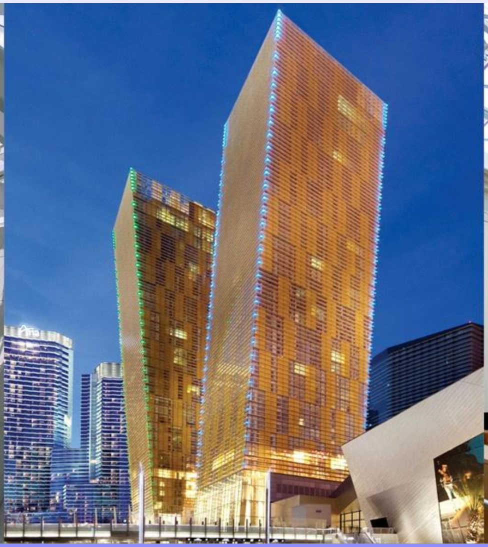
QATAR UNIVERSITY
جامعة قطر

COLLEGE OF ENGINEERING
DEPARTMENT OF CIVIL & ARCHITECTURAL ENGINEERING



CVEN 320 : Design of Reinforced Concrete Members

Introduction & Loads

WAEL I. ALNAHHAL, Ph. D., P. Eng

Fall, 2020

Conversion from US customary units to SI units

Quantity	US customary units	SI units
mass	pound	0.45Kg
mass	kips=1000 pound	450Kg
Length	inch	25.4 mm
Length	Foot=12 inch	304.8 mm
Stress	psi	6.84E-3 MPa
Stress	ksi	6.84 MPa
Distributed load	Psf (pound per square feet)	~1/20 KN/m^2

Concrete and Reinforced Concrete

Concrete – a mixture of fine aggregate (sand), coarse aggregate (eg, limestone), cement, water, air and admixtures.

Admixtures are materials, other than cement, aggregate and water, that are added to concrete either before or during its mixing to alter its properties, such as workability, curing temperature range, set time or color.

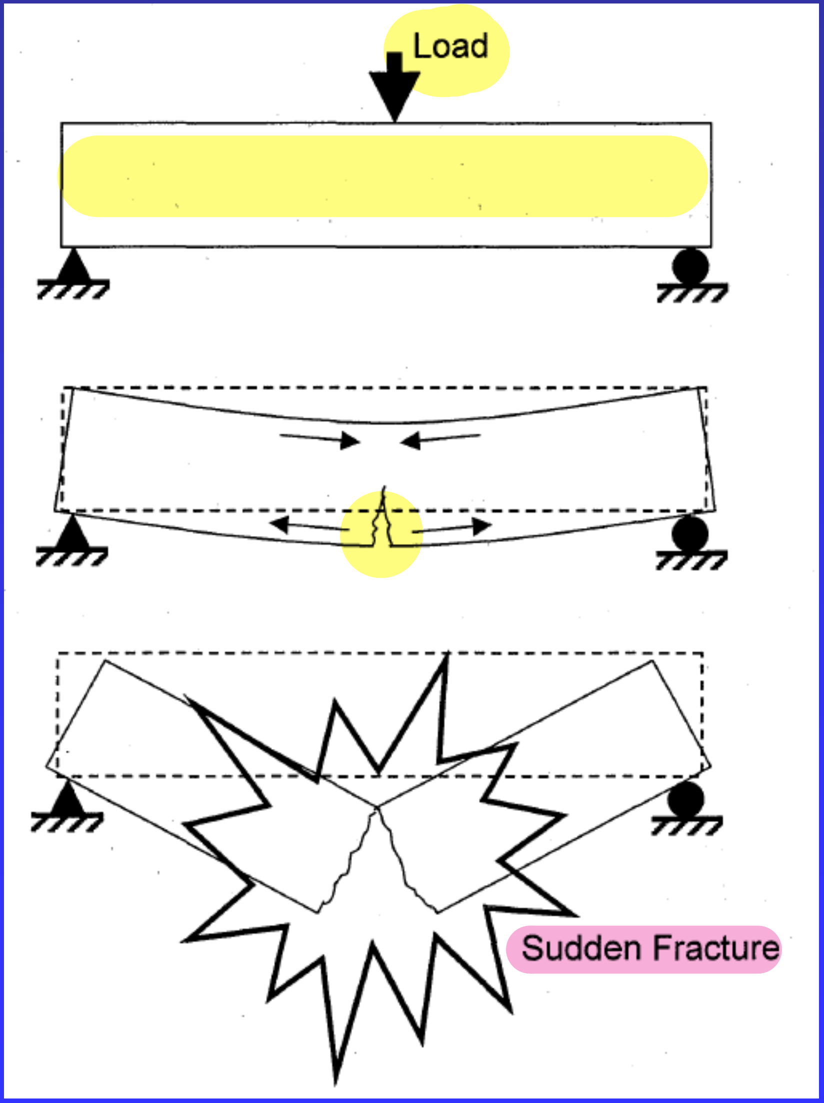
Concrete and Reinforced Concrete

Concrete has high compressive strength and low tensile strength

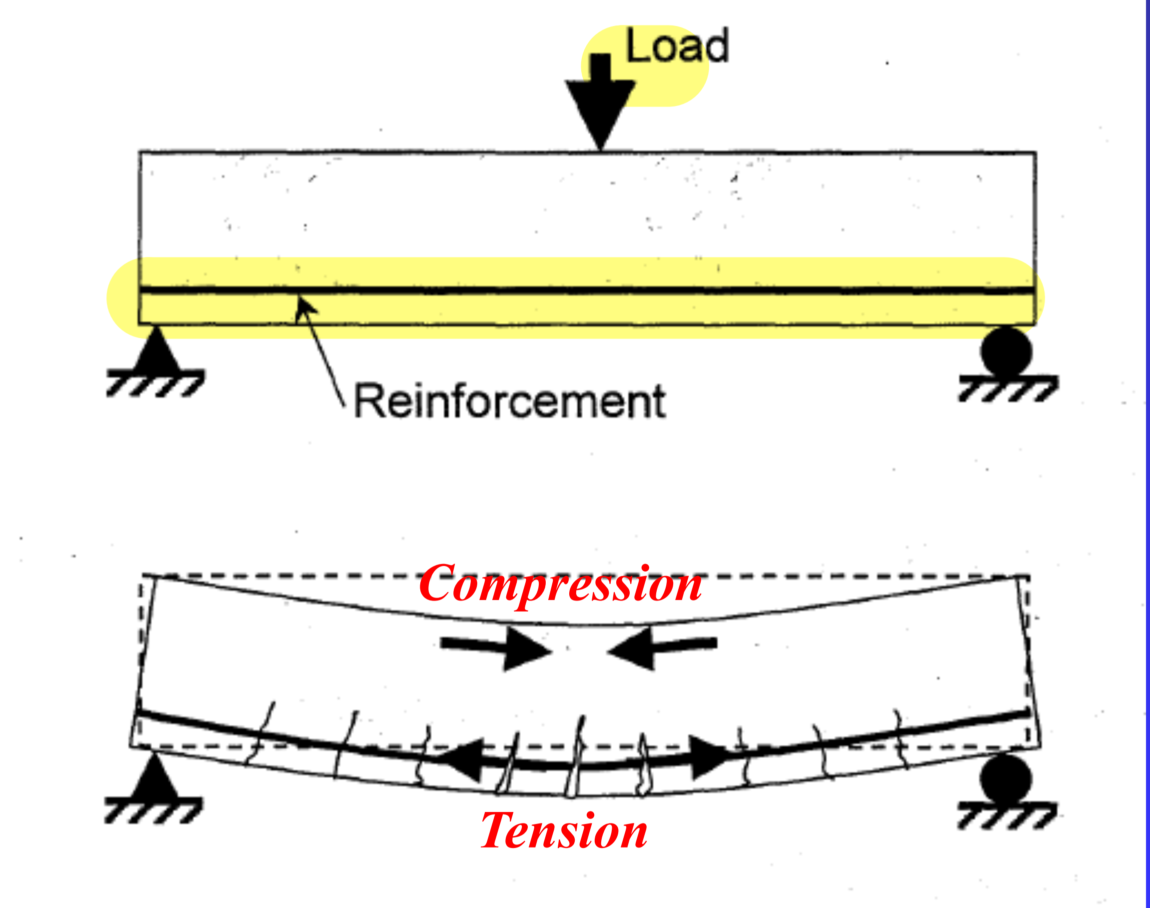
Reinforced concrete is a combination of concrete and steel. The reinforcing steel is used to resist tension

Reinforcing steel can also be used to resist compression (columns)

Plain Concrete –BEAM EXAPMLE



Reinforced Concrete –BEAM EXAPMLE



Advantages of Reinforced Concrete

High compressive strength relative to unit cost

High resistance to effects of fire and water

Reinforced concrete structures have high stiffness

Low maintenance cost

Advantages of Reinforced Concrete

Reinforced concrete structures have a long service life

Reinforced concrete is often the only economical material for footings, floor slabs, basement walls and piers

Reinforced concrete offers architectural flexibility

Advantages of Reinforced Concrete

Reinforced concrete uses local materials for aggregate, and only small amounts of cement and steel, which are items that may not be available locally

Labor skills are not as high for reinforced concrete construction, when compared to some other common materials, such as structural steel

Disadvantages of Reinforced Concrete

- Concrete has a low tensile strength, requiring use of reinforcing steel

- Forms are required to hold the concrete until it hardens. In addition, falsework may be necessary. Formwork and falsework are expensive

- Concrete has relatively low strength when compared to its unit weight

Disadvantages of Reinforced Concrete

High unit weight translates into large dead load and corresponding increase in bending moment

Concrete beams are relatively large, which leads to, for example, larger story heights and taller buildings

Concrete properties can vary widely depending on proportioning, mixing and curing

Codes

Building Code Requirements for Structural Concrete (ACI 318M-14) for SI units

International Building Code (IBC 2015)

Portland Cement

Type I – common, all-purpose cement

Type II – low heat of hydration and some resistance to sulfates

Type III – high, early strength; high heat of hydration

Type IV – low heat of hydration

Type V – used for concrete with exposure to high concentration of sulfates

Portland Cement

Concrete made with Type I portland cement must cure about two weeks to achieve sufficient strength to permit removal of forms and application of small loads

Concrete made with Type I portland cement reaches design strength in about 28 days

Concrete made with Type III portland cement reaches design strength in three to seven days

Portland Cement

Concrete made with Type III portland cement produces high heat of hydration; more likely to cause cracking

Concrete used in seawater or some soils may be subjected to attack by chlorides or sulfates

Air-Entraining Admixtures

Air-entraining admixtures for concrete must conform to either ASTM C260 or ASTM C618

Air-entraining admixtures produce small air bubbles in the concrete

When water in concrete begins to freeze it expands

Air-Entraining Admixtures

The expanding water moves into the space in the air bubbles

In the air bubbles the water has room to expand without creating internal pressure in the concrete

Concrete without entrained air will deteriorate due to freeze-thaw cycles

Important for bridge decks and other concrete members exposed to freeze-thaw cycles

Other Admixtures

Accelerating admixtures, such as calcium chloride, reduce curing time

Calcium chloride can cause corrosion in reinforcing steel, aluminum and other materials

Retarding admixtures slow the rate of set of concrete and reduce temperature increase

Retarding admixtures are useful when a large amount of concrete is to be placed and it is important to reduce temperature

Other Admixtures

Retarding admixtures prolong the plasticity of the concrete, increasing the bond between successive pours

Superplasticizers are made from organic sulfates

Superplasticizers maintain workability with reduced water/cement ratio (usually using less cement)

Other Admixtures

Superplasticizers are used to produce self-consolidating concrete (SCC)

With SCC, vibration is not required to get concrete to flow around reinforcing bars and in congested areas

Properties of Reinforced Concrete

Compressive Strength

F_c'

The specified compressive strength of concrete is denoted by the symbol f_c'

Compressive strength is determined by testing a 6x12 in(150x300 mm) cylinder at an age of 28 days

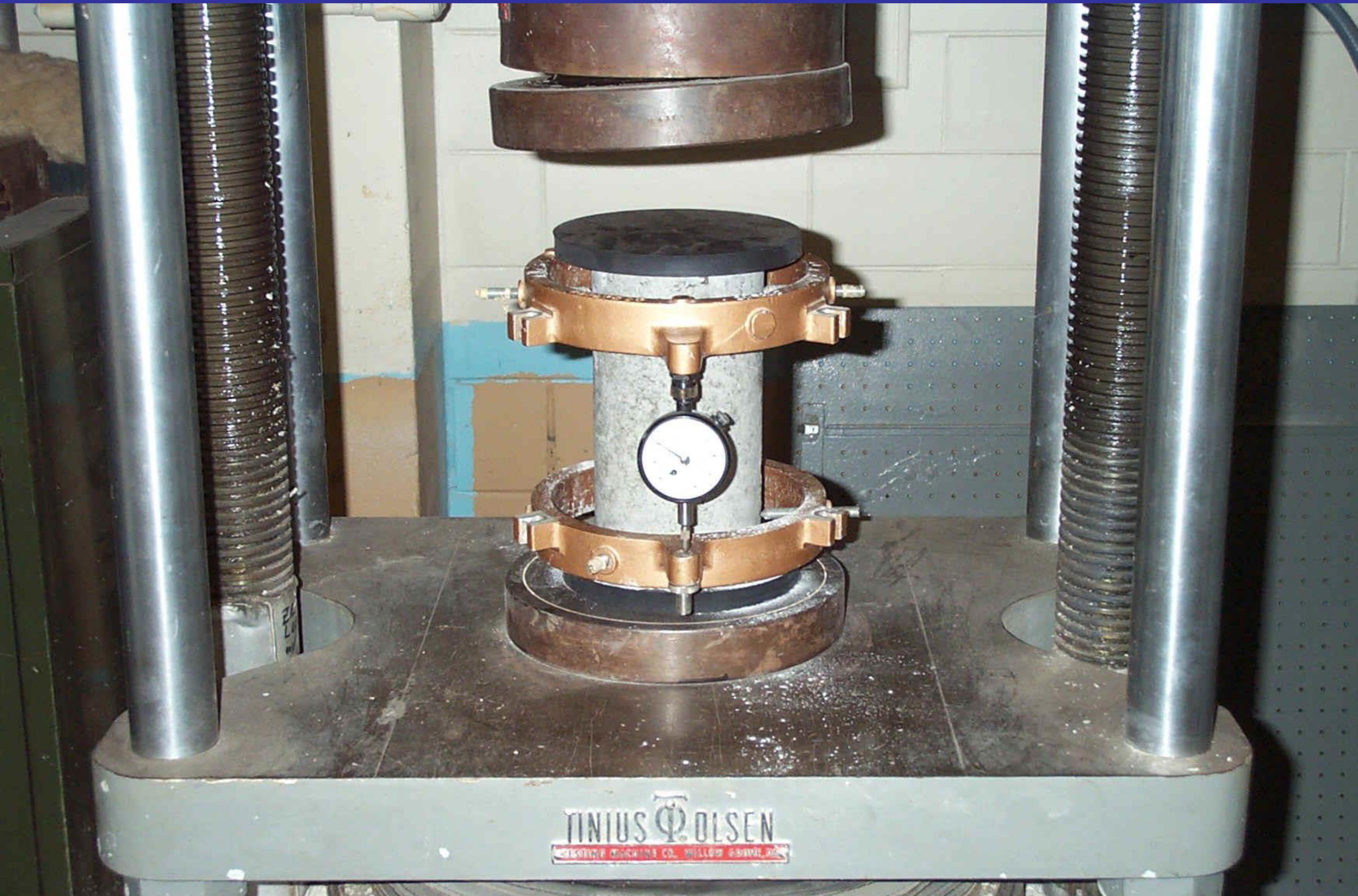
For most applications, the range of concrete strength is 3,000 to 4,000 psi (21 to 28 MPa)

Compressive Strength

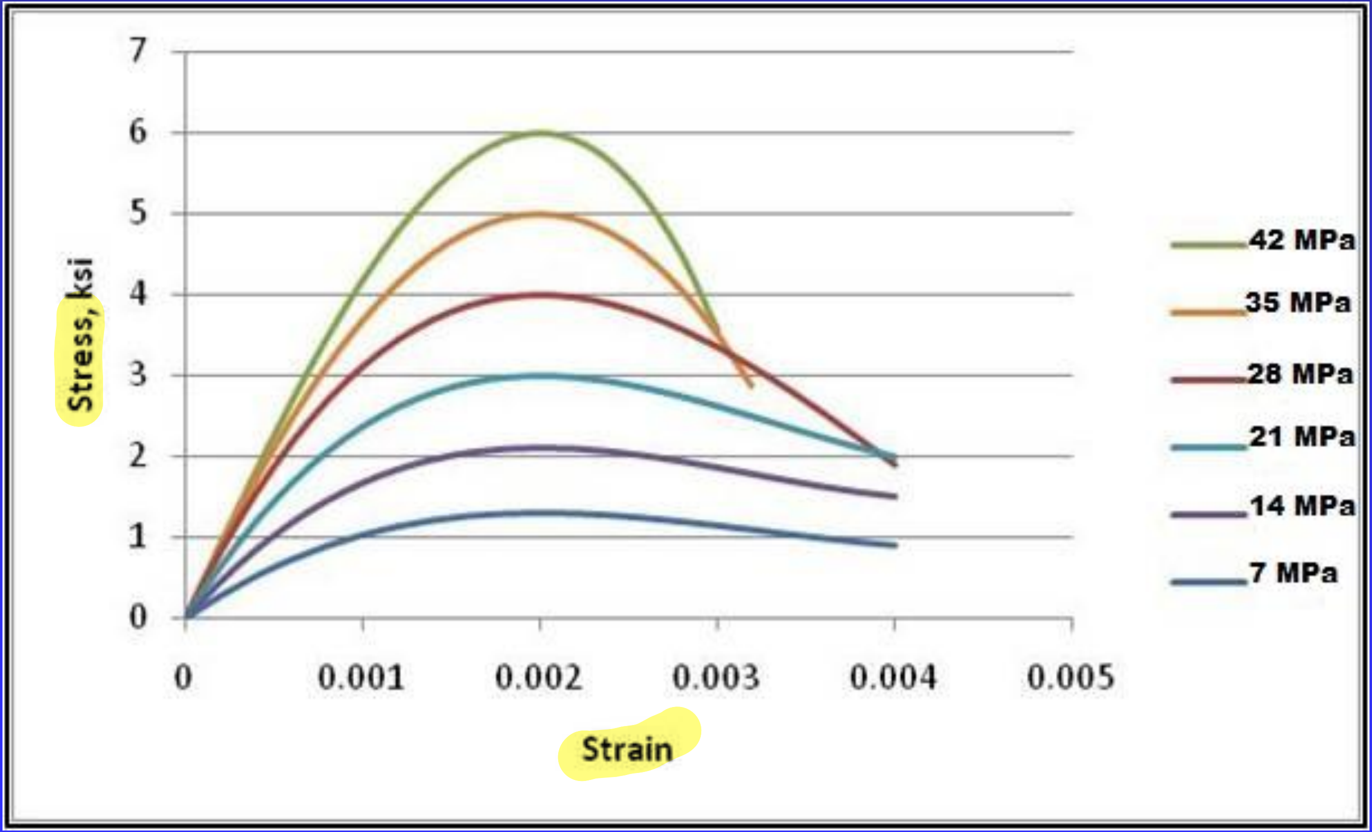
For prestressed concrete, the range of concrete strength is 5,000 to 6,000 psi (35 to 42 MPa)

