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NEPAL ENGINEERING COUNCIL
LICENSE EXAM PREPARATION COURSE

FOR

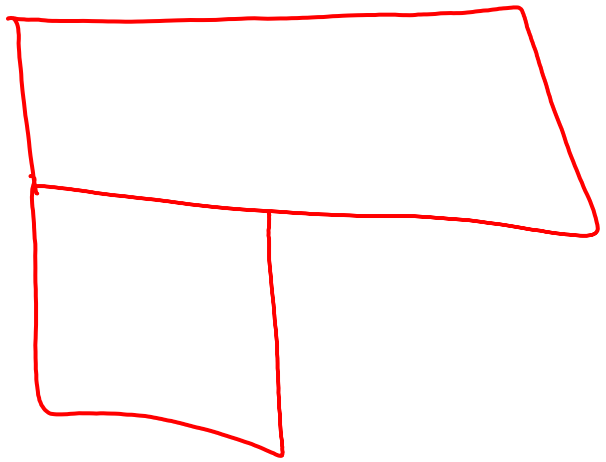
CIVIL ENGINEERS

5. Design of Structure

5.6 Timber and masonry structures

Sub topics

- Design principle of timber beams and columns
- Design of masonry structure
- Failure modes of masonry structure
- Mud mortar, lime mortar and cement mortar



Design principle of timber beam and column

Codes used for design

IS: 883-1994 Code of Practice for Design of Structural Timber in Building
NBC 112:: TIMBER

Density, slope of grain, presence of defects.

Grouped species of timber based on their strength properties namely modulus of elasticity and stress in extreme fiber in bending and tension

Group	Modulus of elasticity (E)	stress in extreme fiber (f_b)
A	$above\ 12.6 \times 10^3 N/mm^2$	$above\ 18.0\ N/mm^2$
B	$above\ 9.8 \times 10^3\ upto\ 12.6 \times 10^3 N/mm^2$	$above\ 12.0\ upto\ 18.0\ N/mm^2$
C	$above\ 5.6 \times 10^3\ upto\ 9.8 \times 10^3 N/mm^2$	$above\ 8.5\ upto\ 12.0\ N/mm^2$

Design principle of timber beam and column

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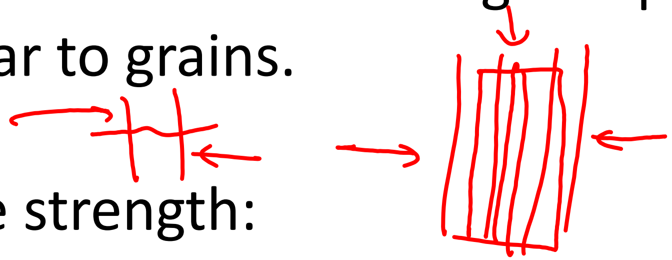
The strength of timber is the highest parallel to the grains and minimum perpendicular to grains.



Compressive strength:

• The compressive strength is found to be the highest when acting parallel to the axis of growth.

• The compressive strength perpendicular to the fibers of wood is much lower than that parallel to fibers of the wood.

Tensile strength:

• Tensile strength along a direction parallel to the grains is found to have the greatest strength that can be developed under any kind of stress.

• Tensile strength parallel to fibers is of the order 80.0 to 190.0 N/cm^2. Generally 2-4 times compressive strength.

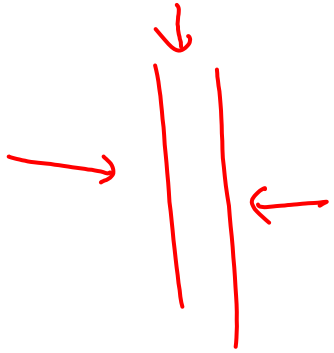
Design principle of timber beam and column

Shearing strength:

- Resistance to shear in across direction is found 3 to 4 times greater than that along fibers.
- The shear strength along the fiber is found of the order 6.5 to 14.5 N/mm^2

