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

PART 3

BD 68/97

CRIB RETAINING WALLS

SUMMARY

This Standard sets out the design and construction requirements for crib retaining walls.

INSTRUCTIONS FOR USE

This is a new document to be inserted into the Manual.

1. Insert BD 68/97 into Volume 2 Section 1 after Part 2.

2. 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 OFFICE DEVELOPMENT DEPARTMENT

THE WELSH OFFICE
Y SWYDDFA GYMREIG

THE DEPARTMENT OF THE ENVIRONMENT FOR
NORTHERN IRELAND

Crib Retaining Walls

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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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SECTION 1 SUBSTRUCTURES

PART 3

BD 68/97

CRIB RETAINING WALLS

Contents

Chapter

1. INTRODUCTION

General

1.1 This Standard states the design and construction requirements for crib retaining walls. It complements the Specification for Highway Works (MCHW1) which is hereafter referred to as the Specification.

1.2 The companion Advice Note (BA 68) provides a commentary to this Standard and additional information on aspects of the design and construction of crib walls.

Scope

1.3 This Standard is applicable to crib retaining walls, sloping between 70° and 85° to the horizontal and greater than or equal to 1.5 metres in height.

The ratio of the length (a) to width (b) of the crib cells shall not be greater than 2.

This Standard is not applicable to:

(1) walls with ground anchors,

(2) walls with some or all of the rear stretchers omitted,

(3) free standing walls without backfill,

(4) bridge abutments,

(5) terraced construction, where an upper crib wall is separated from a lower crib wall by a clear horizontal distance less than the height of the lower wall,

(6) walls supporting a carriageway where the clear distance from the back of the wall to the edge of the carriageway is less than the height of the wall or 4.5 metres, whichever is greater,

(7) walls where the foundations of superimposed structures are closer than 1.0 metre from the back of the crib structure.

Equivalence

1.4 The construction of crib retaining walls will normally be carried out under contracts incorporating the Specification. In such cases, products conforming to equivalent standards or technical specifications of other states of the European Economic Area, and tests undertaken in other states of the European Economic Area will be acceptable in accordance with the 104 and 105 Series of Clauses 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.

Definitions

1.5 The following definitions apply to common terms used in this Standard. Definitions of other specific terms are given as they arise or in the references quoted.

1.6 A *crib retaining wall* is a structure built up of individual elements to form a series of box-like cells into which infill is placed; the infill acts as an integral part of the structure.

1.7 A *crib cell* is a box-like structure formed from headers and stretchers into which infill is placed.

1.8 A *header* is an element that runs normal to the line of the wall.

1.9 A *stretcher* is an element that runs along the line of the wall.

1.10 *Infill* is the material placed within the crib cells.

1.11 *Backfill* is the material located behind the crib wall.

1.12 An *Approval Certificate* is a current British Board of Agrément Roads and Bridges Certificate registered with the Overseeing Organisation, as described in SA 1 (MCHW 0.3.1), or other equivalent certificate.

1.13 A *characteristic value* is a value of a material property determined from the statistical spread of the test data. In this Standard, the 95 percentile value is chosen for design purposes, i.e. 5 per cent of the test data fall above or below the characteristic value. Where adequate statistical data are not available to calculate the characteristic value, then an equivalent *nominal value* may be substituted for the characteristic value.

1.14 A *design value* is that input to a design equation defining the stability or movement of the structure.

1.15 *Superimposed loads* are the loads acting on the structure from sources other than the self-weight of the components of the crib wall, soils and fills.

1.16 The *cell surcharge load* is that load applied by the fill lying directly above the crib wall.

Implementation

1.17 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 progress. Design Organisations should confirm their application to particular schemes with the Overseeing Organisation. Where contract documents are based on the Specification for Highway Works, use of this Standard is mandatory. For use in Northern Ireland, this Standard will be applicable to those roads designated by the Overseeing Organisation.

SYMBOLS

A	m^2	cross-sectional area
a	m	clear distance between headers
B	m	distance between centre lines of front and rear stretchers of the wall measured parallel to the headers
b	m	clear distance between front and rear stretchers of a cell measured parallel to the headers
b_{hd}	m	width of header
b_{st}	m	width of stretcher
c'	kN/m^2	effective cohesion
Cu	kN/m^2	undrained shear strength
D_e	m	embedment depth
d_{hd}	m	depth of header
d_{st}	m	depth of stretcher
E	-	exp $(-z_i/z_0)$
e_s	m	eccentricity of joint loads acting on headers, including lack of fit
e_w	m	eccentricity of resultant force
F_n	kN	shear force acting normal to axis of headers
F_t	kN	shear force acting in plane of joint
f	kN/m^2	material strength
h_s	m	height of surcharge
K	-	earth pressure coefficient
K_a	-	active earth pressure coefficient
K_0	-	at-rest earth pressure coefficient
L	m	length
M	$kN.m$	moment
N	kN	normal force at joints

n_j	-	number of joints
P_n	kN	resultant of external design load components acting normal to potential failure plane
p_h	kN/m^2	horizontal earth pressure
p_v	kN/m^2	vertical earth pressure
Q_k	kN	nominal load
Q^*	kN	design load
q	kN/m^2	design maximum base pressure
q_{ult}	kN/m^2	ultimate base pressure
R	kN	resultant load
R_n	kN	normal component of resultant load
R_t	kN	tangential component of resultant load
R^*	kN	design resistance
S^*	kN	design load effects
T_{hd}	kN	tension in headers
U	m	internal perimeter of crib cell
v	N/mm^2	shear stress in concrete
v_{hd}	m	clear vertical distance between headers
v_{st}	m	clear vertical distance between stretchers
W	kN	self-weight
w	kN/m	uniformly distributed load
z_b	m	depth of backfill
z_i	m	depth of infill
z_0	m	depth parameter used in calculating infill pressures
α	-	coefficient of interaction between sliding surfaces
γ	kN/m^3	unit weight
γ_{fL}	-	partial safety factor for loads

γ_{f3}	-	partial safety factor for load effects
γ_m	-	partial safety factor for material properties
δ'	°	effective angle of interface friction between different materials
δ'_1	°	angle of interface friction between infill and crib skeleton
δ'_2	°	angle of interface friction between foundation base and subsoil
δ'_3	°	angle of interface friction between crib elements and foundation base
δ'_4	°	angle of interface friction between infill and foundation base
δ'_5	°	angle of interface friction between crib elements
δ'_6	°	angle of interface friction between retained backfill and crib skeleton
Δ	-	change in quantity
σ'	kN/m^2	effective stress
ϕ'	°	effective angle of friction of soil/fill
μ		coefficient of friction between different materials (= tan δ')

Subscripts

b	backfill
c	crib cell
cv	constant volume or critical state value
des	design value
f	front (joint)
fb	foundation
h	horizontal
hd	header
i	infill
j	joint
k	characteristic or its equivalent nominal value

m	middle (joint)
pk	peak value
rv	residual value
r	rear (joint)
s	surcharge
st	stretcher
v	vertical

2. DESIGN PRINCIPLES AND OBJECTIVES

General

2.1 Each structure or part of a structure is required to fulfil design performance requirements of stability, strength and stiffness. These requirements are expressed in terms of limit modes, and whenever a structure, or part of a structure, fails to satisfy one of these modes, it is said to have reached a limit state.