For columns with high axial loads (lower stories of tall buildings), concrete with strength in the range 9,000 to 10,000 psi (63 to 70 MPa) may be used

Compression Test Setup for f'c



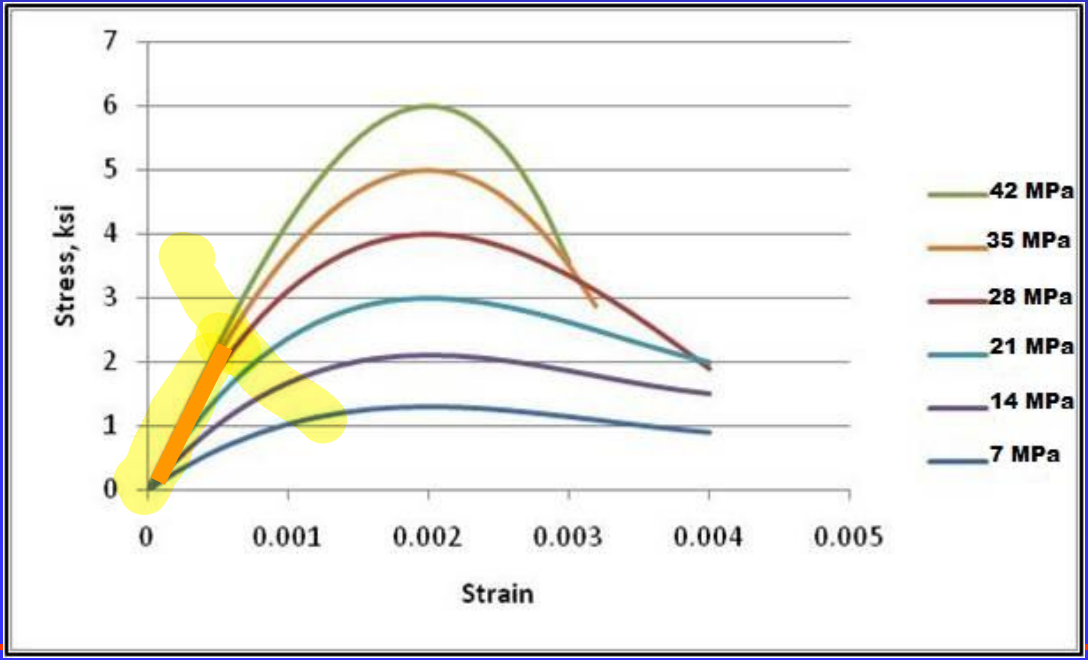
Concrete Stress-Strain



Concrete Stress-Strain

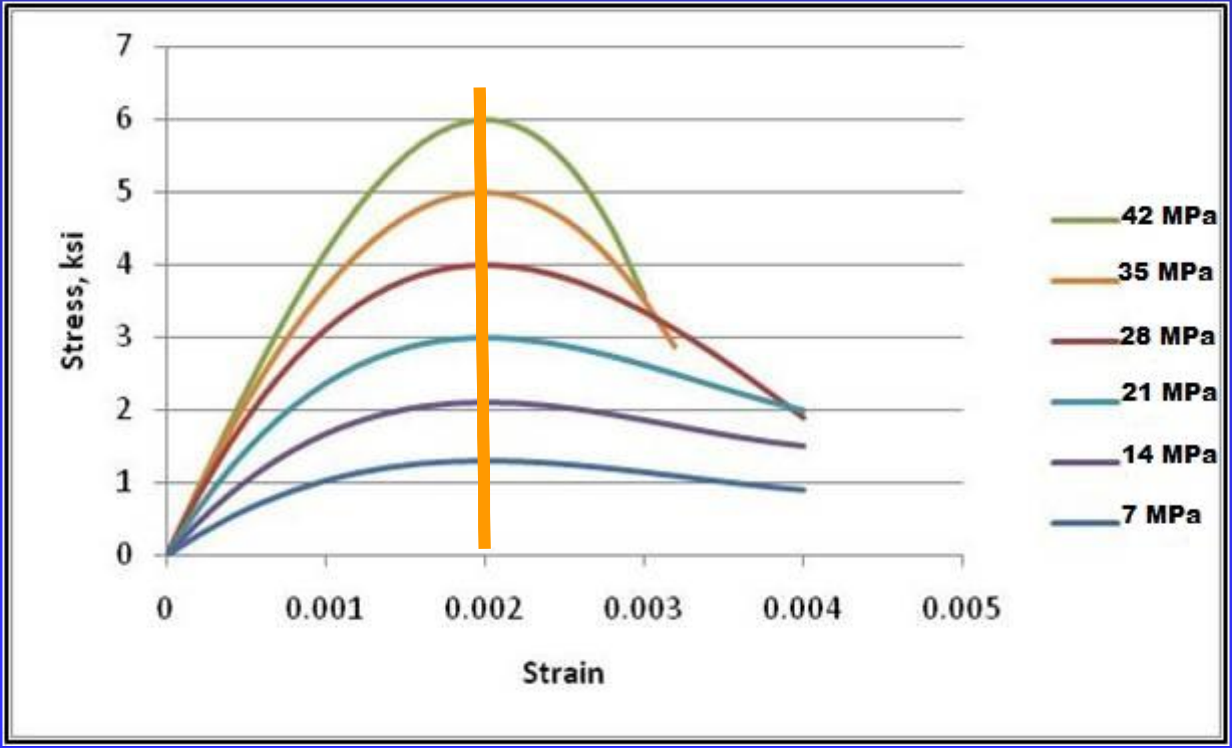
The relationship between stress and strain is roughly linear at stress levels equal to about one-third to one-half the ultimate strength.

Beyond this range the relationship is non-linear



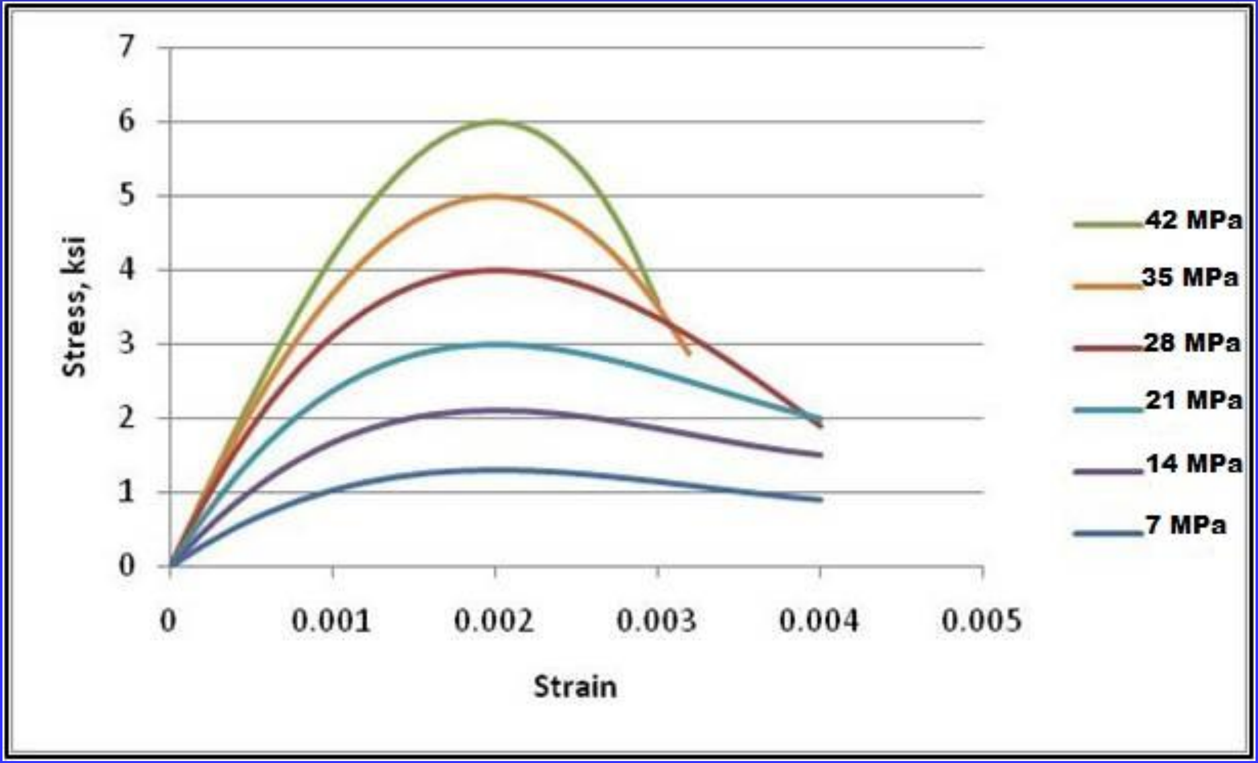
Concrete Stress-Strain

Regardless of compressive strength, all concretes reach their maximum strength at a strain of about 0.002



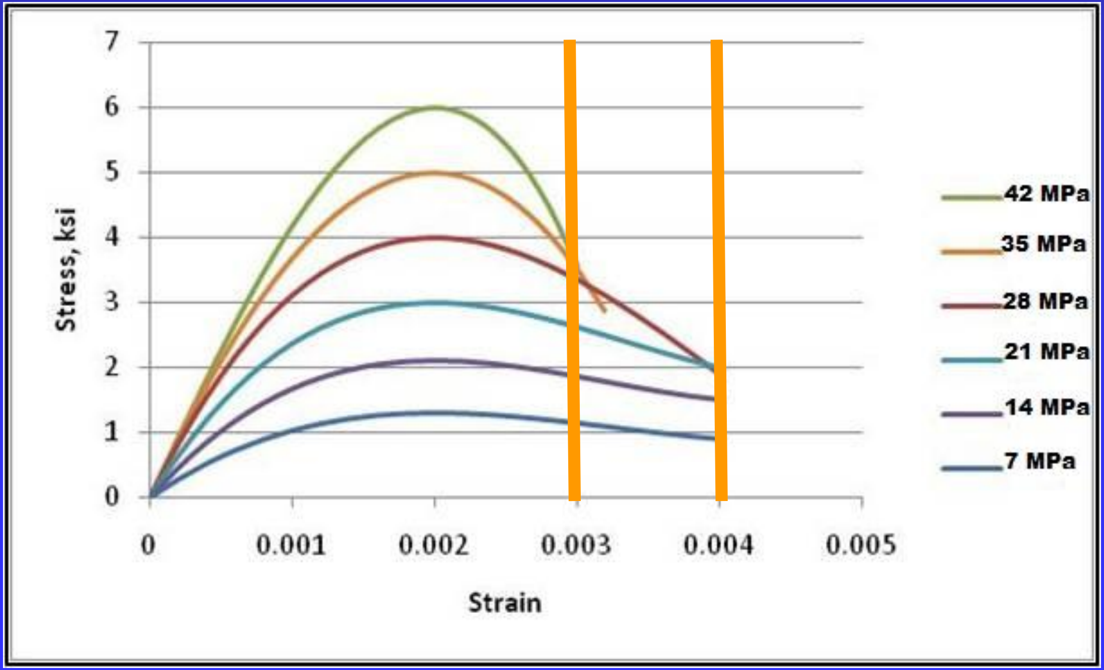
Concrete Stress-Strain

Concrete does not have a well-define yield point.



Concrete Stress-Strain

Ultimate strain achieved is on the order of 0.003 to 0.004. Lower strength concrete achieves higher ultimate strains than does higher strength concrete



Static Modulus of Elasticity

Concrete does not have a single modulus of elasticity

The particular value varies with concrete strength, age, type of loading and proportions of aggregate and cement

ACI Code Section 8.5.1 -

$E_c = 0.043\, w_c^{1.5} \sqrt{f'_c}$ $w_c = 1500 \sim 2500$ kg/m^3

For concrete weighing about 2320 Kg/m^3 :

$E_c = 4700 \sqrt{f'_c}$ E_c & f'_c are in MPa

Static Modulus of Elasticity

High-strength concrete (> 42 MPa)

$$E_c = \left[3.32\sqrt{f_c^{'}} + 6895\right]\left(\frac{w_c}{2320}\right)^{1.5}$$

Dynamic modulus is about 20 to 40 percent higher than the static modulus

Poisson's Ratio

$0 < \nu < 0.5$

About 0.11 for high strength concrete (>42MPa)

About 0.21 for low strength concrete

Average value is about 0.16

Shrinkage

Workable concrete requires more water than is necessary to fully hydrate the cement

As concrete cures, water not used in hydration begins to evaporate

The effect of evaporating water is shrinkage and cracking of the concrete

Shrinkage occurs for many years, but about 90 percent occurs within the first year

Shrinkage

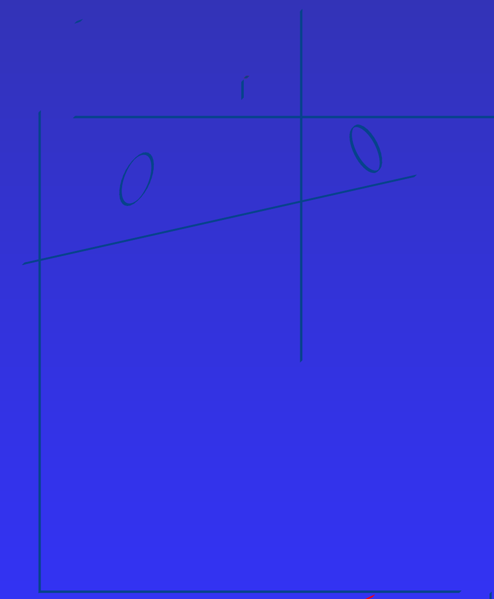
The amount of moisture lost depends on distance from the point in the concrete to the surface

Members with large surface area have a higher rate of shrinkage

The amount of shrinkage depends on exposure of the member

Shrinkage

- Keep mixing water to a minimum
- Cure thoroughly
- Place concrete in small sections
- Use construction joints
- Use shrinkage reinforcement
- Use dense, non-porous aggregate



Creep

Creep is deformation under sustained load

Creep is also called plastic flow

Creep deformations may be two to three times as large as instantaneous deformation

75 percent of creep occurs during the first year

Creep

- The amount of creep is dependent on the stress present
- Creep can also cause concrete strength reduction of 15 to 25 percent
- The longer concrete cures before load is applied, the smaller the creep
- High strength concrete experiences less creep than low strength concrete

Creep

Creep increases with increasing temperature

The higher the humidity, the smaller the creep

The higher w/c, the higher the creep

The presence of compression steel reduces creep

Large members creep less than small members

Tensile Strength

- Tensile strength of concrete is about eight to 15 percent of its compressive strength
- Tensile strength varies with the square root of the compressive strength
- Concrete is filled with micro-cracks
- Micro-cracks affect tensile strength, but not compressive strength

Tensile Strength

Tensile strength is measured indirectly, using either the modulus of rupture or split cylinder test

While tensile strength is small, it nevertheless has a significant impact on deflections, bond strength, shear strength and torsional strength

Modulus of Rupture Test

ASTM C78

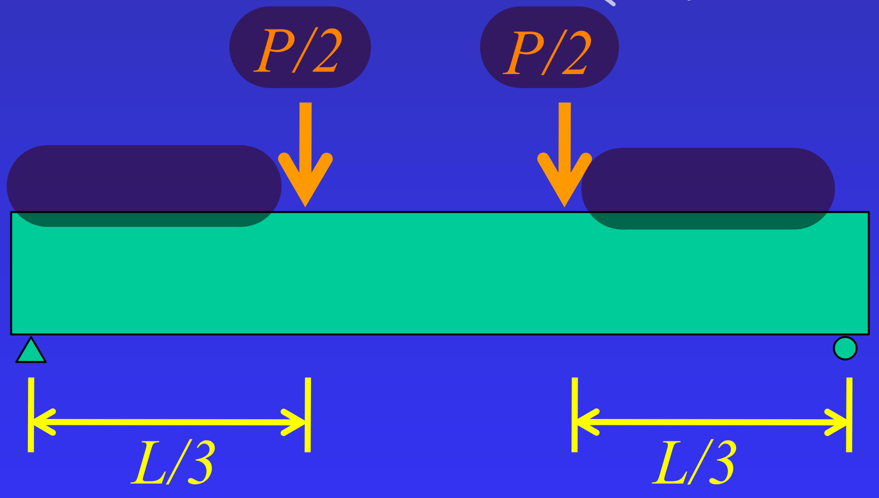
6-in x 6-in x 30-in (150x150x750 mm) unreinforced concrete specimen

Tested as a simple beam on a 24-in(600mm) span

Loaded at third-points with two concentrated loads

Modulus of Rupture Test

Flexural formula for f_r (modulus of rupture)



$$f_r = \frac{Mc}{I}$$

$$M = \frac{PL}{6}$$

$$I = \frac{bh^3}{12}$$

$$f_r = \frac{\left(\frac{PL}{6}\right)\left(\frac{h}{2}\right)}{\frac{bh^3}{12}} = \frac{PL}{bh^2}$$