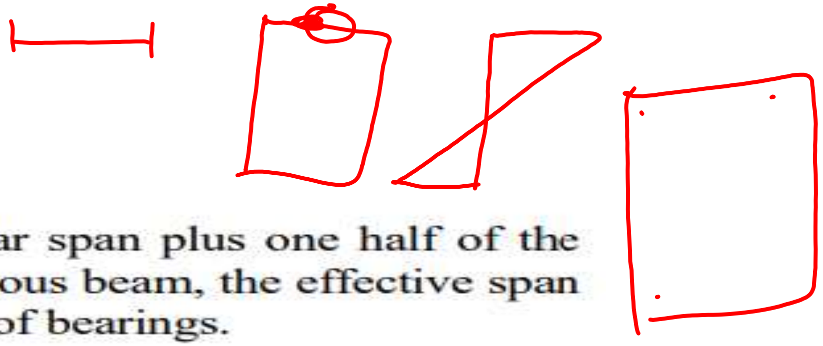
Grading of structural timber

- Select grade
- Grade I
- Grade II



Design principle of timber beam and column

Design of flexural members

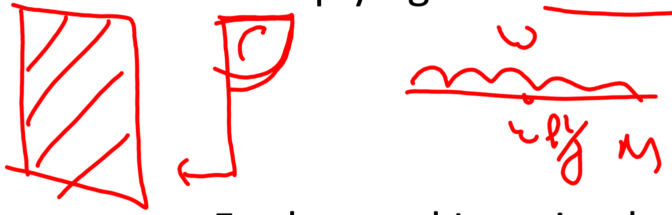


6.3.1 Effective Span

The effective span shall be taken equal to the clear span plus one half of the required length of bearing at each end. For continuous beam, the effective span may be taken equal to the distance between centres of bearings.

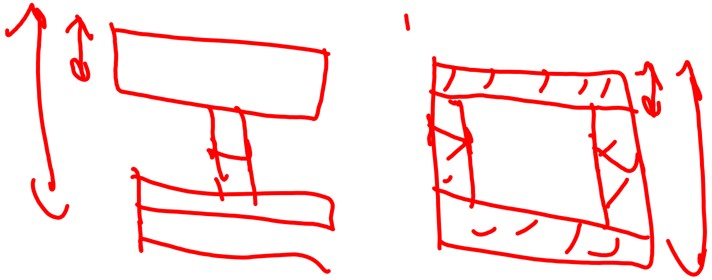
6.3.2 Form Factors for Flexural Members

For depth more than 300 mm, the allowable bending stress in compression will be reduced by multiplying with form factor K_3 as given in the following where D is depth of beam in mm:



$$K_3 = 0.81\left(\frac{D^2 + 89400}{D^2 + 55000}\right)$$

For box and I section beam:



$$K_4 = 0.8 + 0.8Y\left(\frac{D^2 + 89400}{D^2 + 55000} - 1\right)$$

Design principle of timber beam and column

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Design of flexural members

Where :

$Y =$ $p1^2(6\text{-}8p1 + 3p1^2)(1\text{-}q1) + q1$

$p1 =$ ratio of thickness of compression flange to the depth of beam

$q1 =$ ratio of thickness of web or webs to the width of the beam.

Note :

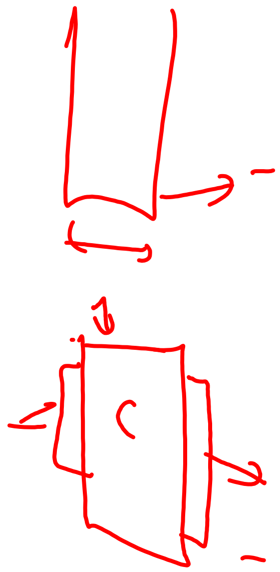
i) For solid circular cross sections, the form factor K_5 shall be taken as 1.18.

ii) For square cross-sections where the load is in the direction of diagonal, the form factor K_6 shall be taken as 1.414.

Design principle of timber beam and column

- Width

The minimum width of the beam or any flexural member shall not be less than 50 mm or 1/50 of the span, whichever is greater.