2.2 The design life of all permanent structures shall be taken as 120 years.

Limit states

2.3 The structure and the surrounding soil must be designed to perform satisfactorily for both the ultimate and serviceability limit states. These limit states are described in 2.4 and 2.5 respectively.

2.4 *The Ultimate Limit State (ULS)* is that state at which a collapse mechanism forms in the ground or in the retaining structure, or when movements lead to severe structural damage to the structure or to nearby structures or services.

2.5 *The Serviceability Limit State (SLS)* is that state at which deformations of the retaining structure affect the appearance or fitness for purpose of the structure or nearby structures or services.

2.6 Limit states are identified in terms of *limit modes*.

Limit modes

2.7 Design involves ensuring the stability of the structure, or part of the structure, against failure in a series of limit modes. The limiting criteria for a structure will generally be determined by one or more of the six limit modes specified in 2.8 to 2.13, and as shown schematically in Figure 2.1. These limit modes must be considered in design, but others identified by the designer must also be checked accordingly.

Limit modes 1 to 4 inclusive relate to the ULS, limit mode 5 relates to both the ULS and SLS, and limit mode 6 relates to the SLS.

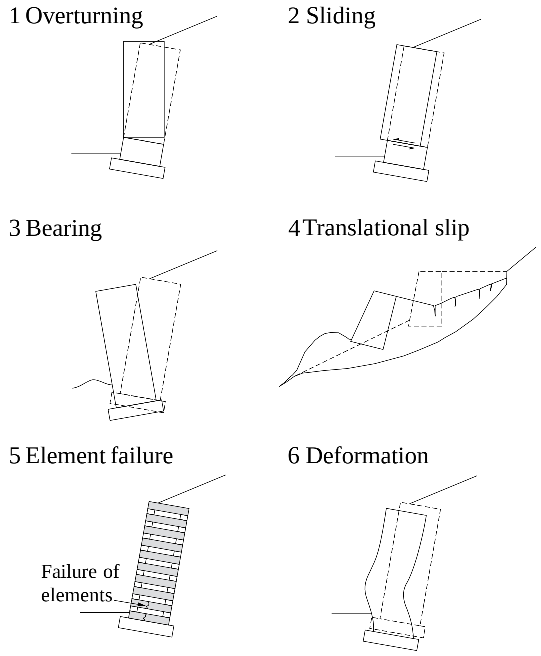


Figure 2.1 Examples of limit modes of failure

2.8 *Limit mode 1: Overturning failure.*

2.9 *Limit mode 2: Sliding failure.*

2.10 *Limit mode 3: Bearing failure of the foundation*.

2.11 *Limit mode 4: Slip failure of the soil.*

2.12 *Limit mode 5: Failure of the headers and stretchers.*

2.13 *Limit mode 6: Deformation of the structure.*

Partial factors

2.14 The following factors are used in this Standard:

(1) γ_{fL} is a partial safety factor that takes account of the possibility of an unfavourable deviation of the loads from their nominal values and of the reduced probability that various loads acting together will attain their nominal values simultaneously.

(2) γ_{f3} is a partial safety factor that takes account of inaccurate assessment of the effects of loading, unforeseen stress distribution within the structure, and variations in the dimensional accuracy achieved in construction.

(3) γ_m is a partial safety factor to cover for possible reductions in the strength of the materials in the structure as a whole, compared with the characteristic or nominal value deduced from control test specimens, and possible weaknesses in the structure due to, for example, manufacturing tolerances and compaction operations.

Loads

2.15 *Nominal loads.* Nominal loads shall be those appropriate to a return period of 120 years. Where adequate statistical data are not available, values that are considered to approximate to a 120 year return period are given in BD 37 (DMRB 1.3).

2.16 *Earth pressures.* The magnitude and distribution of earth pressures shall be calculated in accordance with the principles of soil mechanics.

2.17 *Pore water pressures.* Whenever necessary, account should be taken of transient and permanent pore water pressures. However, the stabilizing effect of negative pore water pressures shall be ignored when assessing long-term stability.

2.18 The loads to be considered in most circumstances are illustrated in Figure 2.2.

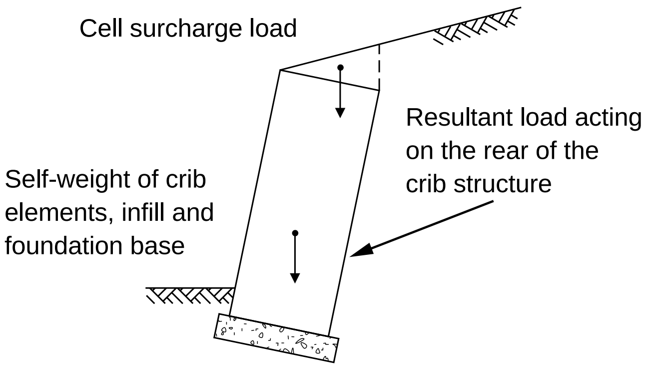


Figure 2.2 Loads that are usually considered in design

Design Values and Structural Adequacy

2.19 The design loads (Q^*) are determined from the nominal loads (Q_k) by the relation:

$$Q^* = \gamma_{fL} \cdot Q_k$$

Values of γ_{fL} are given in Chapter 3 and BD 37 (DMRB 1.3).

2.20 The design load effects (S^*) are obtained from the design loads by the relation:

$$S^* = \gamma_{f3} \cdot (\textit{effects of } Q^*)$$

Values of γ_{f3} are given in Chapter 5.

2.21 The design resistance (R^*) is defined as follows:

$$R^* = \textit{function}\left(f_{des}\right) = \textit{function}\left(\frac{f_k}{\gamma_m}\right)$$

where f_{des} is the design strength, f_k is the characteristic strength, or its equivalent nominal value, and γ_m is the partial material factor. Values of γ_m are given in Chapter 4.

