DESIGN OF REINFORCED CONCRETE STRUCTURES

COMPLEMENTARY PROPERTIES OF PLAIN CONCRETE AND STEEL REINFORCING BARS

CONCRETE	STEEL
GOOD IN COMPRESSION	-
-	GOOD IN TENSION
CHEAP	EXPENSIVE
DURABLE	NOT DURABLE
GOOD FIRE AND CORROSION RESISTANCE	POOR FIRE AND CORROSION RESISTANCE

BS EN 1992:Design of Concrete Structures

BS EN 1992 – Eurocode 2

SCOPE OF EUROCODE 2

- PART 1.1 GENERAL RULES FOR BUILDINGS
- PART 1.2 STRUCTURAL FIRE DESIGN
- PART 2 REINFORCED AND PRE-STRESSED CONCRETE BRIDGES
- PART 3 LIQUID RETAINING AND CONTAINMENT STRUCTURES

EXAMPLES OF BRITISH STANDARDS FOR THE STRUCTURAL USE OF CONCRETE

BS5400: DESIGN OF BRIDGES

(PART 4-CONCRETE BRIDGES)

BS8007: DESIGN OF LIQUID RETAINING STRUCTURES

BS8110: DESIGN OF BUILDINGS

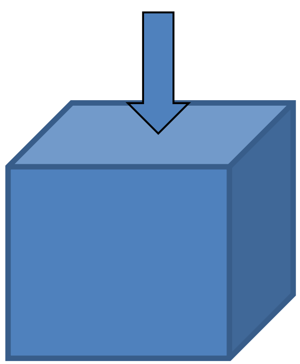
BS8110 IS AVAILABLE IN THREE PARTS

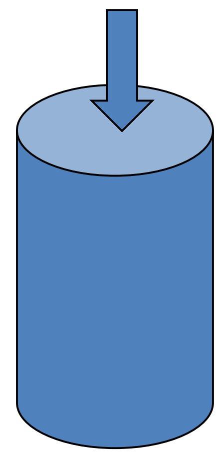
PART 1: CODE OF PRACTICE FOR DESIGN AND CONSTRUCTION

PART 2: CODE OF PRACTICE FOR SPECIAL CIRCUMSTANCES

PART 3: DESIGN CHARTS FOR SINGLY AND DOUBLY REINFORCED BEAMS AND RECTANGULAR COLUMNS

THE DESIGN RULES IN BS8110 ARE BASED ON THE COMPRESSIVE STRENGTH OF CONCRETE CUBES WHEREAS THE DESIGN RULES IN EUROCODE 2 ARE BASED ON THE COMPRESSIVE STRENGTH OF CONCRETE CYLINDERS





FACTORS INFLUENCING THE STRENGTH OF CONCRETE

REINFORCED CONCRETE

- CONCRETE
- STEEL

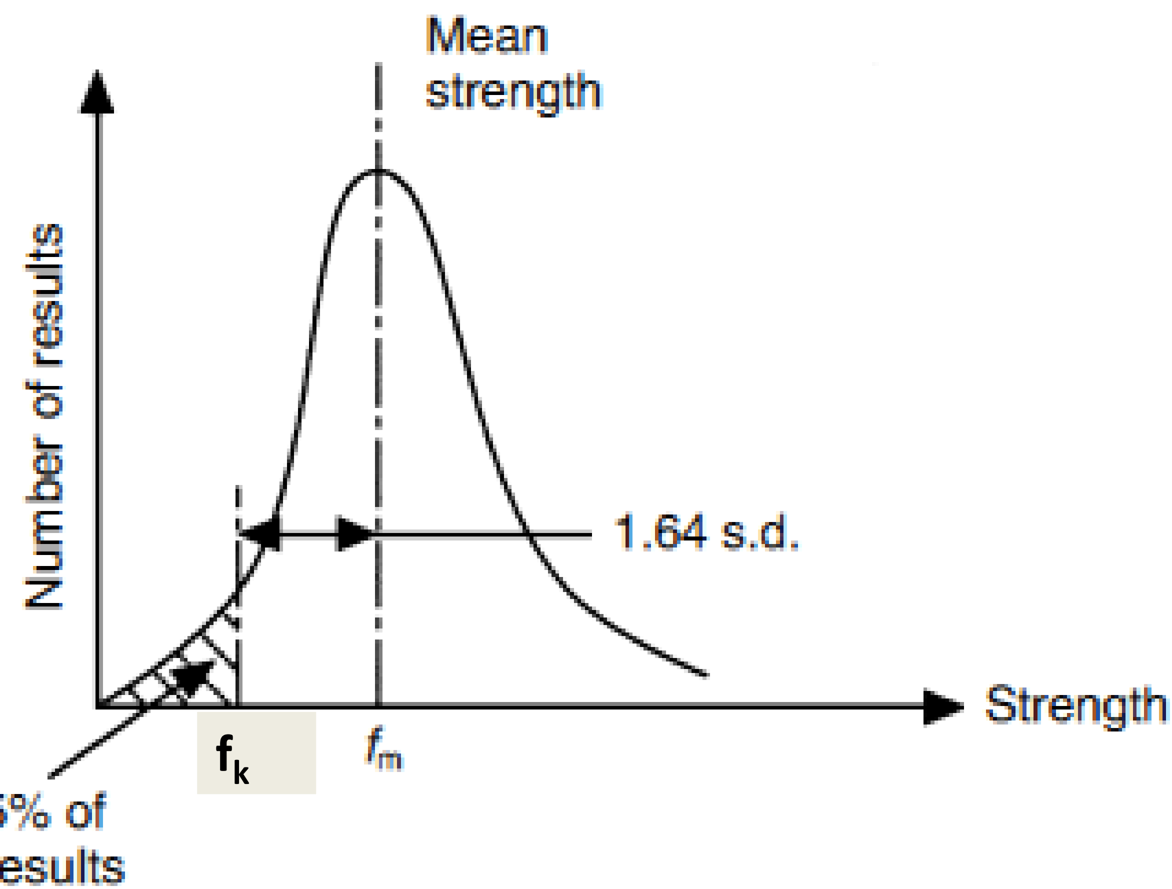
COMPOSITION

- WATER
- COARSE & FINE AGGREGATE
- BINDER (e.g. OPC)

