sufficient although more may be needed to accurately represent the deflected shape of the piles.

A1.2 Step 2

The soil displacements calculated in Step 1 should be applied to the individual piles as lateral displacements with due regard to their end fixities considering each pile as a free-standing frame element without the surrounding soil.

Only differential displacements, that is displacements with respect to one end of the pile, should be used and input as imposed displacements on the structural element.

Any continuous beam or frame analysis structural software package can be used for this.

The points at which the displacements should be applied need to correspond with the soil displacement points selected in Step 1.

The output reactions represent the magnitude of the action required to produce the calculated displacement profile of the piles.

A1.3 Step 3

Calculate the lateral pressures developed along the piles which would result due to the applied deflections.

The lateral pressures can be obtained by dividing the calculated reaction at each displacement point by the contributing pile area, that is the length of pile taken as the mid-point distance between adjacent displacement nodes 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 should then to be analysed using the redistributed total pressure as the applied pressure.

The yield stress, p_y , of the soil can be taken as the greater of Equation A.1 and A.2 according to the response of the material.

Equation A.1 Yield stress of cohesionless soils for pile analysis

$$p_y = 3K_p\sigma_v'$$

where:

p_y	is the yield stress of the soil
K_p	is the coefficient of passive earth pressure
σ_v'	is the effective vertical stress

Equation A.2 Yield stress of cohesive soils for pile analysis

$$p_y = 9c_u$$

where:

p_y	is the yield stress of the soil
c_u	is the undrained shear strength

A1.4 Step 4

The effects of actions (shear forces and bending moments) and any other effects calculated in the piles at the end of the Step 4 should be superimposed on the effects in the pile determined from the pile analysis of the actions transferred to the piles from the structure.

Partial factors can be applied to the effects of actions in accordance with the code provisions to calculate the design effects of actions for both the ultimate and serviceability limit states.

A1.5 Notes

The above procedure is a conservative method to calculate lateral forces and moments induced into a single pile as it has the following simplifications:

1) It makes the assumption that the presence of the pile does not influence the ground movement;
2) It does not allow for soil yield and flow around the pile;
3) 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 (for example, Geotechnique Vol. 44, 2, p277 [Ref 5.I]).

Appendix A of TRL TRL PR 71 [Ref 1.I] describes various design approaches and their advantages and limitations.

Appendix B. Buried concrete box and portal frame structures

B1 Cases to be considered for buried concrete structure assessment

Figure B.1 to Figure B.2 and Table B.1 to Table B.6 show cases to be considered and the directly determined values of earth pressure coefficients that may be used with various loading combinations when the assessment is being undertaken to CS 454 [Ref 1.N] (modified after PD 6694-1 [Ref 20.N]).

These directly determined values of earth pressure coefficient values apply to backfill classes 6N and 6P, specified, installed and compacted in accordance with the MCHW [Ref 19.N], and to structures where there is uniformity of ground conditions.