- Depth

The depth of beam or any flexural member shall not be taken more than three times of its width without lateral stiffening.

$$d \leq 3b$$

- If either or both condition are not met we need to provide lateral stiffeners such that distance between them does not exceed 50 times width

Design principle of timber beam and column

Deflection criteria:

For beam supporting brittle covering like asbestos cement sheets, slates etc.

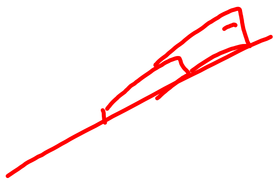
1/360 of span

For beam supporting other flooring

1/240 of span

For cantilever beam

1/150 of clear overhang



Design principle of timber beam and column

Solid column

Seperated into short, intermediate and long based on slenderness ratio(S/d)

Slenderness ratio should not be more than 50 for solid column

$$K_8 = 0.584\sqrt{\frac{E}{f_{cp}}}$$

$$E = modulus\ of\ elasticity\ in\ bending$$

$$f_{cp} = premissible\ stress\ in\ compression\ parallel\ to\ grain$$

Design principle of timber column

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Short column

S/d doesnot exceed 11

$$f_c = f_{cp}$$

Intermidiate column

S/d is between 11 and K_8

$$K_8 = 0.584\sqrt{\frac{E}{f_{cp}}}$$

$$f_c = f_{cp}\left[1 - \frac{1}{3}\left(\frac{S}{K_8 d}\right)^4\right]$$

Long column

S/d is greater than K_8

$$f_c = \frac{0.329E}{\left(\frac{S}{d}\right)^2}$$

Design principle of timber beam and column

Box and Built up column

Seperated into short, intermediate and long based on slenderness ratio($\frac{S}{\sqrt{d_1^2+d_2^2}}$)

Slenderness ratio should not be more than 50 for solid column

$$K_9 = \frac{\pi}{2}\sqrt{\frac{U \times E}{5qf_{cp}}}$$

$E = modulus\ of\ elasticity\ in\ bending$

$f_{cp} = premissible\ stress\ in\ compression\ parallel\ to\ grain$

Design principle of timber column

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Short column

$\frac{S}{\sqrt{d_1^2+d_2^2}}$ doesnot exceed 8

$$f_c = qf_{cp}$$

Intermidiate column

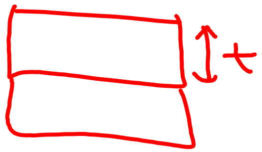
$\frac{S}{\sqrt{d_1^2+d_2^2}}$ is between 8 and K_9

$$f_c = qf_{cp}\left[1 - \frac{1}{3}\left(\frac{S}{K_9\sqrt{d_1^2 + d_2^2}}\right)^4\right]$$

Design principle of timber column

Long column

$\frac{S}{\sqrt{d_1^2+d_2^2}}$ is greater than K_9



$$f_c = \frac{0.329UE}{\left(\frac{S}{\sqrt{d_1^2 + d_2^2}}\right)^2}$$

t (in mm)	U	q
25	0.80	1.0
50	0.60	1.0

Design of masonry structure(NBC 202)

Wall thickness:

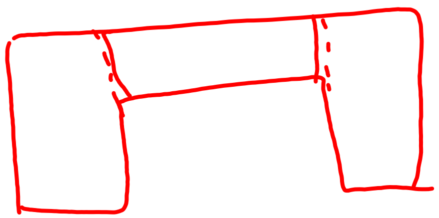
Load bearing stone masonry in cement mortar: 350 mm

Load bearing brick masonry in cement mortar(one storey): 230 mm

Load bearing brick masonry in cement mortar(two storey):

Ground floor: 350 mm

First floor and attic: 230 mm



The cantilever-projection of roof/floor, where provided, shall not exceed 1m. No loadbearing wall shall be constructed over such cantilever projections.

Construction material

PCC M15

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Minimum grade of concrete is M20. Nominal mix 1:1.5:3 with w/c ratio not more than 0.6 can be used.