MANUFACTURE

- TRANSPORTATION
- COMPACTION
- CURING

DISTRIBUTION OF COMPRESSIVE STRENGTHS OF CONCRETE CYLINDERS MADE FROM THE SAME MIX



CHARACTERISTIC STRENGTH

DEFINED AS THE VALUE BELOW WHICH NOT MORE THAN 5% OF TEST RESULTS FALL

$$f_k = f_m - 1.64 \text{ S.D.}$$

CHARACTERISTIC CUBE STRENGTH – f_{cu}

CHARACTERISTIC CYLINDER STRENGTH – f_{ck}

THE CHARACTERISTIC COMPRESSIVE STRENGTH OF CONCRETE IN EC2 IS IDENTIFIED BY ITS STRENGTH CLASS.

STRENGTH CLASS C50/60 CONCRETE, FOR EXAMPLE, HAS A CHARACTERISTIC CYLINDER STRENGTH OF 50 N/mm^2 AND CHARACTERISTIC CUBE STRENGTH OF 60 N/mm^2.

PERMITTED CONCRETE STRENGTH CLASSES – Table 3.1, EC2

Strength classes for concrete															Analytical relation / Explanation
f_{ck} (MPa)	12	16	20	25	30	35	40	45	50	55	60	70	80	90	
$f_{ck,cube}$ (MPa)	15	20	25	30	37	45	50	55	60	67	75	85	95	105	
f_{cm} (MPa)	20	24	28	33	38	43	48	53	58	63	68	78	88	98	$f_{cm} = f_{ck}+8$(MPa)
f_{ctm} (MPa)	1,6	1,9	2,2	2,6	2,9	3,2	3,5	3,8	4,1	4,2	4,4	4,6	4,8	5,0	$f_{ctm}=0,30\times f_{ck}^{(2/3)} \leq$C50/60 $f_{ctm}=2,12\cdot\ln(1+(f_{cm}/10))$ > C50/60
$f_{ctk,\,0,05}$ (MPa)	1,1	1,3	1,5	1,8	2,0	2,2	2,5	2,7	2,9	3,0	3,1	3,2	3,4	3,5	$f_{ctk;0,05} = 0,7\times f_{ctm}$ 5% fractile
$f_{ctk,0,95}$ (MPa)	2,0	2,5	2,9	3,3	3,8	4,2	4,6	4,9	5,3	5,5	5,7	6,0	6,3	6,6	$f_{ctk;0,95} = 1,3\times f_{ctm}$ 95% fractile
E_{cm} (GPa)	27	29	30	31	33	34	35	36	37	38	39	41	42	44	$E_{cm} = 22[(f_{cm})/10]^{0,3}$ (f_{cm} in MPa)
ε_{c1} (‰)	1,8	1,9	2,0	2,1	2,2	2,25	2,3	2,4	2,45	2,5	2,6	2,7	2,8	2,8	see Figure 3.2 ε_{c1} ($^0/_{00}$) = $0,7\ f_{cm}^{0,31} < 2.8$
ε_{cu1} (‰)	3,5									3,2	3,0	2,8	2,8	2,8	see Figure 3.2 for $f_{ck} \geq 50$ Mpa $\varepsilon_{cu1}(^0/_{00})=2,8+27[(98-f_{cm})/100]^4$
ε_{c2} (‰)	2,0									2,2	2,3	2,4	2, 5	2,6	see Figure 3.3 for $f_{ck} \geq 50$ Mpa $\varepsilon_{c2}(^0/_{00})=2,0+0,085(f_{ck}-50)^{0,53}$
ε_{cu2} (‰)	3,5									3,1	2,9	2,7	2,6	2,6	see Figure 3.3 for $f_{ck} \geq 50$ Mpa $\varepsilon_{cu2}(^0/_{00})=2,6+35[(90-f_{ck})/100]^4$
n	2,0									1,75	1,6	1,45	1,4	1,4	for $f_{ck} \geq 50$ Mpa $n=1,4+23,4[(90-f_{ck})/100]^4$
ε_{c3} (‰)	1,75									1,8	1,9	2,0	2,2	2,3	see Figure 3.4 for $f_{ck} \geq 50$ Mpa $\varepsilon_{c3}(^0/_{00})=1,75+0,55[(f_{ck}-50)/40]$
ε_{cu3} (‰)	3,5									3,1	2,9	2,7	2,6	2,6	see Figure 3.4 for $f_{ck} \geq 50$ Mpa $\varepsilon_{cu3}(^0/_{00})=2,6+35[(90-f_{ck})/100]^4$

PERMITTED STEEL REINFORCEMENT CLASSES

PROPERTY		CLASS	
	A	B	C
CHARACTERISITIC YIELD STRENGTH, f_{yk} (N/mm²)	←	500	→
YOUNG'S MODULUS (kN/mm²)	←	200	→
CHARACTERISTIC STRAIN AT ULTIMATE FORCE, ε_{uk} (%)	$\geq$ 2.5	$\geq$ 5.0	$\geq$ 7.5

Partial Factors for Materials, γ_m

DESIGN SITUATION	γ_{mc} FOR CONCRETE	γ_{ms} FOR STEEL
PERSISTENT & TRANSIENT (ULS)	1.5	1.15
SERVICEABILITY LIMIT STATE (SLS)	1.0	1.0

$$\textbf{DESIGN STRENGTH} = \frac{\textit{CHARACTERISITIC STRENGTH, } f_k}{\textit{MATERIAL FACTOR OF SAFETY, } ?_m}$$