2.22 For all appropriate combinations of load effects, the following shall be satisfied:

$$\Sigma R^* \geq \Sigma S^*$$

where ΣR^* and ΣS^* are the sums of the design resistances and the load effects, respectively.

3. LOADS

Self-weight

3.1 The self-weight of the crib skeleton, all soils and fills and the foundation base shall be derived as nominal loads (W_k) from the nominal unit weights of the materials.

The design self-weight (W_{des}) of these components shall be determined from:

$$W_{des} = W_k \cdot \gamma_{fL}$$

where the values of γ_{fL} are given in Table 3.1.

	ULS	SLS
Disturbing Effect	1.2	1.0
Restoring Effect	1.0	1.0

Table 3.1 Values of partial safety factors for self-weight

Superimposed loads

3.2 The loads from superimposed structures shall be input into the design equations (with their appropriate partial safety factors) directly as design loads.

Vertical earth pressures

3.3 The design vertical pressures generated at a depth z_i in the crib cells ($p_{vi\,des}$) shall be determined as follows:

$$p_{vi\,des} = \gamma_{fL} \cdot \left(\gamma_{ik} . z_0 . \ (1 - E) + \gamma_{sk} \cdot h_s \cdot E\right)$$

where γ_{fL} = 1.2 or 0.8 for the ultimate limit state, whichever provides the most adverse effect, and is 1.0 for the serviceability limit state,

γ_{ik} is the nominal unit weight of the infill,

$$z_0 = A_c / \left(U . \ K_0 \ . \ \tan\delta'_{1\,des}\right)$$

where A_c is the clear cross-sectional area of the crib cell,

U is the internal perimeter of the crib cell,

$$K_0 = 1 - \sin \ \phi'_{i\,des} \ ,$$

$\tan \delta'_{1\,des}$ is the design value of the tangent of the angle of interface friction between the infill and the crib skeleton,

γ_{sk} is the nominal unit weight of the surcharge soil,

h_s is the height of the surcharge, and

$$E = \exp \left(-z_i / z_0\right)$$

3.4 The design vertical pressures generated at a depth z_b in the backfill ($p_{vb\,des}$) shall be determined as follows:

$$p_{vb\,des} = \gamma_{fL} \cdot \left(\gamma_{bk} \cdot z_b + \gamma_{sk} \cdot h_s\right)$$

where values of γ_{fL} are given in Table 3.1, γ_{bk} is the nominal unit weight of the backfill, and the other symbols are as defined above.

Horizontal earth pressures

3.5 Horizontal effective pressures (σ'_h) shall be determined from the vertical effective pressures (σ'_v), and the coefficient of lateral earth pressure (K). Where applicable, the effects of friction acting on the crib skeleton, the inclination of the wall face, and the presence of a surcharging slope shall be taken into account.

3.6 The design horizontal pressures generated in the crib cells ($p_{hi\,des}$) and the backfill ($p_{hb\,des}$) shall be determined as follows:

$$p_{hi\,des} = K_{des} \cdot p_{vi\,des}$$

$$p_{hb\,des} = K_{des} \cdot p_{vb\,des}$$

where for the infill: $K_{des} = K_0$

and for the backfill: $K_{des} = K_0$ or $K_{des} = K_a$, values of K_a are provided in BS 8002 : 1994.

The design value of K shall be derived from the design values of its controlling parameters, such as $\sin \phi'_{i\,des}$ - the design value of the sine of the angle of friction of the infill.

Passive earth pressures

3.7 Any beneficial earth pressures exerted on the face of the structure shall be ignored when assessing stability.

Pore water pressures

3.8 The possibility of fluid leakage from any services in the vicinity of the structure shall be taken into account.

Combination of loads

3.9 Consideration shall be given to the coexistence of the various loads when assessing each limit mode.

3.10 Sufficient checks should be completed to ensure that the most critical application of a particular combination of loads has been assessed.

4. STRENGTH OF COMPONENTS

General

4.1 Where design is based on assumed strength parameters, the properties of the structural components shall be measured prior to construction to ensure that the actual values are not inferior to those assumed in design.

Shear strength of soils and fills

4.2 The shear strength of a soil or fill can be characterised in terms of an effective angle of friction (ϕ') and an effective cohesion (c'); these are dealt with in 4.3 and 4.4 respectively. However, where undrained conditions are assumed to apply, shear strength may be based on the undrained cohesion (Cu) of the material; this is dealt with in 4.5.

4.3 Angle of friction

(1) The design value of the tangent of the angle of friction ($\tan \phi'_{des}$) may be taken to be the lesser of:

$$\frac{\tan \phi'_{pk}}{1.2} \quad \textit{and} \quad \tan \phi'_{cv}$$

i.e. γ_m values of 1.2 and 1.0 are applied respectively to the characteristic, or equivalent nominal, peak (ϕ'_{pk}) and critical (ϕ'_{cv}) angles of friction.

(2) Where the structure is sited in ground which has previously experienced movements, the parent soil may contain relic shear planes along which the shear strength approaches a residual value consistent with the re-orientation of the soil particles. In such cases, the design shear strength shall be based on the residual angle of friction (ϕ'_{cv}) of the soil; thus,

$$\tan \phi'_{des} = \frac{\tan \phi'_{rv}}{\gamma_m}$$

the value of γ_m shall adequately reflect the uncertainties in the method used to derive the value of ϕ'_{rv}.

4.4 Effective cohesion

For most practical purposes the effective cohesion of soils and fills can be assumed to be zero. However, for self-cementing materials and heavily over-consolidated soils, an effective cohesion may be derived from the results of shear tests.

Where designs are based on the peak angle of friction, the design value of the effective cohesion (c'_{des}) shall be derived from the effective cohesion generated concurrently with the peak angle of friction; thus,

$$c'_{des} = \frac{c'}{1.2}$$

i.e. a γ_m value of 1.2 is applied to the characteristic, or equivalent nominal, effective cohesion.

It is inappropriate to take account of any effective cohesion where designs are based on the critical or the residual angle of friction.

4.5 Undrained shear strength

The design undrained shear strength (Cu_{des}) shall be derived from measured values; thus,

$$Cu_{des} = \frac{Cu}{1.5}$$

i.e. a γ_m value of 1.5 is applied to the characteristic or equivalent nominal, undrained shear strength.

Shear strength of interfaces between different materials

4.6 The shear strength of an interface between different materials can be characterised in terms of an effective angle of interface friction (δ') and an adhesion. The former is dealt with in 4.7, but for the purposes of this Standard, adhesive forces shall be ignored.

