Practical Design to Eurocode 2

The webinar will start at 12.30

Course Outline

Lecture	Date	Speaker	Title
1	21 Sep	Jenny Burridge	Introduction, Background and Codes
2	28 Sep	Charles Goodchild	EC2 Background, Materials, Cover and effective spans
3	5 Oct	Paul Gregory	Bending and Shear in Beams
4	12 Oct	Charles Goodchild	Analysis
5	19 Oct	Paul Gregory	Slabs and Flat Slabs
6	26 Oct	Charles Goodchild	Deflection and Crack Control
7	2 Nov	Paul Gregory	Columns
8	9 Nov	Jenny Burridge	Fire
9	16 Nov	Paul Gregory	Detailing
10	23 Nov	Jenny Burridge	Foundations

Foundations

Lecture 10

23rd November 2017

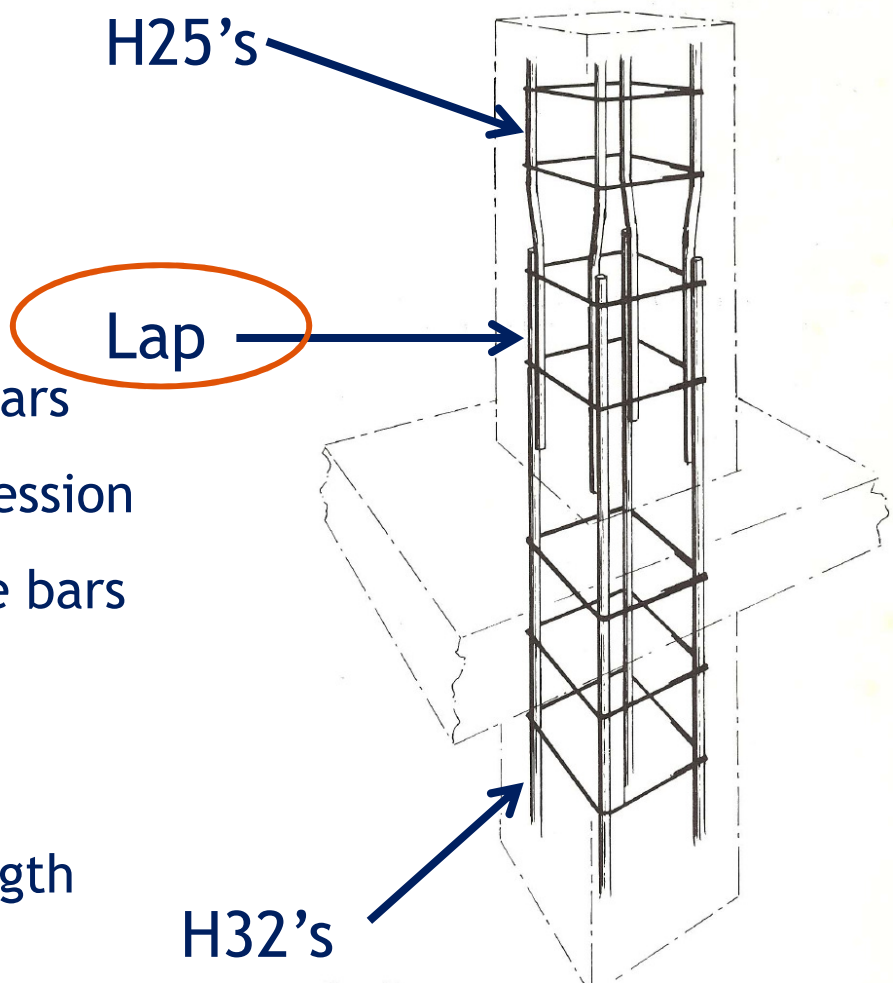
Lecture 9 Exercise

Lap length for column longitudinal bars

Column lap length exercise

Design information

- C40/50 concrete
- 400 mm square column
- 45mm nominal cover to main bars
- Longitudinal bars are in compression
- Maximum ultimate stress in the bars is 390 MPa



Exercise:

Calculate the minimum lap length using EC2 equation 8.10:

$$l_0 = \alpha_1\ \alpha_2\ \alpha_3\ \alpha_5\ \alpha_6\ l_{b,rqd} \geq l_{0,min}$$

Column lap length exercise

Procedure

- Determine the ultimate bond stress, f_{bd} — EC2 Equ. 8.2
- Determine the basic anchorage length, $l_{b,req}$ — EC2 Equ. 8.3
- Determine the design anchorage length, l_{bd} — EC2 Equ. 8.4
- Determine the lap length, l_0 = anchorage length x α_6

Model Answers

Lap length for column longitudinal bars

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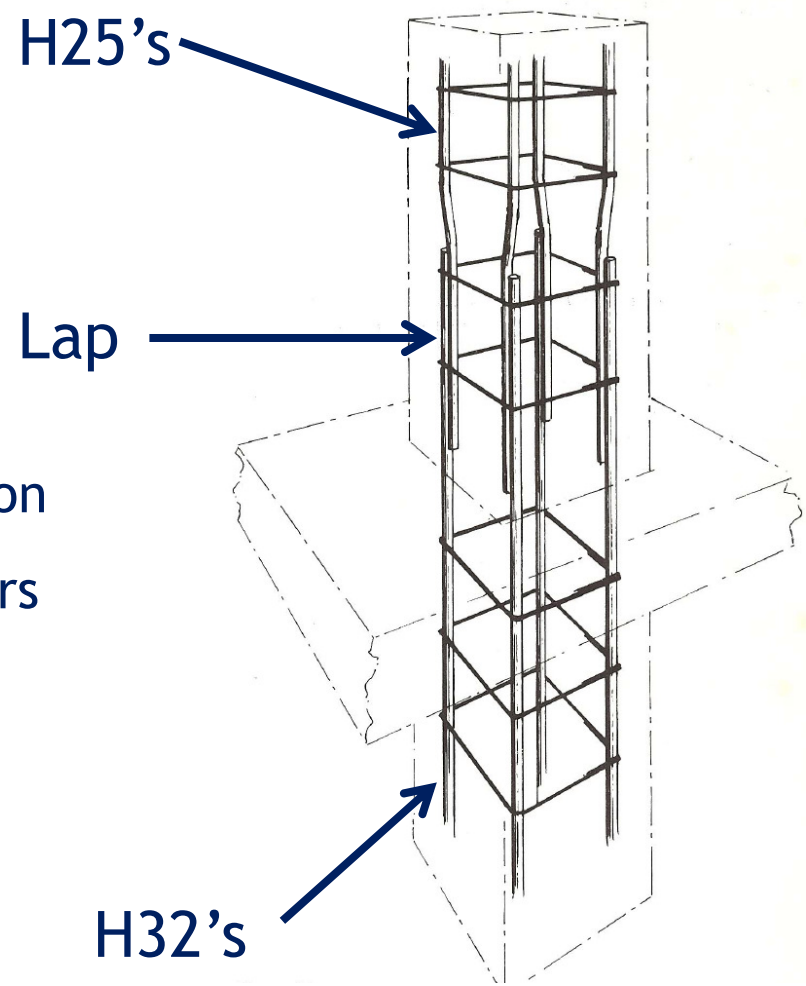

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Calculate the minimum lap length using EC2 equation 8.10:

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Column lap length exercise

Procedure

- Determine the ultimate bond stress, f_{bd} — EC2 Equ. 8.2
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- Determine the design anchorage length, l_{bd} — EC2 Equ. 8.4
- Determine the lap length, l_0 = anchorage length x α_6

Solution - Column lap length

Determine the ultimate bond stress, f_{bd}

$f_{bd} = 2.25\ \eta_1\ \eta_2\ f_{ctd}$ EC2 Equ. 8.2

$\eta_1 = 1.0$ 'Good' bond conditions

$\eta_2 = 1.0$ bar size ≤ 32

$f_{ctd} = \alpha_{ct}\ f_{ctk,0,05} / \gamma_c$ EC2 cl 3.1.6(2), Equ 3.16

$\alpha_{ct} = 1.0$ $\gamma_c = 1.5$

$f_{ctk,0,05} = 0.7 \times 0.3\ f_{ck}^{2/3}$ EC2 Table 3.1

$= 0.21 \times 40^{2/3}$

$= 2.456$ MPa

$f_{ctd} = \alpha_{ct}\ f_{ctk,0,05} / \gamma_c = 2.456/1.5 = 1.637$

$f_{bd} = 2.25 \times 1.637 = 3.684$ MPa

Solution - Column lap length

Determine the basic anchorage length, $l_{b,req}$

$l_{b,req} = (Ø/4)\ (\sigma_{sd}/f_{bd})$ EC2 Equ 8.3

Max ultimate stress in the bar, $\sigma_{sd} = 390$ MPa.

$l_{b,req} = (Ø/4)\ (390/3.684)$

$= 26.47\ Ø$

For concrete class C40/50

Solution - Column lap length

Determine the design anchorage length, l_{bd}

$l_{bd} = \alpha_1\ \alpha_2\ \alpha_3\ \alpha_4\ \alpha_5\ l_{b,req} \geq l_{b,min}$ Equ. 8.4

$l_{bd} = \alpha_1\ \alpha_2\ \alpha_3\ \alpha_4\ \alpha_5\ (26.47Ø)$ For concrete class C40/50

For bars in compression $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = 1.0$

Hence $l_{bd} = 26.47Ø$

Solution - Column lap length

Determine the lap length, l_0 = anchorage length x α_6

All the bars are being lapped at the same section, $\alpha_6 = 1.5$

A lap length is based on the smallest bar in the lap, 25mm

Hence,

$$l_0 = l_{bd} \times \alpha_6$$

$$l_0 = 26.47\ Ø \times 1.5$$

$$l_0 = 39.71\ Ø = 39.71 \times 25$$

$$l_0 = 993\ \text{mm}$$

Foundations

Outline - Week 10, Foundations

We will look at the following topics:

- Eurocode 7: Geotechnical design - Partial factors, spread foundations.
- Pad foundation - Worked example & workshop
- Retaining walls
- Piles

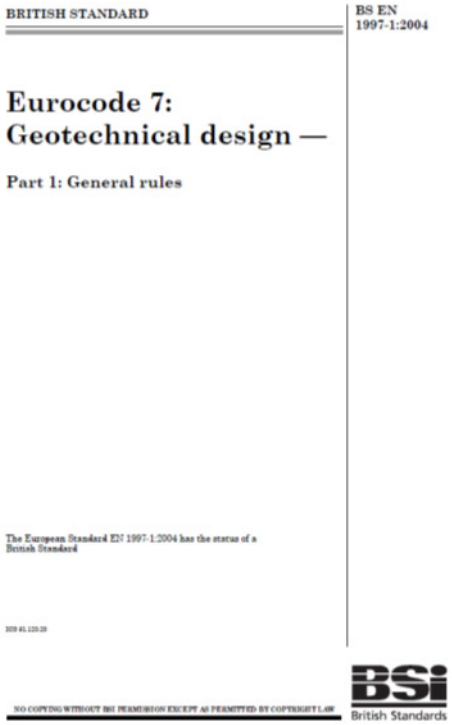
Eurocode 7

6 (p43 et seq)

Eurocode 7 has two parts:

Part 1: General Rules Plus NA

Part 2: Ground Investigation and testing Plus NA


BRITISH STANDARD

BS EN 1997-1:2004

Eurocode 7: Geotechnical design —

Part 1: General rules

The European Standard EN 1997-1:2004 has the status of a British Standard

BSi British Standards

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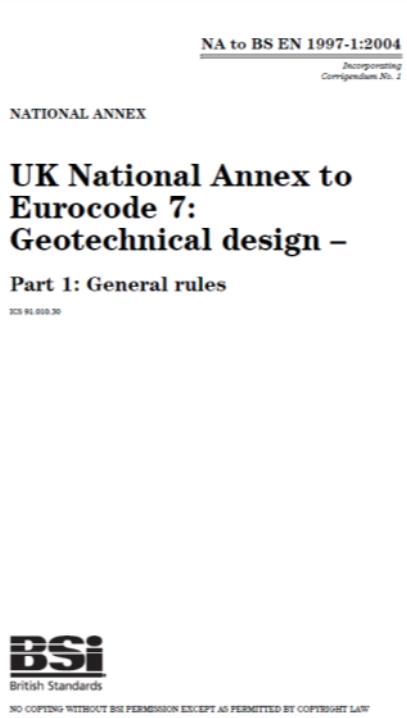
NA to BS EN 1997-1:2004

Incorporating Corrigendum No. 1

NATIONAL ANNEX

UK National Annex to Eurocode 7: Geotechnical design –

Part 1: General rules

ICS 91.010.30

BSi British Standards

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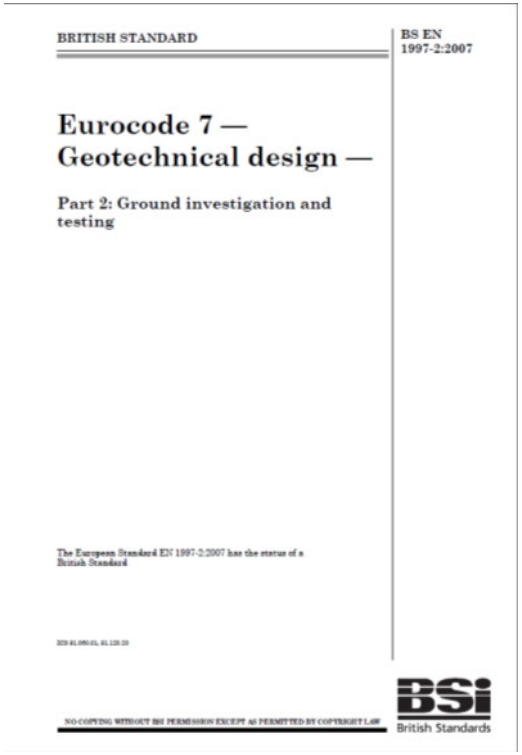
BRITISH STANDARD

BS EN 1997-2:2007

Eurocode 7 — Geotechnical design —

Part 2: Ground investigation and testing

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Eurocode 7

How to…… 6. Foundations

The essential features of EC7, Pt 1 relating to foundation design are discussed.