All cement used shall be Ordinary Portland Cement meeting the requirements of NS : 049-2041.
It is advisable to use cement which has obtained the NS mark if independent tests are not carried out

The aggregates shall conform to the requirements of IS : 383-1970 and IS : 515-1959.

Construction material

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Bricks : The bricks shall be of a standard rectangular shape, burnt red, hand-formed or machine-made, and with a crushing strength not less than 3.5 N/mm2 . The higher the density and the strength, the better they will be. Bricks should be of class A1 or B1.

No of Storey	Floor	Proportion of ingredients for mortar (cement: sand)	Min. crushing strength of bricks (N/mm^2)	Minimum brick wall thickness (mm)
2	First	1:6	3.5	230
	Ground	1:6	7.5	230
			5	350
1	Ground	1:6	3.5	230

Construction material

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Wall Thickness : A minimum thickness of one half-brick (115 mm) and a maximum thickness of one brick (240 mm) shall be used for the walls constructed as non load-bearing walls in these buildings.

Mortar : Cement-sand mixes of 1:6 and 1:4 shall be adopted for one-brick and half brick thick walls, respectively. The addition of small quantities of freshly hydrated lime to the mortar in a lime-cement ratio of ¼:1 to ½:1 will increase its plasticity greatly without reducing its strength.

Construction material

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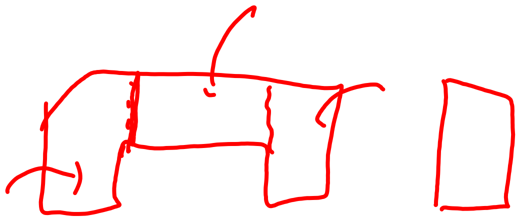
Plaster : All plasters shall have a cement-sand mix not leaner than 1:6 on outside or inside faces. It shall have a minimum 28 days cube crushing strength of $3\ \mathrm{N/mm^2}$. A minimum plaster thickness of 10 mm shall be adopted.

Notes:
Plaster in extreme severe condition in external wall: 1:3
Plaster in external wall: 1:4
Internal plastering without fine sand: 1:5
Internal plastering with fine sand: 1:6

Thickness of 12 mm is generally used, thickness of 6 mm is used underside of RCC members with mortar of strength 1:3

Consideration to be made



(a) Whole or individual block should be as symmetrical as possible.

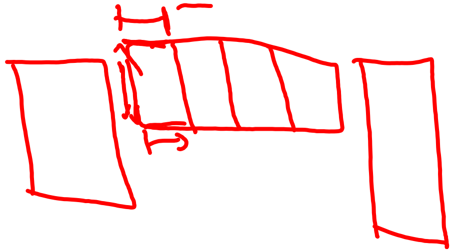
(b) The Complex shapes of plan should be divided into regular blocks(L <3B) with minimum separation of 40 to 50 mm throughout the height

(c) Maximum height of sorey for brick masonry is 3.2 m and for stone masonry is 3.0 m.

(d) Maximum short span of floor for brick masonry is 3.5 m and for stone masonry is 3.2 m.

(e) Maximum span is 4.5m and maximum area of floor is 13.5 m^2.

(f) The footing width should not be less than 900 mm for 2 storey and 800 mm for one story.



Opening in wall

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(a) Openings are to be located away from inside corners by a clear distance equal to at least 1/4 of the height of the opening, but not less than 600 mm.

(b) The total length of openings in a wall is not to exceed 50 % of the length of the wall between consecutive cross-walls in single-storey construction, 42 % in two-storey construction.