Figure B.1 Maximum vertical load with maximum horizontal load

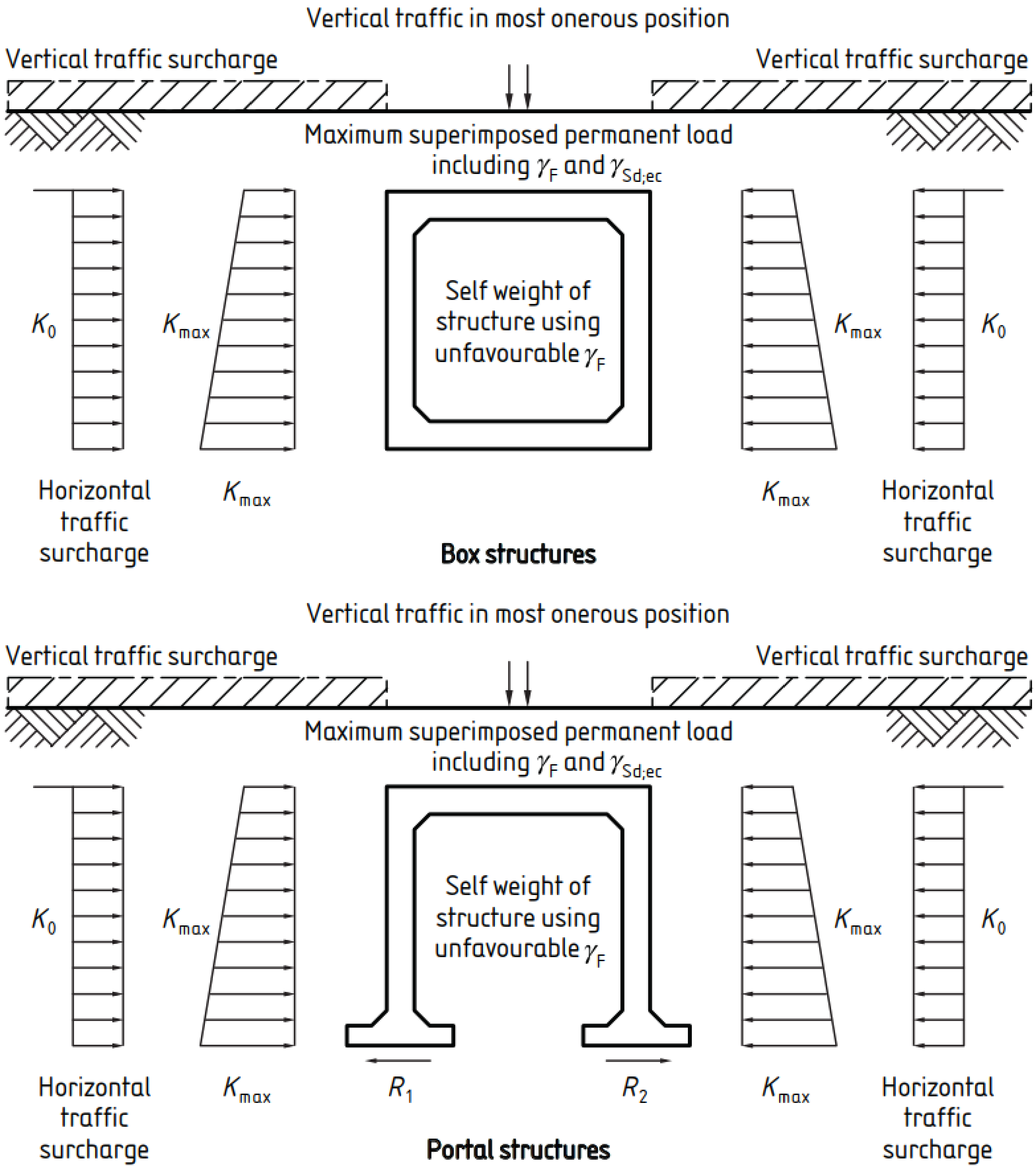


Table B.1 Maximum vertical load with maximum horizontal load

Directly determined design values of the earth pressure coefficient K that may be applied at various limit states				
Horizontal traffic surcharge K_0	Earth pressure $K_{\max}$	Limit state	Earth pressure $K_{\max}$	Horizontal traffic surcharge K_0
0.50	0.60	SLS	0.60	0.50
0.50	0.60	STR	0.60	0.50

