CIV2226 - Concrete Technology (Part 1)

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Cements

Portland Cement (OPC)

Basic chemical components

Calcareous component (65%) [Calcium Ca]
Limestone provides this component however raw materials may vary in composition
i.e chalk, marble, lime sludge

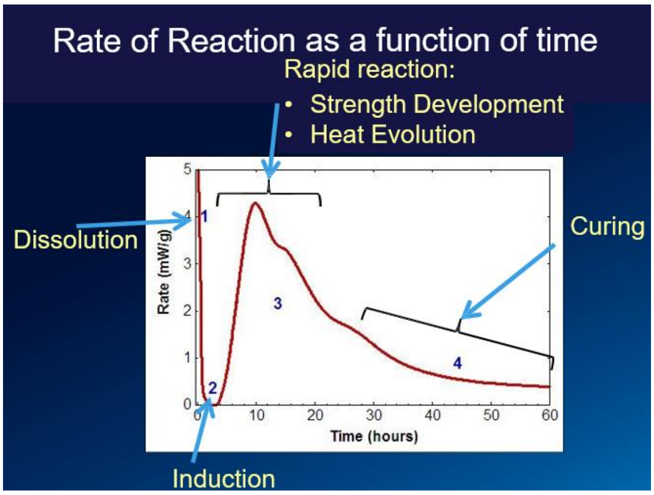
Argillaceous component (35%) [Si, Al & Fe]
Typically shale provides this component however raw materials could include;
i.e clay, ash, slate, glass

Manufacturing and Sourcing of Raw Materials

At dig sites rocks are disintegrated by small blasts
The rock is taken to manufacturing site and put through crushers to make material fine
Once crushed stored into bins then poured together at correct proportions and crushed, then grinded into bins and to the mill. Mix is thrown into the ball mill at a constant speed then heated to high temps
This heating causes chemical reactions further combining the raw materials creating clinkers
After the mill, clinkers are mixed w/ gypsum (for shrinkage control and setting rate) then passed through a final grinder forming PC

Reaction

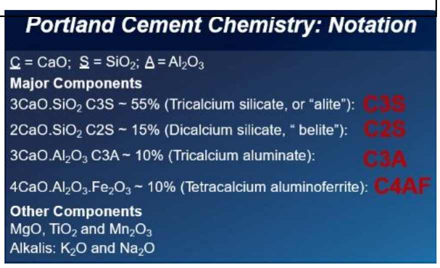
PC and water combine creating a chem reaction generating heat, known as heat of hydration
During mixing the ROR has a short peak (dissolution) then at induction cement isn't chemically active from here after a few hours the heat of hydration ↑ ∴ ↑ ROR and developing strength. The mix then begins to cure giving a favourable temp for hydration to occur for a definite period



Setting Time

Initial set = point where paste stiffens
Time required for the paste to cease being plastic and workable
Final set = Point where paste becomes rigid/solid and develops measurable strength

Properties of the major constituents of cement		
Mineral Phase	**Characteristics**	**Heat of Hydration [J/g]**
C3S	Light in colour. Hardens quickly with evolution of heat. Gives early strength	500
C2S	Light in colour. Hardens slowly. Gives late strength	250
C3A	Light in colour. Sets quickly with evolution of heat. Low strength	850
C4AF	Dark in colour with little cementing value	400



Solids in Hydrated Cement Paste

As cement cures solids are generated

> **Calcium Sulfoaluminate Hydrates: 15-20%**
>
> first : ettringite, after : monosulfate hydrated
>
> Looks like sharp needles

> **Calcium Silicate Hydrate (CSH): 50-60%**
>
> High Surface Area → High Van der Walls Force → Strength
>
> Looks like cigar smoke

> **Calcium Hydroxide**
>
> Hexagonal Crystal

Cement Types (AS3972 = Performance based specifications)

GP = General Purpose Portland Cement

*may contain upto 5% mineral additions; mineral addition are defined as fly ash, slag, limestone)

Intended for general use in concrete construction and is specified where special properties, such as LH of hydration are not required

GB = General Purpose Blended Cement

HE = High Early Strength Cement

Utilized in roads when they need to be used asap

LH = Low Heat Cement

LH cement is intended to limit the heat of hydration (& hence the temperature ↑ in conc) necessary to avoid unacceptable thermal stresses