Note:

This publication covers only the design of simple foundations, which are a small part of EC7.

It should not be relied on for general guidance on EC7.

How to design concrete structures using Eurocode 2

6. Foundations

R Webster CEng, FIStructE O Brooker BEng, CEng, MICE, MIStructE

Eurocode 7: Geotechnical design

Scope

All foundations should be designed so that the soil safely resists the actions applied to the structure. The design of any foundation consists of two components; the geotechnical design and the structural design of the foundation itself. However, for some foundations (e.g. flexible rafts) the effect of the interaction between the soil and structure may be critical and must also be considered. Geotechnical design is covered by Eurocode 7[1], which supersedes several current British Standards including BS 5930[2], BS 8002[3] and BS 8004[4]. The new Eurocode marks a significant change in geotechnical design in that limit state principles are used throughout and this should ensure consistency between the Eurocodes. There are two parts to Eurocode 7, Part 1: *General rules* and Part 2: *Ground investigation and testing*. Guidance on the design of retaining walls can be found in Chapter 9.

The essential features of Eurocode 7, Part 1 relating to foundation design are discussed in this chapter. It should be emphasised that this publication covers only the design of simple foundations, which are a small part of the scope of Eurocode 7. Therefore it should not be relied on for general guidance on this Eurocode.

Limit states

The following ultimate limit states (ULS) should be satisfied for geotechnical design; they each have their own combinations of actions. (For an explanation of Eurocode terminology please refer to Chapter 1, originally published as *Introduction to Eurocodes*[5].)

EQU Loss of equilibrium of the structure.
STR Internal failure or excessive deformation of the structure or structural member.
GEO Failure due to excessive deformation of the ground.
UPL Loss of equilibrium due to uplift by water pressure.
HYD Failure caused by hydraulic gradients.

In addition, the serviceability limit states (SLS) should be satisfied. It will usually be clear that one of the limit states will govern the design and therefore it will not be necessary to carry out checks for all of them, although it is considered good practice to record that they have all been considered.

Geotechnical Categories

Eurocode 7 recommends three Geotechnical Categories to assist in establishing the geotechnical design requirements for a structure (see Table 1).

Limit States

The following ultimate limit states apply to foundation design:

EQU: Loss of equilibrium of the structure

STR: Internal failure or excessive deformation of the structure or structural member

GEO: Failure due to excessive deformation of the ground

UPL: Loss of equilibrium due to uplift by water pressure

HYD: Failure caused by hydraulic gradients

Categories of Structures

Category	Description	Risk of geo-technical failure	Examples from EC7
1	Small and relatively simple structures	Negligible	None given
2	Conventional types of structure – no difficult ground	No exceptional risk	Spread foundations
3	All other structures	Abnormal risks	Large or unusual structures

EC7 - ULS Design

EC7 provides for three Design Approaches

UK National Annex - Use Design Approach 1 – DA1

For DA1 (except piles and anchorage design) there are two sets of combinations to use for the STR and GEO limit states.

Combination 1 – generally governs structural resistance

Combination 2 – generally governs sizing of foundations

STR/GEO ULS - Actions partial factors

	Permanent Actions		Leading variable action	Accompanying variable actions	
	Unfavourable	Favourable		Main	Others
Combination 1					
Exp 6.10	$1.35G_k$	$1.0G_k$	$1.5Q_k$		$1.5\psi_{0,i}Q_k$
Exp 6.10a	$1.35G_k$	$1.0G_k$		$1.5\psi_{0,1}Q_k$	$1.5\psi_{0,i}Q_k$
Exp 6.10b	$1.25G_k$	$1.0G_k$	$1.5Q_k$		$1.5\psi_{0,i}Q_k$
Combination 2					
Exp 6.10	$1.0G_k$	$1.0G_k$	$1.3Q_k$		$1.3\psi_{0,i}Q_k$

Notes:
If the variation in permanent action is significant, use $G_{k,j,sup}$ and $G_{k,j,inf}$
If the action is favourable, $\gamma_{Q,i} = 0$ and the variable actions should be ignored

Factors for EQU, UPL and HYD

Limit state	Permanent Actions		Variable Actions	
	Unfavourable	Favourable	Unfavourable	Favourable
EQU	1.1	0.9	1.5	0
UPL	1.1	0.9	1.5	0
HYD	1.35	0.9	1.5	0

Partial factors - material properties

Parameter	Symbol	Combination 1	Combination 2	EQU
Angle of shearing resistance	γ_{φ}	1.0	1.25	1.1
Effective cohesion	$\gamma_{c'}$	1.0	1.25	1.1
Undrained shear strength	γ_{cu}	1.0	1.4	1.2
Unconfined strength	γ_{qu}	1.0	1.4	1.2
Bulk density	γ_{γ}	1.0	1.0	1.0

Geotechnical Report

The Geotechnical Report should:

- be produced for each project (if even just a single sheet)
- contain details of:
  - the site,
  - interpretation of ground investigation report,
  - geotechnical recommendations,
  - advice

Foundation design recommendations should state:

- bearing resistances,
- characteristic values of soil parameters and
- whether values are SLS or ULS , Combination 1 or Combination 2 values

Spread Foundations

EC7 Section 6

Three methods for design:

- Direct method – check all limit states:
  - Load and partial factor combinations (as before)
  - $q_{ult} = c' N_c s_c d_c i_c g_c b_c + q' N_q s_q d_q i_q g_q b_q + \gamma' B N_\gamma s_\gamma d_\gamma i_\gamma g_\gamma b_\gamma / 2$

    where
    - c = cohesion
    - q = overburden
    - γ = body-weight
    - N_i = bearing capacity factors
    - s_i = shape factors
    - d_i = depth factors
    - i_i = inclination factors
    - g_i = ground inclination factors
    - b_i = base inclination factors

"We just bung it in a spreadsheet"

Settlement often critical

See *Decoding Eurocode 7* by A Bond & A Harris, Taylor & Francis

Spread Foundations

EC7 Section 6

Three methods for design:

- Direct method – check all limit states
- Indirect method – experience and testing used to determine SLS parameters that also satisfy ULS
- Prescriptive methods – use presumed bearing resistance (BS8004 quoted in NA).

Used in sub-sequent slides).

Spread Foundations

Design procedures in:

How to design concrete structures using Eurocode 2

6. Foundations

R Webster CEng, FIStructE **O Brooker** BEng, CEng, MICE, MIStructE

Eurocode 7: Geotechnical design

Scope

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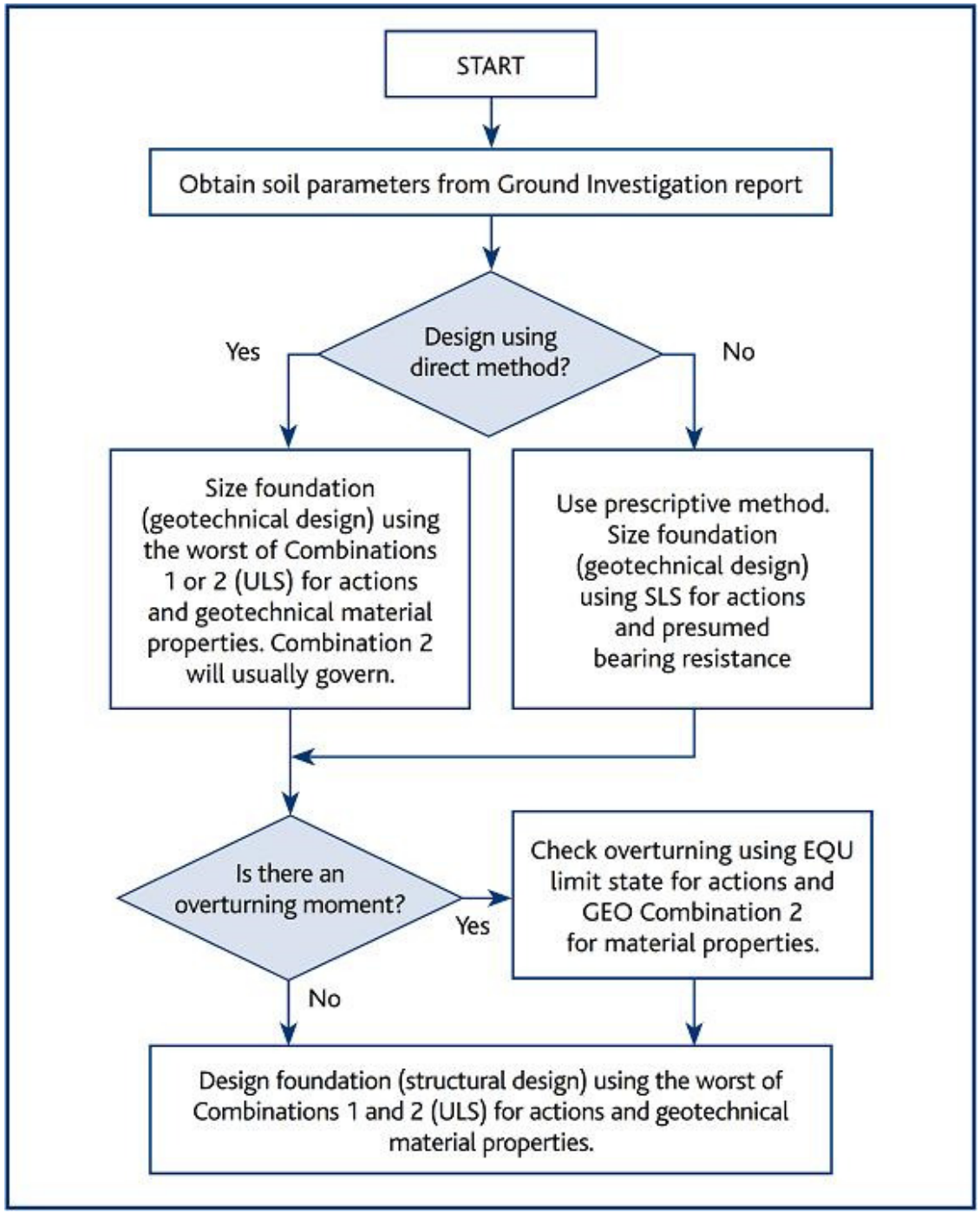
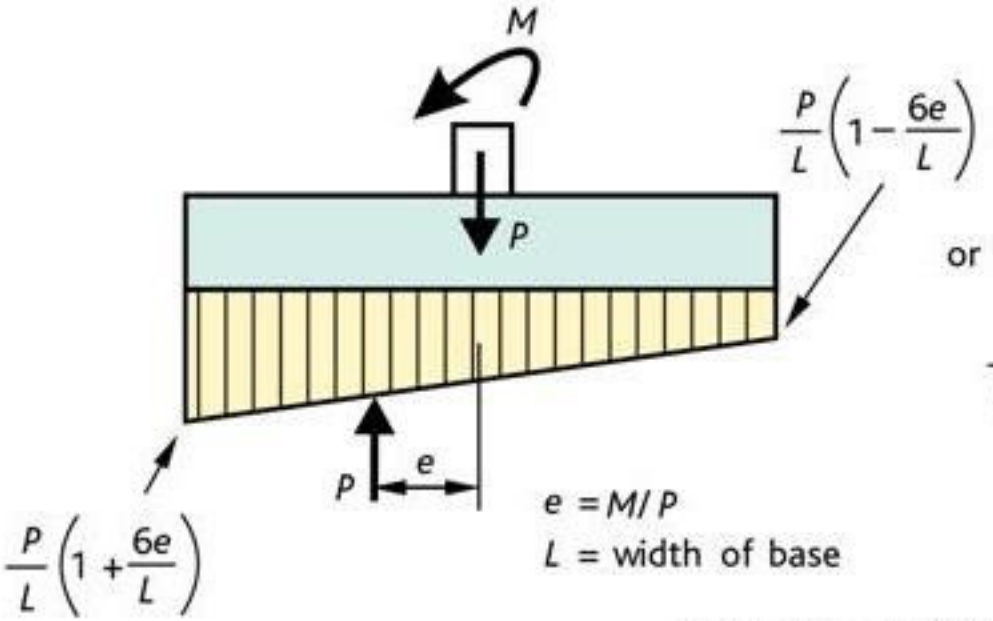


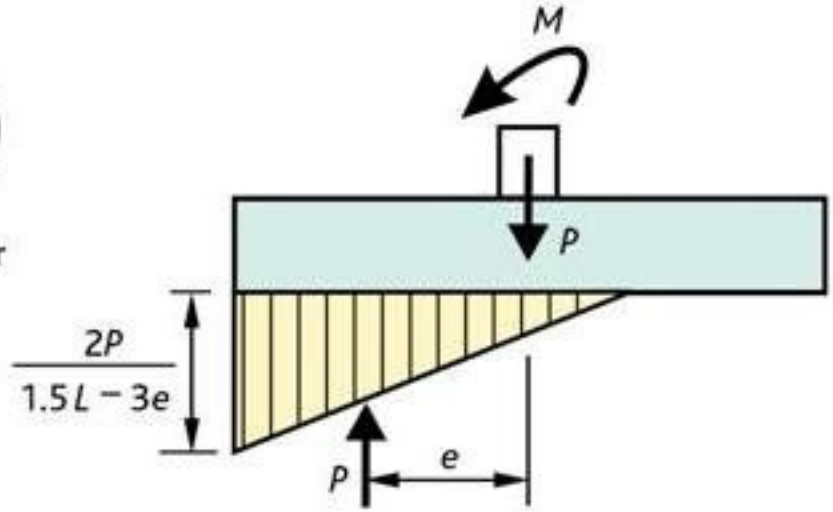
mpa The Concrete Centre

Fig 6/1 (p46)