Figure B.2 Minimum vertical load with maximum horizontal load

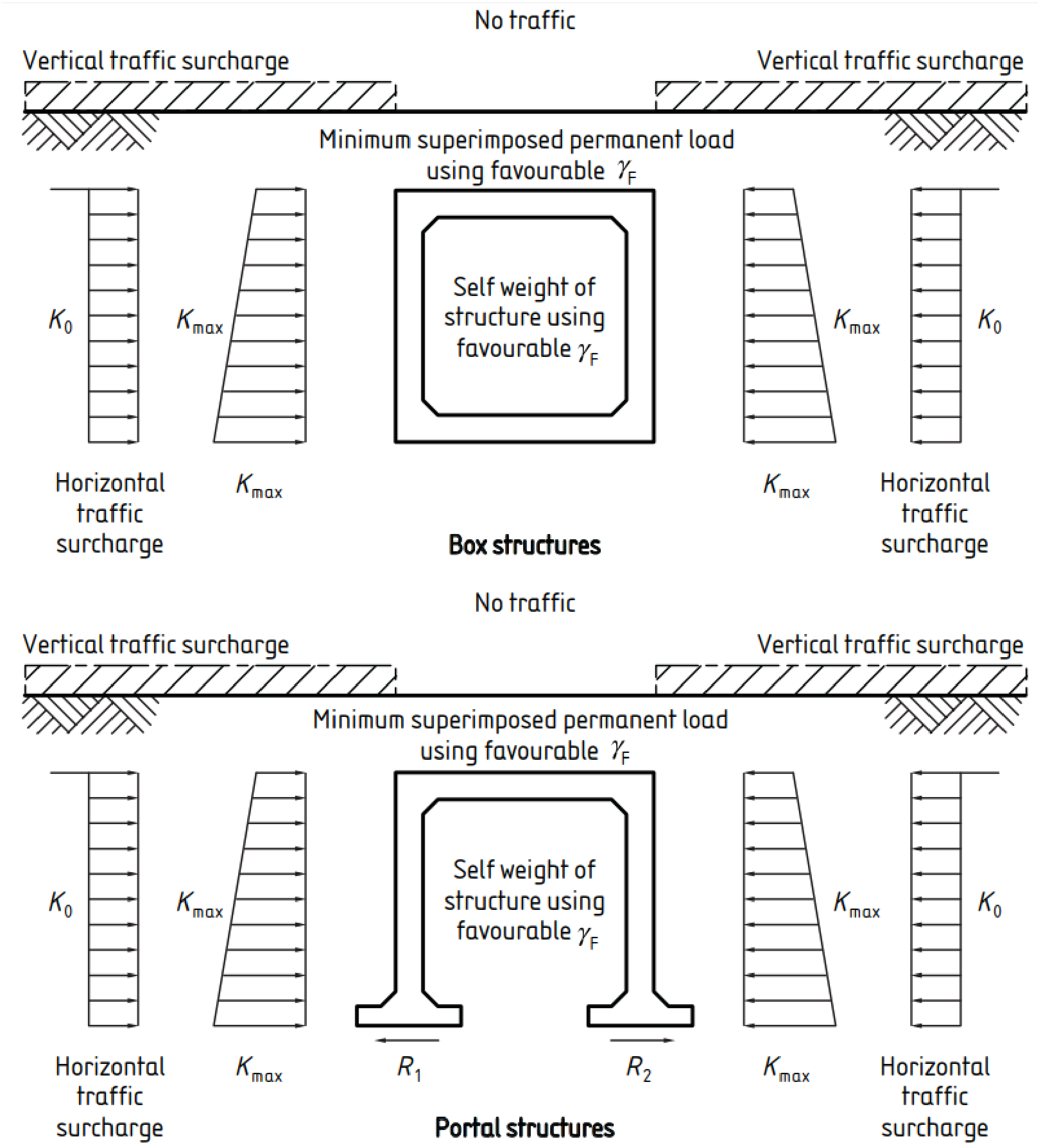


Table B.2 Minimum vertical load with maximum horizontal load

Directly determined design values of the earth pressure coefficient K that may be applied at various limit states				
Horizontal traffic surcharge K_0	Earth pressure $K_{\max}$	Limit state	Earth pressure $K_{\max}$	Horizontal traffic surcharge K_0
0.50	0.60	SLS	0.60	0.50
0.50	0.60	STR	0.60	0.50