*Rate of heat liberation parallels the rate of strength ↑

SL = Shrinkage Limited Cement

Emphasis is placed on drying shrinkage and crack control in concrete structures (eg road pavements)

SR = Sulfate Resistant Cement

Portland cement containing **less than 5% C3A** is classified as sulfate resisting cement. Used where soil or ground water contains high sulfate so sulfate doesn't dominate proportions

Table 1 **Summary of AS 3972 Requirements**

AS 3972 Requirements*	Cement types: GP	GB	HE	LH	SL	SR
Chemical limitations						
Loss on ignition	reported if required – no limit is specified					
Sulfuric anhydride SO_3 (max)%	3.5	3.5	3.5	3.5	3.5	3.5
MgO	Portland cement clinker shall contain less than 4.5%					
Physical properties						
Setting time						
Minimum (minutes)	45	45	45	45	45	45
Maximum (hours)	10	10	10	10	10	10
Soundness maximum (mm)	5	5	5	5	5	5
Compressive strength minimum (MPa)						
3 days	–	–	20	–	–	–
7 days	25	15	30	10	20	15
28 days	40	30	–	30	30	30
Peak temperature rise maximum °(C)	–	–	–	23	–	–
Drying shrinkage maximum (microstrain)						
28-day	–	–	–	–	750	–
Sulfate expansion maximum (microstrain)						
16-week	–	–	–	–	–	900

*Determined in accordance with the methods set out in AS 2350 *Methods of Testing Portland and Blended Cements*[2]

Supplementary Cementious Materials (SCM's)

i.e Blast Furnace slag (iron), Silicia Fume (metal) & Fly ash (coal)

Each blended or interground with PC

Primarily industrial waste materials

Blended cements (BC) are common due to their environmental benefits

1. CO_2 emission ↓ by ~700 kg per tonne of cement replaced
2. Effective use of a by product (1t of steel production = 300kg of slag)
3. Saving limestone resources
4. Energy saving of approx 40% in comparison with OPC

Slag

Waste product from iron; slag floats in blast furnace which is then granulated/chilled with water

To maximise slags hydraulic properties, molten slag is rapidly chilled as it leaves the blast furnace

Can replace upto 65% PC (slow reaction, little cementitious properties)

When grounded to a fine powder reacts with calcium hydroxide forming compounds w/ cementitious properties

Why use slag?

Slow reaction (slow strength development ∴ problem w/ early age strength)

↓ heat of hydration ∴ ↓ thermal cracking risk (↑% of slag ∴ ↓ heat of hydration)

↓ Permeability ↑ long term durability

When comparing slag/OPC to OPC, slag/OPC has ↓ early age strength but a much higher ongoing strength

Fly Ash

Waste product from coal-burning power stations

No additional processing required; doesn't need to be cooled down

Can replace upto 30% of PC

Why use Fly Ash?

Slow reaction (slower strength development than PC)

Fly ash + Calcium Hydroxide becomes cementitious (C-S-H)

Varying levels of reactivity (depends on composition of fly ash)

Lower temps due to ↓ heat of hydration ∴ ↓ thermal cracking risk

↓ Permeability ↑ long term durability

Silica Fume

Produced by arc furnaces, by-product of ferro-silicon alloys

Used as a strength enhancer rather than cement substitute

Found commonly in high-strength (60+MPa) conc

Very effective pozzolanic material, whereby fine powder reacts w/ water gaining cementatious properties

↑ bond strength, ↑ abrasion resistance, ↓ permeability of conc. to chloride ions protecting steel reinf from corrosion

espeicially in costal, salt water environments

↓ slump while mix remains cohesive

CIV2226 - Concrete Design (Part 2)

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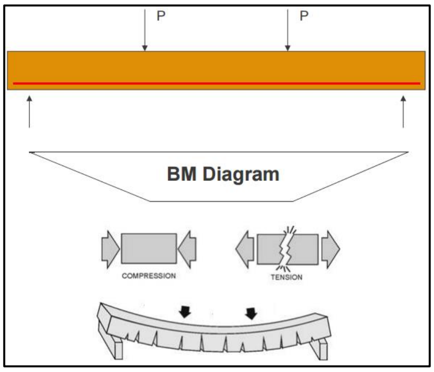
Reinforced Concrete (RC)