CHARACTERISITIC LOADS/ACTIONS, F_k

TWO BASIC TYPES OF ACTIONS:

PERMANENT ACTIONS (G_k, g_k) - **ACTIONS LIKELY TO ACT CONSTANTLY THROUGHOUT A GIVEN REFERENCE PERIOD WITH SMALL VARIATION**

- **SELF-WEIGHT**
- **FINISHES**
- **FAÇADE**
- **SERVICES**
- **ETC**

EN 1991 / MANUFACTURER'S LITERATURE

VARIABLE ACTIONS (Q_k, q_k)- **ACTIONS FOR WHICH THE VARIATION IN TIME IS NOT NEGLIGIBLE**

- **OCCUPANCY LOADS ("LIVE LOADS")**
- **WIND & SNOW**
- **TRAFFIC ETC**

EN 1991

SCOPE OF EUROCODE 1: ACTIONS ON STRUCTURES

DOCUMENT NUMBER	SUBJECT
BS EN 1991-1-1 BS EN 1991-1-2 BS EN 1991-1-3 BS EN 1991-1-4 BS EN 1991-1-5 BS EN 1991-1-6 BS EN 1991-1-7	DENSITIES, SELF WEIGHT AND IMPOSED LOADS ACTIONS ON STRUCTURES EXPOSED TO FIRE SNOW LOADS WIND LOADS THERMAL LOADS ACTIONS DURING EXECUTION ACCIDENTAL ACTIONS
BS EN 1991-2	TRAFFIC LOADS
BS EN 1991-3	CRANES
BS EN 1991-4	SILOS AND TANKS

LOADING ON STRUCTURE MAY BE GREATER THAN THE CHARACTERISTIC VALUE BECAUSE OF:

1. **CONSTRUCTION INACCURACIES**
2. **ERRORS IN ANALYSIS**
3. **ERRORS IN DESIGN**
4. **POSSIBLE UNUSUAL CIRCUMSTANCES**

EN 1990: BASIS OF STRUCTURAL DESIGN

DESIGN VALUE OF ACTION, E_d

$$E_d = \sum_{j \geq 1} \gamma_{G,j} G_{k,j} \text{ "+" } \gamma_{Q,1} Q_{k,1}$$

where

"+" implies "to be combined with"

Σ implies "the combined effect of"

PARTIAL SAFETY FACTORS FOR ACTIONS

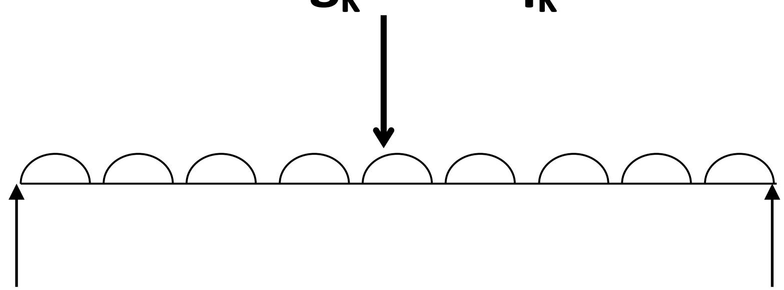
	PERMANENT, γ_G	VARIABLE, γ_Q
EN 1990	1.35	1.5
BS 8110	1.4	1.6

DESIGN ACTION = $\gamma_f F_k$

$$\left.\begin{array}{l} 1.0 \geq \gamma_f \geq 1.35 \text{ FOR PERMANENT ACTIONS} \\ 0 \geq \gamma_f \geq 1.50 \text{ FOR VARIABLE ACTIONS} \end{array}\right\} \text{EN 1990}$$

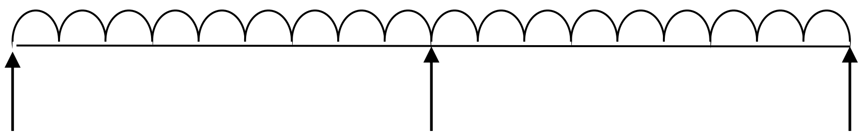
CRITICAL

$1.35g_k + 1.5q_k$



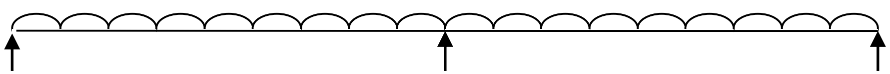
SINGLE SPAN BEAM

TWO SPAN BEAM

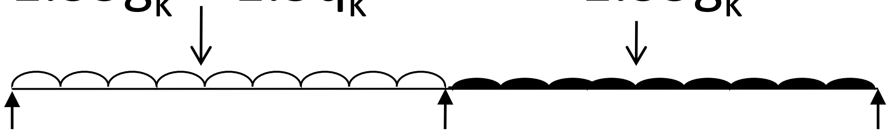


$1.35g_k + 1.5q_k$

LOAD CASE (1)