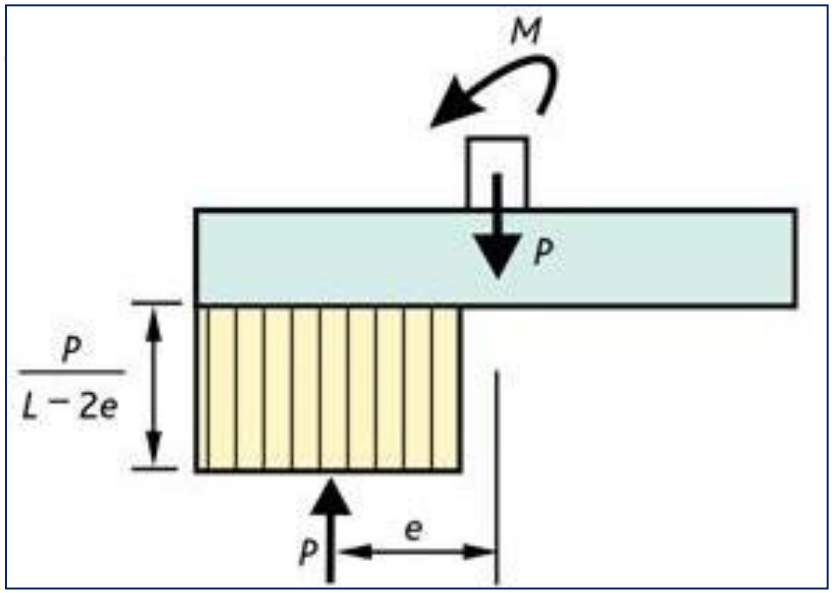
Procedure for depth of spread foundations

Pressure distributions





SLS pressure distributions



ULS pressure distribution

Load cases

EQU : $0.9\ G_k + 1.5\ Q_k$ (assuming variable action is destabilising e.g. wind, and permanent action is stabilizing)

STR : $1.35\ G_k + 1.5\ Q_k$ (Using (6.10). Worse case of Exp (6.10a) or (6.10b) could be used)

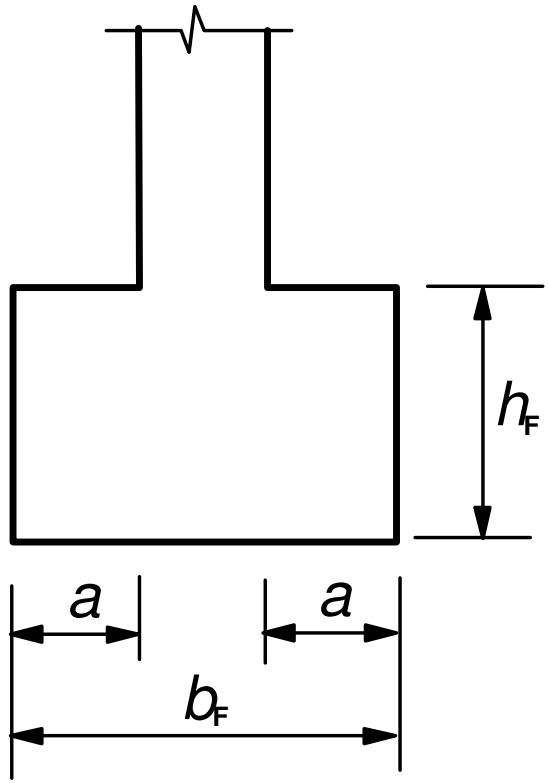
Plain Concrete Strip Footings & Pad Foundations:

Cl. 12.9.3, Exp (12.13)

$$\frac{0{,}85 \cdot h_F}{a} \geq \sqrt{(3\sigma_{gd}/f_{ctd,pl})}$$

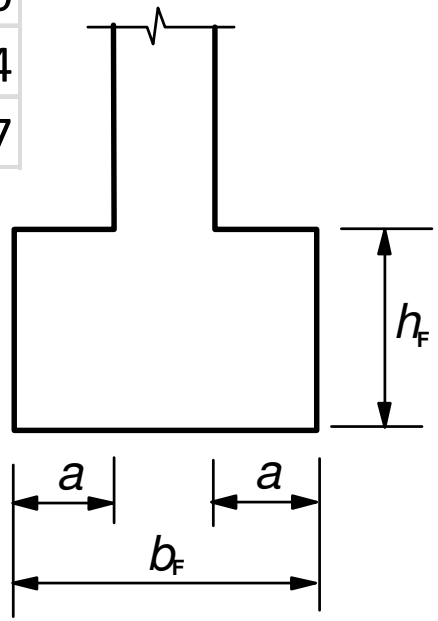
where:
σ_{gd} is the design value of the ground pressure

- as a simplification $h_f/a \geq 2$ may be used



Plain Concrete Strip Footings & Pad Foundations

		C16/20	C20/25	C25/30	C30/37
allowable pressure	σ_{gd}	h_F/a	h_F/a	h_F/a	h_F/a
50	70	0.65	0.60	0.55	0.52
100	140	0.92	0.85	0.78	0.74
150	210	1.12	1.04	0.95	0.90
200	280	1.29	1.21	1.10	1.04
250	350	1.45	1.35	1.23	1.17



e.g. cavity wall 300 wide carrying 80 kN/m onto 100 kN/m^2 ground:

b_f = 800 mm

a = 250 mm

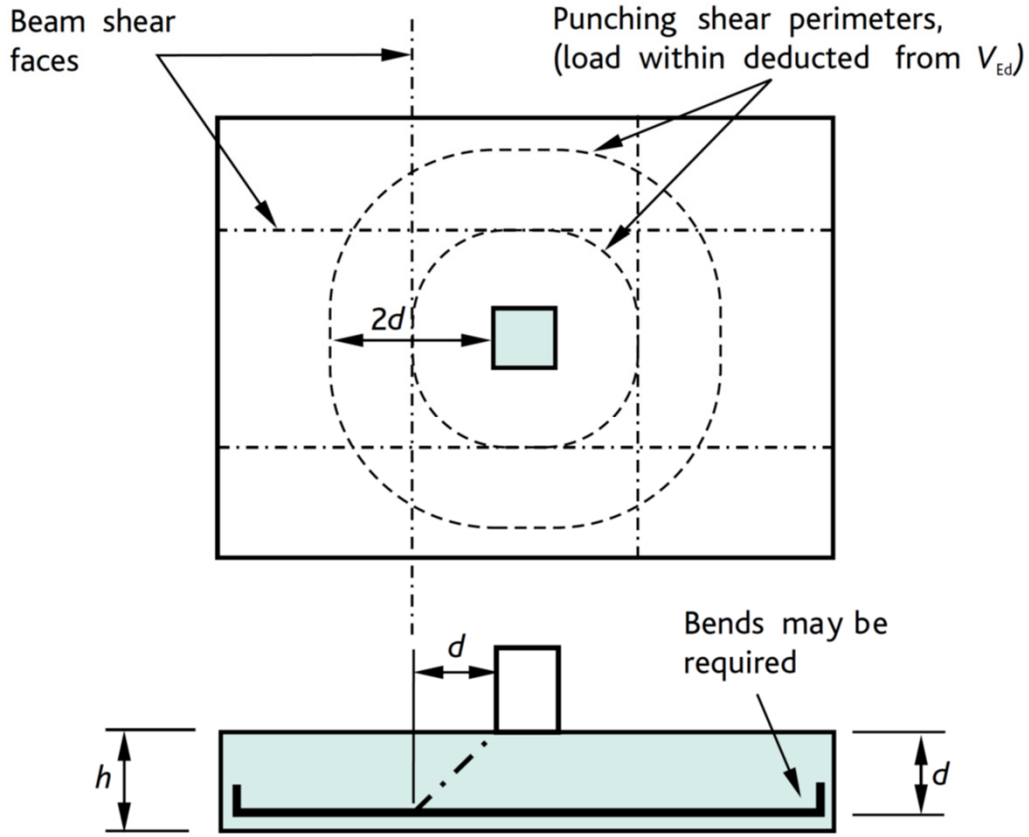
h_f = say assuming C20/25 concrete

0.85 x 250 = 213 say 225 mm

Reinforced Concrete Bases

- Check critical bending moments at column faces
- Check beam shear and punching shear

For punching shear the ground reaction within the perimeter may be deducted from the column load



Pad foundation

Worked example

Worked Example

Design a square pad footing for a 350 × 350 mm column carrying G_k = 600 kN and Q_k = 505 kN. The presumed allowable bearing pressure of the non-aggressive soil is 200 kN/m^2.

Answer:

Category 2. So using prescriptive methods:

Base area: (600 + 505)/200 = 5.525m^2

=> 2.4 x 2.4 base x 0.5m (say) deep.

Worked Example

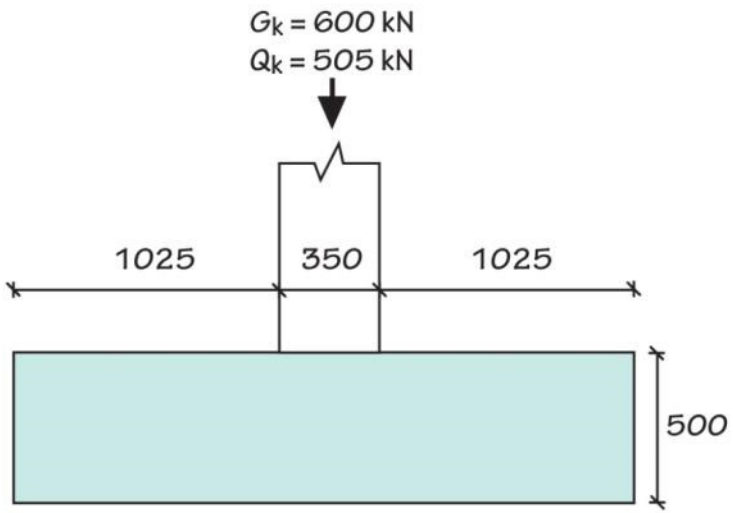


Figure 7.2 Section through pad foundation

Use C30/37 concrete

Loading = 1.35 x 600 + 1.5 x 505

= 1567.5 kN

ULS bearing pressure = $1567.5/2.4^2$

= 272 kN/m^2

Critical section at face of column

M_{Ed} = $272 \times 2.4 \times 1.025^2 / 2$

= 343 kNm

d = 500 – 50 – 16

= 434 mm

K = $343 \times 10^6/(2400 \times 434^2 \times 30)$

= 0.025

Worked Example

$\Rightarrow z = 0.95d \qquad = 0.95 \times 434 = 412mm$

$\Rightarrow A_s = M_{Ed}/f_{yd}z \qquad = 343 \times 10^6 / (435 \times 412) = 1914mm^2$

$\Rightarrow$ Provide 10H16 @ 250 c/c b.w ($2010\ mm^2$) ($804\ mm^2/m$)

Beam shear:

Check critical section d away from column face

$V_{Ed} = 272 \times (1.025 - 0.434) = 161kN/m$

$v_{Ed} = 161 / 434 = 0.37MPa$

$\rho = 2010/ (434 \times 2400) = 0.0019 = 0.19\%$

$v_{Rd,c}$ (from table) = 0.42MPa

=> beam shear ok.

6/Table 6 (p47)

Concise Table 15.6

Worked Example

Punching shear:

Basic control perimeter at 2d from face of column

$v_{Ed} = \beta V_{Ed} / u_i d < v_{Rd,c}$

$\beta = 1$, $u_i = (350 \times 4 + 434 \times 2 \times 2 \times \pi) = 6854\text{mm}$

V_{Ed} = load minus net upward force within the area of the control perimeter)

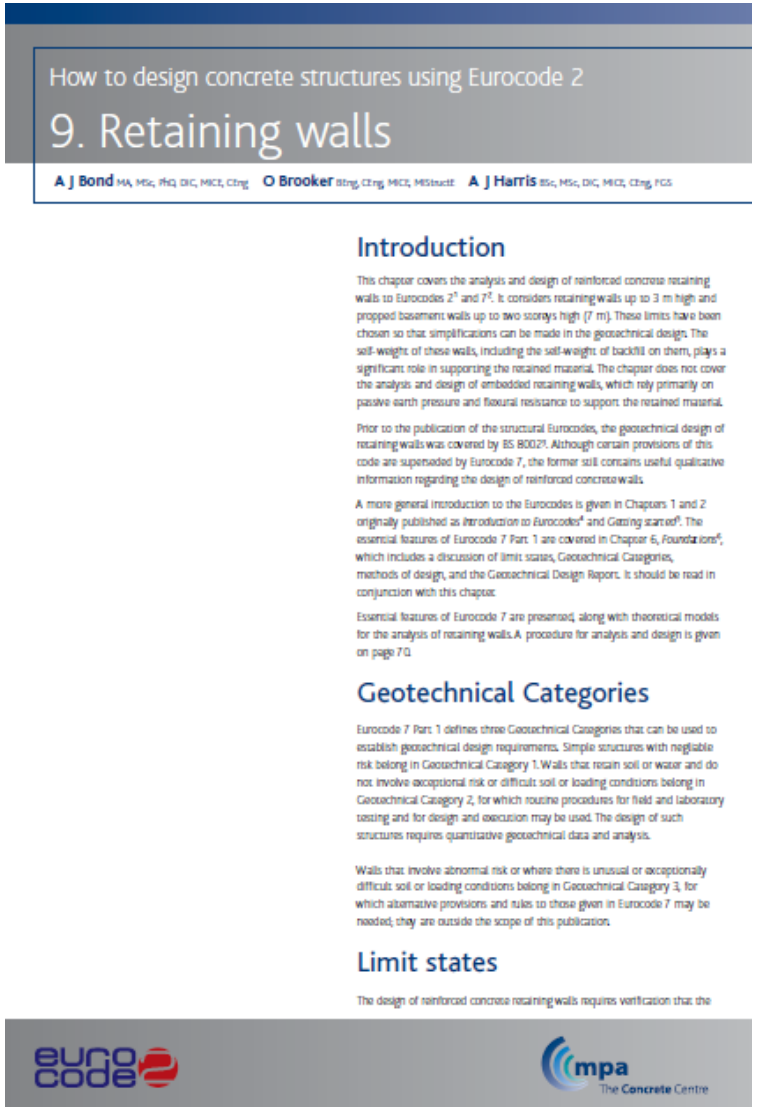
$= 1567.5 - 272 \times (0.35^2 + \pi \times .868^2 + .868 \times .35 \times 4)$

$= 560\text{kN}$

$v_{Ed} = 0.188$ MPa; $v_{Rd,c} = 0.42$ (as before) => ok

Retaining Walls

Chapter 9



How to design concrete structures using Eurocode 2

9. Retaining walls

A J Bond MA, MSc, PhD, DIC, MICE, CEng O Brooker BEng, CEng, MICE, MIStructE A J Harris BSc, MSc, DIC, MICE, CEng, FGS

Introduction

This chapter covers the analysis and design of reinforced concrete retaining walls to Eurocodes 2[1] and 7[2]. It considers retaining walls up to 3 m high and propped basement walls up to two storeys high (7 m). These limits have been chosen so that simplifications can be made in the geotechnical design. The self-weight of these walls, including the self-weight of backfill on them, plays a significant role in supporting the retained material. The chapter does not cover the analysis and design of embedded retaining walls, which rely primarily on passive earth pressure and flexural resistance to support the retained material.