Figure B.3 Maximum vertical load with minimum horizontal load

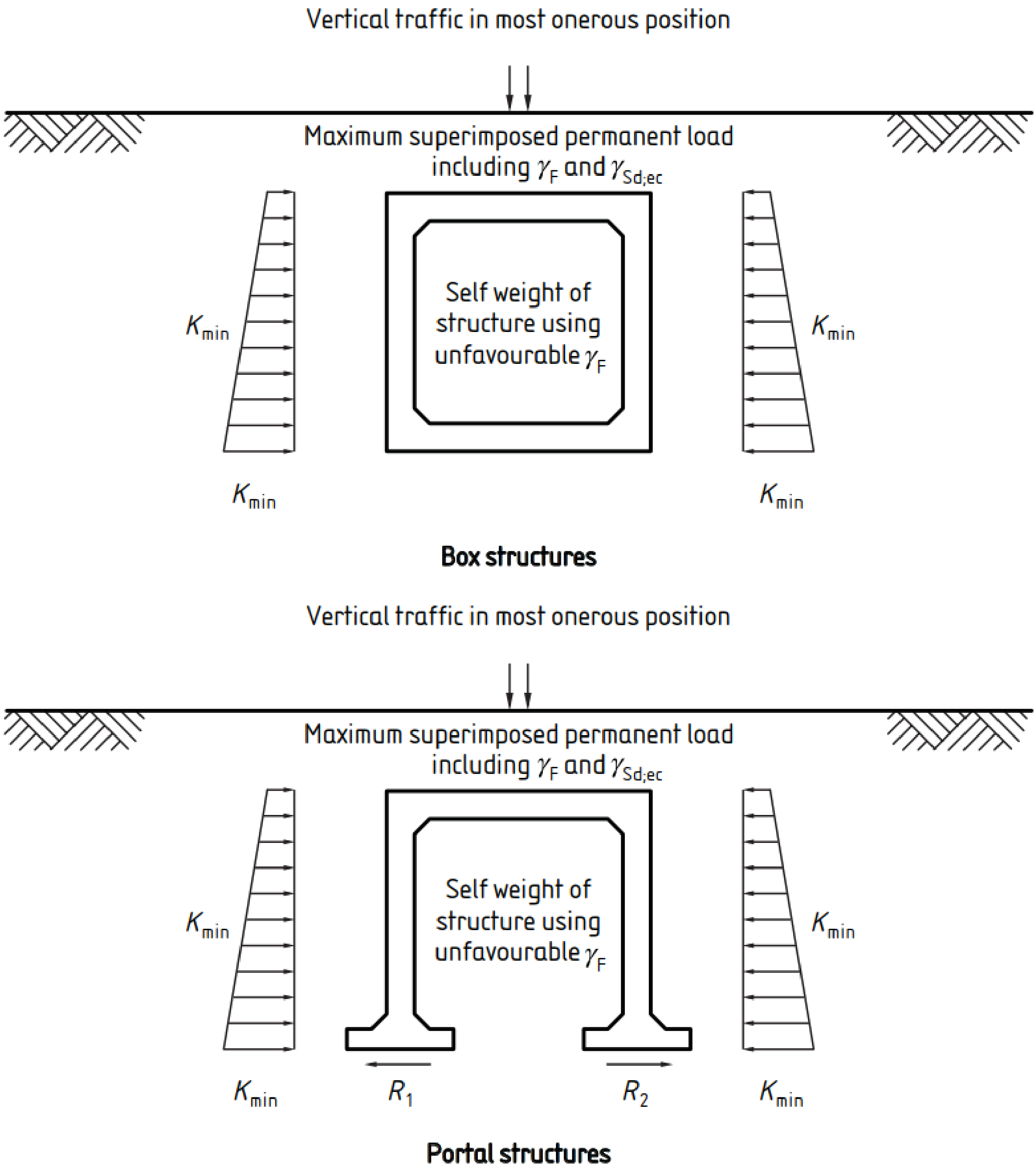


Table B.3 Maximum vertical load with minimum horizontal load

Directly determined design values of the earth pressure coefficient K that may be applied at various limit states		
Earth pressure $K_{\min}$	Limit state	Earth pressure $K_{\min}$
0.20	SLS	0.20
0.20	STR	0.20

Figure B.4 Braking and acceleration with maximum vertical load and active pressure