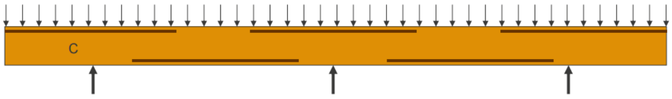
Concrete vs. Steel

Concrete = Brittle, weak in tension, strong in compression
Steel = Ductile, hence used to carry tension



Beams

Reo should be placed on tension side of beam
E.g. Simply supported beam:
Tension side = bottom, place bars near bottom
Cantilever beam:
Tension side = top, place bars near top
Continuous beam (under UDL):
Tension varies



Loads & Actions

Action
Any agent, such as imposed load, foundation movement or temperature gradient, which acts on structure
Dead Load (G) • G
Self-weight of the structure plus weight of permanently installed equipment.
Live Load (Q) • Q
Loads specified for various uses and occupancies (people)
Action effects
Forces and moments, deformations, cracks and other effects, which are produced in a structure or in its component members by an action

Load Paths

How the externally applied loads are transferred through the member and into its supports
Use strut and tie model
Strut = Compression reaction in concrete
Tie = Tensile reaction in reo
E.g. Load Paths in Beams

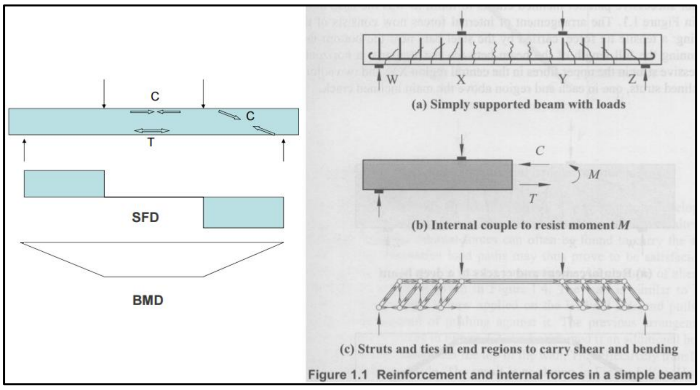


Figure 1.1 Reinforcement and internal forces in a simple beam

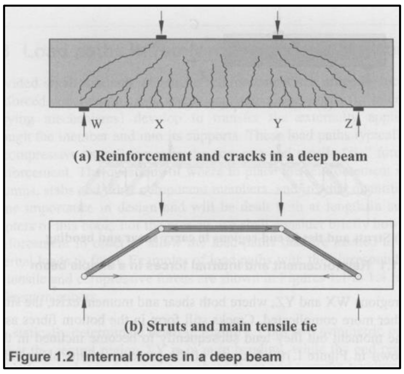


Figure 1.2 Internal forces in a deep beam

E.g. Load Paths in Walls

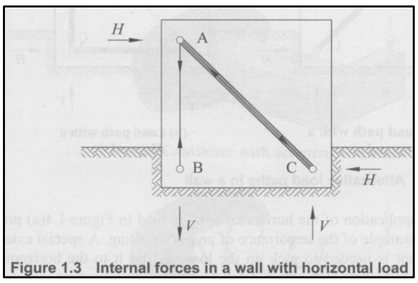
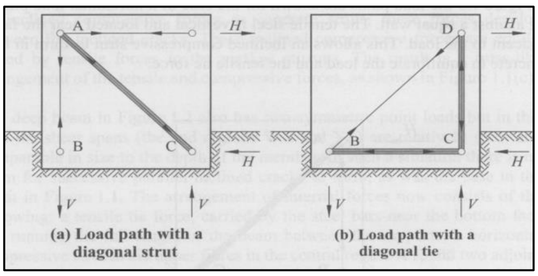


Figure 1.3 Internal forces in a wall with horizontal load



Analysis & Design of Flexural Strength of RC Beam

Strength design for RC beams in bending

1. Over reinforced: brittle failure
2. Under reinforced: ductile failure
3. Bending capacity
    a) Force equilibrium (C=T)
    b) Check k or p for under-reinforced beam design
    c) Ultimate moment capacity = force*lever arm
4. Check p_{min} to avoid sudden collapse