4.7 Angle of interface friction

The design value of the tangent of the angle of interface friction ($\tan \delta'_{des}$) shall be the lesser of:

$$\frac{\tan \delta'_{pk}}{1.2} \;,\quad \tan \delta'_{cv} \;,\quad \frac{\tan \phi'_{des}}{1.33}$$

i.e. γ_m values of 1.2 and 1.0 are applied respectively to the tangent values of the peak (δ'_{pk}) and critical (δ'_{cv}) angles of interface friction; and a value of 1.33 is applied to tan ϕ'_{des} for the soil or fill. Where the interface is between two such materials, the lower value of tan ϕ'_{des} shall be used.

In the absence of measured values, the design value of tan δ' for sliding between a soil or fill and another structural component may be based on the design value of tan ϕ' for the soil/fill; thus,

$$\tan \delta'_{des} = \alpha . \tan \phi'_{des}$$

where $\alpha \not> 0.75$.

In some cases it may be more convenient to describe the frictional forces between two materials in terms of a coefficient (μ) rather than by a tangent angle (δ'), where $\mu_{des} = \tan \delta'_{des}$.

Mechanical interaction

4.8 The strength of interlocking devices shall not be relied upon to provide any shear resistance between crib elements.

Bearing capacity of soils and fills

4.9 The bearing capacity of soils and fills shall be determined in accordance with the principles of soil mechanics.

Strength of reinforced concrete components

4.10 The values of γ_m for reinforced concrete components shall be in accordance with BD 24 (DMRB 1.3).

Strength of proprietary products

4.11 The values of f_k and γ_m, or the value of f_{des}, for a proprietary product shall be taken from the current Approval Certificate.

5. DESIGN

General

5.1 The design principles defined in Chapter 2 shall be followed with the input values to the design equations being derived according to Chapter 3 for loads, and to Chapter 4 for the strength of the components.

Limit mode 1 : Overturning failure

5.2 Overturning about the following points shall be checked:

(1) toe of the foundation base,

(2) toe of the crib structure,

(3) about any joint between the crib elements at the front of the wall.

In each case the section of the structure considered as the potential toppling body shall be treated as a monolith.

5.3 The following condition shall be satisfied for all appropriate combinations of load:

$$\sum M_{RS} \geq \gamma_{f3} . \sum M_{OT}$$

where ΣM_{RS} is the sum of the design restoring moments,

γ_{f3} for this limit mode has a value of 1.1, and

ΣM_{OT} is the sum of the design overturning moments.

Calculations shall be based on active earth pressures acting on the back of the crib structure.

Limit mode 2 : Sliding failure

5.4 Sliding along the following potential failure planes shall be checked:

(1) between the foundation base and the subsoil,

(2) between the crib structure and the foundation base,

(3) within the crib structure.

5.5 The following condition shall be satisfied for all appropriate combinations of load:

$$\sum R^* \geq \gamma_{f3} . \sum R_t$$

where ΣR^* is the sum of the design sliding resistances generated along the potential failure plane,

γ_{f3} for this limit mode has a value of 1.1, and

ΣR_t is the sum of the design load components acting parallel to the potential failure plane.

Calculations shall be based on active earth pressures acting on the back of the crib structure.

5.6 For 5.4 (1), ie sliding between the foundation base and subsoil, the design resistance (R^*) shall be determined from:

$$R^* = \left[\Sigma W. \tan \delta'_2\right]_{des}$$

where ΣW_{des} is the design total load, determined from the design values of the loads (W_c , W_i , W_{fb} , P_n), that act *normal* to the interface considered,

$W_{c\ des}$ being the design self-weight of the crib skeleton,

$W_{i\ des}$ the design self-weight of the infill,

$W_{fb\ des}$ the design self-weight of the foundation, and

$P_{n\ des}$ is the sum of the external design load components (including any surcharging slope),

$\tan \delta'_{2\ des}$ is the design value of the tangent of the angle of interface friction between the foundation base and subsoil.

5.7 For 5.4 (2), ie sliding between the crib structure and the foundation, the design resistance (R^*) shall be determined from:

$$R^* = \left[\left(W_c + W_i - \Sigma\left(p_{vi} . b\right) + P_n\right) . \tan \delta'_3 + \Sigma\left(p_{vi} . b\right) . \tan \delta'_4\right]_{des}$$

where, in addition to the definitions above,

$\tan \delta'_{3\,des}$ is the design value of the tangent of the angle of interface friction between the crib elements and the foundation base,

$\Sigma(p_{vi}.b)_{des}$ is the sum of the products of the design vertical earth pressure (determined in accordance with 3.3) and the nominal clear distance between stretchers for the column of cells at the cross-section considered,

$\tan \delta'_{4des}$ is the design value of the tangent of the angle of interface friction between the infill and the foundation.

5.8 For 5.4 (3), ie sliding through the crib structure, the design resistance (R^*) shall be determined from:

$$R^* = \left[\left(W_c + W_i - \Sigma\left(p_{vi}\,.\,b\right) + P_n\right).\ \tan\delta'_5 + \Sigma\left(p_{vi}\,.\,b\right).\ \tan\phi'_i\right]_{des}$$

where , in addition to the factors defined above,

$\tan \delta'_{5\,des}$ is the design value of the tangent of the angle of interface friction between the crib elements, and

$\tan \phi'_{i\,des}$ is the design value of the tangent of the angle of friction of the infill.

The presence of packers, shims or bedding materials between the elements must be taken into account when determining the design value of $\tan \delta'_5$: for reinforced concrete elements the value of $\tan \delta'_{5\,des}$ shall, in the absence of measured values, not be greater than 0.5.

The effect of lugs, interlocking dowels, etc shall be ignored when assessing sliding resistance between the crib elements.

Limit mode 3 : Bearing failure of the foundation

5.9 The following condition shall be satisfied for all combinations of load:

$$q_{ult} \geq \gamma_{f3}\,.\,q$$

where q_{ult} is the design ultimate bearing capacity of the soil,

γ_{f3} for this limit mode has a value of 1.1, and

q is the design maximum base pressure.

Calculations shall be based on active earth pressures acting on the back of the crib structure.

5.10 The crib structure shall be treated as a monolith. A trapezoidal distribution of pressure shall be assumed to apply at the base of the foundation, and the pressure distribution for all load combinations shall be wholly compressive over the area of the foundation.

Limit mode 4 : Slip failure of the soil

5.11 Overall stability shall be checked by considering rotational and translational slips. The potential failure surface may be modelled as:

(i) a slip circle, or

(ii) a wedge formed by the intersection of two or more planar surfaces.

In assessing stability, it may be assumed that each block of soil behaves as a monolith.