ACI Value for f_r

ACI Code Section 9.5.2.3

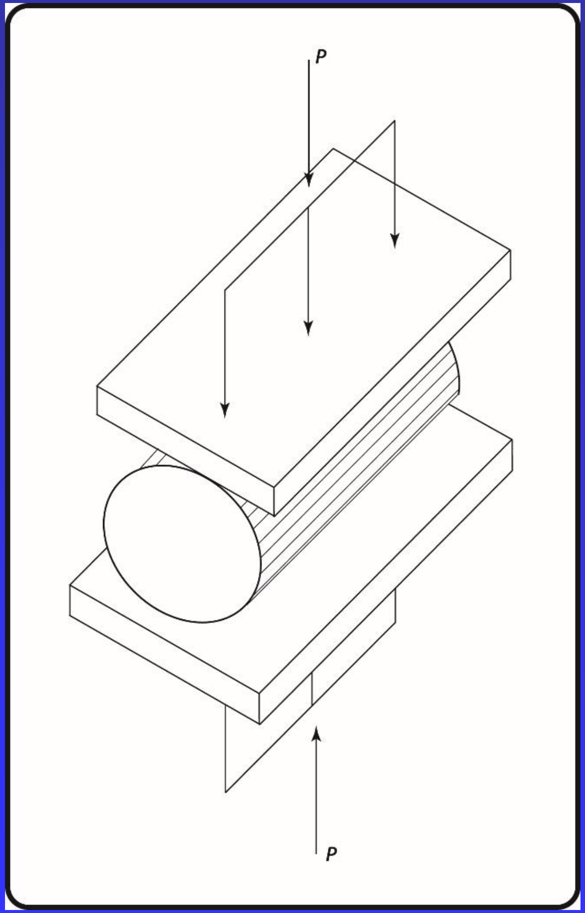
$$f_r = 0.7\ \lambda \sqrt{f_c^{'}} \quad \text{SI units}$$

λ is a parameter to account for lightweight concrete:

$\lambda = 1$ for normal weight concrete
$= 0.85$ for sand-lightweight concrete
$= 0.75$ for all-lightweight concrete

Split Cylinder Test

Split Cylinder Test



ASTM C496

$$f_r = \frac{2P}{\pi L D}$$

$L \Rightarrow$ length of specimen

$D \Rightarrow$ diameter of specimen

Aggregates

Aggregates occupy about three-quarters of the concrete volume

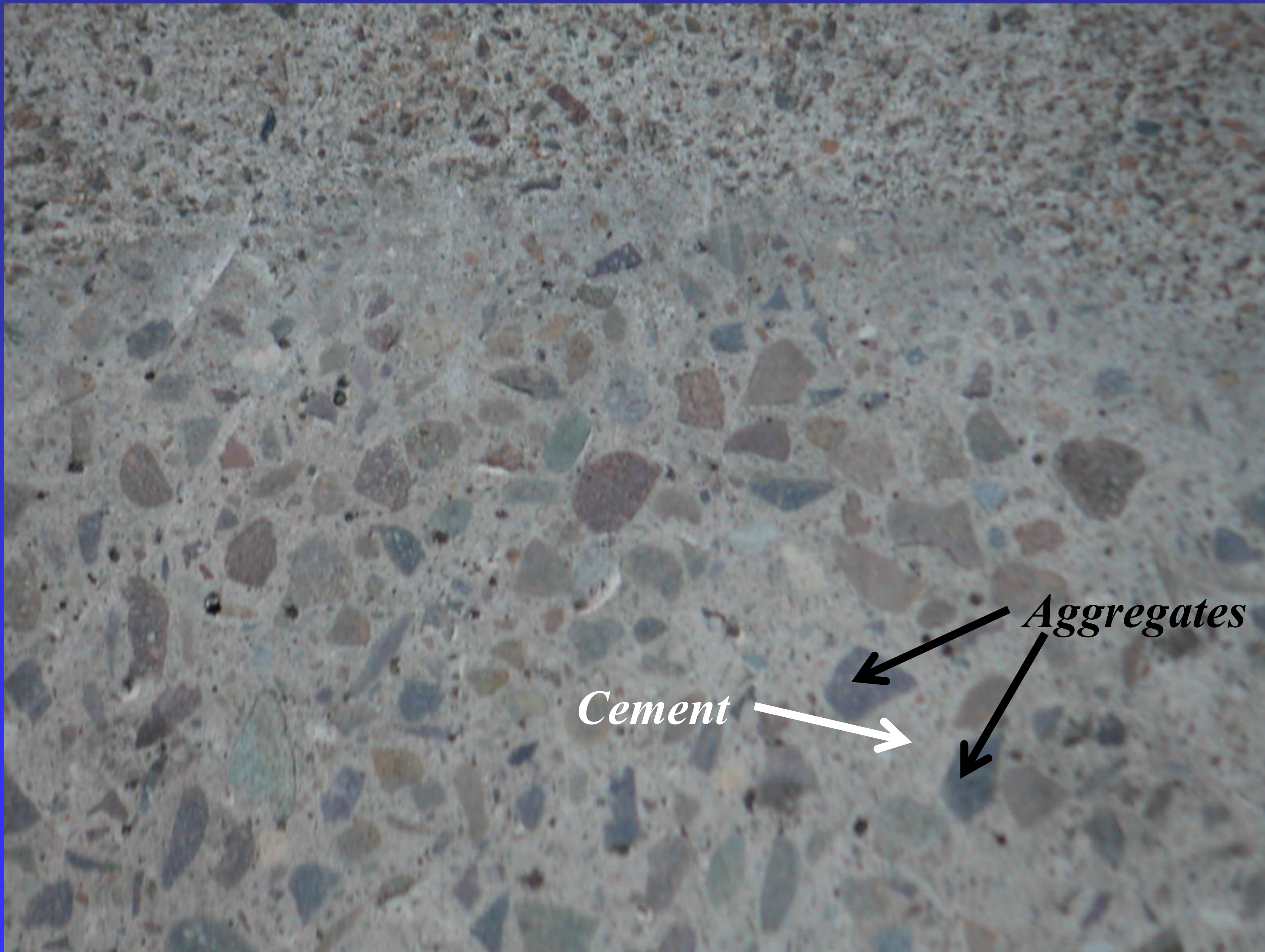
Aggregate is relatively inexpensive and economical concrete uses as much aggregate as possible, relative to the other components

Concrete aggregate consists of a fine component (sand) and a coarse component

Aggregates

ACI Code Section 3.3.2 limits aggregate size:

1. one-fifth narrowest dimension between sides of forms;
2. one-third the depth of slabs;
3. three-quarters of the minimum clear space between reinforcement


Aggregates
Cement

Reinforcing Steel

Bars or welded wire fabric (WWF)

Bars can be plain or deformed

Plain bars are rarely used

Bars are given a number in US units equivalent to one eighth of the diameter in inches and an equivalent SI number that is nearly equal to the diameter in mm

Reinforcing Steel

Table 1.1 Reinforcement Bar Sizes and Areas

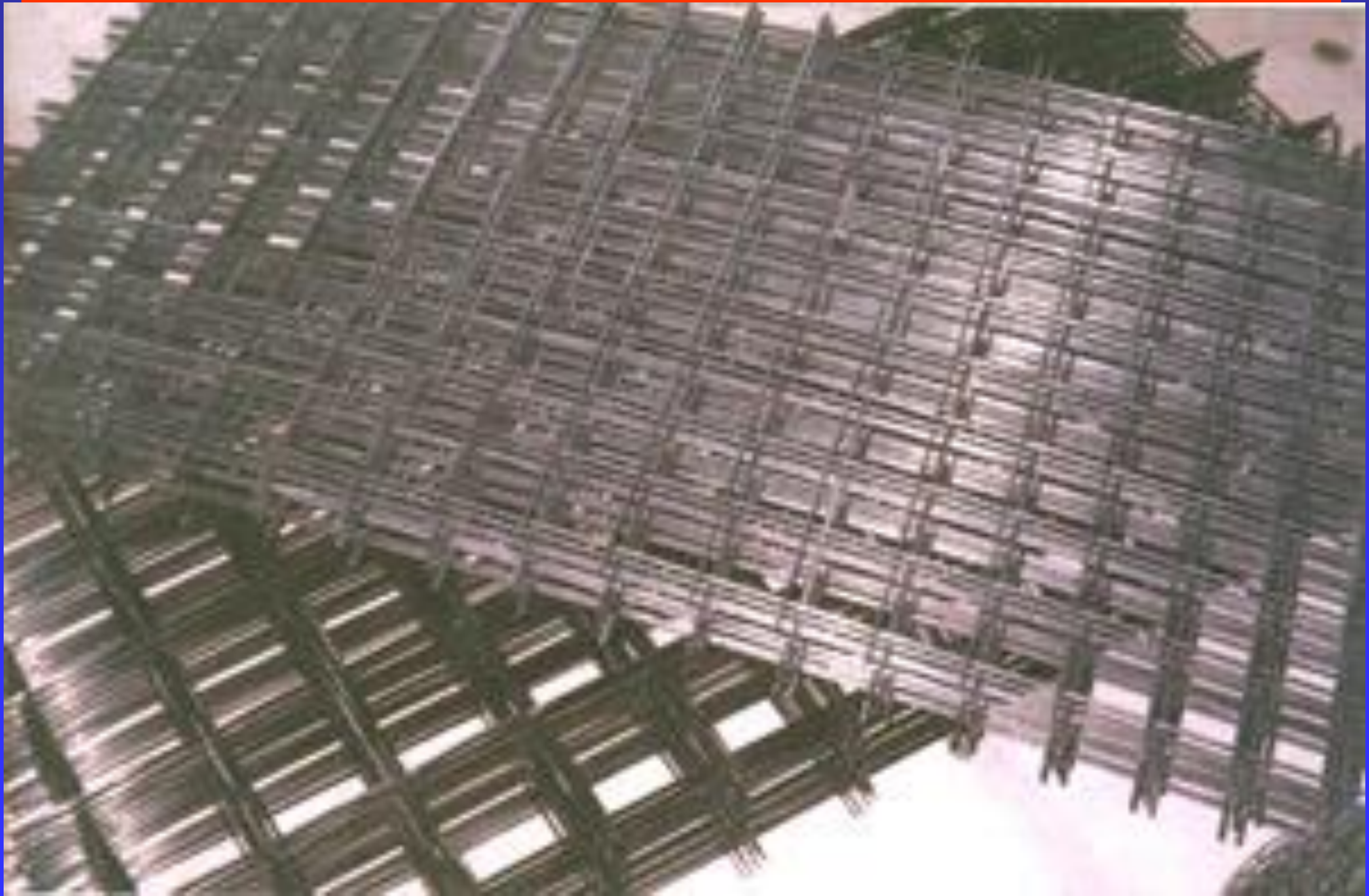
Standard inch-pound bars			Soft metric bars		
Bar no.	Diameter (in.)	Area (in.^{2})	Bar no.	Diameter (mm)	Area (mm^2)
3	0.375	0.11	10	9.5	71
4	0.500	0.20	13	12.7	129
5	0.625	0.31	16	15.9	199
6	0.750	0.44	19	19.1	284
7	0.875	0.60	22	22.2	387
8	1.000	0.79	25	25.4	510
9	1.128 ✓	1.00	29	28.7	645
10	1.270	1.27	32	32.3	819
11	1.410	1.41	36	35.8	1006
14	1.693	2.25	43	43.0	1452
18	2.257	4.00	57	57.3	2581

Reinforcing Steel-Qatar Steel Company

Designation	Nominal Dia. (d) (mm)	Nominal Cross Section Area (mm^2)	Unit Mass (kg/m)	Maximum of Average Knot Space (mm)	Height of Knot		Ltgd/Ri Width (mm)	Nominal Mass kg/piece		
					Min (mm)	Max (mm)		6m	9m	12m
D8	08	50.27	0.395	5.6	0.3	0.6	3.14	2.37	3.56	4.74
D10	10	78.54	0.617	7.0	0.4	0.8	3.9	3.7	5.55	7.40
D12	12	113.1	0.888	8.4	0.5	1.0	4.7	5.33	7.99	10.66
D14	14	153.9	1.21	9.8	0.6	1.2	5.5	7.26	10.89	14.52
D16	16	201.1	1.58	11.2	0.7	1.4	6.3	9.48	14.22	18.96
D18	18	254.5	2.00	12.6	0.8	1.6	7.1	12.00	18.00	24.00
D20	20	314.2	2.47	14.0	1.0	2.0	7.9	14.82	22.23	29.64
D22	22	380.1	2.98	15.4	1.1	2.2	8.6	17.88	26.82	35.76
D25	25	490.9	3.85	17.5	1.3	2.6	9.8	23.10	34.65	46.20
D28	28	615.8	4.83	19.6	1.4	2.8	11.0	28.98	43.47	57.96
D30	30	706.9	5.55	21.0	1.5	3.0	11.8	33.30	49.95	66.60
D32	32	804.2	6.31	22.4	1.6	3.2	12.6	37.86	56.79	75.72
D36	36	1017.9	7.990	25.2	1.8	3.6	14.1	47.94	71.99	95.88
D40	40	1256.6	9.864	28.0	2.0	4.0	15.7	59.18	88.78	118.37

ISO 6935-2 B500B-R / ASTM A615 GRADE 60 / SASO 2/1992

Welded Wire Fabric (WWF)



ASTM Reinforcing Steel Standards

ASTM A615 – deformed or plain billet steel – most commonly used

ASTM A706 – low alloy deformed or plain bars – properties intended to enhance weldability or bendability

ASTM A996 – deformed rail steel or axle steel bars – very limited availability

Grades of Reinforcing Steel

Grade	40,	50,	60,	75	
Yield stress	300,	350,	420,	520	MPa

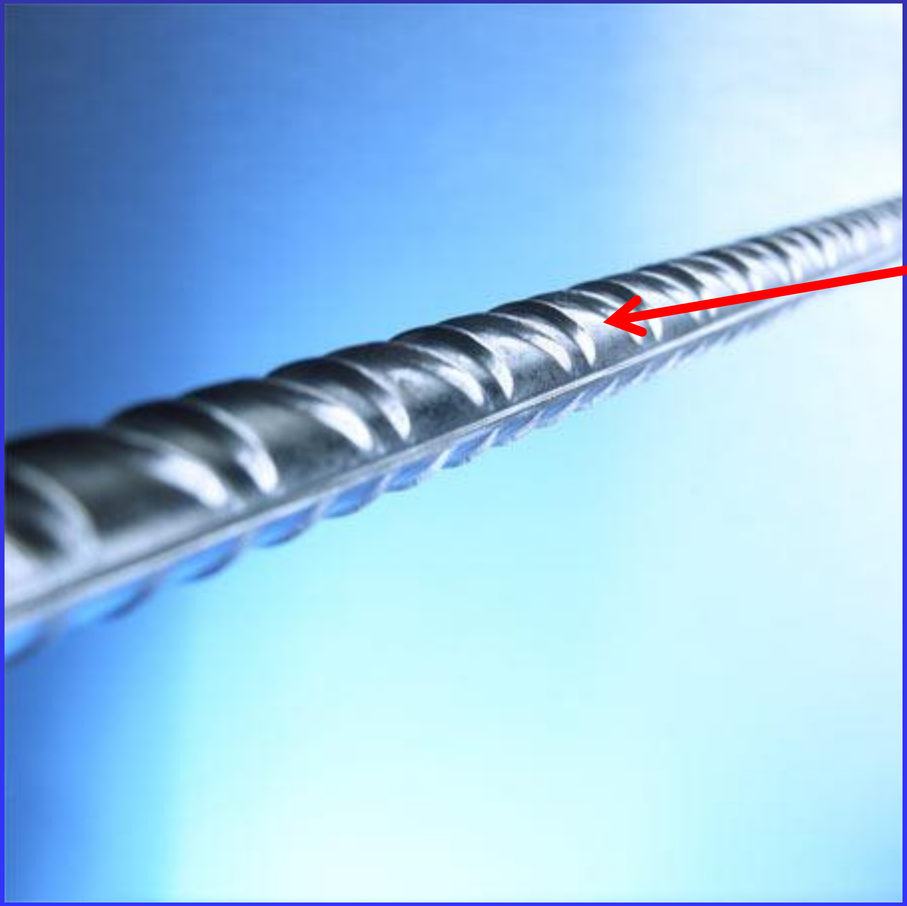
Grade 60 -> 60 ksi yield stress

Grade 60 most commonly used

Grades 40 and 50 intended to be Grade 60
but does not have adequate yield strength