*

Find k.u (depth of NA factor)

From stress/strain graph we know

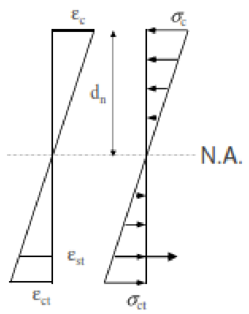
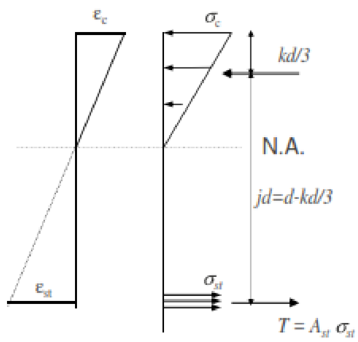
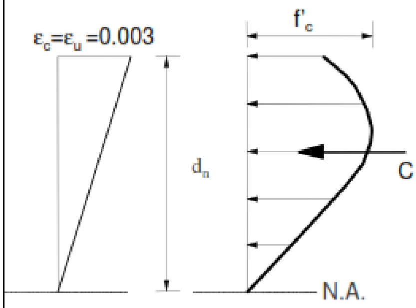
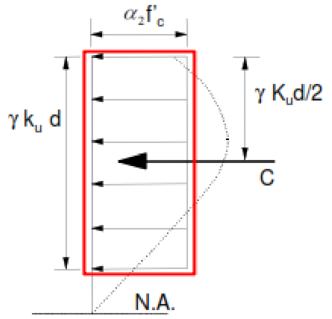
For steel: the **stress at yield point = f.sy**

∴ **ε.sy = f.sy / E** = .0025

For concrete: **peak stress = fc'**

& crushing of concrete occurs **ε.cu = 0.003**

The stress σ.c < fc' when strain reaches ε.cu (point of crushing)

Changes in Compressive Stress w/ ↑ Bending Moment			
As we ↑ bending moment, compressive stresses in the beam will change			
 Before cracking (Bottom concrete: linear Top concrete: linear)	 After cracking (Bottom concrete: cracked Top concrete: linear)	 Crushing of concrete (Bottom concrete: cracked Top concrete: non-linear)	 Equivalent stress block
Before cracking we have linear stress, w/ max at top and bottom of member	↑ BM causes cracking As conc cant resist tension we ignore it at bottom ∴ only consider steel **tensile force, T = stress*A.st**	Further↑ BM the conc begins to crush	Use equivalent stress block AS3600 clause 8.1.3

Distribution of Compressive Stresses in Concrete Near Failure of Beam

As Its hard to model crushing stress we use the **equivalent stress block**

$\alpha_2 = 1.0 - 0.003 f'_c$

(within the limits of $0.67 \le \alpha_2 \le 0.85$)

$\gamma = 1.05 - 0.007 f'_c$

(within the limits $0.67 \le \gamma \le 0.85$)

For normal strength concretes with $f'_c \le 50$ MPa:

$\alpha_2 = 0.85$

AS3600 Clause 8.1.3

If a.2 or γ are outside lim, use max/min

Failure Modes

Balanced Failure

ε.st = ε.sy

Steel starts to yield (yellow dot)

Brittle Failure

(Over-Reinforced Section)

ε.st < ε.sy

Conc crushes at top (red dot)