5.12 The following condition shall be satisfied for all appropriate combinations of load:

$$\sum R^* \geq \gamma_{f3} \sum S^*$$

where ΣR^* is the sum of the design resistance to movement of the block,

γ_{f3} for this limit mode has a value of 1.1, and

ΣS^* is the sum of the design load effects.

5.13 The design resistance (R^*) of a potential slip surface through a soil or a fill can be determined from:

(1) for effective stress analyses,

$$R^* = \left[N.\tan\phi' + c'.L\right]_{des}$$

where N is the resultant of the design load components acting normal to the potential slip surface,

$\tan \phi'_{des}$ is the design value of the tangent of the angle of friction of the material,

c'_{des} is the design effective cohesion of the material, and

L_{des} is the length over which cohesion is deemed to be generated.

(2) for undrained conditions,

$$R^* = [Cu.L]_{des}$$

where Cu_{des} is the undrained shear strength of the material, and

L_{des} is the length over which shear resistance is deemed to be generated.

For both (1) and (2) above the design shear resistance of a potential slip surface between different soils and/or fills shall be taken as the lowest value of R^* determined for the materials.

Limit mode 5: Failure of the headers and stretchers

5.14 The following shall be considered:

(1) headers and stretchers spanning between joints, considered both as simply supported and with fixed ends, and loaded by pressures determined according to 5.16,

(2) bearing failure at joints due to forces determined according to 5.17,

(3) rupture of the headers at joints between the crib elements due to forces determined according to 5.18.

5.15 The following condition shall be satisfied for all combinations of load:

$$R^* \geq \gamma_{f3} \,.\, \Sigma S^*$$

where R* is the design strength of the element or joint,

γ_{f3} for this limit mode has a value of 1.1 for the ultimate limit state and a value of 1.0 for the serviceability limit state, and

ΣS^* is the sum of the design loads to be resisted.

Calculations shall be based on at rest pressures acting on the back of the crib structure and within the crib cell.

5.16 For 5.14 (1), ie failure of the headers and stretchers spanning between joints, the design earth pressures at depth z_i within the crib cell shall be determined in accordance with 3.3 and 3.6.

The earth pressures acting on the elements due to the infill and backfill are defined in Table 5.1 and Figure 5.1.

The design tensile load, $T_{hd\,des}$, to be sustained by the headers, shall be determined as follows:

$$T_{hd\,des} = \Delta P_h \,.\, a \,.\, (d_{st} + v_{st})$$

where a is the nominal clear distance between the headers,

Δ_{ph} is the maximum positive value of the design horizontal earth pressure within a crib cell ($p_{hi\,des}$) less the design horizontal earth pressure adjacent to that cell. For the front column of cells the adjacent cell pressure shall be taken to be zero,

d_{st} is the nominal depth of the stretchers, and

v_{st} is the nominal clear vertical distance between the stretchers.

Rear Stretcher	σ_{hi}	$p_{hi} \,.\, (d_{st} + v_{st})/d_{st}$
	σ_{vi}	$p_{hi} \,.\, tan\delta'_1 \,.\, (d_{st} + v_{st})/d_{st}$
	σ_{v}	$\gamma_i \,.\, v_{st}$
	σ_{hb}	$p_{hb} \,.\, (d_{st} + v_{st})/d_{st}$
	σ_{vb}	$p_{hb} \,.\, tan\delta'_6 \,.\, (d_{st} + v_{st})/d_{st}$
Front Stretcher	σ_{hi}	$0.5p_{hi} \,.\, (d_{st} + v_{st})/d_{st}$
	σ_{vi}	$0.5p_{hi} \,.\, tan\delta'_1 \,.\, (d_{st} + v_{st})/d_{st}$
	σ_{v}	$0.5\gamma_i \,.\, v_{st}$
Header	σ_{hi}	$p_{hi} \,.\, (d_{hd} + v_{hd})/d_{hd}$
	σ_{vi}	$p_{hi} \,.\, tan\delta'_1 \,.\, (d_{hd} + v_{hd})/d_{hd}$
	σ_{v}	$\gamma_i \,.\, v_{hd}$

Table 5.1 Values of infill pressure (for clarity the subscript *des* has been omitted from the above)

5.17 For 5.14 (2), ie bearing failure of the joints, it shall be assumed that the normal component of the load carried by the joints (R_{nj}) is the normal component of the total resultant load (R_n) less the normal component of the load carried by the infill (R_{ni}). These loads are illustrated in Figure 5.2 and may be determined as follows:

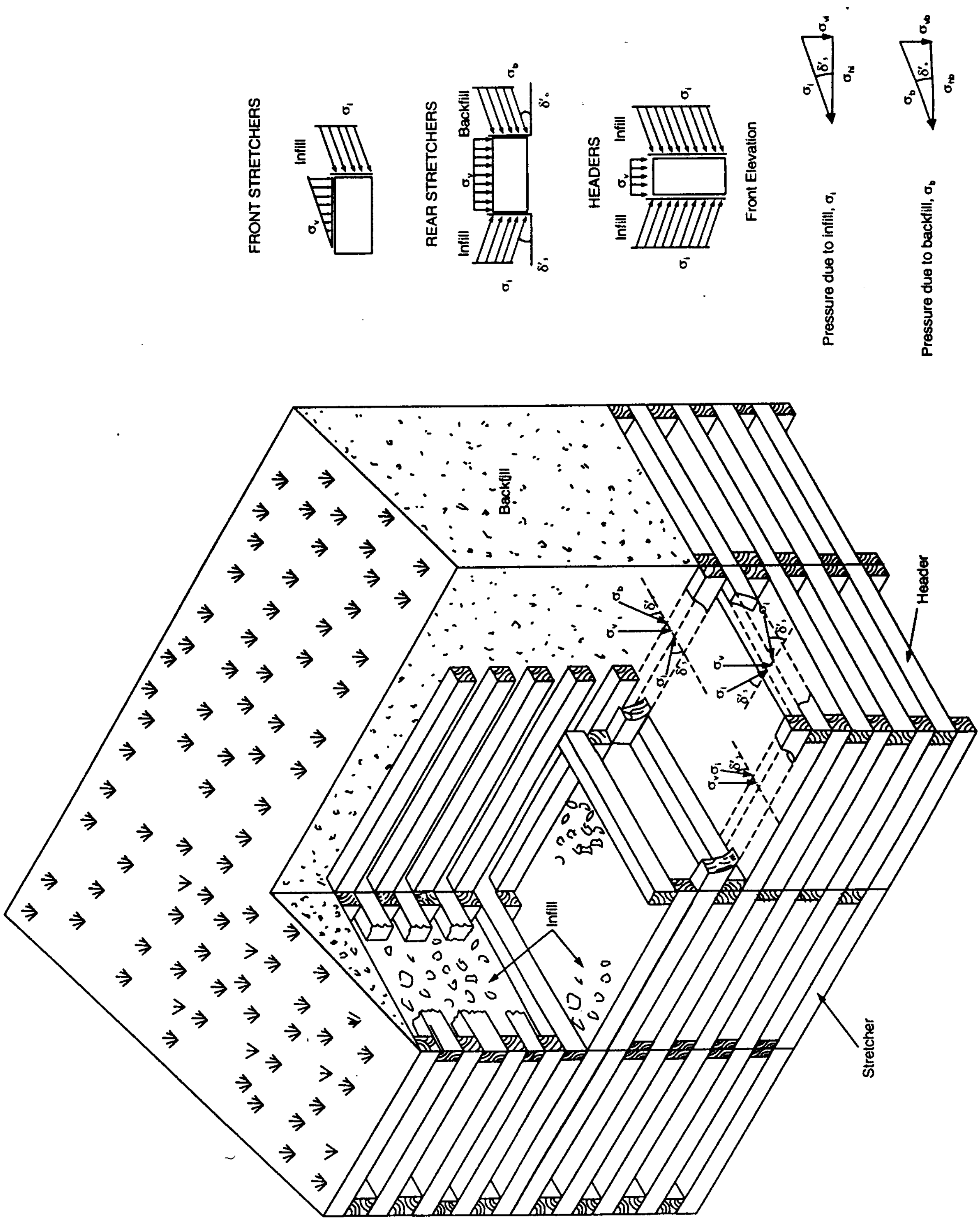
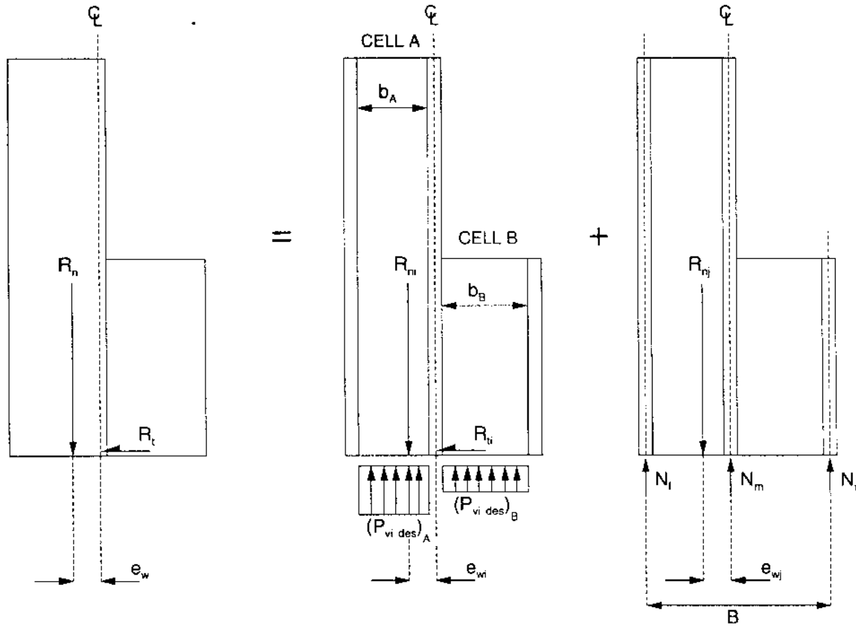


Figure 5.1 Loading on elements due to earth pressure



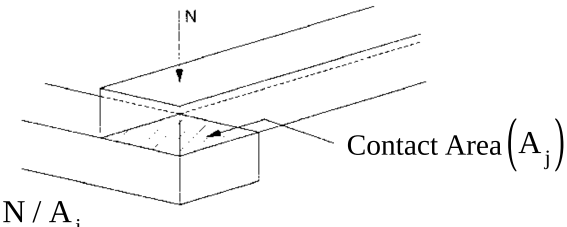
$$e_w \not> B/6$$

$$R_{ni} = \Sigma\left[\left(P_{vi\ des} \cdot b\right)_A + \left(P_{vi\ des} \cdot b\right)_B + \ldots + \left(P_{vi\ des} \cdot b\right)_n\right]$$

$$R_n = R_{ni} + R_{nj}$$

$$R_n \cdot e_w = R_{ni} \cdot e_{wi} + R_{nj} \cdot e_{wj}$$

For purposes of design: $e_{wj} \not< B/12$



Bearing stress $\sigma_j = N / A_j$

Figure 5.2 Joint loads and bearing stresses

(i) calculate the component of the resultant of the applied loads acting normal to the section being considered (R_n), assuming the wall above that section acts as a monolith.

(ii) the eccentricity of the resultant force from the centreline of the wall (e_w) shall not be greater than B/6, where B is the distance between the centrelines of the front and rear stretchers at the section considered, as illustrated in Figure 5.2.

(iii) assume that the load per unit length carried by the crib infill (R_{ni}) is the sum of the products of the design vertical earth pressure within the crib cells ($p_{vi\ des}$), (determined in accordance with 3.3, and the width of the cells (b) for that section). Calculate the eccentricity (e_{wi}) from the wall centreline of the resultant force carried by the infill.

(iv) The normal component of the resultant of the loads carried by the joints (R_{nj}) and its eccentricity of the wall centreline (e_{wj}) shall be determined from:

$$R_{nj} = R_n - R_{ni}$$

$$R_{nj} \cdot e_{wj} = R_n \cdot e_w - R_{ni} \cdot e_{wi}$$

(v) for the purposes of determining joint loads, e_{wj} shall be taken as the greater of the actual value or B/12.

(vi) the normal loads (N) at the joints between elements shall be taken as the sum of the normal load (R_{nj}) distributed between the joints and the effect of the moment $R_{nj} \cdot e_{wj}$.

For a single cell crib wall

$$N_f\ ,\ N_r\ =\ R_n\left(0.5\ \pm\ \frac{e_w}{B}\right)$$

and for a double cell crib wall

$$N_f\ ,\ N_r\ =\ R_n\left(0.25\ \pm\ \frac{e_{wj}}{B}\right)$$

$$N_m\ =\ \frac{R_{nj}}{2}$$

where N_f, N_m and N_r are the normal loads at the front, middle and rear joints respectively.

For walls of three or more cells wide, the normal loads can be determined by adopting any reasonable distribution of forces in equilibrium with the applied loads.