Prior to the publication of the structural Eurocodes, the geotechnical design of retaining walls was covered by BS 8002[3]. Although certain provisions of this code are superseded by Eurocode 7, the former still contains useful qualitative information regarding the design of reinforced concrete walls.

A more general introduction to the Eurocodes is given in Chapters 1 and 2 originally published as *Introduction to Eurocodes*[4] and *Getting started*[5]. The essential features of Eurocode 7 Part 1 are covered in Chapter 6, *Foundations*[6], which includes a discussion of limit states, Geotechnical Categories, methods of design, and the Geotechnical Design Reports. It should be read in conjunction with this chapter.

Essential features of Eurocode 7 are presented, along with theoretical models for the analysis of retaining walls. A procedure for analysis and design is given on page 70.

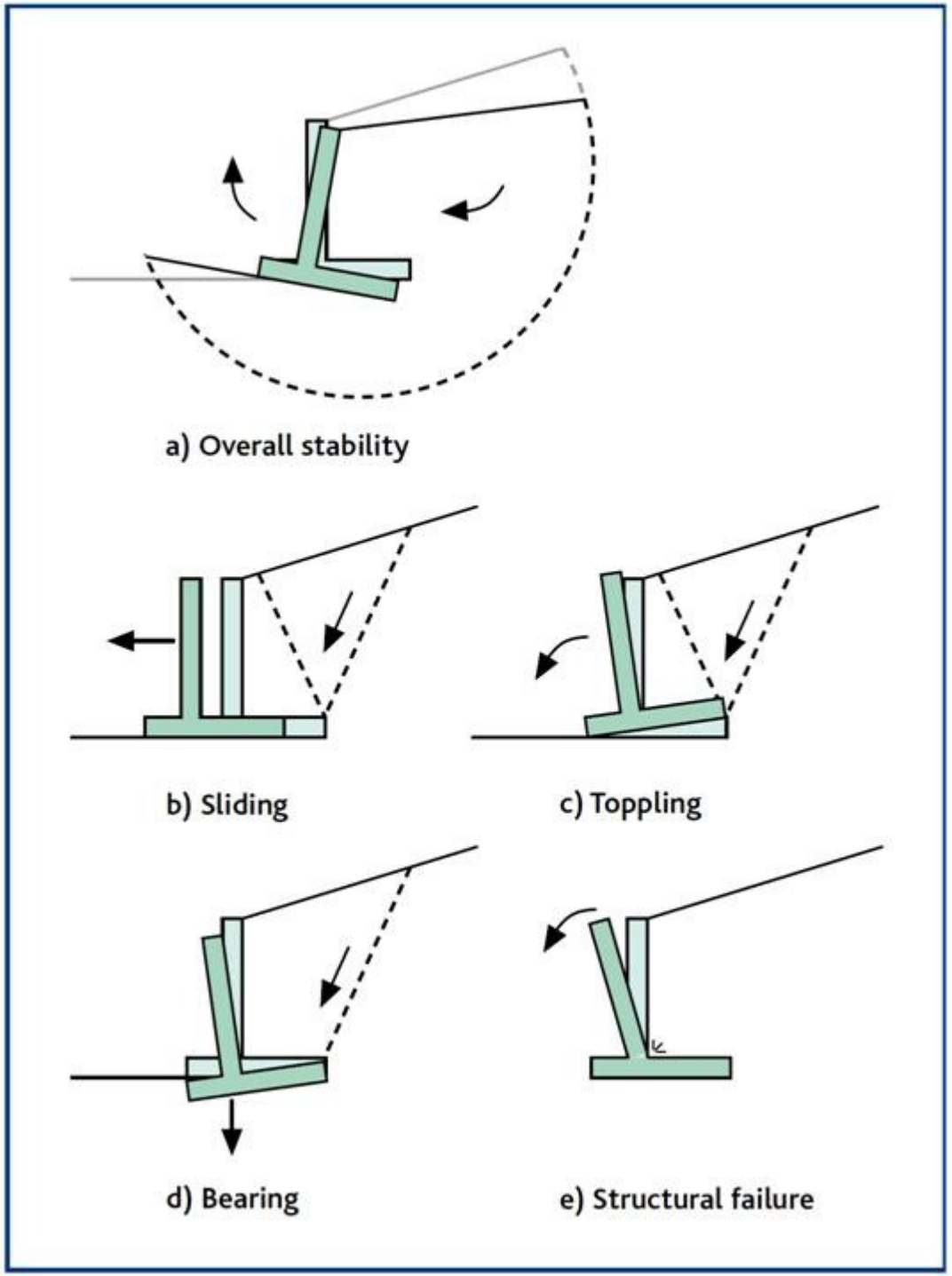
Geotechnical Categories

Eurocode 7 Part 1 defines three Geotechnical Categories that can be used to establish geotechnical design requirements. Simple structures with negligible risk belong in Geotechnical Category 1. Walls that retain soil or water and do not involve exceptional risk or difficult soil or loading conditions belong in Geotechnical Category 2, for which routine procedures for field and laboratory testing and for design and execution may be used. The design of such structures requires quantitative geotechnical data and analysis.

Walls that involve abnormal risk or where there is unusual or exceptionally difficult soil or loading conditions belong in Geotechnical Category 3, for which alternative provisions and rules to those given in Eurocode 7 may be needed; they are outside the scope of this publication.