∴ steel at bottom isn't yielding

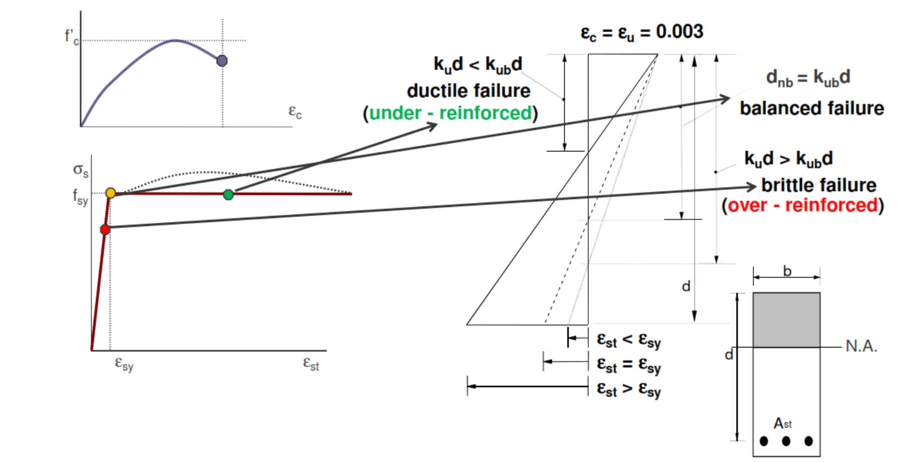
Ductile Failure

(Under-Reinforced Section)

ε.st > ε.sy

Conc starting to crush &

Steel has yielded (green dot)



Ductility Limits on depth of NA factor k

To ensure a gradual ductile failure, the beam has to be *under-reinforced*

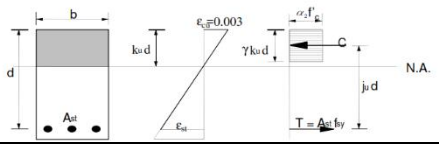
According to AS 3600, **k.u <= 0.36**. This will result in an adequate ductility provided in the beam

Ductility Limits on amount of steel tension p_{max}

- C=T

  $\alpha_2 f_c' (\gamma k_u d * b) = A_{st\,max} f_{sy}$ (force equilibrium)
- Maximum allowable steel ratio for sections with tension reinforcement only:

  $p_{max} = A_{stmax} / bd = \alpha_2 \gamma k_u f_c' / f_{sy}$ (when k_u=0.36)
- Steel ratio $p = A_{st} / bd < p_{max}$



Comp force in conc = Comp force in steel

C = T

C = area*stress

depth = y*k.u*d

width = b

Stress = α.2*fc'

f.sy = yielding stress for steel

Minimum amount of flexural reinforcement, p_{min}

AS3600 sets a lower limit on the steel ratio (p) p.min based on the requirement that ultimate moment capacity (M.u) is greater than cracking moment (M.cr) by 20%

M.u > M.cr by 20% (This is to avoid sudden collapse by steel fracturing upon initiation of cracking)

$$A_{st} \geq [\alpha_b (D/d)^2 f'_{ct.f}/f_{sy}] b_w d$$

OR $$p = \frac{A_{st}}{b_w d} \geq p_{min} = \alpha_b \left(\frac{D}{d}\right)^2 \frac{f'_{ct,f}}{f_{sy}}$$

$$A_{st} \geq [\alpha_b (D/d)^2 f'_{ct.f}/f_{sy}] b_w d$$

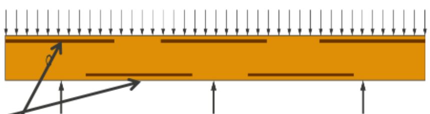
where

For rectangular sections:

$$\alpha_b = 0.20$$

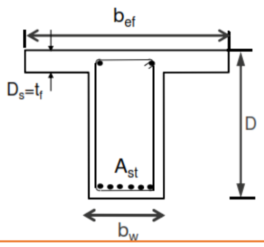
For T-sections and L-sections with the web in tension:

$$\alpha_b = 0.20 + \left(\frac{b_{ef}}{b_w} - 1\right)\left(0.4\frac{D_s}{D} - 0.18\right) \geq 0.20\left(\frac{b_{ef}}{b_w}\right)^{1/4}$$



For T-sections and L-sections with the flange in tension:

$$\alpha_b = 0.20 + \left(\frac{b_{ef}}{b_w} - 1\right)\left(0.25\frac{D_s}{D} - 0.08\right) \geq 0.20\left(\frac{b_{ef}}{b_w}\right)^{2/3}$$



b_{ef}: effective width of the flange

b_w: width of web

f_{sy}: characteristic yield strength of steel reinforcement

$f'_{ct.f}$: characteristic flexural tensile strength of concrete = $0.6 \sqrt{f'_c}$

D_s: overall depth of a slab (= t_f, depth of flange)

To ensure ductile failure

k.u < 0.36 and p<p.max

then,

check p>p.min

avoids sudden collapse

CIV2226 – Masonry (Part 3)