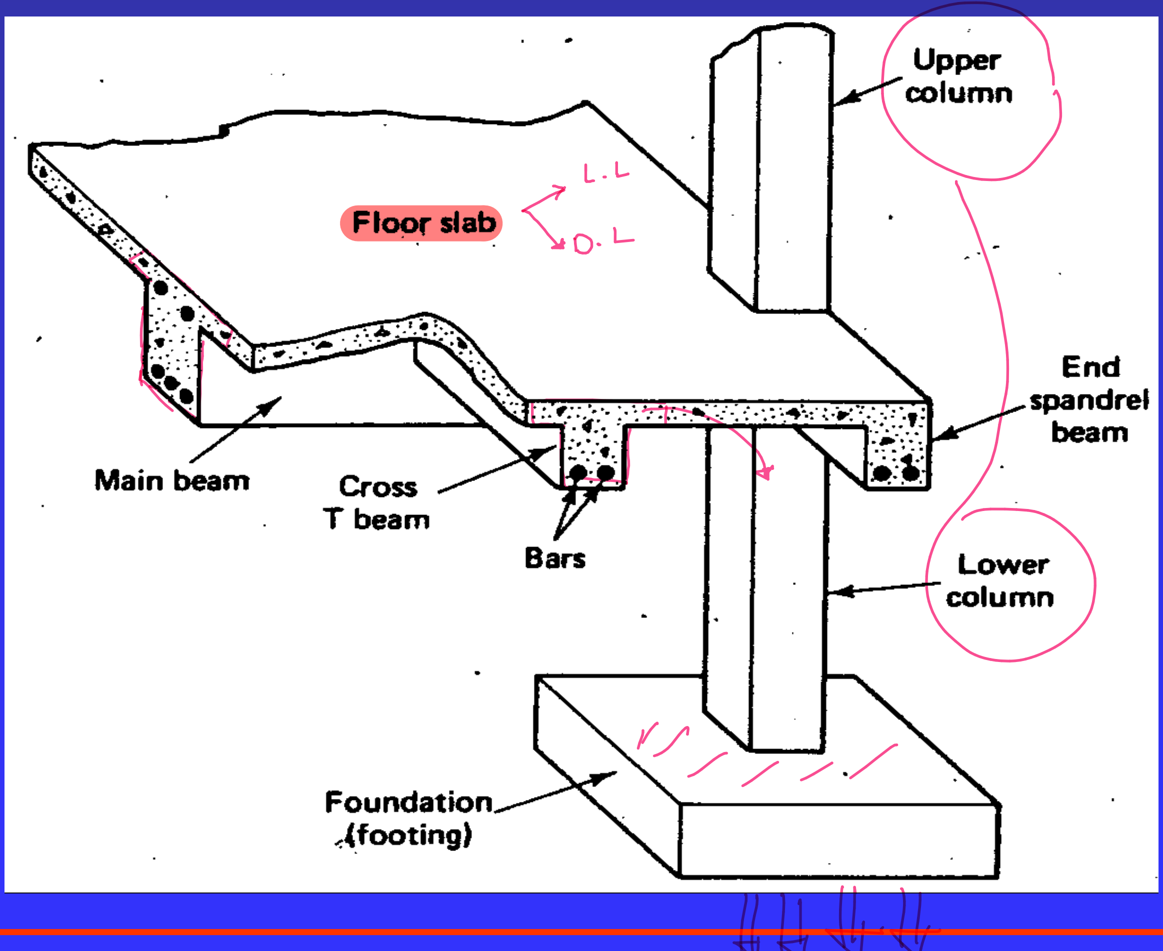
Deformed Rebars

Deformed Rebar

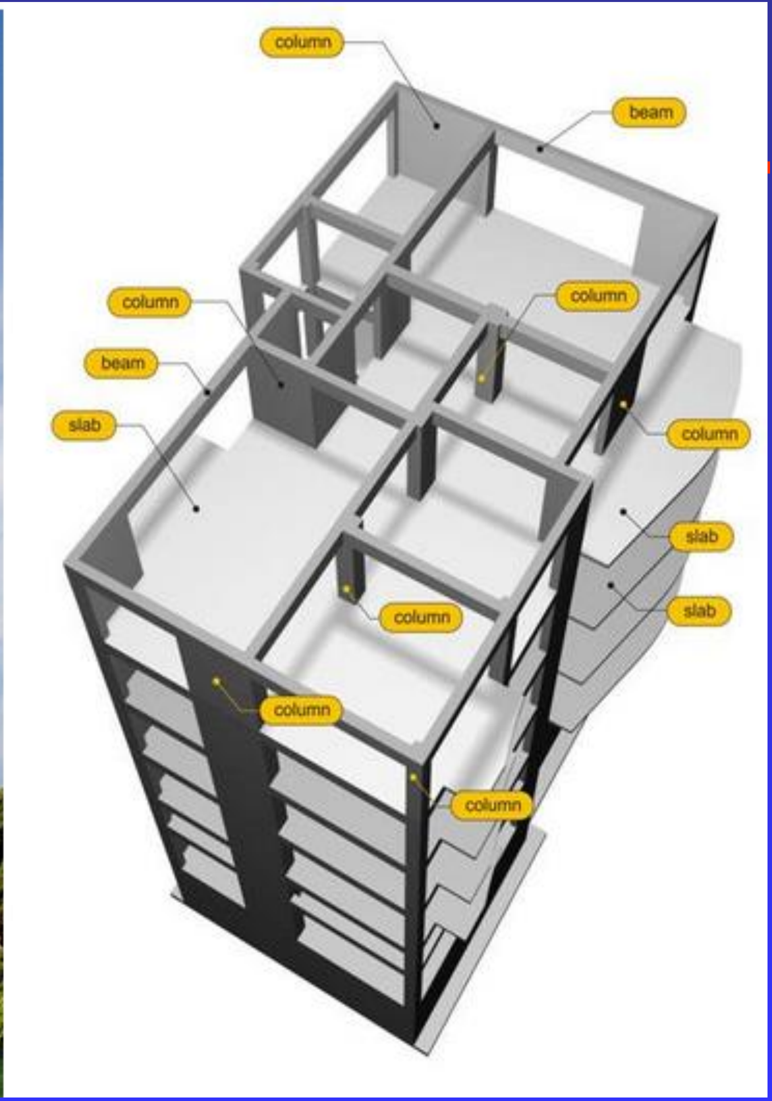


Ribs

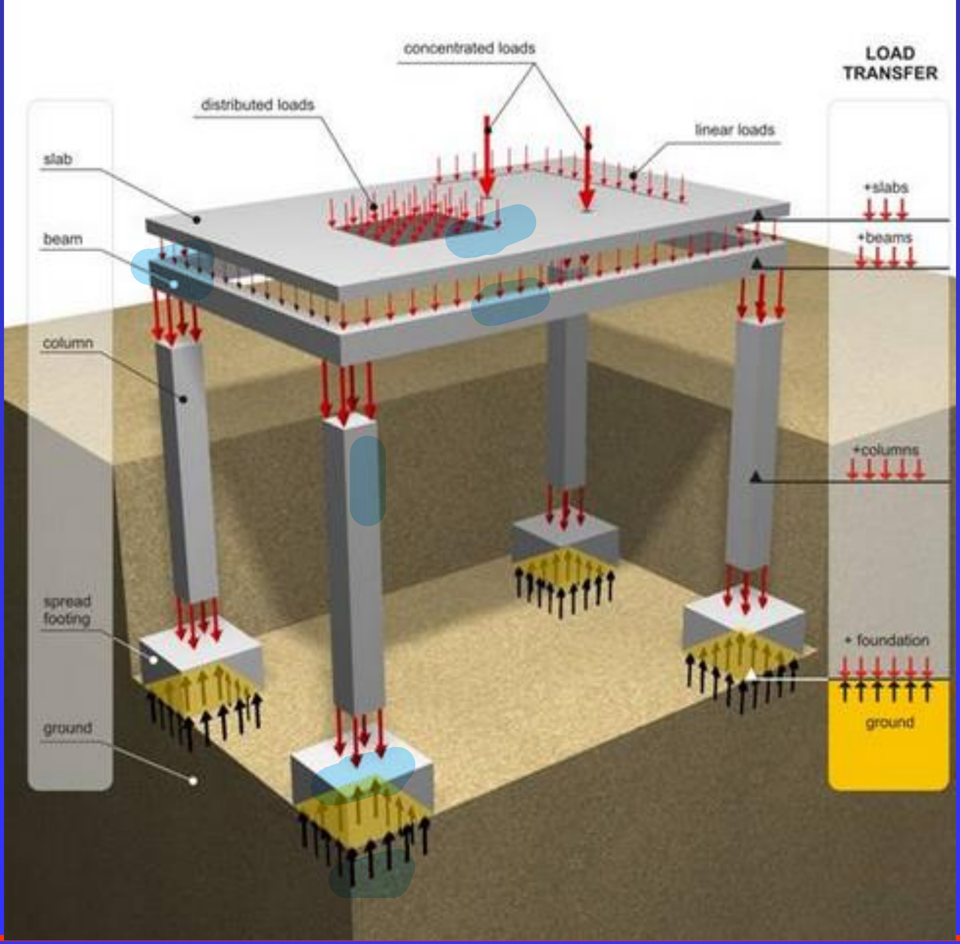
Structural System



IDEALIZED STRUCTURE

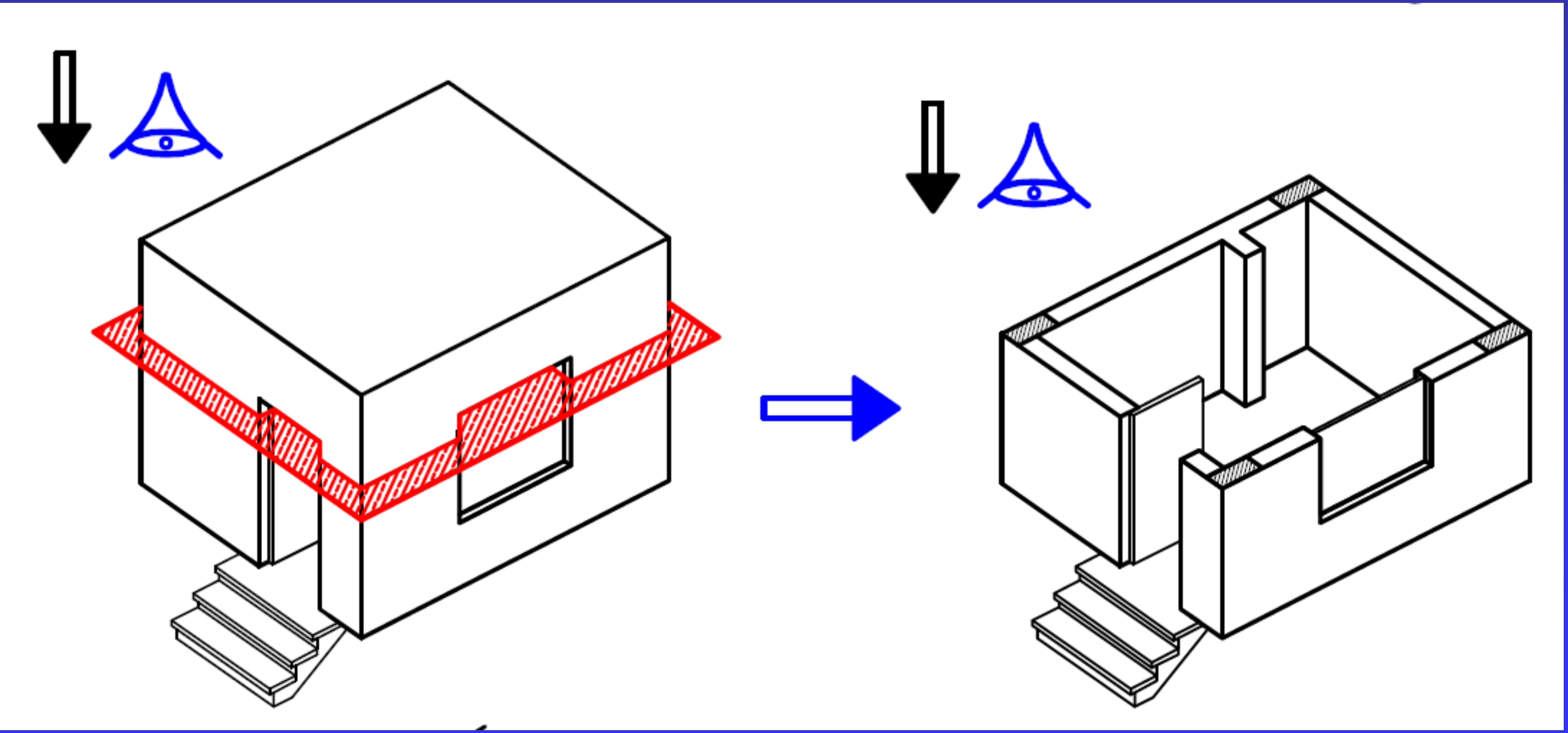


LOAD PATHS IN STRUCTURES

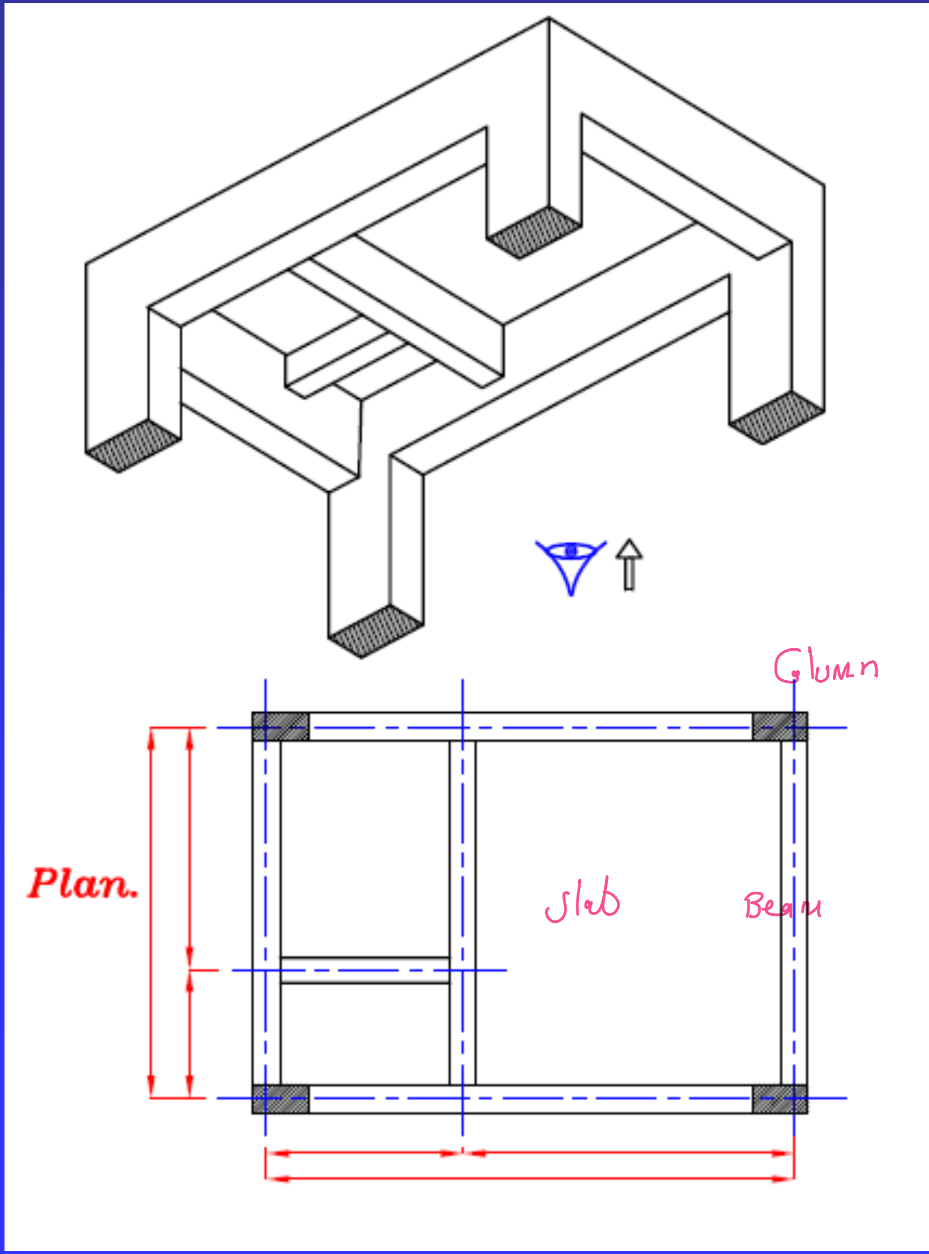


ARCH. DWGS vs. STR. DWGs

ARCH. DWGS



STR. DWGS



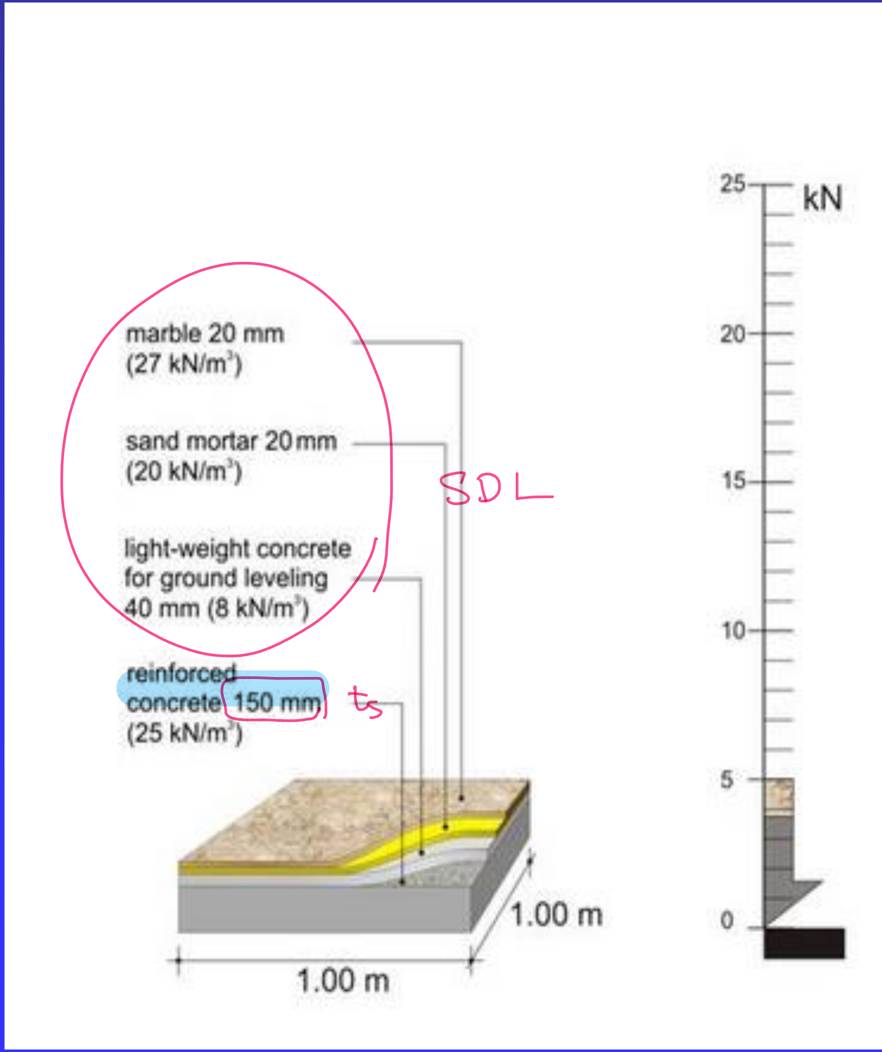
Loads and Load Effects

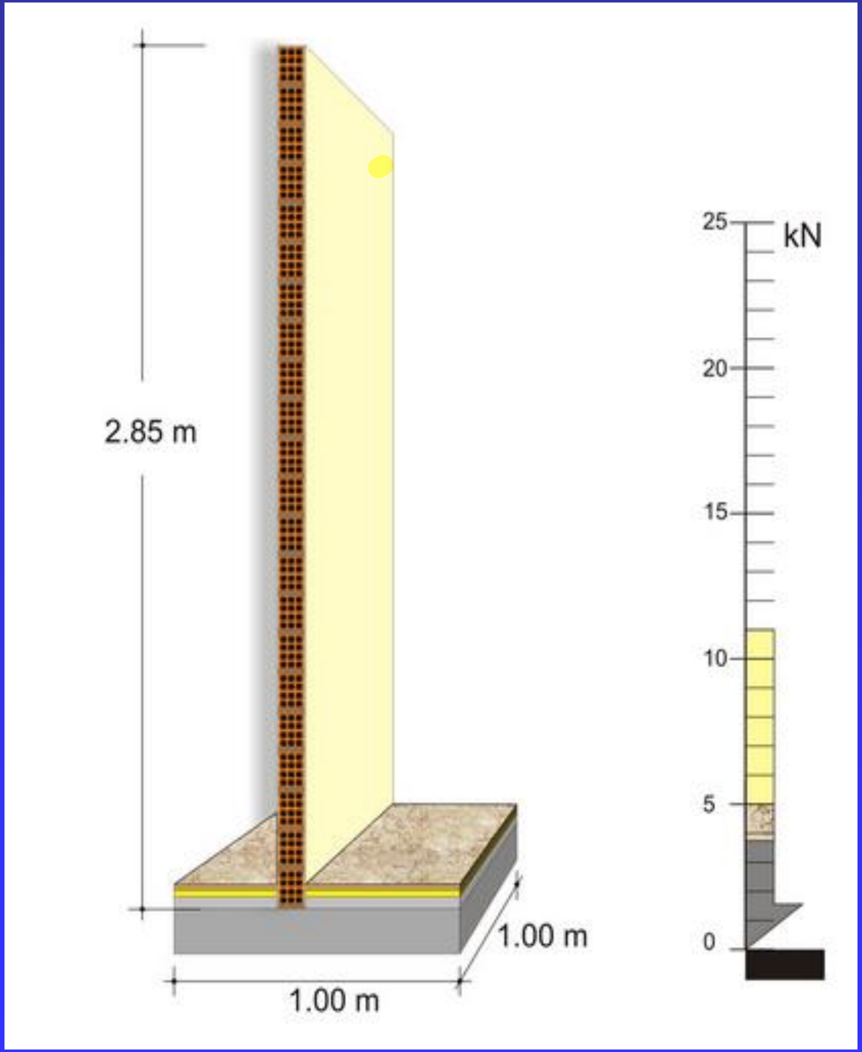
- Types of loads encountered when designing reinforced concrete: dead, live, roof live, snow and ice, rain, temperature, wind and seismic
- Loads produce load effects (axial force, shear, moment and torsion)

axial Force ⇒ Columns

Shear } Beam
Moment } slab

DEAD LOAD


marble 20 mm
(27 kN/m³)
sand mortar 20 mm
(20 kN/m³)
light-weight concrete
for ground leveling
40 mm (8 kN/m³)
reinforced
concrete 150 mm
(25 kN/m³)
SDL
ts
1.00 m
1.00 m
25
20
15
10
5
0
kN


2.85 m
1.00 m
1.00 m
25
20
15
10
5
0
kN

DEAD LOAD (CONT'D)

TABLE 1–2 Minimum Densities for Design Loads from Materials*

	lb/ft^3	kN/m^3 = γ
Aluminum	170	26.7
Concrete, plain cinder	108	17.0
Concrete, plain stone	144	22.6
Concrete, reinforced cinder	111	17.4
Concrete, reinforced stone	150	23.6
Clay, dry	63	9.9
Clay, damp	110	17.3
Sand and gravel, dry, loose	100	15.7
Sand and gravel, wet	120	18.9
Masonry, lightweight solid concrete	105	16.5
Masonry, normal weight	135	21.2
Plywood	36	5.7
Steel, cold-drawn	492	77.3
Wood, Douglas Fir	34	5.3
Wood, Southern Pine	37	5.8
Wood, spruce	29	4.5

*Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10. Copies of this standard may be purchased from ASCE at www.pubs.asce.org.

