Codes of practice for embedded retaining wall design

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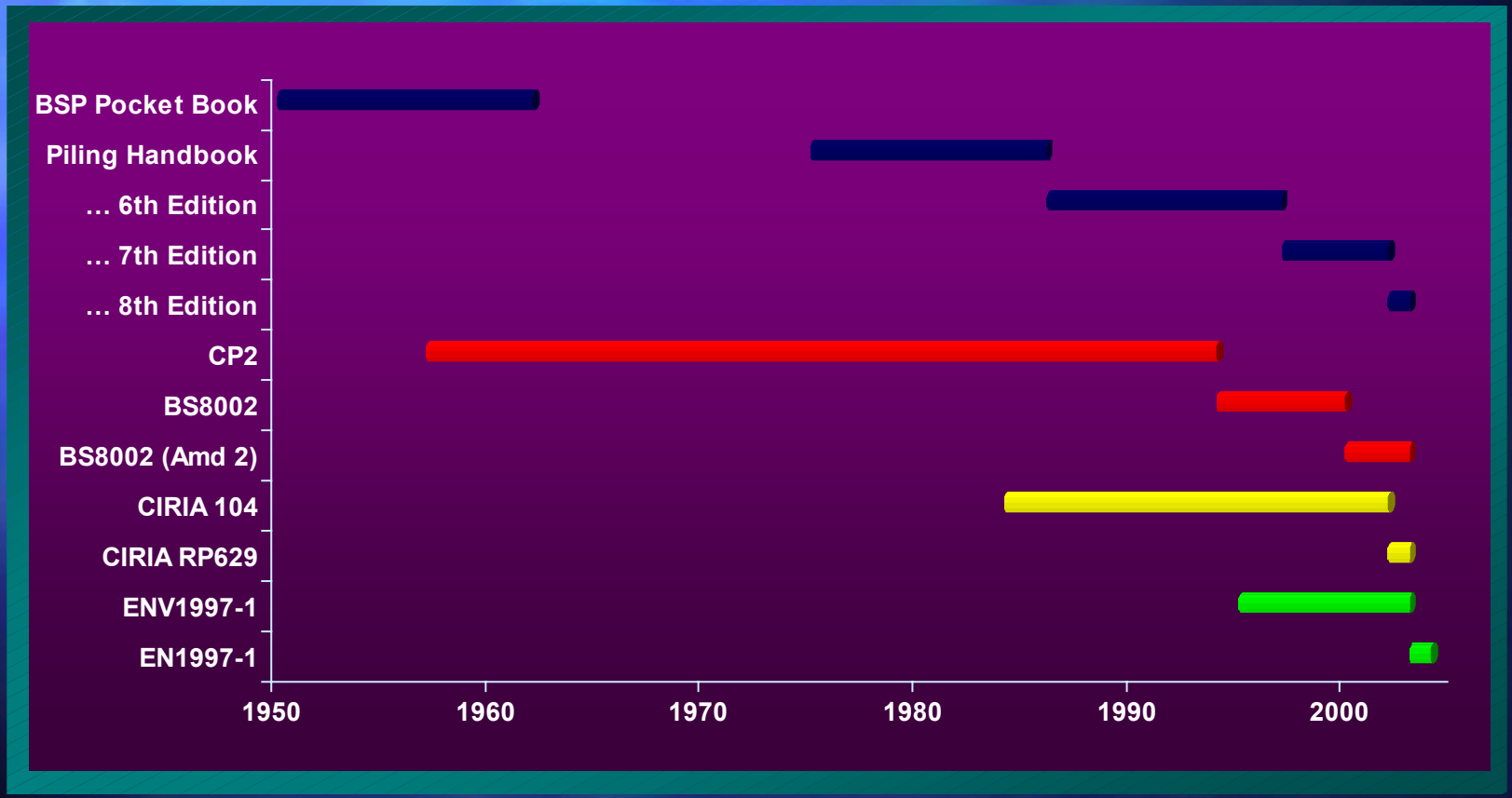
Outline of lecture

- Timeline for retaining wall codes
- Codes of practice in the 20th Century
  - Factors of safety
  - Complications
- Codes of practice for the 21st Century
  - BS8002
  - CIRIA RP629
  - Eurocode 7
- Conclusions

Timeline for retaining wall codes



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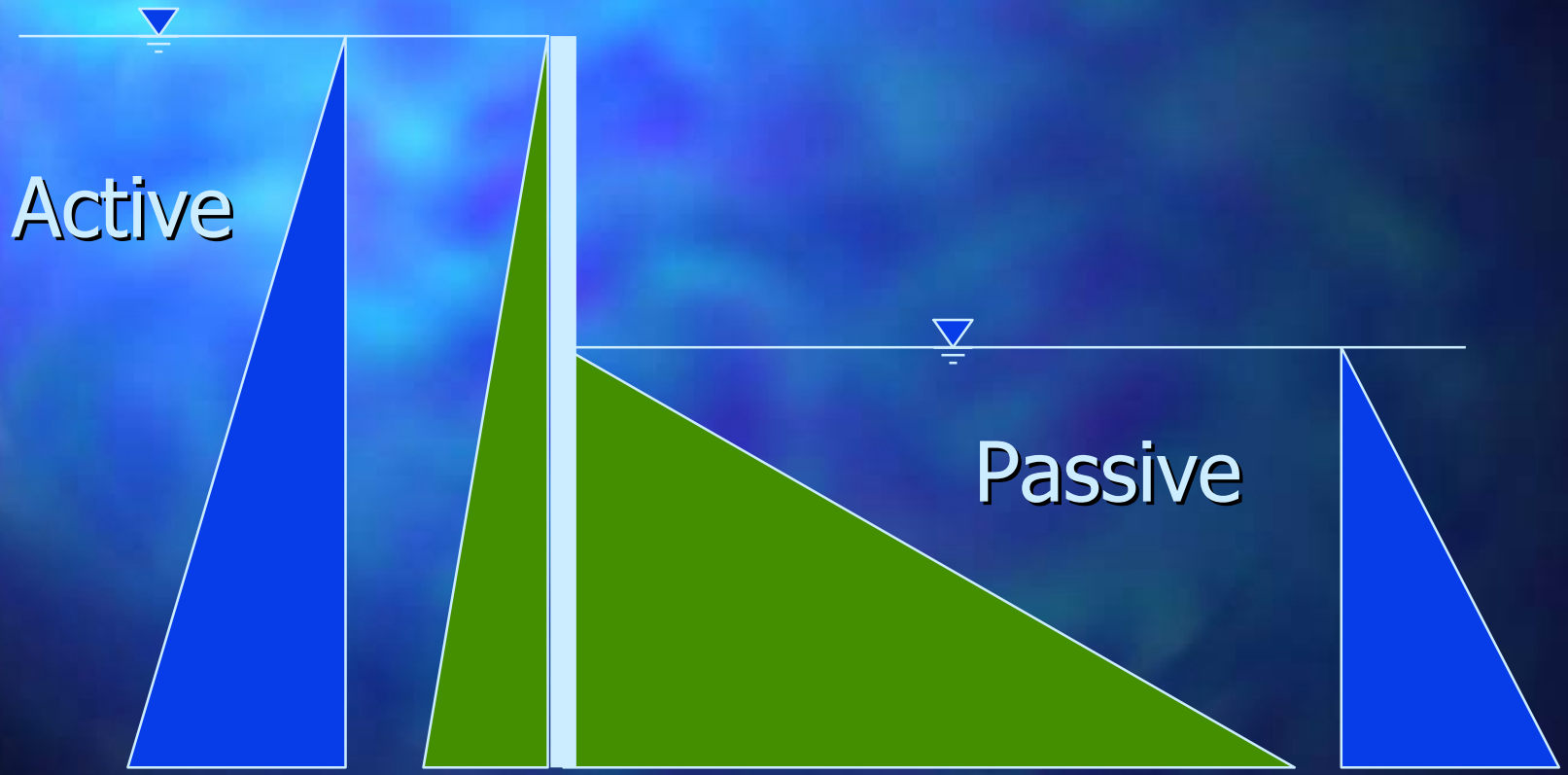
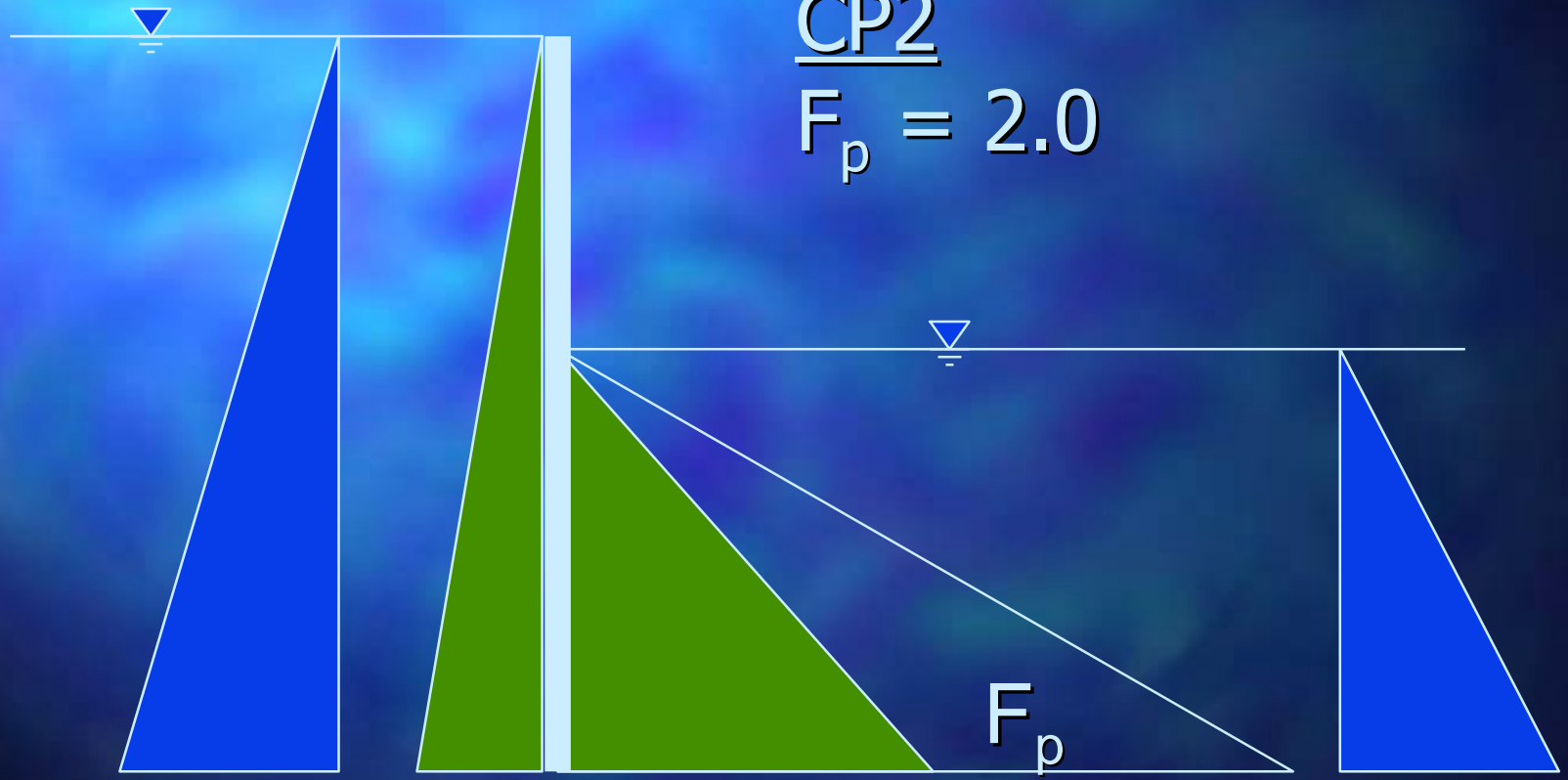
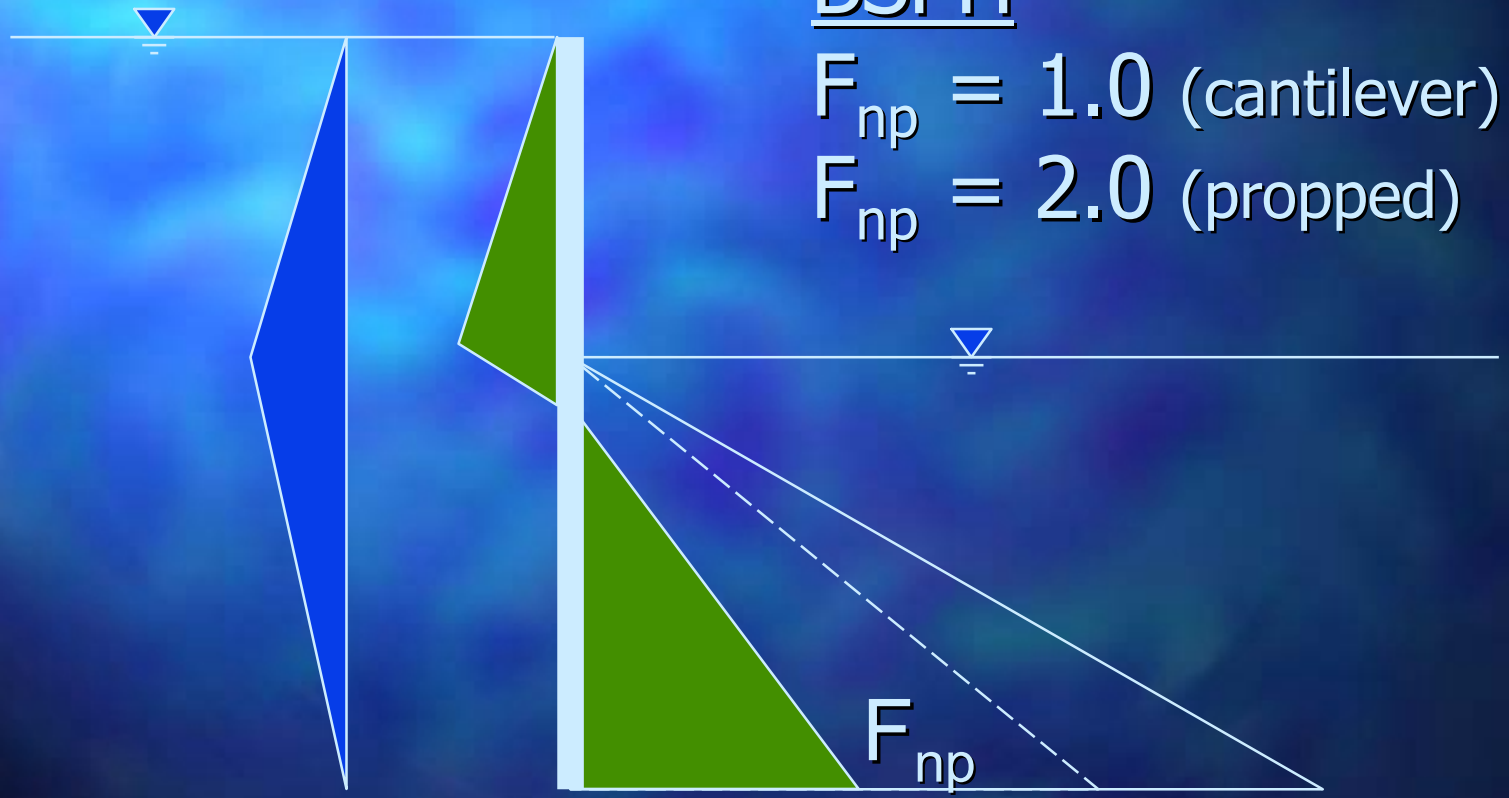
Limit equilibrium earth pressures