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Masonry Introduction

Masonry code = AS3700

Masonry Outline:

- Introduction to Masonry Structures
- Structural Forms and Terminologies
- Failure Modes
- General Design Aspects
- Structural Design of Unreinforced Masonry
- Masonry Walls in Bending
- Structural Design of Reinforced Masonry
- Durability of Masonry
- Miscellaneous topics and exam review

Modern Masonry Construction

Masonry has become a popular cladding material for residential purposes
Adopted slender wall designs utilizing masonries high compressive & shear strengths with cellular designs

Recent developments:

- Reinforced Masonry
    - i.e core filled block walls
- Prestressed Masonry
    - ↑ compressive strength
    - Anchored at top w/ steel lintel and threaded rod then wound to ↑ compression
- Prefabricated Masonry
    - Prefab = built offsite and transferred to
    - Requires great measures to protect structure during transport & handling
    - (usually requires experienced trades to install)

Advantages of Masonry:

- Cheaper than steel or conc
- Provides excellent weather protection, sound and thermal insulating, fire resistant
- Also flexible as an architectural medium in terms of easy to drill/saw etc

Disadvantages of Masonry:

- Labour intensive
- Quality is variable based on trades experience
- Highly susceptible to cracking/movement
- Can be used as load bearing or non-load bearing (cladding)

Structural Forms & Terminology

Masonry Units

Units are preformed components used for bonded masonry (i.e bricks)

E.g. Common units manufactured

Clay bricks; cored or pressed

<10% recess, ~10MPa strength

230x110x76

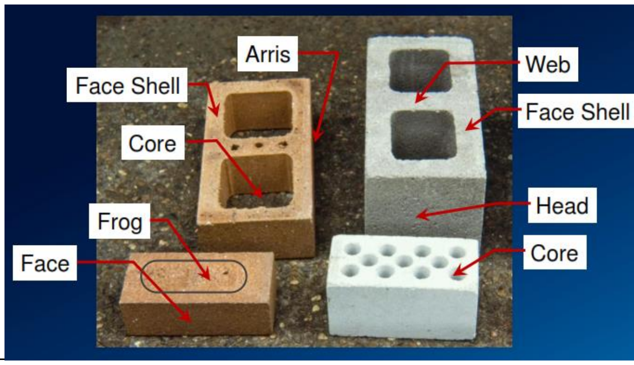
Concrete blocks; hollow

15MPa strength

390x190x190

Can order special shapes (Fired clay)

Bullnosed, angled



Mortar

Mortar helps distribute the load of the units as it takes up any irregularities in the unit and bonds w/ the units giving tensile strength

Essentially acts as a glue to bond masonry units to resist loading

Involves plastic mixture of cement, lime and sand (CLS)

4 standard mortar types according to strength & durability

Mortar Type	Comment	Bond	Durability
M1	Seldom used except for repair of older buildings.	low	very low
M2	General purpose mortar for moderate exposure. For use above damp-proof course in internal or sheltered external locations.	good	low
M3	General-purpose mortar for most building applications.	good	medium
M4	Used for damp-proof courses and reinforced masonry.	unreliable	high

Extract from AS3700-2001

Table 10.1 DEEMED-TO-SATISFY MORTAR COMPOSITIONS

Mortar Class	Mix portions by volume					Mortar suitability			
	Cement (GB/GP)	Masonry cement	Building lime	Sand	Water thickener	Fired clay	Concrete	Calcium silicate	AAC
M1	0	0	1	3	No	✓	X	X	X
(see Note 5)	1	0	3	12	No	✓	X	X	X
M2	1	0	2	9	No	✓	X	X	X
M3	1	0	1	6	Optional	✓	✓	✓	X
	1	0	0	5	Yes	✓	✓	✓	X
	0	1	0	4	No	✓	✓	✓	X
M3	Thin-bed mortar for use with AAC (see Note 4)								
M4	1	0	0.5	4.5	Optional	✓	✓	✓	X
	1	0	0	4	Yes	✓	✓	✓	X
	1	0	0 to 0.25	3	Optional	✓	✓	✓	X
	0	1	0	3	No	✓	X	X	X