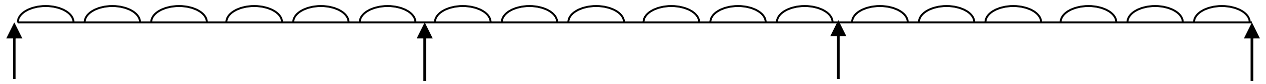


$1.35g_k + 1.5q_k$ $1.35g_k$

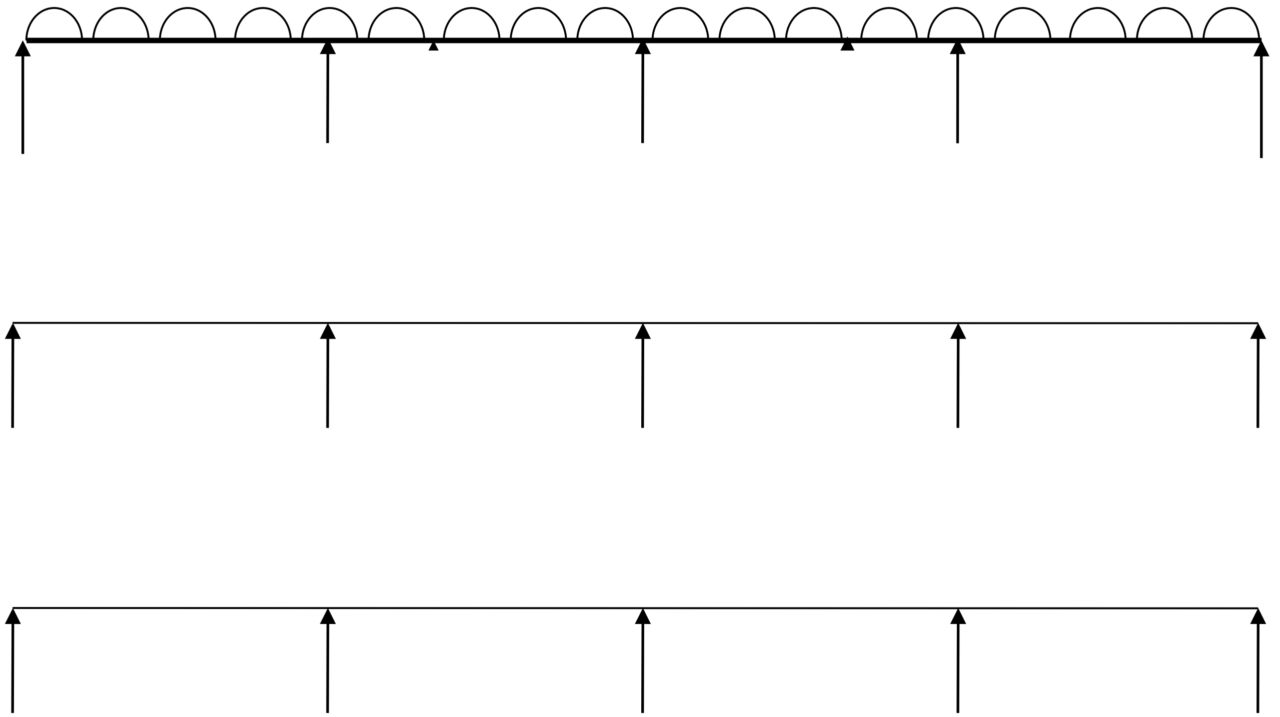


LOAD CASE (2)