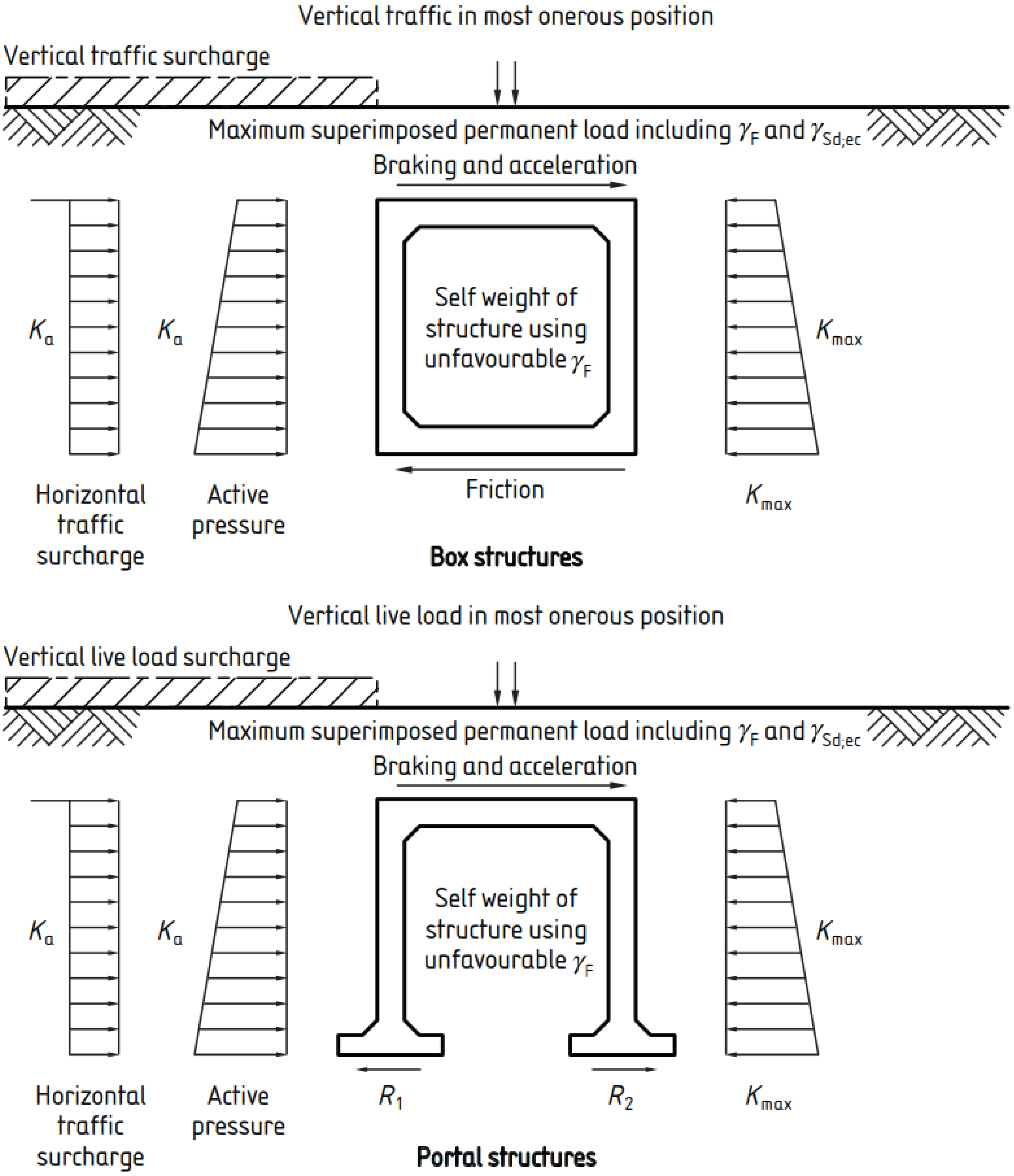


Table B.4 Braking and acceleration with maximum vertical load and active pressure

Directly determined design values of the earth pressure coefficient K that may be applied at various limit states			
Horizontal traffic surcharge K_a	Earth pressure K_a	Limit state	Earth pressure $K_{\max}$
0.33	0.33	SLS	0.60
0.33	0.33	STR	0.60
NOTE 1 If the structure sways towards the active side, this load case may be ignored. NOTE 2 The earth pressure coefficient for the passive wall may be taken as greater than $K_{\max}$ for bearing, sliding and overturning provided the associated displacements are acceptable at the relevant limit state.			

Figure B.5 Braking and acceleration with minimum vertical load and active pressures

