Ministry of Economics
Republic of Latvia

Apmācību semināru cikls
«Datoraprēķini būvkonstrukciju projektēšanā»

ID Nr. EM 2020/46

Rīga, 2020

Ministry of Economics
Republic of Latvia

Training seminar / Apmācību seminārs

Good Practice in Retaining Wall Design
Laba prakse atbalstsienu projektēšanā

October 28, 2020, Riga

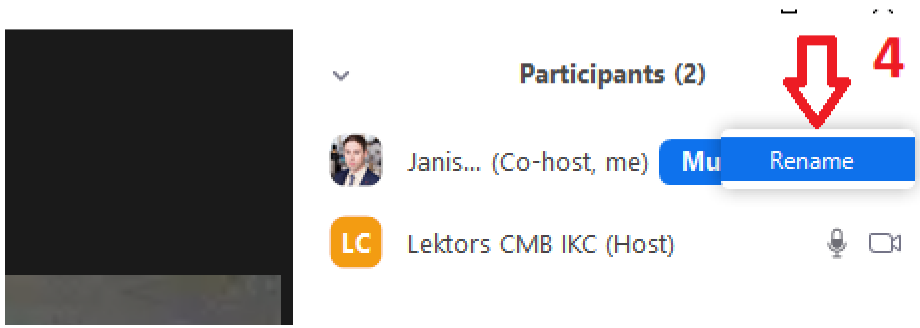
Dr Andrew Bond (United Kingdom)

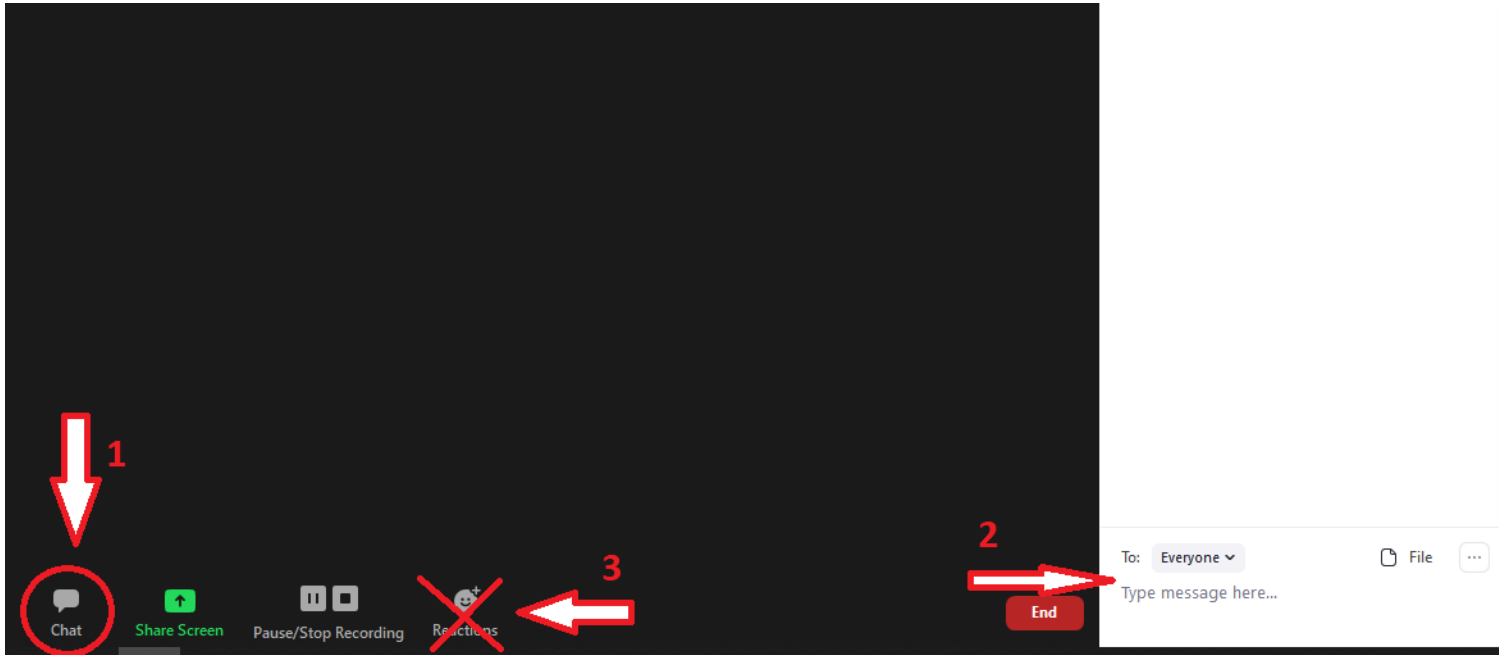
Agenda

09:00 – 10:00	Registration
10:00 – 11:30	Introduction to retaining wall design. Retaining wall selection Basis of geotechnical design
11:30 – 12:00	Coffee break
12:00 – 13:30	General rules for the design of retaining structures
13:30 – 14:00	Lunch break
14:00 – 15:30	Verification of limit states for retaining structures
15:30 – 16:00	Question and answer session

Asking questions

1. For questions use the chat functionality
2. Enter your question at the chat window on the right side
3. Do not use the reactions
4. Write your full name





Introducing your speaker …
Dr Andrew Bond

- Director, Geocentrix Ltd
  - Geotechnical consultant to contractors, consultant, and clients
  - Co-author, 'Earth pressure and earth retaining structures, 3rd ed., 2014
- Architect/developer of commercial design software:
  - ReWaRD (embedded retaining walls) 1992-present
  - ReActiv (reinforced slopes) 1994-present
  - Repute (pile foundations) 2002-present
- Chair CEN TC250/SC7 (Eurocode 7 committee) 2010-19
  - Co-author, 'Decoding Eurocode 7' (2008)
  - Co-author, 'How to design concrete structures using Eurocode 2' (2006)
  - Co-author, PP1990 'Extracts from the Structural Eurocodes' (2004/2007/2010)
- Member BSI committee B/526 Geotechnics
  - Technical author of BS 8004:2015 'Code of practice for foundations'
  - Technical author of BS 8002:2015 'Code of practice for earth retaining structures'
- Invited speaker on Eurocodes to:
  - BGA, NCE, IStructE, Highways Agency, Health and Safety Executive, Singapore Building Control Authority, University of Cape Town, Singapore Land Transport Authority, BSI China, North China Power Engineering, Moscow State University

Agenda / 10:00 - 11:30

Introduction to retaining wall design (link)

- Wall selection (overview of different types of retaining wall construction)

Basis of geotechnical design (link)

- General rules
- Principles of limit state design
- Basic variables
- Verification by the partial factor method
- Verification by the prescriptive measures
- Verification by testing
- Verification by the Observational Method
- Design assisted by testing

Coffee break / 11:30 - 12:00

Agenda / 12:00 - 13:30

General rules for the design of retaining structures (link) (link)

- Materials (soil parameters, concrete, steel, etc.)
- Groundwater
- Geotechnical analysis
- Methods of analysis (limiting equilibrium, soil-spring, finite element)
- Determination of earth pressure (Coulomb, Rankine, Brinch-Hansen, Kerisel and Absi)
- Limiting, at-rest, and intermediate values of earth pressure
- Compaction pressures
- Water pressures
- Testing
- Execution
- Reporting

Lunch break / 13:30 - 14:00

Agenda 14:00-15:30

Verification of limit states for retaining structures (link)

- Ultimate limit states
- Overall stability
- Stability of excavations
- Structural failure
- Serviceability limit states
- Displacements
- Mobilization of earth pressure

Agenda 15:30 -16:00

Question and answer session

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Introduction to retaining wall design.
Basis of geotechnical design.
Ievads atbalstsienu projektēšanā.
Ģeotehniskās projektēšanas pamati.

Dr Andrew Bond (United Kingdom)

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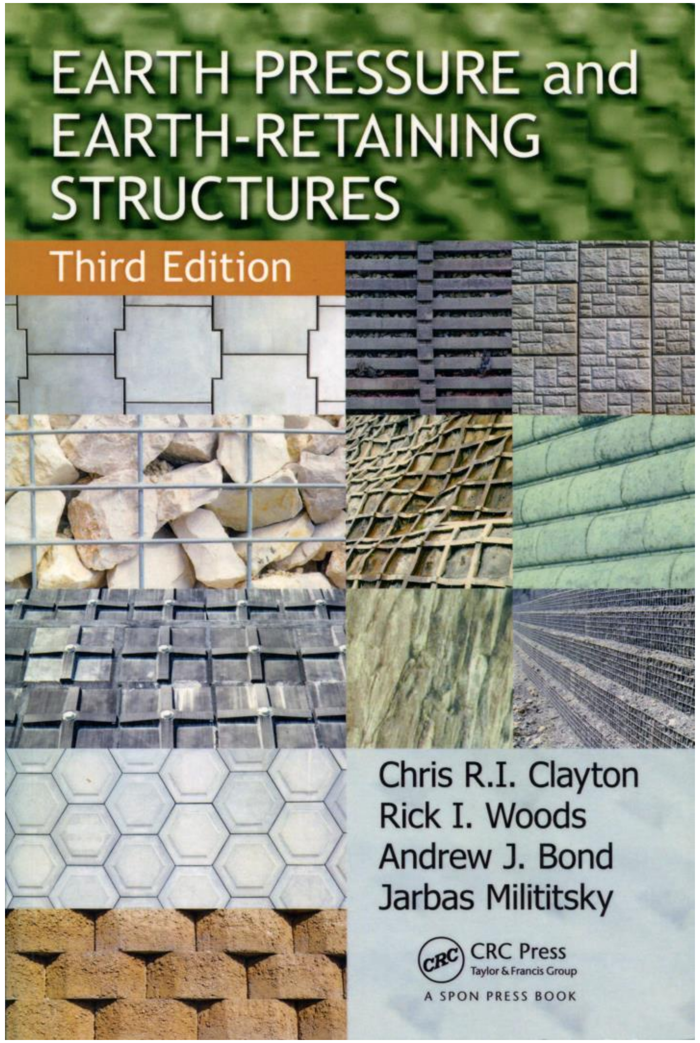
Introduction to retaining wall design

Dr Andrew Bond (Geocentrix)
Immediate-Past Chair TC250/SC7 Geotechnical design

Introduction to retaining wall design

- Reasons for selecting a retaining wall
- Gravity walls
- Embedded walls
- Composite walls and other support systems
- Summary of key points
- Questions and answers

Earth pressure & earth-retaining structures
www.earthpressurebook.com



- 1st edition, published 1986
- 2nd edition, published 1993
- 3rd edition, published 2013
- Authors: Chris Clayton, Rick Woods, Andrew Bond, and Jarbas Militisky
- Key features
  - Covers the principles of the geotechnical design of gravity walls, embedded walls, and composite structures
  - Helps non-specialists understand the geotechnical issues involved
  - Provides background to uncertainty of parameters and partial factor issues that underpin recent codes (for example Eurocode 7)
- Published by CRC Press in paperback
- ISBN: 978-1-4665-5211-1

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Reasons for selecting particular wall types

Introduction to retaining wall design

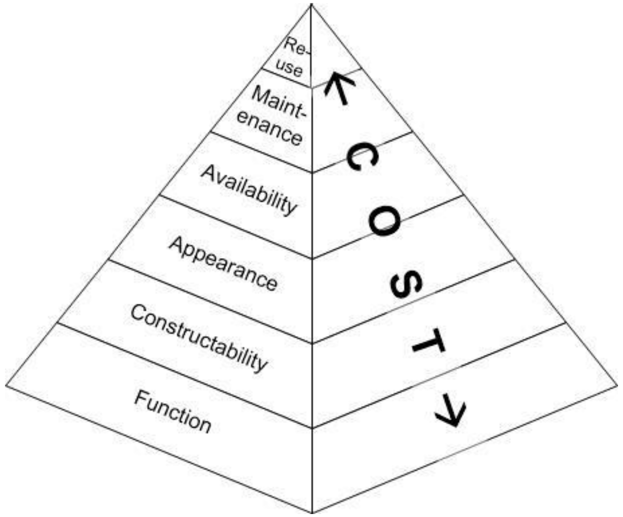
Reasons for selecting a retaining wall

Material is retained if it is kept at a slope steeper than it would eventually adopt if no structure were present

EN 1997-1, 9.1.1(1)P Eurocode 7

Rock faces may need limited support, e.g. Hong Kong MTRC North Point plant building during excavation (left, Geo Publication 1/2007)

Hierarchy of design considerations (right, Clayton et al., 2013)



Types of retaining structures EN 1997-1, 9.1.2

- Gravity walls
  - Walls of stone or plain or reinforced concrete having a base with or without a heel, ledge, or buttress (e.g. concrete gravity walls; spread footing r.c. walls; buttress walls)
  - **The weight of wall plays a significant role in supporting the retained material**
    - e,g. concrete gravity walls; spread footing reinforced concrete walls; buttress walls

- Embedded walls
  - Relatively thin walls of steel, reinforced concrete, or timber – supported by anchors, struts, and/or passive earth pressure
  - **The bending capacity of such walls plays a significant role in the support of the retained material**
    - e.g. cantilever steel sheet pile walls; anchored or strutted steel or concrete sheet pile walls; diaphragm walls

- Composite retaining structures
  - **Walls composed of elements of the above two types**
    - e.g. double sheet pile wall cofferdams; earth structures reinforced by tendons, geotextiles, or grouting; structures with multiple rows of ground anchors or soil nails

- Silos are <u>not</u> considered to be ground retaining structures

Preliminary selection of wall type (after Clayton et al., 2013)

Preliminary design considerations include:

- The need to support soil, structural loads, and/or adjacent structures
- The desired geometry for the completed structure
- Constraints due to subsoil and groundwater conditions
- Available construction methods

Factors which may influence the choice of structure are:

- height of ground to be supported
- type of retained soil
- type of foundation soil
- groundwater regime
- adjacent structures
  - magnitude of external loads
  - allowable movements
- available space for construction and construction plant
- experience and local practice
- available standards and codes of practice
- available construction techniques and equipment
- cost

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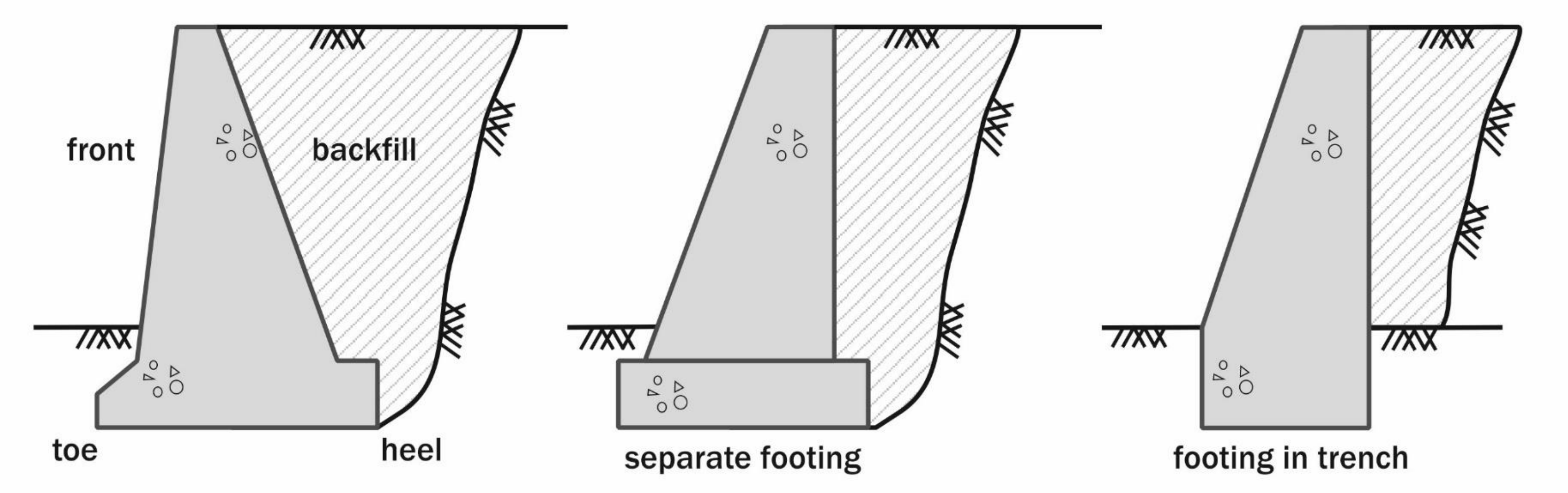
Gravity walls

Introduction to retaining wall design

Gravity wall types (after Clayton et al., 2013)

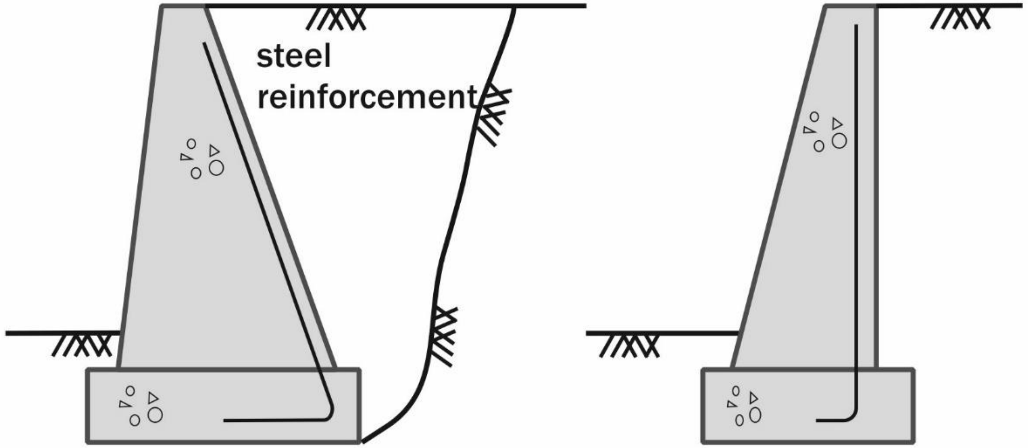
- Mass concrete gravity walls
- 'Semi-gravity' concrete walls
- Reinforced concrete cantilever walls
- Gabions
- Crib walling
- Interlocking block walls
- Masonry walls
- Counterfort walls
- Buttressed walls

Mass concrete gravity walls



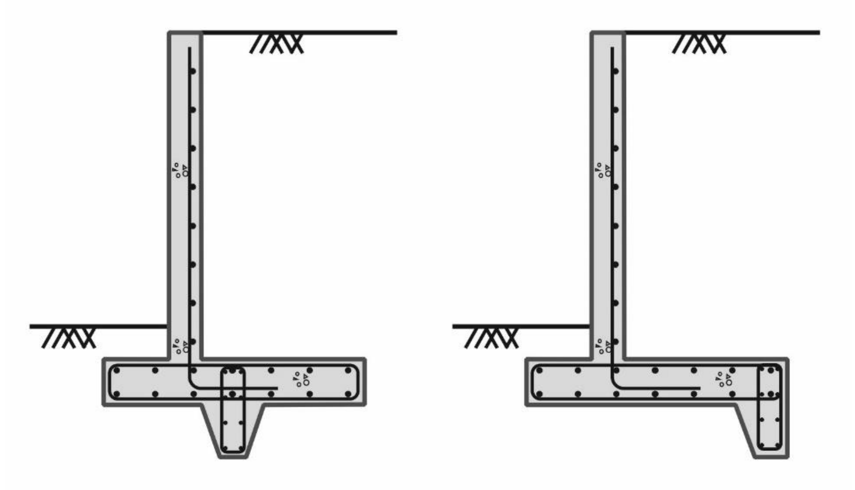
- Suitable for walls up to 3 m high
- Dimensions should result in earth pressures that produce no tensile stress in any part of the wall, since joints between concrete lifts or masonry blocks have littler if any tensile strength.
- They can be designed for greater heights but as the height increases other types of wall become more economical

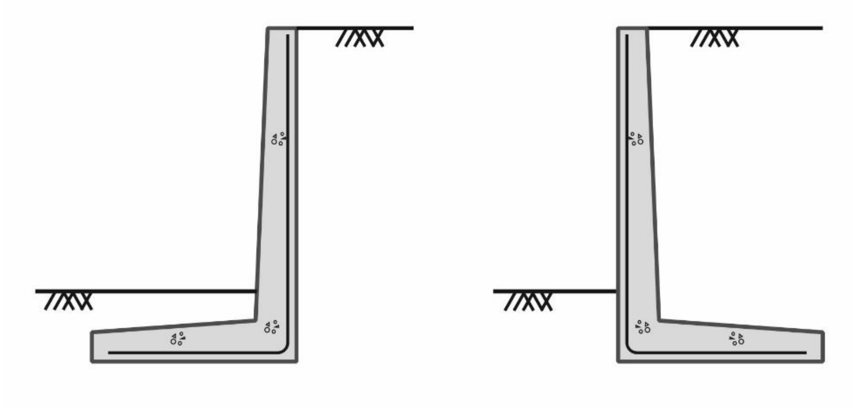
'Semi-gravity' concrete walls



- Relies more on bending and shear resistance, less on self weight, than gravity walls
- Reinforcement in the back of the wall connects the vertical stem and the base
- Reinforcement between concrete 'lifts' allows a more slender stem to be used
- Compromise between simplicity of mass concrete and low content of reinforced concrete
- Cost trade-off between volume of concrete saved and amount of steel required
- Durability of mass concrete is easier to maintain and so whole-life costs may be lower
- Thinner section of reinforced concrete will be easier to break up for recycling

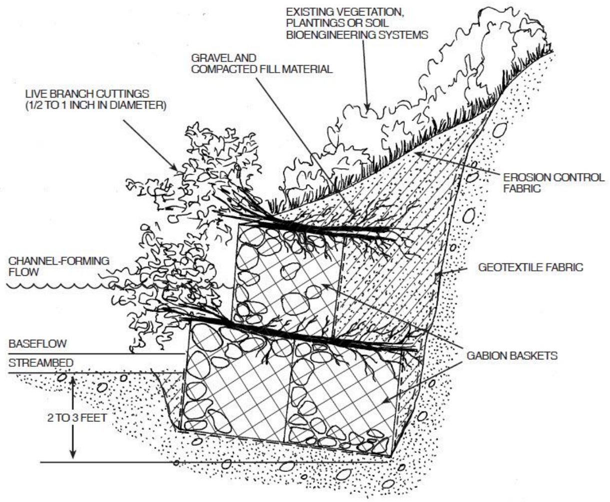
Reinforced concrete cantilever walls

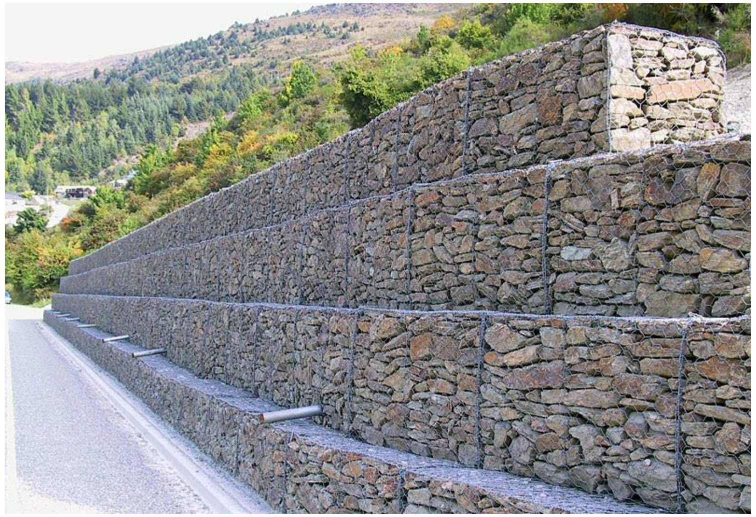




- Suitable for walls up to 6 m high (for higher walls, need to add counterforts or buttresses)
- Common forms of reinforced-concrete cantilever walls are inverted-T (left) or L (right) shapes
- Wall stem retains soil behind the wall; stability comes from the weight of the soil on the wall's heel
- A shear key may be used to increase sliding resistance
- Pre-cast units may be used, allowing quick assembly on site
- Finish can be textured to make them more visually attractive
- Quality of pre-cast concrete is higher than in-situ concrete, but this is offset by greater cost of transport and handling

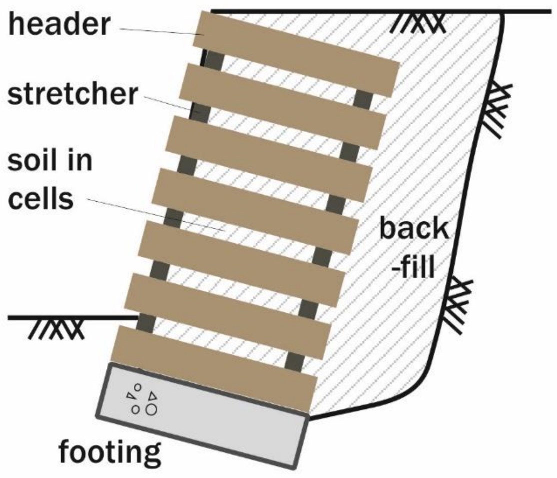
Gabions





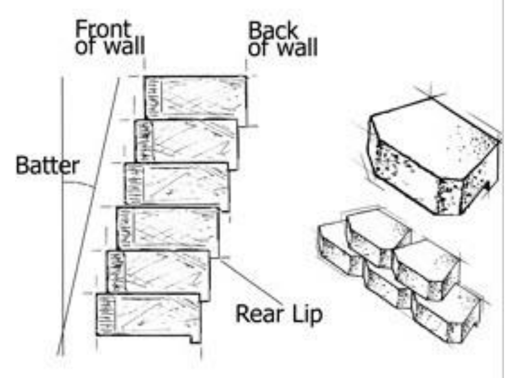
- A gabion comprises a metal or plastic mesh box filled in situ with coarse material
- Major advantage of the system is its flexibility
- When constructing in remote areas, only the mesh needs be transported to the site. Local labour and materials are used to build the structure
- Particularly good at absorbing impact energy and often used as rock fall barriers
- Visually attractive (blends in well with mountainous natural environment)
- Simple to maintain and repair if damaged
- Particularly easy to reuse or recycle

Crib walling



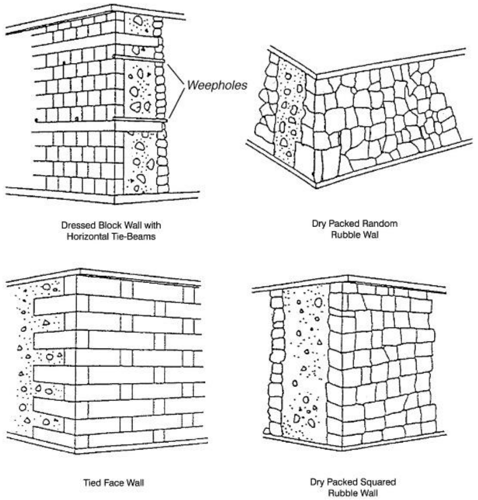
- Suitable for walls up to 6–9 m high, subjected to moderate earth pressure
- Timber components used for landscaping and temporary works; precast concrete for civil works
- Crib components are backfilled with (compacted) granular soil
- Large movements tolerated without damage since the structure is flexible
- Site work is very simple with no need of any major plant or facilities
- Use of permeable fill improves the drainage of the soil retained behind the wall
- Visually attractive (especially when surface vegetation has grown between the stretchers)
- Easy to assemble, dismantle, and reuse; maintenance is straightforward

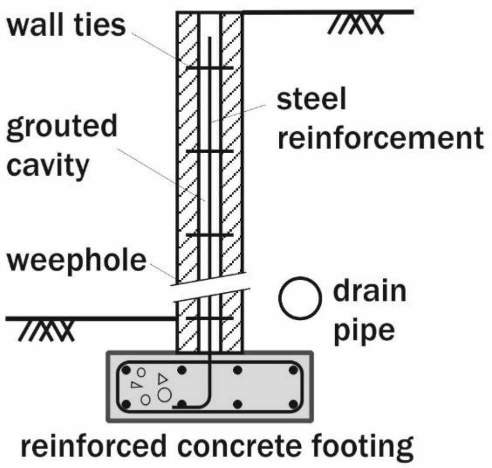
Interlocking block walls



- Suitable for walls up to 3 m high (higher with additional measures)
- Can accommodate face angles between 68-73°
- Precast concrete blocks interlock with each other (without cement mortar)
- Typically proprietary systems with different shapes of precast concrete blocks
- Interlocking between units via rear lip or protrusions on the upper or lower surfaces
- Easy to construct and to dismantle and reassemble – allowing reuse.
- Visually attractive (resembling dry stone walls)
- High standards of quality control in manufacture lead to reliable individual units that are unlikely to fail if constructed to the recommended geometry

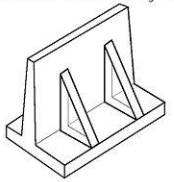
Masonry walls
(figure, left, from Bishop and Koor, 2000)





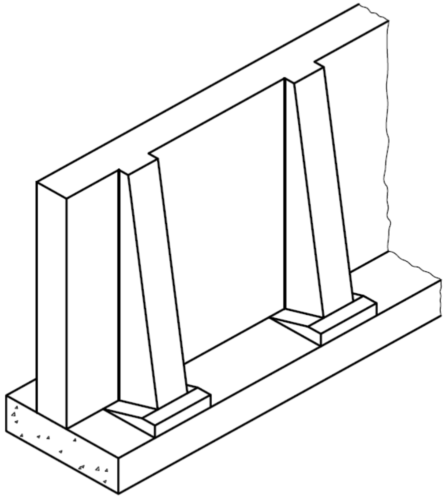
- Suitable for walls up to about 4 m high
- Mass brickwork walls generally only suitable for small walls, up to 1 m high
- A 330 mm thick 'quetta bond' wall can be used to retain up to 3 m of soil
- Economical solution that can also be attractive
- Design guidance is provided by the Brick Development Association (Haseltine and Tutt, 1991)
- Double-skinned reinforced and grouted cavity walls are suitable for greater retained heights

Counterfort walls



- Suitable for walls up to 10-12 m high or where very high pressure is applied behind the wall
- A reinforced concrete cantilever wall but with counterforts (buried in the retained soil) that connect the wall and base
- Counterfort reduces bending moments and shear stresses in the stem
- Seldom used nowadays (diaphragm or secant bored pile walls are preferred)
- Complicated to build because of the counterforts

Buttressed walls



- Alternatively known as reverse-counterfort walls
- Similar to counterfort walls but the bracing is at the front
- Counterfort is subject to compression instead of tension
- Can be constructed in masonry
- Construction more difficult than for other types of semi-gravity wall
- Common (in the UK) in previous centuries, but little used today

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Embedded walls

Introduction to retaining wall design

Embedded walls types (after Clayton et al., 2013)

- Trenching systems
- Sheet-pile walls
- Bored pile wall
- Diaphragm walls
- King post (‘soldier pile’ or ‘Berlin’) walls
- Jet-grouted walls

Trenching systems

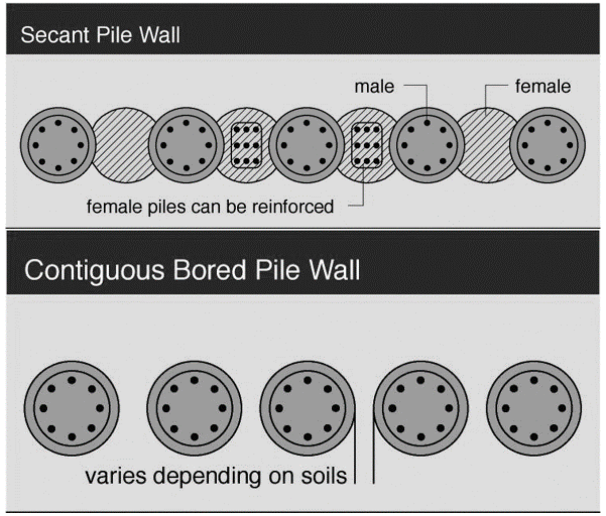
- Very common in urban areas, for installation, repair, and replacement of buried utilities
- Trench support systems are always temporary and must be highly reusable
- Typically used for narrow excavations but can be up to several metres deep
- Prefabricated units can be lifted in and out as necessary
- Individual steel sheets/timber planks require struts and walings
- Visual appearance is (almost) irrelevant

Sheet-pile walls

- Widely used to construct flexible support systems, for waterfront structures or in temporary works
- Often used in unfavourable soil conditions (for example, soft clays) because no foundations are needed
- Easily driven from ground level, construction is straightforward even where water is present
- Made of steel, timber, or pre-cast reinforced concrete
- Allows complex plan shapes and causes minimal soil displacement during driving
- Speed of installation and extraction leads to a high degree of sustainability
- Can be expensive if used to provide a permanent solution
- Modern installation methods have low environmental impact but traditional methods can be very noisy
- Wall depth limited by section size, loads, and stock lengths, but extended by water jetting or pre-augering