THREE SPAN BEAM



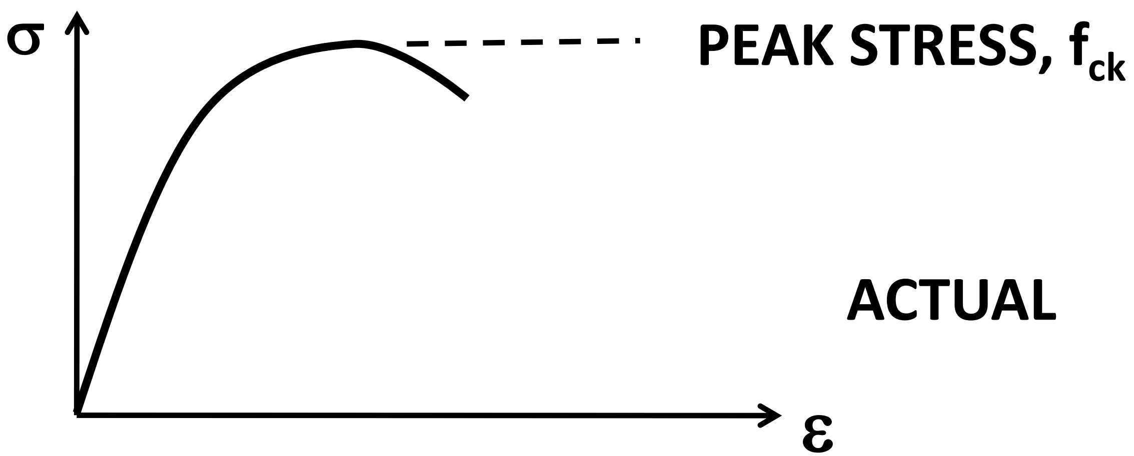
FOUR SPAN BEAM

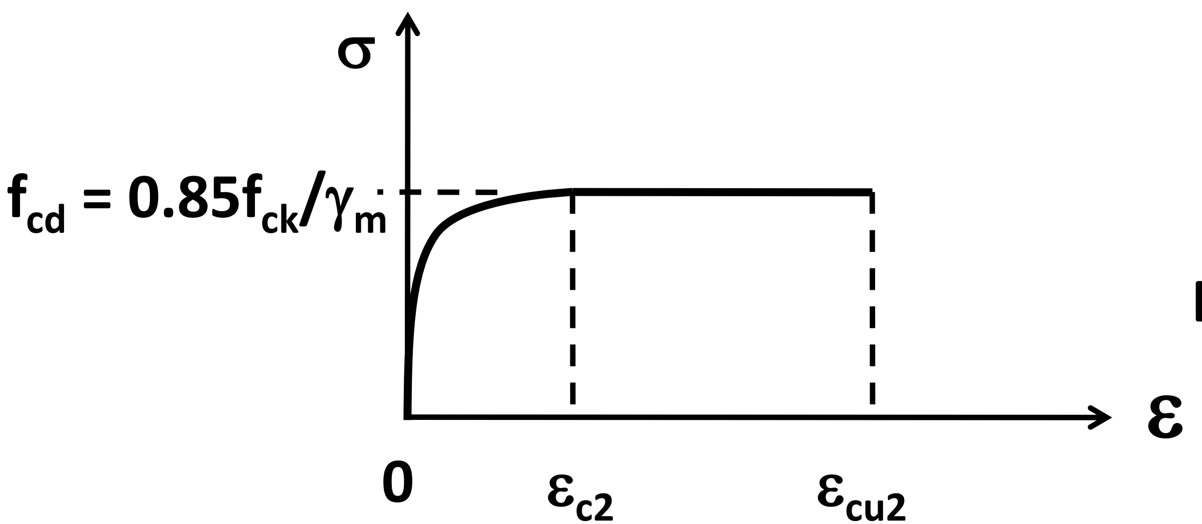


LOAD CASES FOR FOUR SPAN CONTINUOUS BEAM

STRESS-STRAIN CURVES

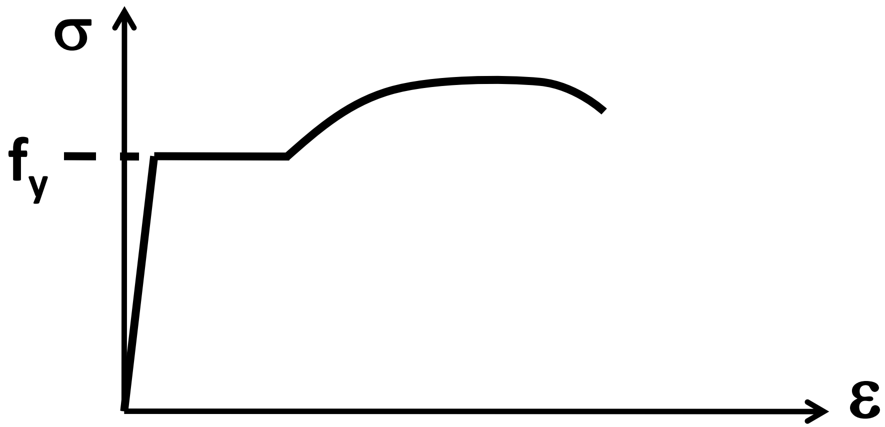
CONCRETE



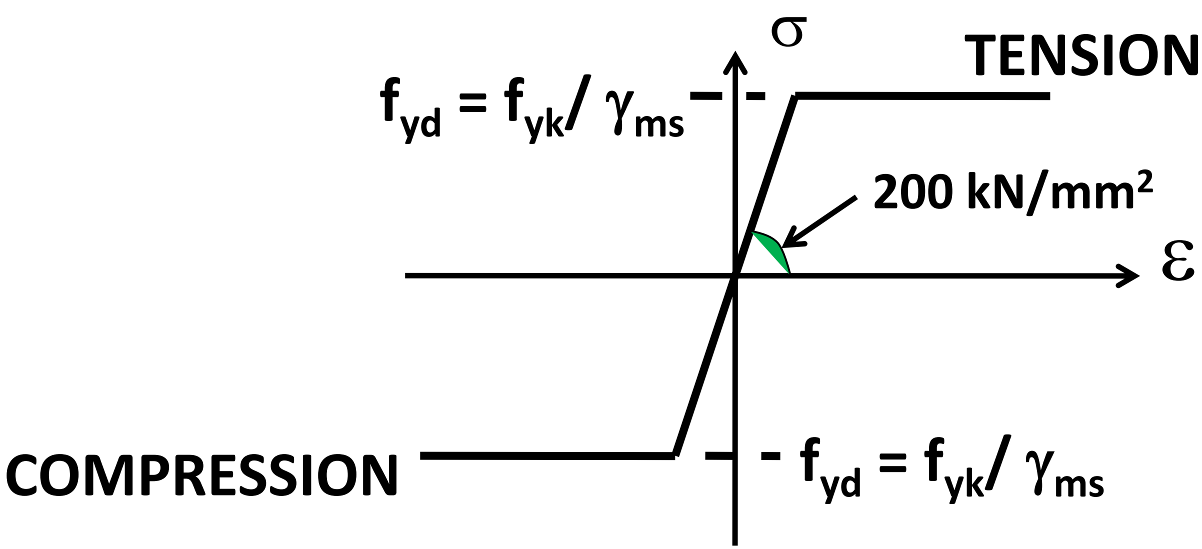


STRESS-STRAIN CURVES

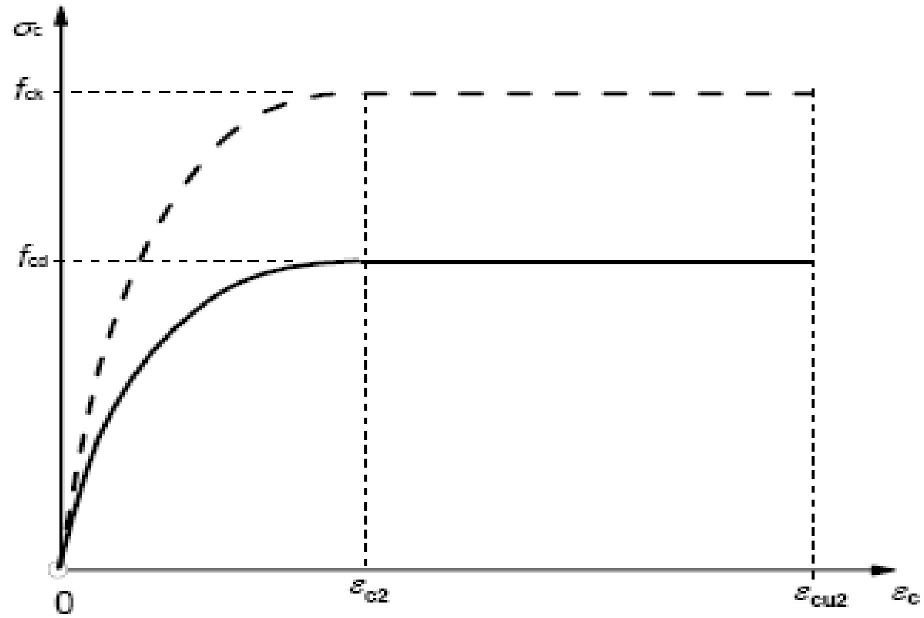