✓ = satisfactory
X = unsatisfactory

NOTES:
1. Mortar mixes are designated by the proportions of their ingredients following an initial letter, the chief cementing agent being given as unity, eg, C 1:L 0.5:S 4.5.
2. Volumes refer to materials in the dense-packed condition.
3. The water thickener referred to in this Table is cellulose based. The particular cellulose-based product used is to be specifically suited to this application, and used in accordance with the manufacturer's or supplier's instruction.
4. The thin-bed mortars referred to in this Table are proprietary materials purpose made for use with AAC.
5. Type M1 should be used only in restoration work to match existing construction

Mortar additives;

Can add **air entrainers**, to enhance workability (for sands w/ low clay)

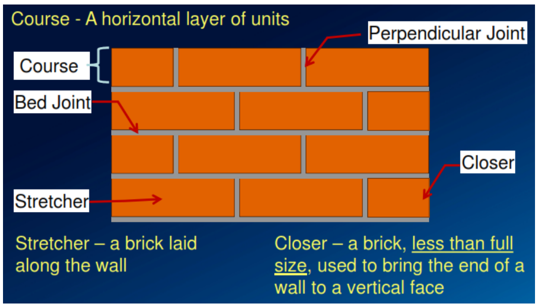
Water thickeners i.e Dynex helps retain water against suction of the masonry unit

Or pigments, set retarders, bonding polymers

Wall construction

Can have **single skin walls** used for cladding, fences

Cavity walls, double skin w/ cavity, can be load bearing, allows air circulation & ↓ noise minimizes rain penetration

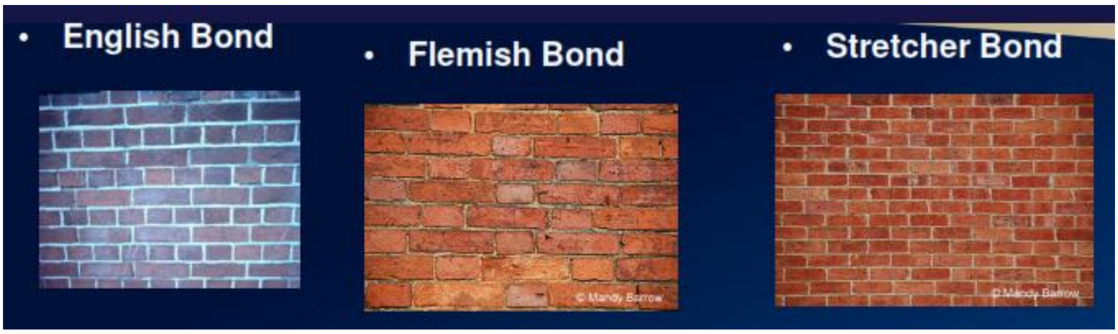


Mortar Bedding:

Full bedding for clay bricks (solid & cored)

Face bedding for conc blocks

Bedding can also be raked (mortar is grooved)



Design of Reinforced Masonry

Reinforced Masonry

AS3700 Section 8

Reinforced Masonry are typical block walls, core filled w/ reinforcement bars

The **Grout used** to core fill is a sand/cement mixture

- Grout used is highly flowable (the grout needs to have high workability but designed to avoid segregation)
- Min cement content = 300kg/m3 and > 12MPa strength
- Take care to avoid blow outs in masonry units due to hydrostatic pressure

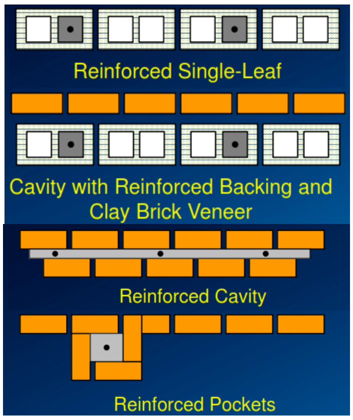
The **reinforcement used** is placed into grouted cores and cavities

- The spacers/bracing needs to be placed carefully
- Provide corrosion protection to suit exposure conditions

Reinforcement in masonry has two purposes:

- **Primary** reinforcements resists compressions, bending, shear & tension
- **Secondary** reinforcement resist shrinkage and temperature effects