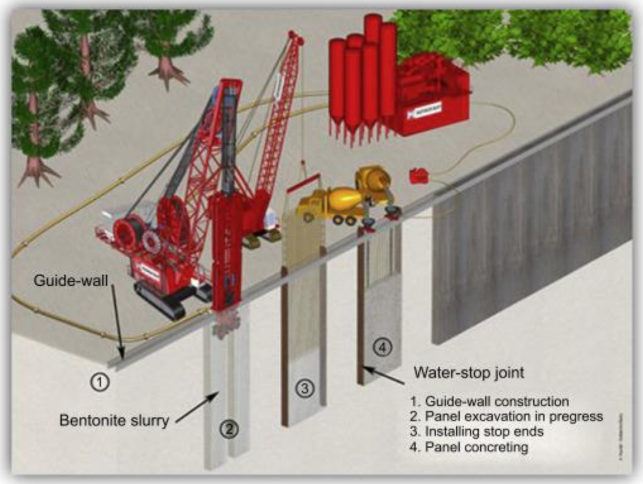
Bored pile walls

- Can be constructed in a wide range of diameters and to almost any geometric layout, in almost any ground conditions
- Construction noise and vibration are relatively low, allowing installation close to existing structures.
- Can support high vertical loads in addition to lateral earth pressures
- Bored-pile walls may be Intermittent (spacing exceeds diameter), Contiguous (piles touching) or Secant (piles interlocking)
- Typically covered with non-load bearing facing
- Not normally feasible to extract bored piles them from the ground
- Horizontal deformations can be restricted to 1-2% of the retained height, when tied back with anchors
- More expensive than sheet-pile or soldier pile walls but cheaper than diaphragm walls



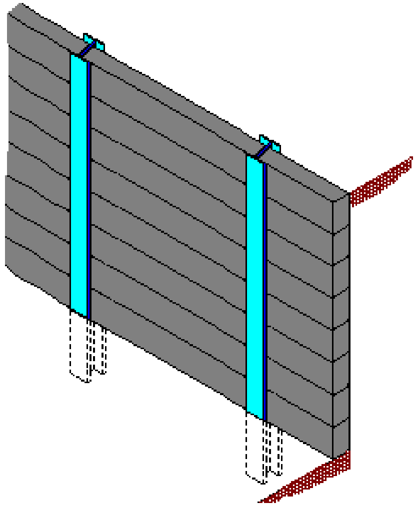
Diaphragm walls (figure, left, from Heath, 2016)

- Can be used as both a retaining structure and a load-bearing element (barrette) for deep basements:
  - buildings, traffic underpasses, underground mass-transit stations,
  - cut-and-cover tunnels, car parks, underground industrial facilities,
  - docks and waterfront installations, and waterworks
- Economical for temporary and permanent ground support
- Avoids need to underpin adjacent (existing) structures
- Allows groundwater control
- Allows maximum use of a plot of ground in crowded inner-city areas
- Can be built to great depths ahead of the main excavation, so acting as support for adjacent structures
- Cost depends on a number of factors, such as the configuration and physical dimensions of the wall



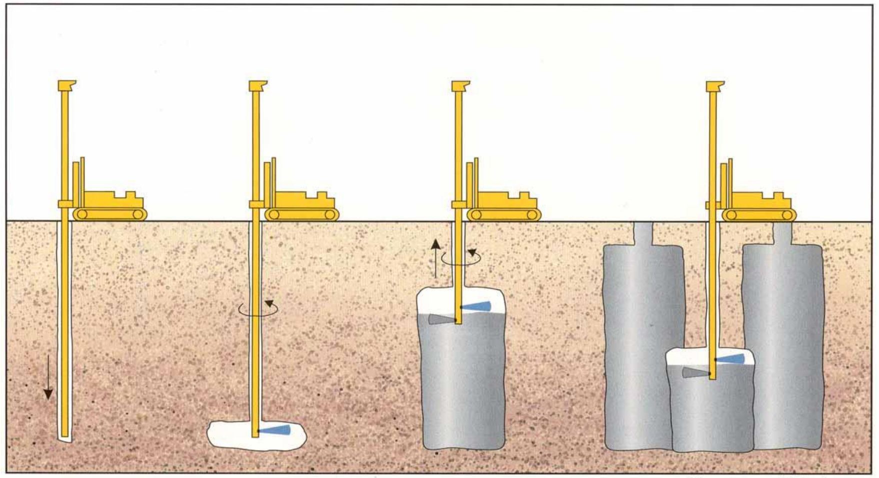
King post (‘soldier piles’ or ‘Berlin’) walls (figure, right, from aarsleff.co.uk)

- Typically constructed using vertical steel H-piles, driven at regular spacings
- Pre-cast or in-situ concrete panels placed horizontally between the posts
- The panels transfer earth pressure horizontally to the king posts, which transmit the load vertically, and support the retained height through bending.
- King posts may be supported by props, ground anchors, and/or soil beneath the retained soil (where they are driven below the base of the supported soil)



Jet-grouted walls

- Creates a column of soil-cement by rotating a horizontal jet of grout in the ground over a specified depth of treatment, mixing grout with the in-situ soil
- Columns at relatively close centres form a wall similar to a secant pile wall (but with much lower strength)
- An open hole is first drilled to the required wall depth
- Columns are constructed from the bottom upwards, with alternate columns being formed before the infill columns
- In favourable ground conditions, the process is both cheaper and faster than bored piling
- End product has poorer aesthetics and is scores very low for sustainability and reusability



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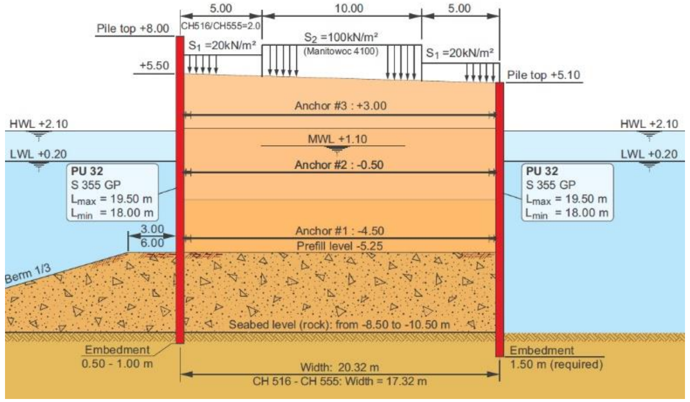
Composite walls and other support systems

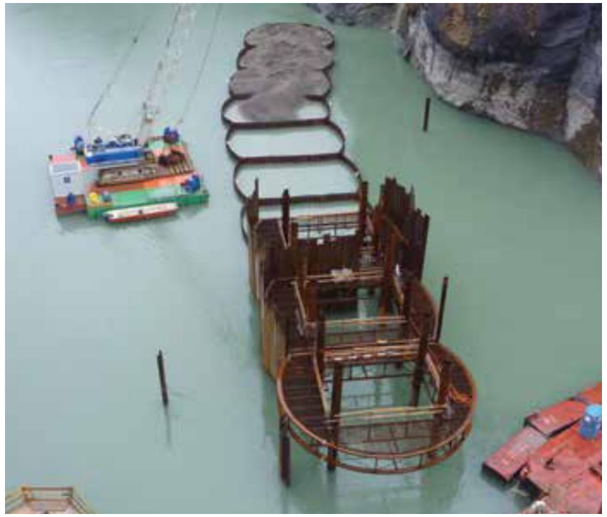
Introduction to retaining wall design

Composite walls types and other systems (after Clayton et al., 2013)

- Cofferdams
- Reinforced soil structures
- Anchored earth structures
- Support using ground anchors
- Soil nailing

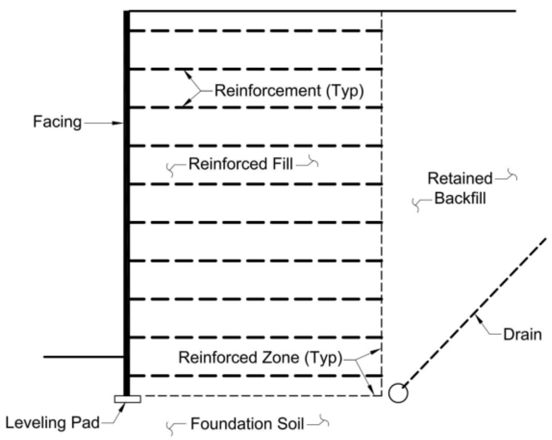
Cofferdams





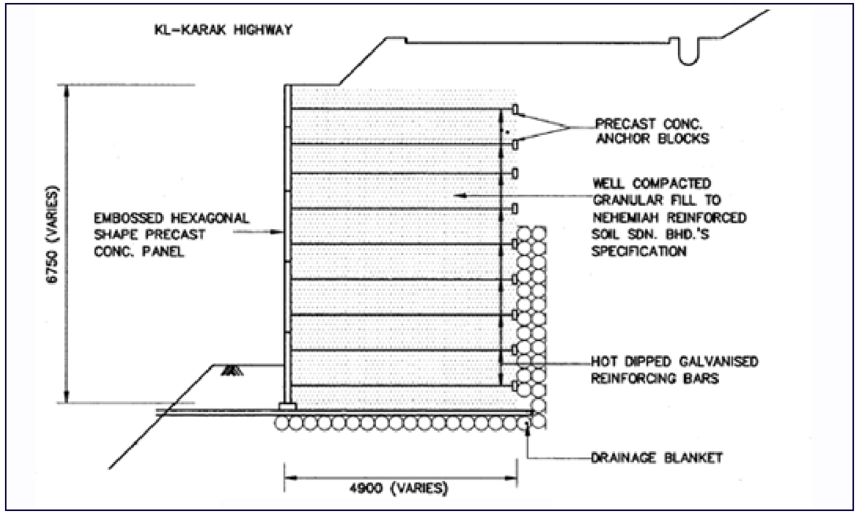
- The term 'cofferdam' or 'caisson' is used for any structure built to facilitate construction or repair in areas that are normally submerged, allowing work to be carried out in the dry
- Cofferdams are used to construct spread foundations in the middle of a river. Circular sheet pile walls can be driven from a barge, around the proposed site of construction and, after stiffening using wales and bracing, pumped dry. After construction of the bridge foundation and pier the cofferdam would be flooded before sheet pile extraction
- Double-skin cofferdams can be categorised into two groups: double-wall cofferdams, and cellular cofferdams. Both are essentially gravity structures, made up by placing granular backfill between a series of sheet-pile retaining structures
- Double-wall cofferdams consists of two parallel walls of sheet piling, connected at one or more levels by steel rods, bearing on external walings. The space between the sheet piles is filled with granular soil, rock, or hardcore
- Cellular cofferdams are constructed from inter-linked smaller circular cofferdams known as cells, made from straight-web steel sheet piling

Reinforced soil structures (figures from Geosynthetics, 2019)



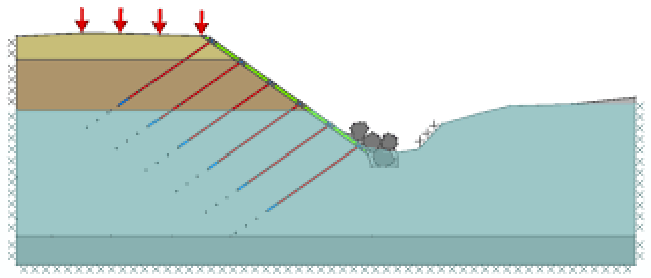
- Also known as 'mechanically stabilized earth' (or MSE) structures
- Reinforced soil structures comprise a strip foundation; facing units; reinforcement; and capping beam
- Reinforced soil structures are gravity walls, with the wall made from compacted soil and a large number of closely spaced reinforcing elements
- Reinforcement is initially unstressed, taking load only as the soil mass tries to deform under its self weight, and any applied loads
- As the reinforcement interacts with the surrounding soil it develops bond stresses along its whole length
- From late 1920s, systems were patented by Coyne in France and Munster in the United States
- In 1960s, Vidal developed a system using concrete facings and steel strips, termed 'La Terre Armée' or Reinforced Earth®

Anchored earth structures (figures from www.nehemiahwalls.com)



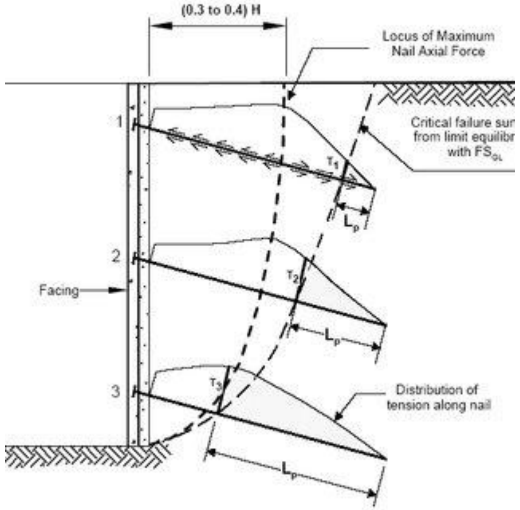
- Anchored earth structures are gravity walls, with the wall made from compacted soil and a number of closely spaced passive anchors
- Anchored earth and reinforced soil provide two different methods of binding a soil mass together.
- Anchored earth uses a similar number of elements as reinforced soil, but is composed of a bar or strip with a relatively small surface area, terminating at a passive block or hoop at the rear of the backfill
- Anchored earth transmits most load directly from the wall facing to the remote block or hoop

Support using ground anchors (figure from www.anchorsystems.co.uk)



- Anchoring of in-situ ground can be used with pre-cast facing units
- Individual precast concrete 'slabs' can be used to provide a retaining structure at the toe of a pre-existing area of slope instability, which if unsupported might threaten the highway below.
- The use of ground anchors to hold back retaining structures is distinctly different from reinforced soil, which aims to bind a soil mass together to form a gravity structure
- Ground anchors comprise a smaller number of more widely spaced elements that are highly stressed before the retaining structure is commissioned
- Ground anchors transmit load directly from the wall to a remote "fixed length" with little stress transfer along the "free length" in between

Soil nailing



- Soil nailing is a method of reinforcing the ground in-situ, in which steel bars are either driven, drilled and grouted, or fired ballistically into the excavated face
- Nail installation proceeds in parallel with staged top-down excavation, usually with some form of shotcrete and steel mesh facing being applied in panels
- The technique is best suited to near vertical faces in relatively good ground

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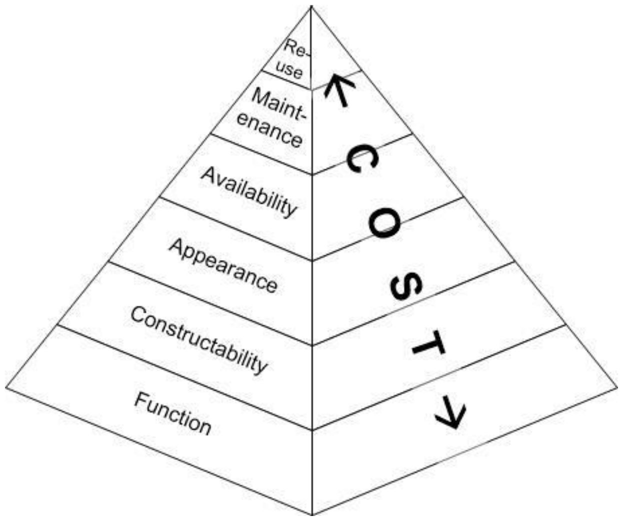
Summary of key points

Introduction to retaining wall design

Summary of key points

- Retaining walls can be categorized by type, as follows:
  - Gravity walls
  - Embedded walls
  - Composite walls and other support systems
- Key factors to consider when for selecting a retaining wall are:
  - Function
  - Constructability
  - Appearance
  - Availability
  - Maintenance
  - Re-use
- These factors all affect the cost



Questions and answers

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www.geocentrix.co.uk

References

- Chris R.I Clayton, Rick I. Woods, Andrew J. Bond, and Jarbas Militisky (2014), *Earth Pressure and Earth-Retaining Structures*, Third Edition, CRC Press.
- I. Bishop and N. P. Koor (2000), *Integrated geophysical and geotechnical investigations of old masonry retaining walls in Hong Kong*, Quarterly Journal of Engineering Geology and Hydrogeology, 33, 335-349, 1 November 2000
- K. Heath (2016), *Marinas in the Arabian Gulf region*, Marine Concrete Structures, 2016

Ministry of Economics
Republic of Latvia

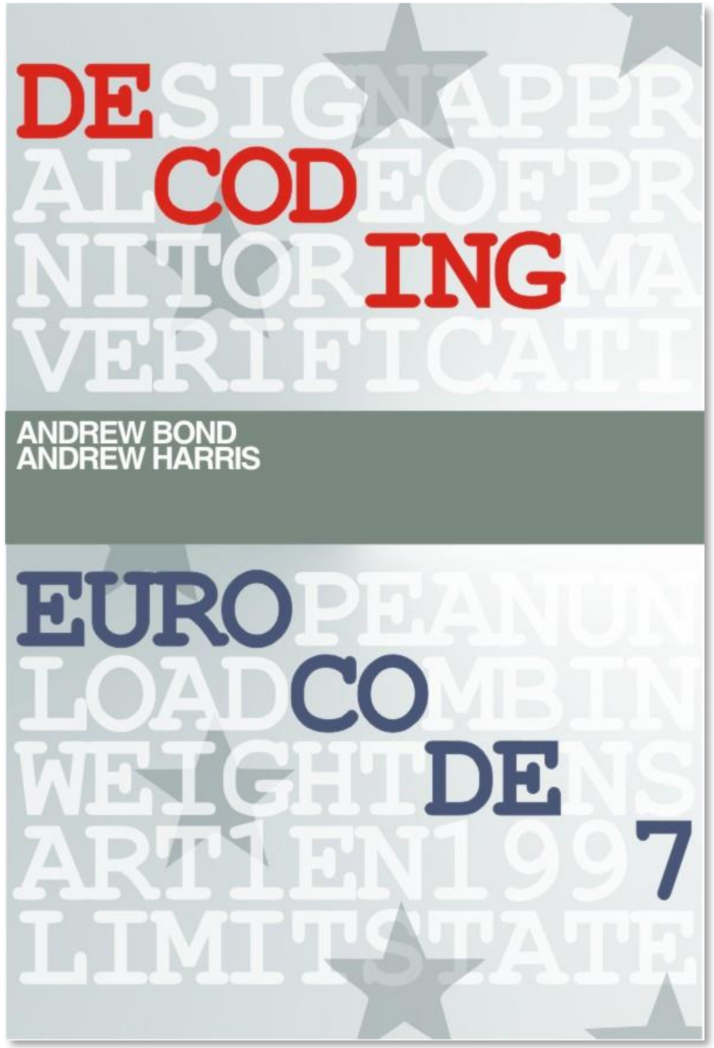
Basis of geotechnical design

Dr Andrew Bond (Geocentrix)
Immediate-Past Chair TC250/SC7 Geotechnical design

Basis of geotechnical design

- Standards for structural and geotechnical design
- General rules
- Principles of limit state design
- Basic variables
- Verification by the partial factor method
- Summary of key points
- Questions and answers

Decoding Eurocode 7
www.decodingeurocode 7.com



Book published August 2008

Key features

- Covers ENs 1997-1 and -2, plus relevant parts of other Eurocodes
- Also covers associated execution and testing standards
- Explains key principles
- Illustrates application rules with real-life case studies
- Material extensively tested on training courses over 5 years

Authors Andrew Bond and Andy Harris

Published by Taylor and Francis in hardback, with colour section

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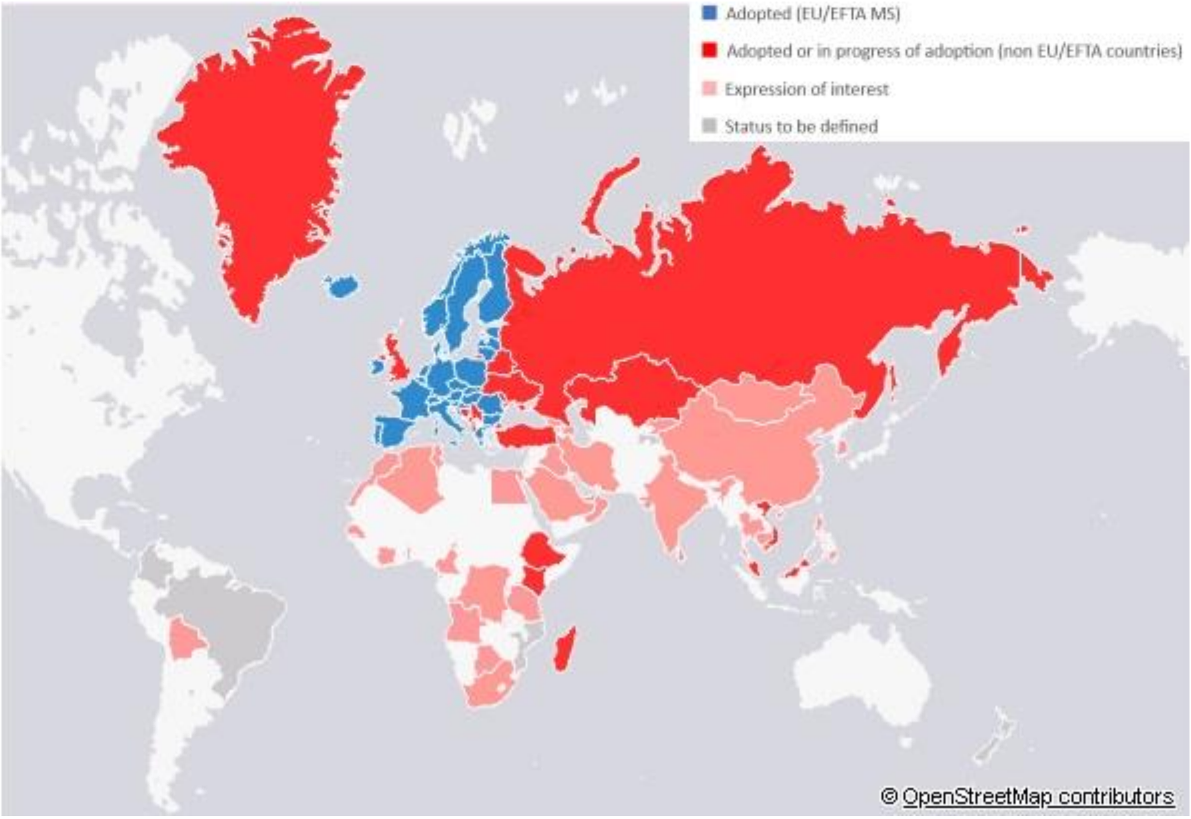
Standards for structural and geotechnical design

Basis of geotechnical design

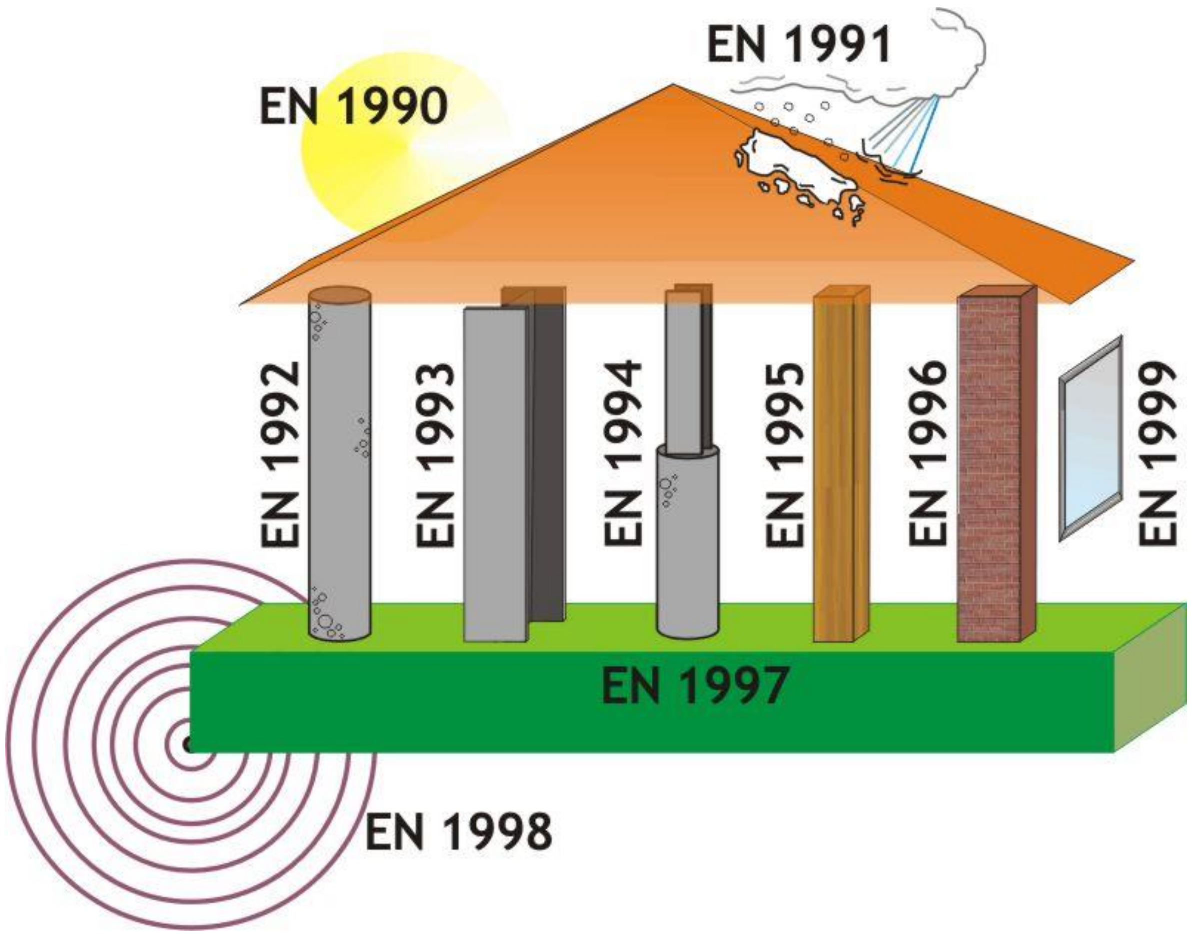
Worldwide interest in Eurocodes (https://eurocodes.jrc.ec.europa.eu, 2020)



Members of CEN – the European standards organization (after Bond and Harris, 2008)

Austria	Greece	Poland
Belgium	Hungary	Portugal
Bulgaria	Iceland	Romania
Croatia	Ireland	Serbia
Cyprus	Italy	Slovakia
Czech Republic	Latvia	Slovenia
Denmark	Lithuania	Spain
Estonia	Luxembourg	Sweden
Finland	Malta	Switzerland
France	Netherlands	North Macedonia
Germany	Norway	Turkey
(Total: 34 as of October 2020)		United Kingdom

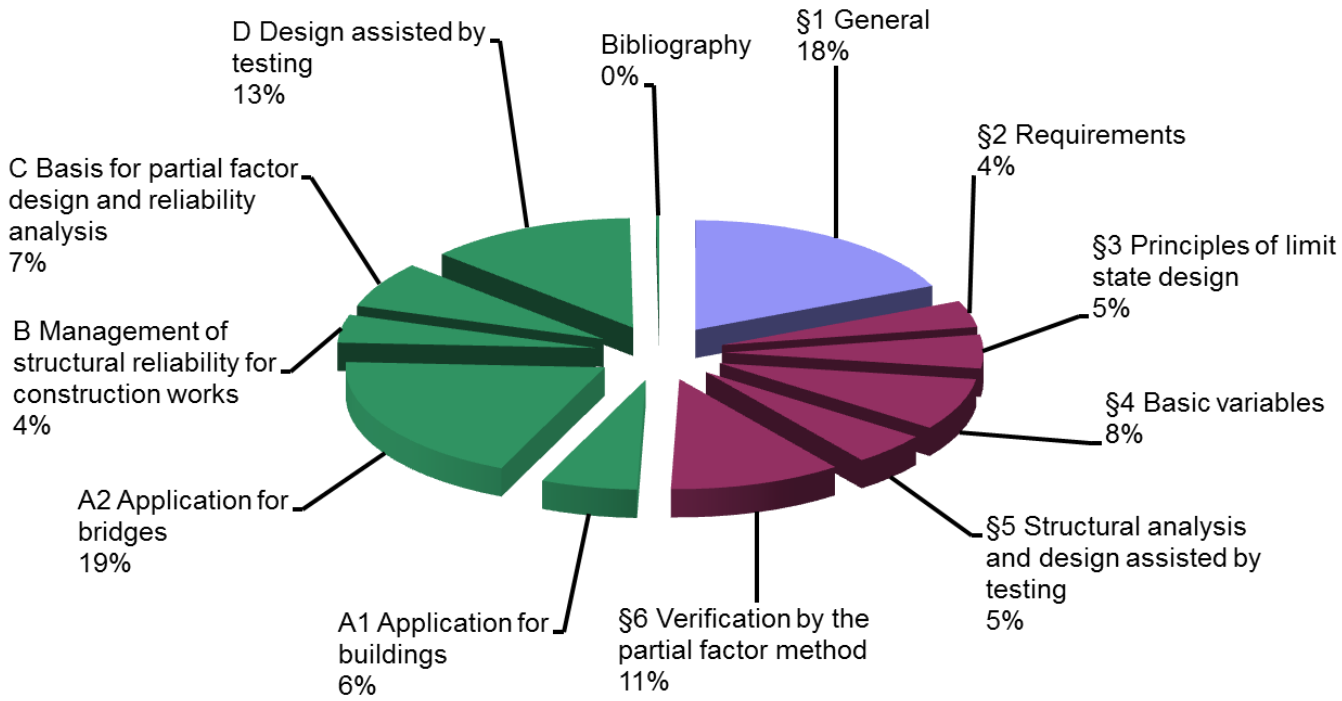
The 1st generation Eurocode family
Bond and Harris (2008)



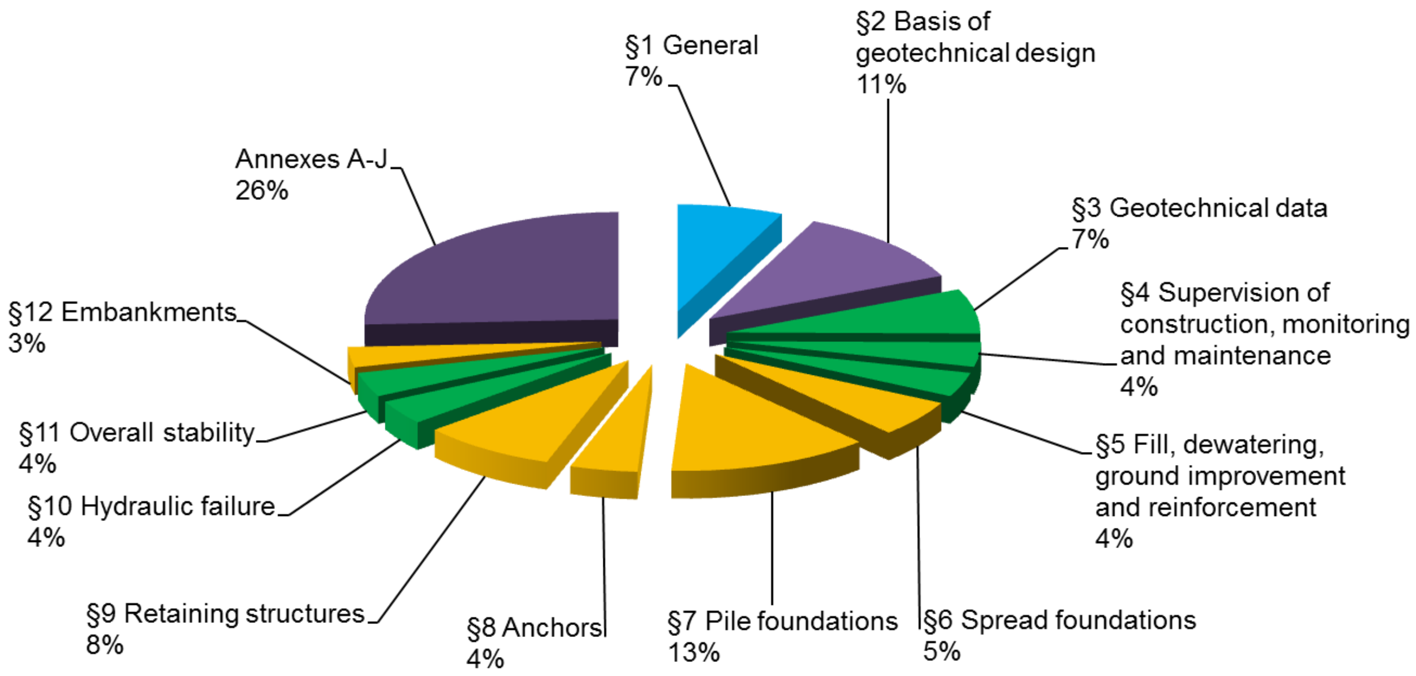
List of 1st generation Eurocodes with rules for geotechnical design

EN	Eurocode	Parts (w/sub-parts)	Geo?
1990	Basis of structural design	1	Yes
1991	Actions on structures	4 (10)	Yes
1992	Design of concrete structures	3 (4)	Yes
1993	Design of steel structures	6 (20)	Yes
1994	Design of composite steel and concrete structures	2 (3)	
1995	Design of timber structures	2 (3)	
1996	Design of masonry structures	3 (4)	
1997	Geotechnical design	2	Yes
1998	Design of structures for earthquake resistance	6	Yes
1999	Design of aluminium structures	1 (5)	
	Total	30 (58)	

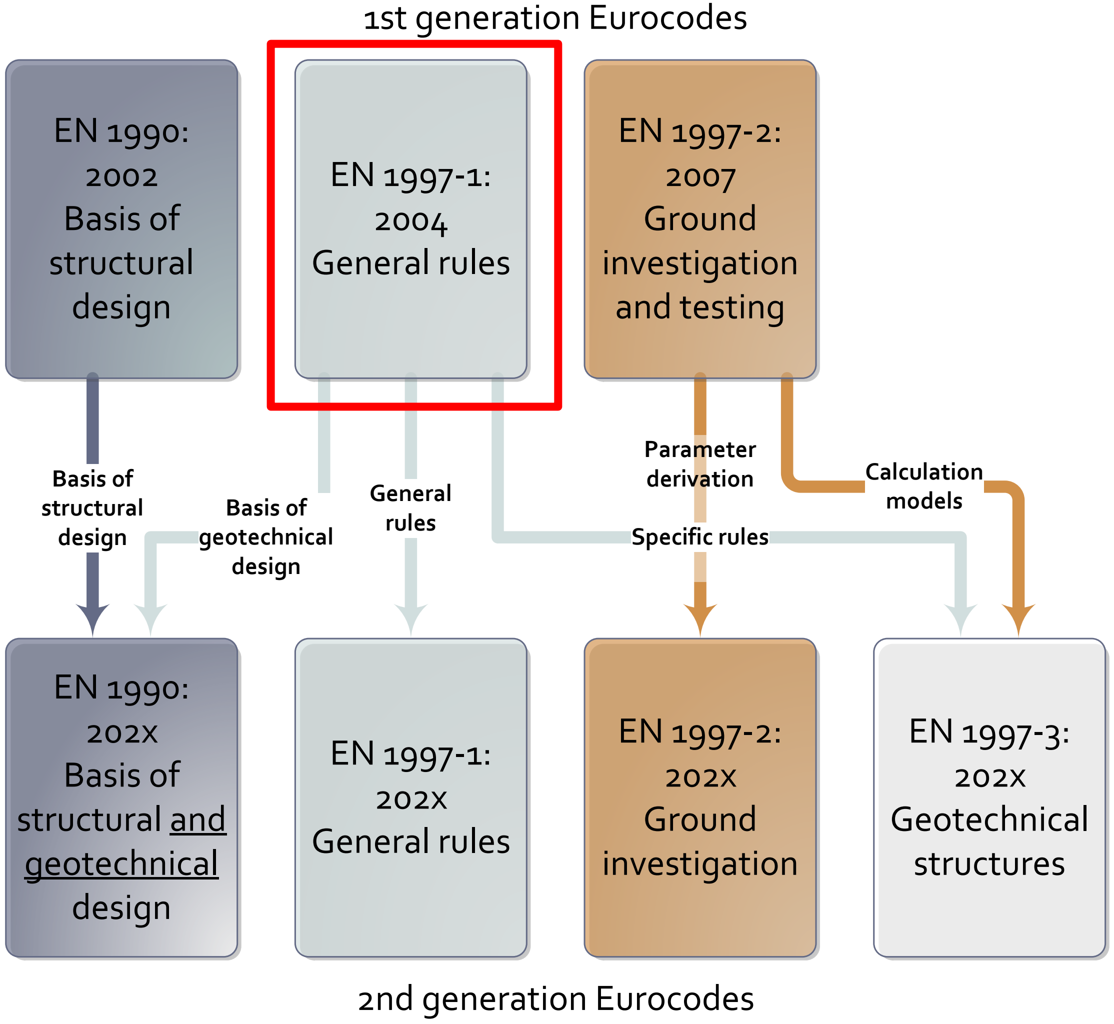
EN 1990: 2002
Basis of structural design



EN 1997-1:2004
Geotechnical design – General rules



Basis of geotechnical design in 1st and 2nd generation Eurocodes



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General rules

Basis of geotechnical design

General rules

- Basic requirements
- Structural reliability
- Consequences of failure
- Design service life
- Quality management

Basic requirements

A structure shall be designed and executed in such a way that it will, during its design service life, with appropriate degrees of reliability and in an economical way:

- sustain all foreseeable and specified actions and influences that are likely to occur during its execution and use
- meet the specified serviceability requirements for the structure or a structural member
- meet the specified durability requirements for the structure of the structural member

In the case of fire, the structural resistance shall be adequate for the required period of time

Source: prEN 1990, September 2020 draft

Structural reliability

Appropriate measures should be taken to avoid gross human errors and omissions and to limit their effects on the structural reliability.