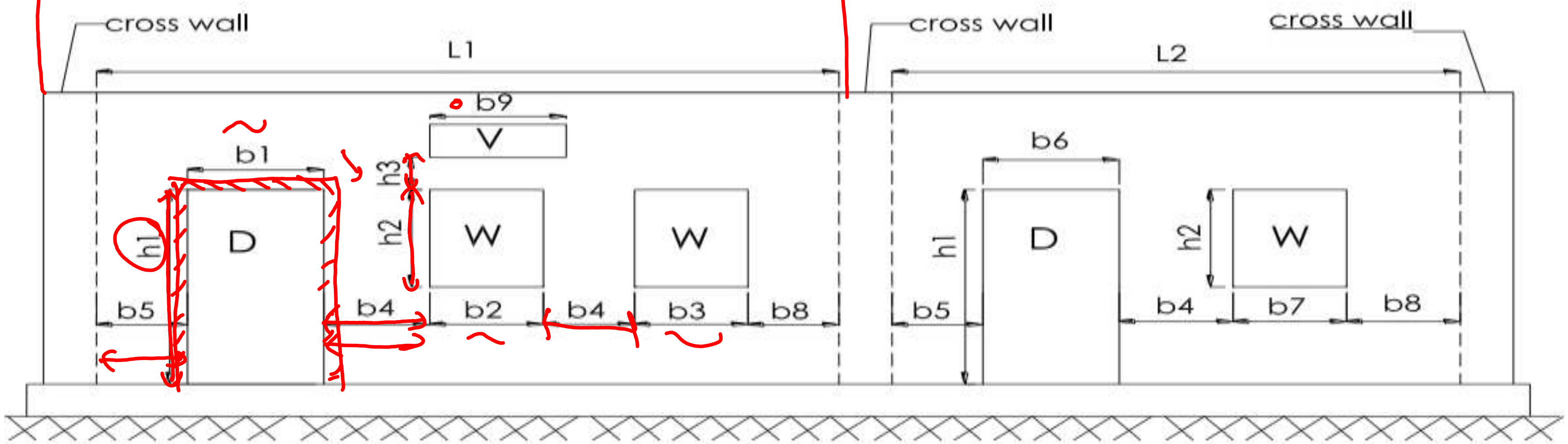
(c) The horizontal distance (pier width) between two openings is to be not less than one half of the height of the shorter opening (seeFigure 5-2), but not less than 600 mm.

(d) The vertical distance from one opening to another opening directly above it shall not be less than 600 mm, nor less than one half the width of the openings

Opening in wall

e) When an opening does not comply with requirements (i) to (iv), it shall be boxed in reinforced jambs through the masonry

f) If the vertical opening of the wall is more than 50 % of the wall height, vertical bars shall be compulsorily provided in the jambs.



Note:
b1+b2+b3 ≤ 0.5L1 for one storey and 0.42L1 for two storey
b6+b7 ≤ 0.5L2 for one storey and 0.42L2 for two storey
b4 ≥ 0.5h2 but not less than 600mm
b8 ≥ 0.25h2 but not less than 600mm
b5 ≥ 0.25h1 but not less than 600mm
h3 ≥ (greater of 0.5b2, 0.5b9 and 600mm)

D = Door
W = Window
V = Ventilation

RC bands in masonry structure

Table 6-1: Requirement for steel in RC BAND

Band /Beam	RC band minimum thickness	Min. No. Of bars	Min. Diameter of Bars (mm)
Plinth	150mm[*1]	4	12
Sill/Parapet[#]	75mm	2	10
Lintel	75mm[*2]	2	12
	150mm[*2]	2 2	10(top) 12(bottom)
Roof	75mm[*3]	2	12
	300mm[*3]	4	12
Dowel (Stitch)	75mm	2	8

*Note: *1: Plinth band thickness can be reduced to 75mm reinforced with 2-12mm dia bars in case of hard soil.*

RC bands in masonry structure

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**1: Plinth band thickness can be reduced to 75mm reinforced with 2-12mm dia bars in case of hard soil.*

**2: Where opening width does not exceed 1.25m and masonry height above opening does not exceed 0.9m, 75mm thick lintel is sufficient. In such lintels, longitudinal reinforcement shall be placed maintaining 25mm cover from bottom. For opening width up to 2m and masonry height above opening upto 1.2m, 150mm thick lintel band is necessary.*

**3: Roof band of at least 75mm thickness shall be provided where flexible floor/roof (eg. timber floor) rests. For RCC roof/floor, 300mm deep RCC beam (including slab) cast monolithically with slab, shall be provided.*