DEAD LOAD (CONT'D)

TABLE 1–3 Minimum Design Dead Loads*

Walls	psf	kN/m^2
4-in. (102 mm) clay brick	39	1.87
8-in. (203 mm) clay brick	79	3.78
12-in. (305 mm) clay brick	115	5.51
Frame Partitions and Walls		
Exterior stud walls with brick veneer	48	2.30
Windows, glass, frame and sash	8	0.38
Wood studs 2 × 4 in., (51 × 102 mm) unplastered	4	0.19
Wood studs 2 × 4 in., (51 × 102 mm) plastered one side	12	0.57
Wood studs 2 × 4 in., (51 × 102 mm) plastered two sides	20	0.96
Floor Fill		
Cinder concrete, per inch (mm)	9	0.017
Lightweight concrete, plain, per inch (mm)	8	0.015
Stone concrete, per inch (mm)	12	0.023
Ceilings		
Acoustical fiberboard	1	0.05
Plaster on tile or concrete	5	0.24
Suspended metal lath and gypsum plaster	10	0.48
Asphalt shingles	2	0.10
Fiberboard, $\frac{1}{2}$-in. (13 mm)	0.75	0.04

*Reproduced with permission from American Society of Civil Engineers *Minimum Design Loads for Buildings and Other Structures*, ASCE/SEI 7-10.

Dead Load - Slabs

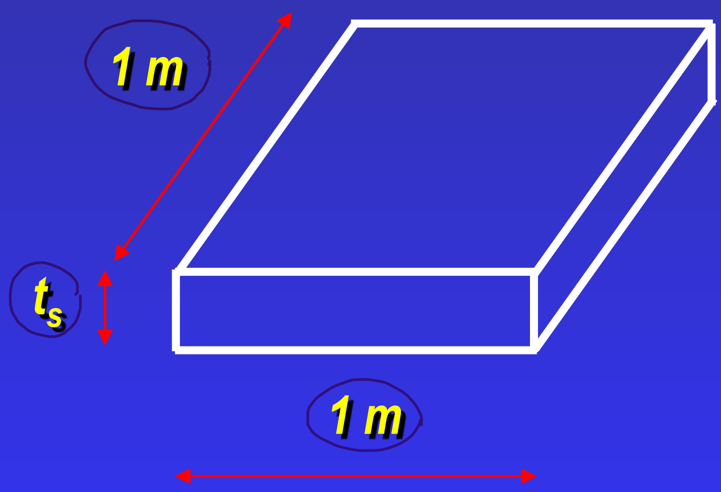
$w_D = \gamma_c \cdot t_s + SDL$ (kN/m^2)

w_D = dead load of **1 m²** of the slab

t_s = thickness of slab (m)

γ_c = unit weight of concrete (kN/m^3)

SDL = Superimposed Dead Load (kN/m^2)



Dead Load – Beams

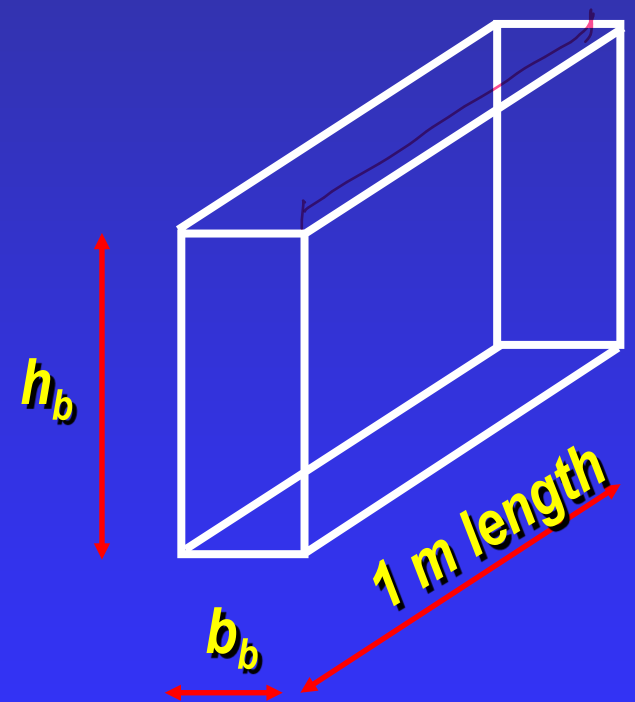
$o.w_{beam} = b_b \, h_b \, \gamma_c$ (kN/m)

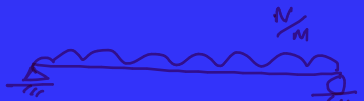
$o.w_{beam}$ = o.w of **1 m length** of the beam

b_b = thickness of beam (m)

h_b = height of beam (m)

γ_c = unit weight of concrete (kN/m³)





Dead Load - Walls

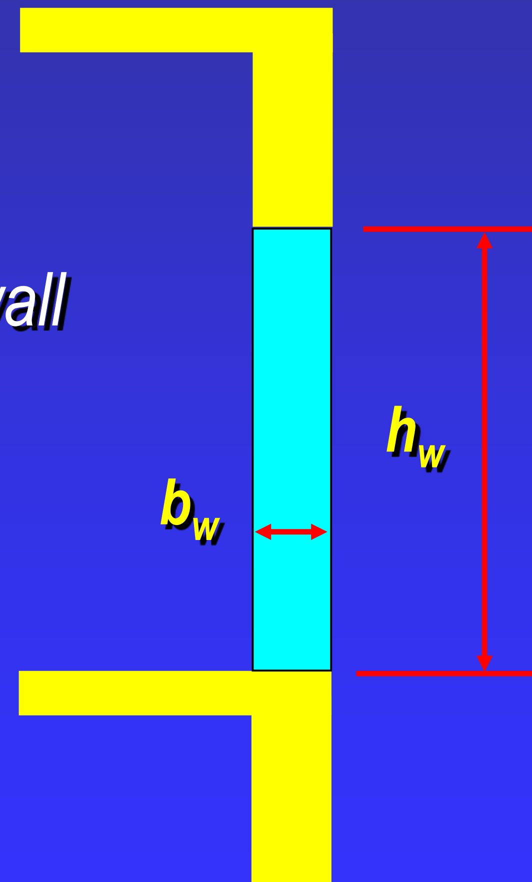
$o.w_{wall} = b_w \, h_w \, \gamma_w$ (kN/m)

$o.w_{wall}$ = own weight of **1 m length** of the wall

b_w = thickness of wall (m)

h_w = height of wall (m)

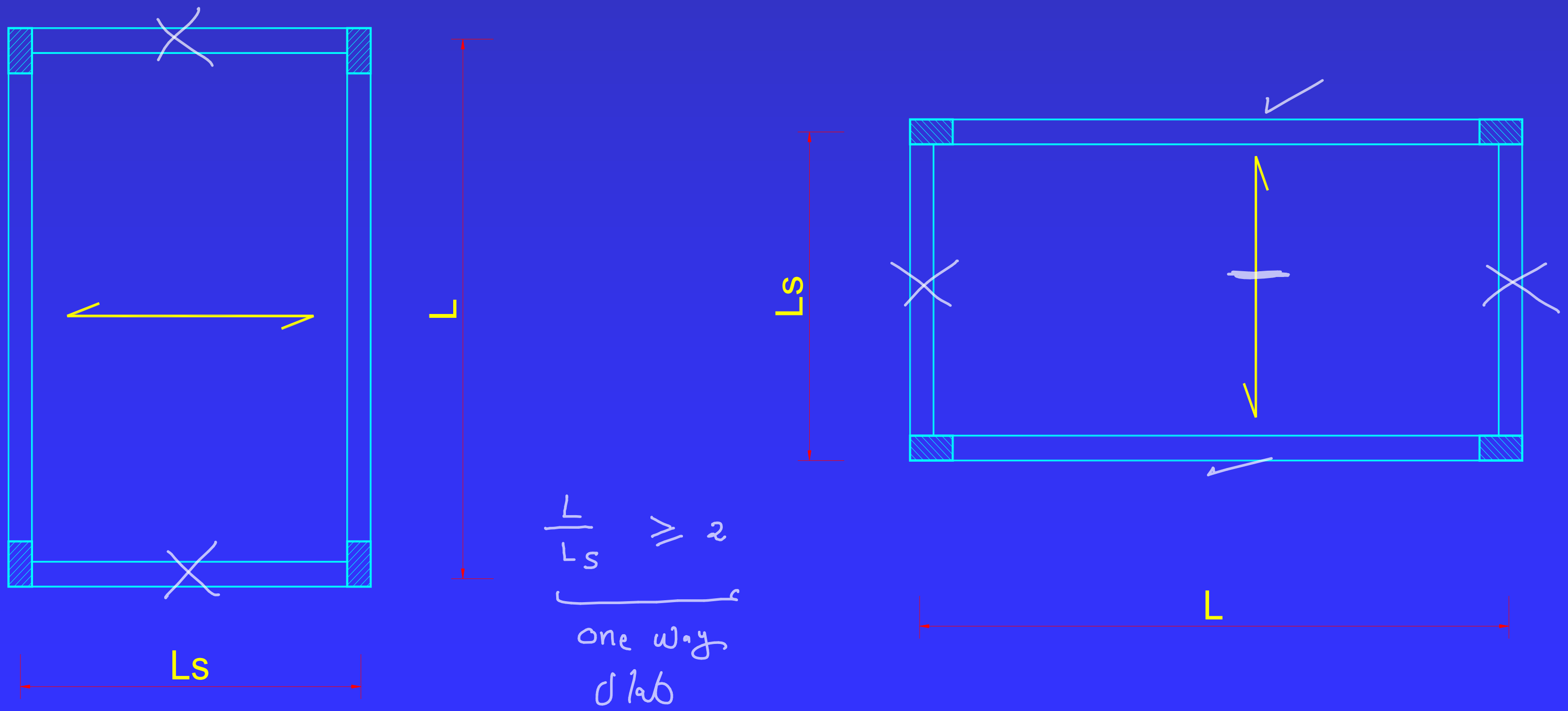
γ_w = unit weight of wall (kN/m^3)



One Way Slabs

✓ Slabs Supported by 4-Beams:

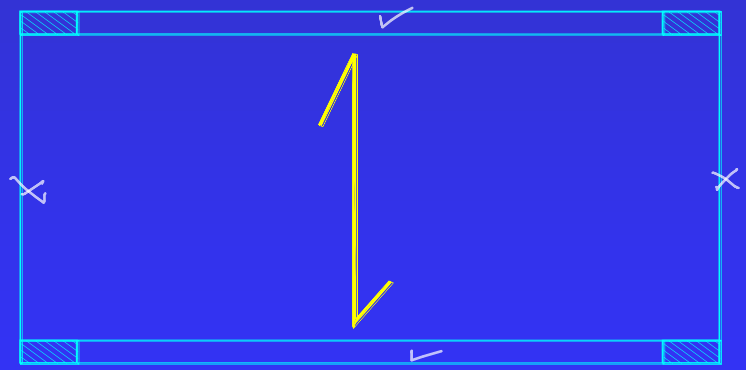
- $L/L_s \geq 2$
- Slab load is carried in **Short Direction** to supporting beams
- Load direction is the Short Direction

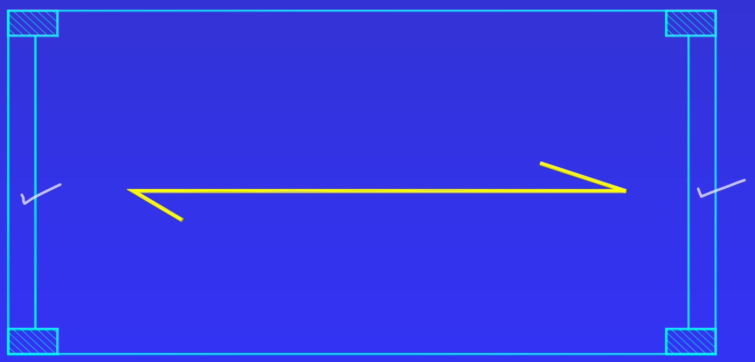


One Way Slabs

✓ **Slabs Supported by 2-Beams on opposite sides:**

- *Slab load is carried in a Direction Perpendicular to Supporting Beams*
- *Load direction might be short direction OR long direction*





Slab Load

$w_{slab} = w_D + w_L$ (kN/m²)

⇒ $w_D = t_s \gamma_c + SDL$

⇒ w_L = Given kN/m² or table

w_{slab} = Total load of 1 m² of the slab = $w_D + w_L$

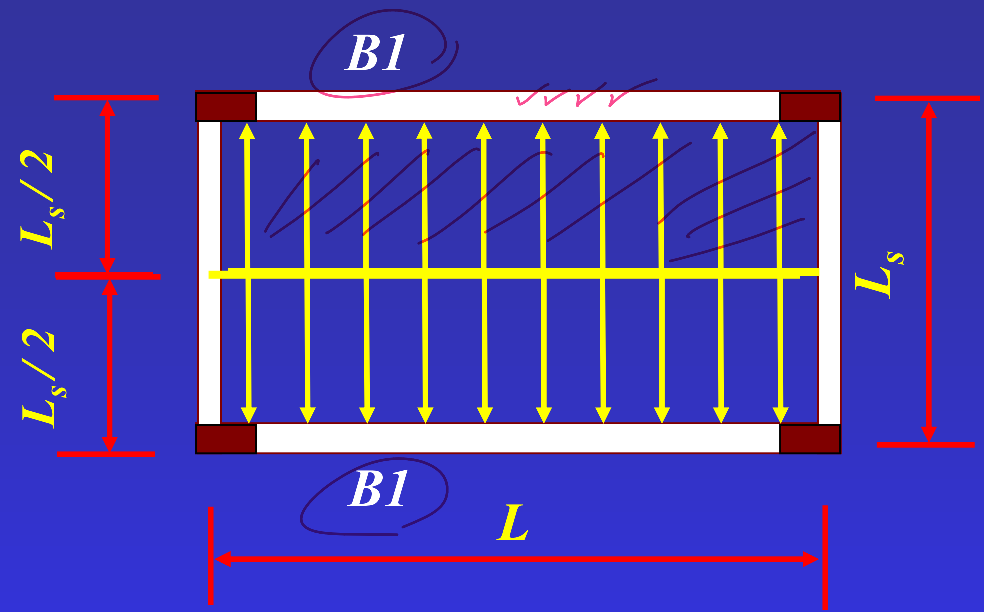
t_s = thickness of slab (m)

γ_c = unit weight of concrete (kN/m³)

SDL = given superimposed dead load (kN/m2)

Load Distribution

One-Way Slabs ($L / L_s \geq 2$)



Slab load:

$w_D = t_s \gamma_c + SDL$ (kN/m^2)

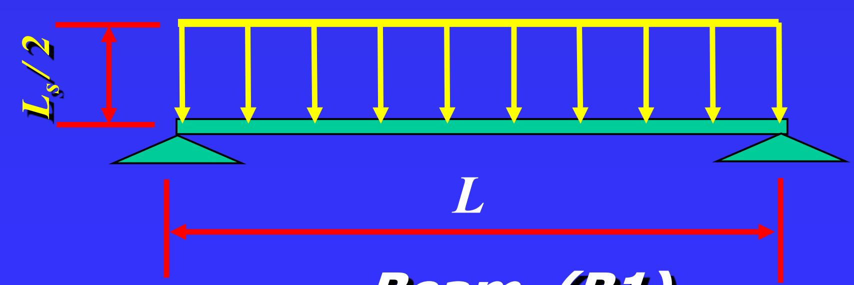
w_L = Given

$w_u = w_D + w_L$ (kN/m^2)