Typical Reinforced Masonry Walls



Single skin block wall core filled

Brick veneer wall for façade and reinforced block wall to take loading

Load taken by both skins w/ cavity filled

Reinforced pocket acts as column

Behaviour of Masonry

Masonry = strong in compression but weak in tension

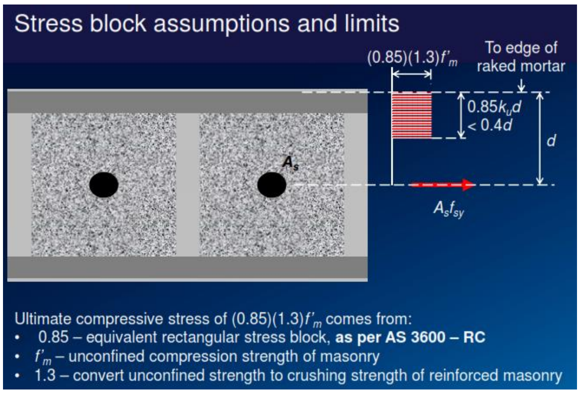
∴ reinforcement is used to transmit tensile loads & control cracking

Failure occurs by yielding of reinforcement then masonry crushes on compression face

∴ strength & serviceability check are required for design due to the ↑ ductility of cross-sections

Masonry Design Assumptions

- Max compression strength = 0.85(1.3)f'm
- Max compressive strain = 0.0035
- Tensile strength of masonry units is assumed 0
- Mechanical properties of reinforcement AS3700.3.6
- Effective depth measured from face of raked mortar (not face of masonry unit)



Design for Compression (Reinforced)

$$F_d \le \phi k_s \left[f'_m A_b + k_c \sqrt{\left(\frac{f'_{cg}}{1.3}\right)} A_g + f_{sy} A_s \right]$$

F.d = design for compressive force acting on cross-section
ϕ = capacity reduction factor (Tb 4.1 = 0.75)
k.s = reduction factor = 1.18 – 0.03*Sr > 1
Sr = Slenderness ratio (CL 7.3.4.3)
f'm = characteristic compressive strength (CL 3.3.2)
A.b = bedded area of a masonry cross-section (CL 4.5.4)
k.c = strength factor for grout in compression
k.c = 1.4 for hollow units w/ density > 2000kg/m3 else k.c = 1.2
f'cg = design compressive strength for grout (CL 3.5)
Ag = design cross section for grout = A.tot – A.b
f'sy = design yield strength of reinforcement (CL 3.6.1 table 3.7)
A.s = total cross section area of reinforcement

But, if **e1/tw > 0.05**
Member must ∴ be designed for combined axial compression & bending **(hence find k)**
(eccentricity of vertical force / wall thickness > 0.05 can lead to buckling)
Reinforcement requirements:
Must be located symmetrically in cross-section and have area > 0.002*A.d
A.d = combined bedded area & grout area
Reinforcement must be tied > ϕ6mm steel ties at centres <= the lesser of:
(i) 400mm or, (ii) smallest cross section dimension

Reinforced Masonry in Bending

$$M_d \le \phi M_u$$

M.d = design bending moment acting on cross-section of member
ϕ = 0.75
Mu = bending moment capacity

$$M_d \le \phi f_{sy} A_{sd} d \left[1 - \frac{0.6 f_{sy} A_{sd}}{(1.3 f'_m) bd} \right]$$

Yellow circle = equivalent to γk.ud/2 in RC design

M.d = design bending moment acting on cross-section of member
A.sd = portion of steel reinforcement cross-sectional area to be used for calculations is the lesser of:
- (0.29*1.3*f'm*b*d) / f.sy or,
- A.st

Steel reinforcement must:
be spaced at centres s<2000 mm
have an area > 0.0013*b*d
have 100mm2 w/in 300mm of end of member
provide M.d>=1.2 capacity for unreinf. Masonry
(w/ horizontal & vertical reinforcement (two-way bending), these must be met in both directions)
d = effective depth of reinforcement
f'm = compressive strength of masonry
b = width of compression face on masonry member
= 1000mm for continues length of wall
= distance between outer bars + smaller value of:
- 400mm (vertical reinf. Only) or,
- 2*wall thickness (1.5 for horiz. Reinf.) or,
- the distance to the structural end of masonry