Footing in masonry structure

202-MRT

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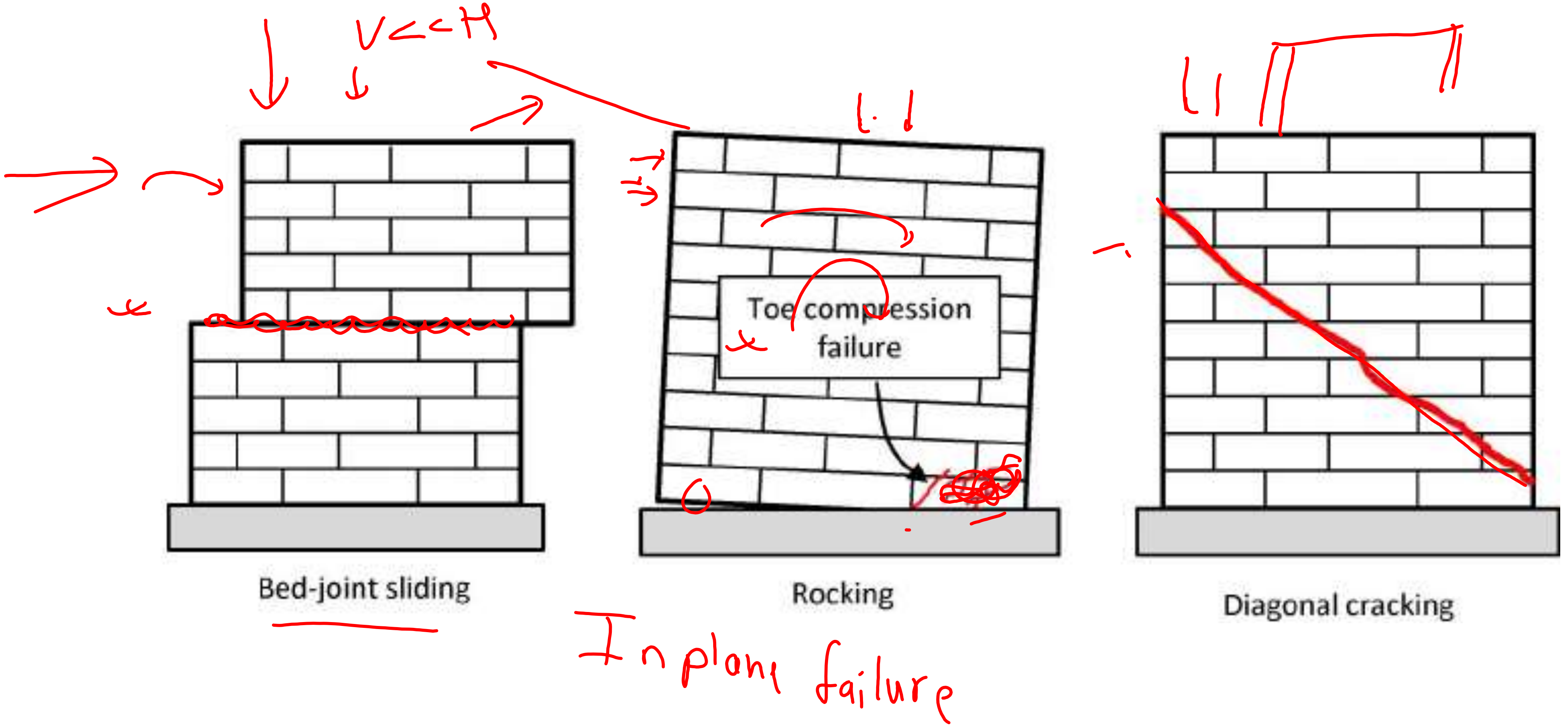
The footing should be provided at a depth below the zone of deep freezing in cold regions and below the level of shrinkage cracks in clayey soils but not less than 800 mm for one storey building and not less than 900mm for two storey building.