Gross pressure method



Nett pressure method



BSPH

$F_{np} = 1.0$ (cantilever)

$F_{np} = 2.0$ (propped)

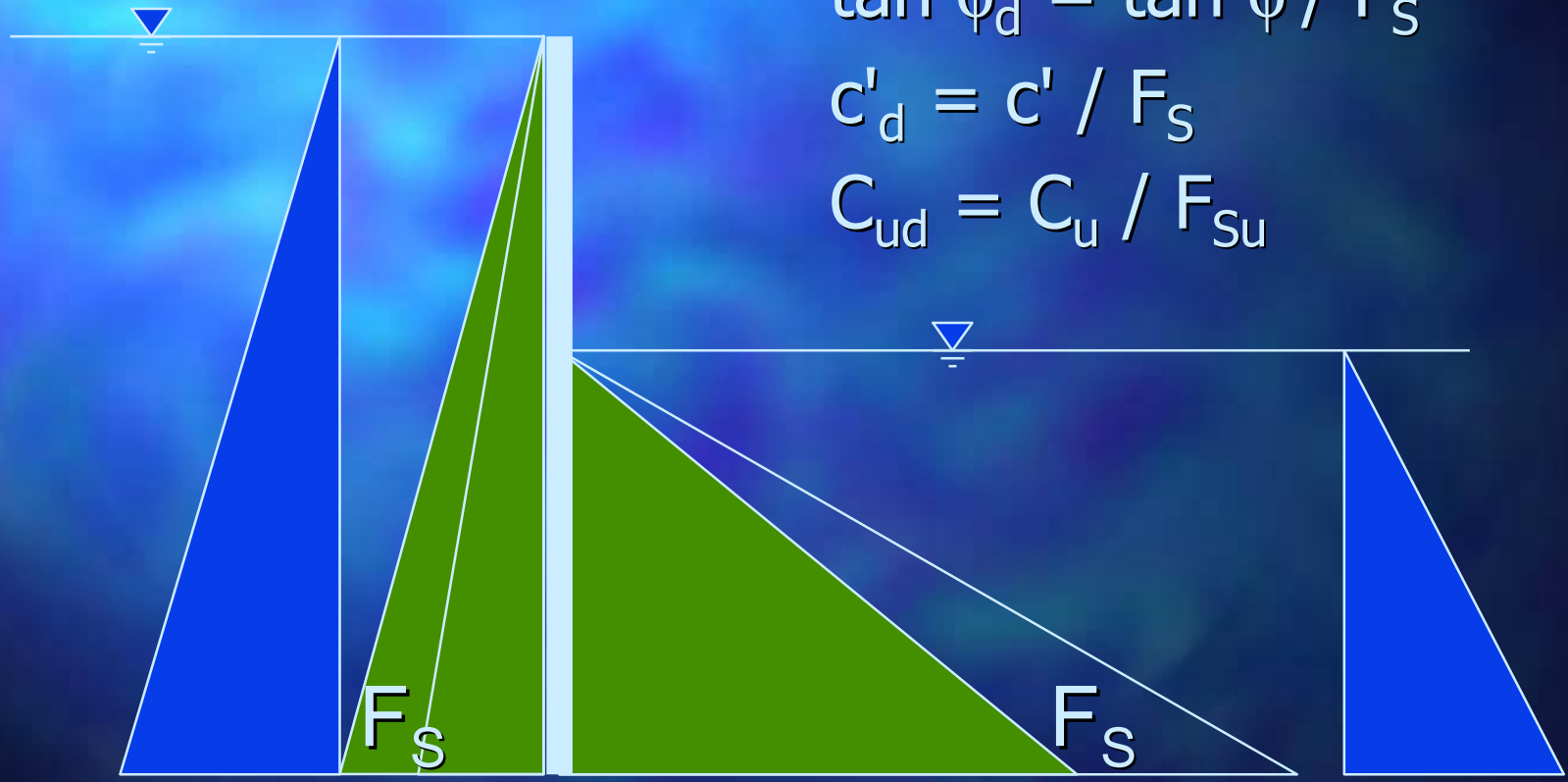
Factor on strength

CIRIA 104:

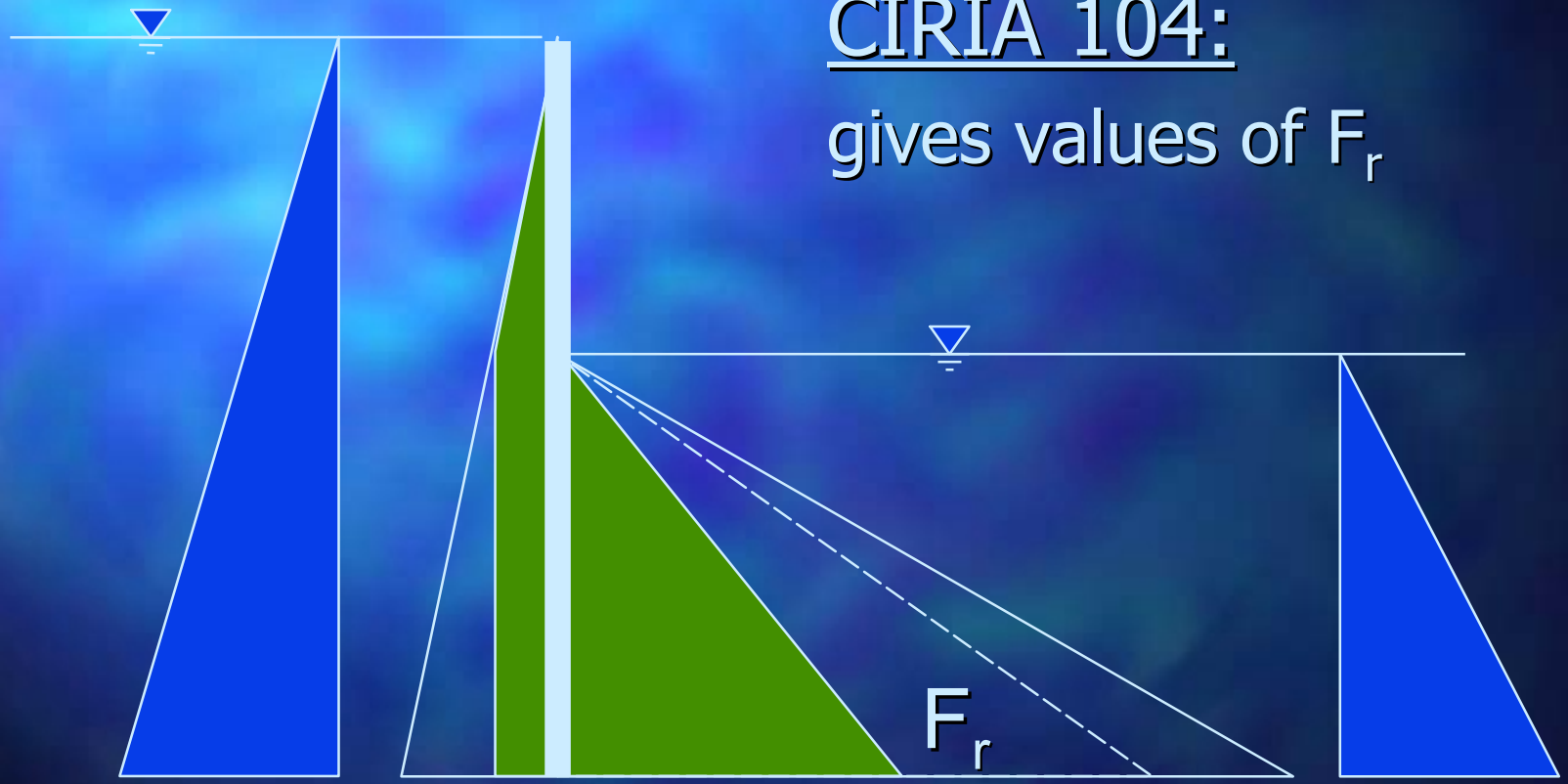
$\tan \phi_d = \tan \phi / F_S$

$c'_d = c' / F_S$

$C_{ud} = C_u / F_{Su}$



Revised (Burland-Potts) method

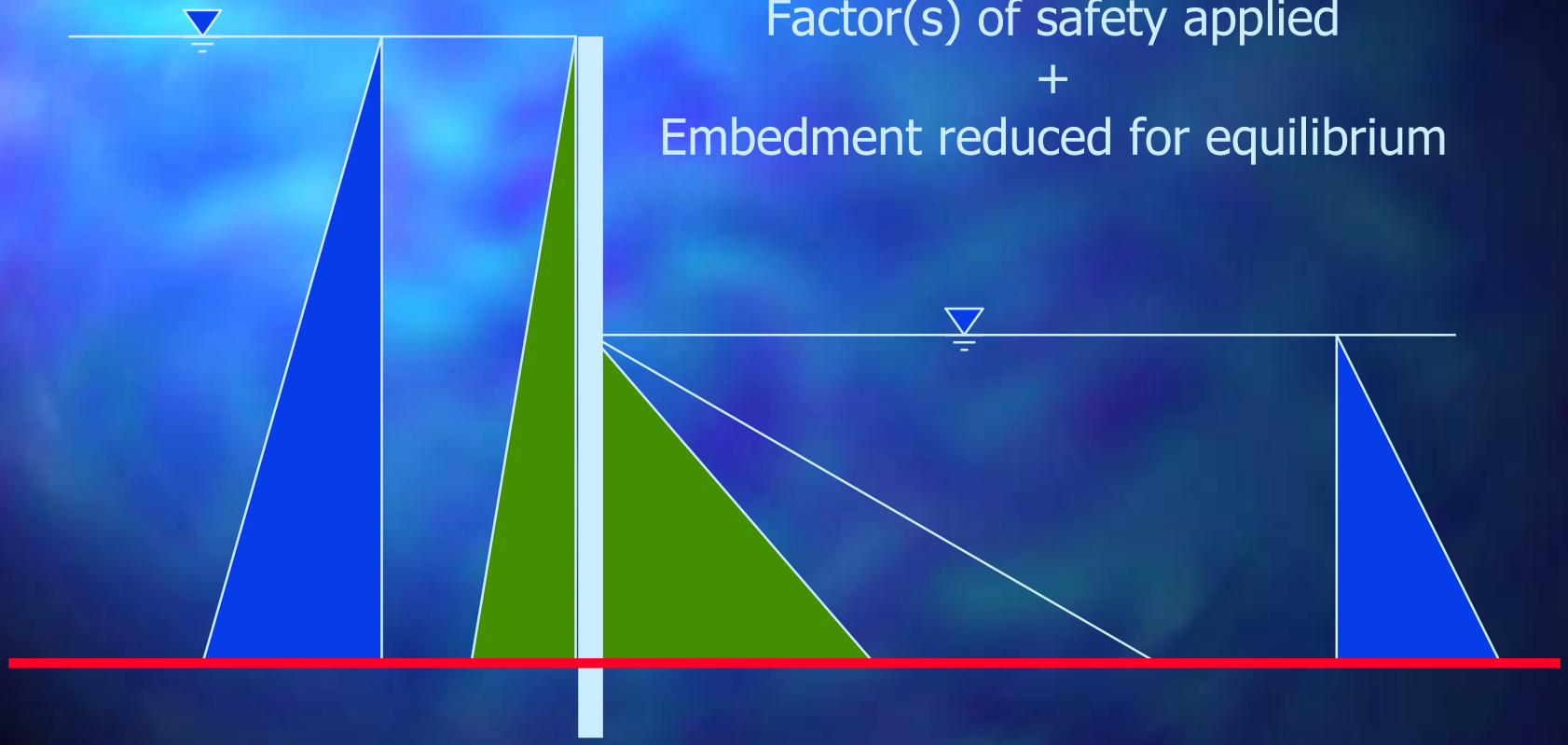


CIRIA 104:

gives values of F_r

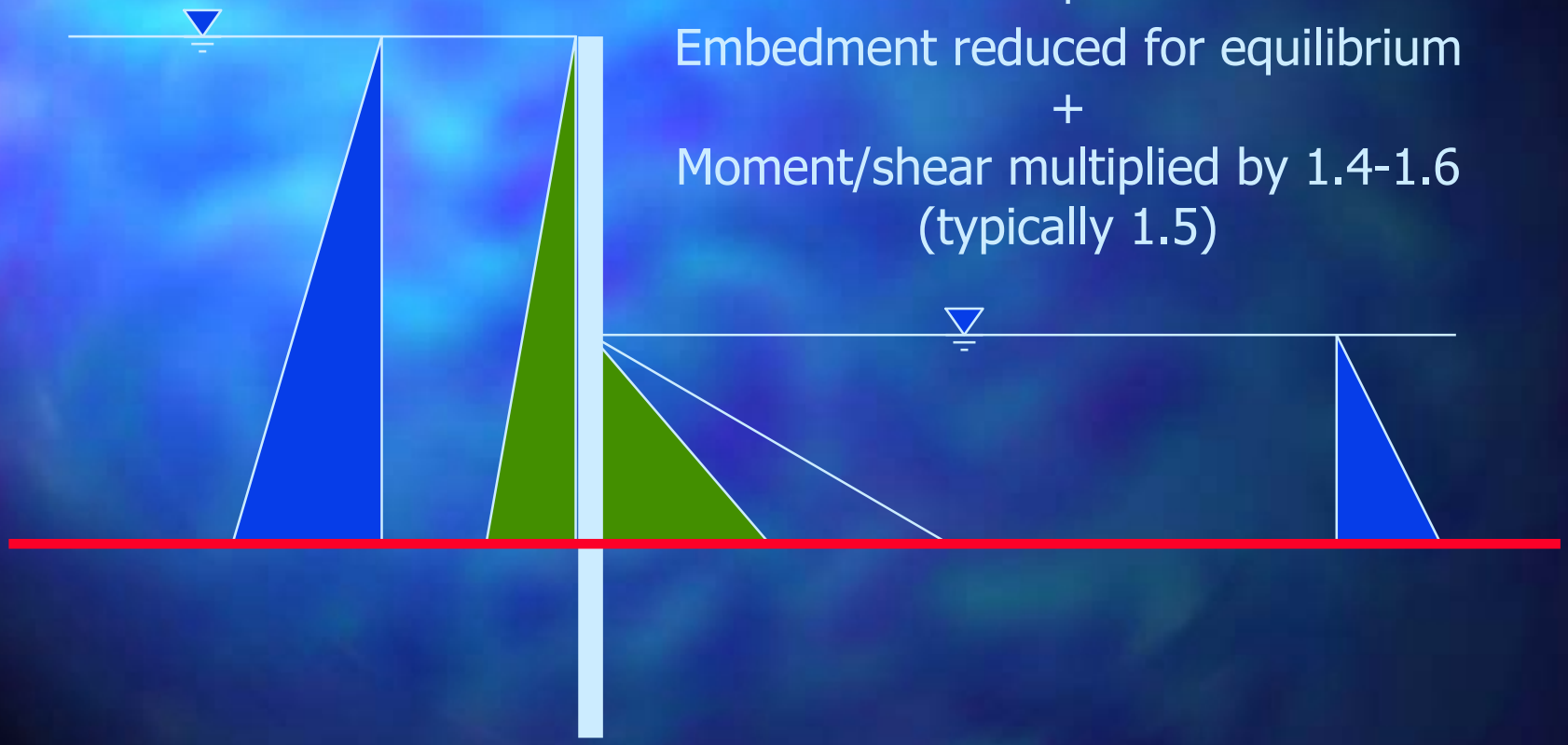
Structural forces - Method 1

Factor(s) of safety applied
+
Embedment reduced for equilibrium

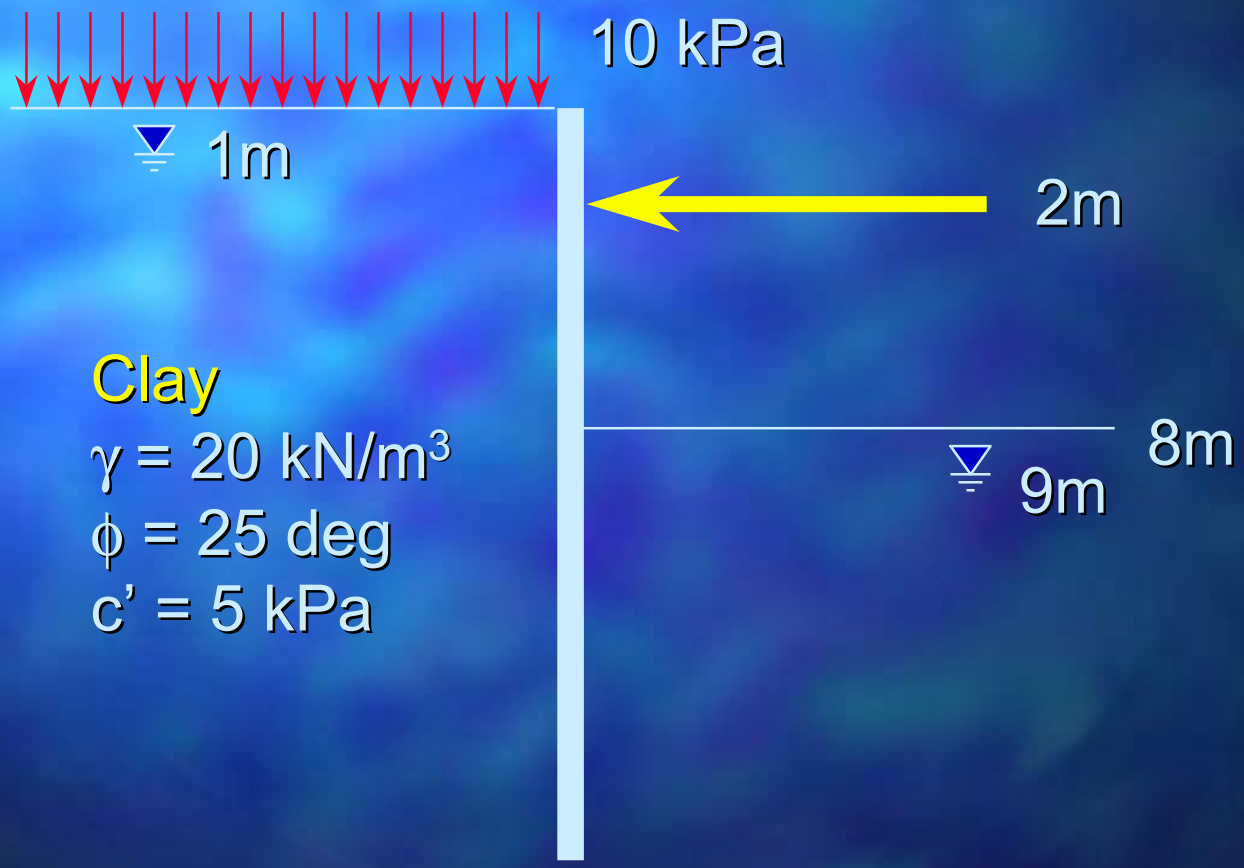


Structural forces - Method 2

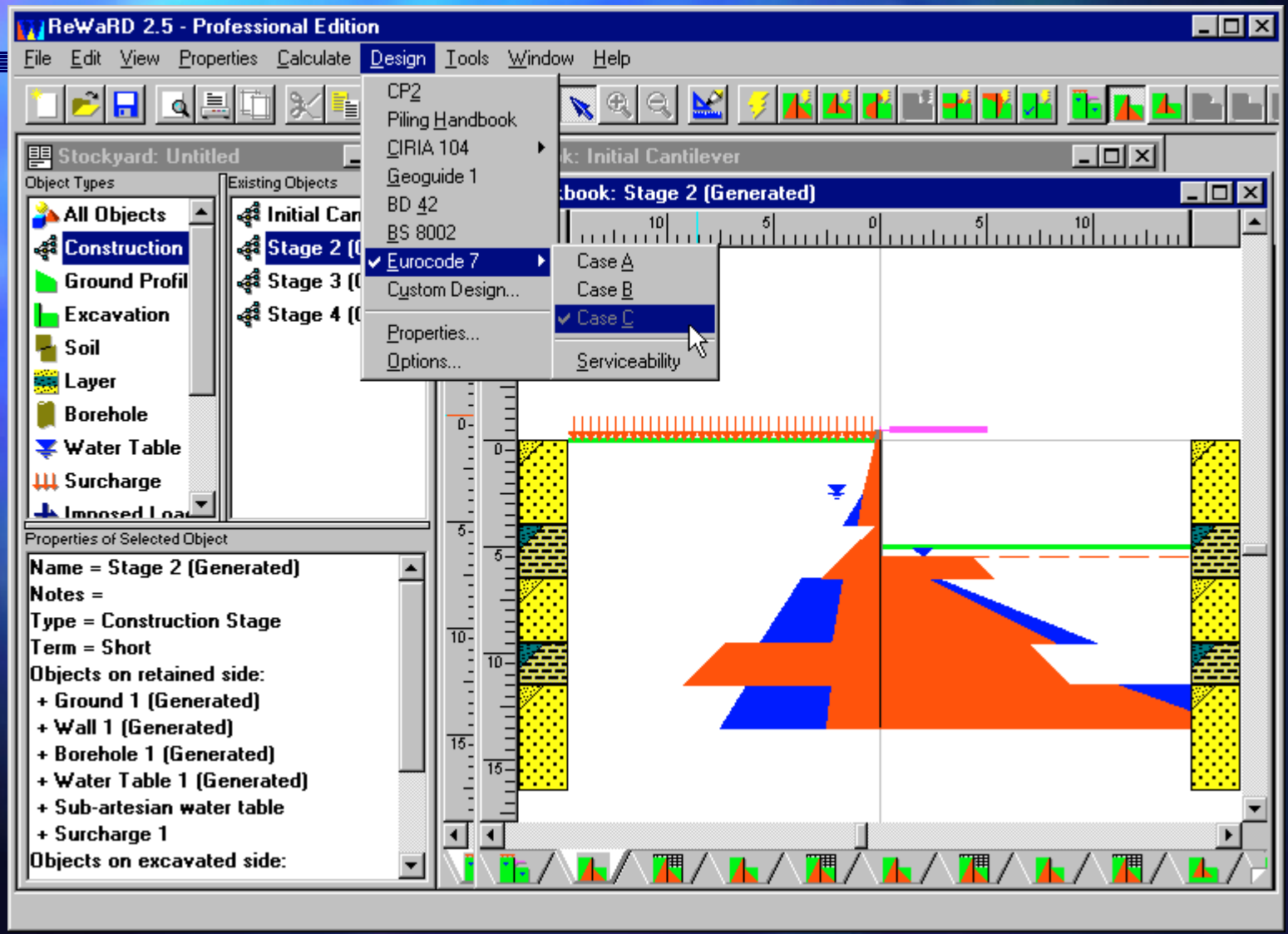
Factor(s) of safety *not* applied
+
Embedment reduced for equilibrium
+
Moment/shear multiplied by 1.4-1.6
(typically 1.5)