- **Slab load transferred to beam**

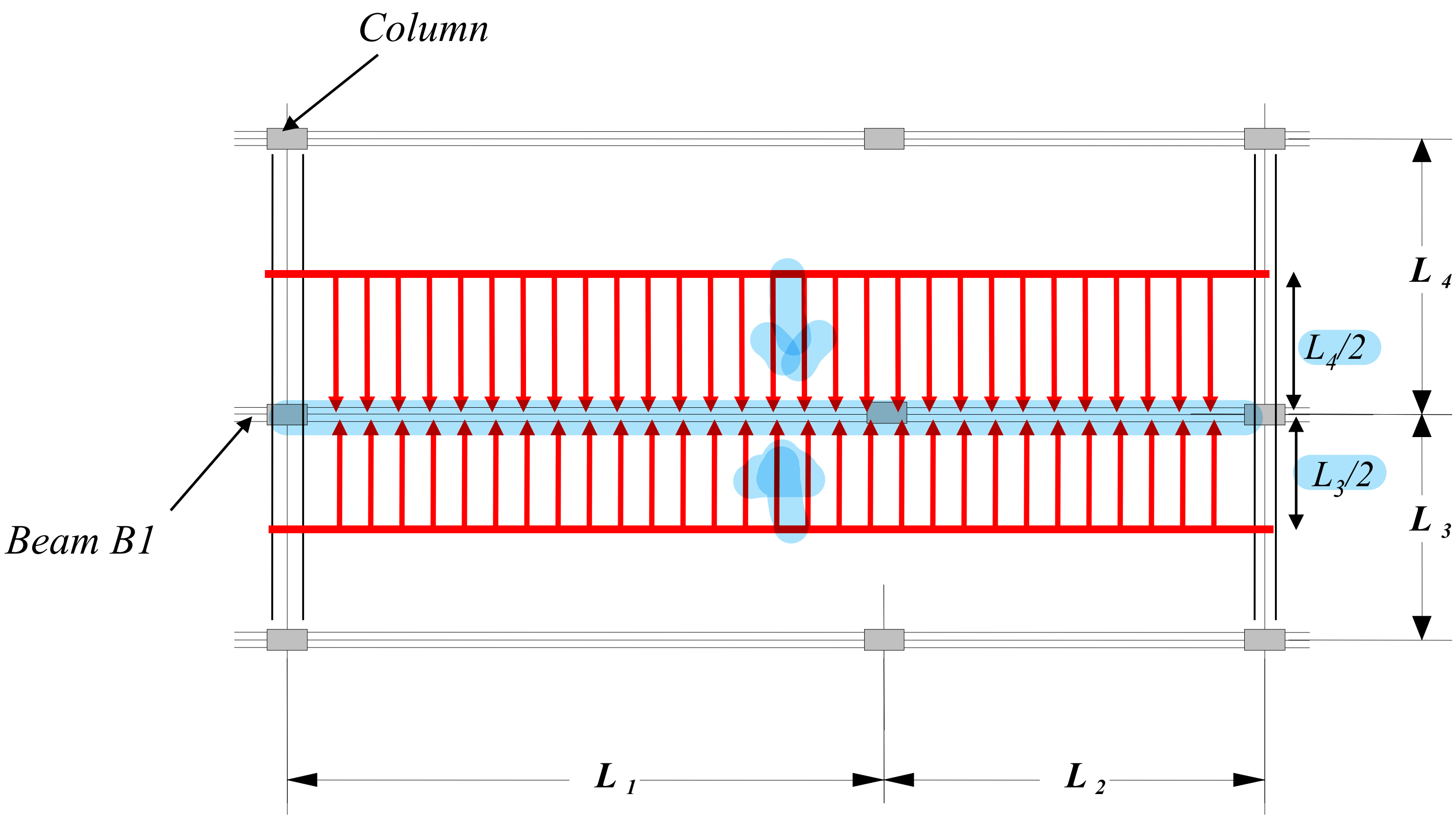
$w_{From\ slab} = w_{slab} * \frac{L_s}{2}$ (kN/m)

Slab height carried by the beam

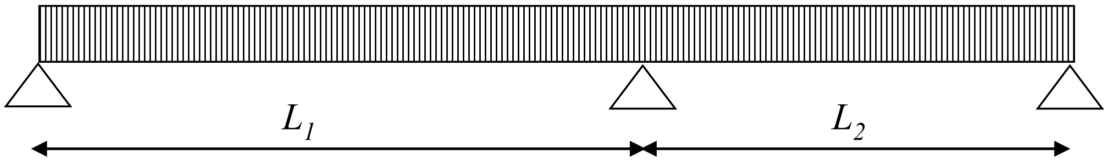


Beam (B1)

Load Distribution



Load from slab (kN/m) = $w_{slab}(L_3/2+L_4/2)$



Beams Loads & System

✓ Beam own weight

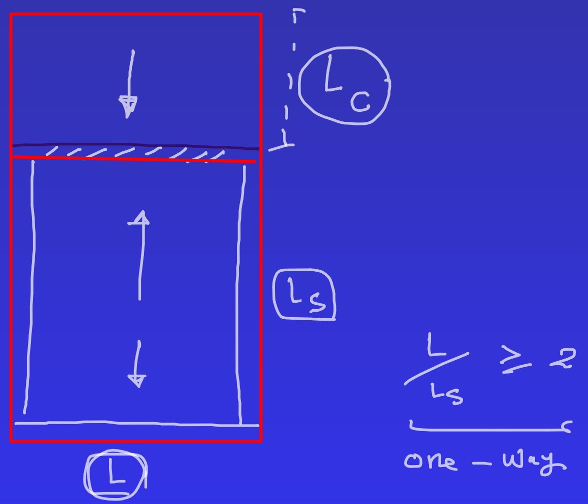
- $o.w_{beam} = b_b\, h_b\, \gamma_c$ (kN/m)

✓ Wall own weight

- $o.w_{wall} = b_w\, h_w\, \gamma_w$ (kN/m)

✓ Load from slabs

- $w_{from,slab} = \Sigma w_{slab}\, (L_s/2) + w_{slab}\, (L_c)$ (kN/m)



$$w_{beam} = b_b\, h_b\, \gamma_c + b_w\, h_w\, \gamma_w + \Sigma w_{slab}\, (L_s/2) + w_{slab}\, (L_c) \quad (kN/m)$$

Example (1)

Given Data:

Slab thickness = 0.2 m

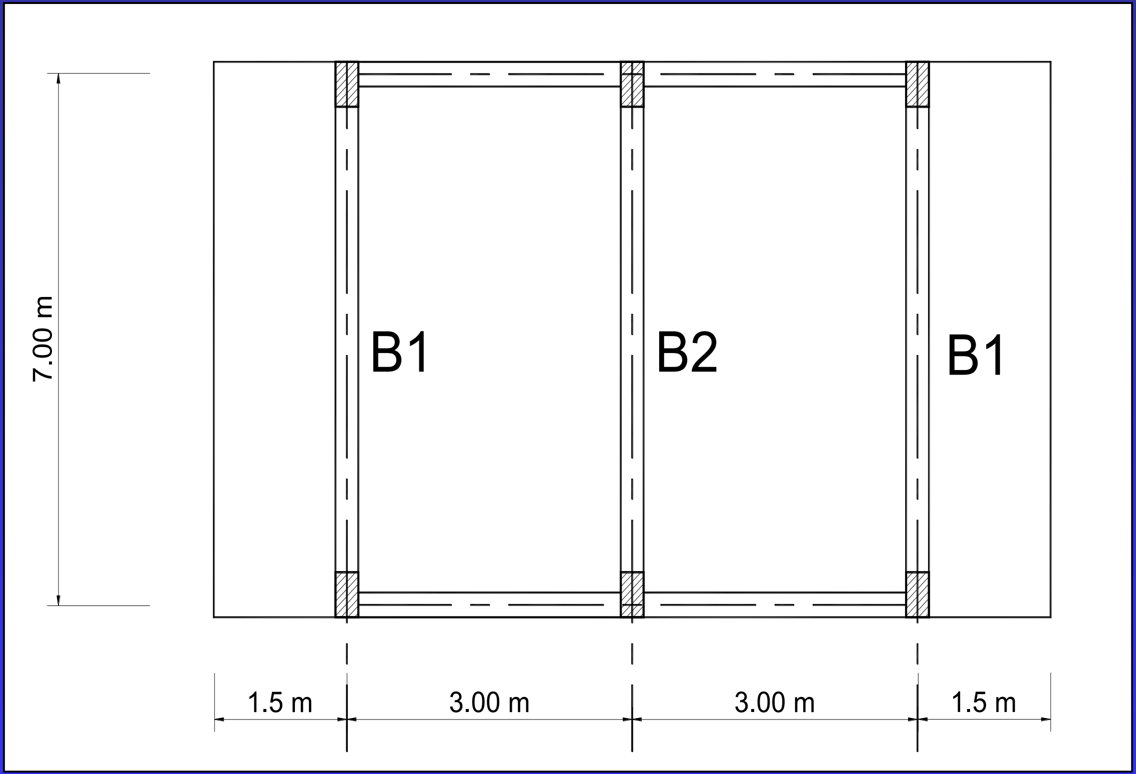
Live Load = 3.0 kN/m^2

Floor cover = 1.5 kN/m^2

Beams 0.25 m x 0.6 m

Walls 0.25 width & 3 m height

γ_c = 25 kN/m^3 & γ_w = 10 kN/m^3



Required:

- Show tributary areas for beams on plan
- Calculate the load carried by beams B1 & B2

Example (1)

Given Data:

Slab thickness = 0.2 m

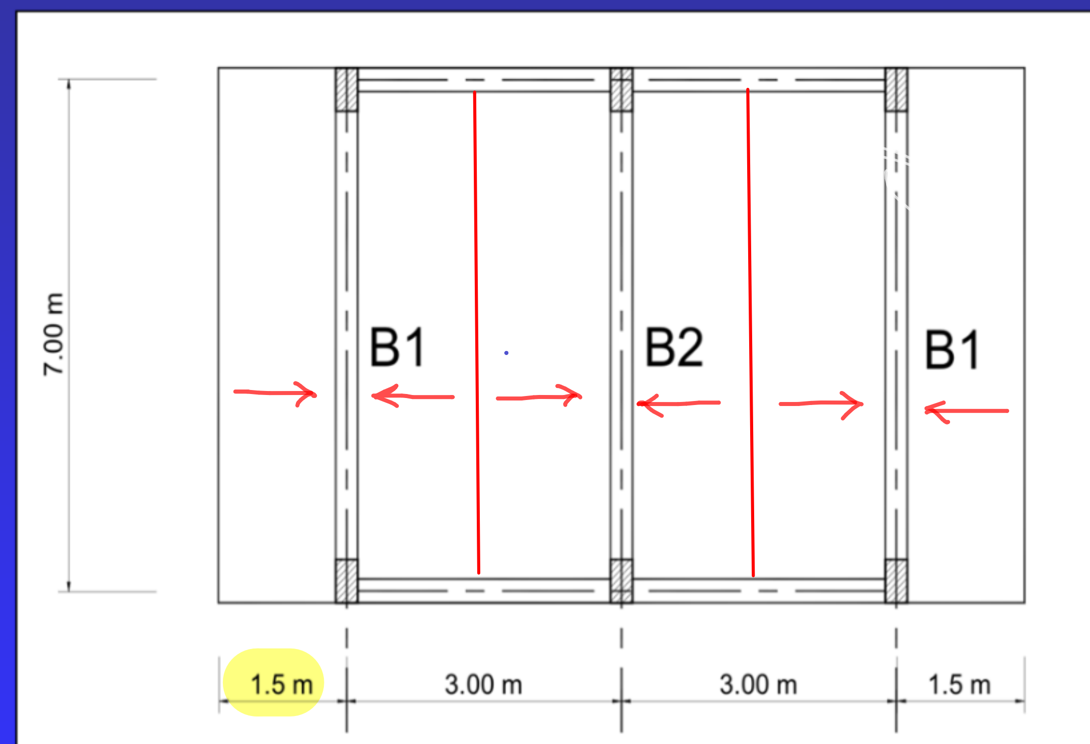
Live Load = 3.0 kN/m²

Floor cover = 1.5 kN/m²

Beams 0.25 m x 0.6 m

Walls 0.25 width & 3 m height

γ_c = 25 kN/m³ & γ_w = 10 kN/m³



Required:

- Show tributary areas for beams on plan
- Calculate the load carried by beams B1 & B2

$7/3 = 2.33 > 2 \rightarrow$ one way slab

Beam B_1

$$w_{beam} = o.w_{Beam} + o.w_{wall} + w_{From\ slab}$$

$$w_{slab} = w_D + w_L$$

$$w_D = t_s \gamma_c + SDL = 0.2 * 25 + 1.5 = 6.5 \ kN/m^2$$

$$w_{slab} = 6.5 + 3 = 9.5 \ kN/m^2$$

$$o.w_{beam} = b_b h_b \gamma_c$$

$$= 0.25 * 0.6 * 25 = 3.75 \ kN/m$$

$$o.w_{wall} = b_w h_w \gamma_w$$

$$= 0.25 * 3 * 10 = 7.5 \ kN/m$$

$$w_{From\ slab} = w_{slab}\left(\frac{L_s}{2}\right) + w_{slab} * L_c$$

$$= 9.5\left(\frac{3}{2}\right) + 9.5 * 1.5 = 28.5 \ kN/m$$

$$w_{beam} = 3.75 + 7.5 + 28.5 = 39.75 \ kN/m$$

Beam B_2

$$w_{beam} = o.w_{Beam} + o.w_{wall} + w_{From\ slab}$$

$$o.w_{beam} = 3.75 \ kN/m$$

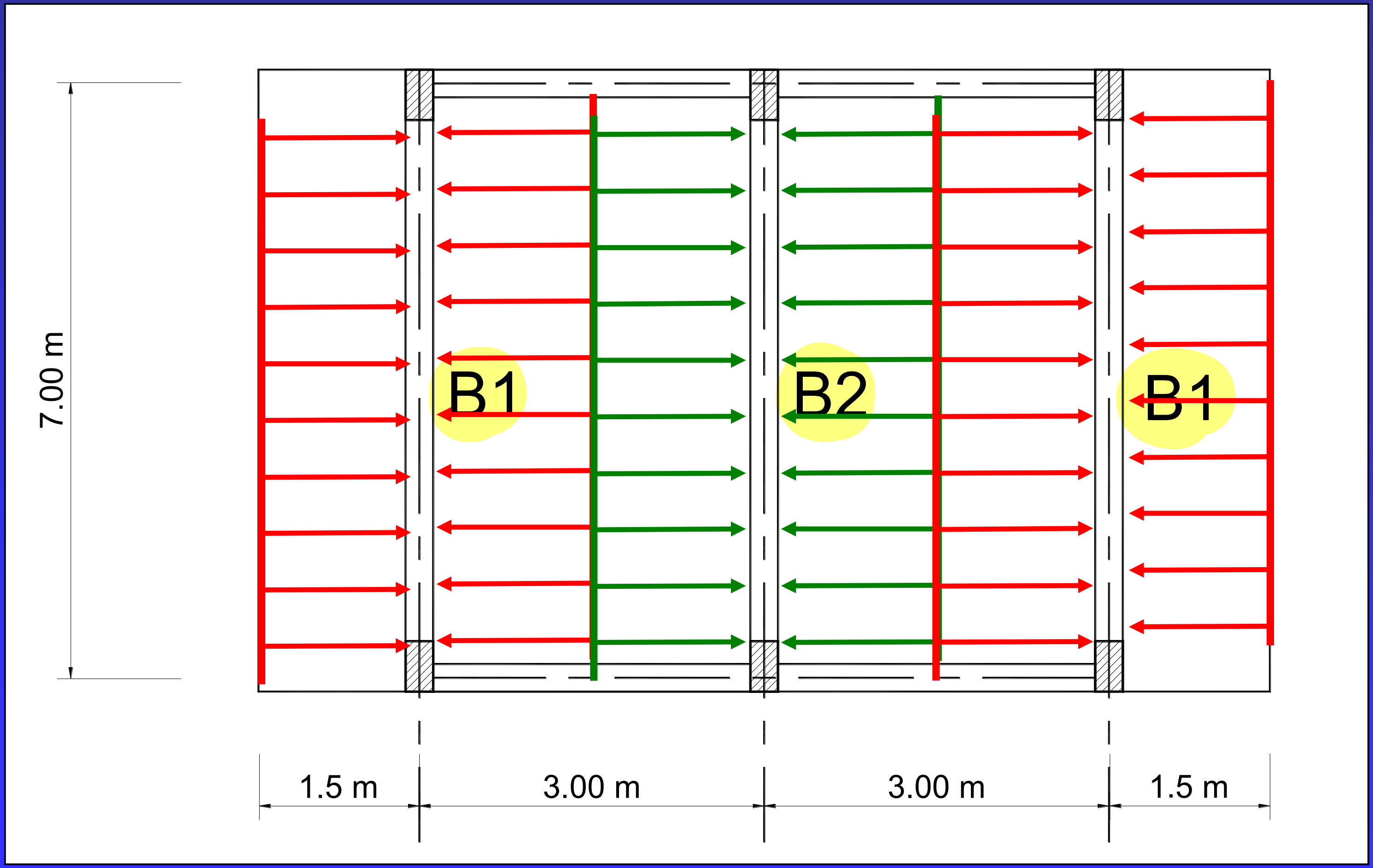
$$o.w_{wall} = 7.5 \ kN/m$$

$$w_{From\ slab} = w_s\left(\frac{L_s}{2}\right) + w_s\left(\frac{L_s}{2}\right)$$