Levels of reliability for structural failure and serviceability are achieved by:

- appropriate representation of the basic variables
- accuracy of the mechanical models used and interpretation of their results
- prevention of errors in design and execution of the structure, including gross human errors
- adequate inspection

Source: prEN 1990, September 2020 draft

Consequences of failure

Consequence class	Indicative qualification of consequences		Consequence factor K_F
	Loss of human life or personal injury*	Economic, social or environmental consequences*	
CC4 - Highest	Extreme	Huge	-
CC3 – Higher	High	Very great	1.1
CC2 – Normal	Medium	Considerable	1.0
CC1 – Lower	Low	Small	0.9
CC0 – Lowest	Very low	Insignificant	-
*The consequence class is chosen based on the more severe of these two columns			

- The Eurocodes do not entirely cover design rules needed for structures in CC4, for which additional provisions can be needed
- For CC0, either the Eurocodes or alternative provisions may be used
- **The consequence class is used to determine the value of consequence factor k_F**

Examples of buildings and geotechnical structures in different consequences classes

Class	Examples	
	Buildings where people…	Geotechnical structures
CC4	(no examples given in EN 1990)	Geotechnical constructions whose integrity is of vital importance for civil protection, e.g. underground power plants, road/railway embankments with fundamental role in the event of natural disasters, earth dams connected to aqueducts and energy plants, levees, tailing dams and earth dams with extreme consequences upon failure (very high risk-exposure), etc. In cases with significative landslide hazards
CC3	… assemble, e.g. grandstands, concert halls	Retaining walls and foundations supporting public buildings, with high exposure. Man-made slopes and cuts, retaining structures with high exposure. Major road/railway embankments, bridge foundations that can cause interruption of service in emergency situations. Underground constructions with large occupancy (e.g. underground parking).
CC2	… normally enter, e.g. residential and office buildings	All geotechnical structures not classified as CC1 or CC3 or CC4
CC1	… do not normally enter, e.g. agricultural buildings, storage buildings	Retaining walls and foundations supporting buildings with low occupancy. Man-made slopes and cuts, in areas where a failure will have low impact on the society. Minor road embankments not vital for the society. Underground constructions with occasional occupancy.
CC0	(no examples given in EN 1990)	Not applicable
Examples taken from prEN 1990:2020 and prEN 1997-1:2019		

Design service life

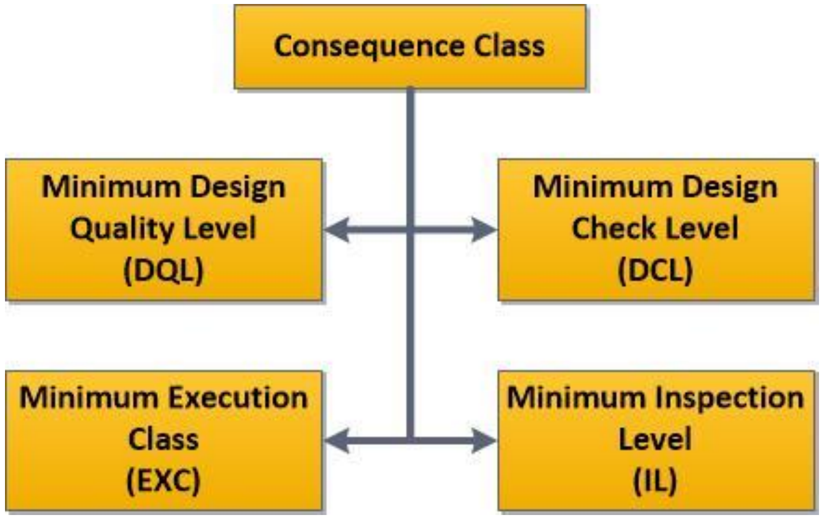
- The design service life T_{life} of the structure should be specified
- The design service life should be used to determine the time-dependent performance of the structure (e.g. durability, fatigue, and deformation due to consolidation of the ground)
- Structures or parts of structures that can be dismantled in order to be re-used should not be classified as temporary structures

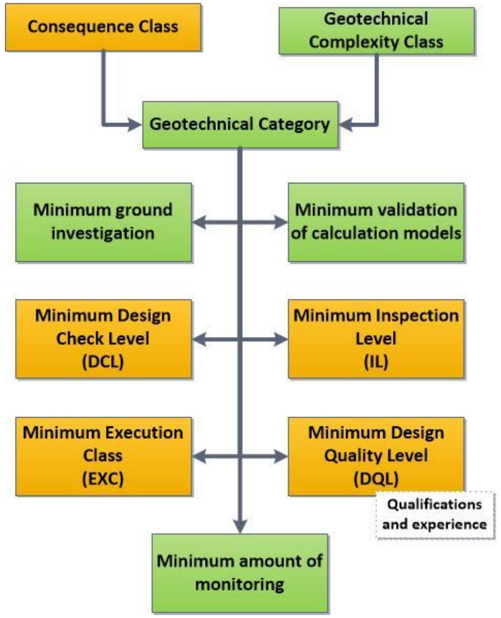
Category of buildings	Design service life T_{life} (years)
Monumental building structures	100
Building structures not covered by another category	50
Agricultural, industrial, and similar structures, Replaceable structural parts	25
Temporary structures	$\leq$ 10
For specific temporary structural members, such as anchors, $T_{life} \leq 2$ years can be used	

Quality management

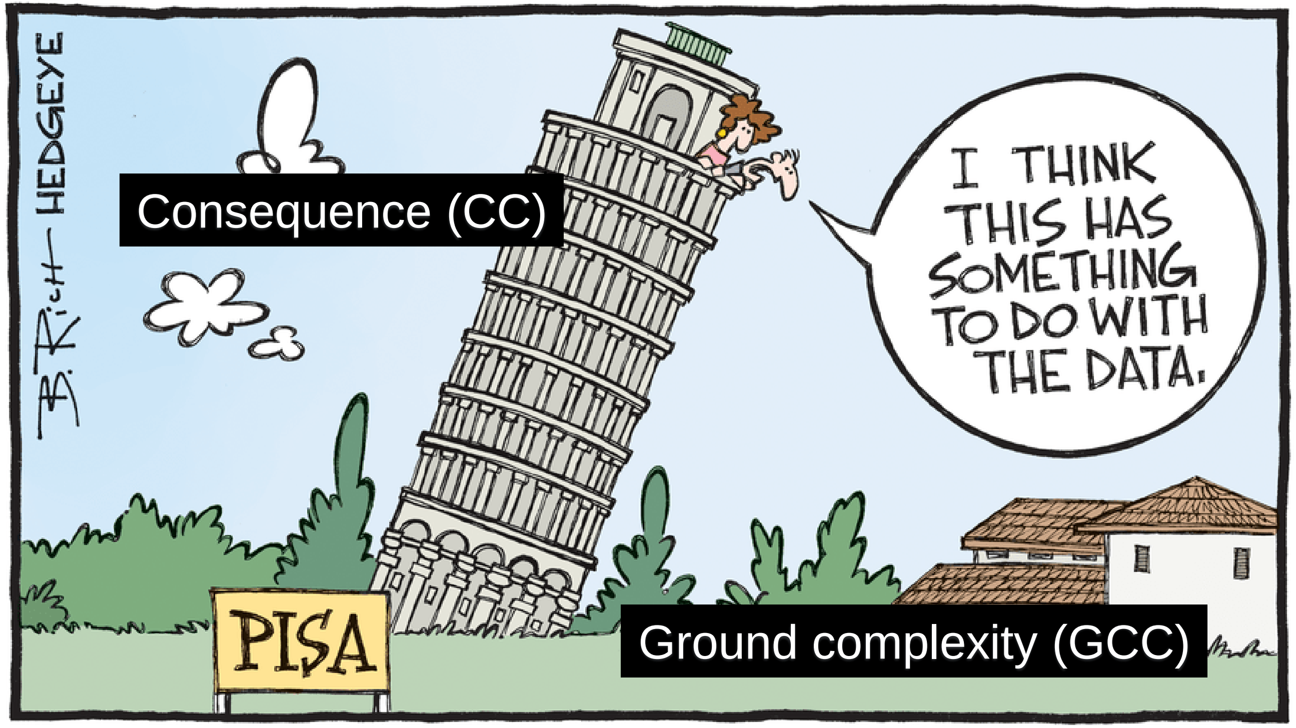
Consequence class	Minimum design quality level	Minimum design check level	Minimum execution class	Minimum inspection level
Higher (CC3)	DQL3	DCL3	See relevant execution and product standards	IL3
Normal (CC2)	DQL2	DCL2		IL2
Lower (CC1)	DQL1	DCL1		IL1

Consequence Class (CC)	Geotechnical Complexity Class (GCC)		
	Lower (GCC1)	Normal (GCC2)	Higher (GCC3)
Higher (CC3)			GC3
Medium (CC2)		GC2	
Lower (CC1)	GC1		





Separation of consequence and complexity



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Principles of limit state design

Basis of geotechnical design

Principles of limit state design

- Design situations
- Ultimate limit states
- Serviceability limit states
- Structural and load models

Design situations

design situation

physical conditions that could occur during a certain time period for which it is to be demonstrated, with sufficient reliability, that relevant limit states are not exceeded

- Design situations shall be sufficiently severe and varied so that they encompass all conditions that can reasonably be foreseen to occur during execution and use of the structure

Source: prEN 1990, September 2020 draft

Design situation	Conditions	Examples
Persistent	Normal use and exposure	During everyday use
Transient	Temporary use and exposure during a period much shorter than the design service life of the structure	During execution, repair or temporary environmental influence
Accidental	Exceptional conditions or exposure	During flooding, fire, explosion, or impact; or local failure
Seismic	Exceptional conditions during a seismic event	During an earthquake
Fatigue	Conditions caused by repeated load or deformation induced stress cycles	Owing to traffic loads on a bridge, wind induced vibration of chimneys, or machinery induced vibration

Ultimate limit states

ultimate limit state (ULS)

state associated with collapse or other forms of structural failure

The following ultimate limit states shall be verified, as relevant:

- failure of the structure or the ground, or any part of them including supports and foundations, by rupture, excessive deformation, transformation into a mechanism, or buckling
- loss of static equilibrium of the structure or any part of it
- failure of the ground by hydraulic heave, internal erosion, or piping caused by excessive hydraulic gradients
- failure caused by fatigue
- failure caused by vibration
- failure caused by other time-dependent effects

Serviceability limit states

serviceability limit state (SLS)

state that corresponds to conditions beyond which specified service requirements for a structure or structural member are no longer met

Verification of serviceability limit states should be based on criteria concerning the following:

- deformations that adversely affect the appearance, the comfort of users, or the functioning of the structure (including the functioning of machines or services)
- deformations that cause damage to finishes or elements other than structural
- vibrations that cause discomfort to people or limit the functional effectiveness of the structure
- damage that is likely to adversely affect the appearance, durability, or functioning of the structure

Structural and load models

The structural models and load models that are used to verify limit states shall be based on design values for:

- actions
- material and product properties
- geometrical properties

All relevant design situations shall be identified

The structure shall be verified for all critical load cases in each relevant design situation

Design values for the basic variables given in (2) should be obtained using the partial factor method

Design based on probabilistic methods may be used when specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties

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Basic variables

Basis of geotechnical design

Basic variables

- Actions and environmental influences
  - Classification of actions
  - Representative values of actions
  - Representative values of water actions
- Material and product properties
- Geometrical properties

Classification of actions

Action	Symbol	Definition
Permanent	*G*	action that is likely to act throughout the design service life and for which any variation in magnitude is either small, compared with the mean value, or monotonic; i.e. it either only increases or decreases, until it reaches a limit value
Variable	*Q*	action that is likely to occur during the design service life for which the variation in magnitude with time is neither negligible nor monotonic
Accidental	*A*	action, usually of short duration but of significant magnitude, that is unlikely to occur during the design service life (an accidental action can be expected in many cases to cause severe consequences unless appropriate measures are taken)
Seismic	A_E	action that arises due to earthquake

Representative values of actions

Action	Condition	Representative value F_{rep} is
Permanent	CoV is small¶	Single characteristic value $G_k = G_{mean}$
	CoV is not small	Upper characteristic value $G_{k,sup}$ (95% fractile*) Lower characteristic value $G_{k,inf}$ (5% fractile*)
Variable	ULS	Characteristic value Q_k (50 yr return period)
	ULS Irreversible SLS	Combination value Q_{comb} (= $\psi_0 Q_k$)
	Accidental ULS Reversible SLS	Frequent value Q_{freq} (= $\psi_1 Q_k$)
	Accidental/seismic ULS Reversible SLS	Quasi-permanent value Q_{qper} (= $\psi_2 Q_k$)
Accidental		Determined directly
Seismic		Determined directly

¶COV $\leq$ 5% for overturning or uplift; $\leq$ 10% otherwise
*Different fractiles apply for ground

Representative values of water actions

Representative value of a variable water action ($Q_{w,rep}$) is:

$$Q_{w,rep} = G_{w,rep} + \underbrace{Q_{w,\mathrm{rep}}}_{=Q_{w,k}|Q_{w,comb}|Q_{w,freq}|Q_{w,qper}}$$

$$\underbrace{=Q_{w,k}|Q_{w,comb}|Q_{w,freq}|Q_{w,qper}}_{depending\ on\ design\ situation}$$

Value of variable water action	Symbol	Probability of exceedance	Return period (years)
Characteristic	$Q_{w,k}$	2% per annum	50
Combination	$Q_{w,comb}$	5% per annum	20
Frequent	$Q_{w,freq}$	1% during design service life	-
Quasi-permanent	$Q_{w,qper}$	50% during design service life	-
Accidental	$A_{w,rep}$	0.1% per annum	1000

Material and product properties

Unless otherwise stated in the Eurocodes, when the verification of a limit state is sensitive to the variability of a material property, its characteristic value should be defined as:

- the **5 % fractile value** where a low value of material or product property is unfavourable; or
- the **95 % fractile value** where a high value of material or product property is unfavourable.

See EN 1997 for the specification of characteristic values of ground properties.

When the verification of a limit state is insensitive to the variability of a material property, its characteristic value should be defined as the **mean value**, unless otherwise stated in the other Eurocodes.

When insufficient statistical data is available to establish the characteristic value of a material or product property, the characteristic value may be taken as a **nominal value**.

Geometrical properties

Unless the design of the structure is sensitive to deviations of a geometrical property, that property should be represented by its **nominal value**.

When there is sufficient data, the characteristic value of a geometrical property may be **determined from its statistical distribution** and used instead of a nominal value.

For geotechnical design, geometrical properties that affect the mechanical behaviour of the ground should be considered when determining ground properties, as specified in EN 1997.

For example, the spacing and orientation of discontinuities are taken into account when selecting the characteristic material properties of rock.

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Verification by the partial factor method

Basis of geotechnical design

Verification by the partial factor method

- Verification of ultimate limit states
- Combinations of actions
- Partial factors on actions and effects
- Design values of material properties
- Verification of serviceability limit states

Verification of ultimate limit states

Ultimate limit states must be verified using:

Factored actions (DC1-3) $E_d \leq R_d$ Material factor approach (MFA)

Factor may be applied to actions:

$$E_{\mathrm{d}} = \underbrace{E\left\{\Sigma\left(\boxed{\gamma_{\mathrm{F}}}\psi F_{\mathrm{k}}\right); a_{\mathrm{d}}; X_{\mathrm{Rd}}\right\}}_{\gamma_{\mathrm{F}}=\gamma_{\mathrm{Sd}}\times\gamma_{\mathrm{f}}}$$

or to effects:

$$E_{\mathrm{d}} = \underbrace{\boxed{\gamma_{\mathrm{E}}}E\{\Sigma(\psi F_{\mathrm{k}}); a_{\mathrm{d}}; X_{\mathrm{Rd}}\}}_{\gamma_{\mathrm{E}}=\gamma_{\mathrm{Sd}}\times\gamma_{\mathrm{f}}}$$

Factored effects (DC4)

Factors may be applied to materials:

$$R_{\mathrm{d}} = \underbrace{R\left\{\frac{\eta X_{\mathrm{k}}}{\boxed{\gamma_{\mathrm{M}}}}; a_{\mathrm{d}}; \Sigma F_{Ed}\right\}}_{\gamma_{\mathrm{M}}=\gamma_{\mathrm{Rd}}\times\gamma_{\mathrm{m}}}$$

or to resistance:

$$R_{\mathrm{d}} = \underbrace{\frac{R\{\eta X_{\mathrm{k}}; a_{\mathrm{d}}; \Sigma F_{\mathrm{Ed}}\}}{\boxed{\gamma_{\mathrm{R}}}}}_{\gamma_{\mathrm{R}}=\gamma_{\mathrm{M}}=\gamma_{\mathrm{Rd}}\times\gamma_{\mathrm{m}}}$$

Resistance factor approach (RFA)

Combinations of actions

Design combination of actions $\sum F_d$ is given by:

$$\sum F_{\mathrm{d}} = \overbrace{\sum_{\mathrm{i}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}}}^{permanent} + \overbrace{\underbrace{\gamma_{\mathrm{Q,1}} Q_{\mathrm{k,1}}}_{leading} + \underbrace{\sum_{\mathrm{j>1}} \gamma_{\mathrm{Q,j}} \psi_{0,\mathrm{j}} Q_{\mathrm{k,j}}}_{accompanying}}^{variable} + \overbrace{(\gamma_{\mathrm{P}} P_{\mathrm{k}})}^{prestress}$$

or:

$$\sum F_{\mathrm{d}} = \begin{cases} \sum_{\mathrm{i}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}} + \gamma_{\mathrm{Q,1}} \boxed{\psi_{0,1}} Q_{\mathrm{k,1}} + \sum_{\mathrm{j>1}} \gamma_{\mathrm{Q,j}} \psi_{0,\mathrm{j}} Q_{\mathrm{k,j}} + (\gamma_{\mathrm{P}} P_{\mathrm{k}}) \\ \sum_{\mathrm{i}} \boxed{\xi_{\mathrm{i}}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}} + \gamma_{\mathrm{Q,1}} Q_{\mathrm{k,1}} + \sum_{\mathrm{j>1}} \gamma_{\mathrm{Q,j}} \psi_{0,\mathrm{j}} Q_{\mathrm{k,j}} + (\gamma_{\mathrm{P}} P_{\mathrm{k}}) \end{cases}$$

or:

$$\sum F_{\mathrm{d}} = \begin{cases} \boxed{\sum_{\mathrm{i}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}} + (\gamma_{\mathrm{P}} P_{\mathrm{k}})} \\ \sum_{\mathrm{i}} \boxed{\xi_{\mathrm{i}}} \gamma_{\mathrm{G,i}} G_{\mathrm{k,i}} + \gamma_{\mathrm{Q,1}} Q_{\mathrm{k,1}} + \sum_{\mathrm{j>1}} \gamma_{\mathrm{Q,j}} \psi_{0,\mathrm{j}} Q_{\mathrm{k,j}} + (\gamma_{\mathrm{P}} P_{\mathrm{k}}) \end{cases}$$

Partial factors on actions and effects prEN 1990:2019

Action or effect				Partial factors γ_F and γ_E for Design Cases 1 to 4				
Type	Group	Symbol	Resulting effect	Structural resistance	Static equilibrium and uplift		Geotechnical design	
Design case				DC1[a]	DC2(a)[b]	DC2(b)[b]	DC3[c]	DC4[d]
Formula				(8.4)	(8.4)		(8.4)	(8.5)
Permanent action (G_k)	All[f]	γ_G	unfavourable /destabilizing	$1{,}35k_F$	$1{,}35k_F$	1,0	1,0	G_k is not factored
	Water	γ_{Gw}		$1{,}2k_F$	$1{,}2k_F$	1,0	1,0	
	All[f]	$\gamma_{G,stb}$	stabilizing[g]	not used	1,15 [e]	1,0	not used	
	Water[l]	$\gamma_{Gw,stb}$			1,0 [e]	1,0		
	All	$\gamma_{G,fav}$	favourable[h]	1,0	1,0	1,0	1,0	
Prestressing (P_k)		γ_P [k]						
Variable action (Q_k)	All[f]	γ_Q	unfavourable	$1{,}5k_F$	$1{,}5k_F$	$1{,}5k_F$	1,3	$\frac{\gamma_{Q,1}}{\gamma_{G,1}}$ [j]
	Water[l]	γ_{Qw}		$1{,}35k_F$	$1{,}35k_F$	$1{,}35k_F$	1,15	1,0
	All	$\gamma_{Q,fav}$	favourable	0				
Effects of actions (E)		γ_E	unfavourable	effects are not factored				$1{,}35k_F$
		$\gamma_{E,fav}$	favourable					1,0

Design values of material properties

Design value of a material property X_d should be calculated from:

$$X_d = \frac{\boxed{X_{rep}}}{\gamma_M} = \frac{\boxed{\eta} X_k}{\gamma_M}$$

Example, for concrete:

$$\overbrace{f_{c,d} = \alpha_{cc}\frac{f_{c,k}}{\gamma_C}}^{\text{EN 1992-1-1:2004}} \equiv \overbrace{\frac{(\eta_{cc}k_{tc})f_{c,k}}{\gamma_C}}^{\text{prEN 1992-1-1}} \Rightarrow f_{c,rep} = (\eta_{cc}k_{tc})f_{c,k}$$

For ground properties:

$$X_{rep} = \begin{cases} \eta X_k & \textit{based on statistics (mostly, 50\% fractiles)} \\ X_{nom} & \textit{based on judgement} \text{ ("cautious estimate")} \end{cases}$$

Verification of serviceability limit states

Serviceability limit states must be verified using:

$$\overbrace{E_\mathrm{d}}^{\substack{Effects\ of\\ unfactored\\ actions}} \leq \overbrace{C_\mathrm{d}}^{\substack{Limiting\ values\\ of\ those\\ effects}}$$

Design combination of actions $\sum F_\mathrm{d}$ is given by:

$$\sum F_\mathrm{d} = \overbrace{\sum_\mathrm{i} G_\mathrm{k,i}}^{permanent} + \overbrace{\underbrace{Q_\mathrm{k,1}}_{leading} + \underbrace{\sum_\mathrm{j>1} \psi_\mathrm{0,j} Q_\mathrm{k,j}}_{accompanying}}^{variable} + \overbrace{(\gamma_\mathrm{P} P_\mathrm{k})}^{prestress}$$

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Summary of key points

Basis of geotechnical design

Summary of key points

The Eurocodes are intended for use by designers, clients, manufacturers, constructors, relevant authorities (in exercising their duties in accordance with national or international regulations), educators, software developers, and committees drafting standards for related product, testing and execution standards.

Introduction to the Eurocodes (2nd generation)

- In Europe – and in many other countries of the world – structural and geotechnical design is governed by the EN Eurocodes
- The 1st generation of EN Eurocodes was published between 2002 and 2007 and are still current
- The 2nd generation Eurocodes will be published in the mid 2020s

Questions and answers

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Good practice in retaining wall design

www.geocentrix.co.uk

References

- Andrew Bond and Andrew Harris (2008), *Decoding Eurocode 7*, Taylor & Francis
- EN 1990:2002, *Basis of structural design*, European Committee for Standardization
- EN 1997-1:2002, *Eurocode 7 – Geotechnical design: Part 1 – General rules*, European Committee for Standardization
- prEN 1990:2020, *Basis of structural and geotechnical design*, CEN TC250
- prEN 1997-1:2019, *Eurocode 7 – Geotechnical design: Part 1 – General rules*, CEN TC250/SC7

Kafijas pauze / 11:30 - 12:00

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Training seminar / Apmācību seminārs

General rules for the design of retaining structures
Vispārīgie noteikumi atbalstsienu projektēšanai

Dr Andrew Bond (United Kingdom)

Ministry of Economics
Republic of Latvia

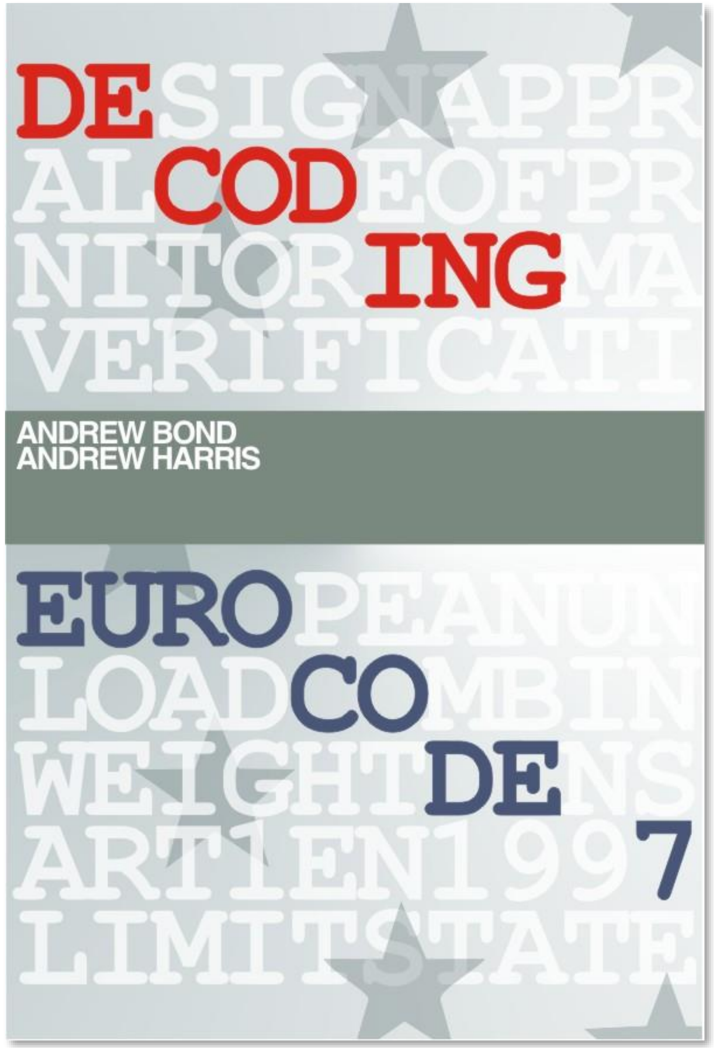
General rules for the design for retaining structures – Part 1

Dr Andrew Bond (Geocentrix)
Immediate-Past Chair TC250/SC7 Geotechnical design

General rules for the design for retaining structures – Part 1

- Materials
- Groundwater
- Geotechnical analysis
- Execution
- Guidance documents
- Summary of key points
- Questions and answers

Decoding Eurocode 7
www.decodingeurocode 7.com



Book published August 2008

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- Also covers associated execution and testing standards
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Authors Andrew Bond and Andy Harris

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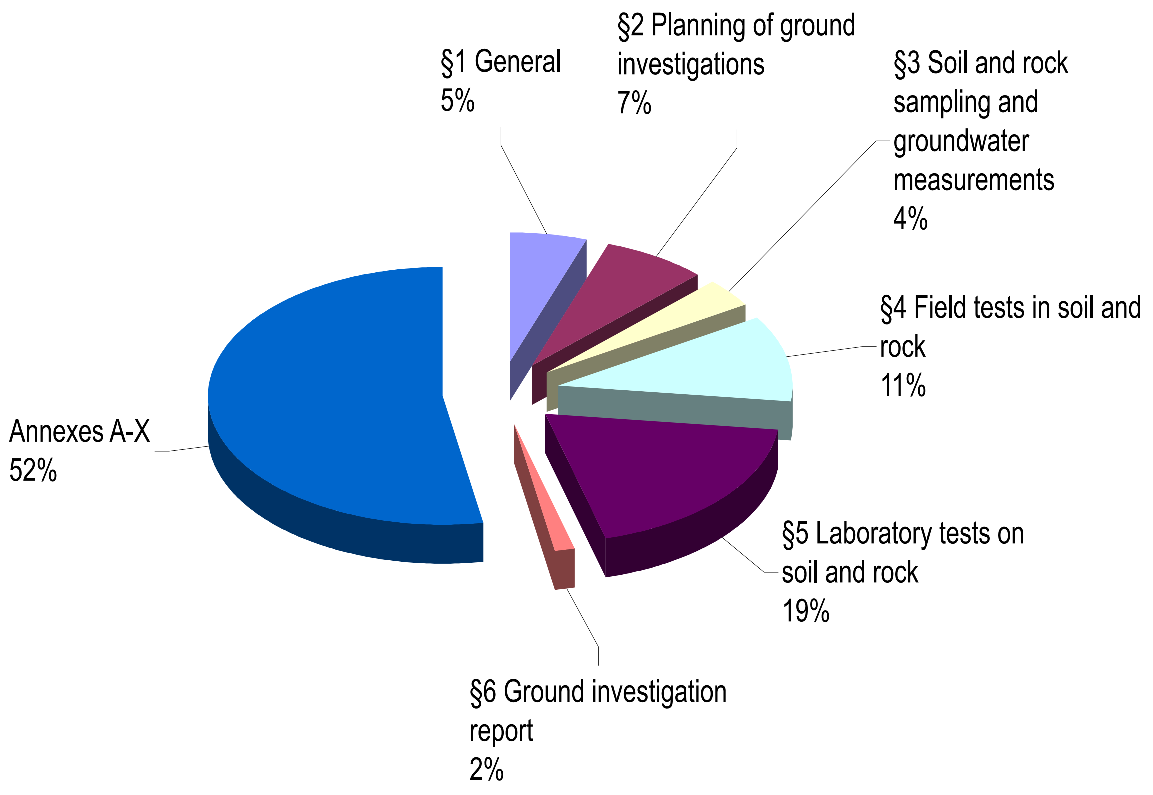
Materials

General rules for the design for retaining structures – Part 1

Materials

- Eurocode 7 Part 2 for ground investigation and testing
- EN ISO standards for geotechnical investigation and testing
- Material/product standards for … structural steel
- Material/product standards for … reinforced concrete

Eurocode 7 Part 2 for ground investigation and testing

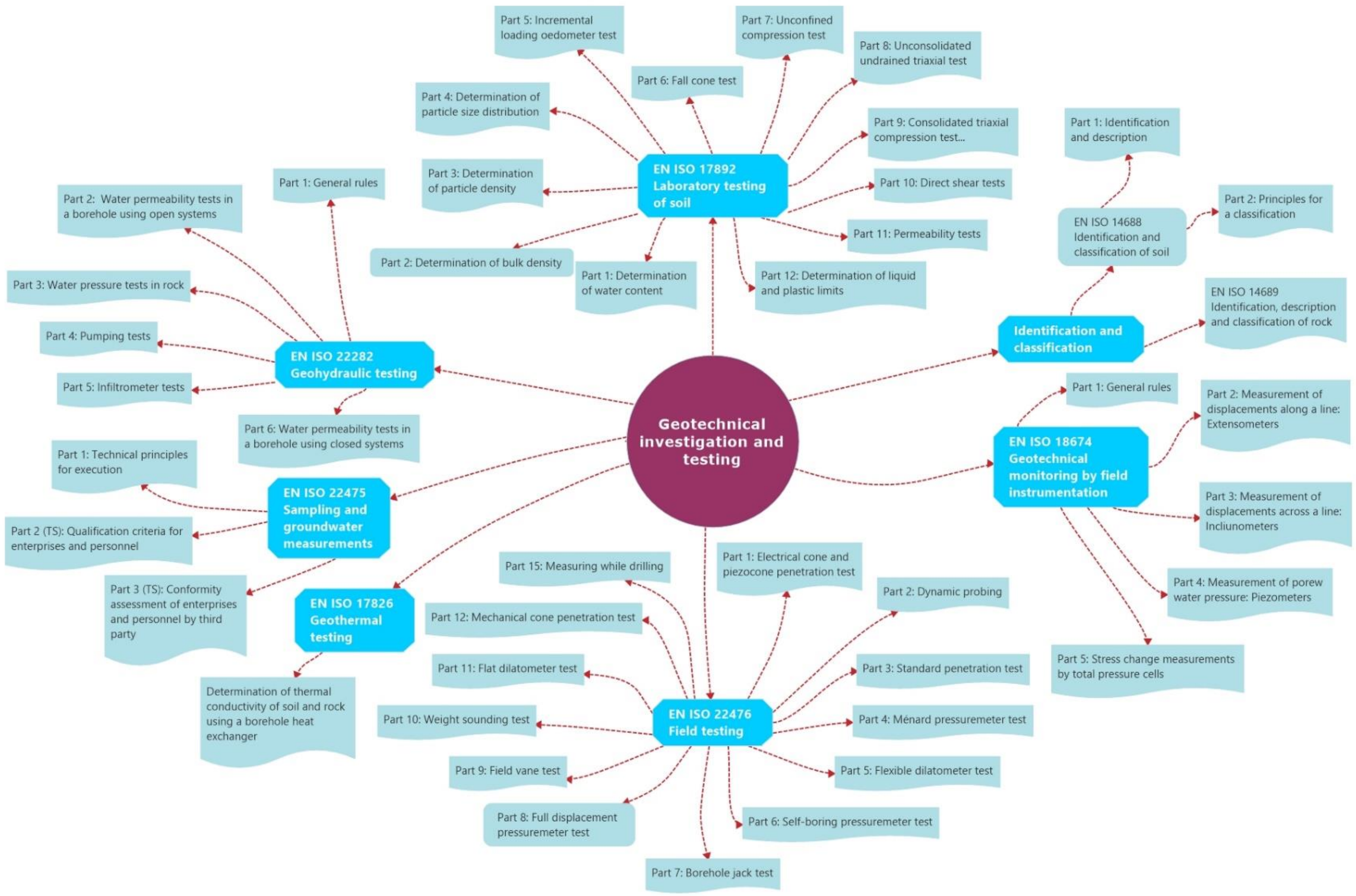


Ground investigation for retaining structures shall comply with EN 1997-2

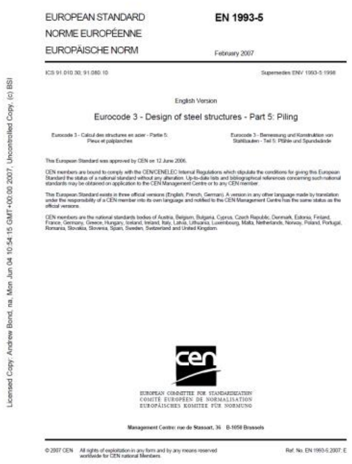
All ground areas and layers, and expected variations in groundwater levels and pressures, likely to influence the limit states considered in the design of the retaining structure shall be investigated

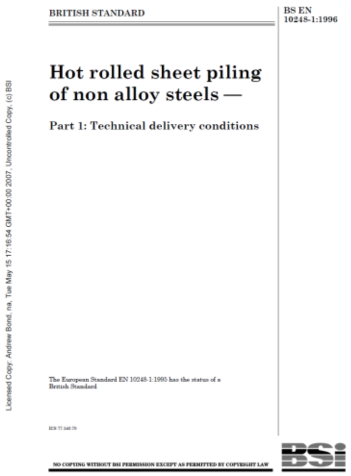
Investigations should include the installation of sufficient devices piezometers to measure groundwater within each geotechnical unit and their monitoring for sufficient time to enable seasonal changes to be determined.