Example C3 from CIRIA 104



Dedicated software makes this easy

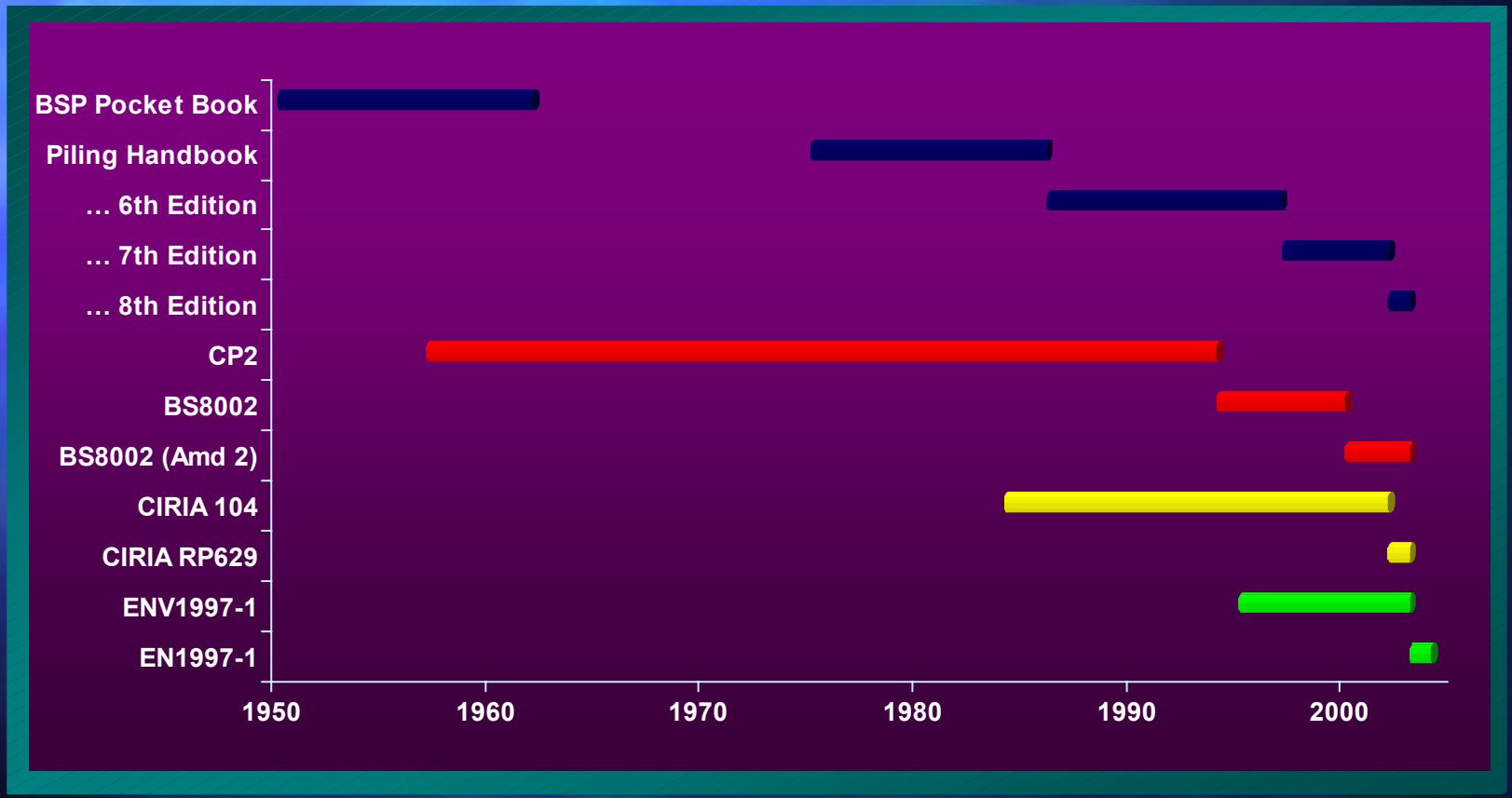


Results for Example C3

Design standard		Embedment (m)	Bending (kNm/m)	Shear (kN/m)
CP2	F_p	19.8	823	285
BSPH	F_{np}	14.6	727	263
CIRIA 104	F_r	16.5	695*	253*
CIRIA 104	F_s	17.8	695*	253*

*after multiplication by 1.5

Timeline for retaining wall codes



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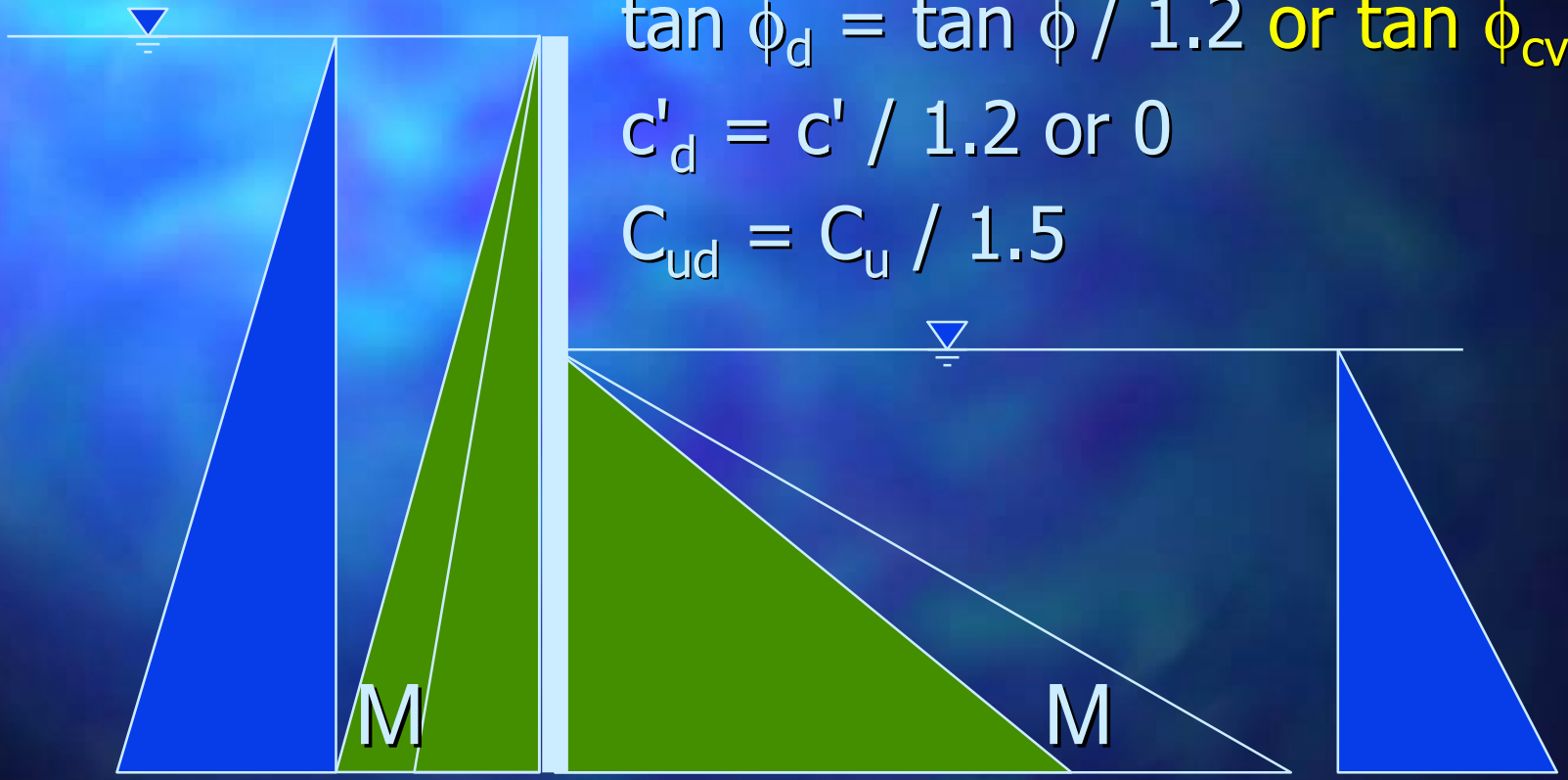
BS8002's "mobilization factor"

BS8002:

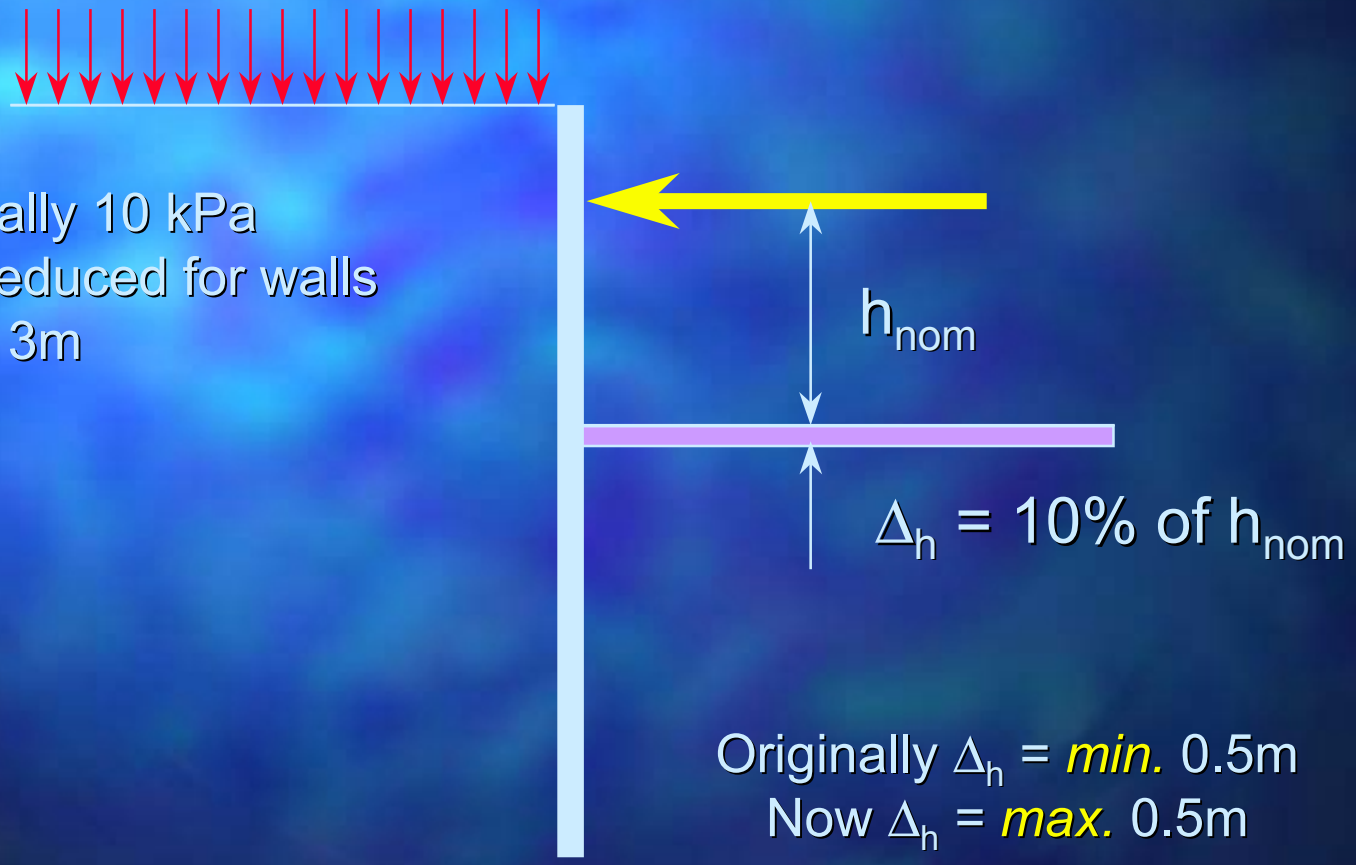
$\tan \phi_d = \tan \phi / 1.2$ or $\tan \phi_{cv}$