$$= 9.5\left(\frac{3}{2}\right) * 2 = 28.5 \ kN/m$$

$$w_{beam} = 3.75 + 7.5 + 28.5 = 39.75 \ kN/m$$

Example (1) – Tributary Areas for Beams



Example (1) – Beam B1

$$w_{beam} = o.w_{beam} + o.w_{wall} + w_{from,slab} \quad (kN/m)$$

$o.w_{beam} = b_b\, h_b\, \gamma_c$

$= 0.25 \times 0.6 \times 25 = 3.75$ kN/m

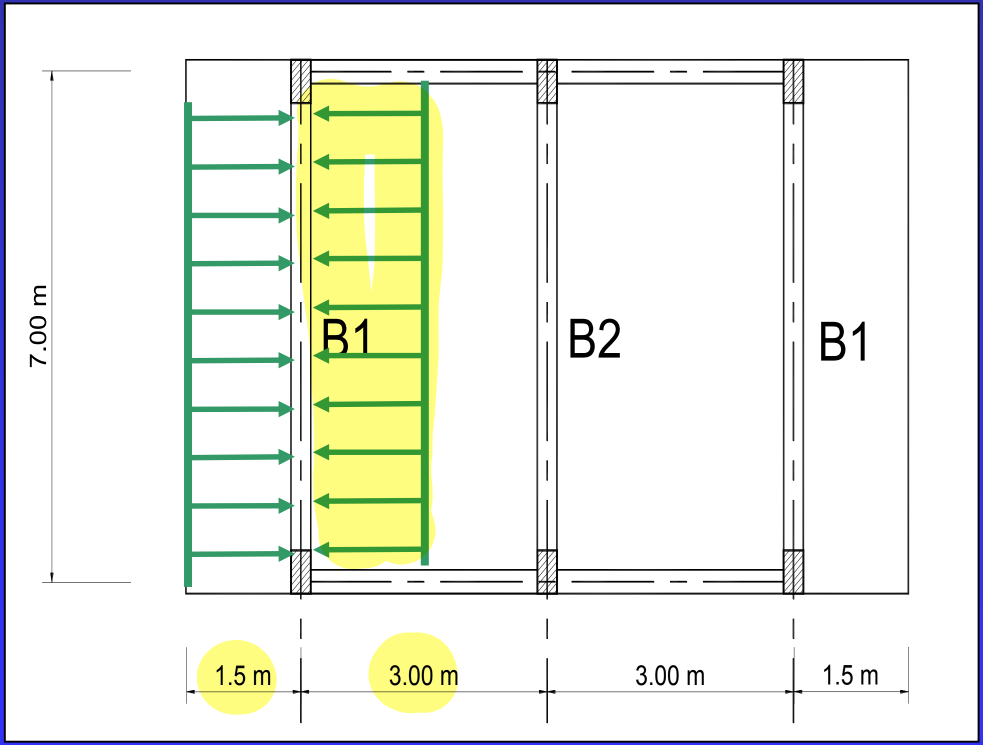
$o.w_{wall} = b_w\, h_w\, \gamma_w$

$= 0.25 \times 3 \times 10 = 7.5$ kN/m

From Slab $= \Sigma w_{slab} (L_s/2) + w_{slab} (L_c)$

$= 9.5 \times (3/2) + 9.5 \times 1.5$

$= 28.5$ kN/m



$$w_{beam} = 3.75 + 7.5 + 28.5 = \underline{39.75} \quad kN/m$$

Example (1) – Beam B2

$$w_{beam} = o.w_{beam} + o.w_{wall} + w_{from,slab} \quad (kN/m)$$

$o.w_{beam} = b_b \, h_b \, \gamma_c$

$= 3.75 \; kN/m$

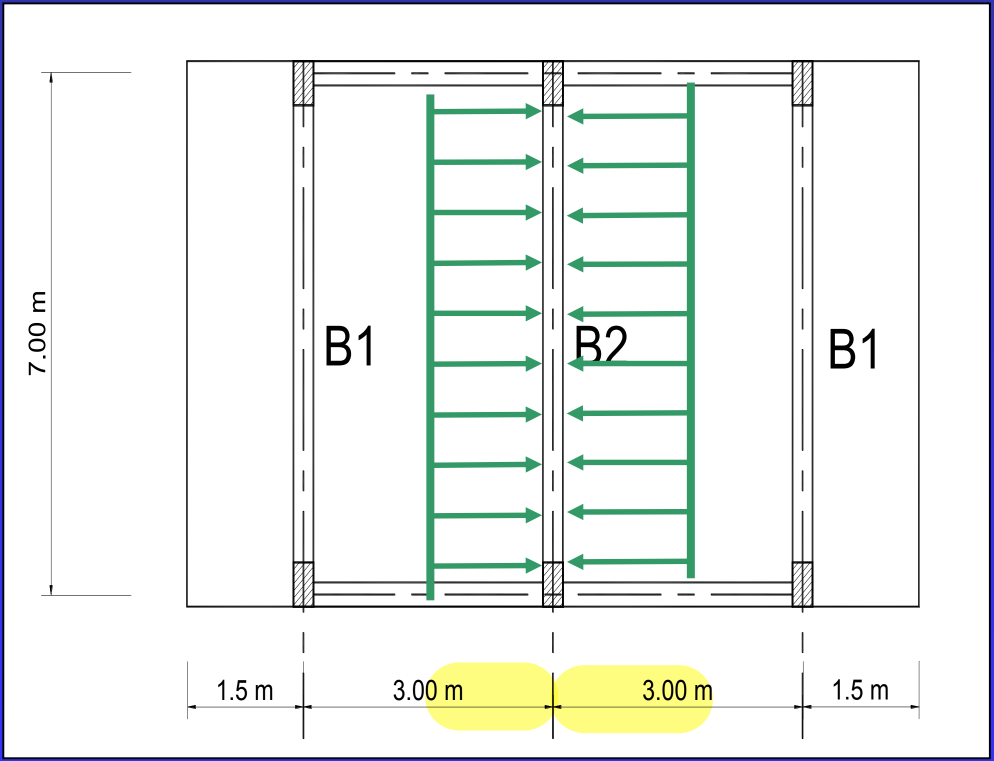
$o.w_{wall} = b_w \, h_w \, \gamma_w$

$= 7.5 \; kN/m$

$w_{from,slab} = \Sigma w_{slab} (L_s/2) + w_{slab} (L_c)$

$= 9.5 \times (3/2) \times 2 + 0$

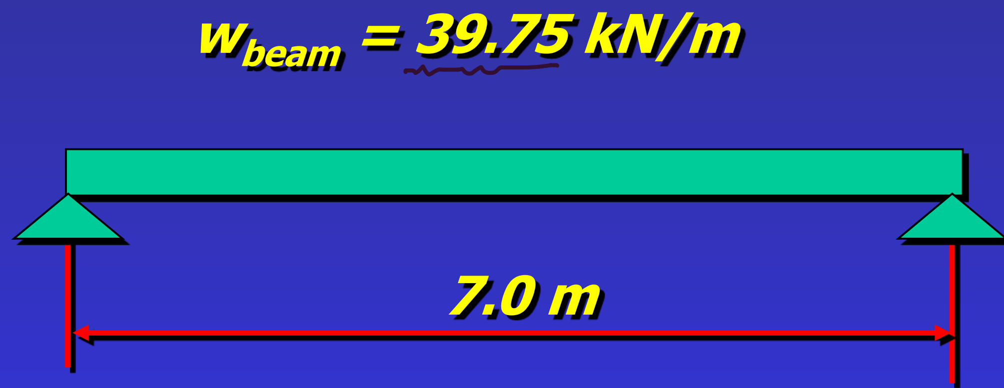
$= 28.5 \; kN/m$



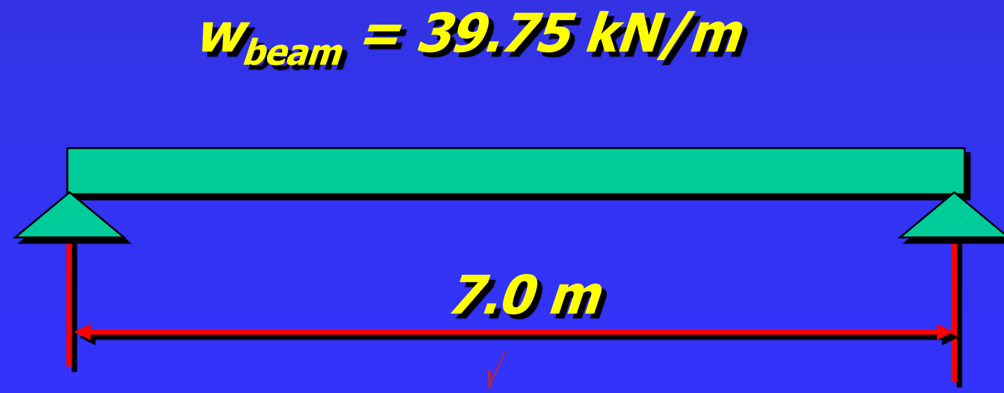
$$w_{beam} = 3.75 + 7.5 + 28.5 = \underline{39.75} \quad kN/m$$

Example (1) – Beams System / Loads

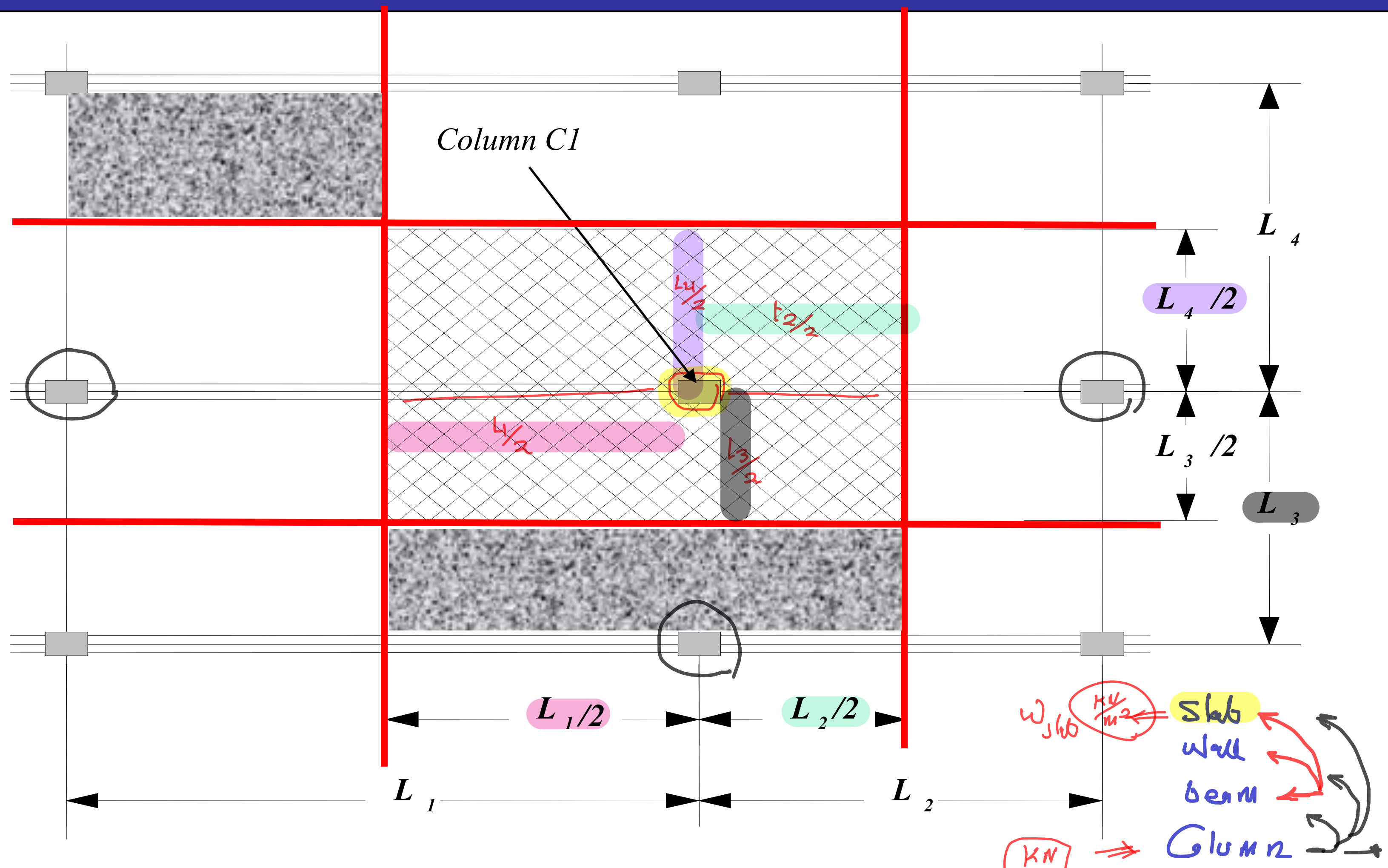
Beam B1



Beam B2



Columns



Tributary Areas for Column C1

Columns Loads

$P_{col} = w_{slab} \times A_{slab} + \Sigma o.w_{beam} * L_{beam} + \Sigma o.w_{wall} * L_{wall} + o.w_{col}$ (kN)

A_{slab}	=	Slab Tributary area carried by the column (m^2)
w_{slab}	=	Uniform total load of the slab (kN/m^2)
$o.w_{beam}$	=	own weight of beam (kN/m)
$o.w_{wall}$	=	own weight of wall (kN/m)
$o.w_{col}$	=	own weight of column (kN) $= \gamma_c * h_c b_c t_c$
L_{beam}	=	length of beams within tributary area (m)
L_{wall}	=	length of wall within tributary area (m)

Columns

Columns Loads:

- ✓ **Loads from slab**

$$P_{from\ slab}\ (KN) = w_{slab}\ (kN/m^2) \times A_{slab}\ (m^2)$$

- ✓ **Loads from beam weight**

$$P_{from\ beam}\ (KN) = \Sigma\ o.w_{beam}\ (kN/m) \times L_{beam}\ (m)$$

- ✓ **Loads from wall weight**

$$P_{from\ wall}\ (KN) = \Sigma\ o.w_{wall}\ (kN/m) \times L_{wall}\ (m)$$

- ✓ **Column own weight**

$$o.w_{col}\ (KN) = (b_{col})\ (t_{col})\ (h_{col})\ (\gamma_c)$$

Example (2)

Given Data:

Slab thickness = 0.2 m

Live Load = 3.0 kN/m^2

Floor cover = 1.5 kN/m^2

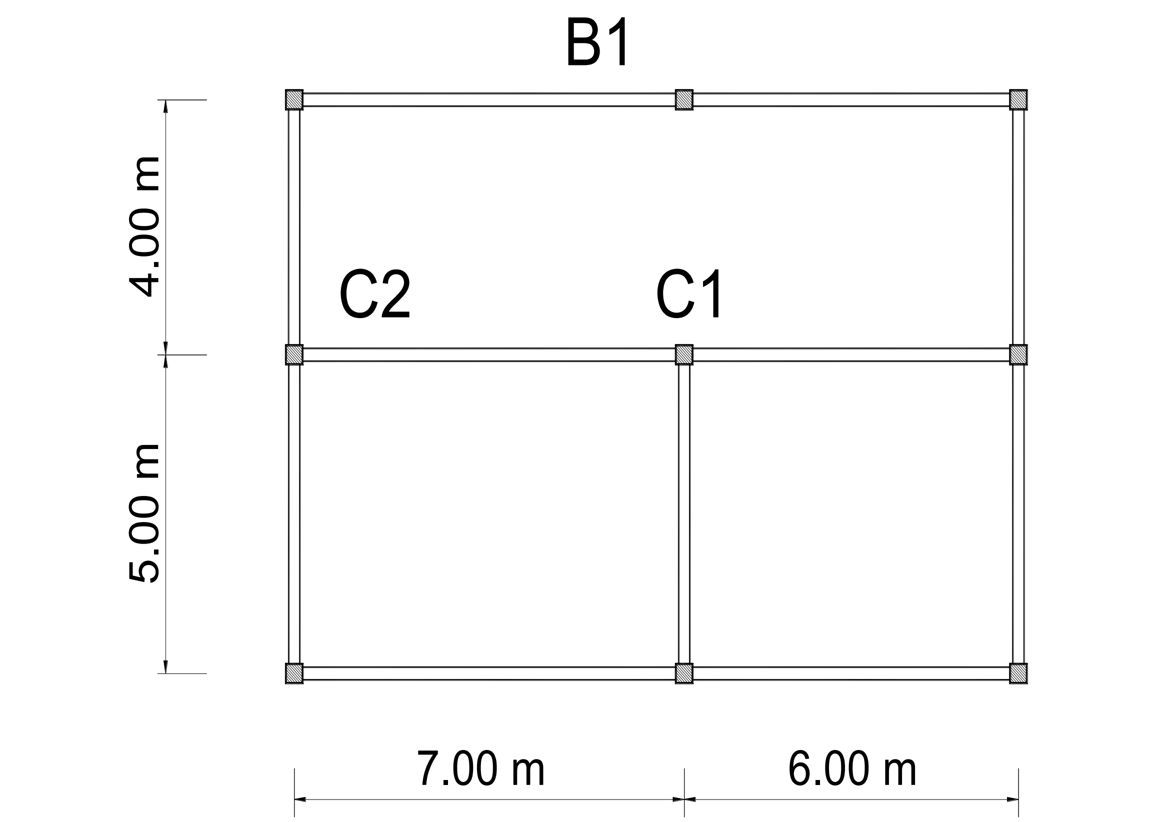
Beams 0.25 m x 0.6 m

Walls 0.25 width & 3 m height

Floor height = 4.0 m

γ_c = 25 kN/m^3 & γ_w = 10 kN/m^3

Column dimensions 0.4 x 0.4 m.



Required:

- *Load carried by the columns C1 & C2 per floor*
- *Load carried by the beam B1*

Example (2)

Given Data:

Slab thickness = 0.2 m

Live Load = 3.0 kN/m^2

Floor cover = 1.5 kN/m^2

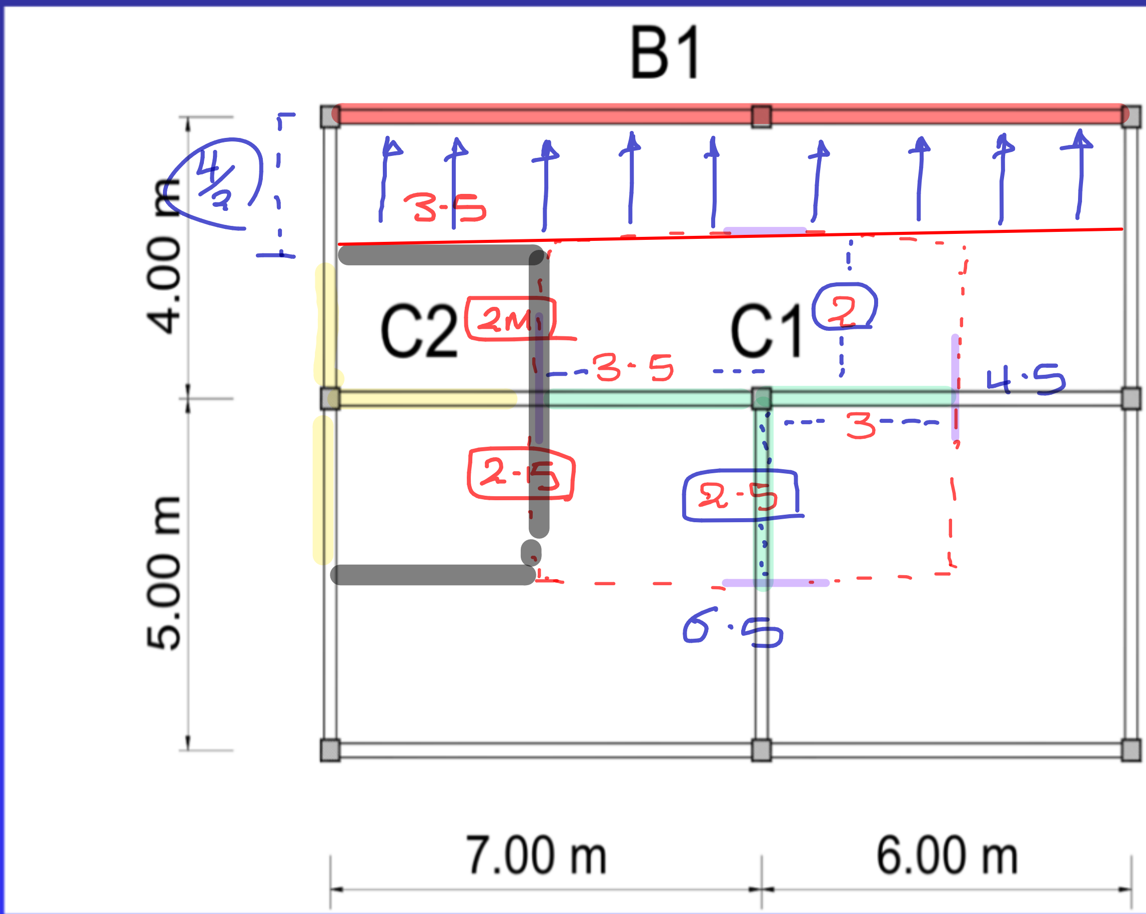
Beams 0.25 m x 0.6 m

Walls 0.25 width & 3 m height

Floor height = 4.0 m

γ_c = 25 kN/m^3 & γ_w = 10 kN/m^3

Column dimensions 0.4 x 0.4 m.