EN ISO standards for geotechnical investigation and testing



Material/product standards for… structural steel





- Parameters from EN 1993-1-1 and EN 1993-5
- Hot rolled steel products: EN 10025, EN 10083, and EN 10149
  - Hot rolled sheet piling: EN 10248
- Cold formed hollow steel sections: EN 10210 and EN 10219
  - Cold formed sheet piling: EN 10249
- Durability of steel: EN 1993-1-1

Material/product standards for… reinforced concrete

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1992-1-1

December 2004

English version

Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings

This European Standard was approved by CEN on 16 April 2004.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: Avenue Marnix 17, B-1000 Brussels

NEN-EN 206:2014

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 206

December 2013

ICS 91.100.30

Supersedes EN 206-1:2000, EN 206-9:2010

English Version

Concrete - Specification, performance, production and conformity

Béton - Spécification, performances, production et conformité

Beton - Festlegung, Eigenschaften, Herstellung und Konformität

This European Standard was approved by CEN on 28 September 2013.

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EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Avenue Marnix 17, B-1000 Brussels

Ref. No. EN 206:2013 E

- Parameters from EN 1992-1-1 and EN 206
- Steel reinforcement for retaining structures: EN 10080, EN 10138 and EN 1993-5, as appropriate.
- Exposure classes: EN 206
- Concrete cover requirements: EN 1992-1-1
- Spayed concrete: EN 14487-1

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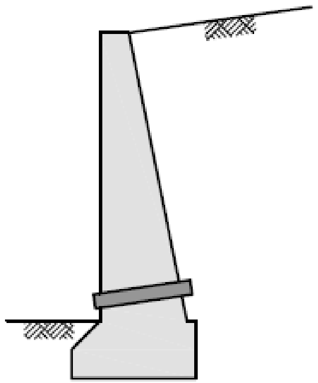
Groundwater

General rules for the design for retaining structures – Part 1

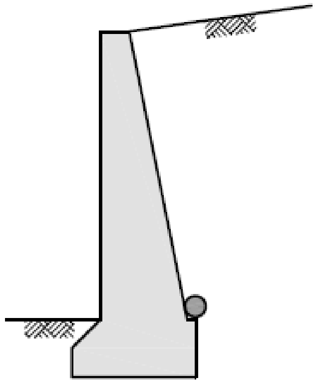
Groundwater

- Typical drainage systems behind gravity retaining walls
- Should water pressures be factored?
- Possible ways of treating water pressures
- Providing a balance between reliability and realism

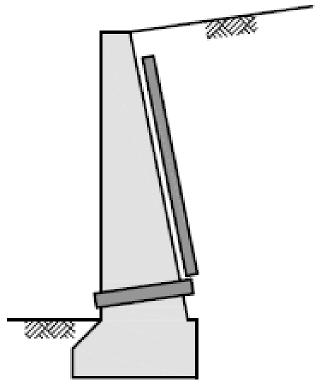
Typical drainage systems behind gravity retaining walls (BS 8002:2015)



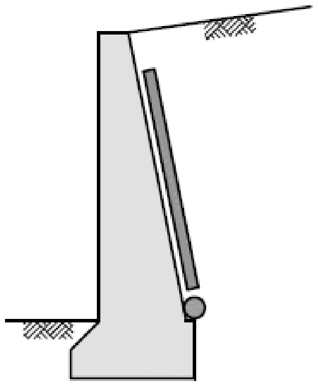
a) Weepholes at base of wall



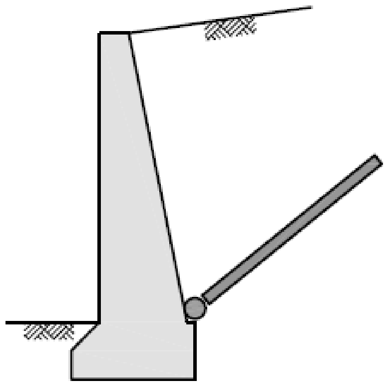
b) Drainpipe at wall heel



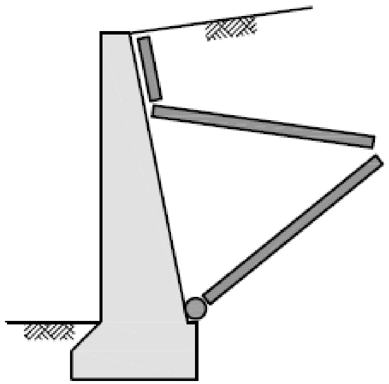
c) Chimney drain with weepholes



d) Chimney drain with drainpipe



e) Inclined drain



f) Interceptor drains with drainpipe

NOTE Based on Earth Pressure and Earth-Retaining Structures *[2].*

Should water pressures be factored?

For ultimate limit states (ULSs)…

design values [of groundwater pressures] shall represent the most unfavourable values that could occur during the design lifetime of the structure

For serviceability limit states (SLSs)…

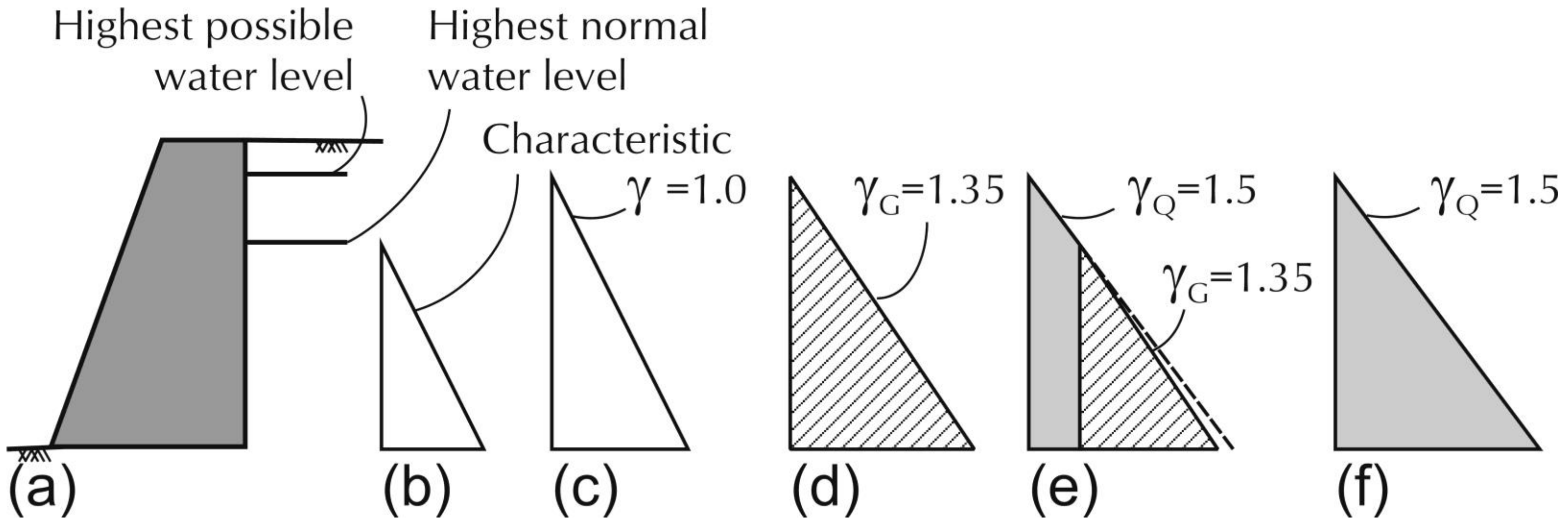
design values shall be the most unfavourable values which could occur in normal circumstances

EN 1997-1:2004 §2.4.6.1(6)P

Design values of ground-water pressures may be derived either by applying partial factors to characteristic water pressures or by applying a safety margin to the characteristic water level…

EN 1997-1:2004 §2.4.6.1(8)

Possible ways of treating water pressures Bond and Harris (2008)



- (a) Design water levels for ULS and SLS design situations
- (b) Characteristic water pressures for SLS design situation

Design pressures for ULS, with...

- (c) no factor applied (γ = 1.0)
- (d) factor on permanent actions (γ_G = 1.35)
- (e) factor on permanent actions (γ_G = 1.35) applied to normal water level and factor on variable actions (γ_Q = 1.5) applied to rise in water level
- (f) factor on variable actions (γ_Q = 1.5)

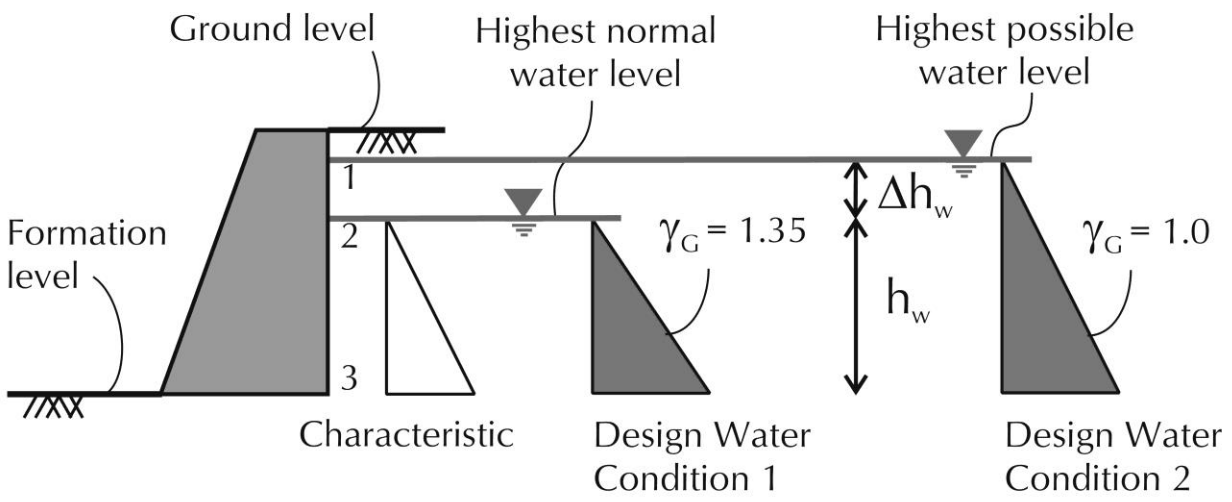
Question: which of options (c)-(f) would you choose?

Providing a balance between reliability and realism
Bond and Harris (2008)

"When partial factors $\gamma_G > 1.0$ are applied to effective earth pressures, then pore water pressures should also be multiplied by $\gamma_G > 1.0$ but calculated from highest normal (i.e. serviceability) water levels – i.e. no safety margin is applied (Design Water Condition 1)

"When partial factors $\gamma_G = 1.0$ are applied [they should be] multiplied by $\gamma_G = 1.0$ but calculated from highest possible (i.e. ultimate) water levels – after an appropriate safety margin has been applied (Design Water Condition 2)"

Bond and Harris (2008)



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Geotechnical analysis

General rules for the design for retaining structures – Part 1

Geotechnical analysis

- Calculation models (next lecture will cover this topic)
- Angle of interface friction
- Constant volume angle of internal friction
- Constant volume friction angle for sands
- Constant volume friction angle for clays

Angle of interface friction EN 1997-1 §9.5.1(6)

Eurocode 7 allows δ_d to be determined from the soil's design constant-volume angle of shearing resistance $\varphi_{cv,d}$:

$$\delta_d = k\varphi_{cv,d} = k\tan^{-1}\overbrace{\underbrace{\left(\frac{\tan\varphi_{cv,k}}{\gamma_\varphi}\right)}_{is\ 1.25\ too\ high?}}^{critical\ state\ value}$$

Values of k are:

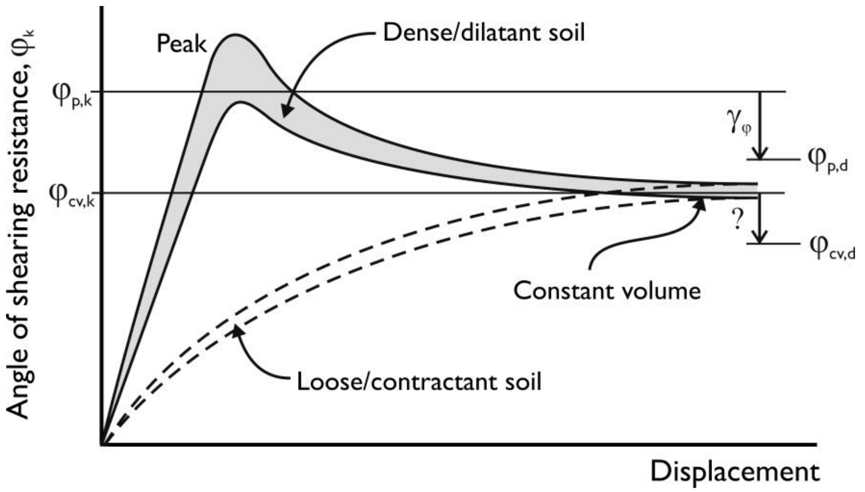
- 1 for soil against cast in-situ concrete
- ⅔ for soil against precast concrete

The UK National Annex states:

It might be more appropriate to select the design value of φ_{cv} directly

The 2nd generation of Eurocode 7 will specify $\gamma_{\tan\varphi,cv} = 1.0 < \gamma_\varphi$:

$$\delta_d = k\varphi_{cv,d} = k\tan^{-1}\left(\frac{\tan\varphi_{cv,k}}{\boxed{\gamma_{\tan\varphi,cv}}}\right)$$



Constant volume angle of internal friction BS 8002:2015

<u>For siliceous sands and silts</u>:

$$\varphi'_{\mathrm{cv,k}} = 30° + \varphi'_{\mathrm{ang}} + \varphi'_{\mathrm{PSD}}$$

with fines content less than 15%:

$$\varphi'_{\mathrm{pk,k}} = \varphi'_{\mathrm{cv,k}} + \varphi'_{\mathrm{dil}}$$

where (using n = 3 for triaxial and 5 for plane strain):

$$\varphi'_{\mathrm{dil}} = nI_{\mathrm{R}} = n[I_{\mathrm{D}} \times \ln(\sigma_{\mathrm{c}}/\sigma'_{\mathrm{f}}) - 1]$$

<u>For fine soils:</u>

with plasticity index 5% ≤ I_{P} ≤ 100%:

$$\varphi'_{\mathrm{cv,k}} = 42° - 12.5 \log_{10} I_{\mathrm{P}}$$

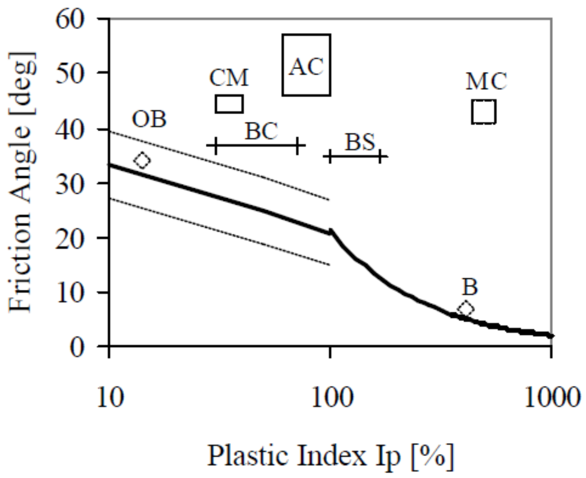
$$0° \leq \varphi'_{\mathrm{dil}} \leq 4°$$

Constant volume friction angle for sands from BS 8002:2015, Table 1

Property	Determined from	Classification	Parameter
Angularity of particles	Visual description of soil	Rounded to well-rounded	$\varphi'_{ang} = 0°$
		Sub-angular to sub-rounded	$\varphi'_{ang} = 2°$
		Very angular to angular	$\varphi'_{ang} = 4°$
Uniformity coefficient, C_U	Soil grading	$C_U < 2$ (evenly graded) or high C_U (gap graded), with C_U of fines < 2	$\varphi'_{PSD} = 0°$
		$2 \leq C_U < 6$ (evenly graded) or high C_U (gap graded), with $2 \leq C_U$ of fines < 6	$\varphi'_{PSD} = 2°$
		$C_U \geq 6$ (medium to multi graded)	$\varphi'_{PSD} = 4°$
Density index, I_D	Standard penetration test blow count, corrected for energy rating and overburden pressure, $(N_1)_{60}$	I_D = 0-25 %	$\varphi'_{dil} = 0°$
		I_D = 50 %	$\varphi'_{dil} = 3°$
		I_D = 75 %	$\varphi'_{dil} = 6°$
		I_D = 100 %	$\varphi'_{dil} = 9°$

Constant volume friction angle for clays from BS 8002:2015 Table 2

Plasticity index, I_P	Constant volume angle of friction, $\varphi'_{cv,k}$
15 %	27°
30 %	24°
50 %	21°
80 %	18°
Values of φ'_{cv} in excess of 40° have been observed for clays that classify as highly plastic but show signs of bioturbation or the presence of microfossils	



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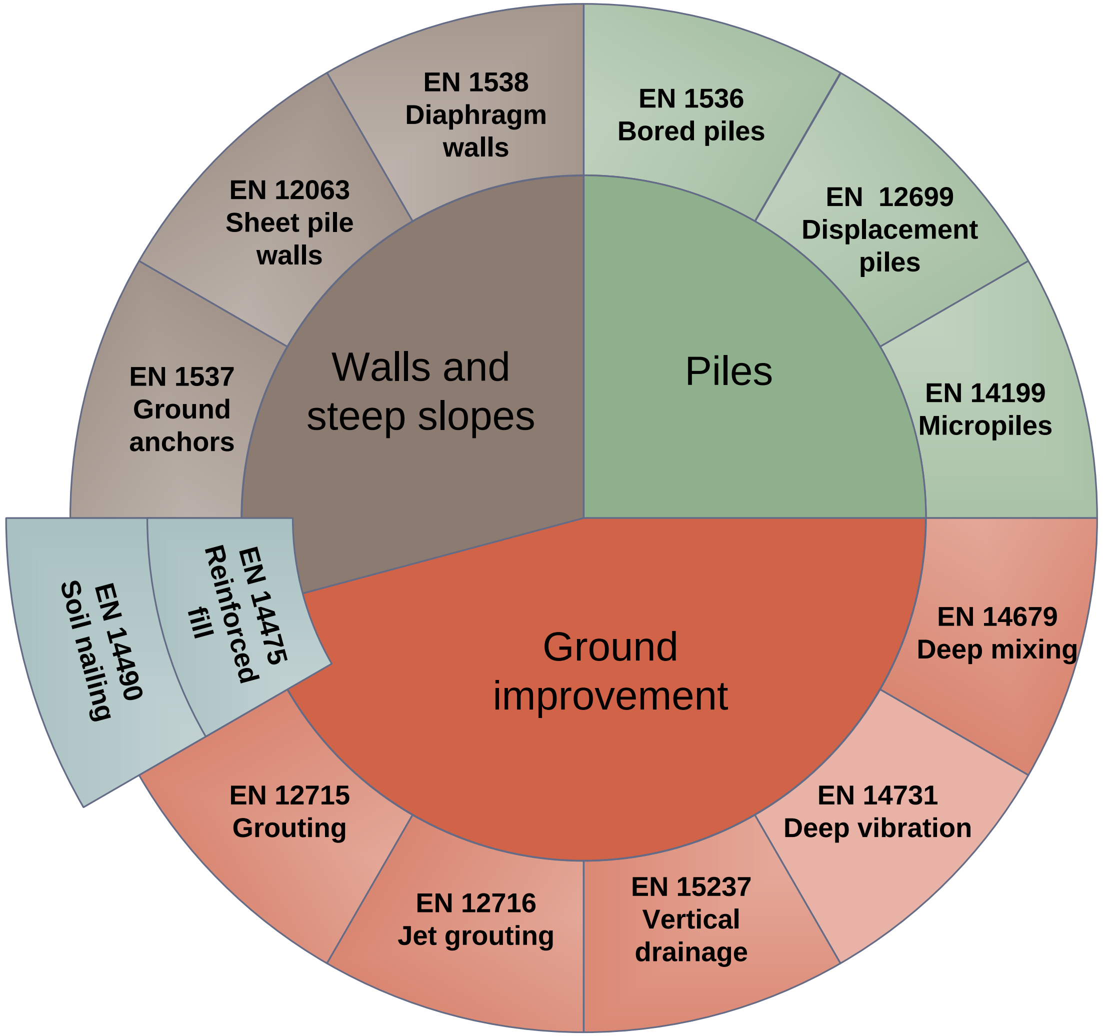
Execution

General rules for the design for retaining structures – Part 1

Execution

- EN standards for execution of geotechnical works
- Execution standards for embedded retaining walls
- Scope of EN 1538 Execution of … diaphragm walls
- Scope of EN 12063 Execution of … sheet pile walls
- SPERW (‘SPERWall’)

EN standards for execution of geotechnical works (Bond and Harris, 2008)



Execution standards for embedded retaining walls

BS EN 1538:2010+A1:2015

BSI Standards Publication

Execution of special geotechnical work — Diaphragm walls

bsi.

...making excellence a habit.™

BRITISH STANDARD

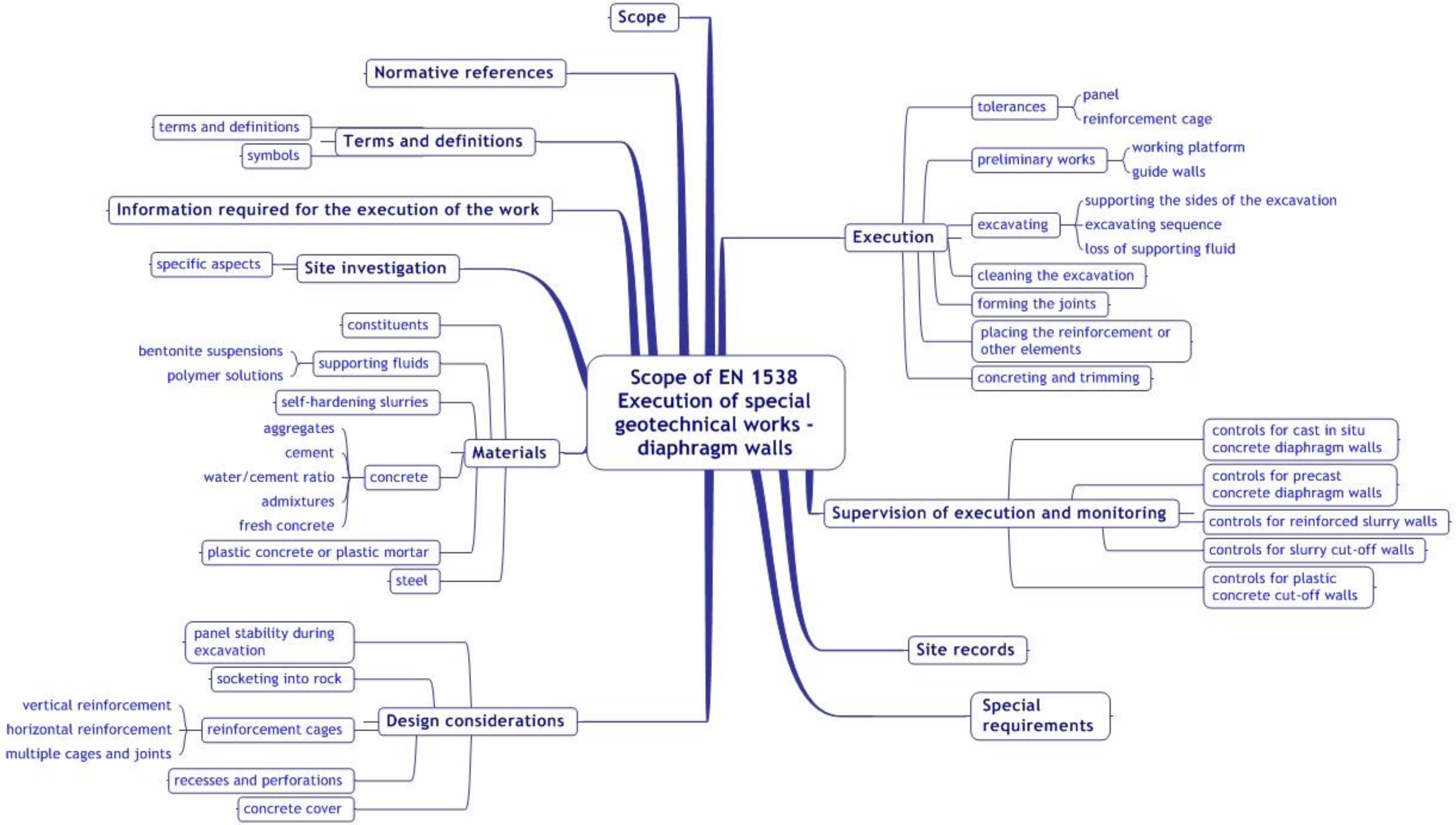
BS EN 12063:1999

Execution of special geotechnical work — Sheet pile walls

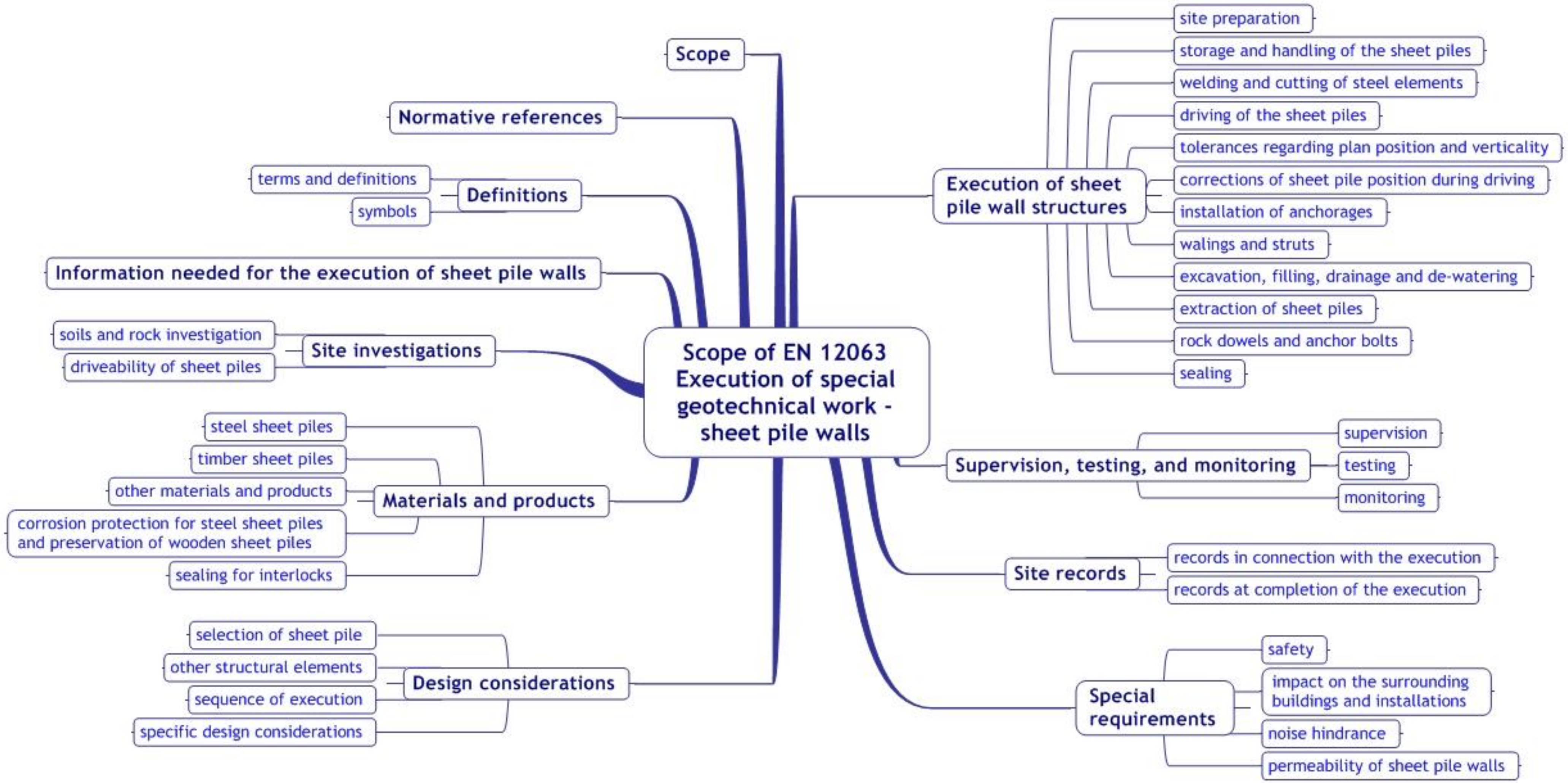
ICS 93.020

BSi

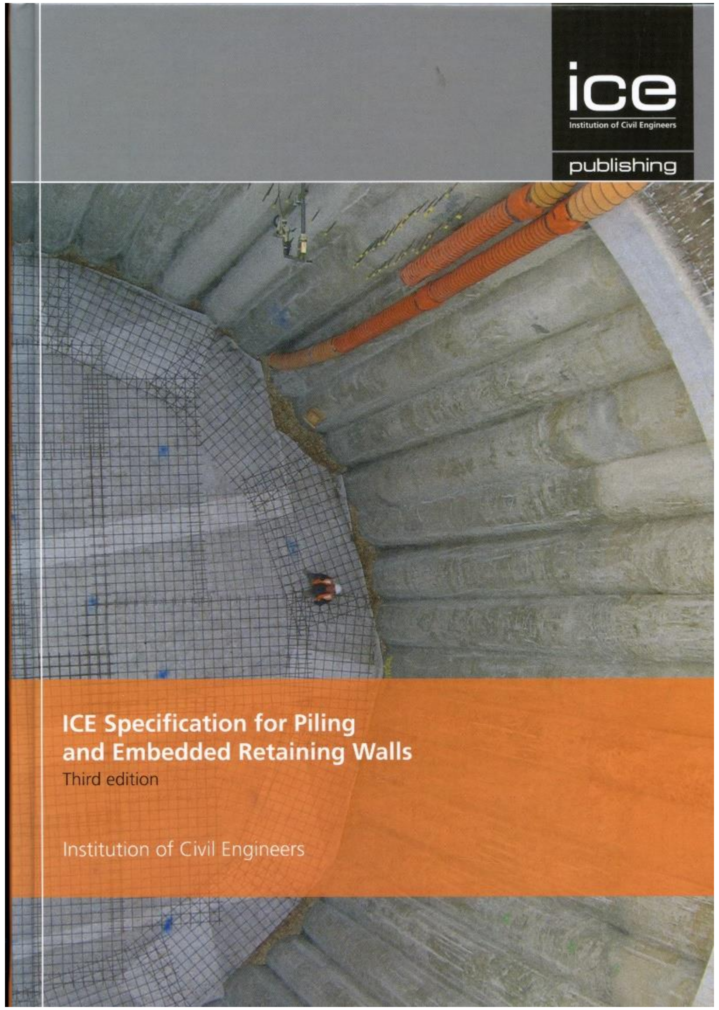
Scope of EN 1538 Execution of … diaphragm walls (after Bond and Harris 2008)