$c'_d = c' / 1.2$ or 0

$C_{ud} = C_u / 1.5$



BS8002's minimum surcharge and unplanned excavation



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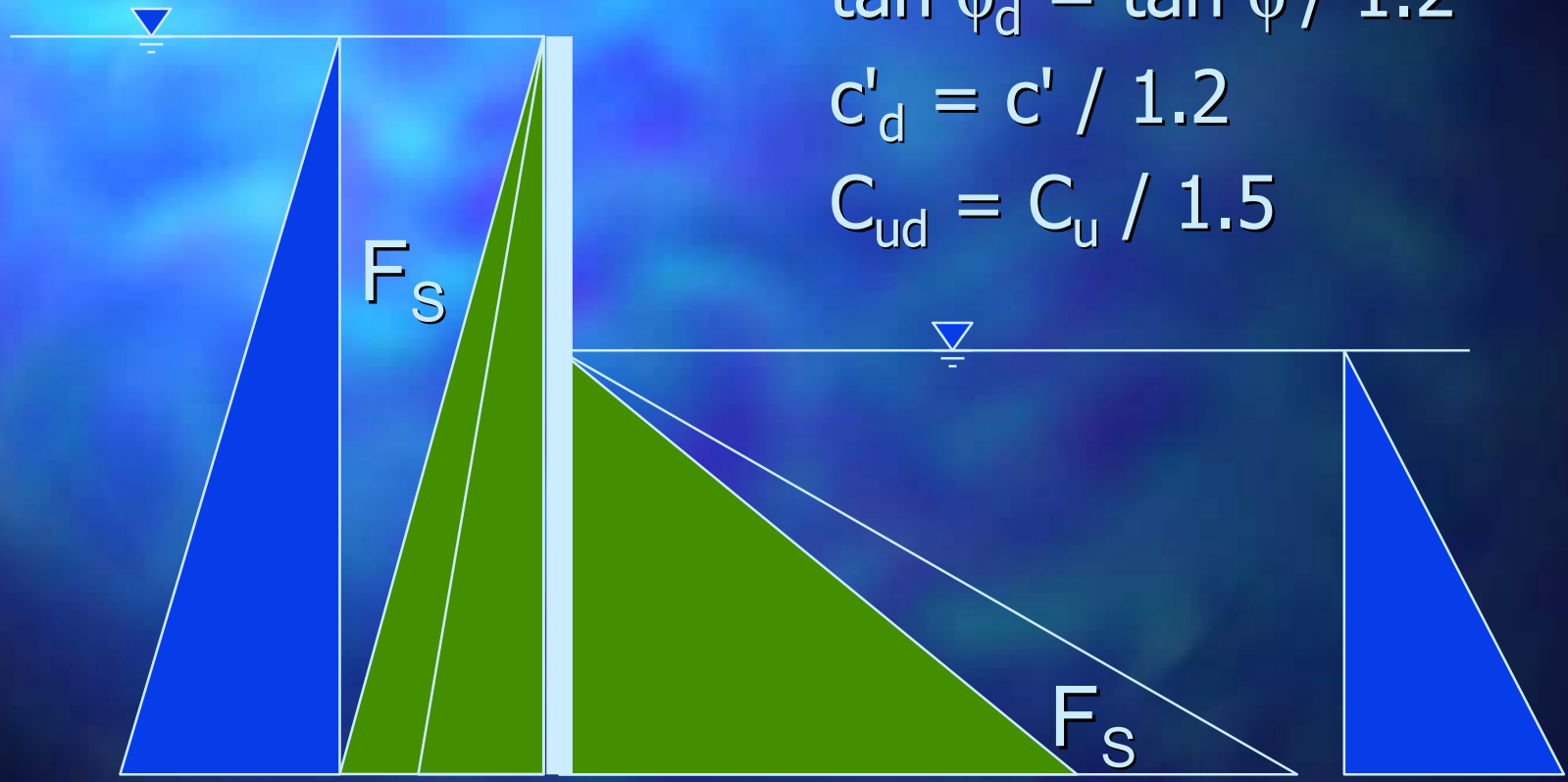
Factor on strength

CIRIA RP629:

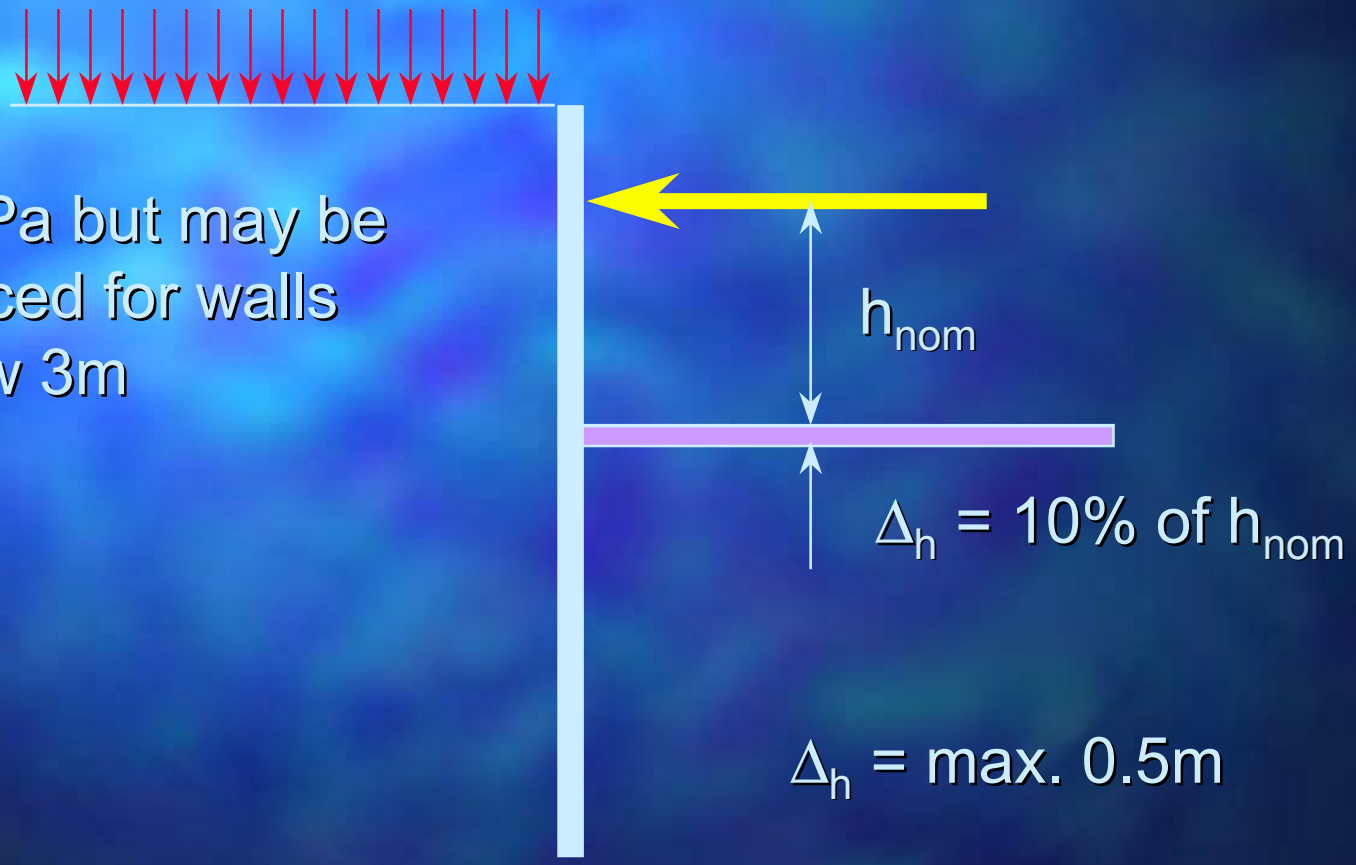
$\tan \phi_d = \tan \phi / 1.2$

$c'_d = c' / 1.2$

$C_{ud} = C_u / 1.5$



CIRIA RP629's minimum surcharge and unplanned excavation



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Structural Eurocode programme

- Basis of design
- Eurocode 1 - Actions on structures
- Eurocode 2 - Design of concrete structures
- Eurocode 3 - Design of steel structures
- Eurocode 4 - Design of composite steel and concrete structures
- Eurocode 5 - Design of timber structures
- Eurocode 6 - Design of masonry structures
- Eurocode 7 - Geotechnical design
- Eurocode 8 - Design of structures for earthquake resistance
- Eurocode 9 - Design of aluminium structures

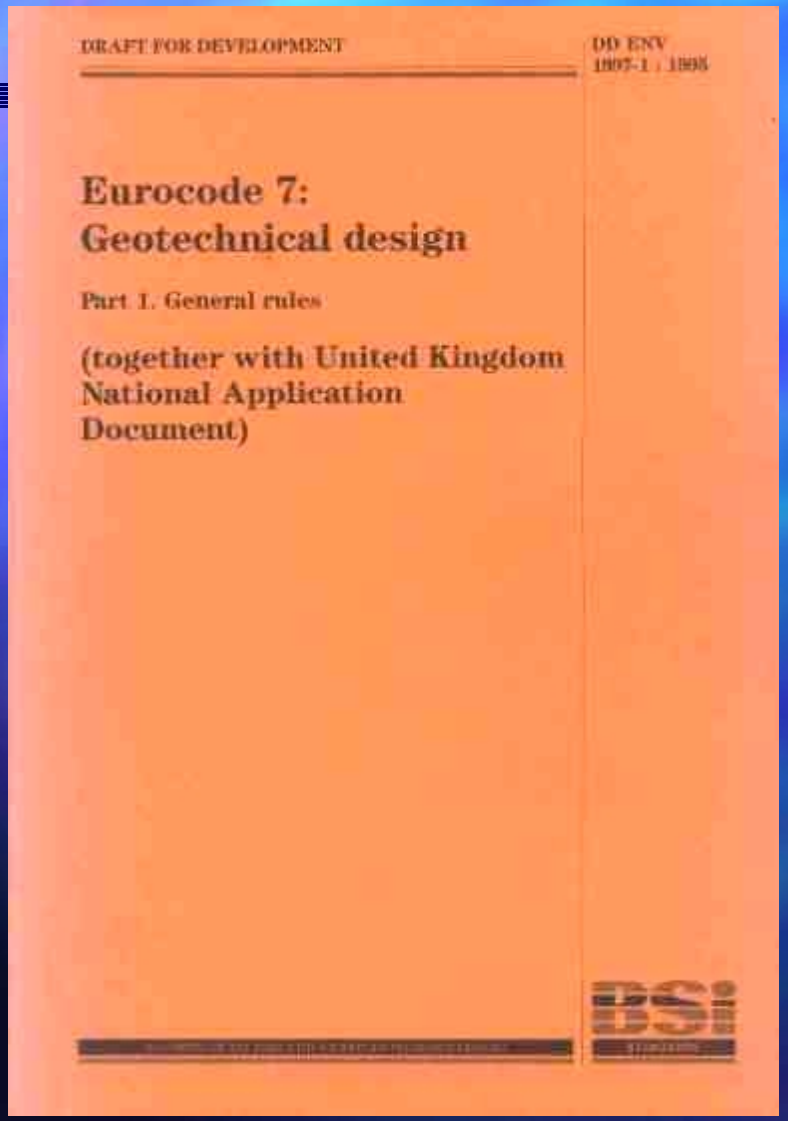
Relevance of Eurocode 3 Part 5 to steel sheet piles

- Provides advice on durability
- Allows for plastic design
- Good summary of various ground models:
  - Limit earth pressures
  - Subgrade reaction
  - Fully numerical (finite element)

Eurocode 7: Geotechnical design

- Part 1: General rules
  - ENV issued 1995
  - EN expected 2003?
- Part 2: Design assisted by laboratory testing
  - ENV issued April 1999
- Part 3: Design assisted by field testing
  - ENV issued July 1999