STEEL



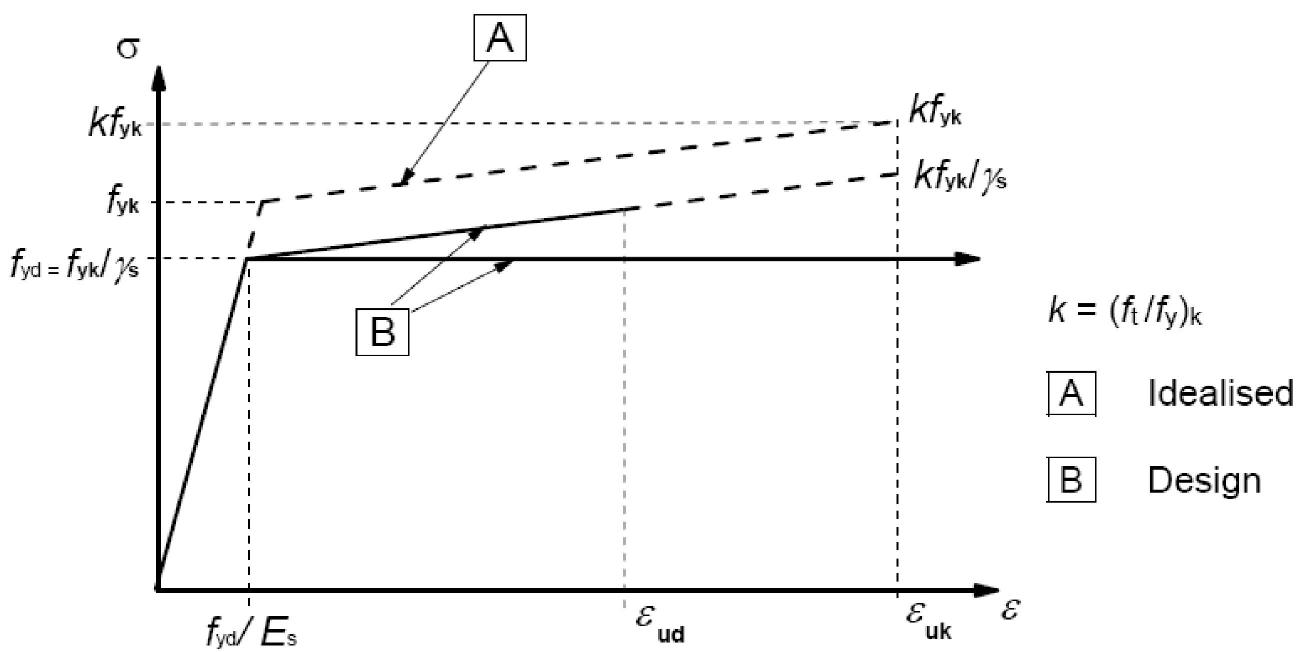
ACTUAL



DESIGN

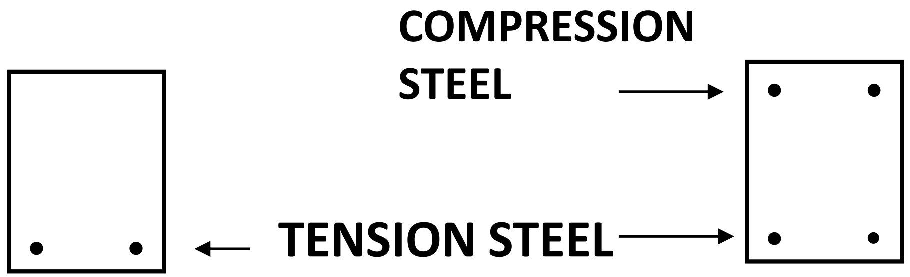


σ_c
f_{ck}
f_{cd}
0
ε_{c2}
ε_{cu2}
ε_c



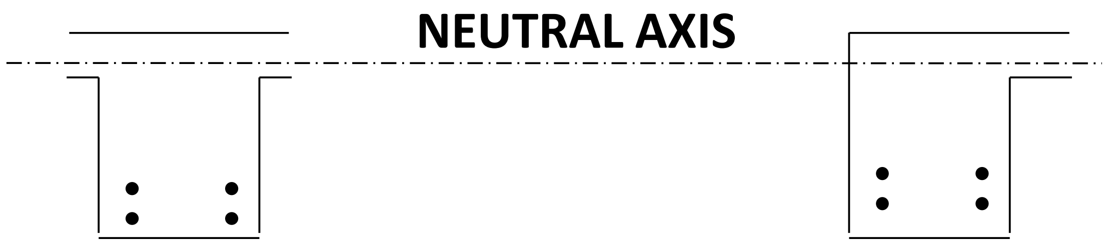
σ
A
kf_{yk}
f_{yk}
$f_{yd} = f_{yk}/\gamma_s$
kf_{yk}
kf_{yk}/γ_s
B
f_{yd}/E_s
ε_{ud}
ε_{uk}
ε
$k = (f_t/f_y)_k$
A Idealised
B Design