Scope of EN 12063 Execution of … sheet pile walls (after Bond and Harris 2008)†



SPERW ('SPERWall')
Institution of Civil Engineers (2016)



- SPERW = 'Specification for piling and embedded retaining walls'
- 1st edition, published 1996
- 2nd edition, published 2007
- 3rd edition, published 2016
- Key features
  - Part A offers general guidance, describing requirements necessary for successful construction of piling and embedded retaining walls
  - Part B is the main technical specification, in 19 parts
  - Part C provides specific guidance for all 19 parts of Part B
- Chairman of Steering Group: J. De Waele (Chairman)
- Published by Thomas Telford in hardback
- ISBN: 978-0-7277-6157-6

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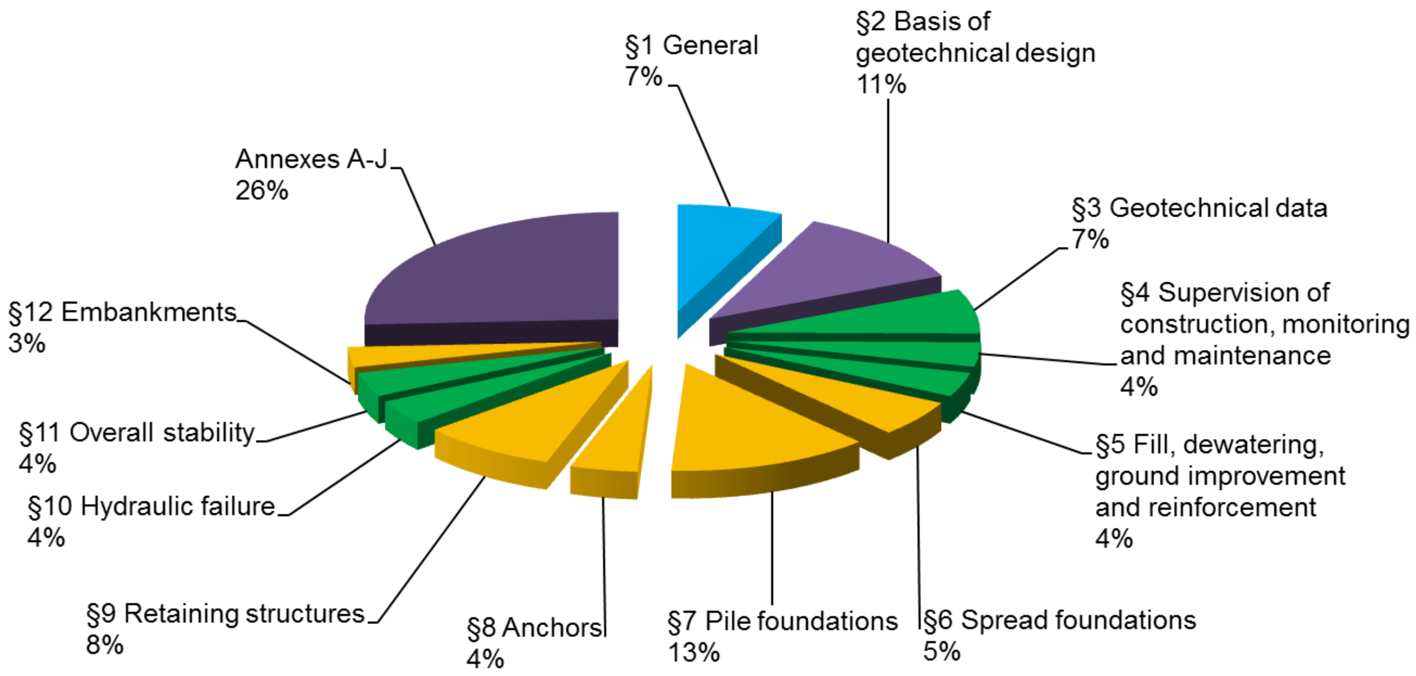
Guidance documents

General rules for the design for retaining structures – Part 1

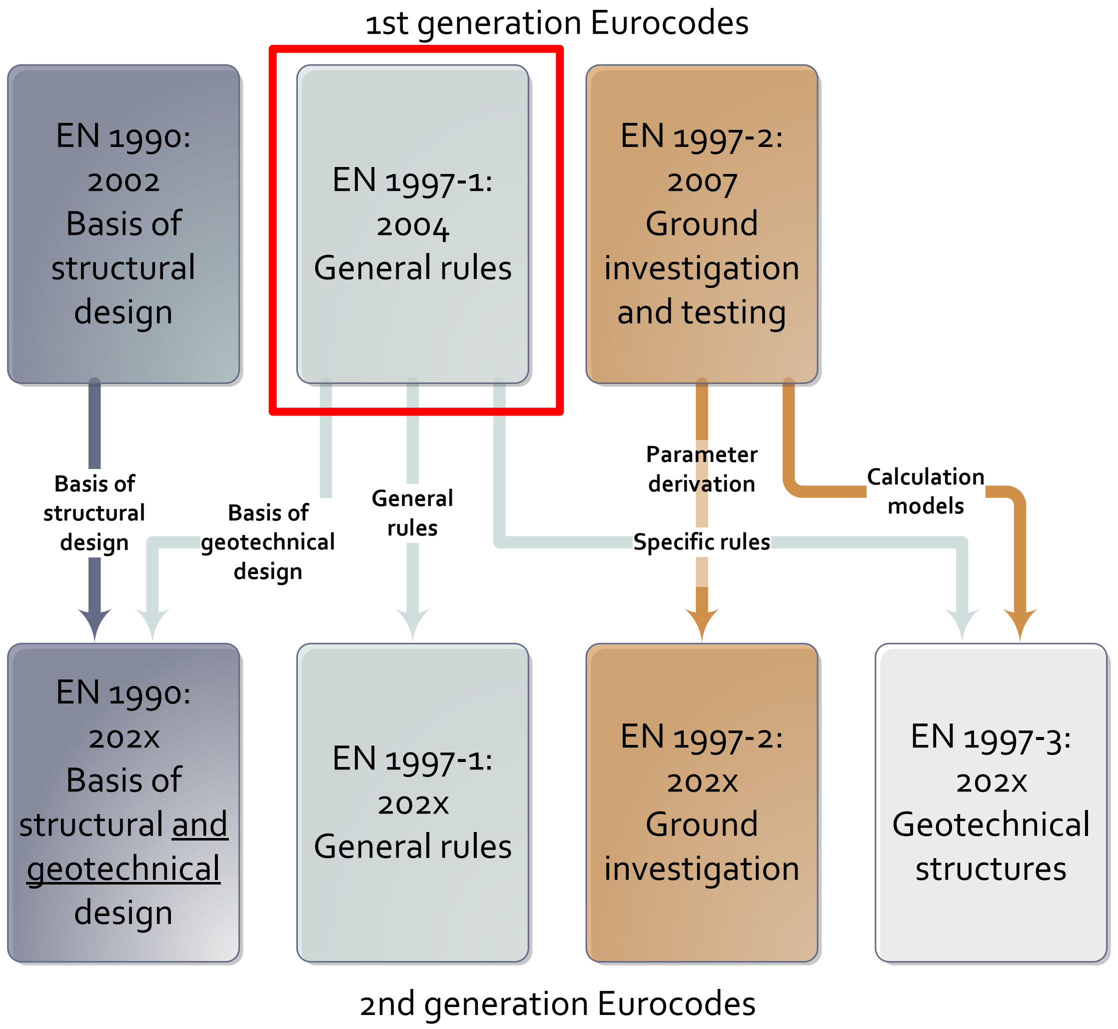
Guidance documents

- EN 1997-1:2004 Geotechnical design – General rules
- Basis of retaining wall design from 1st to 2nd generation Eurocodes
- BS 8002:2015 Code of practice for earth retaining structures
- CIRIA guidance on embedded retaining wall design
- EAU recommendations for waterfront structures, harbours, and waterways

EN 1997-1:2004 Geotechnical design – General rules (after Bond and Harris, 2008)

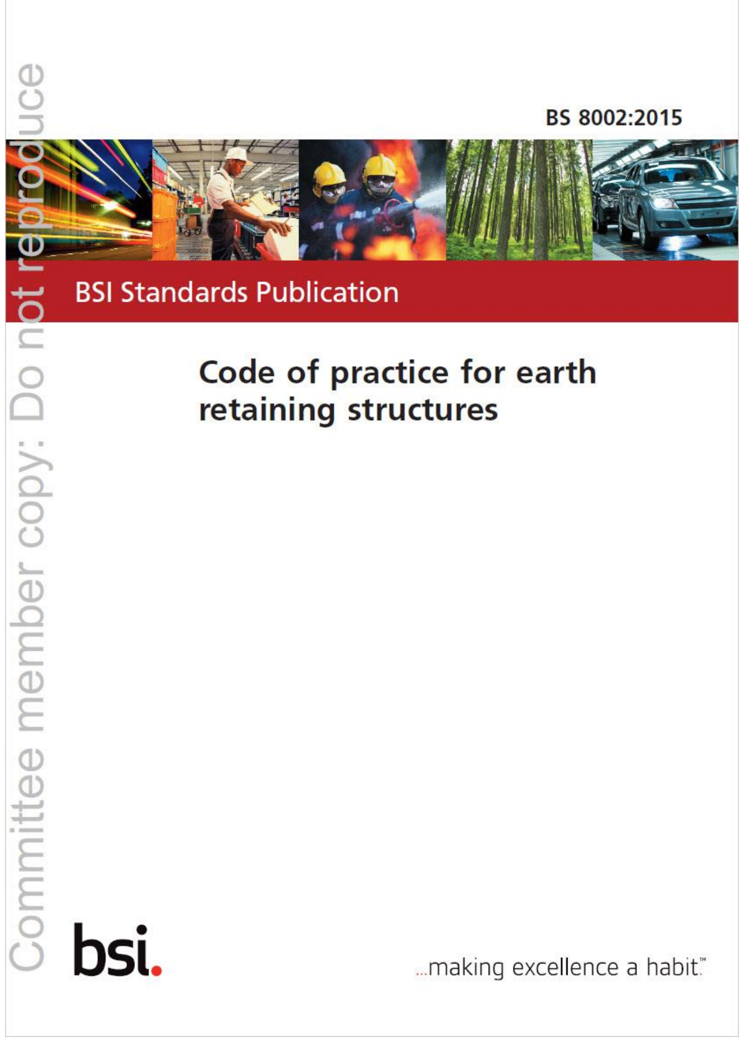


Basis of retaining wall design from 1st to 2nd generation Eurocodes



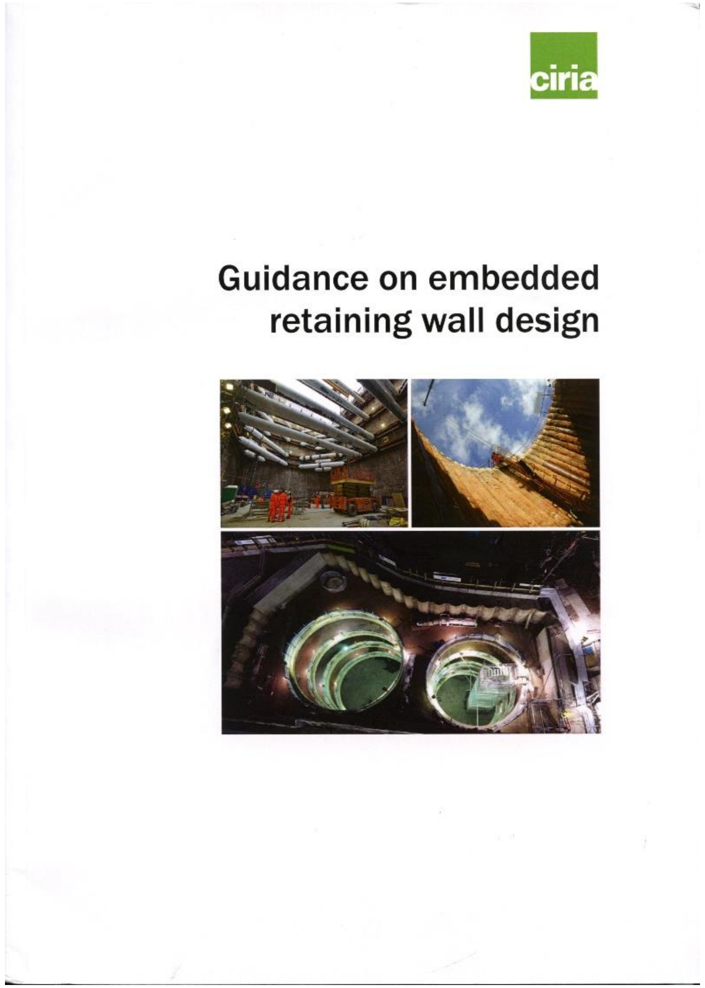
BS 8002:2015 Code of practice for Earth retaining structures

- BS 8002 is listed as 'non-conflicting, complementary information' (NCCI) in the UK NA to EN 1997-1
- BS 8002:1994 was withdrawn in April 2010 and is no longer a current standard
- A new version of BS 8002 was published in June 2015
- The first amendment is due in 2020



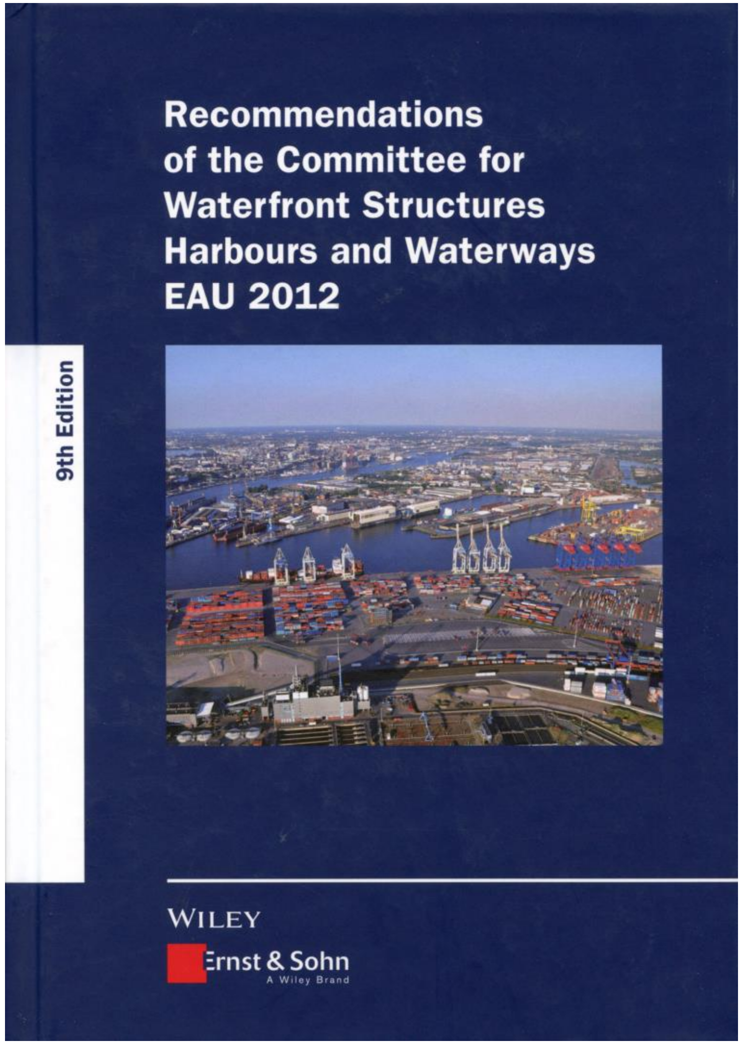
CIRIA guidance on embedded retaining wall design, CIRIA C760 (2017)

- CIRIA C760 is the follow-up to CIRIA C580 and hence might be considered as 'non-conflicting, complementary information' (NCCI)
- C760 was prepared following extensive public consultation and is intended to be compatible with both BS 8002:2015 and BS EN 1997-1:2004+A1:2013
- C760's objectives are to:
  - Discuss available wall types and construction methods
  - Provide a comprehensive update of the ground movements database presented in [C580]
  - Offer good practice guidance consistent with recent research and current analytical techniques
- Requirements of Eurocode 7 and BS 8002 take precedence over C760



EAU recommendations for waterfront structures, harbours, and waterways (2012)

- The full title of the "EAU" is "Recommendations of the Committee for Waterfront Structures, Harbours, and Waterway"
- Latest English edition is 9th (a translation of the 11th German edition)
- Produced by the German Port Technology Association (HTG) and the German Geotechnical Society (DGGT)
- Published by Ernst and Sohn
- Follows the requirements of Eurocode 7



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Summary of key points

General rules for the design for retaining structures – Part 1

Summary of key points

- Retaining wall design involves a large variety of materials and techniques
- There are many supporting standards covering:
  - Ground investigation and testing
  - Material specification
  - Execution
- There are many good guidance documents supporting these standards, including:
  - CIRIA C760
  - EAU 2012

Questions and answers

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Good practice in retaining wall design

www.geocentrix.co.uk

References

- Andrew Bond and Andrew Harris (2008), *Decoding Eurocode 7*, Taylor & Francis
- EN 1997-1:2004, *Eurocode 7 – Geotechnical design: Part 1 – General rules*, European Committee for Standardization
- EN 1997-2:2007, *Eurocode 7 – Geotechnical design: Part 2 – Ground investigation and testing*, European Committee for Standardization
- prEN 1997-1:2019, *Eurocode 7 – Geotechnical design: Part 1 – General rules*, CEN TC250/SC7

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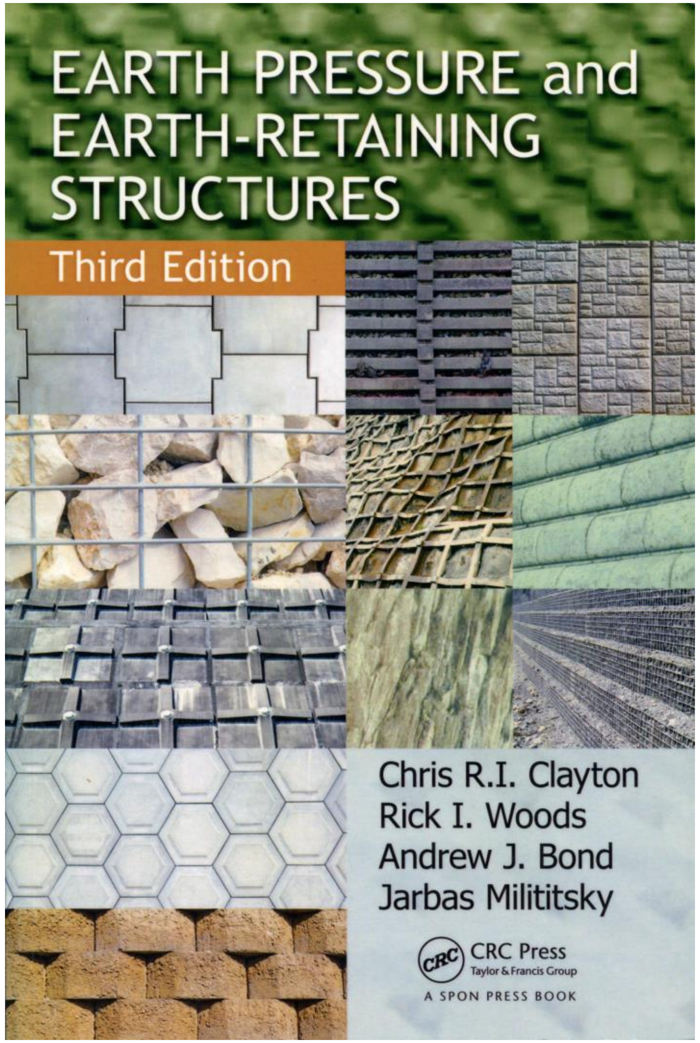
General rules for the design for retaining structures – Part 2

Dr Andrew Bond (Geocentrix)
Immediate-Past Chair TC250/SC7 Geotechnical design

General rules for the design for retaining structures – Part 2

- Earth pressures
  - Factors that affect earth pressures
  - Active and passive earth pressures
  - At-rest earth pressures
  - Intermediate values of earth pressure
  - Compaction pressures
- Water pressures
- Methods of analysis
- Summary of key points
- Questions and answers

Earth pressure & earth-retaining structures
www.earthpressurebook.com



- 1st edition, published 1986
- 2nd edition, published 1993
- 3rd edition, published 2013
- Authors: Chris Clayton, Rick Woods, Andrew Bond, and Jarbas Militisky
- Key features
  - Covers the principles of the geotechnical design of gravity walls, embedded walls, and composite structures
  - Helps non-specialists understand the geotechnical issues involved
  - Provides background to uncertainty of parameters and partial factor issues that underpin recent codes (for example Eurocode 7)
- Published by CRC Press in paperback
- ISBN: 978-1-4665-5211-1

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Earth pressure theory

General rules for the design for retaining structures – Part 2

Factors that affect earth pressures

- surcharge on the ground surface
- inclination of the ground surface
- inclination of the wall to the vertical
- water tables and the seepage forces in the ground
- swelling potential of the ground
- potential for strain ratcheting
- amount and direction of movement of the wall relative to the ground
- horizontal and vertical equilibrium for the entire retaining structure
- shear strength and weight density of the ground
- inclination of the ground strata and potential discontinuities
- effect of initial stresses and stiffness of the ground
- rigidity of the structure and its supporting system relative to the stiffness of the ground
- wall roughness

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Active and passive earth pressures

General rules for the design for retaining structures – Part 2

Active and passive earth pressures

- Effective stress formulation
- Total stress formulations
- Analytical and graphical earth pressure coefficients
- Wedge-shaped mechanisms
  - Müller-Breslau’s formula
- Mohr’s circles of stress
  - Rankine’s formula
- Log-spiral failure mechanism
  - Kerisel and Absi’s values
- Method of characteristics
  - Brinch-Hansen’s formula
- Movement required to reach limiting conditions

Active and passive earth pressures

For soil in an active state, the total earth pressure normal to the wall face is given by:

$$p_{\mathrm{a}} = p'_{\mathrm{a}} + u_{\mathrm{a}} \geq p_{\mathrm{a,min}}$$

p_a = total earth pressure normal to the wall face at depth z_a below retained surface
p'_a = effective active earth pressure normal to the wall face
u_a = groundwater pressure at depth z on active side of wall
$p_{a,min}$ = minimum value of p_a

For soil in a passive state, the total earth pressure normal to the wall face is given by:

$$p_{\mathrm{p}} = p'_{\mathrm{p}} + u_{\mathrm{p}}$$

p_p = total earth pressure normal to the wall face at depth z_p below formation level
p'_p = effective passive earth pressure normal to the wall face at depth z_p
u_p = groundwater pressure at depth z_p on passive side of wall

Effective stress formulation

In terms of effective stresses:

$$\left.\begin{matrix} p'_{\mathrm{a}} \\ p'_{p} \end{matrix}\right\} = K_{\gamma}\left(\int_0^z \gamma \mathrm{d}z - u\right) \mp K_{\mathrm{c}}c' + K_{\mathrm{q}}q$$

p'_{a} = effective active earth pressure normal to the wall face

p'_{p} = effective passive earth pressure normal to the wall face

γ = weight density of ground

z = depth below ground (retained or formation) surface

c' = effective cohesion

q = vertical surcharge applied at ground surface

$K_{\gamma}, K_{\mathrm{c}}, K_{\mathrm{q}}$ = earth pressure coefficients

Total stress formulation

In terms of total stresses (for undrained conditions only):

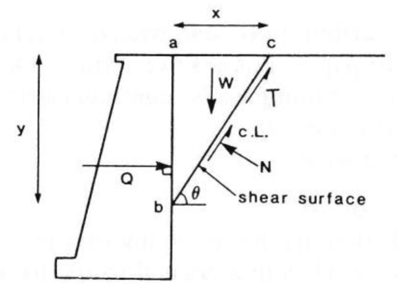
$$\left.\begin{matrix} p_{\mathrm{a}} \\ p_{p} \end{matrix}\right\} = \int_0^z \gamma \mathrm{d}z \mp K_{\mathrm{cu}} c_{\mathrm{u}} + q$$

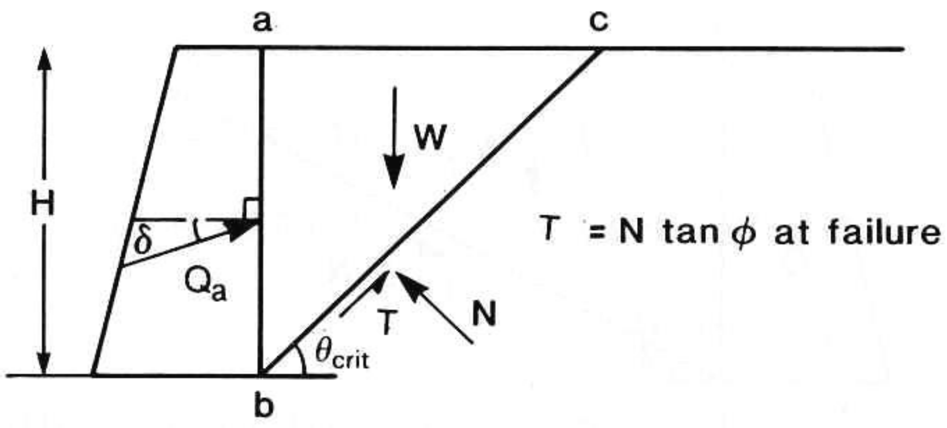
p_a = total active earth pressure normal to the wall face
p_p = total passive earth pressure normal to the wall face
γ = weight density of ground
z = depth below ground (retained or formation) surface
c_u = undrained shear strength
q = vertical surcharge applied at ground surface
K_{cu} = undrained earth pressure coefficient
$K_{\gamma u}$ = K_q = 1.0 and are omitted from the equation

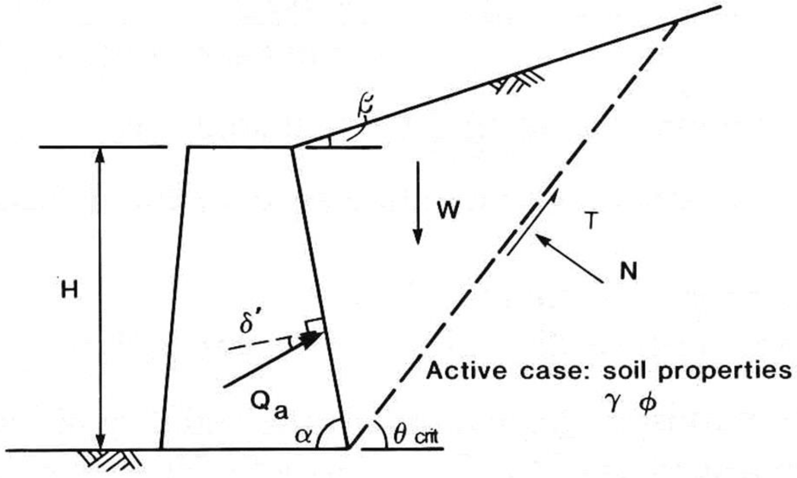
Analytical and graphical earth pressure coefficients (after Clayton et al, 2013)

Source	Capability						Active or passive
	α	β	c'	φ'	c'_w	δ	
Coulomb (1776)	90°	0°	-	φ'	-	0	Both
Mayniel (1808)	90°	0°	-	φ'	-	δ	Both
Rankine (1857)	90°	β	-	φ'	-	$= \beta$	Active
Muller-Breslau (1906)	α	β	-	φ'	-	δ	Active
Bell (1915)	90°	0°	c'	φ'	0	0	Both
Caquot & Kerisel (1948)	α	β	-	φ'	-	δ	Passive
Packshaw (1946)*	90°	0°	c'	φ'	c'_w	δ	Both
Kerisel & Absi (1990)**	90°	β	c'	φ'	c'_w	δ	Both
Brinch-Hansen ()***	α	β	c'	φ'	c'_w	δ	Both
Used in design standards *BS CP2:1951, **BS 8002:1994; ***EN 1997-1:2004							

Wedge-shaped mechanisms (upper bound) Coulomb, Maniel (top), Müller-Breslau (btm)







Müller-Breslau's formula

Müller-Breslau's (1906) solution for K_a and K_p is:

$$\left.\begin{matrix} K_\mathrm{a} \\ K_\mathrm{p} \end{matrix}\right\} = \frac{\sin^2(\alpha \pm \varphi')}{\sin^2(\alpha \mp \varphi')\left[1 \pm \sqrt{\dfrac{\sin(\varphi' + \delta)\sin(\varphi' \mp \beta)}{\sin(\alpha \mp \delta)\sin(\alpha + \beta)}}\right]^2}$$

K_a = active earth pressure coefficient at an angle δ to the wall

K_p = passive earth pressure coefficient at an angle δ to the wall

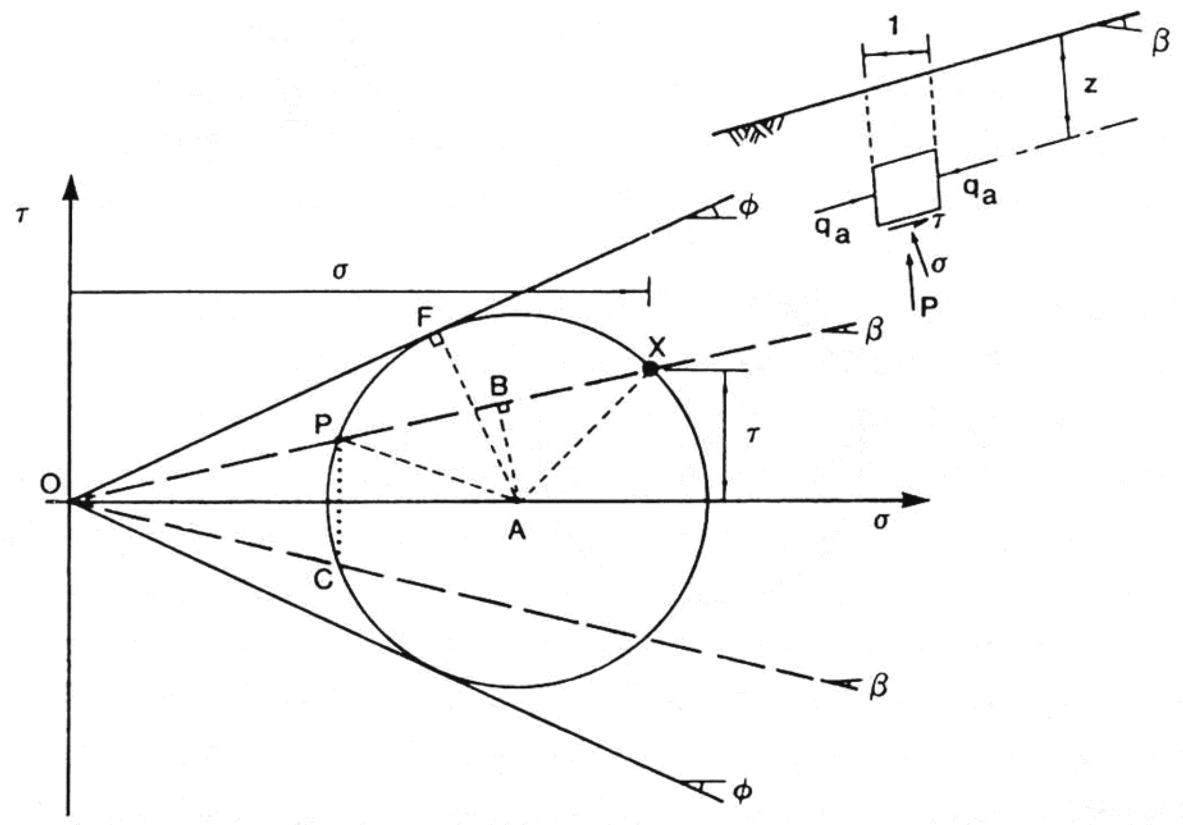
φ' = angle of internal friction of the soil