ENV1997-1:1995

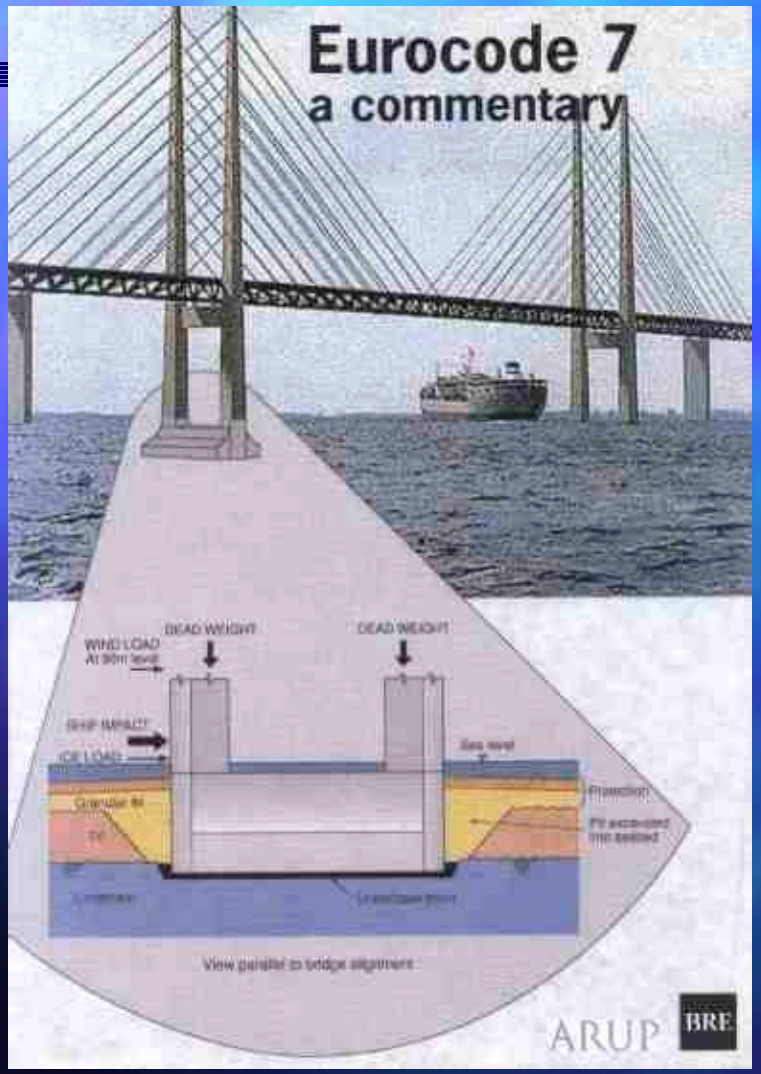


1: General
2: Basis of geotechnical design
3: Geotechnical data
4: Supervision of construction, monitoring, and maintenance
5: Fill, dewatering, ground improvement, and reinforcement
6: Spread foundations
7: Pile foundations
8: Retaining structures
9: Embankments
Annexes

It's English, Jim…
but not as we know it

A.N. Beal
Thomason Partnership

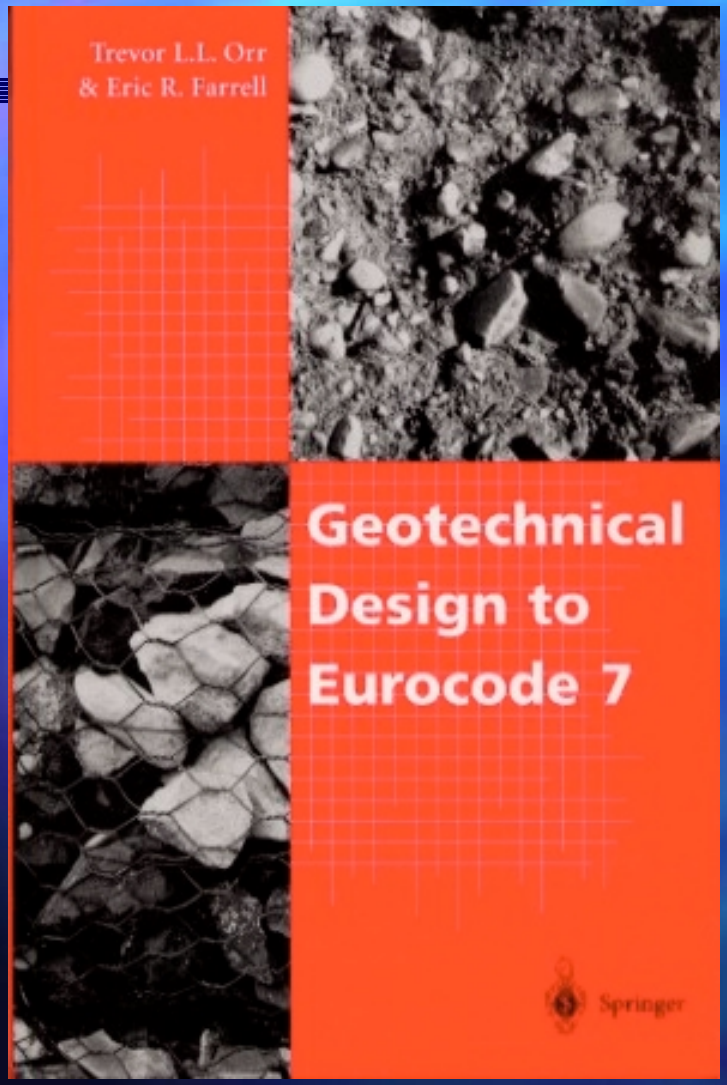
Eurocode 7 - a commentary



A. Fundamentals
B. Important features of Eurocode 7 Part 1
C. Clause-by-clause commentary
D. The way ahead
E. Worked examples

Written by:
Dr Brian Simpson (Arups) &
Richard Driscoll (BRE)

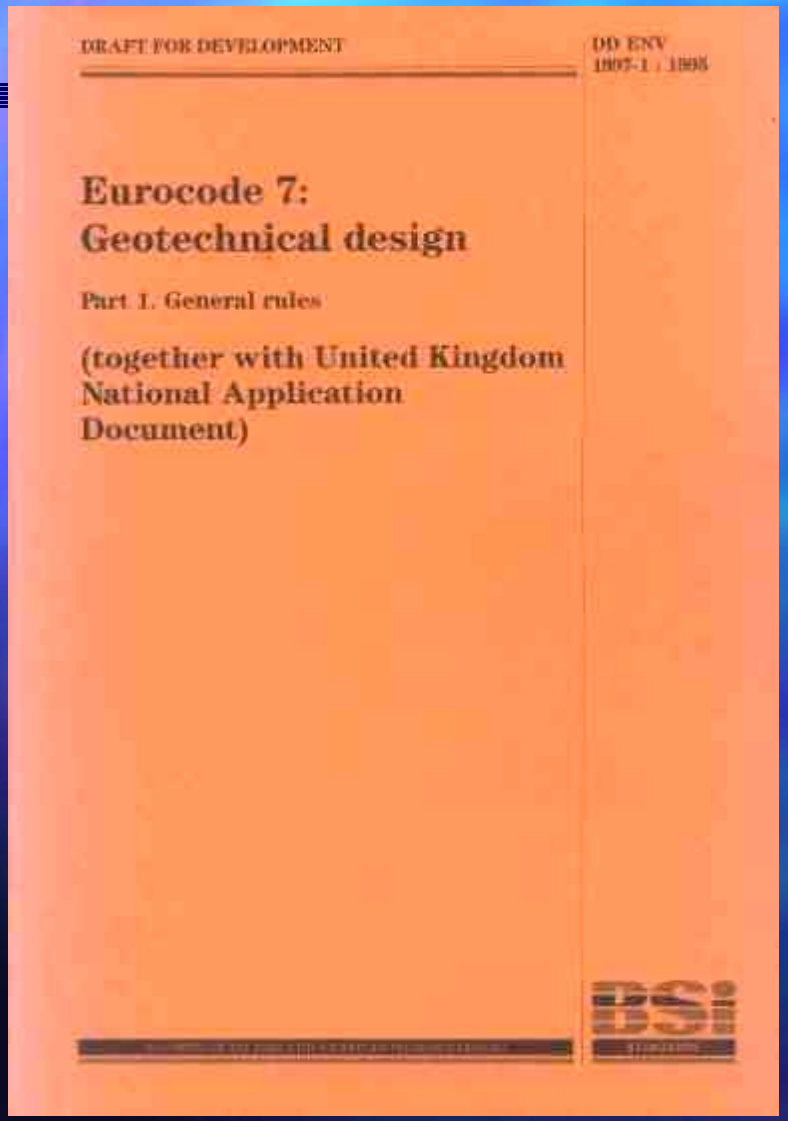
Geotechnical design to Eurocode 7



1: Introduction
2: Basis of geotechnical design
3: Geotechnical investigations and geotechnical data
4: Supervision of construction, monitoring, and maintenance
5: Fill, dewatering, ground improvement, and reinforcement
6: Spread foundations
7: Pile foundations
8: Retaining structures
9: Embankments and slopes

Written by Drs Trevor Orr and Eric Farrell (Trinity College, Dublin)

EN1997-1:200x



1: General
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3: Geotechnical data
4: Supervision of construction, monitoring, and maintenance
5: Fill, dewatering, ground improvement, and reinforcement
6: Spread foundations
7: Pile foundations
8: Anchorages
9: Retaining structures
10: Hydraulic failure
11: Overall stability
12: Embankments
Annexes

Authority for European standards

- European Commission
  - Council Directive 89/106/EEC on construction projects
  - Council Directives 71/305/EEC & 89/440/EEC on public works
- European Free Trade Association
- European Committee for Standardization (CEN)
  - Technical Committee CEN/TC250 Structural Eurocodes
  - Standing Committee SC7 Geotechnical design

EN 1990 Foreword

Legal status of the Eurocodes

- The Structural Eurocodes shall be given the status of a national standard…
  - either by publication of an identical text
  - or by endorsement
- Conflicting national standards shall be withdrawn

EN 1990 Foreword

Key features of Eurocode 7

- Limit state concept
  - in conjunction with a partial factor method
- Principles and application rules
- Characteristic material properties
- 3 design approaches
  - Compromise between UK/Denmark, France, & Germany

EN 1990 Foreword

Principles & application rules - 1

- Principles
  - General statements and definitions for which there is no alternative
  - Requirements and analytical models for which no alternative is permitted unless specifically stated
  - Principles are identified by the letter P following the paragraph number

EN 1990 §1.4

Principles & application rules - 2

- Application rules
  - Generally recognized rules which follow the principles and satisfy their requirements
  - It is permissible to use alternative design rules from those given in EN 1990, provided they:
    - accord with the relevant principles
    - achieve at least equivalent resistance, serviceability, and durability as the Eurocodes

EN 1990 §1.4

Verification by the partial factor method: ultimate limit states

- (P) When designing construction works, the following limit states shall be verified:
  - EQU - loss of static equilibrium, in which the strength of construction materials or ground are not governing
  - STR - internal failure of the structure or structural elements, in which the strength of construction materials or excessive deformation of the structure governs
  - GEO - failure or excessive deformation of the ground, in which the strengths of soil or rock are significant
  - FAT - fatigue failure of the structure or structural elements