BEAM SECTIONS



SINGLY REINFORCED

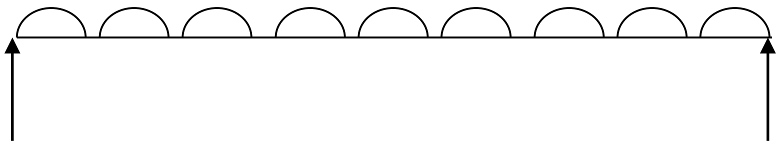
DOUBLY REINFORCED



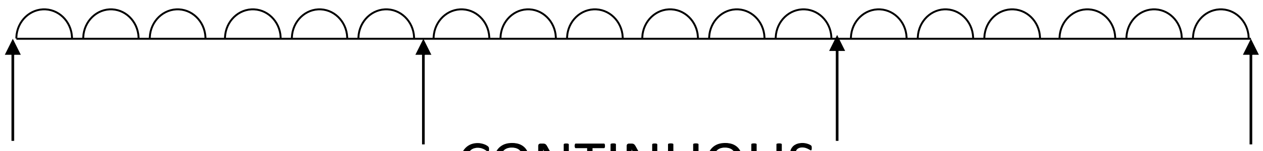
T-SECTION

L-SECTION

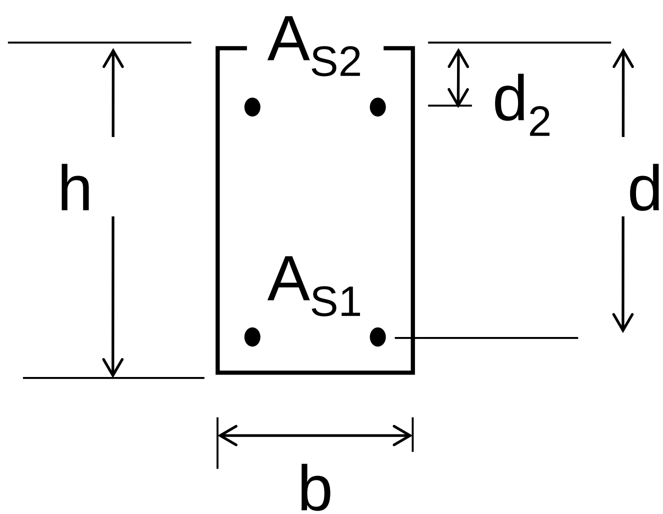
BEAM TYPES AND NOTATION



SINGLE SPAN. SIMPLE SUPPORTS



CONTINUOUS

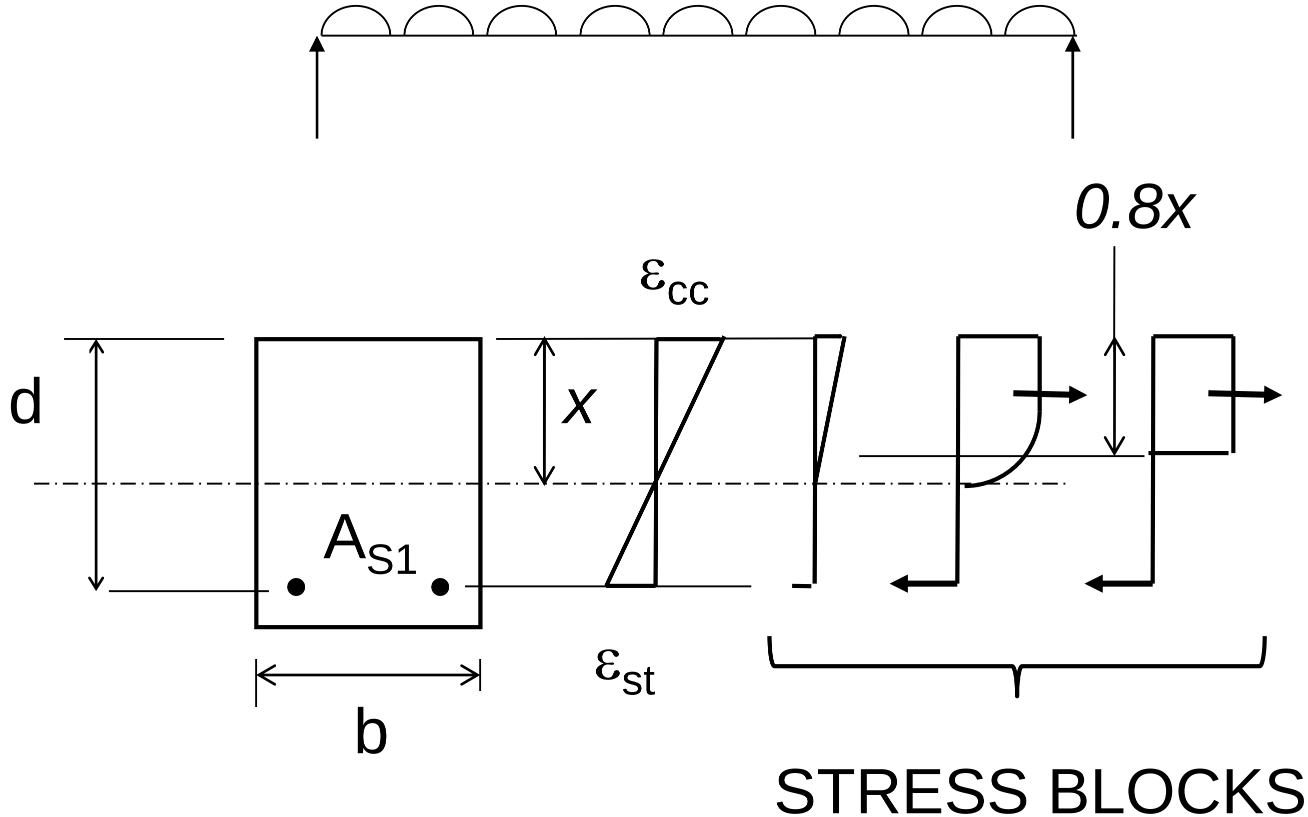


DESIGN OF SINGLY REINFORCED BEAMS

GENERALLY REQUIRES CONSIDERATION OF THE FOLLOWING

- ❑ **BENDING**
- ❑ **SHEAR**
- ❑ **DEFLECTION**

BENDING



BEAM FAILS ONCE THE CONCRETE CRUSHES. THIS MAY OCCUR EITHER

(1) BEFORE THE STEEL YIELDS

(2) AFTER THE STEEL HAS YIELDED

THE FIRST SITUATION ARISES IF THE SECTION IS OVER-REINFORCED. THE LATTER ARISES IF THE SECTION IS UNDER REINFORCED.