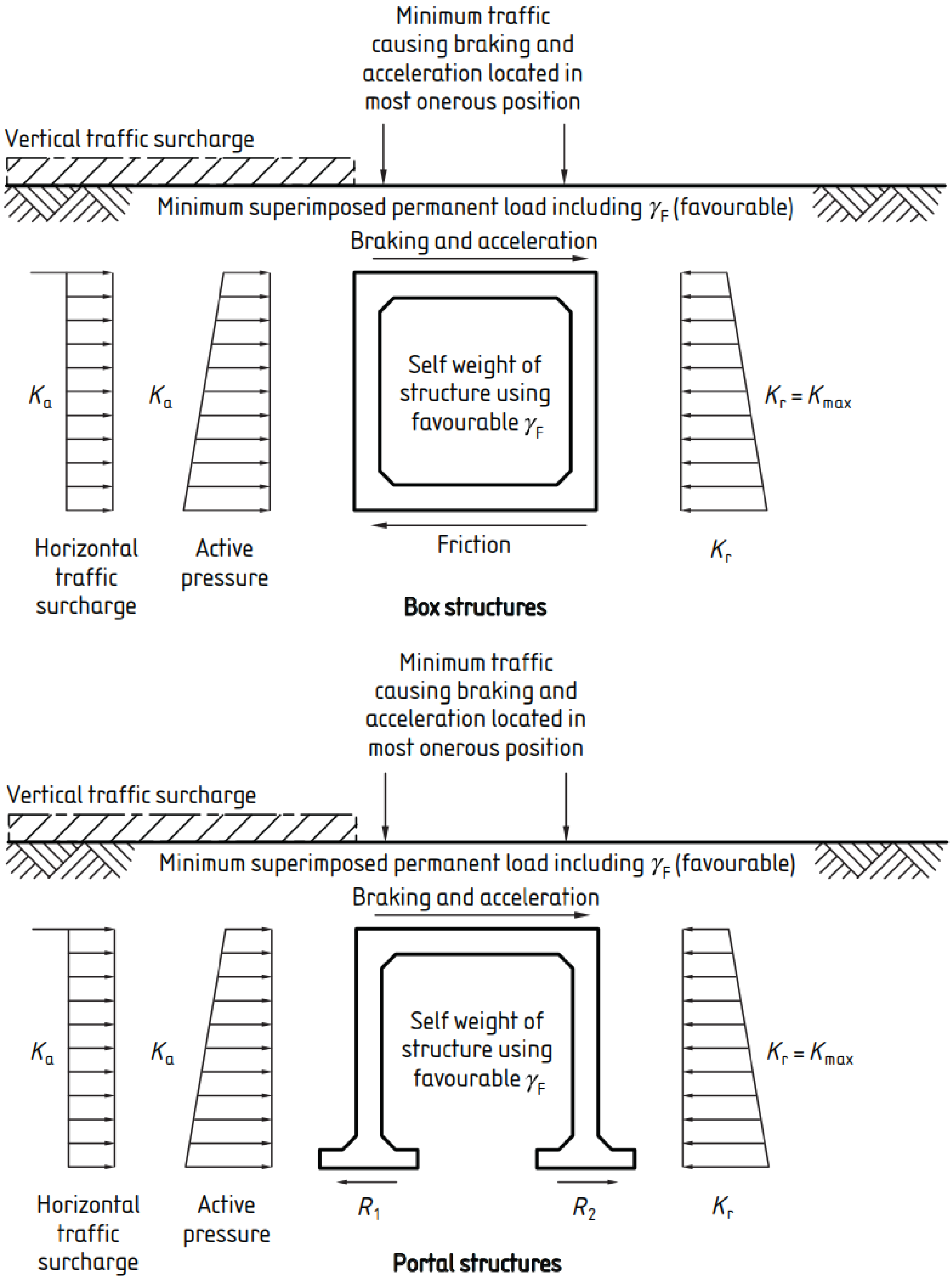
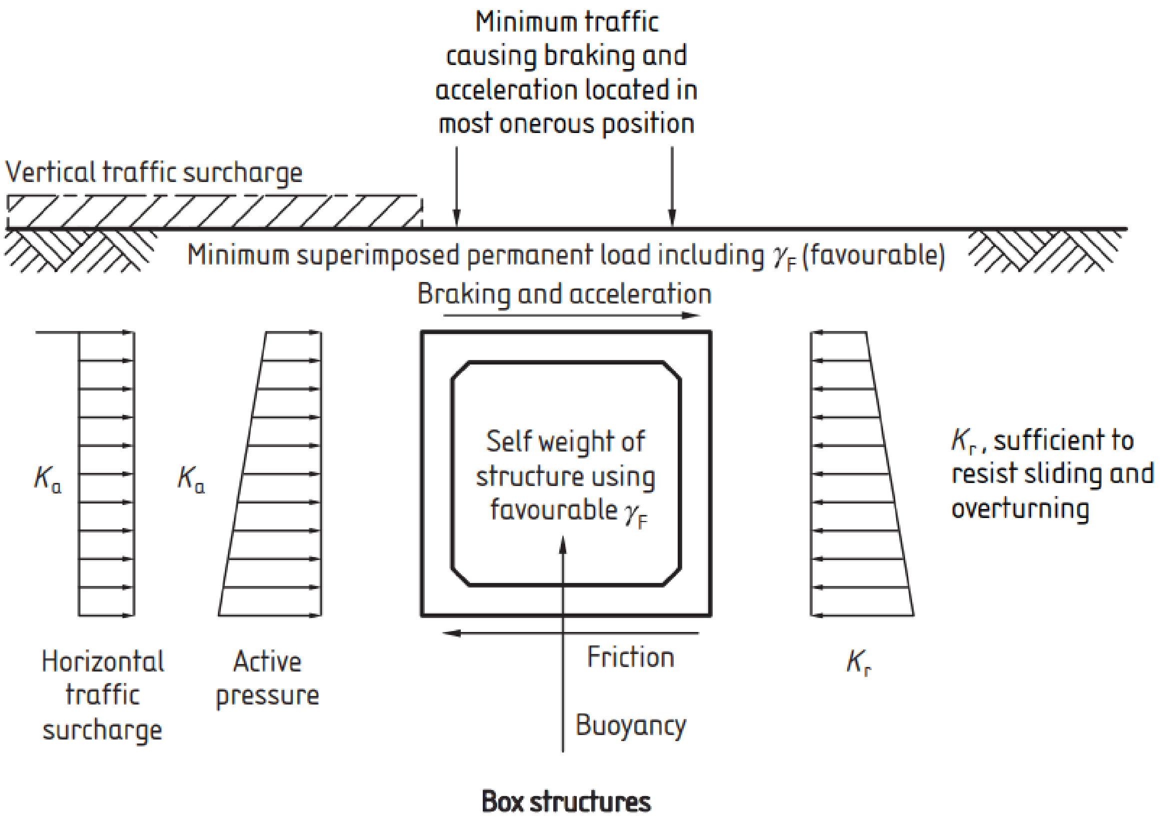


Table B.5 Braking and acceleration with minimum vertical load and active pressures

Directly determined design values of the earth pressure coefficient K that may be applied at various limit states			
Horizontal traffic surcharge K_a	Earth pressure K_a	Limit state	Earth pressure $K_{\max}$
0.33	0.33	SLS	0.60
0.33	0.33	STR	0.60
NOTE 1 If the structure sways towards the active side, this load case may be ignored. NOTE 2 The earth pressure coefficient for the passive wall may be taken as greater than $K_{\max}$ for bearing, sliding and overturning provided the associated displacements are acceptable at the relevant limit state.			