Table 5-1: Base width of footings

Masonry Type	No of Storey	Minimum base width (mm) of wall footing for soil type:		
		Soft	Medium	Hard
Brick	Two	900	650	550
	One	650	550	450
Stone	Two	*	800	600
	One	800	600	600

Failure modes of masonry structure



Failure modes of masonry structure

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1. Sliding shear failure

It results in a building sliding off its foundation or on one of the horizontal mortar joints. It is caused by low vertical load and poor mortar. If the building is adequately anchored to the foundation, the next concern is for adequate resistance of the foundation itself, in the form of some combination of horizontal sliding friction and lateral earth pressure. The dislocation of a lightly attached roof is also an example of this type of failure. A wall with poor shear strength, loaded predominantly with horizontal forces can exhibit this failure mechanism.

Aspect ratio for such walls is usually 1:1 or less (1:1.5)

Failure modes of masonry structure

2. Diagonal cracks

Diagonal cracks in masonry walls when the tensile stresses, developed in the wall under a combination of vertical and horizontal loads, exceed the tensile strength of the masonry material.

Failure modes of masonry structure

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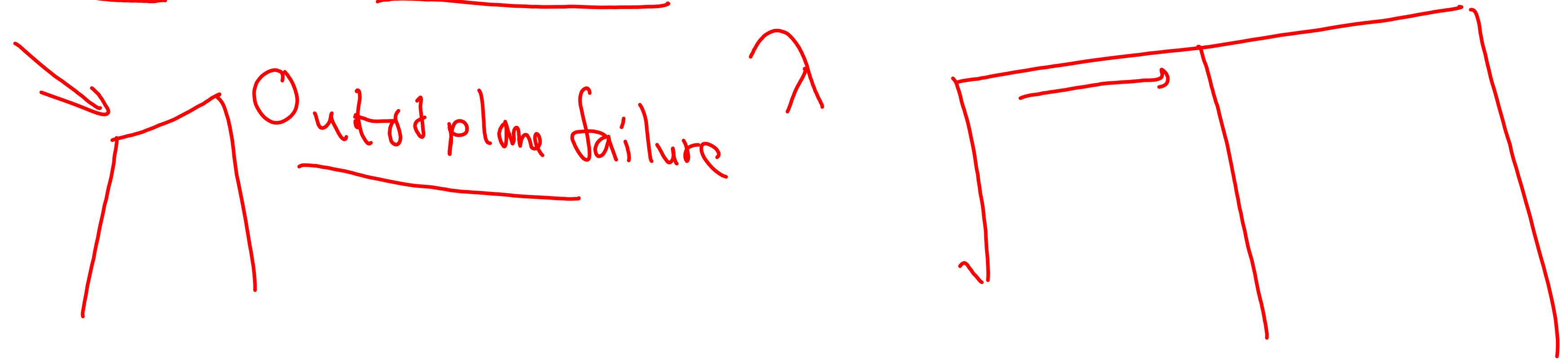
3. Non structural failure

While structural elements of a building should be the prime concern for earthquake resistance, everything in the building construction should resist forces generated by earthquakes. Non structural walls, suspended ceilings, window frames and fixtures should be secure against movement during the shaking actions. Failure here may not lead to building collapse, but it still constitutes danger for occupants and requires costly replacements or repair.

Failure modes of masonry structure

4. Failure due to overturning

The critical nature of the overturning effect has much to do with the form of the building's vertical profile. A wall that is too tall or too long in comparison to its thickness is particularly vulnerable to shaking in its weak direction. Thus the tendency of a wall to topple when pushed in the weak direction can be reduced by limiting its length-to-thickness and height-to-thickness ratios.