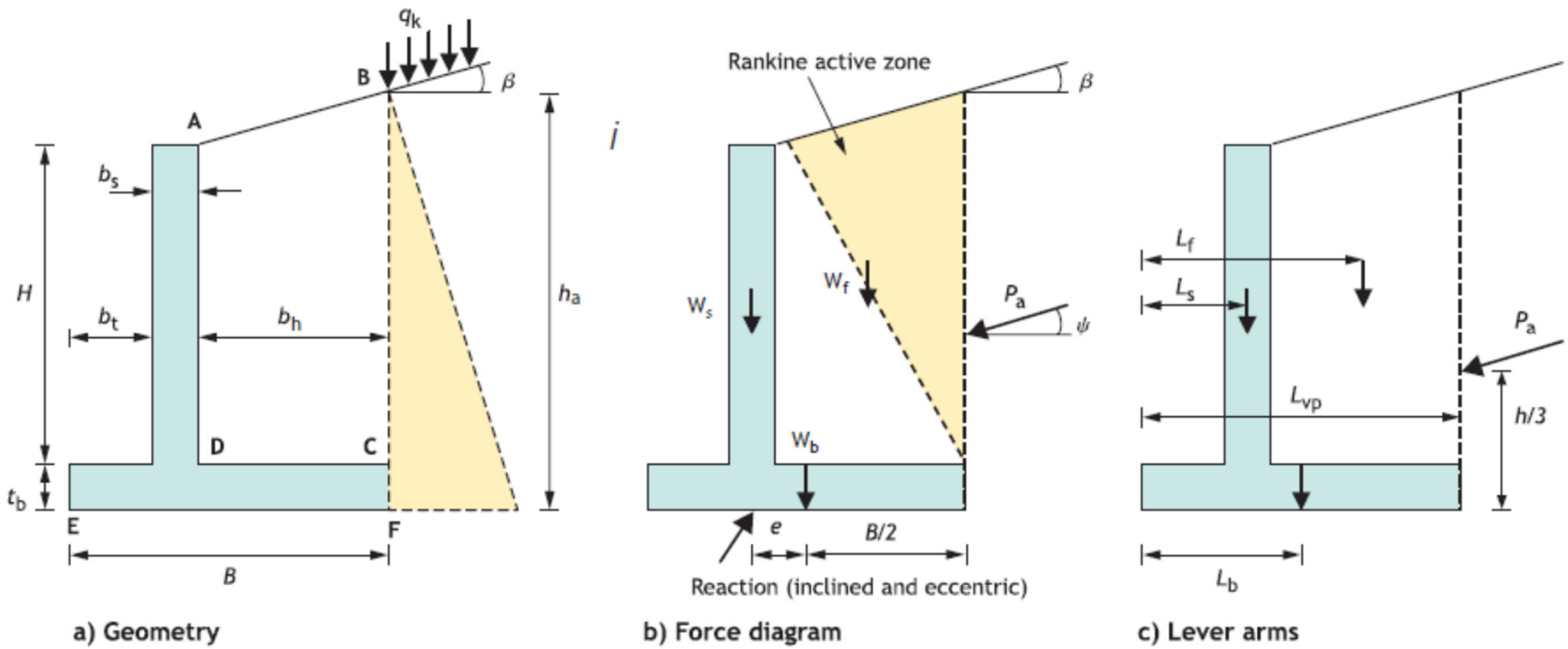
Limit states

The design of reinforced concrete retaining walls requires verification that the



Ultimate Limit States for the design of retaining walls

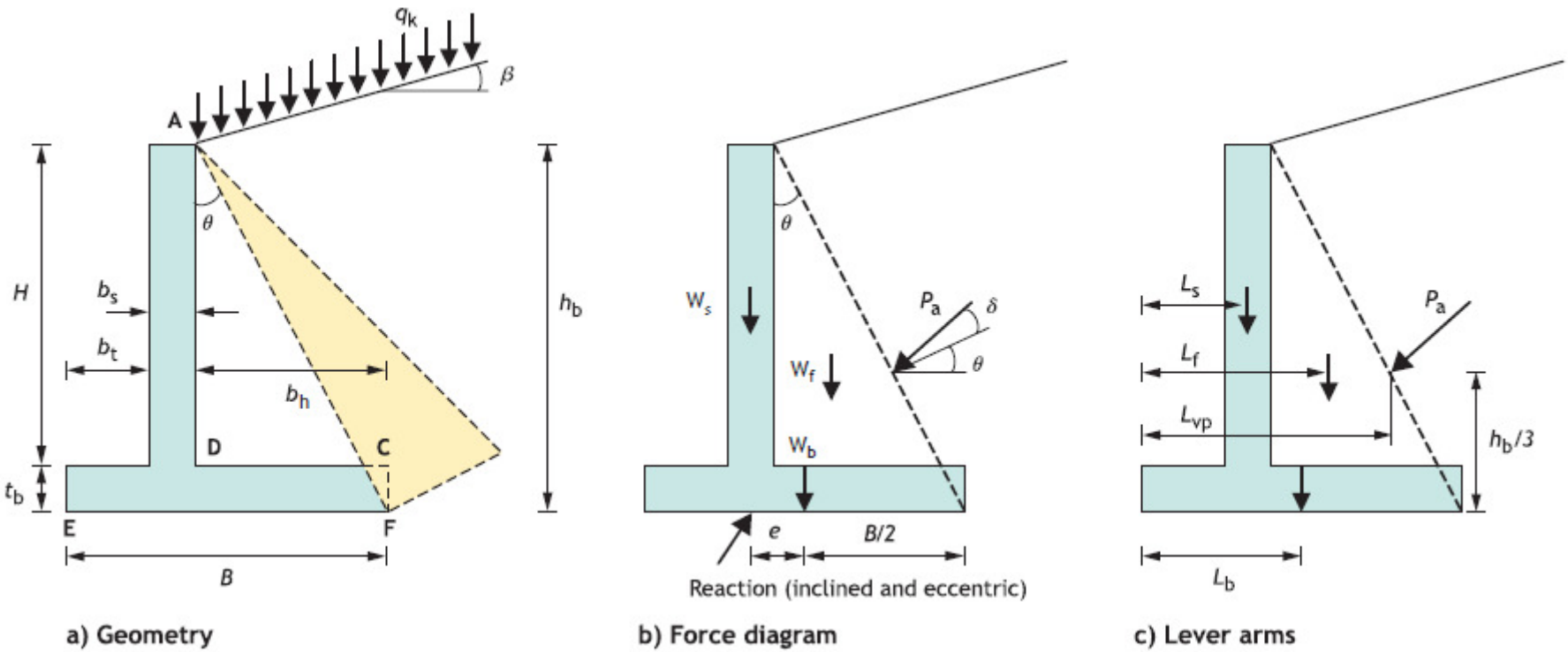
Calculation Model A



Rankine theory

Model applies if $b_h \geq h_a \tan(45 - \varphi'_d/2)$

Calculation Model B



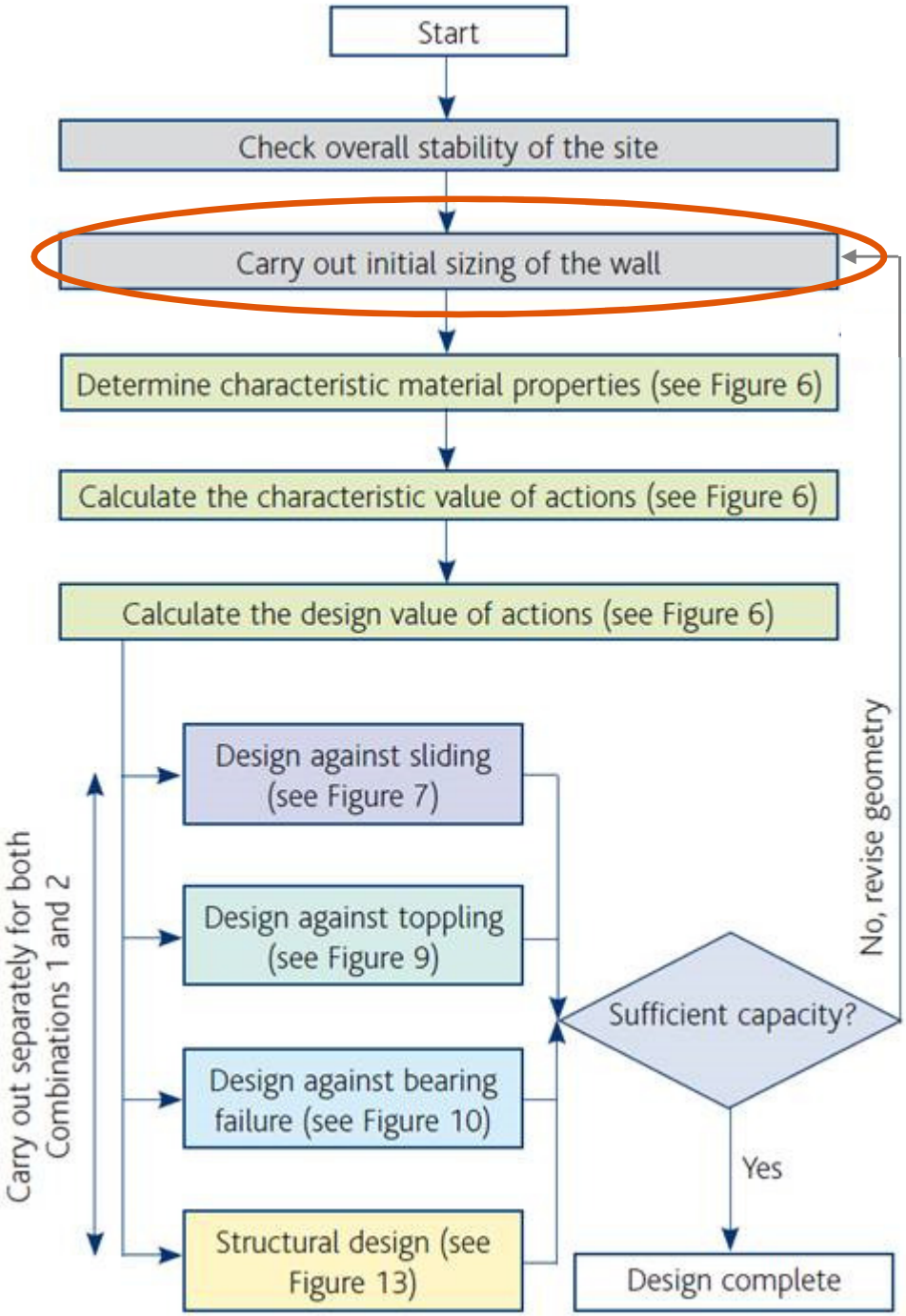
a) Geometry b) Force diagram c) Lever arms

Inclined ‘ virtual’ plane theory

Model applies to walls of all shapes and sizes

General expressions

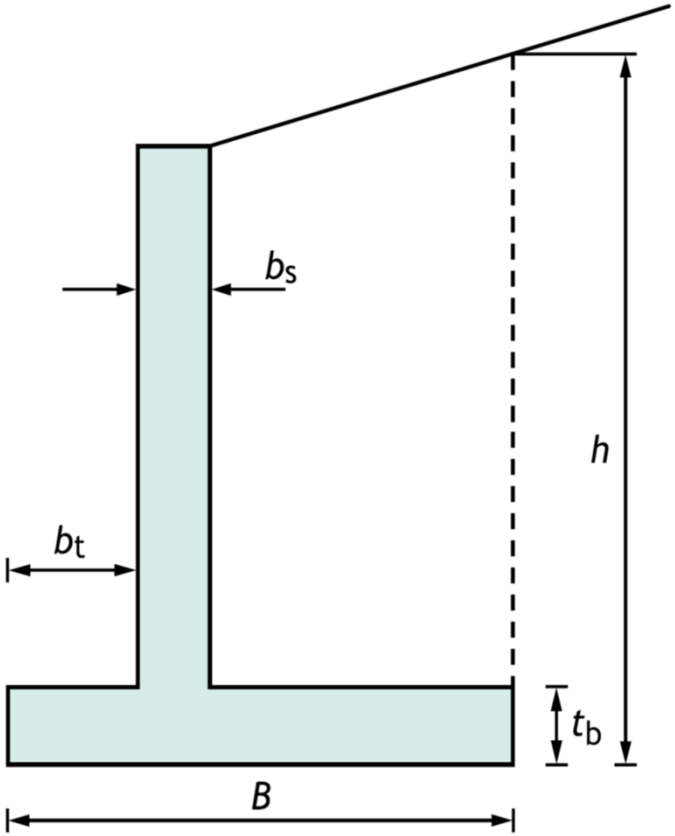
General	Model A	Model B
$W_s = b_s H \gamma_{k,c}$ $W_b = t_b B \gamma_{k,c}$ $b_h = B - b_s - b_t$ $L_s = b_t + \frac{b_s}{2}$ $L_b = \frac{B}{2}$	$h = t_b + H + b_h \tan\beta$ $W_f = b_h \left(H + \frac{b_h \tan\beta}{2} \right) \gamma_{k,f}$ $L_f \approx b_t + b_s + \frac{b_h}{2}$ $\Omega = \beta$ $L_{vp} = B$	$h_b = t_b + H$ $W_{k,f} \approx \frac{b_h H}{2} \gamma_{k,f}$ $L_f = b_t + b_s + \frac{b_h}{3}$ $\theta = \tan^{-1}\left[\frac{b_h}{h_b} \right]$ $\Omega = \theta$ $L_{vp} = B - \frac{b_h}{3}$



9 (Figure 4)

Overall design procedure

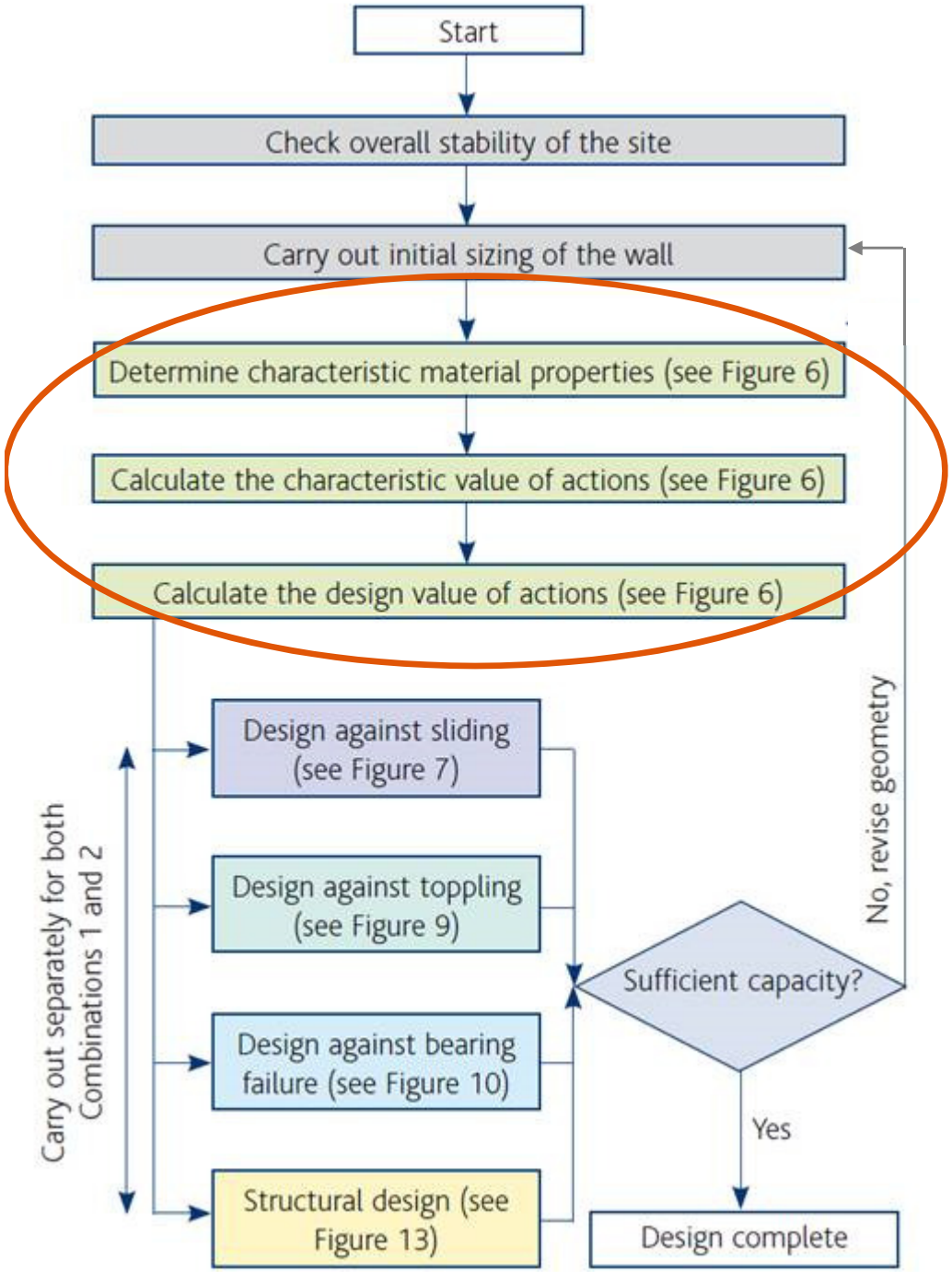
Initial sizing



$b_s \approx t_b \approx h/10$ to $h/15$

$B \approx 0.5h$ to $0.7h$

$b_t \approx B/4$ to $B/3$



9 (Figure 4)

Overall design procedure

Determine characteristic material properties

- Weight density ($\gamma_{k,f}$) and angle of shearing resistance ($\varphi'_{k,f}$) of backfill
- Weight density ($\gamma_{k,fdn}$), undrained strength ($c_{uk,fdn}$), and angle of shearing resistance ($\varphi'_{k,fdn}$) of foundation soil
- Weight density ($\gamma_{k,c}$) and cylinder strength (f_{ck}) of concrete

Determine initial geometry and actions (see Panel 1)

1 Determine initial geometry (see Figure 5)
   - For calculation model B find inclination of virtual plane (θ)

2 Determine lever arms (see Figures 2c or 3c)

3 Calculate forces
   - Characteristic self-weights ($W_{k,s}$, $W_{k,b}$, $W_{k,f}$)
   - Total weight $\Sigma W_{k,i} = W_{k,s} + W_{k,b} + W_{k,f}$
   - Total moment $\Sigma(W_{k,i}\, L_i) = (W_{k,s}\, L_s) + (W_{k,b}\, L_b) + (W_{k,f}\, L_f)$

Carry out separately for both Combinations 1 and 2

Determine design material properties and earth pressures (see Panel 2)

1 Apply partial material factors to obtain design material properties
   - Weight density $\gamma_d = \gamma_k / \gamma_\gamma = \gamma_k$ since $\gamma_\gamma = 1$
   - Angle of shearing resistance $\varphi'_d = \tan^{-1}(\tan \varphi'_k / \gamma_{\varphi'})$
   - Undrained strength $c_{ud} = c_{uk} / \gamma_{cu}$

2 Determine earth pressure
   - Earth pressure coefficient K_{ad} = function of $\varphi'_{d,f}$ and β (depending on calculation model used)
   - Earth pressure is function of vertical load and K_{ad}

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9 (Figure 6)

Figure 6 for overall design procedure

Soil Densities

Soil type	Moist bulk density, γ (kg/m^3)		Saturated bulk density, γ (kg/m^3)	
	Loose	Dense	Loose	Dense
Granular				
Gravel	1600	1800	2000	2100
Well graded sand and gravel	1900	2100	2150	2300
Coarse or medium sand	1650	1850	2000	2150
Well graded sand	1800	2100	2050	2250
Brick hardcore	1300	1750	1650	1900
Cohesive				
Soft clay	1700		1700	
Firm clay	1800		1800	
Stiff clay	1900		1900	
Stiff or hard glacial clay	2100		2100	

Ex *Concrete Basements*

Design value of effective angle of shearing resistance, φ'_d

$\tan \varphi'_d = \tan (\varphi'_k/\gamma_\varphi)$

where

$\varphi'_k = \varphi'_{max}$ for granular soils and

$= \varphi'$ for clay soils,

φ'_{max} and φ' are as defined as follows

γ_φ = 1.0 or 1.25 dependent on the *Combination* being considered.