Figure B.6 Sliding



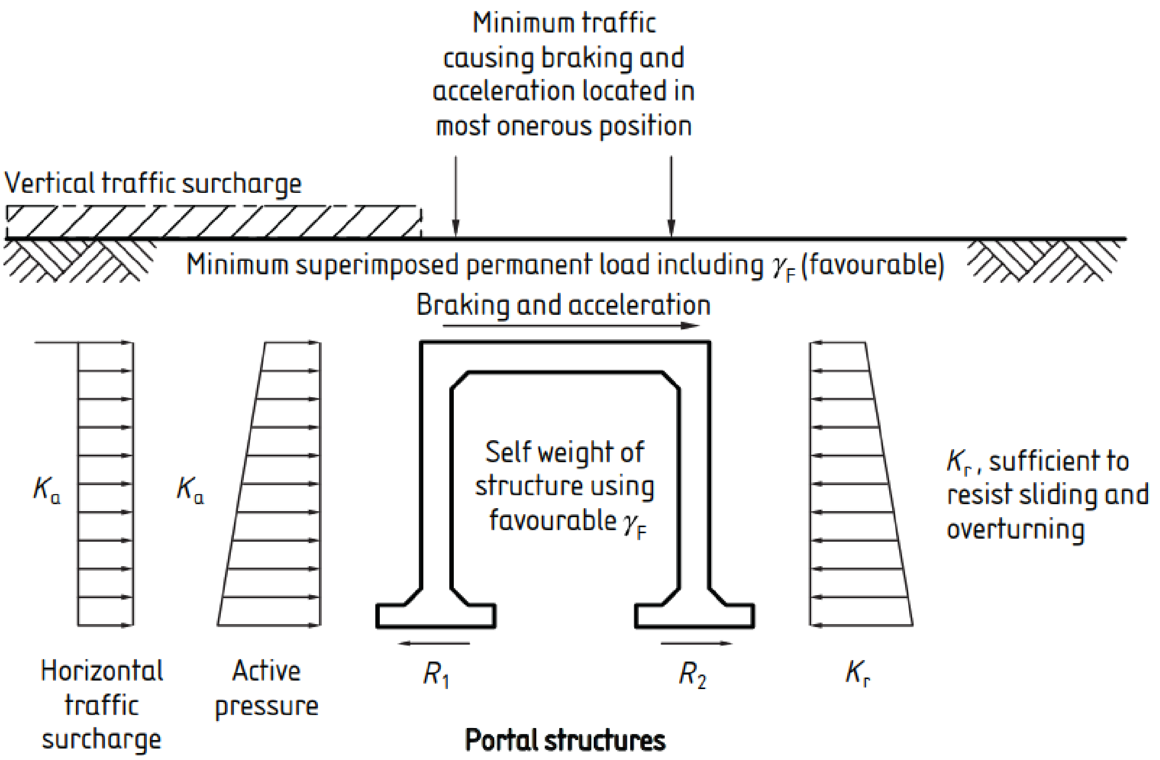


Table B.6 Sliding

Directly determined design values of the earth pressure coefficient K that may be applied at various limit states			
Horizontal traffic surcharge K_a	Earth pressure K_a	Limit state	Earth pressure $K_{\max}$
0.33	0.33	SLS	K_r
0.33	0.33	STR	K_r

Appendix C. Dry-stone walls

C1 Construction and behaviour

Dry-stone walls are normally constructed without recognisable foundations and out of marginal quality material. Only the front face contains dressed masonry, the remainder usually being rubble.

Dry-stone walls were constructed as facing walls to vertical or near vertical cuts in unstable or friable material or as free-standing burr and retaining walls. In the latter cases construction and backfilling proceeded together.

The absence of mortar results in stone to stone contact, and since the stones used in the walls are usually irregular or roughly squared off, point contact between stones is common.

Contact pressure may be high especially at the base of tall stones and crushing is often evident.

Dry-stone walls can move and distort until sufficient interlock strength has been gained between stones. This can give an irregular profile however the wall can still provide satisfactory performance in service.