The bearing stress (σ_j) at a joint is given by:

$$\sigma_j\ =\ \frac{N}{A_j}$$

where A_j is the contact area between the elements.

5.18 For 5.14 (3), ie rupture of the headers at joints, the forces to be considered are illustrated in Figure 5.3 and are as follows:

(i) normal loads (N) determined in accordance with 5.17 and the associated moment due to the eccentricity (e_s) caused by lack of fit between units. The minimum eccentricity (e_s) between upper and lower normal joints loads shall be taken as 10mm.

(ii) shear force acting in the plane of the joints (F_t) and the associated moment ($F_t \cdot d_{hd}$). The shear force (F_t) shall be determined assuming the tangential component of the resultant load at the section considered is distributed to the joints in proportion to the normal load carried by each joint. No part of the tangential load is distributed to the crib infill, ie:

$$F_t\ =\ N\ .\ \frac{R_t}{R_{nj}}$$

where N is the normal load at the joint determined in accordance with 5.17,

R_{nj} is the normal component of the resultant load carried by the joints determined in accordance with 5.17,

R_t is the tangential component of the total resultant load.

(iii) Tension in the headers (T_{hd}) determined in accordance with 5.16.

(iv) Moment in the headers due to end restraint of the header spanning between joints, loaded by pressures determined in accordance with 5.16.

(v) Vertical shear in headers (F_n) taken as the greater of:

(a) the shear force (F_n) resulting from the distribution of normal joint loads (N) in the wall. It shall be assumed that the full joint load is transferred to the wall via shear in the headers and that shear forces vary linearly from zero at the top of the wall to a maximum at the base, with due cognisance being taken of changes in wall section. The normal joint loads at the top of part-height buried wall sections shall be determined from the backfill pressures acting on the rear stretchers. The effect of backfill pressures acting on the back of the wall may also be considered when determining the shear force in the headers.

(b) The shear force (F_n) calculated considering the header spanning between joints loaded by the pressures determined in accordance with 5.16.

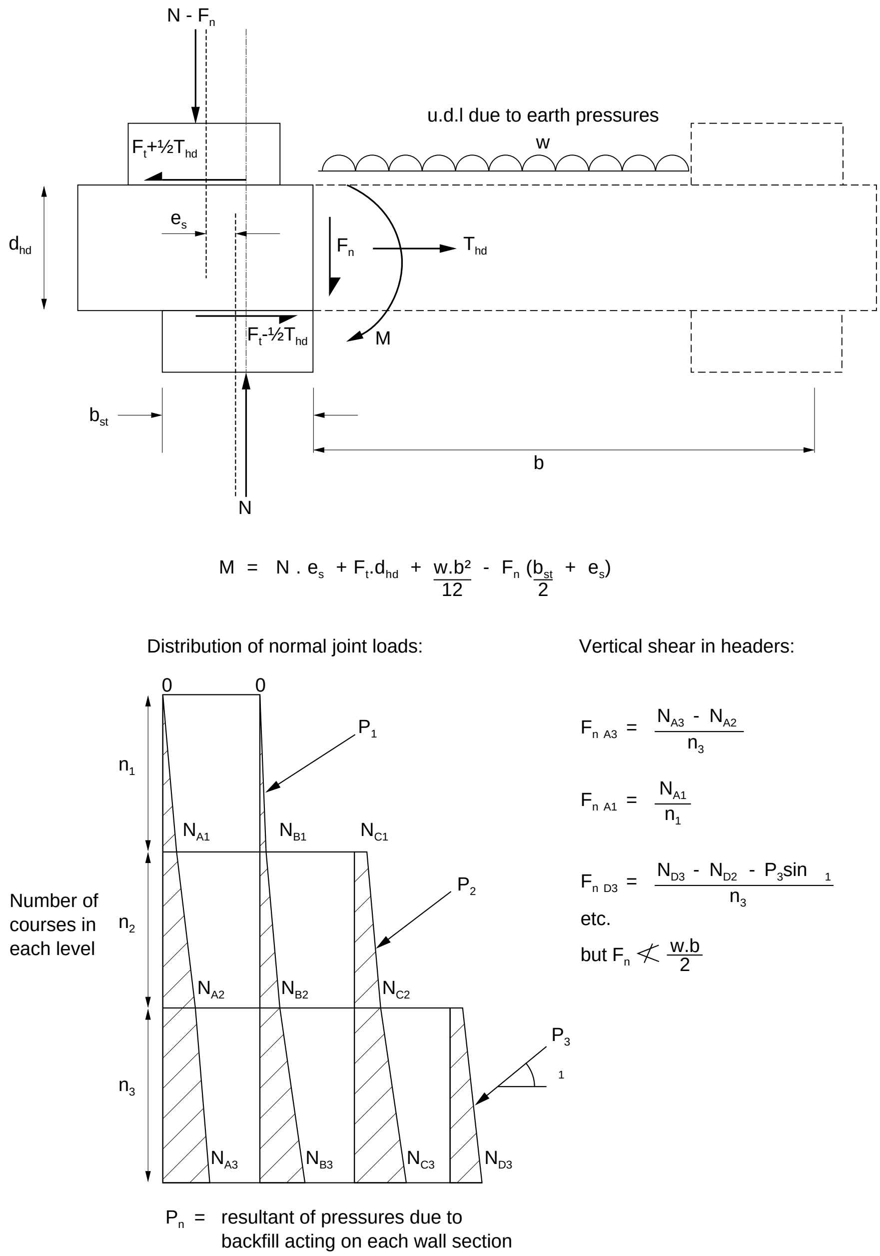


Figure 5.3 Forces acting on headers

Limit mode 6 : Deformation

5.19 The following shall be checked:

(1) settlement of the structure,

(2) lateral distortion of the structure, and

(3) rotation and translation of the structure.

5.20 The permissible deformation at the end of construction is to be specified by the designer, and checked against the actual deformation of the structure on site.

The designer should ensure that the design of the structural elements takes account of the forces generated by:

(1) the predicted final deformed profile of the structure compared with the initial 'as built' profile;

(2) the final deformed profile of the structure being different from that predicted due to unforeseen 'hard' and 'soft' spots in the bearing stratum or strata.

6. MATERIALS AND CONSTRUCTION DETAILS

General

6.1 The components of the structure shall be designed for a service life of 120 years.

Materials

6.2 *Fills.* Infill material shall be of class 6N complying with Table 6/1 of the Specification, having a permeability coefficient greater than $1x10^{-3}$ cm/sec and a maximum nominal particle size less than 0.1 times the minimum cell dimension. Backfill shall be of 6N complying with Table 6/1 of the Specification.