Angle of shearing resistance

Granular Soils

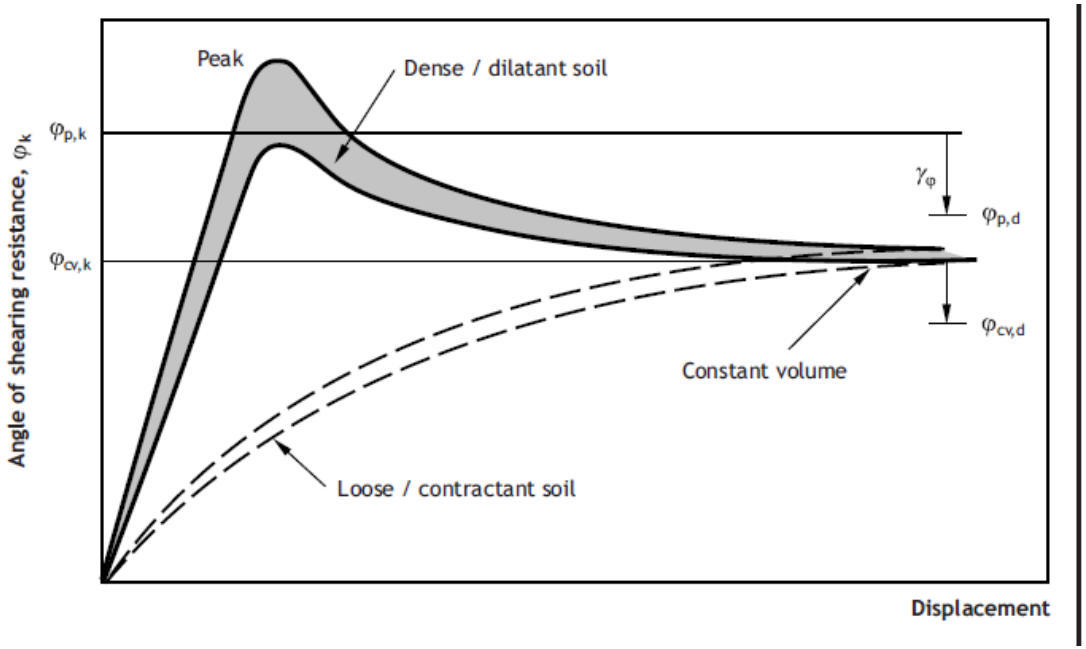
Estimated peak effective angle of shearing resistance,
$\varphi'_{max} = 30 + A + B + C$

Estimated critical state angle of shearing resistance,
$\varphi'_{crit} = 30 + A + B$, which is the upper limiting value.

Angularity	A (degrees)	Grading	B (degrees)	Number of blows, *N'*	C (degrees)
Rounded	0	Uniform	0	**<10**	0
Sub-angular	2	Moderate grading	2	**20**	2
				40	6
Angular	4	Well graded	4	**60**	9

Ex *Concrete Basements*

Clay soils



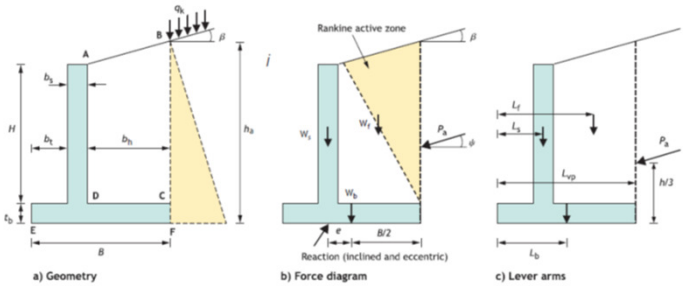
Long term ≡ Granular Soils

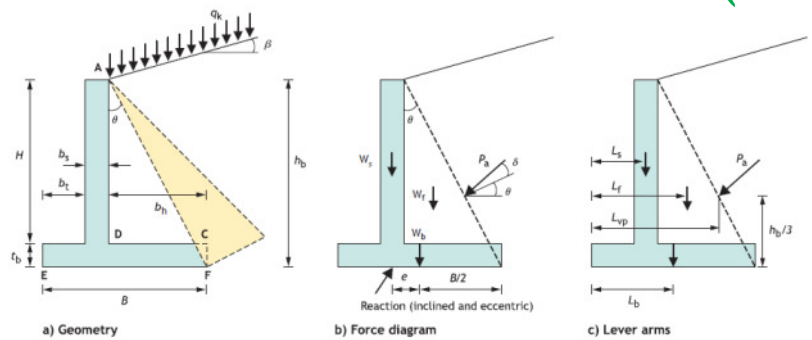
Plasticity index (%)	15	30	50	80
φ' (degrees)	30	25	20	15

Calcs -

Material properties & earth pressures

9 (Panel 2)





For calculation model A:

$$K_{ad} = \left[\frac{\cos\beta - \sqrt{\sin^2\varphi_{d,f} - \sin^2\beta}}{\cos\beta + \sqrt{\sin^2\varphi_{d,f} - \sin^2\beta}} \right] \cos\beta$$

$$P_{ad} = K_{ad} \left[\gamma_G \frac{\gamma_{k,f} h^2}{2} + \gamma_Q q_k h \right]$$

For calculation model B:

$$m_t = \frac{1}{2} \left[\cos^{-1} \left[\frac{\sin\beta}{\sin\varphi'_{d,f}} \right] + \varphi'_{d,f} - \beta \right]$$

$$K_n = \left[\frac{1 + \sin^2\varphi'_{d,f}}{1 - \sin\varphi'_{d,f} \sin(2m_t - \varphi'_{d,f})} \right] e^{-2(m_t + \beta - \varphi'_{d,f} - \theta)\tan\varphi'_{d,f}}$$

$$K_q = K_n \cos^2\beta$$

$$K_\gamma = K_n \cos\beta \cos(\beta - \theta)$$

$$P_{ad} = \gamma_G K_\gamma \frac{\gamma_{k,f} h^2}{2} + \gamma_Q K_q q_k h$$

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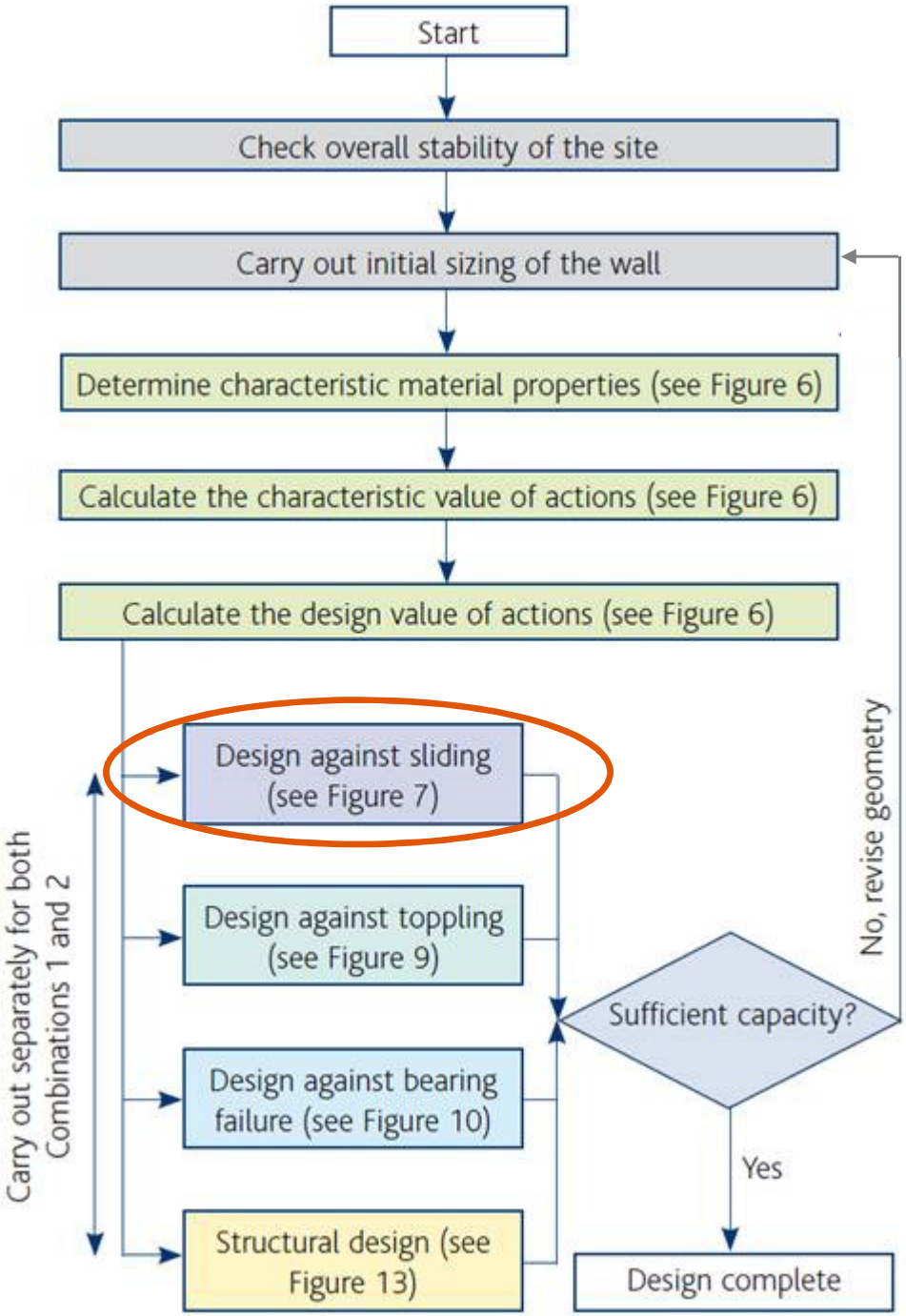
9 (Figure 4)

Overall design procedure



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9 (Figure 7)

Design against sliding (Figure 7)

Carry out separately for both Combinations 1 and 2

Determine horizontal thrust on virtual plane (see Panel 2)

- $H_{Ed} = P_{ad} \cos \Omega$

If appropriate determine undrained sliding resistance on underside of wall base

- $H_{Rd} = c_{ud,fdn} B$

Determine drained sliding resistance on underside of wall base

- Calculate vertical action $V_d = \gamma_a \sum_i W_{k,i}$
- Calculate vertical traction from P_{ad} (Panel 2)
- Calculate drainned sliding resistance, H'_{Rd} (Panel 3)

Verify $H_{Ed} \leq H_{Rd}$ (if appropriate) and $H_{Ed} \leq H'_{Rd}$

If necessary, repeat the above with a shear key

Sliding Resistance

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9 (Panel 3)

Undrained sliding resistance:

$$H_{Rd} = c_{ud,fdn} \; B$$

Drained sliding resistance:

$$\delta_{d,fdn} = \varphi_{cvd,fdn}$$

$$H'_{Rd} = V_d \tan \delta_{d,fdn} = \left[\gamma_{G,fav} \sum_i W_{k,i} \right] \tan \varphi_{cvd,fdn}$$

With a shear key:

$$H'_{Rd} \approx \left[\gamma_{G,fav} \sum_i W_{k,i} \right] \tan \varphi'_{d,fdn} \sqrt{1 + \left[\frac{\Delta t_0}{B} \right]^2}$$

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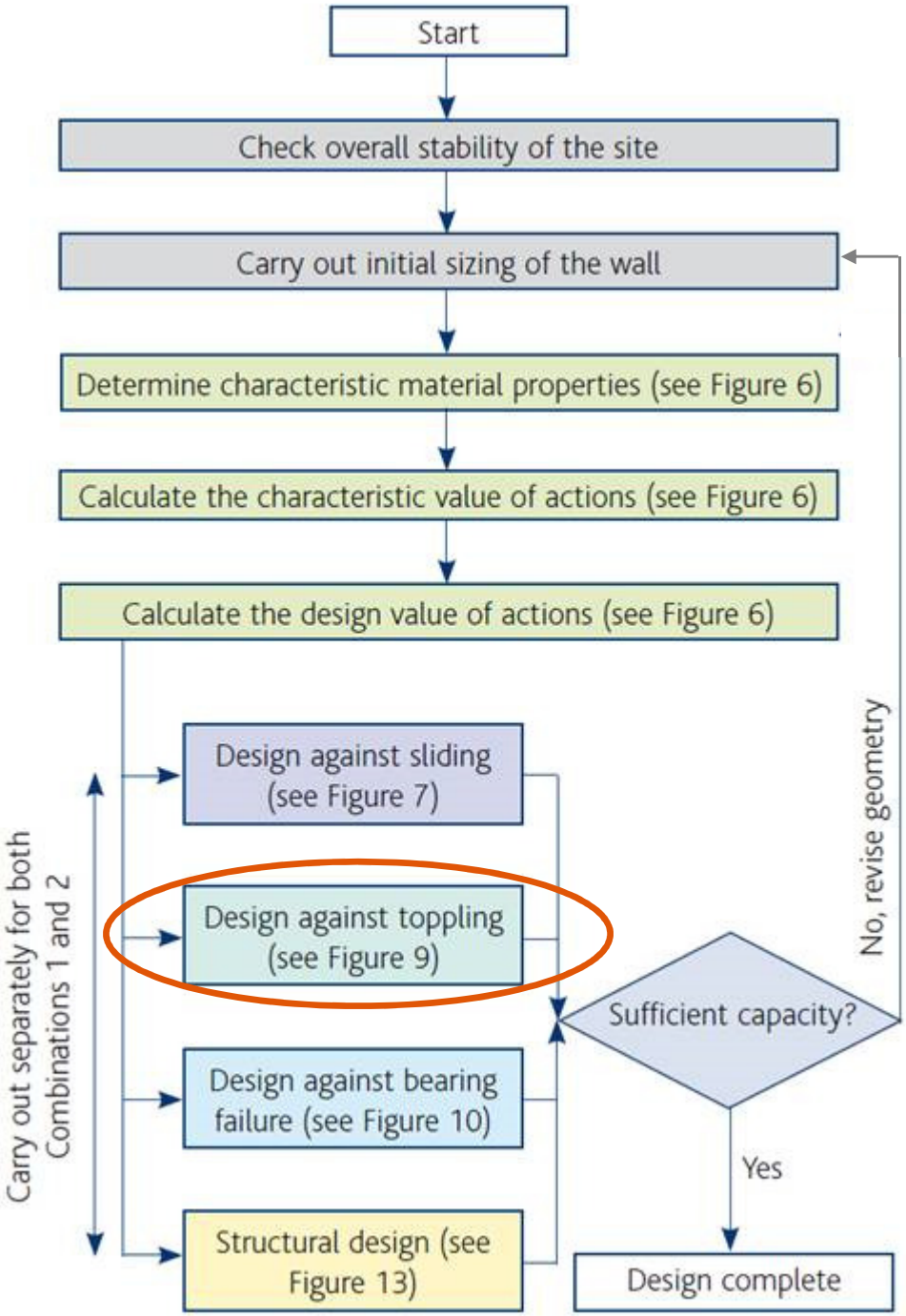
9 (Figure 4)