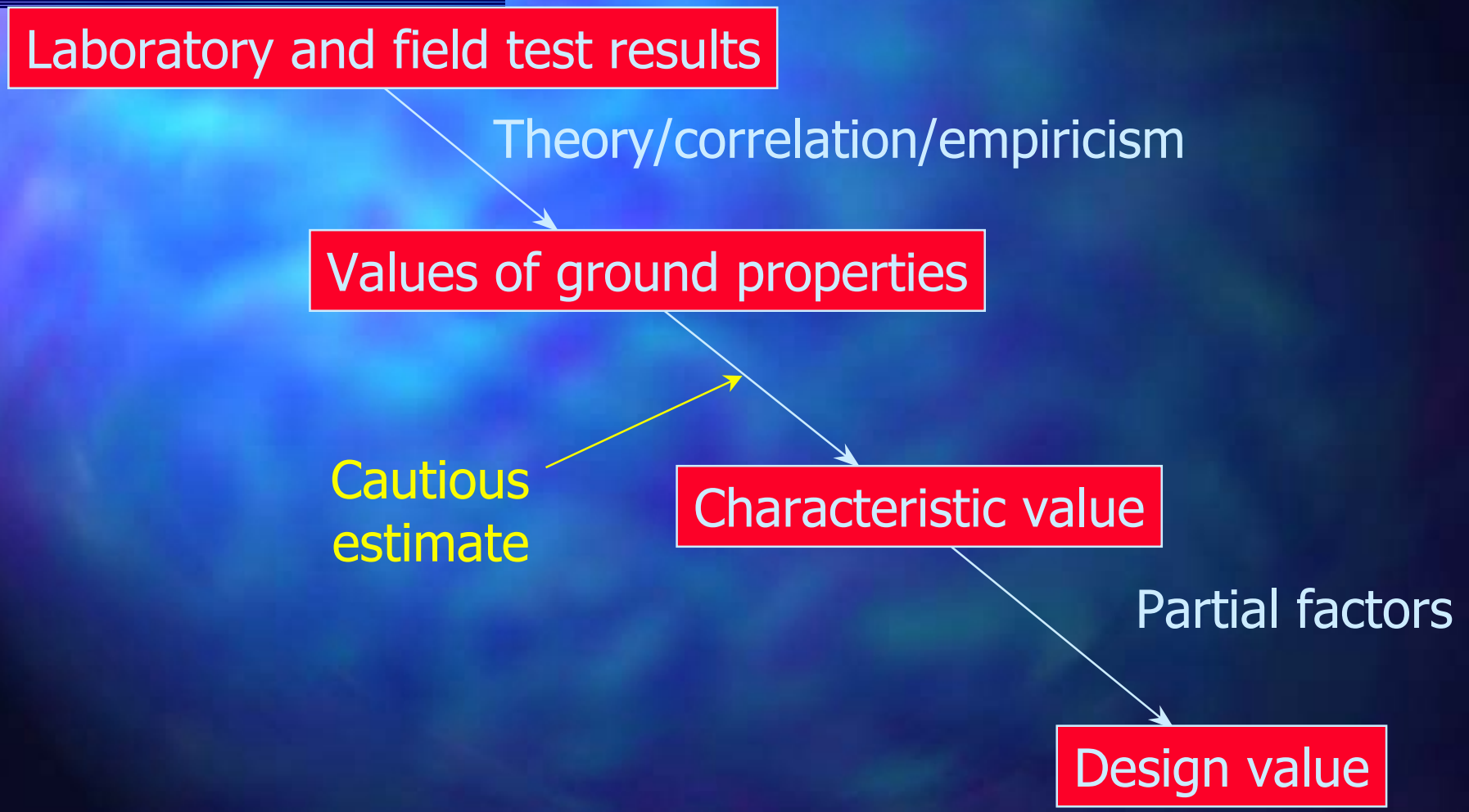
EN 1990 §6.4.1

Ground properties

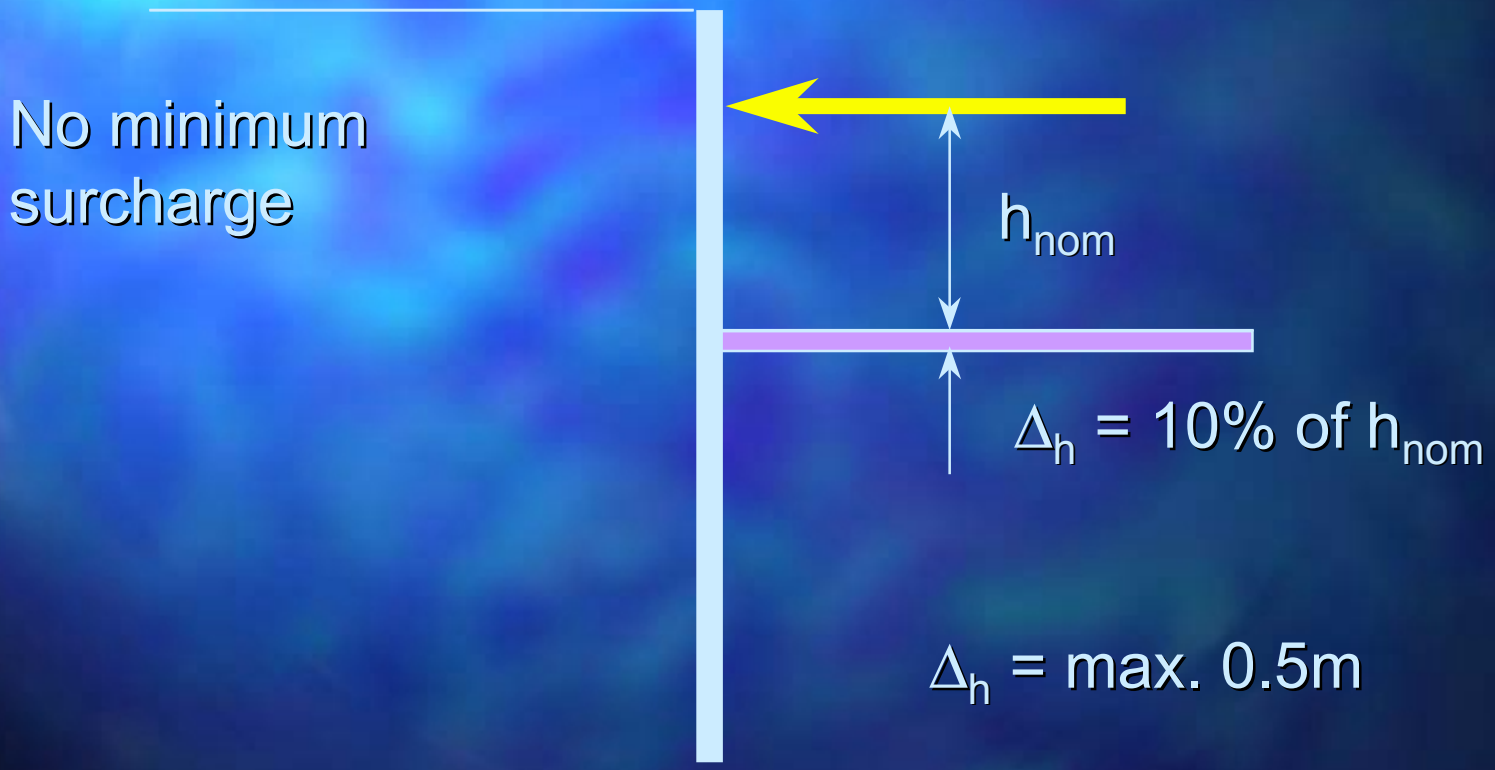
- (P) Values of ground properties shall be obtained from test results either directly or through correlation, theory, or empiricism
- (P) The characteristic value of a soil or rock parameter shall be selected as a cautious estimate of the value affecting the occurrence of the limit state

EN 1997-1 §2.4.4.2

From lab. & field to design...



Eurocode 7's unplanned excavation



Factors on actions (γ_F)/effects (γ_E)

Action		Symbol	EQU	STR/GEO	
				A1	A2
Permanent	Unfavourable	γ_G	1.1	1.35	1.0
	Favourable		0.9	1.0	1.0
Variable	Unfavourable	γ_Q	1.5	1.5	1.3
	Favourable		0	0	0

EN 1997-1 (Draft G, Feb 2001 + UK modification) A.1.1 & A.2.1

Partial material factors (γ_M)

Ground property	Symbol	EQU	STR/GEO	
			M1	M2
Shearing resistance	γ_ϕ	1.25	1.0	1.25
Effective cohesion	$\gamma_{c'}$	1.25	1.0	1.25
Undrained strength	γ_{cu}	1.4	1.0	1.4
Unconfined strength	γ_{qu}	1.4	1.0	1.4
Unit weight	γ_σ	1.0	1.0	1.0

EN 1997-1 (Draft G, Feb 2001 + UK modification) A.1.2 & A.2.2

Partial resistance factors (γ_R)

Resistance	Symbol	STR/GEO		
		R1	R2	R3
Bearing capacity	γ_{Rv}	1.0	1.0	1.4
Sliding resistance	γ_{Rh}	1.0	1.0	1.1
Earth resistance	γ_{Re}	1.0	1.0	1.4

EN 1997-1 (Draft G, Feb 2001 + UK modification) A.2.3.2.1

Design Approaches

- Design approach 1
  - Original method from ENV 1997-1
  - Load and material factor approach using two separate combinations of partial factors
- Design approach 2
  - Load and resistance factor approach
- Design approach 3
  - Load and material factor approach

EN 1997-1 Annex A

Design Approach 1

- Partial factors for STR and GEO limit states:
  - Combination 1: A1+M1+R1
    - $\gamma \geq 1.0$ on actions
  - Combination 2: A2+M2+R1
    - $\gamma \geq 1.0$ on ground properties
- But for piles and anchorages…
  - Combination 1: A1+M1+R1
    - $\gamma \geq 1.0$ on actions
  - Combination 2: A2+(M1 or M2)+R2
    - $\gamma \geq 1.0$ on resistances

EN 1997-1 Annex A

Design Approach 2

- Partial factors for STR and GEO limit states:
  - Combination 1: A1+M1+R3
    - $\gamma \geq 1.0$ on action effects and resistances
- But for slopes and overall stability…
  - Combination 1: A2+M2+R1 (same as DA1)
    - $\gamma \geq 1.0$ on actions and ground properties
  - Combination 2: (A1 or A2)+M2+R1
    - $\gamma \geq 1.0$ on ground properties