δ = angle of interface friction between wall and soil

β = angle of inclination of ground surface

α = angle of inclination of wall to the horizontal

Mohr's circles of stress (lower bound)
Rankine



Rankine's formula

Rankine's (1857) solution for K_a and K_p is:

$$\left.\begin{matrix} K_\mathrm{a} \\ K_\mathrm{p} \end{matrix}\right\} = \cos^2\beta \left(\frac{\cos\beta \mp \sqrt{\cos^2\beta - \cos^2\varphi'}}{\cos\beta \pm \sqrt{\cos^2\beta - \cos^2\varphi'}} \right) \rightarrow \overbrace{\frac{1 \mp \sin\varphi'}{1 \pm \sin\varphi'}}^{\text{when } \beta = 0}$$

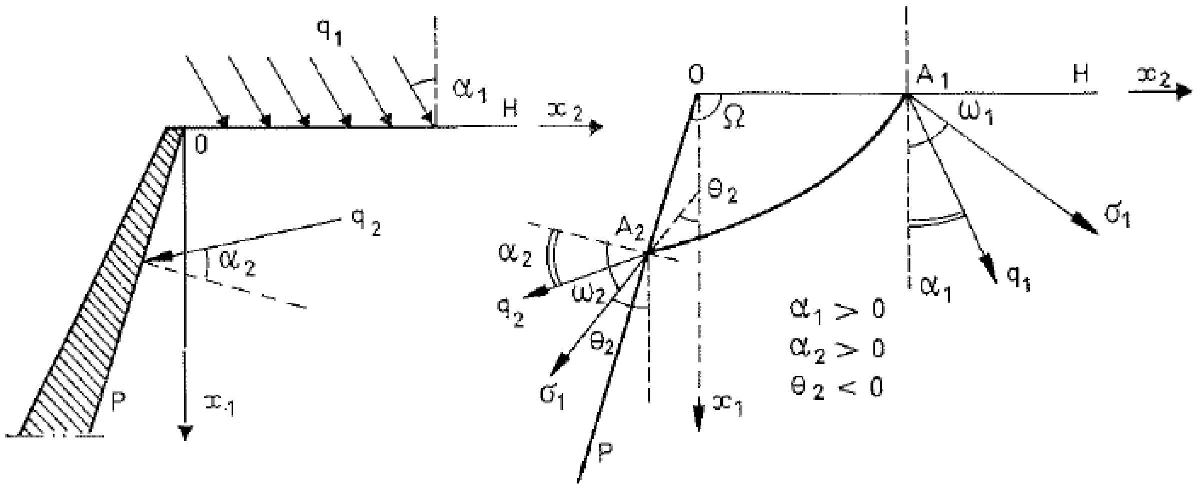
K_a = active earth pressure coefficient normal to the wall

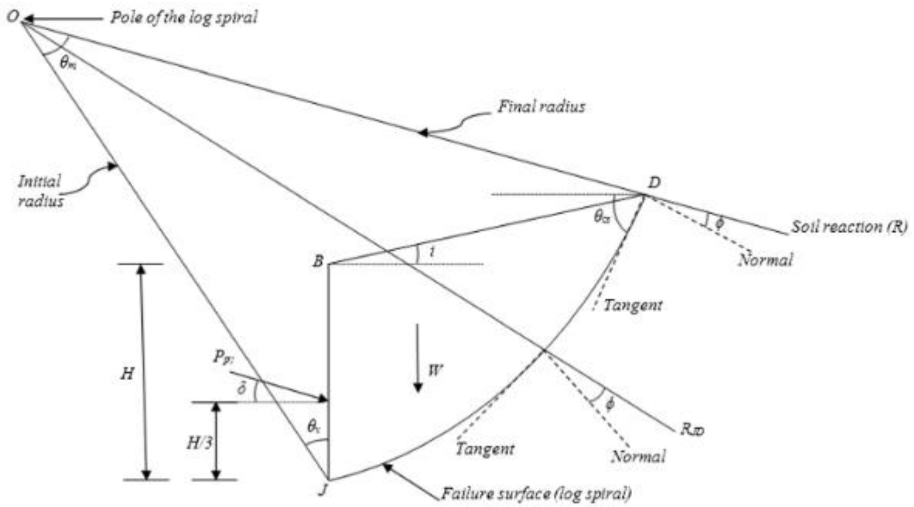
K_p = passive earth pressure coefficient normal to the wall:

$$K_\mathrm{p} = \frac{1}{K_\mathrm{a}} \text{ when } \beta = 0$$

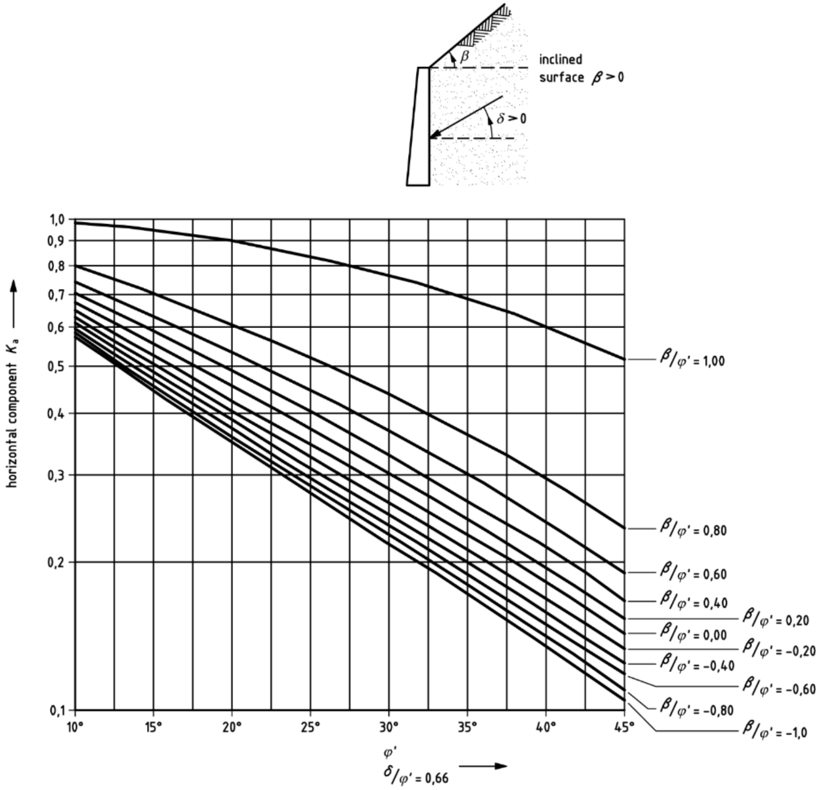
φ' = angle of internal friction of the soil

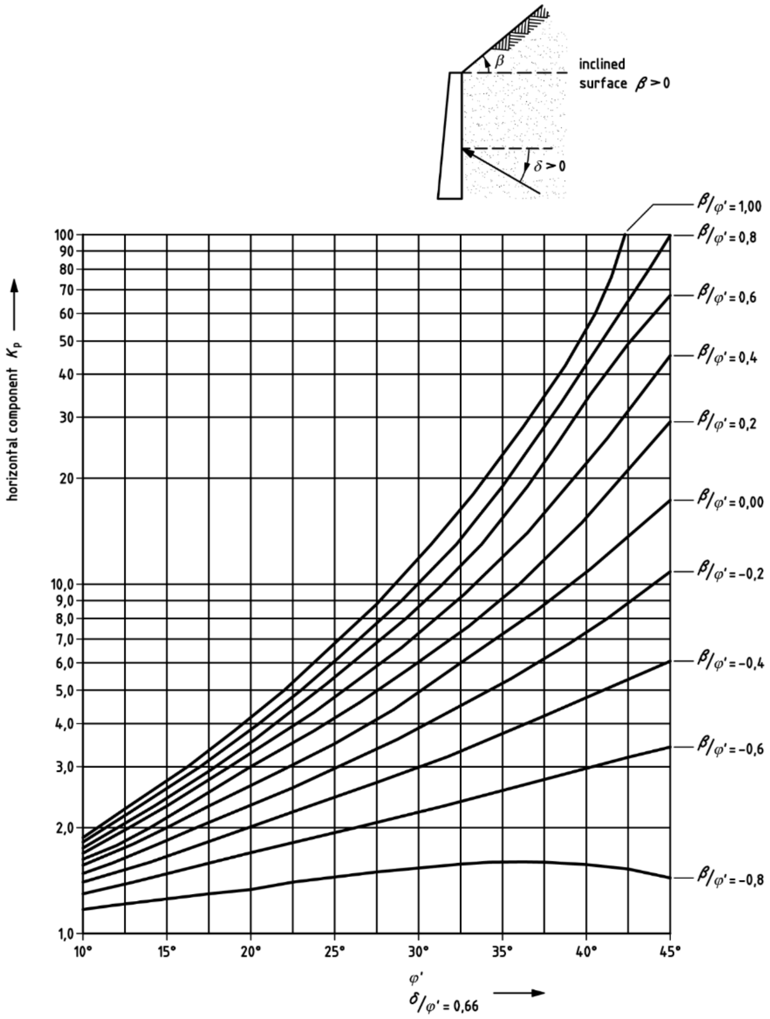
Log-spiral failure mechanism
Caquot and Kerisel, Kerisel and Absi





Kerisel and Absi's values (in EN 1997-1)





Method of characteristics (lower bound) Brinch-Hansen and Lundgren

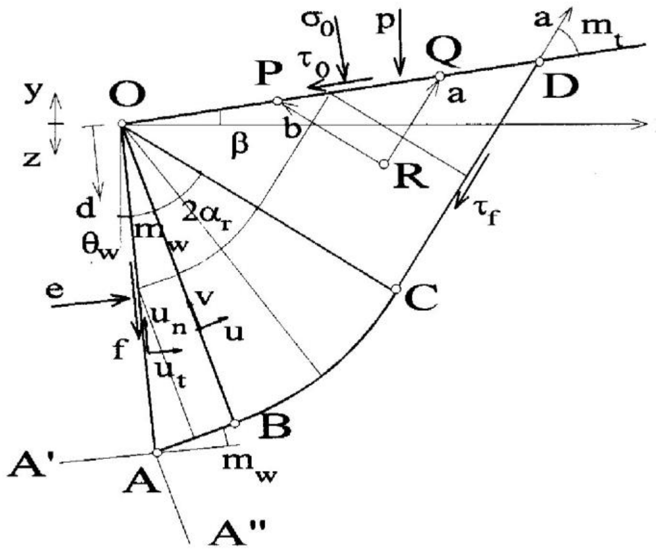


Figure 6.10: Zone Rupture Figure for Earth Pressure

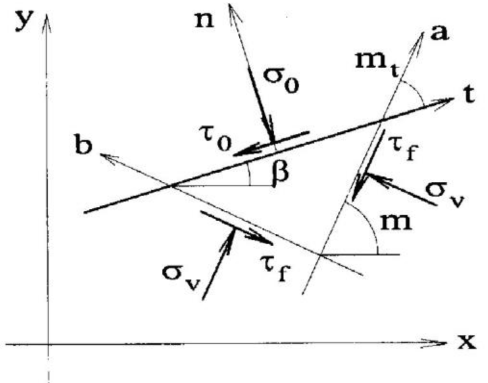


Figure 6.7: Soil Element at Surface

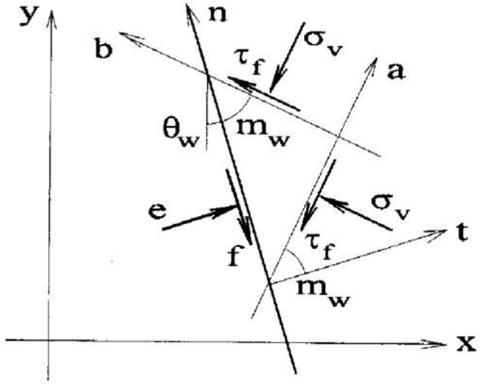


Figure 6.8: Soil Element at Wall

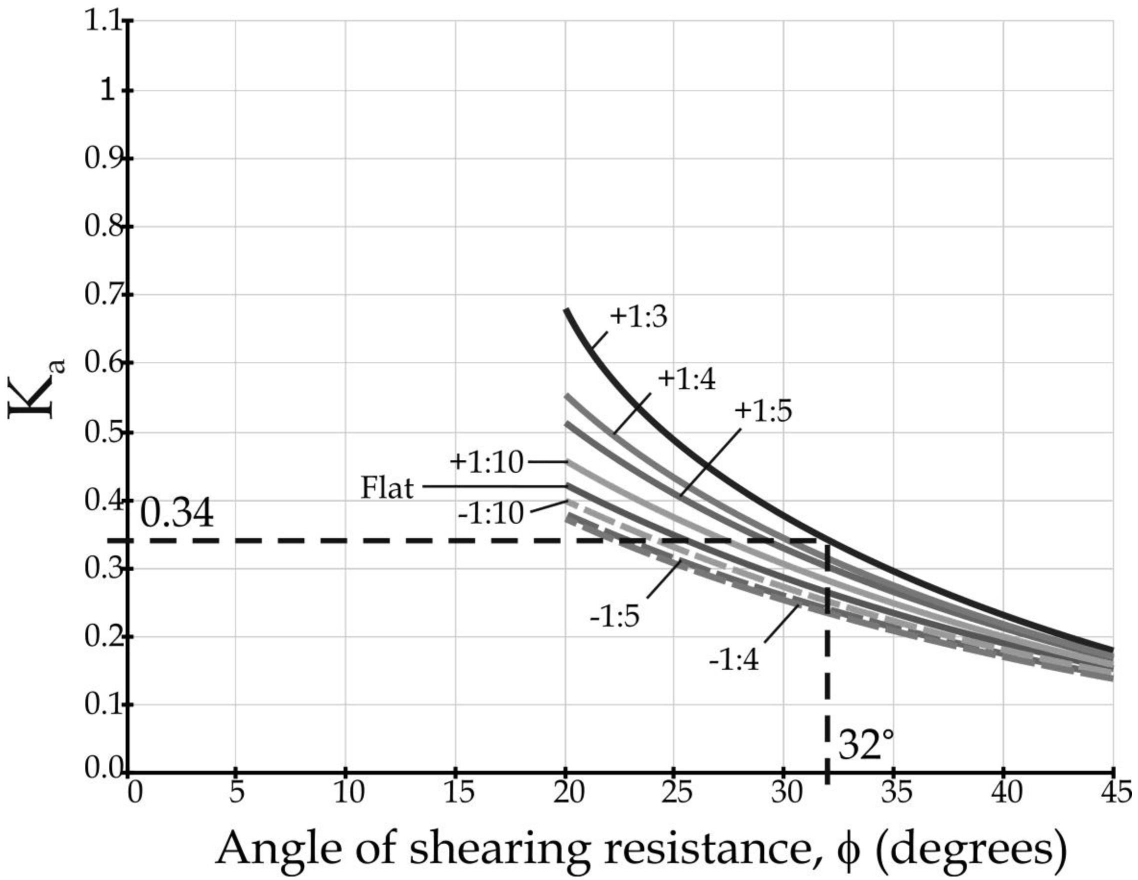
Brinch-Hansen's formula (from EN 1997-1)

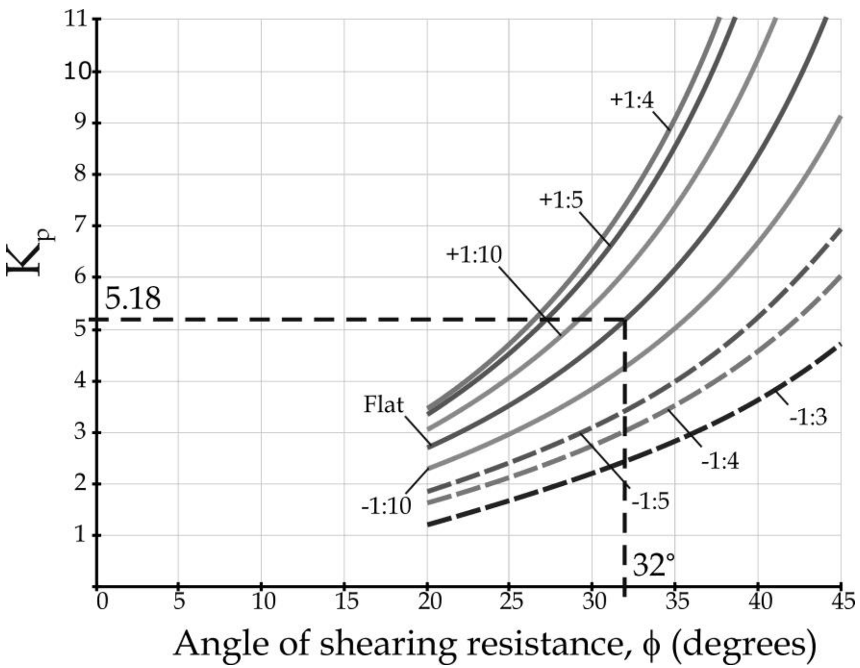
Brinch-Hansen's and Lundgren's (1960) solution for K_a and K_p is:

$$\left.\begin{matrix} K_{\mathrm{a}} \\ K_{\mathrm{p}} \end{matrix}\right\} = \frac{1 \pm \overbrace{\sin\varphi' \sin(2m_{\mathrm{w}} \pm \varphi')}^{2m_{\mathrm{w}} = \cos^{-1}\left(\frac{\sin\delta}{\sin\varphi'}\right) \mp \varphi' \mp \delta}}{1 \mp \underbrace{\sin\varphi' \sin(2m_{\mathrm{t}} \pm \varphi')}_{2m_{\mathrm{t}} = \cos^{-1}\left(\frac{-\sin\beta}{\pm\sin\varphi'}\right) \mp \varphi' - \beta}} e^{\pm 2(m_{\mathrm{t}} + \beta - m_{\mathrm{w}} - \vartheta) \tan\varphi'}$$

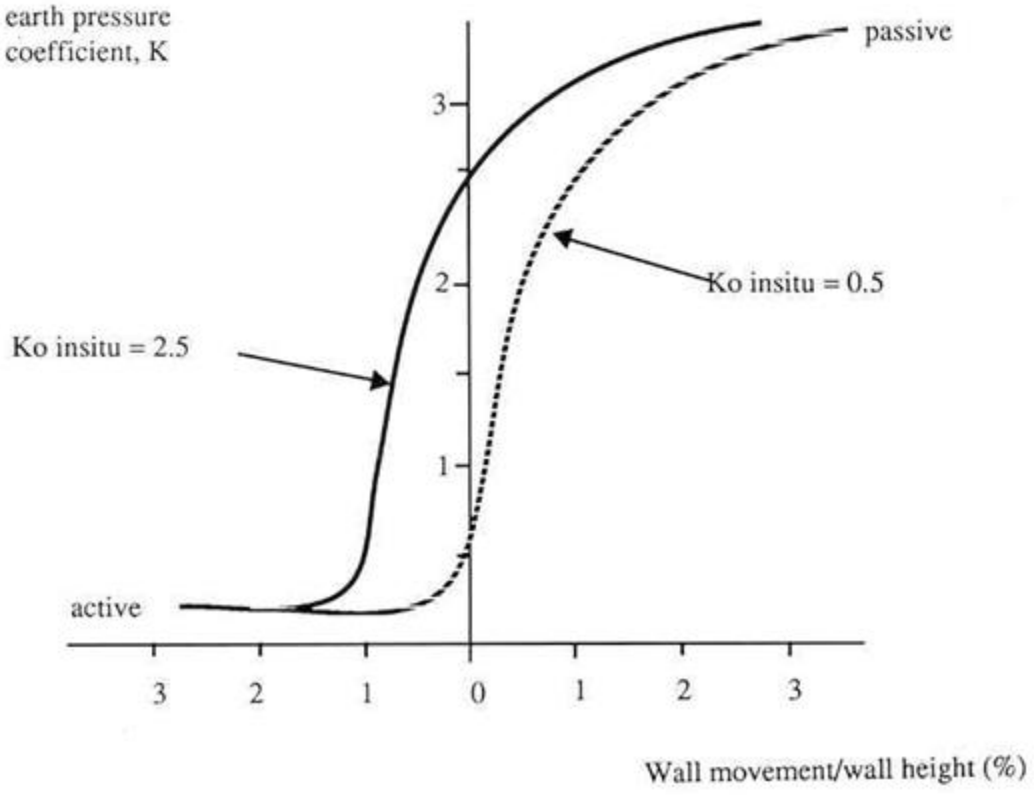
K_a = active earth pressure coefficient at an angle δ to the wall
K_p = passive earth pressure coefficient at an angle δ to the wall
φ' = angle of internal friction of the soil
δ = angle of interface friction between wall and soil
β = angle of inclination of ground surface
α = angle of inclination of wall to the horizontal
θ = angle of inclination of wall to the horizontal (= α in other formulae)

Earth pressure coefficient charts
Bond and Harris (2008)





Movement required to reach limiting conditions



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At-rest earth pressures

General rules for the design for retaining structures – Part 2

At-rest earth pressures for normally consolidated soils

Jaky's (1944) solution for normally consolidated soils:

$$K_{0,\mathrm{nc}} = (1 - \sin\varphi')\left(\frac{1 + \frac{2}{3}\sin\varphi'}{1 + \sin\varphi'}\right)$$

Hendron's (1963) solution:

$$K_{0,\mathrm{nc}} = \frac{1}{2}\left(\frac{1 + \frac{\sqrt{6}}{8} - 3\frac{\sqrt{6}}{8}\sin\varphi'}{1 - \frac{\sqrt{6}}{8} + 3\frac{\sqrt{6}}{8}\sin\varphi'}\right) \approx \frac{1}{2}\left(\frac{1.3 - 0.92\sin\varphi'}{0.7 + 0.92\sin\varphi'}\right)$$

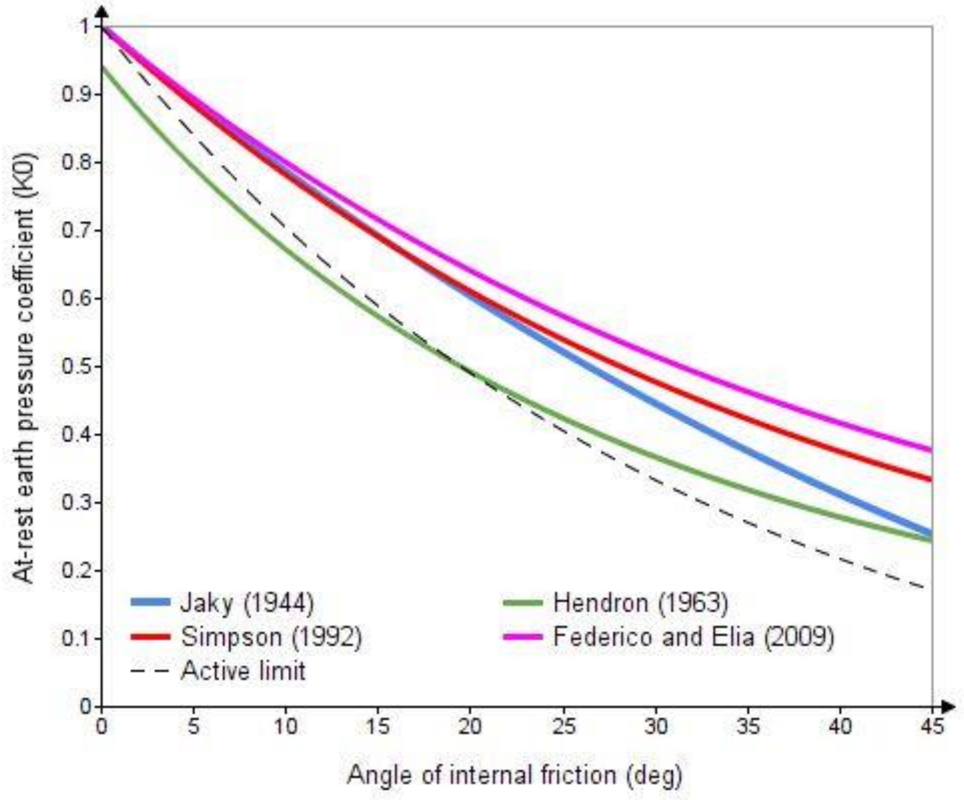
Simpson's (1992) solution, using the BRICK model:

$$K_{0,\mathrm{nc}} = \frac{1 - \frac{1}{\sqrt{2}}\sin\varphi'}{1 + \frac{1}{\sqrt{2}}\sin\varphi'} \approx \frac{1 - 0.7\sin\varphi'}{1 + 0.7\sin\varphi'}$$

Federico and Elia's (2009) correlation:

$$K_{0,\mathrm{nc}} = \frac{1 - 0.64\sin\varphi'}{1 + 0.64\sin\varphi'}$$

At-rest formulations compared



At-rest earth pressures for overconsolidated soils

Meyerhof's (1976) formula for overconsolidated soils:

$$K_{0,\mathrm{oc}} = (1 - \sin\varphi')\sqrt{OCR}$$

OCR = overconsolidation ratio (= $\sigma'_\mathrm{h}/\sigma'_\mathrm{v}$)
σ'_h = horizontal effective stress
σ'_v = vertical effective stress

Mayne and Kulhawy's (1982) correlation:

$$K_{0,\mathrm{oc}} = (1 - \sin\varphi')OCR^{\sin\varphi'}$$

EN 1997-2:2004 equation, incorporating Kezdi's (1972) adjustment for sloping ground:

$$K_{0,\mathrm{oc}} = (1 - \sin\varphi')\sqrt{OCR}(1 + \sin\beta)$$

β = inclination of ground surface

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Compaction earth pressures

General rules for the design for retaining structures – Part 2

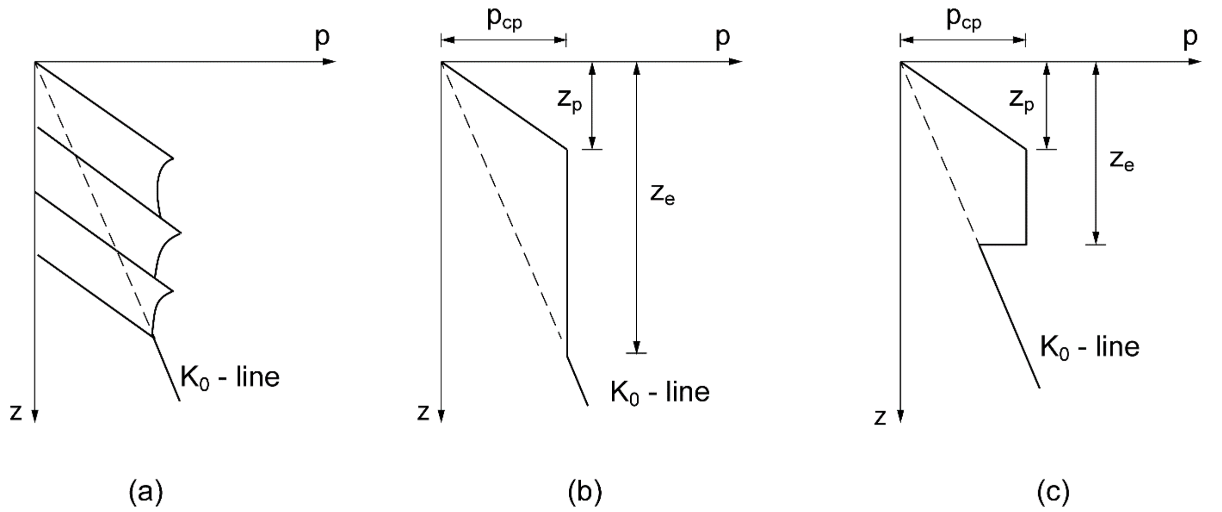
Earth pressures due to compaction

- Compaction induces passive earth pressures in upper layers
- As compaction proceeds, the earth pressure reaches a maximum value
- At greater depth, at-rest conditions prevail

$$\left.\begin{array}{c} z \le z_{\mathrm{c,min}} \\ z_{\mathrm{c,min}} \text{ to } z_{\mathrm{c,max}} \\ z \ge z_{\mathrm{c,max}} \end{array}\right\} p'_{\mathrm{c}} = \begin{cases} K_{\mathrm{p}\gamma}\overline{\gamma}_{\mathrm{c}} z \\ p'_{\mathrm{c,max}} \\ K_0 \overline{\gamma}_{\mathrm{c}} z \end{cases}$$

$$z_{\mathrm{c,min}} = p'_{\mathrm{c,max}} / \overline{\gamma}_{\mathrm{c}} K_{\mathrm{p}\gamma}$$

$$z_{\mathrm{c,max}} = p'_{\mathrm{c,max}} / \overline{\gamma}_{\mathrm{c}} K_0$$



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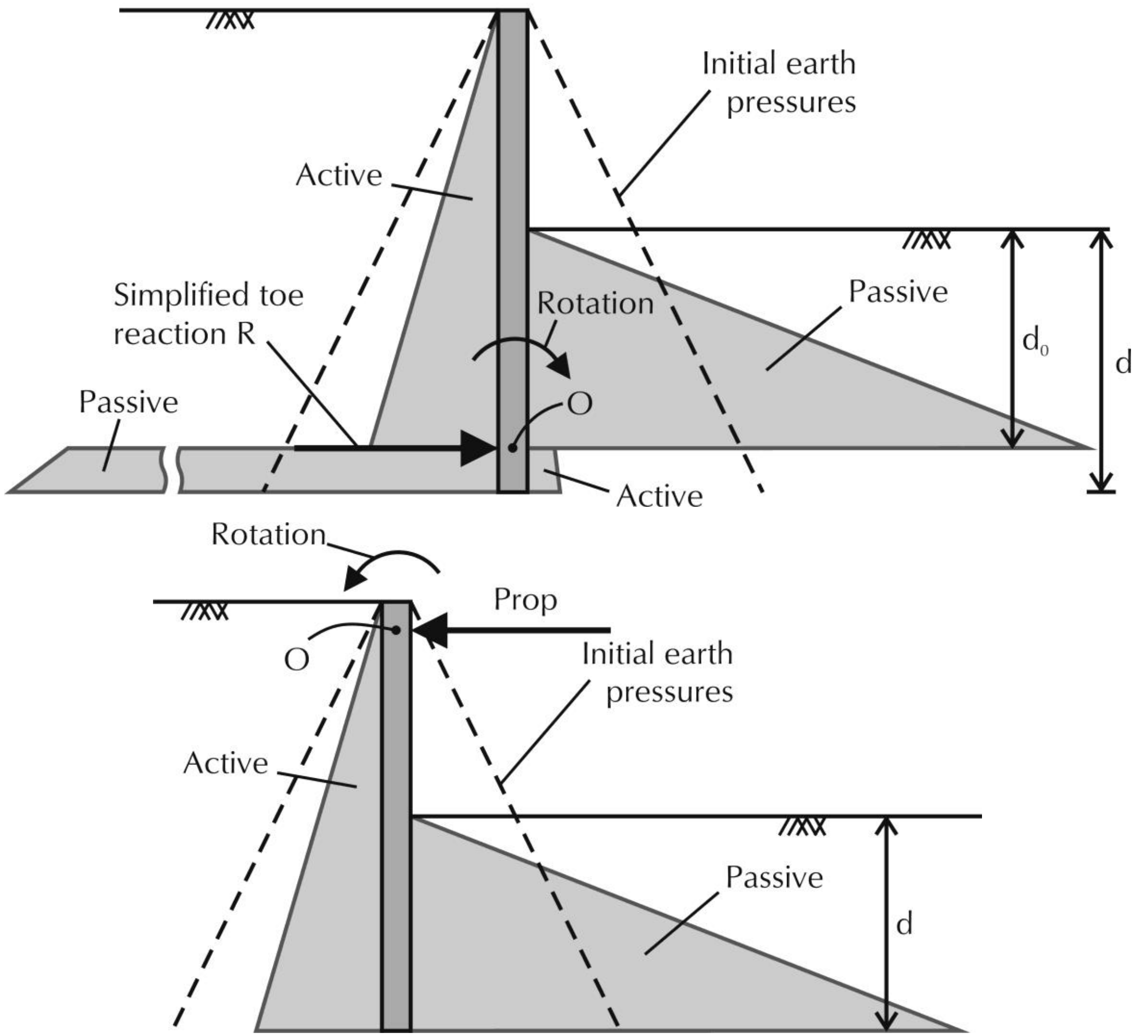
Methods of analysis

General rules for the design for retaining structures – Part 2

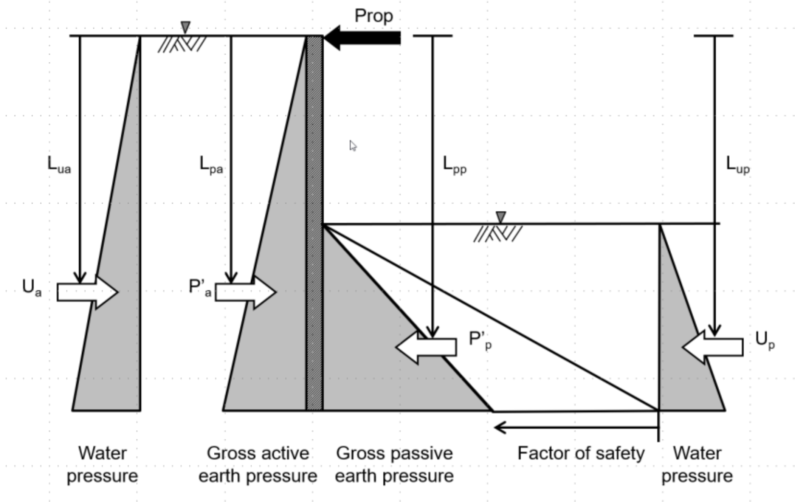
Methods of analysis

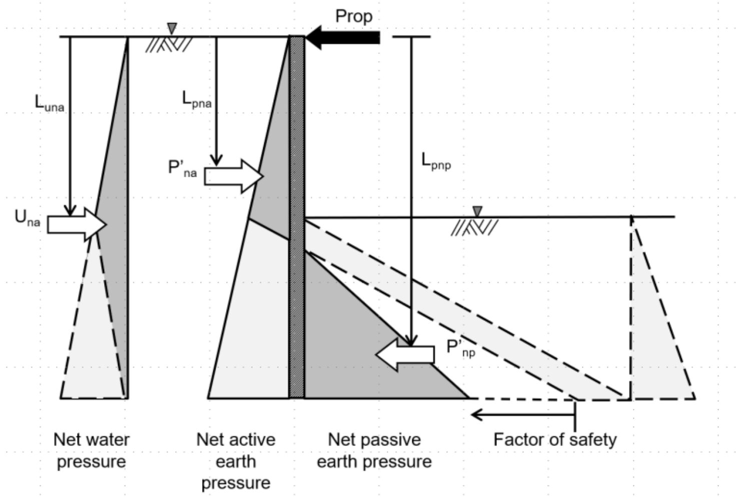
- Limiting equilibrium models
  - Where to put the factor of safety?
  - Software is needed to make this practical
- Beam-on-springs models
- Earth pressure envelopes
- Distributed prop loads
- Continuum numerical models

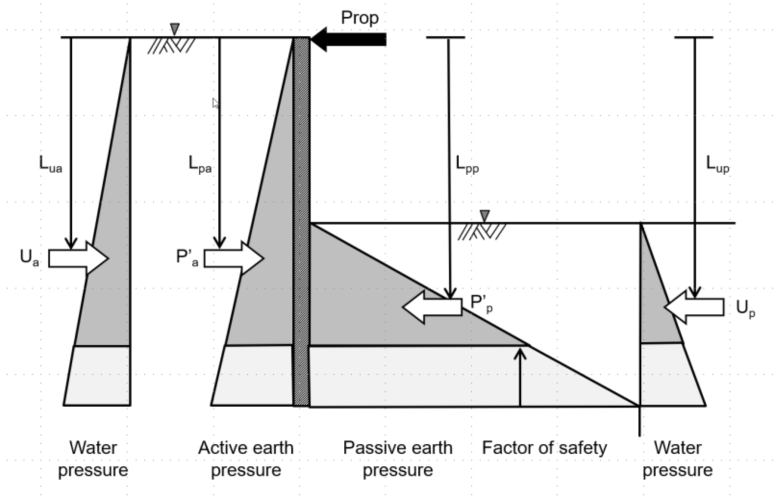
Limiting equilibrium models
Bond and Harris (2008)

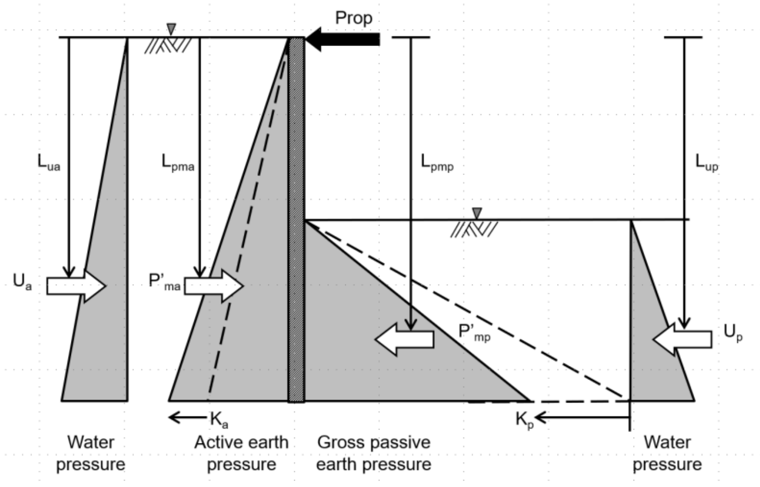


Where to put the factor of safety?