Failure modes of masonry structure

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Slenderness ratio of wall

Load bearing $\lambda \leq 27$

Non load bearing $\lambda \leq 30$

$$\lambda_{wall} = minimum\ of \begin{cases} \dfrac{Effective\ length}{Actual\ thickness} \\ \dfrac{Effective\ height}{Modified\ thickness} \end{cases}$$

$$Modified\ thickness = Stiffening\ coefficient\ of\ wall \times Actual\ thickness$$

Failure modes of masonry structure

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If the actual thickness of a brick masonry wall is 19 cm, its effective length is 2.70 m, its effective height is 2.82 m and its code-specified stiffening coefficient is 1.2, then for design considerations, the slenderness ratio of the wall will be taken as (Ans 12.4)

$\lambda_{wall} = \min \text{ of } \begin{cases} \dfrac{2.70}{19} = ~~12.36~~ \; 14.21 \\ \dfrac{282}{1.2 \times 19} = ~~14~~ \; 12.36 \end{cases}$

{ A/C / Bracing / lacing
MRT

Mortar

1:6

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Mixture of sand ,binding material made into paste.
Additional materials are added to impart strength in mortars

1. Mud mortar
2. Lime mortar
3. Cement mortar – sand
4. Surkhi mortar

Mortar

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1. Mud mortar

Made up of clayey soil and water
Additional saw dust, rice husk may be added
The additional of fibrous materials helps reduce shrinkage and cracks.

Mortar

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2. Lime mortar

Lime is used as binding material and sand or clay is additionally added

Hydraulic lime contains substances which set by hydration so it can set under water.

Non-hydraulic lime sets by carbonation and so needs exposure to carbon dioxide in the air and cannot set under water or inside a thick wall.

Mortar

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$Ca(OH)_2$

Non-hydraulic lime is primarily composed of (generally greater than 95%) calcium hydroxide, Ca(OH)2. Non-hydraulic lime is produced by first heating sufficiently pure calcium carbonate to between 954° and 1066 °C, driving off carbon dioxide to produce quicklime (calcium oxide).

$Ca(OH)_2 + CO_2 \quad CaCO_3$

The quicklime is then *slaked* to form slaked lime, fat lime, lime putty or air lime.

$CaO + H_2O \rightarrow Ca(OH)_2$

Mortar

$Ca(OH)_2$

CaO

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Hydraulic lime (HL) is a general term for calcium oxide, a variety of lime also called quicklime, that sets by hydration. Hydraulic lime provides a faster initial set and higher compressive strength than air lime, and hydraulic lime will set in more extreme conditions, including under water.

Mortar

3. Cement Mortar
4. Surkhi Mortar

Made by mixture of brick dust with other binding material (usually lime) in place of sand.
It imparts strength and color.

Surkhi mixed cement concrete is more plastic, bleeds less and segregates less as compared to ordinary cement concrete.

Mortar

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Mortar is produced by mixing a binding material (cement or lime) with fine aggregate (sand, surki, etc) with water. For construction purpose, different types of mortar are used. Depending upon the materials used for mortar mixture preparation, the mortar could be classified as follows.

1. Cement Mortar
2. Lime Mortar
3. Surki Mortar
4. Gauged Mortar
5. Mud Mortar

Mortar

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Cement Mortar

Cement mortar is a type of mortar where cement is used as binding material and sand is used as fine aggregate. Depending upon the desired strength, the cement to the sand proportion of cement mortar varies from 1:2 to 1:6.

Lime Mortar

Lime mortar is a type of mortar where lime (fat lime or hydraulic lime) is used as binding material and sand is used as fine aggregate. The lime to the sand proportion of cement mortar is kept 1:2. The pyramids at Giza are plastered with lime mortar.

Mortar

Gauged Mortar

Gauged mortar is a type of mortar where cement and lime both are used as binding material and sand is used as fine aggregate. Basically, it is a lime mortar where cement is added to gain higher strength. The process is known as gauging. The cement to the lime proportion varies from 1:6 to 1:9. Gauged mortar is economical than cement concrete and also possess higher strength than lime mortar.

Surki Mortar

Surki mortar is a type of mortar where lime is used as binding material and surki is used as fine aggregate. Surki mortar is economic.

Mortar

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Mud Mortar

Mud mortar is a type of mortar where mud is used as binding material and sawdust, rice husk or cow-dung is used as fine aggregate. Mud mortar is useful where lime or cement is not available.

Thank YOU !!!

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