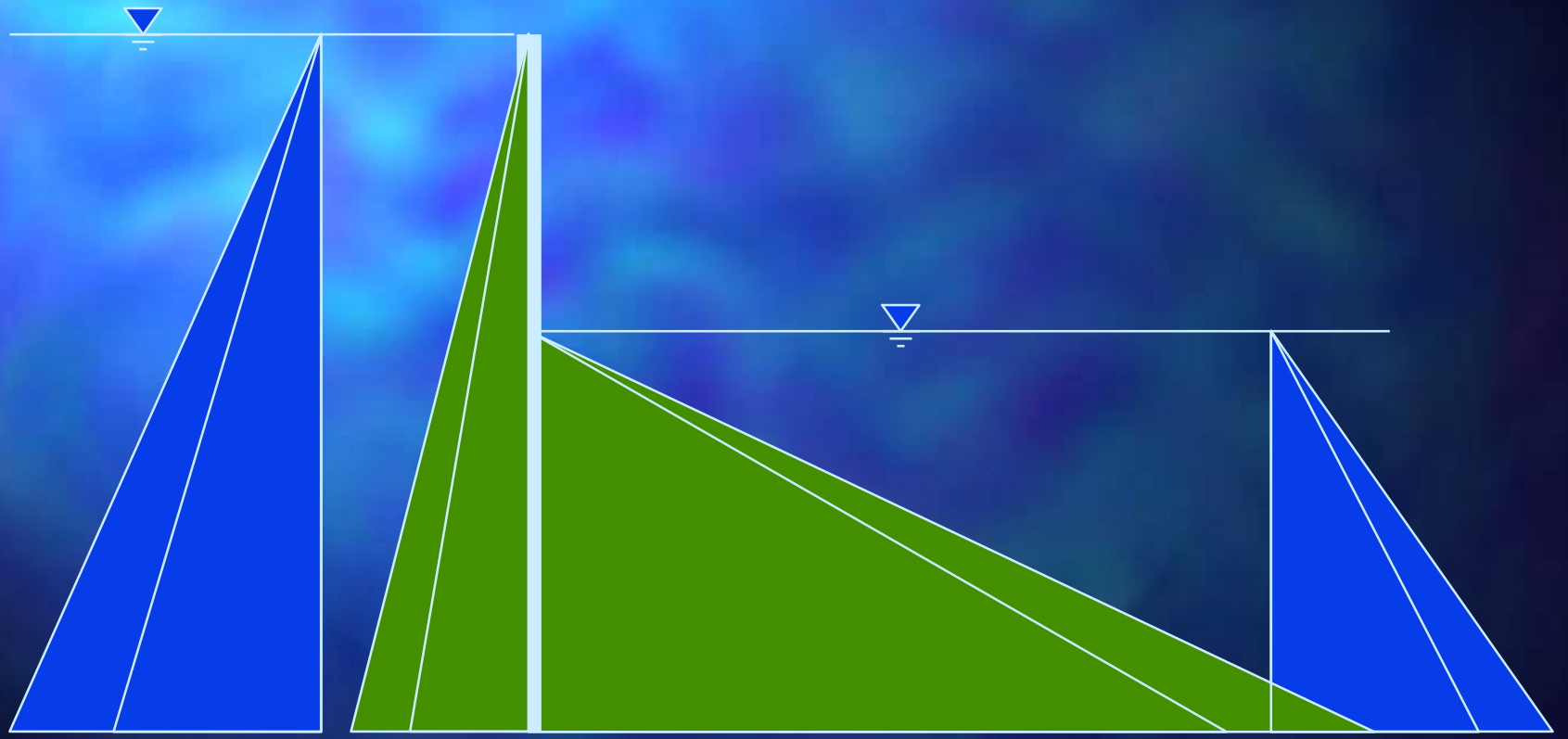
EN 1997-1 Annex A

Design Approach 3

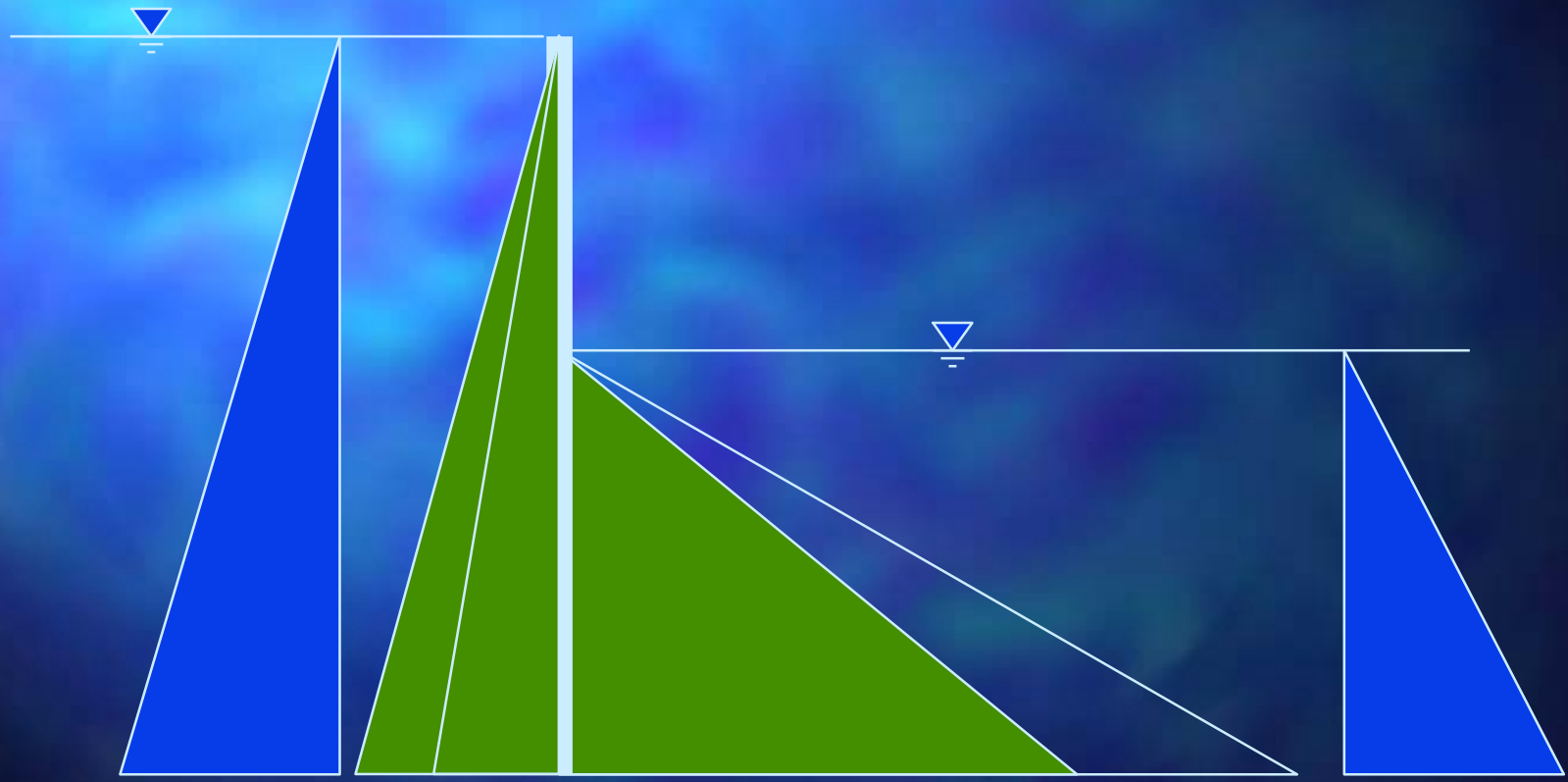
- Partial factors for STR and GEO limit states:
  - Combination 1: (A1 or A2)+M2+R1
    - $\gamma \geq 1.0$ on structural actions only (A1)
    - $\gamma \geq 1.0$ on ground properties

EN 1997-1 Annex A

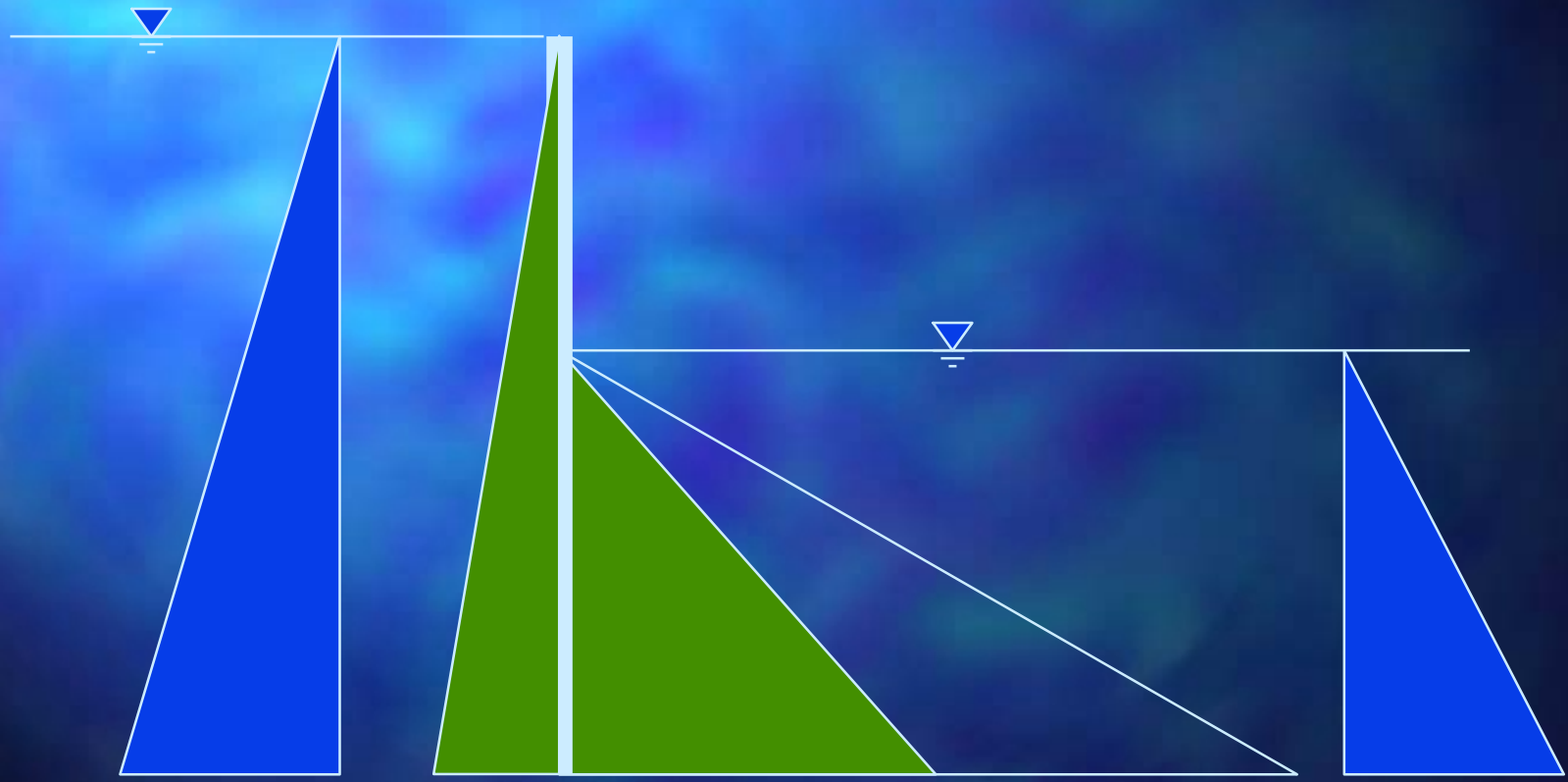
Partial factors on actions (Set A1)



Partial material factors (Set M2)

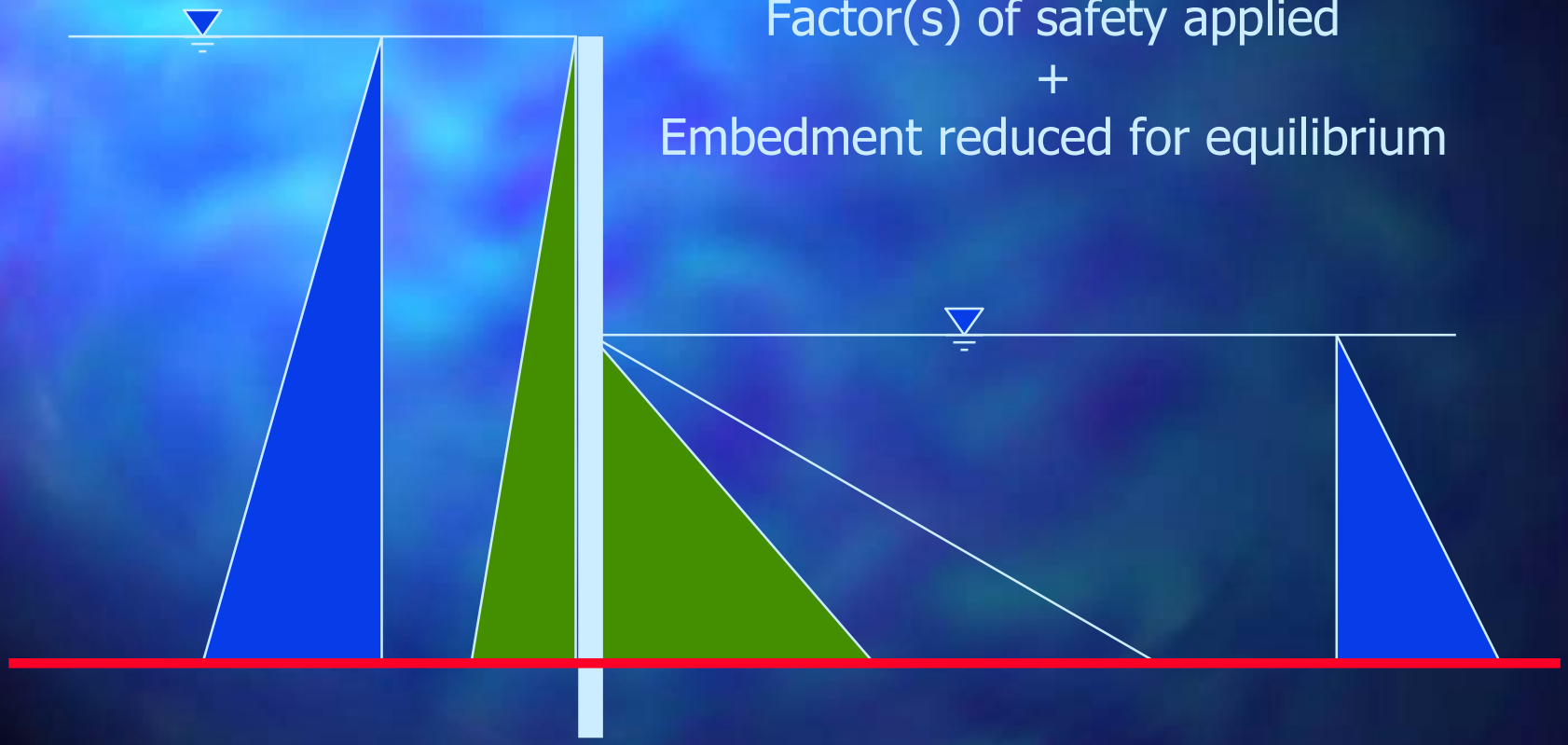


Partial resistance factors (Set R3)



Calculation of structural forces

Factor(s) of safety applied
+
Embedment reduced for equilibrium



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20th vs 21st Century codes

- 20th Century codes
  - Various ways of introducing safety
  - 2 ways of determining structural forces
  - Little agreement in end results
- 21st Century codes
  - Factor on strength preferred in UK
  - Logical frameworks for the design of geotechnical structures
  - Eurocode 7 offers prospect of a universal design approach based on sound engineering principles

Codes of practice for embedded retaining wall design

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