UNDER REINFORCING OF BEAMS IS PREFERABLE BECAUSE

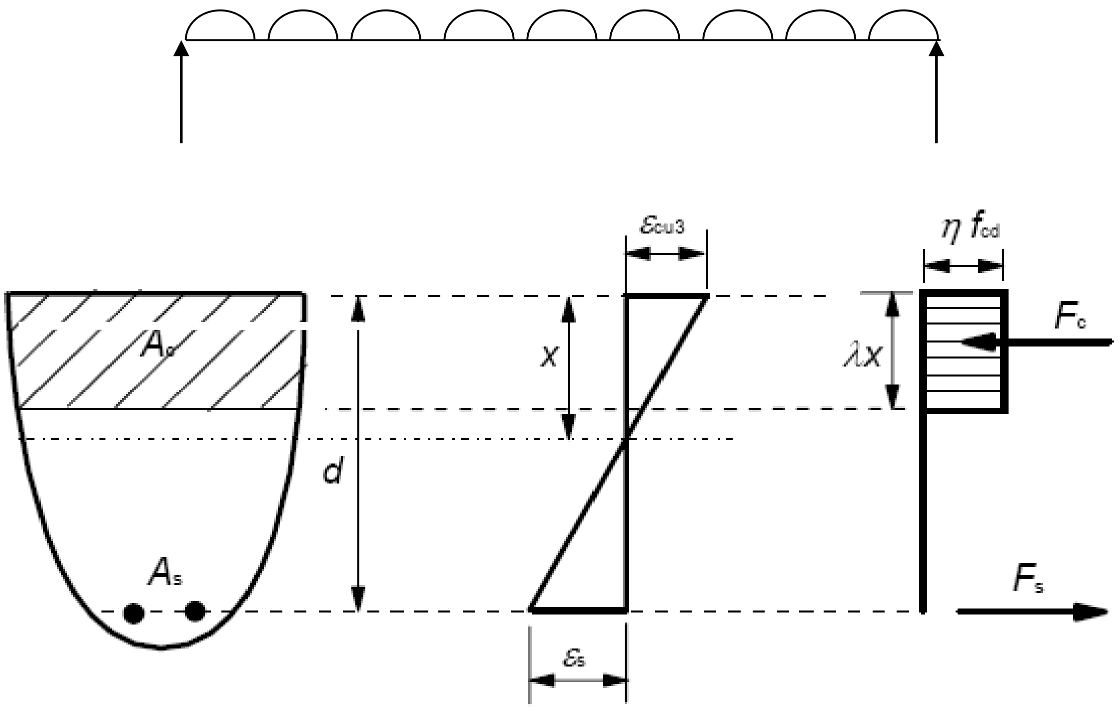
a) ECONOMY OF DESIGN

b) AMPLE WARNING OF FAILURE IS PROVIDED.

THIS CONDITION IS ACHIEVED BY LIMITING THE DEPTH OF THE NEUTRAL AXIS, x, TO

$$x \leq 0.45d \ (f_{ck} \leq 50 \text{ N/mm}^2)$$

BENDING



$\lambda = 0,8$ for $f_{ck} \leq 50$ MPa
$\lambda = 0,8 - (f_{ck} - 50)/400$ for $50 < f_{ck} \leq 90$ MPa

$\eta = 1,0$ for $f_{ck} \leq 50$ MPa
$\eta = 1,0 - (f_{ck} - 50)/200$ for $50 < f_{ck} \leq 90$ MPa

ULTIMATE MOMENT OF RESISTANCE, M_{Rd}

FOR EQUILIBRIUM

$F_c = F_s$ ---------(1)

$M_{Rd} = M = F_c z = F_s z$ ---------(2)

$F_c = (0.85 f_{ck}/\gamma_{mc})\ 0.8xb$ ---------(3)

$z = d - 0.4x$ ---------(4)

$x \leq 0.45d$ ---------(5)

COMBINING (2)-(5) AND PUTTING $\gamma_{mc} = 1.5$ GIVES

$M_{Rd} = 0.167 f_{ck} b d^2$ ---------(6)

AREA OF TENSION REINFORCEMENT, A_{s1}

FROM EQUATION (2), THE MOMENT AT THE SECTION, M, IS GIVEN BY

$$M = F_s z$$

WHERE F_s = STRESS $\times$ AREA = $(f_y/\gamma_{ms})A_{s1}$

REARRANGING AND PUTTING γ_{ms} = 1.15 GIVES

$$A_{s1} = M/0.87 f_y z \qquad \text{-----------(7)}$$

SOLUTION OF THIS EQUATION REQUIRES AN EXPRESSION FOR THE LEVER ARM (z)

LEVER ARM, z

FROM EQUATION (2)

$M = F_c z$

$= (0.85 f_{ck}/\gamma_{mc})\ (0.8xb)\ z$

SINCE $z = d - 0.4x \Rightarrow x = (d - z)/0.4$ AND PUTTING $\gamma_{mc} = 1.5$ GIVES

$M = (3.4/3) f_{ck} b(d - z)z$

DIVIDING BOTH SIDES BY $f_{ck}bd^2$ GIVES

$M/f_{ck}bd^2 = (3.4/3)(z/d)(1 - z/d)$

SUBSTITUTING $K = M/f_{ck}bd^2$ AND $z_o = z/d$ GIVES

$$0 = z_o^{\,2} - z_o - 3K/3.4$$

THIS IS A QUADRATIC AND CAN BE SOLVED TO GIVE

$$z_o = z/d = 0.5 + \sqrt{}(0.25 - 3K/3.4)$$

OR MORE CONVENIENTLY

$$z = d(0.5 + \sqrt{}(0.25 - 3K/3.4)) \qquad \text{----------}(8)$$

NB These equations are only valid provided $M_{Ed} \leq M_{Rd}$

FOR DETAILING PURPOSES THIS AREA OF STEEL HAS TO BE TRANSPOSED INTO A CERTAIN NUMBER OF BARS OF A GIVEN DIAMETER