Overall design procedure



Design against Toppling

9 (Figure 9)

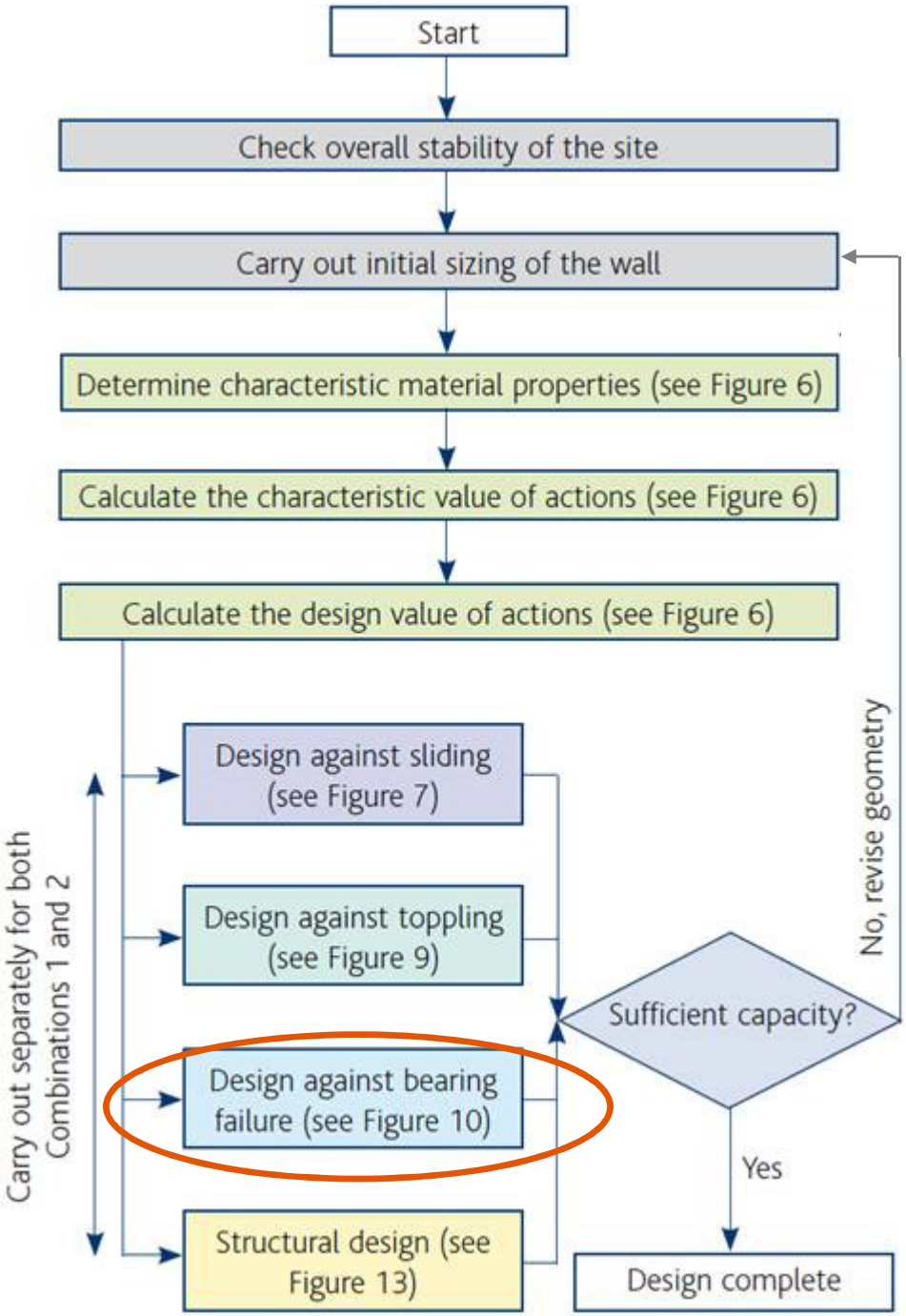
Carry out separately for both Combinations 1 and 2

Determine destabilising moment M_{Ed} about point E.
(see Panels 1 and 2) $M_{Ed} = P_{ad} \cos \Omega \, h/3$

Determine stabilising moments about point E

- Wall stem $M_{d,s} = W_{d,s} \, L_s$
- Wall base $M_{d,b} = W_{d,b} \, L_b$
- Backfill $M_{d,f} = W_{d,f} \, L_f$
- From active thrust, $M_{d,vp} = P_{ad} \sin \Omega \, L_{vp}$
- $M_{Rd} = M_{d,s} + M_{d,b} + M_{d,f} + M_{d,vp}$

Verify $M_{Ed} \leq M_{Rd}$

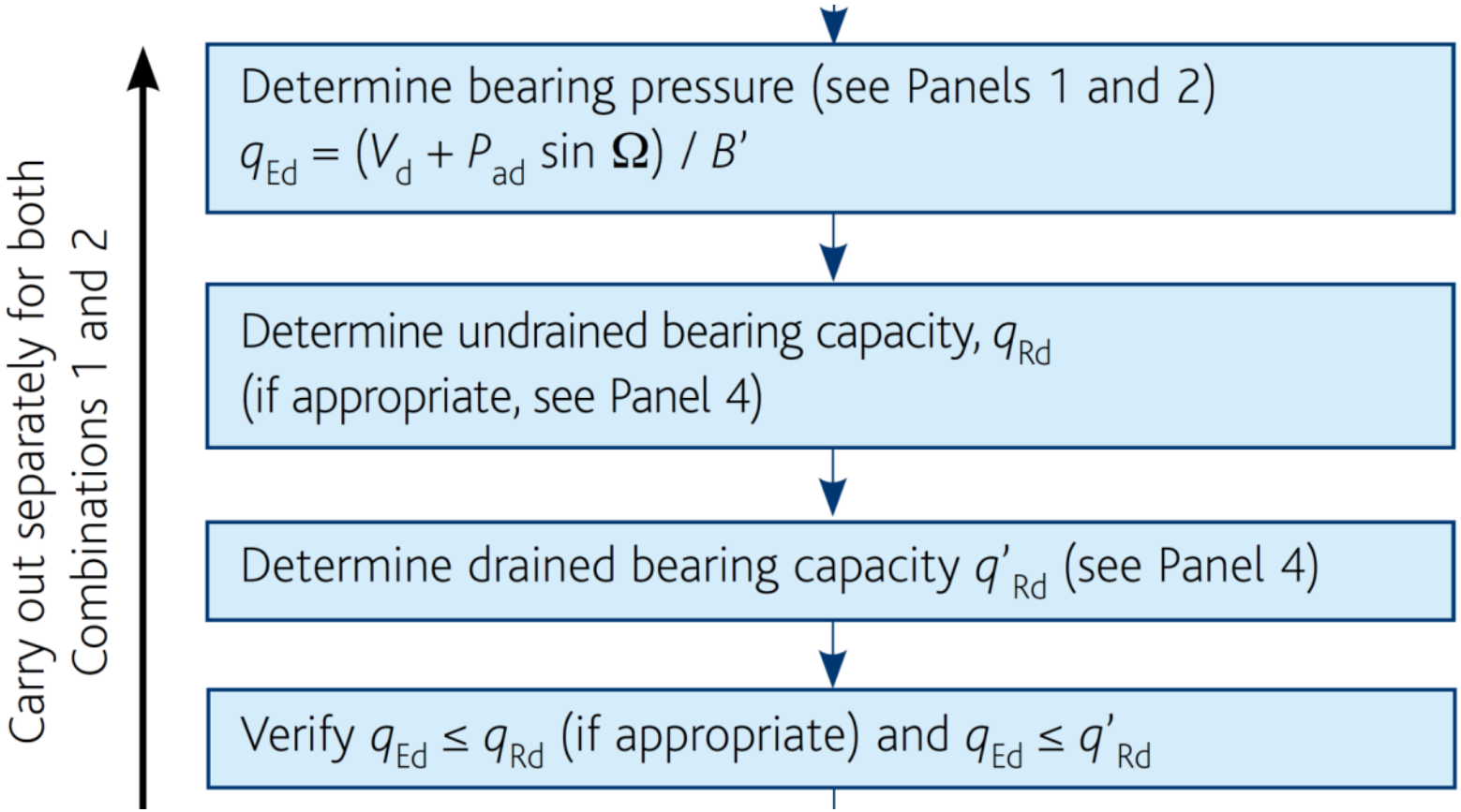


9 (Figure 4)

Overall design procedure

Design against bearing failure

9 (Figure 10)



Expressions for bearing resistance

9 (Panel 4,Figure 11)

$$e = \frac{B}{2} - \left[\frac{\gamma_G \sum_i (W_{k,i}\, L_i) + (P_{ad} \sin \Omega\, L_{vp}) - \left[P_{ad} \cos \Omega \frac{h}{3} \right]}{V_d + (P_{ad} \sin \Omega)} \right]$$

$$B' = B - 2\,e$$

Undrained bearing resistance:

$$q_{Rd} = c_{ud,fdn}(\pi+2) i_c + q_d,$$

$$i_c = \frac{1}{2} \left[1 + \sqrt{\left[1 - \frac{P_{ad} \cos \Omega}{B'\, c_{ud,fdn}} \right]} \right]$$

Drained bearing resistance:

$$q'_{Rd} = q'_d N_q i_q + (\gamma_{d,fdn} - \gamma_w) \frac{B'}{2} N_\gamma i_\gamma + c' N_c i_c$$

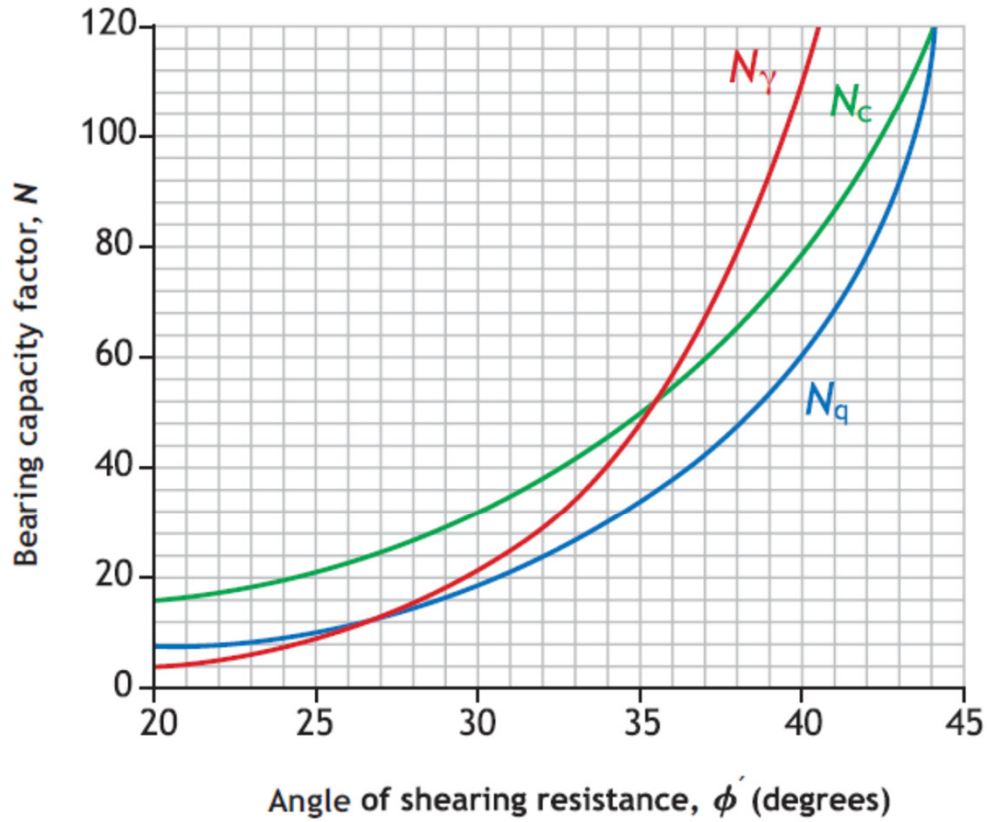
$$i_q = \left[1 - \frac{P_{ad} \cos \Omega}{\gamma_G \sum_i W_{k,i} + (P_{ad} \sin \Omega)} \right]^2$$