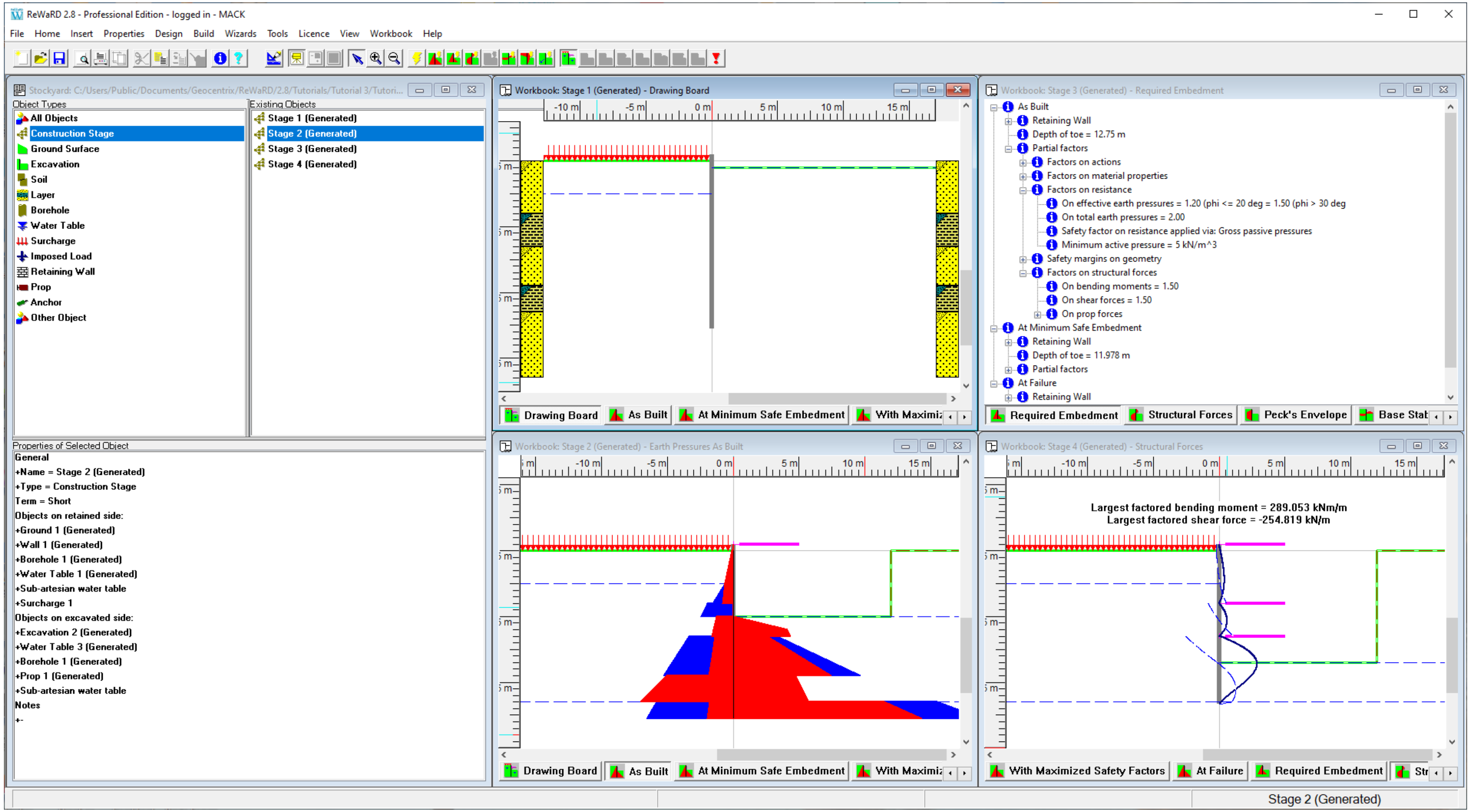








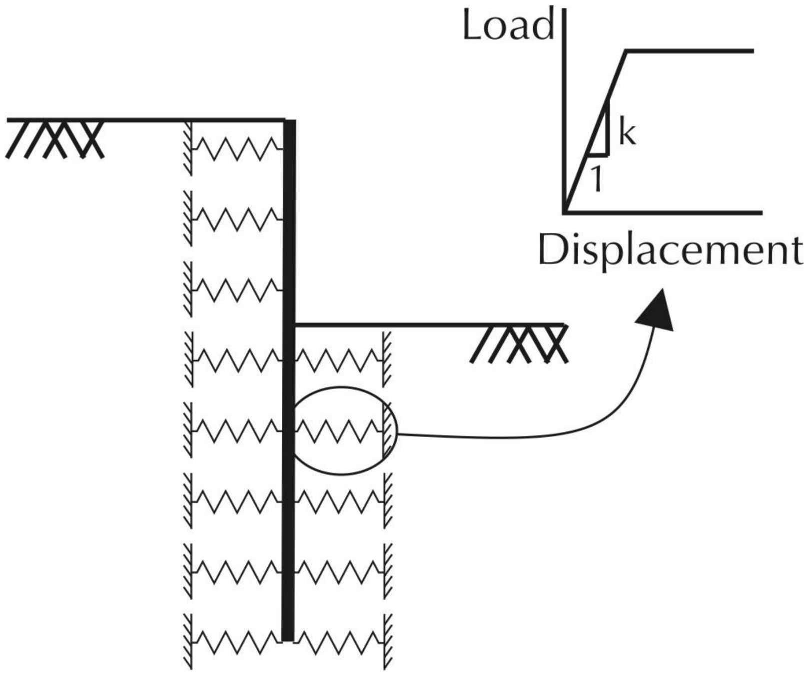
Software is needed to make this practical
www.geocentrix.co.uk/reward



EM iepirkums „Apmācību semināru "Datoraprēķini būvkonstrukciju projektēšanā" organizēšana un norises nodrošināšana" ID Nr. EM 2020/46

Beam-on-springs models

- Forces on wall and in any props or anchors supporting it are calculated from deformations along the wall
- Iteration brings forces into equilibrium while keeping movements compatible with the elastic properties of the wall
- Spring coefficients *k* are estimated from field and lab. measurements of soil stiffness (when available) or from crude rules-of-thumb
- Spring capacities are defined using limiting earth pressure coefficients (K_a for tension, K_p for compression)



Beam-on-springs models

In Winkler's (1867) spring model, soil stiffness is defined as pressure/displacement (unlike Hook's spring constant, which is force/displacement):

$$k = \frac{\sigma}{\delta} = \frac{E}{0.95(1 - \upsilon^2)h}$$

The governing equation for beam bending is:

$$EI\frac{\mathrm{d}^4 u}{\mathrm{d}z^4} = -bk_{\mathrm{h}}u$$

Earth pressure envelopes (after Peck, 1969)

Worst-case earth pressures are used to construct envelopes that allow preliminary sizing of props

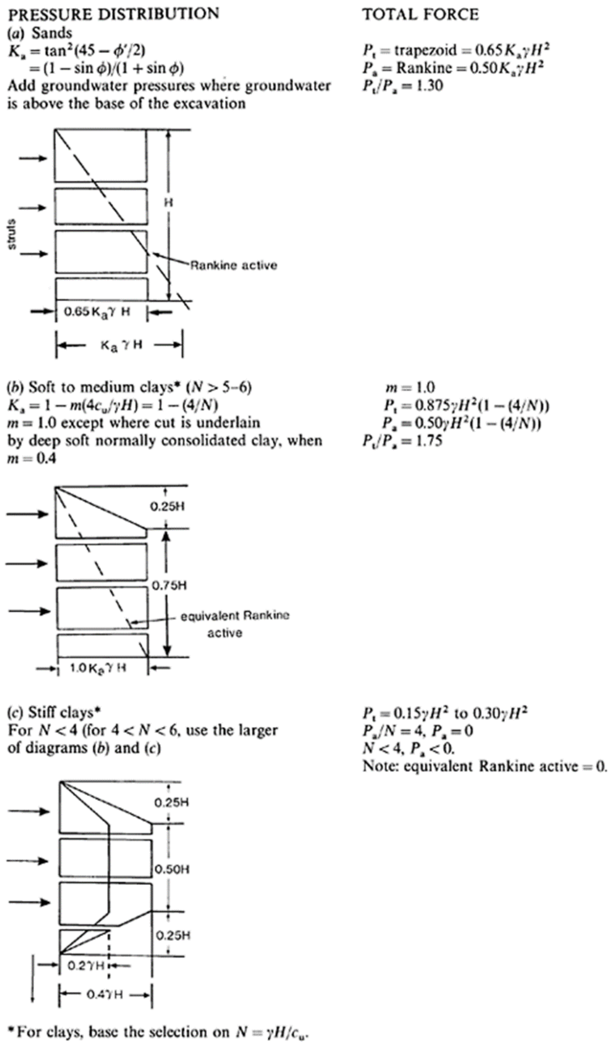
Peck's method is based on monitoring data from full-scale braced excavations, largely in stiff fissured clays of Chicago

The envelopes are upper bounds to the earth pressures (and hence prop forces) likely to be experienced, not actual pressures under working conditions

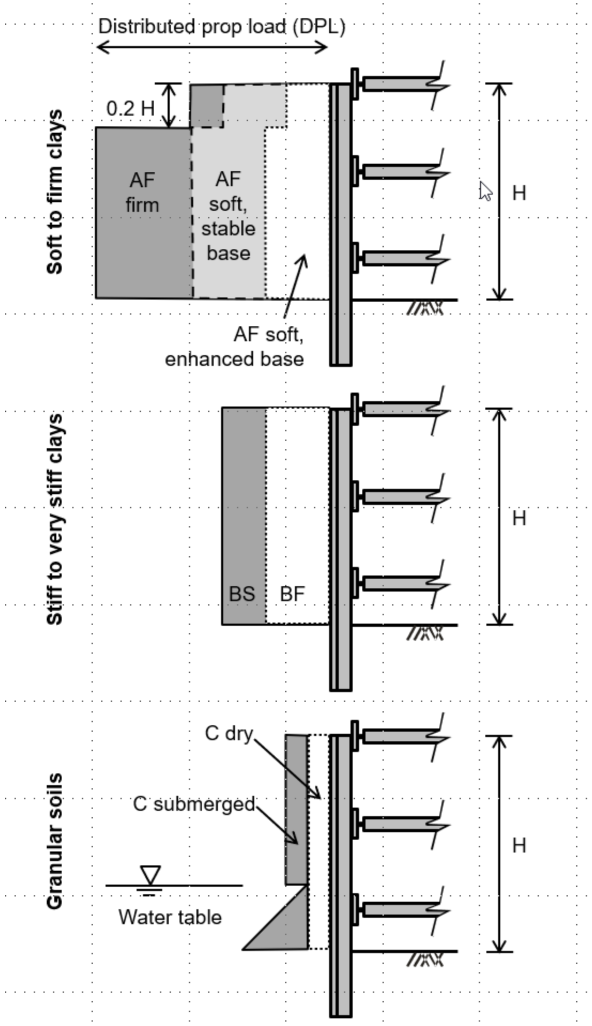
Observations are grouped by soil type

Correct application of the diagrams requires:

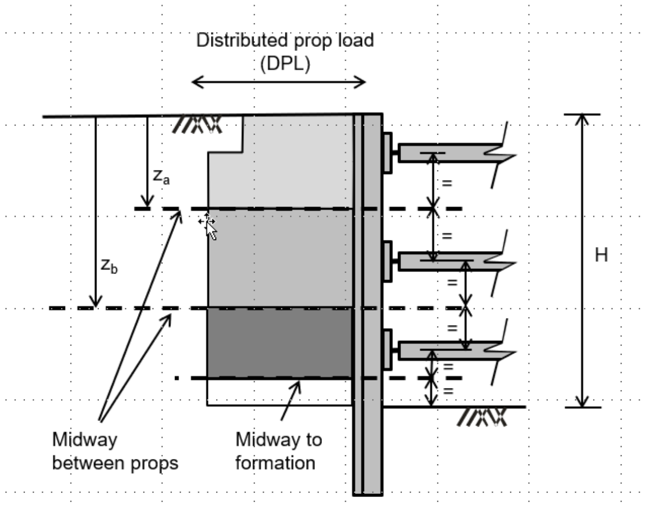
- deep excavation (> 6 m)
- water table below base of the excavation
- sand assumed drained (i.e. diagram givers effective stresses)
- clay assumed undrained (i.e. diagram gives total stresses)
- bottom stability must be checked separately



Distributed prop loads (from CIRIA C517)



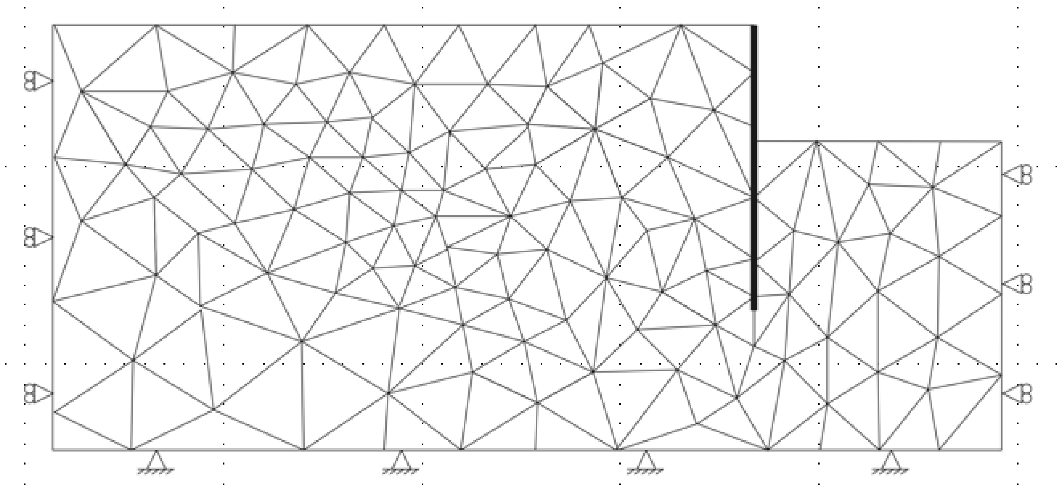
Soil class	Description
A	Normally and slightly OC clay soils
B	Heavily OC clay soils
C	Coarse grained soils
D	Mixed soils

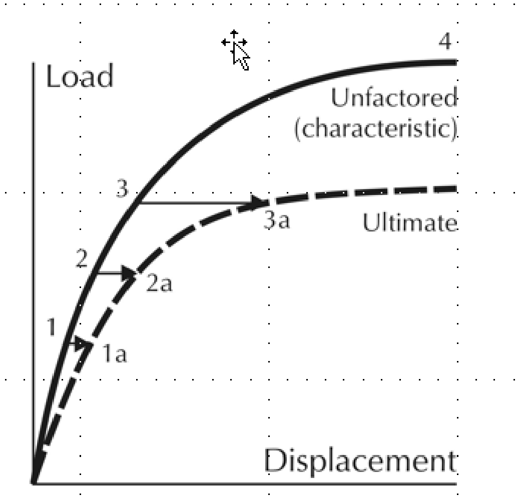


Distributed prop load values

Class	Soil		DPL over…	
			Top 20%	Bottom 80%
AS	Same as AF for firm clay			
AF	Firm clay		$0.2\ \gamma H$	$0.3\ \gamma H$
	Soft clay with stable base		$0.5\ \gamma H$	$0.65\ \gamma H$
	Soft clay with enhanced base stability		$0.65\ \gamma H$	$1.15\ \gamma H$
BS	Stiff to very stiff clay		$0.5\ \gamma H$	
BF			$0.3\ \gamma H$	
C	Granular soil, dry		$0.2\ \gamma H$	
	Granular soil, submerged	Above water	$0.2\ \gamma H$	
		Below water	$0.2\ (\gamma - \gamma_w)H + \gamma_w(z - d_w)$	

Continuum numerical models





There are a variety of continuum models used in geotechnical practice:

- Finite element method
- Finite different method
- Boundary element method

The key features of all these types of model are:

- Discretization
- Boundary conditions
- Types of elements
- Constitutive model
  - Linear elasticity
  - Non-homogeneity
  - Anisotropy
  - Non-linearity
  - Plasticity

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Summary of key points

General rules for the design for retaining structures – Part 2

Summary of key points

- Earth pressure theory has been formulated in terms of:
  - effective stress
  - total stress
- Several methods available to obtain earth pressure coefficients:
  - analytical and graphical
  - wedge-shaped mechanisms
  - Mohr's circles of stress
  - log-spiral failure mechanism
  - method of characteristics
- Commonly used calculation models include:
  - Limiting equilibrium models
  - Beam-on-springs models
  - Earth pressure envelopes
  - Distributed prop loads
  - Continuum numerical models

Questions and answers

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Good practice in retaining wall design

www.geocentrix.co.uk

References

- Chris R.I Clayton, Rick I. Woods, Andrew J. Bond, and Jarbas Militisky (2013), Earth Pressure and Earth-Retaining Structures, Third Edition, CRC Press.

Pusdienu pārtraukums / 13:30 - 14:00

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Training seminar / Apmācību seminārs

Verification of limit states for retaining structures
Struktūru noturības stāvokļu pārbaude

Dr Andrew Bond (United Kingdom)

Ministry of Economics
Republic of Latvia

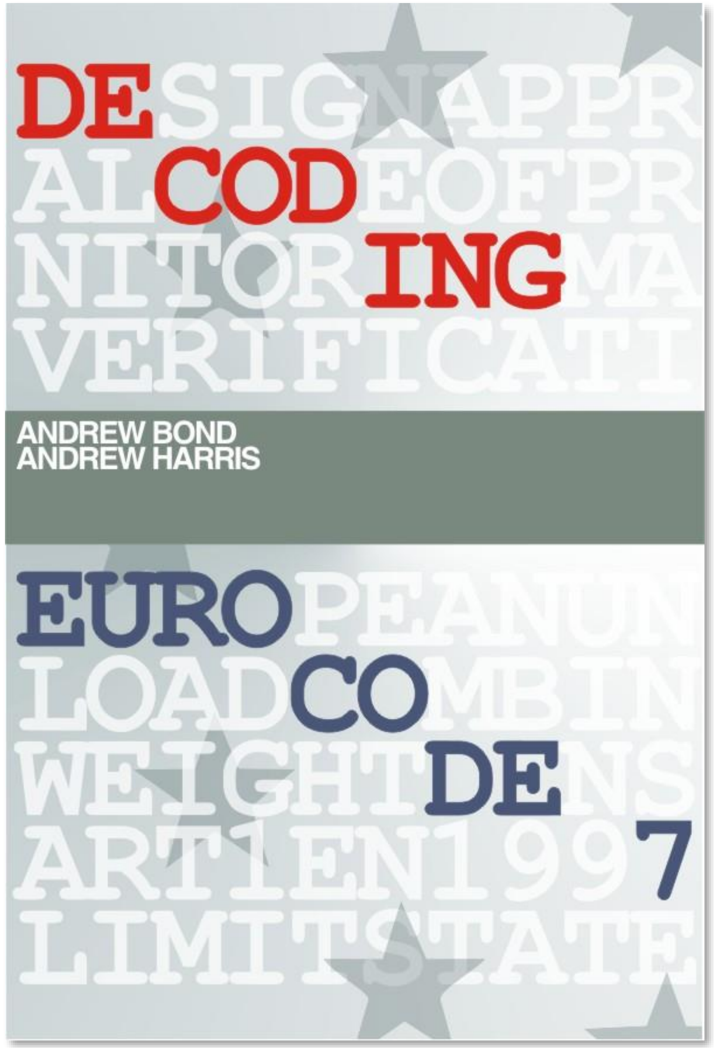
Verification of limit states for retaining structures

Dr Andrew Bond (Geocentrix)
Immediate-Past Chair TC250/SC7 Geotechnical design

Verification of limit states for retaining structures

- Design situations
- Ultimate limit states
- Serviceability limit states
- Changes coming in 2^{nd} generation Eurocodes
- Summary of key points
- Questions and answers

Decoding Eurocode 7
www.decodingeurocode 7.com



Book published August 2008

Key features

- Covers ENs 1997-1 and -2, plus relevant parts of other Eurocodes
- Also covers associated execution and testing standards
- Explains key principles
- Illustrates application rules with real-life case studies
- Material extensively tested on training courses over 5 years

Authors Andrew Bond and Andy Harris

Published by Taylor and Francis in hardback, with colour section

ISBN: 9780415409483

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Design situations

Verification of limit states for retaining structures

Design situations

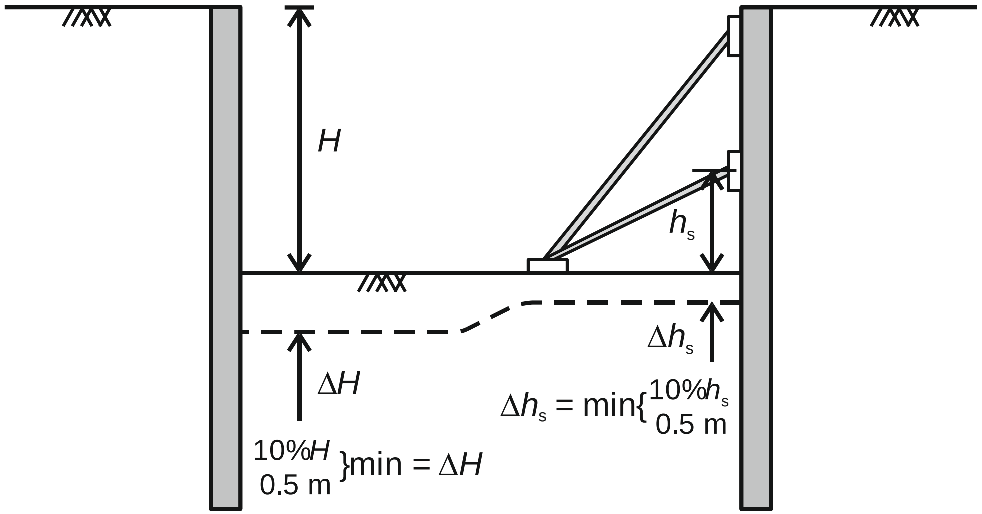
- Design situations for retaining structures
- Anticipated and unplanned excavations

Design situations for retaining structures

Include – but are not limited to:

- stages of excavation, construction, operation, and maintenance
- anticipated future structures or any anticipated future loading or unloading within the zone of influence of the geotechnical structure
- effects of waterfront structures, ice, and wave force
- potential adverse effects of repeated surcharge loading

Anticipated and unplanned excavations
EN 1997-1:2004 §9.3.2.2(2)



Design geometry shall account for anticipated excavation or possible scour in front of the retaining structure. For ULS verifications, "with a normal degree of control":

$$a_{\mathrm{d}} = a_{\mathrm{nom}} \pm \Delta a \Rightarrow H_{\mathrm{d}} = H_{\mathrm{nom}} + \Delta H$$

'Values of Δa smaller than those given [in the figure], including Δa = 0, may be used when the surface level is specified to be controlled reliably throughout the relevant execution period.

'Values of Δa larger than [in the figure] should be used when the surface level is particularly uncertain'

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Ultimate limit states

Verification of limit states for retaining structures

Ultimate limit states (ULSs)

- Ultimate limit states for retaining structures
- Verification of ultimate limit states for embedded retaining walls
- Verification of strength for GEO/STR
- Partial factors for GEO/STR
- Latvian National Annex to EN 1997-1
- National choice of Design Approach
- Overall stability
- Rotational stability of embedded walls
- Stability of excavations (basal heave)
- Structural failure
- Load-effects in props, struts, and anchors

Ultimate limit states for retaining structures

In addition to the 'regular' limit states (specified in EN 1997-1), the following ultimate limit states shall be verified for all retaining structures:

- failure of a structural element, including the wall, anchor, rock bolt, waling, or strut
- failure of the connection or interface between structural elements
- combined failure in the ground and in the structural element
- excessive movement of the retaining structure, which may cause collapse of the structure or nearby structures or services that rely on it
- For gravity walls and composite retaining structures…
  - bearing resistance failure of the ground below the base, taking into account eccentricity and inclination of loads
  - failure by sliding along the base
  - failure by toppling
- For embedded walls…
  - failure by rotation or translation of the wall or parts thereof;
  - failure by lack of vertical equilibrium.

ULSs other than those above should be verified as necessary

When nearby structures are sensitive to ground movements, measures should be taken to prevent those structures from exceeding an ultimate limit state

Verification of ultimate limit states for embedded retaining walls

- Verification of bearing resistance (from §6 Spread foundations):

$$V_d \leq R_d \Rightarrow q_{Ed} \leq q_{Rd}$$

- Verification of rotational stability (often dictates wall length) :

$$M_{Ed} \leq M_{Rd} \Rightarrow M_O \leq M_R$$

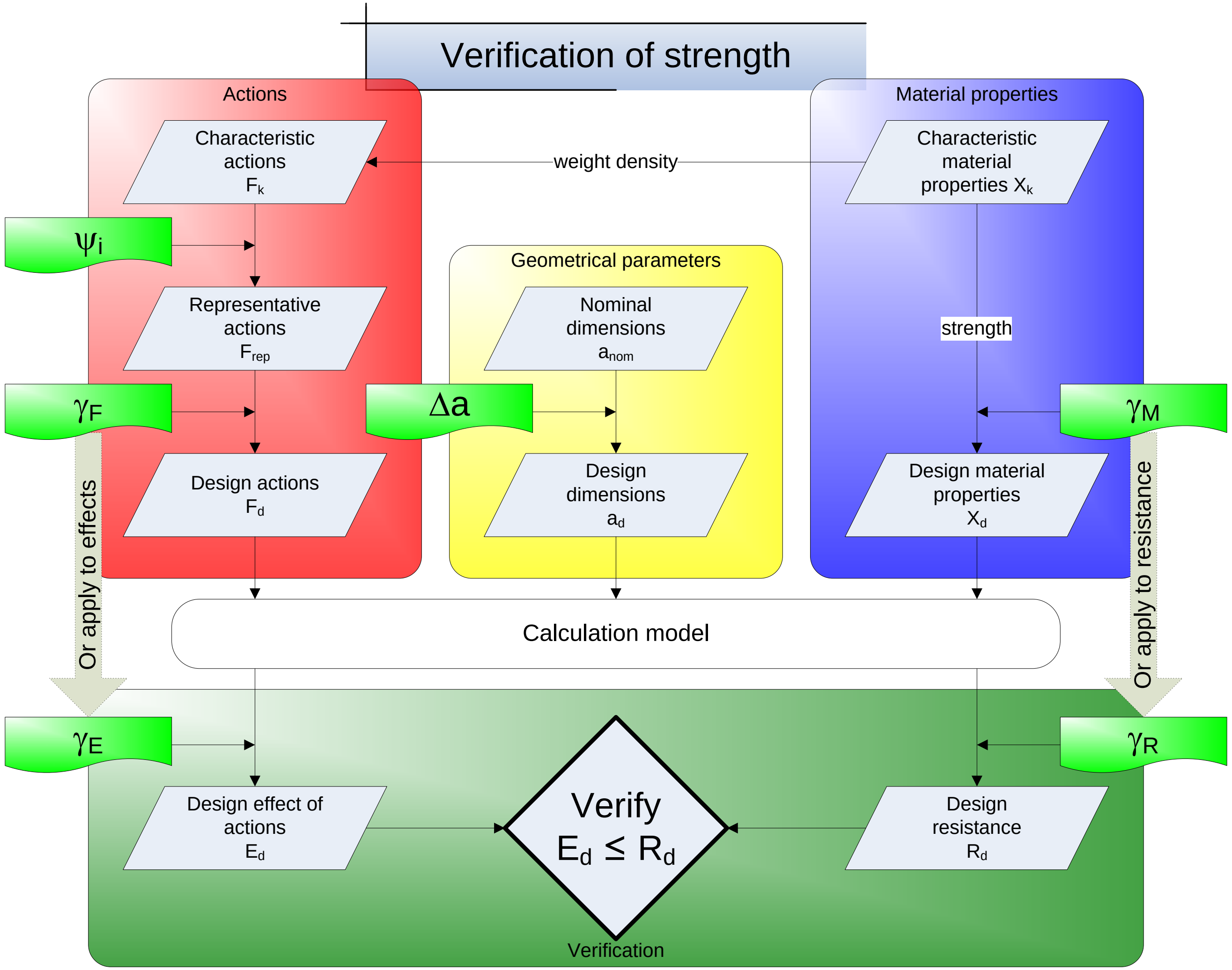
- Verification of structural resistance (bending moments, shear) according to Eurocodes 2 and 3:

$$M_{Ed} \leq M_{Rd} \text{ and } V_{Ed} \leq V_{Rd}$$

- Verification of global stability:

$$M_{Ed} \leq M_{Rd} \Rightarrow M_{over} \leq M_{rest}$$

Verification of strength for GEO/STR
Bond and Harris (2008)



Partial factors for limit states GEO/STR from EN 1997-1:2004 (Bond & Harris, 2008)

<table>
<tr><th colspan="2" rowspan="2">Parameter</th><th rowspan="2">Sym-bol</th><th colspan="2">Action factors</th><th colspan="2">Material factors</th><th colspan="4">Resistance factors</th></tr>
<tr><th>A1</th><th>A2</th><th>M1</th><th>M2</th><th>R1</th><th>R2</th><th>R3</th><th>R4</th></tr>
<tr><td rowspan="2">Permanent action (G)</td><td>Unfavourable</td><td>γ_G</td><td>1.35</td><td rowspan="2">1.0</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Favourable</td><td>($\gamma_{G,fav}$)</td><td>1.0</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Variable action (Q)</td><td>Unfavourable</td><td>γ_Q</td><td>1.5</td><td>1.3</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Favourable</td><td>-</td><td>(0)</td><td>(0)</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Shearing resistance (tan φ)</td><td>γ_φ</td><td></td><td></td><td rowspan="5">1.0</td><td rowspan="2">1.25</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Effective cohesion (c')</td><td>γ_c</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Undrained shear strength (c_u)</td><td>γ_{cu}</td><td></td><td></td><td rowspan="2">1.4</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Unconfined compressive strength (q_u)</td><td>γ_{qu}</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Weight density (γ)</td><td>γ_γ</td><td></td><td></td><td>1.0</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="2">Bearing resistance (R_v)</td><td>γ_{Rv}</td><td></td><td></td><td></td><td></td><td rowspan="4">1.0</td><td>1.4</td><td rowspan="4">1.0</td><td rowspan="4">(1.0)</td></tr>
<tr><td colspan="2">Sliding resistance (R_h)</td><td>γ_{Rh}</td><td></td><td></td><td></td><td></td><td>1.1</td></tr>
<tr><td rowspan="2">Earth resistance (R_e)</td><td>Walls</td><td rowspan="2">γ_{Re}</td><td></td><td></td><td></td><td></td><td>1.4</td></tr>
<tr><td>Slopes</td><td></td><td></td><td></td><td></td><td>1.1</td></tr>
<tr><td colspan="2">Pile resistance</td><td></td><td></td><td></td><td></td><td></td><td colspan="4">See separate table</td></tr>
<tr><td colspan="11">Factors given for persistent and transient design situations</td></tr>
</table>

Latvian National Annex to EN 1997-1

- The National Standards Body for Latvia (LVS) published its National Annex to EN 1997-1 in 2019
- LVS EN 1997-1/NA
- The Latvian NA specifies:
  - Design Approach 2 for verifying retaining wall design
  - Design Approach 3 for verifying overall stability

LVS LATVIJAS STANDARTS

LVS EN 1997-1/NA

2019. gada 12. decembris

ICS 91.120.20 Aizstāj: LVS EN 1997-1:2005 A /NA:2013

7.Eirokodekss. Ģeotehniskā projektēšana. 1.daļa: Vispārīgie noteikumi. Nacionālais pielikums

Eurocode 7 - Geotechnical design - Part 1: General rules - National annex

Priekšvārds

Latvijas standarta nacionālais pielikums LVS EN 1997-1:2005/NA:2019 "7.Eirokodekss. Ģeotehniskā projektēšana. 1.daļa: Vispārīgie noteikumi. Nacionālais pielikums" ir standarta LVS EN 1997-1:2005 „7.Eirokodekss. Ģeotehniskā projektēšana. 1.daļa: Vispārīgie noteikumi" pielikums, kurā ietverti nacionāli nosakāmie parametri.