6.3 *Crib elements.* The crib elements are usually formed from either:

(1) reinforced concrete, or

(2) timber.

6.4 *Concrete components.* Concrete components shall meet the requirements of the clause 1700 series of the Specification, and the concrete shall be not less than Grade 30. The requirements of BD 24 (DMRB 1.3) regarding the cover to the reinforcements and crack widths shall be met. Where the design shear stress (υ) exceeds the design ultimate shear resistance (υ_c) of an element, shear reinforcement shall be provided in accordance with Table 7 of BS 5400 : Part 4 : 1990 as implemented by BD 24. Where the design shear stress is less than the design ultimate shear resistance of an element, shear reinforcement can be omitted provided that a minimum factor of safety of 1.25 can be demonstrated from appropriate tests.

6.5 *Timber components.* An independent Approval Certificate for the durability of timber components is required.

6.6 *Proprietary products.* Crib wall construction may make use of proprietary products for which no British Standard exists. In such cases an independent Approval Certificate is required. This ensures that the properties of the material are clearly defined, that the product is suitable for the purpose for which it is intended, and that it is possible to maintain adequate production quality control.

6.7 *Metallic components.* Metallic components, other than used for reinforcing concrete, shall consist of:

(1) carbon steel, to BS EN 10025 (1993), galvanized in accordance with BS 729 (1986), or

(2) grade 316S31 or 316S33 stainless steel, to BS 1449 (1983).

These components shall have a non-structural sacrificial thickness to allow for corrosion: the appropriate minimum sacrificial thicknesses for each surface are:

(1) carbon steel 0.75mm

(2) stainless steel 0.10mm

* Metallic dowels or interlocking devices between crib elements shall not be used.

6.8 *Joints and spacers.* Joint fillers and spacers between the crib elements shall be resistant to the effect of air pollution, exposure to sunlight and water which may be contaminated with, for example, de-icing salts.

Construction procedure

6.9 The profile of any excavation required for the backfill shall be benched to enable proper compaction of the backfill to be achieved, and to establish an effective key between the backfill and the existing ground.

6.10 The wall shall be filled and backfilled as the crib is erected. Construction of the crib skeleton shall not precede the placement of the infill or backfill by more than three courses of elements. Filling of adjacent crib cells shall, as far as possible, be carried out at equal rates with the maximum permitted differential not exceeding three courses.

Foundations

6.11 A reinforced or plain concrete strip foundation shall be provided beneath the full width of the wall, but this may be substituted by a bedding layer of mortar where the wall is founded on rock or other suitably hard material.

6.12 The toe of the structure shall be embedded below the finished ground level by not less than 800mm. Embedment depth, D_e, is defined in Figure 6.1. Greater embedment depths shall be considered on sites where erosion is possible.

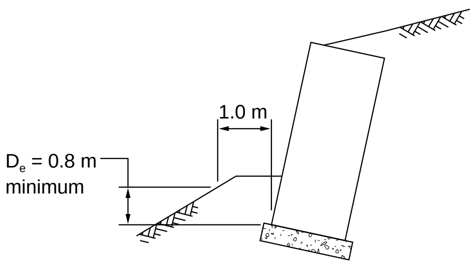


Figure 6.1 Definition of embedment depth, D_e

Crib elements

6.13 Elements are to be free from defects that may impair strength and durability.

6.14 The minimum area of reinforcement in reinforced concrete crib elements shall be 0.9 per cent of their gross cross-sectional area. The reinforcement shall be suitably distributed to resist the design load effects, and the spacers used to locate the reinforcement shall not generate stress concentrations detrimental to the performance of the element.

6.15 Headers at any one section shall lie in a vertical plane and shall not be staggered unless they are designed to withstand the additional loading. Support blocks, or 'false headers', may be used in such cases to reduce bending in the stretchers. These support blocks shall be dimensioned so as not to cause additional restraints and stresses due to lack-of-fit.

6.16 Elements that are cut to size on site for corners and curved walls shall be treated to ensure adequate durability at the cut faces.

Drainage

6.17 The retained ground shall be adequately drained to prevent the build-up of water behind the wall.

6.18 A continuous system of perforated or porous drainage pipes, not less than 150mm in diameter, shall be provided at the rear of the structure at foundation level. Adequate provision shall be made for such drains to be maintained by rodding.

6.19 When necessary a filter shall be provided to prevent the contamination of the backfill or infill from the ingress of fines. The possible introduction of a slip surface along this filter must be considered in design.

Planting

6.20 Consideration shall be given to the need to ensure there will be an adequate supply of moisture to establish and to support vegetation before a decision to include planting is taken. Advice on planting may be found in 'The Good Roads Guide' (DMRB Vol 10). Topsoil required for growth of vegetation on the front face of the wall shall be prevented from contaminating the infill. The effects of planting on the stability of the wall must be properly assessed and considered in design.

Services

6.21 The possible effects arising from the presence of services adjacent to the crib structure shall be examined. The installation, maintenance, removal and replacement of the services shall also be considered.

Excavation in front of a crib structure

6.22 Consideration shall be given to possible excavations in front of a crib structure and their effect shall, where appropriate, be taken into account in design.

Vehicle containment

6.23 Where a crib wall retains a carriageway, the wall shall be protected from accidental wheel loads by an appropriate vehicle restraint system.

6.24 Where a carriageway is located at the toe of a crib wall, the face of the wall shall be protected by an appropriate vehicle restraint system.

7. REFERENCES

7.1 Design Manual for Roads and Bridges (HMSO)

Volume 1: Section 3 General Design

BD 24 The Design of Concrete Highway Bridges and Structures. Use of BS 5400 : Part 4 : 1990. (DMRB 1.3.1)

BD 37 Loads for Highway Bridges. (DMRB 1.3)

Volume 10: Environmental Design

7.2 Manual of Contract Documents for Highway Works (HMSO)

Volume 0: Model Contract Document for Major Works and Implementation Requirements. Advice Notes (MCHW 0.3)

SA 1 Lists of Approved/Registered Products. (MCHW 0.3.1)

Volume 1: Specification for Highway Works HMSO 1993. (MCHW 1).

7.3 British Standards (BSI)

BS 729 : 1971 (1986). Specification for Hot Dip Galvanized Coatings on Iron and Steel Articles.

BS 1449 : Part 2 : 1983. Specification for Stainless and Heat Resisting Steel Plate, Sheet and Strip.

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

BS 8004 : 1986. Code of Practice for Foundations.

BS EN 10025 : 1993. Hot Rolled Products of Non-Alloy Structural Steels.

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

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