$$i_\gamma = i_q^{\,1.5}$$

$$i_c = i_q - (1 - i_q)/N^{c\tan\varphi}$$

Figure 11

Bearing capacity factors, *N*, from ground properties



Values for N_c, N_γ and N_q can be obtained from Figure 11

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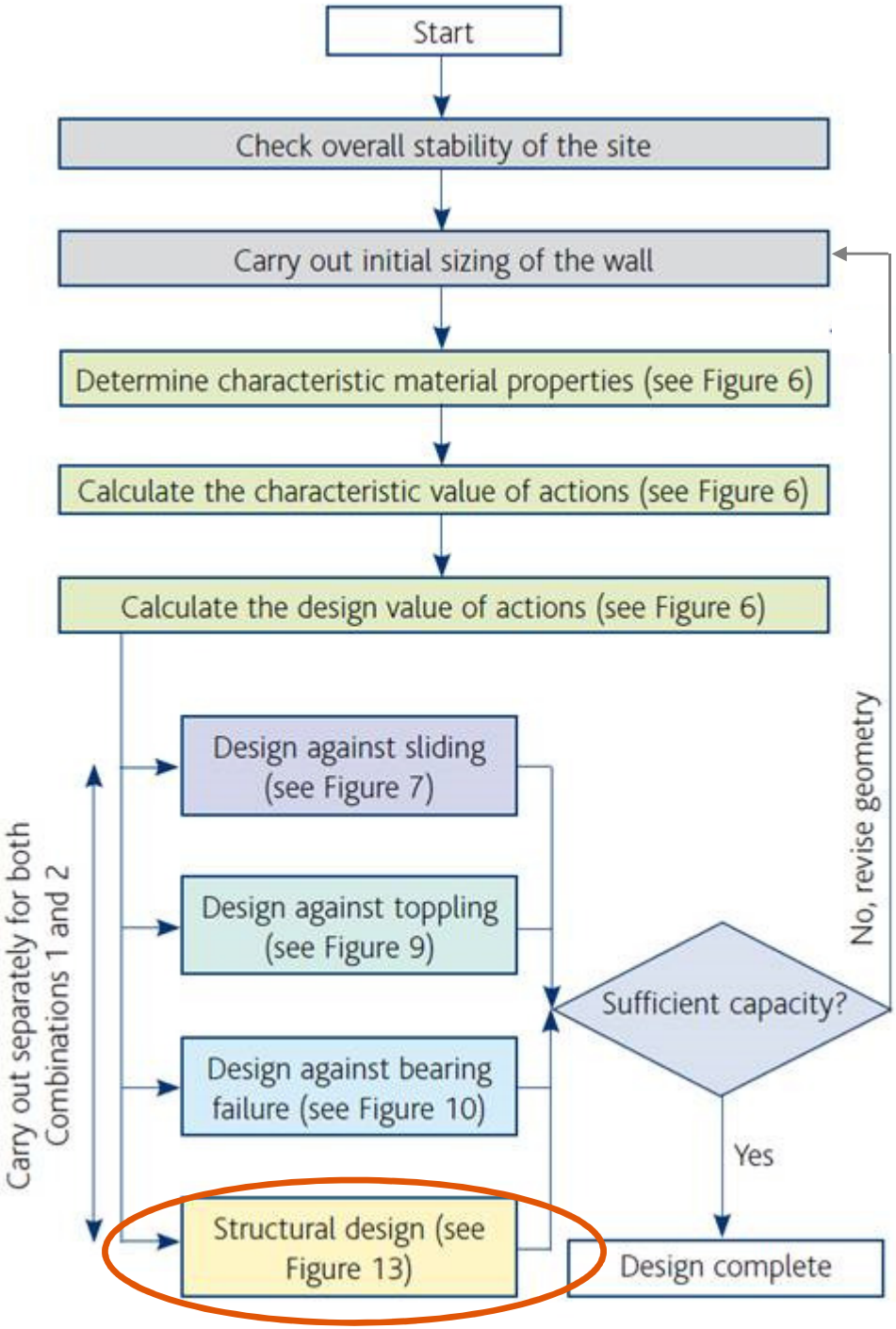
9 (Figure 4)

Overall design procedure



Structural design

9 (Figure 13)

Carry out separately for both Combinations 1 and 2

Check the stem of the retaining wall for compaction pressures or at-rest conditions as appropriate:

- Maximum design moment = M_S (see Panel 5 or 6)
- Maximum design shear force = V_S
- Refer to Chapter 3, originally published as *Slabs*[11] for the design expressions to use to check bending, shear and deflection

Check the toe and heel of the wall in bending and shear using the expressions in Panel 5 to determine applied forces and the design expressions from Chapter 3 to check bending, shear and deflection

Remember: Load and Partial Factor Combinations

Parameter	Symbol	Comb. 1	Comb. 2
Actions			
Permanent action : unfavourable	$\gamma_{G,unfav}$	1.35	1.0
Permanent action: favourable	$\gamma_{G,fav}$	1.00	1.00
Variable action	γ_Q	1.50	1.30
Soil Properties			
Angle of shearing resistance	γ_φ	1.0	1.25
Effective cohesion	$\gamma_{c'}$	1.0	1.25
Undrained shear strength	γ_{cu}	1.0	1.4
Unconfined strength	γ_{qu}	1.0	1.4
Bulk density	γ_γ	1.0	1.0

Piles

Flexural and axial resistance of piles

'Uncertainties related to the cross-section of cast in place piles and concreting procedures shall be allowed for in design'

'In the absence of other provisions', the design diameter of cast in place piles without permanent casing is less than the nominal diameter D_{nom}:

- $D_d = D_{nom} - 20$ mm for $D_{nom} < 400$ mm
- $D_d = 0.95\ D_{nom}$ for $400 \leq D_{nom} \leq 1000$ mm
- $D_d = D_{nom} - 50$ mm for $D_{nom} > 1000$ mm

ICE Specification for piling and embedded retaining walls (ICE SPERW)

B1.10.2 states 'The dimensions of a constructed pile or wall element shall not be less than the specified dimensions'. A tolerance of 5% on auger diameter, casing diameter, and grab length and width is permissible.

Flexural and axial resistance of piles

- The partial factor for concrete, γ_c, should be multiplied by a factor, k_f, for calculation of design resistance of cast in place piles without permanent casing.
- The UK value of k_f = 1.1, therefore $\gamma_{c,pile}$ = 1.65
- "If the width of the compression zone decreases in the direction of the extreme compression fibre, the value $\eta\ f_{cd}$ should be reduced by 10%"

Bored piles

Reinforcement should be detailed for free flow of concrete.

Minimum diameter of long. reinforcement = 16mm

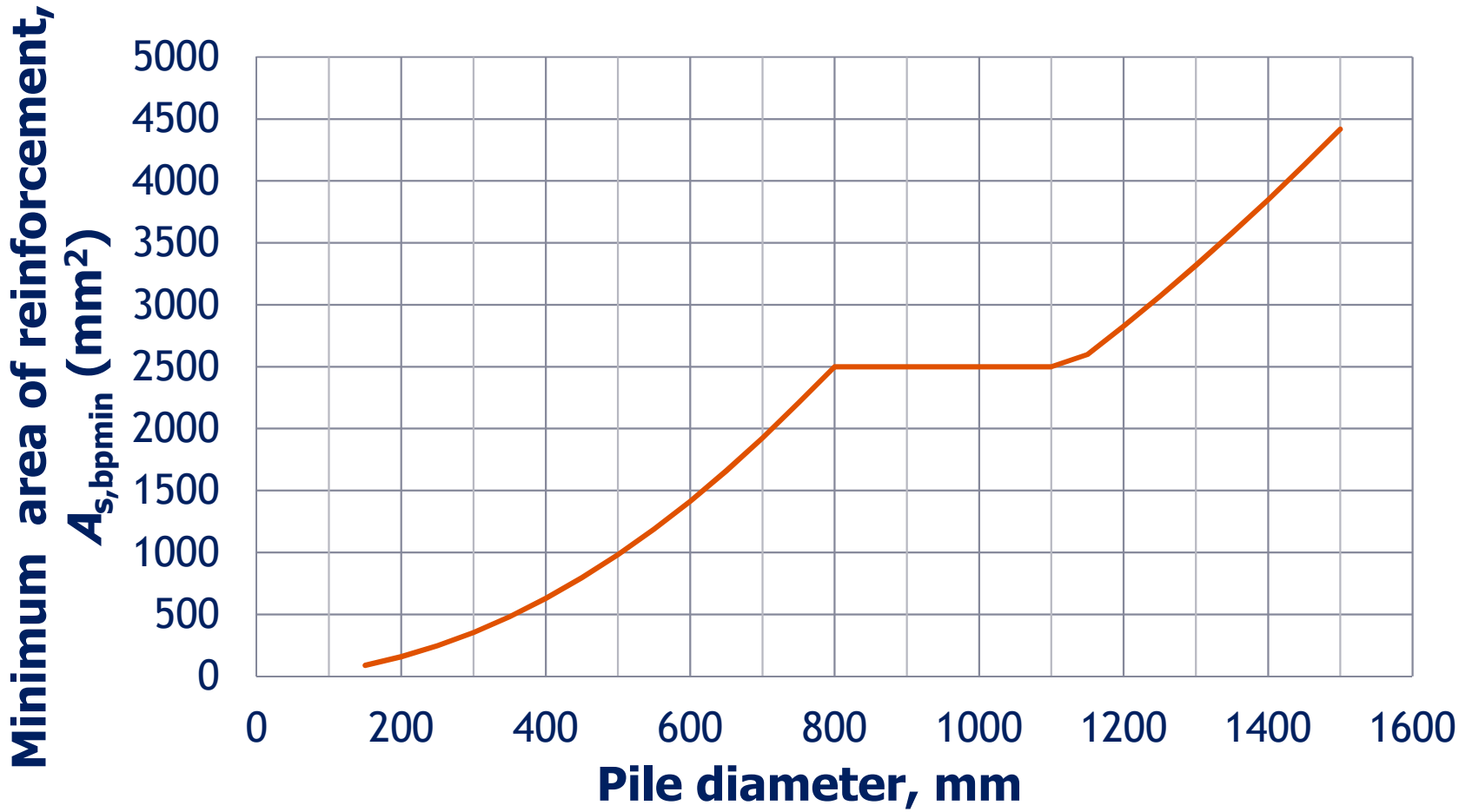
Minimum number of longitudinal bars = 6

[BUT – BS EN 1536 *Execution of special geotechnical work Bored Piles* says 12 mm and 4 bars!]

Minimum areas:

Pile cross section: A_c	Min area of long. rebar, $A_{s,bpmin}$	Pile diameters
$A_c \leq 0.5\ m^2$	$\geq 0.5\%\ A_c$	< 800 mm
$0.5\ m^2 < A_c \leq 1.0\ m^2$	$\geq 2500\ mm^2$	
$A_c > 1.0\ m^2$	$\geq 0.25\%\ A_c$	>1130 mm

Minimum reinforcement



Workshop

Design a pad foundation for a 300mm square column taking

G_k = 600kN, Q_k = 350kN.

Permissible bearing stress = 225kPa.

Concrete for base C30/37.

Work out

- size of base,
- tension reinforcement and
- any shear reinforcement.

Workshop Problem

Category 2, using prescriptive methods

Base size: $(G_k + Q_k)$/bearing stress = _____ __ _____ __

= __ __ __ _ _m^2

⇒ _____ x _____ base x _____mm deep (choose size of pad)

Use C 30/37 (concrete)

Loading = γ_g x G_k + γ_q x Q_k = _____= _____kN

ULS bearing pressure = _____/_____^{2} = _____kN/m^2

Critical section at face of column

M_{Ed} = _____ x _____ x _____^{2} / 2 = _____kNm

d = _____ - cover - assumed ø = _____= ____mm

K = M/bd^2f_{ck}= _____

Workshop Problem

$\Rightarrow$ z = ____d = _____ x _____= ____mm Table 15.5

$\Rightarrow$ $A_s = M_{Ed}/f_{yd}z$ = _____mm^2

$\Rightarrow$ Provide H____ @ _____ c/c (_____mm^2)

Check minimum steel

$100A_{s,prov}/bd$ = _____

For C30/37 concrete $A_{s,min}$ = ____ $\therefore$ OK/not OK 12.3.1

Beam shear

Check critical section d away from column face

V_{Ed} = _____ x _____= _____kN/m

$v_{Ed} = V_{Ed} / d$ = _____MPa

ρ = _____/ (_____ x _____) = _____ = _____ %

$v_{Rd,c}$ (from table) = ____MPa $\therefore$ beam shear OK/not OK.

Workshop Problem

Punching shear

Basic control perimeter at 2d from face of column

$v_{Ed} = \beta V_{Ed} / u_i d < v_{Rd,c}$

$\beta = 1$, u_i = = _____mm

V_{Ed} = load minus net upward force within the area of the control perimeter)

= _____ - _____ x ( )

= _____kN

v_{Ed} = _____MPa; $v_{Rd,c}$ = _____ (as before) => ok/not ok

End of Lecture 10
(and the course!)

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Model answer: Workshop Problem

Category 2, using prescriptive methods

Base size: (600 + 350)/225 = 4.22m^2

$\Rightarrow$ 2.1 x 2.1 base x 450mm (say) deep

Use C30/37

Loading = 1.35 x 600 + 1.5 x 350 = 1335kN

ULS bearing pressure = 1335/2.1^2 = 303kN/m^2

Critical section at face of column

M_{Ed} = 303 x 2.1 x (1.05-0.15)^2 / 2 = 258kNm

d = 450 – 50 – 16 = 384mm

K = 258 x 10^6 / (2100 x 384^2 x 30) = 0.028

Model answer: Workshop Problem

$\Rightarrow$ z = 0.95d = 0.95 x 384 = 365mm

$\Rightarrow$ $A_s = M_{Ed}/f_{yd}z$ = 258 x 10^6 / (435 x 365) = 1626mm^2

$\Rightarrow$ Provide H16 @ 250 c/c (1688mm^2) (804 mm2/m)

Check minimum steel

$100A_{s,prov}/bd$ = 100 x 1688 / 2100 / 384 = 0.209

For C30/37 concrete $A_{s,min}$ = 0.151 $\therefore$ OK

Beam shear

Check critical section d away from column face

V_{Ed} = 303 x (0.9 – 0.384) = 156kN/m

v_{Ed} = 156 / 384 = 0.41MPa

$v_{Rd,c}$ (from table) = 0.44MPa => beam shear ok.

Model answer: Workshop Problem

Punching shear

Basic control perimeter at 2d from face of column

$v_{Ed} = \beta V_{Ed} / u_i d < v_{Rd,c}$

$\beta = 1$, $u_i = (300 \times 4 + 384 \times 2 \times 2 \times \pi) = 6025$mm

V_{Ed} = load minus net upward force within the area of the control perimeter)

$= 1335 - 303 \times (0.3^2 + \pi \times .768^2 + .768 \times .3 \times 4)$

$= 467$kN

$v_{Ed} = 467 \times 10^3/(6025 \times 384) = 0.202$MPa;

$v_{Rd,c} = 0.44$ (as before) => ok