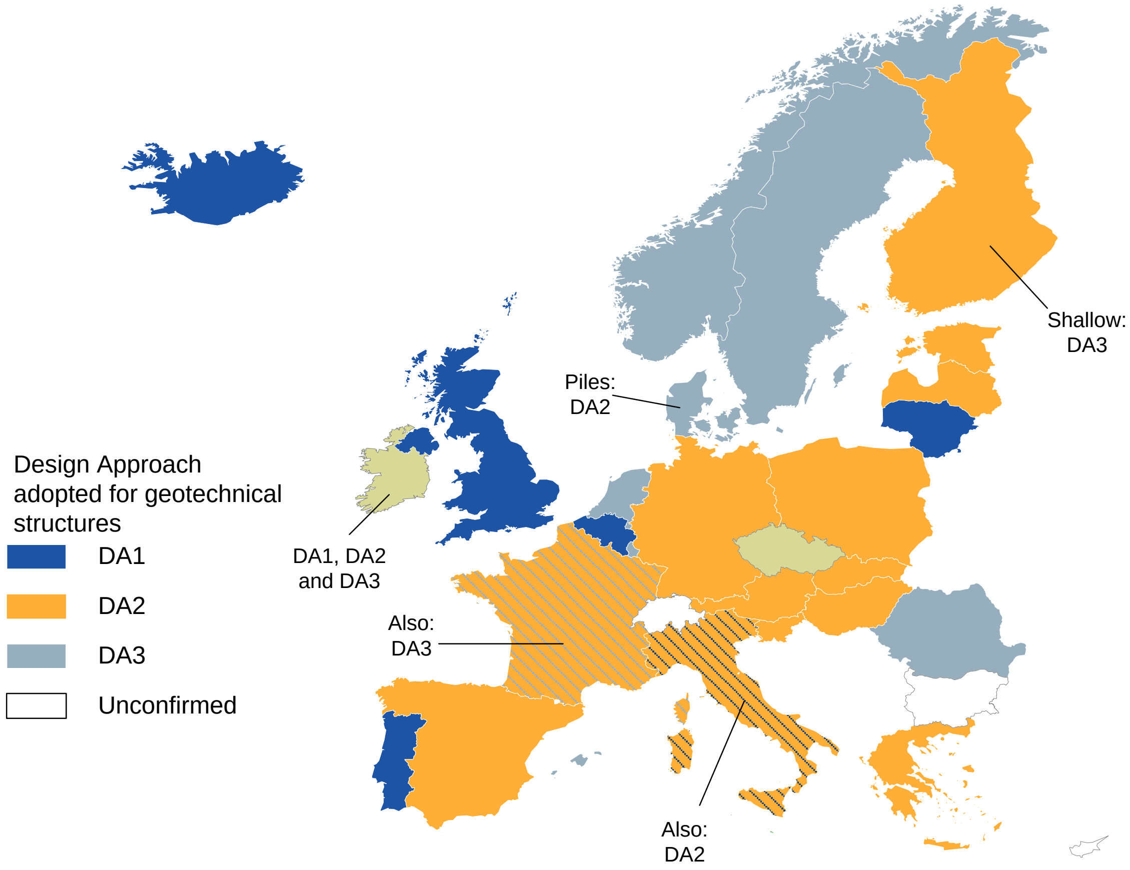
Nacionālais pielikums ir izstrādāts un apstiprināts standartizācijas tehniskajā komitejā LVS/STK 30 Būvniecība.

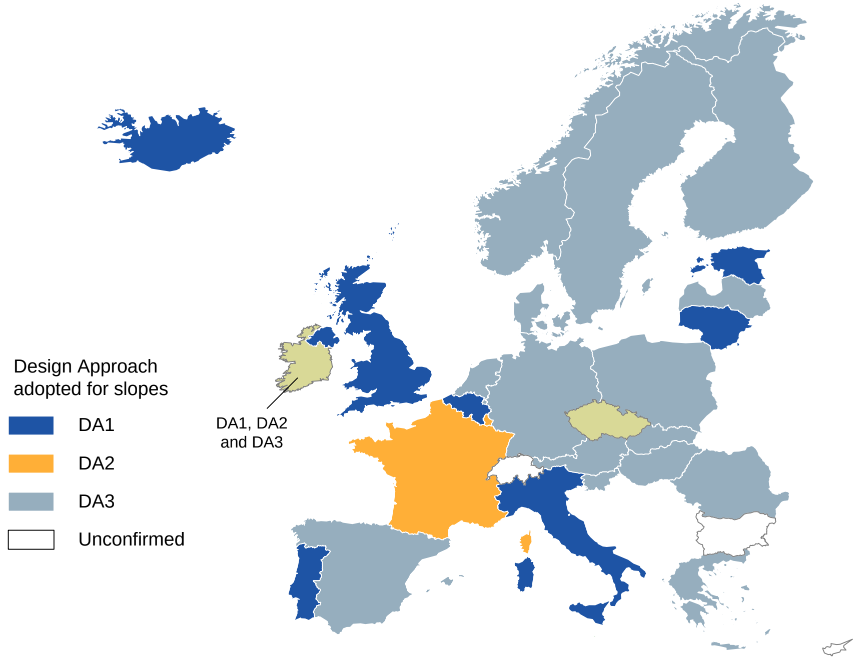
Šī pielikuma prasību ievērošana ir obligāta, piemērojot standartu LVS EN 1997-1:2005 Latvijas Republikā.

Lappuses: 5

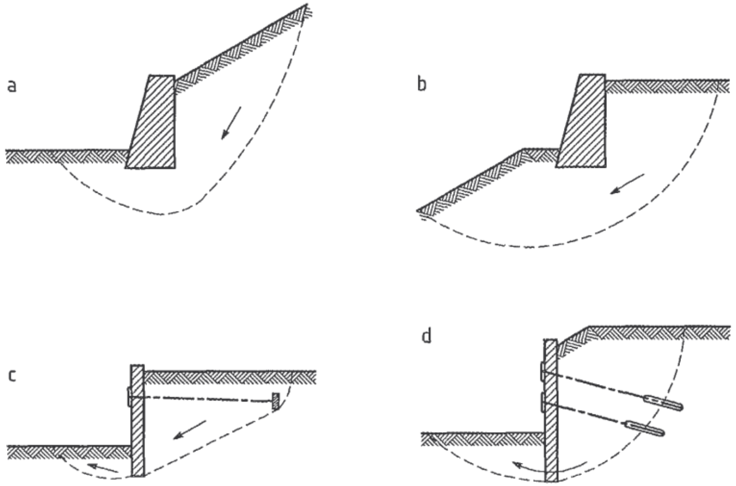
 Atsauce: LVS EN 1997-1:2005/NA:2019

National choice of Design Approach
l) structures, r) slopes (after Bond, 2013)





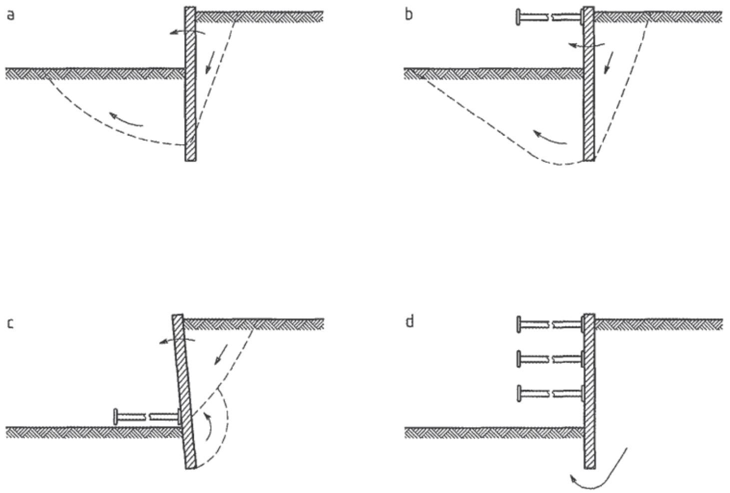
Overall stability



Design Approach from EN 1997-1:2004			
1		2	3
Combination 1	Combination 2		
A1 + M1 + R1	A2 + M2 + R1	A1 + M1 + R2	A2 + M2 + R3
Actions	Actions & Material properties	Effects of actions & resistances	Actions & material properties
Major factors >> 1.0; minor factors > 1.0; factors that have no effect = 1.0 Sets A1-A2 = on actions/effects; M1-M2 = material properties; R1-R3 = resistances			

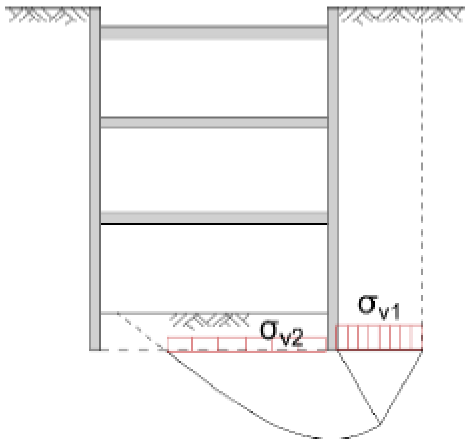
EM iepirkums „Apmācību semināru "Datoraprēķini būvkonstrukciju projektēšanā" organizēšana un norises nodrošināšana" ID Nr. EM 2020/46

Rotational stability of embedded walls



Design Approach from EN 1997-1:2004			
1		2	3
Combination 1	Combination 2		
A1 + M1 + R1	A2 + M2 + R1	A1 + M1 + R2	A1/A2 + M2 + R3
Actions	Actions & Material properties	Actions & Resistances	Structural actions, geotechnical actions & material properties
Major factors >> 1.0; minor factors > 1.0; factors that have no effect = 1.0 Sets A1-A2 = on actions/effects; M1-M2 = material properties; R1-R3 = resistances			

Stability of excavations (basal heave)



The limit pressure that can be applied at toe level outside the excavation is:

$$\sigma_{v1} \leq \frac{\gamma B}{2} N_{\gamma} + \sigma_{v2} N_{q} + c N_{c}$$
$$\rightarrow \sigma_{v2} N_{q} + c N_{c}$$

γ = weight density of ground beneath the wall

B = width outside the excavation

σ_{v2} = vertical stress at toe level inside the excavation

c = effective soil cohesion

The simplified formula applies in (undrained) fine soils (N_{γ} = 0) and coarse soils where hydraulic gradients are concentrated next to the wall ($B \rightarrow 0$)

Structural failure

The structural resistance of retaining structures and their component members shall be verified in accordance with:

- EN 1992-1-1 for reinforced or plain concrete retaining walls
- EN 1993-1-1 and EN 1993-5 for steel retaining walls
- EN 1994-1-1 for composite steel and concrete retaining walls
- EN 1995-1-1 for timber members in retaining walls
- EN 1996-1-1 for masonry retaining walls

Load-effects in props, struts, and anchors BS 8002:2015 §7.7.5 & Table 11

Design axial resistance from support must be at least equal to a design axial force (F_d) given by:

$$F_d = max \begin{cases} \overbrace{F_{Ed,ULS}}^{ultimate} = \overbrace{\gamma_{Sd}}^{model\ factor} \times \overbrace{P_{d,ULS}}^{inc.\ load\ factor} \\ \gamma_F \times \underbrace{F_{Ed,SLS}}_{serviceability} = \underbrace{\gamma_F}_{load\ factor} \times \underbrace{\gamma_{Sd}}_{model\ factor} \times \underbrace{P_{d,SLS}}_{unfactored} \end{cases}$$

$F_{Ed,ULS}$ = design force (effect) in the support at the ultimate limit state; $F_{Ed,SLS}$ at the serviceability limit state
$P_{d,ULS}$ = axial force calculated using ULS parameters to prevent earth retaining structure exceeding a ULS
$P_{d,SLS}$ = axial force calculated using SLS parameters to prevent earth retaining structure exceeding an SLS

Number of wall supports	Level of support	Model factor γ_{Sd} for different methods of analysis		
		Limiting equilibrium	Discrete spring or continuum models	Distributed prop load method
≥ 1	Top	1.3	1.0	1.0
	Other	1.15	1.0	1.0

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Serviceability limit states

Verification of limit states for retaining structures

Serviceability limit states (SLSs)

- Serviceability limit states for retaining structures
- Verification of movements for SLS
- Terms for describing foundation movement
- Limiting deformations
- Comparable experience is paramount

Serviceability limit states for retaining structures

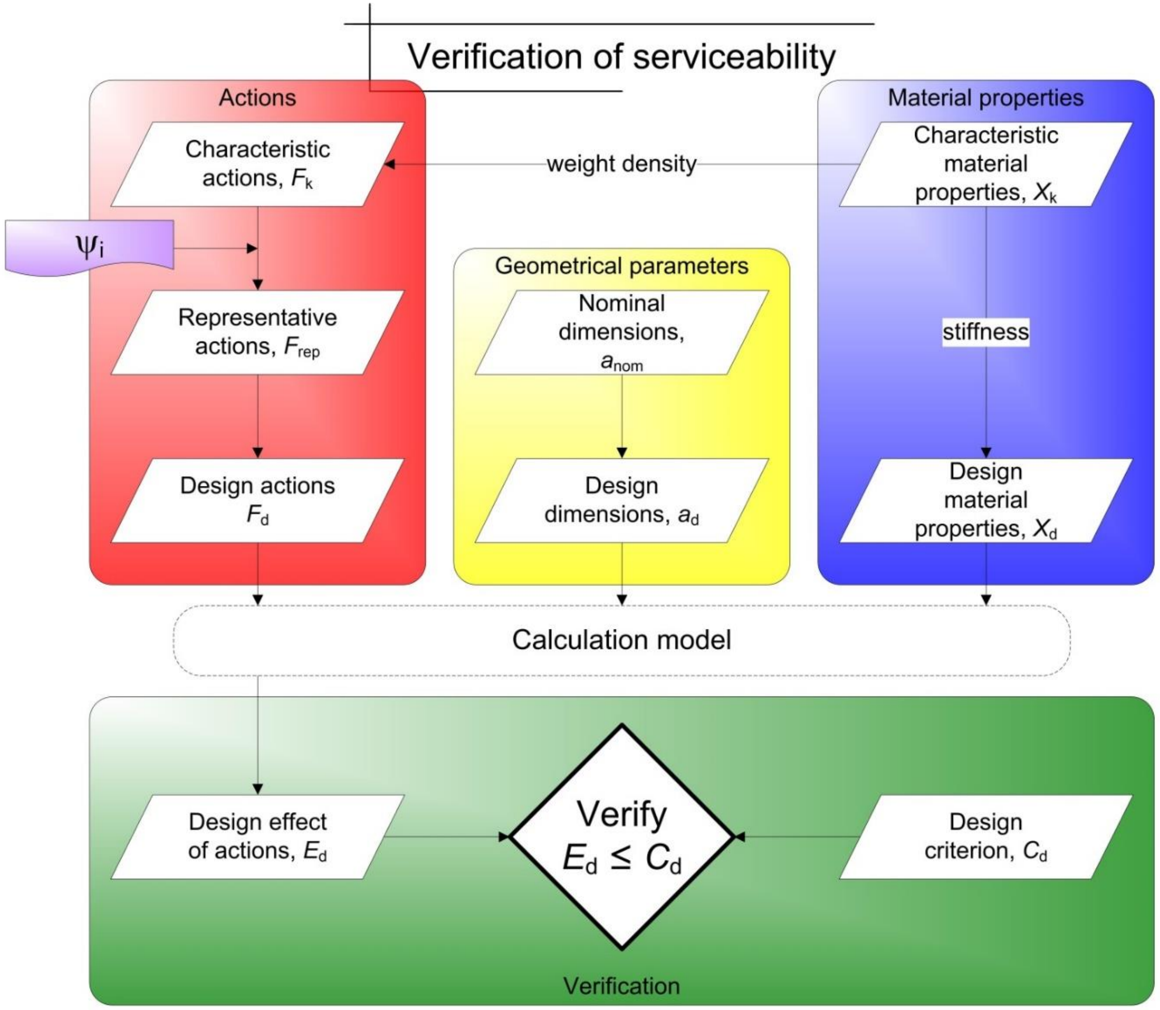
In addition to the ‘regular’ limit states specified in EN 1997-1, the following serviceability limit states shall be verified for all retaining structures:

- unacceptable leakage through or beneath the structure;
- unacceptable change in the groundwater regime;
- movements of the retaining structure that cause damage or affect the appearance or efficient use of the structure or nearby structures or services that rely on it.

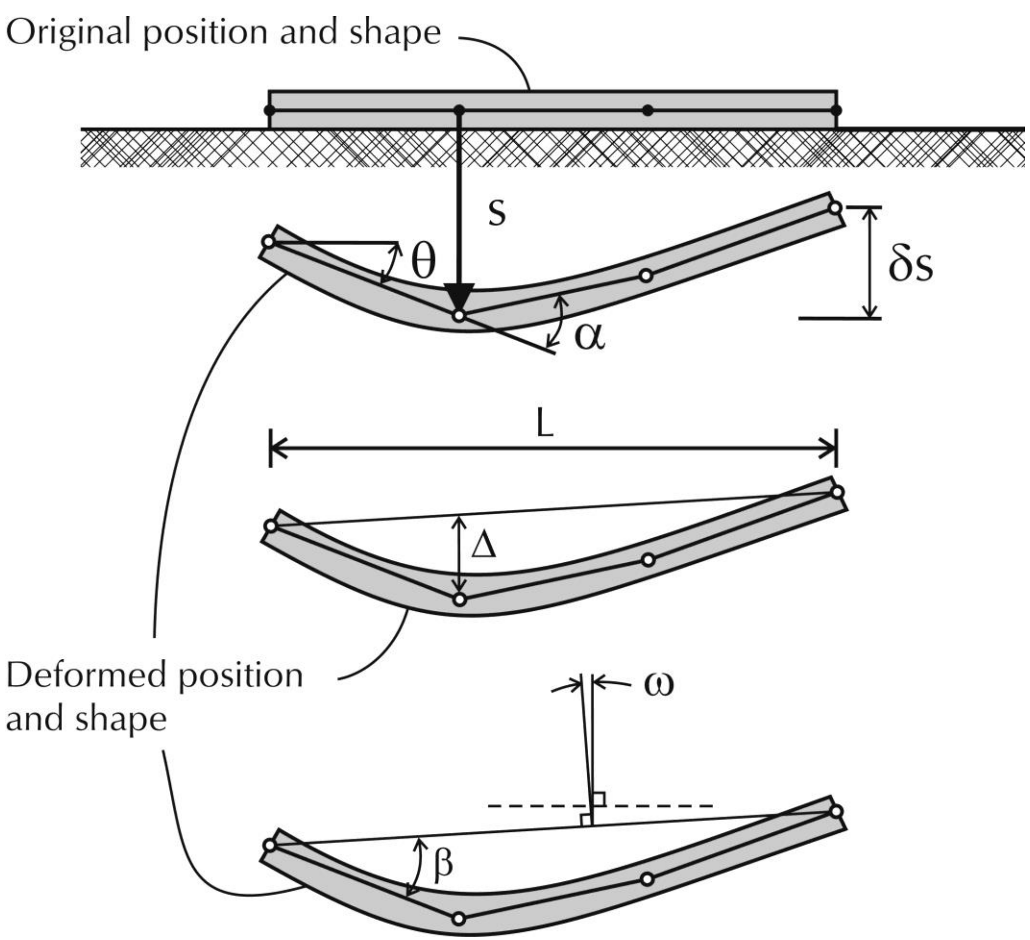
SLSs states other than those above should be verified as necessary

When nearby structures are sensitive to ground movements, measures should be taken to prevent those structures from exceeding a serviceability limit state

Verification of movements for SLS (after Bond & Harris, 2008)



Terms for describing foundation movement EN 1997-1 Annex H



- Burland & Wroth's (1975) terms for describing foundation movement:
  - settlement, *s*
  - differential settlement, δs
  - rotation, θ
  - angular strain, α
  - relative deflection, Δ
  - deflection ratio, Δ/L
  - tilt, ω
  - relative rotation (angular distortion), β

Limiting deformations
EN 1997-1 Annex H

Maximum allowable relative rotations (β_{Cd}) to meet serviceability limit states vary with type of structure

- typically 1/2000 to 1/300 (0.05-0.33%)
- 1/500 reasonable for most structures (0.2%)

Values apply to a sagging mode of settlement (most common)

If mode is hogging, values should be halved

- i.e. 1/1000 (0.1%)

Settlements (s_{Cd}) up to 50 mm are often tolerable for isolated foundations

- depends on nature of structure and intended use

"... some guidance is given [in Annex H] on the maximum acceptable structural deformations but in a very conservative way"

Smoltczyk, Netzel, and Kany (2003)

Geotechnical Engineering Handbook, Vol. 2 (German)

Comparable experience is paramount

A cautious estimate of the distortion and displacement of retaining walls, and the effects on supported structures and services, shall always be made on the basis of comparable experience. This estimate shall include the effects of construction of the wall. The design may be justified by checking that the estimated displacements do not exceed the limiting values

EN 1997-1:2004 §9.8.2(2)P

- Displacement calculations shall be undertaken:
  - where nearby structures and services are unusually sensitive to displacement
  - where comparable experience is not well established
- Displacement calculations should be considered where the wall …
  - retains more than 6 m of cohesive soil of low plasticity
  - retains more than 3 m of soils of high plasticity
  - is supported by soft clay within its height or beneath its base

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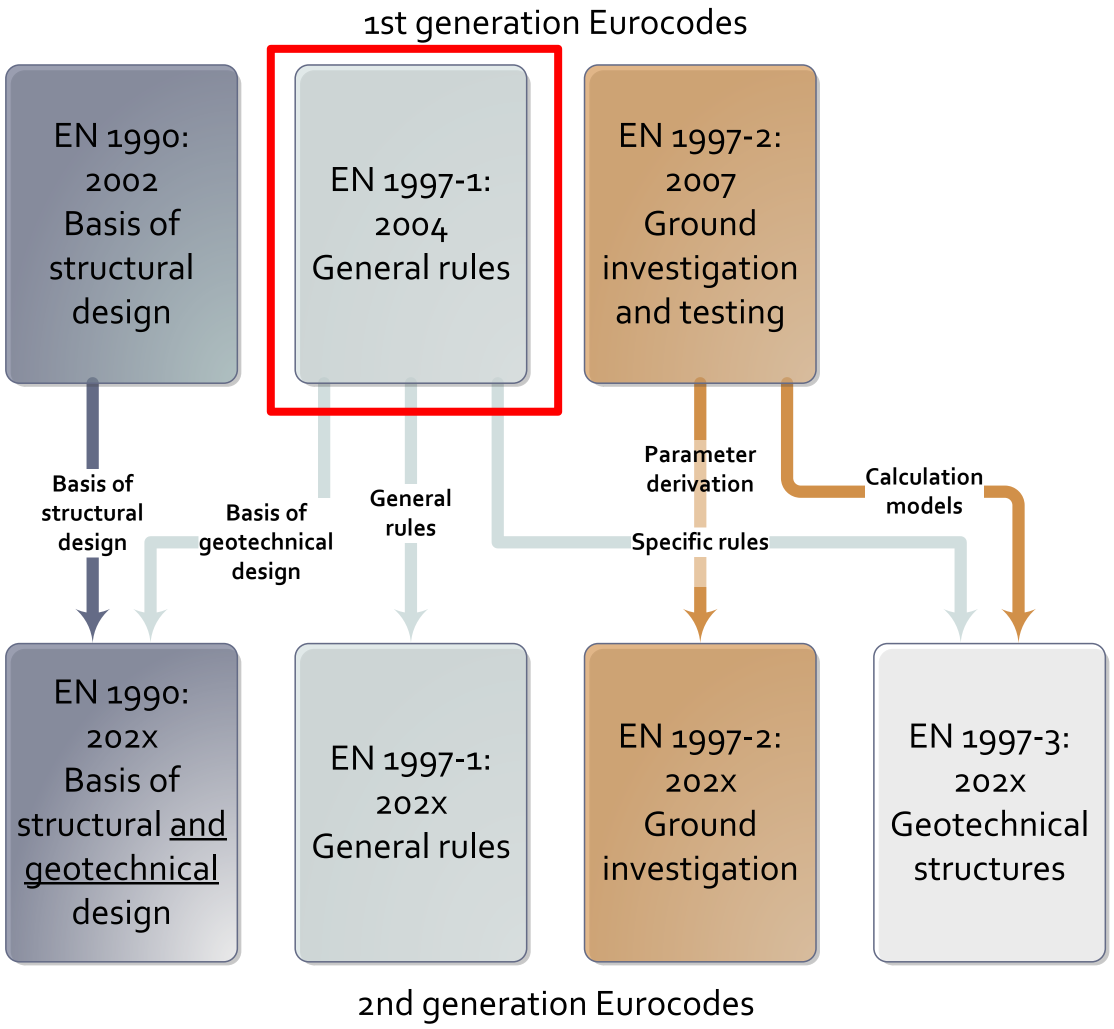
Changes coming in 2nd generation Eurocodes

Verification of limit states for retaining structures

Basis of geotechnical design in 1st and 2nd generation Eurocodes



Partial factors for ultimate limit states from prEN 1997-3:2019

Table 7.2 (NDP) – Partial factors for the verification of ground resistance against retaining structures for fundamental (persistent and transient) design situations

Verification of	Partial factor on	Symbol	Material factor approach (MFA) – both combinations (a) and (b)		Resistance factor approach (RFA)
			(a)	(b)	
Overall stability	See Clause 4[3]				
Bearing resistance of gravity walls	See Clause 5				
Bearing resistance of embedded walls	See Clause 6				
Rotational resistance	Actions and effects-of-actions	γ_F and γ_E	DC4[1]	DC3[1]	DC4[1]
	Ground properties	γ_M	M1[2]	M3[2]	Not factored
	Passive earth resistance	γ_{Re}	Not factored		1,4
Basal heave	See Clause 5				

[1]Values of the partial factors for Design Cases (DCs) 3 and 4 are given in EN 1990 Annex A.
[2]Values of the partial factors for Sets M1 and M3 are given in EN 1997-1 Annex A.

Partial factors on actions and effects from prEN 1990:2020

Action or effect				Partial factors γ_F and γ_E for Design Cases 1 to 4				
Type	Group	Symbol	Resulting effect	Structural resistance	Static equilibrium and uplift		Geotechnical design	
Design case				DC1[a]	DC2(a)[b]	DC2(b)[b]	DC3[c]	DC4[d]
Formula				(8.4)	(8.4)		(8.4)	(8.5)
Permanent action (G_k)	All[f]	γ_G	unfavourable /destabilizing	$1{,}35k_F$	$1{,}35k_F$	1,0	1,0	G_k is not factored
	Water	γ_{Gw}		$1{,}2k_F$	$1{,}2k_F$	1,0	1,0	
	All[f]	$\gamma_{G,stb}$	stabilizing[g]	not used	1,15 [e]	1,0	not used	
	Water[l]	$\gamma_{Gw,stb}$			1,0 [e]	1,0		
	All	$\gamma_{G,fav}$	favourable[h]	1,0	1,0	1,0	1,0	
Prestress-ing (P_k)		γ_P [k]						
Variable action (Q_k)	All[f]	γ_Q	unfavourable	$1{,}5k_F$	$1{,}5k_F$	$1{,}5k_F$	1,3	$\frac{\gamma_{Q,1}}{\gamma_{G,1}}$ [j]
	Water[l]	γ_{Qw}		$1{,}35k_F$	$1{,}35k_F$	$1{,}35k_F$	1,15	1,0
	All	$\gamma_{Q,fav}$	favourable	0				
Effects of actions (E)		γ_E	unfavourable	effects are not factored				$1{,}35k_F$
		$\gamma_{E,fav}$	favourable					1,0

Partial factors for overall stability (prEN 1997-3: 2019)

Partial factor on	Symbol	Material factor approach (MFA)	Resistance factor approach (RFA)
Actions (except from water)	γ_G γ_Q	1.0 1.3	Not allowed
Water actions	γ_{Gw} γ_{Qw}	1.0 1.15	
Ground properties	$\gamma_{\tan\varphi}$ γ_{cu}	1.25 K_M 1.4 K_M	
CV and residual friction	$\gamma_{\tan\varphi,cv}$ $\gamma_{\tan\varphi,res}$	1.1 K_M 1.1 K_M	
Earth resistance	γ_R	(Not factored)	
Effects of actions	γ_E	(Not factored)	

Partial factors for rotational stability of retaining structures (prEN 1997-3: 2019)

Partial factor on	Symbol	Material factor approach (MFA)		Resistance factor approach (RFA)
		(a)	(b)	
Actions (except from water)	γ_G γ_Q	(Not factored) 1.11	1.0 1.3	(Not factored) 1.11
Water actions	γ_{Gw} γ_{Qw}	(Not factored) 1.0	1.0 1.15	(Not factored) 1.0
Ground properties	$\gamma_{\tan\varphi}$ γ_{cu}	1.25 1.4	1.25 K_M 1.4 K_M	(Not factored)
Passive earth pressure	γ_{Re}	(Not factored)		1.4
Effects of actions	γ_E	1.35 K_F		1.35 K_F

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Summary of key points

Verification of limit states for retaining structures

Summary of key points

Ultimate limit states for retaining structures

- EN 1997-1:2004 requires verification of GEO/STR limit state, applied to:
  - Overall stability
  - Rotational stability of embedded walls
  - Stability of excavations (basal heave)
  - Structural failure
  - Load-effects in props, struts, and anchors
- Design Approach is a national choice

Serviceability limit states for retaining structures

- Limiting deformations are project specific
- Comparable experience is paramount

2nd generation Eurocode 7 will:

- Simplify the choice of Design Approach (DAs 1/2/3 become MFA or RFA)

Questions and answers

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Good practice in retaining wall design

www.geocentrix.co.uk

References

- Andrew Bond and Andrew Harris (2008), *Decoding Eurocode 7*, Taylor & Francis
- Bond A.J. (2013). *Implementation and evolution of Eurocode 7,* in 'Modern Geotechnical Design Codes of Practice', IOS Press, Amsterdam, pp3-14.
- EN 1997-1:2004, *Eurocode 7 – Geotechnical design: Part 1 – General rules*, European Committee for Standardization
- EN 1997-2:2007, *Eurocode 7 – Geotechnical design: Part 2 – Ground investigation and testing*, European Committee for Standardization
- prEN 1990:2020, *Basis of structural and geotechnical design*, CEN TC250
- prEN 1997-1:2019, *Eurocode 7 – Geotechnical design: Part 1 – General rules*, CEN TC250/SC7
- prEN 1997-3:2020, *Eurocode 7 – Geotechnical design: Part 3 – Geotechnical structures*, CEN TC250/SC7

Agenda 15:30 -16:00

Question and answer session

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Thank you for your attention!

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