The open nature of a dry-stone wall permits weathering of the face and in the open joints, reducing the area of contact and encouraging further crushing.

Percolation of ground water and waterborne salts through the fabric of the wall results in weathering and the leaching of fines from within the structure.

Salt spray resulting from deicing salts may cause deterioration in the fabric of the lower parts of the wall.

Weathering occurs more in some areas of wall than in others due to the very variable quality of the masonry used.

Random weathering and unsatisfactory foundations results in differential settlements, movements and bulging which induces acute stresses in some elements of the structure causing cracking whilst elsewhere stones become loose and may be dislodged.

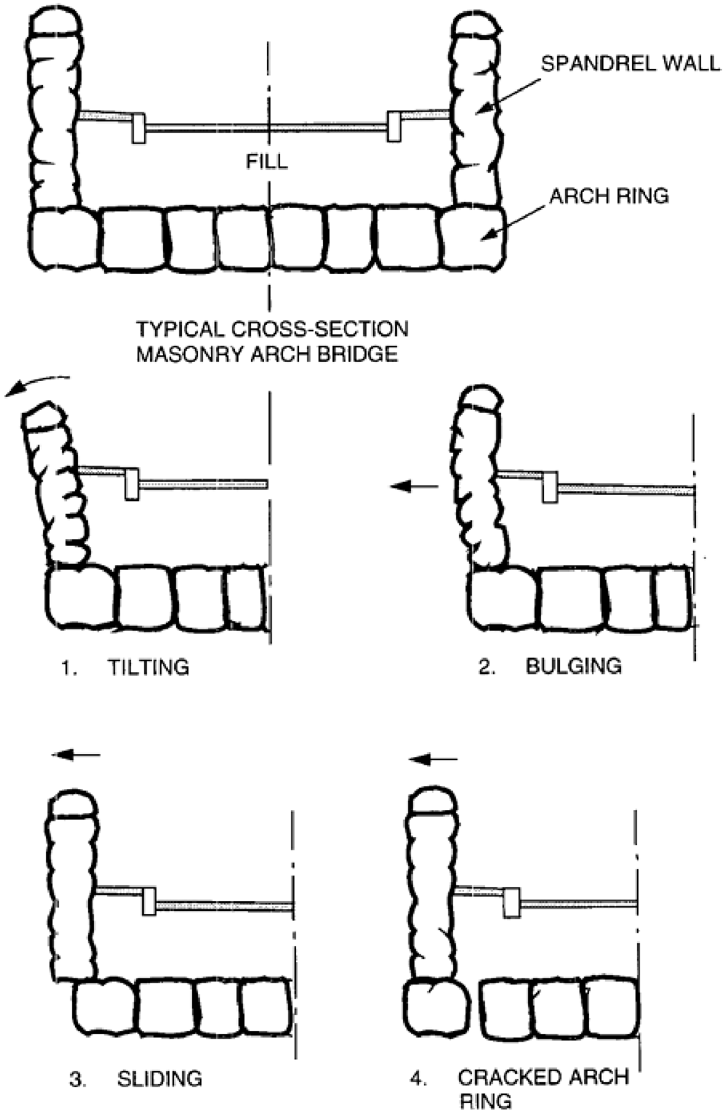
Appendix D. Spandrel walls

D1 Construction and behaviour

Spandrel walls are normally formed from dressed material and suffer the normal problems associated with exposed masonry such as weathering, loss of pointing and so forth. In addition, deterioration of bridge spandrels is frequently a function of permanent and variable lateral actions generated through the bridge infilling or as a result of direct vehicular impact. In both cases some outward movement is caused.

Lateral actions may cause the wall to rotate outward from the arch barrel, to slide on the arch barrel, to be displaced bodily outwards whilst taking part of the arch ring with it, or to bulge (see Figure D.1).

Figure D.1 Masonry spandrel wall failures



Dry-stone spandrel walls are not common. Where they occur there are difficulties, which are similar to those of dry-stone retaining walls, but the effects of variable actions are more significant.

Spandrel walls are more vulnerable to damage or displacement if no footway exists to restrain vehicles passing close to the side of the bridge. Without footpaths, vehicular impact is more likely and the effects of the lateral actions generated by the vehicle through the bridge fill may be more acute.

Poor bridge drainage may also be a feature leading to deterioration of the spandrel, particularly if saturation of the bridge fill occurs. Work on Statutory Undertakers' and Private Utilities' equipment passing through the bridge may also lead to deterioration of the spandrels by permitting an increase of water percolation into the fill, thereby reducing the shear strength of the fill.