Required:

- Load carried by the columns C1 & C2 per floor
- Load carried by the beam B1

C1

$* \; P_{From\ slab} = w_{slab} \times A_{slab} = 9.5 \times 6.5 \times 4.5$

$= 277.875$ kN

$* \; P_{From\ beam} = \sum o.w_{beam} * L_{beam}$

$= 3.75 * (3 + 3.5 + 2.5) = 33.75$ kN

$P_{From\ Wall} = 7.5(3 + 3.5 + 2.5) = 67.5$ kN

$o.w_{CL} = \gamma_c \, b_{CoL} \, t_{CoL} \, h_{CoL}$

$= 25 * 0.4 * 0.4 * (4 - 0.6)$

$= 13.6$ kN

$P_{C1} = 277.875 + 33.75 + 67.5 + 13.6$

$= 392.725$

C2

$P_{From\ slab} = w_{slab} * A_{slab}$

$= 9.5 * (4.5 * 3.5) = 149.63$ kN

$P_{From\ beam} = \sum o.w_{beam} * L_{beam}$

$= 3.75 * (3.5 + 2 + 2.5) = 30$ kN

$P_{From\ Wall} = 7.5(3.5 + 2 + 2.5) = 60$ kN

$o.w_{CL} = 13.6$ kN

$P_{Col} = 149.63 + 30 + 60 + 13.6 = 253.23$ kN

$\frac{13}{4} > 2 \Longrightarrow$ one way slab

$* \; o.w_{beam} = \gamma_c \, b_b \, h_b = 3.75 \; kN/m$

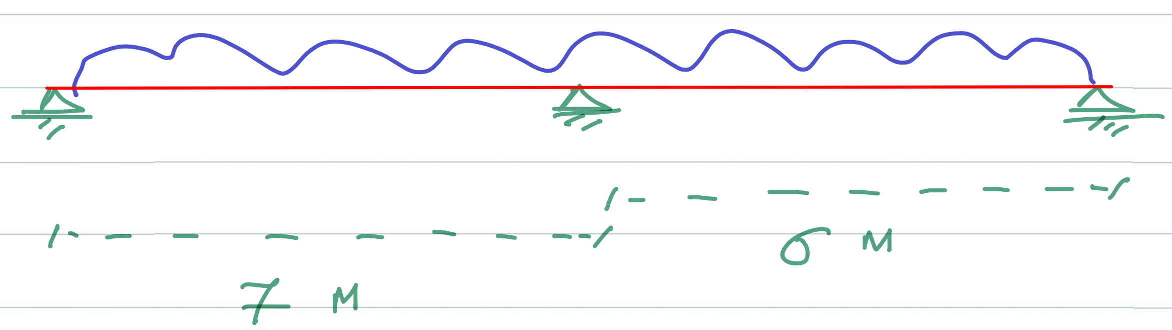
$* \; o.w_{wall} = \gamma_w \, b_w \, h_w = 7.5 \; kN/m$

$* \; w_{From\ slab} = w_{slab} * 2$

$= 9.5 * 2 = 19 \; kN/m$

$w_{beam} = 3.75 + 7.5 + 19 = 30.25 \; kN/m$

$w_{beam} = 30.25 \; kN/m$



Example (2) – Column C1

$P_{from\ slab} = w_{slab} \times A_{slab}$

$= 9.5 \times (6.5 \times 4.5)$

$= 277.875$ kN

$P_{from\ beam} = \Sigma\ o.w_{beam} \times L_{beam}$

$= 3.75 \times (3 + 3.5 + 2.5)$

$= 33.75$ kN

$P_{from\ wall} = \Sigma\ o.w_{wall} \times L_{wall}$

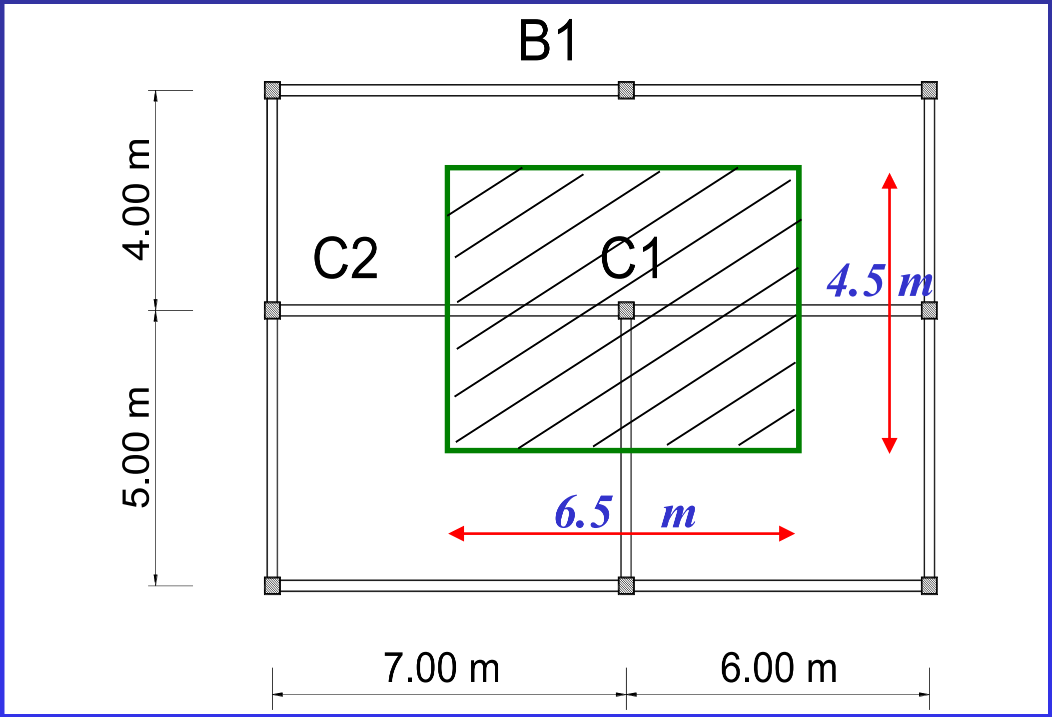
$= 7.5 \times (3 + 3.5 + 2.5)$

$= 67.5$ kN

$o.w_{col} = (b_{col})\ (t_{col})\ (h_{col})\ (\gamma_c)$

$= 0.4 \times 0.4 \times (4 - 0.6) \times 25$

$= 13.6$ kN



$P_{col} = 392.725$ kN

Example (2) – Column C2

$P_{from\ slab} = w_{slab} \times A_{slab}$

$= 9.5 \times (3.5 \times 4.5)$

$= 149.63$ kN

$P_{from\ beam} = \Sigma\ o.w_{beam} \times L_{beam}$

$= 3.75 \times (3.5+4.5)$

$= 30$ kN

$P_{from\ wall} = \Sigma\ o.w_{wall} \times L_{wall}$

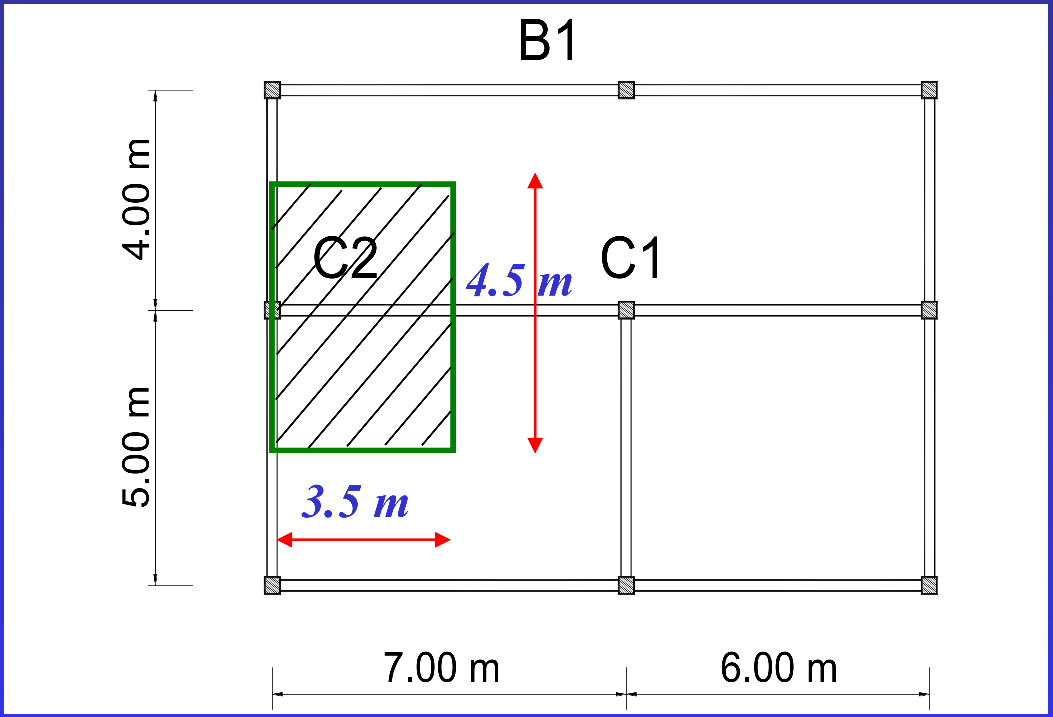
$= 7.5 \times (3.5+4.5)$

$= 60$ kN

$o.w_{col} = (b_{col})\ (t_{col})\ (h_{col})\ (\gamma_c)$

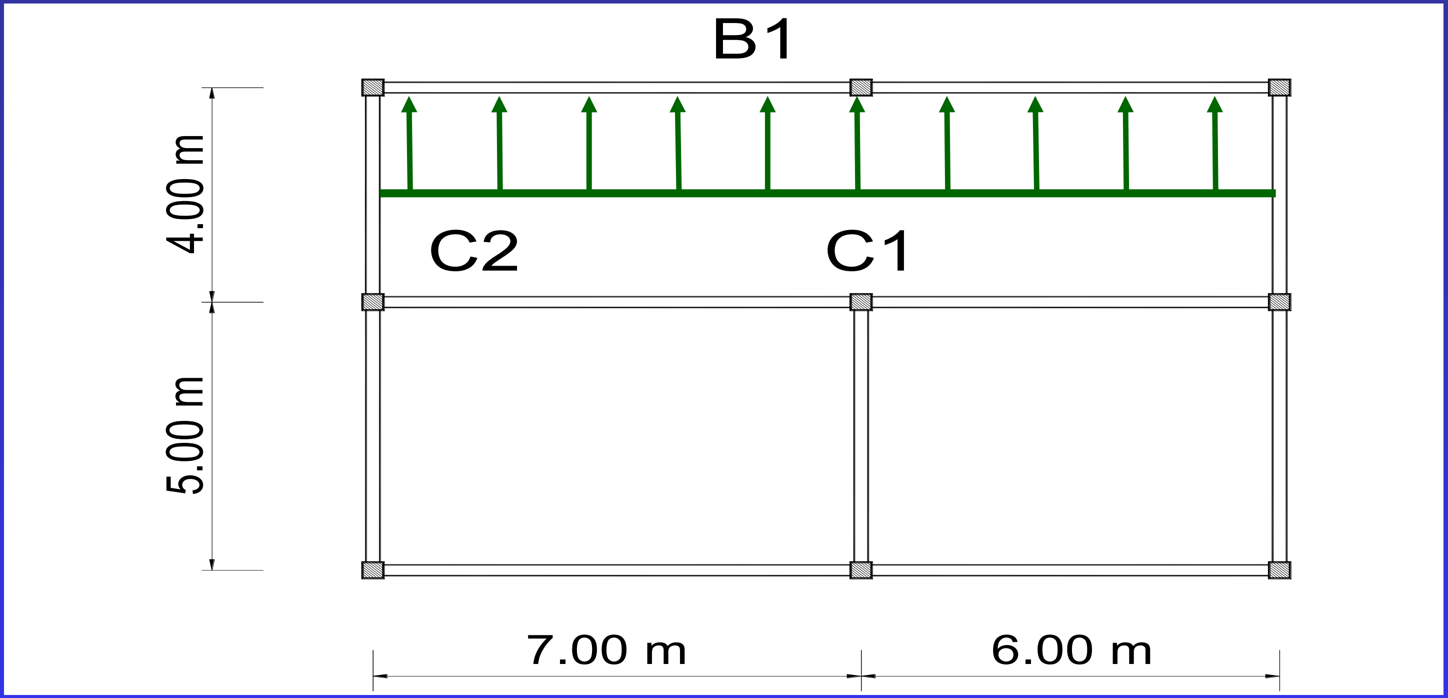
$= 0.4 \times 0.4 \times (4 - 0.6) \times 25$

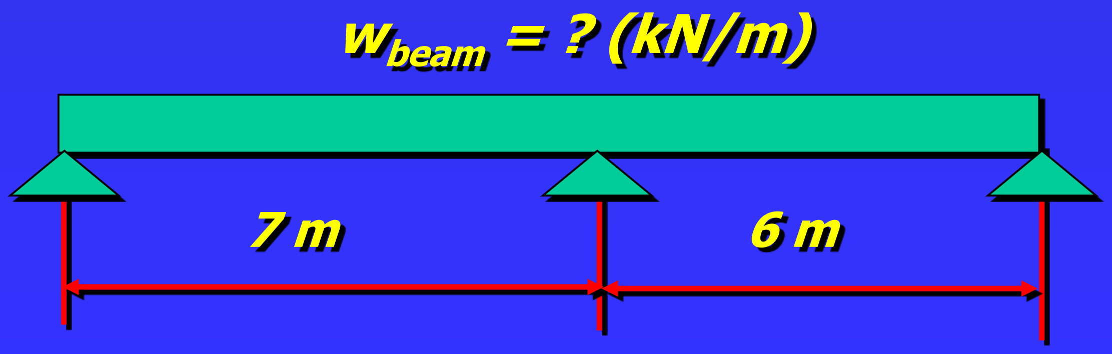
$= 13.6$ kN



$P_{col} = 253.23$ kN

Example (2) - Beam B1



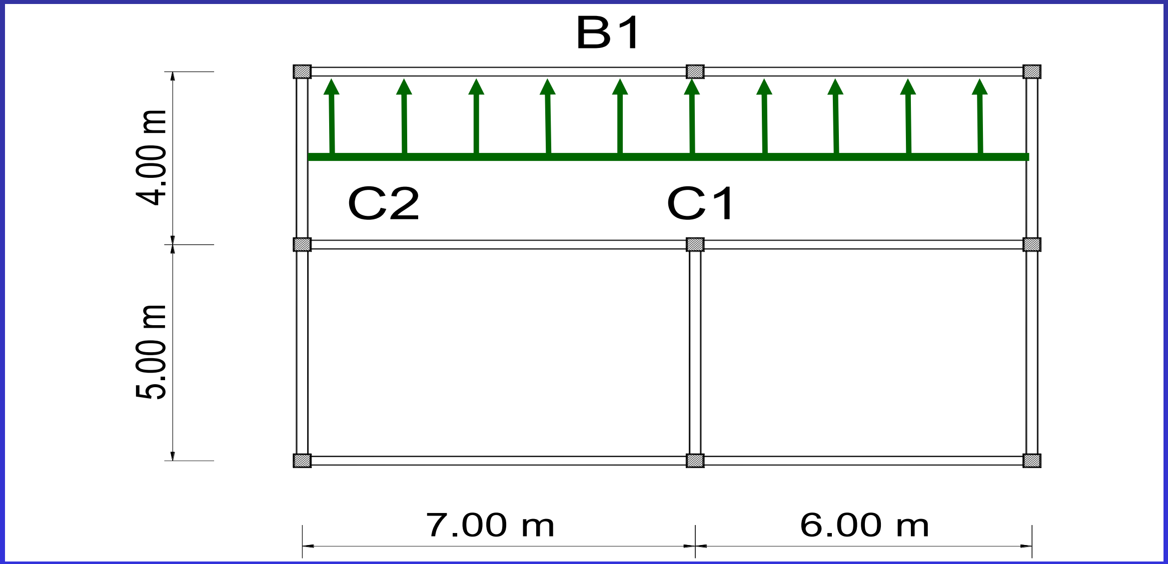


Beam B1

Example (2) - Beam B1

$o.w_{beam} = b_b \, h_b \, \gamma_c$

$= 3.75 \text{ kN/m}$



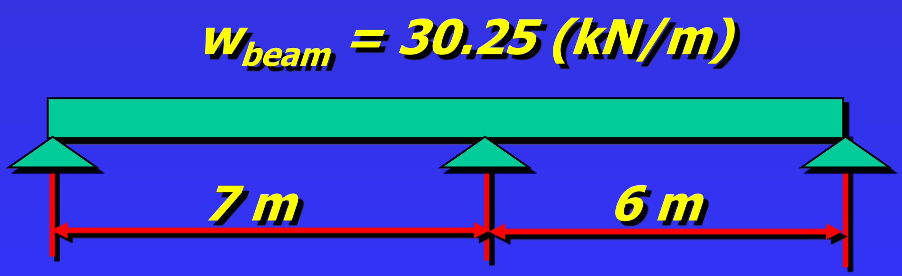
$o.w_{wall} = b_w \, h_w \, \gamma_w$

$= 7.5 \text{ kN/m}$

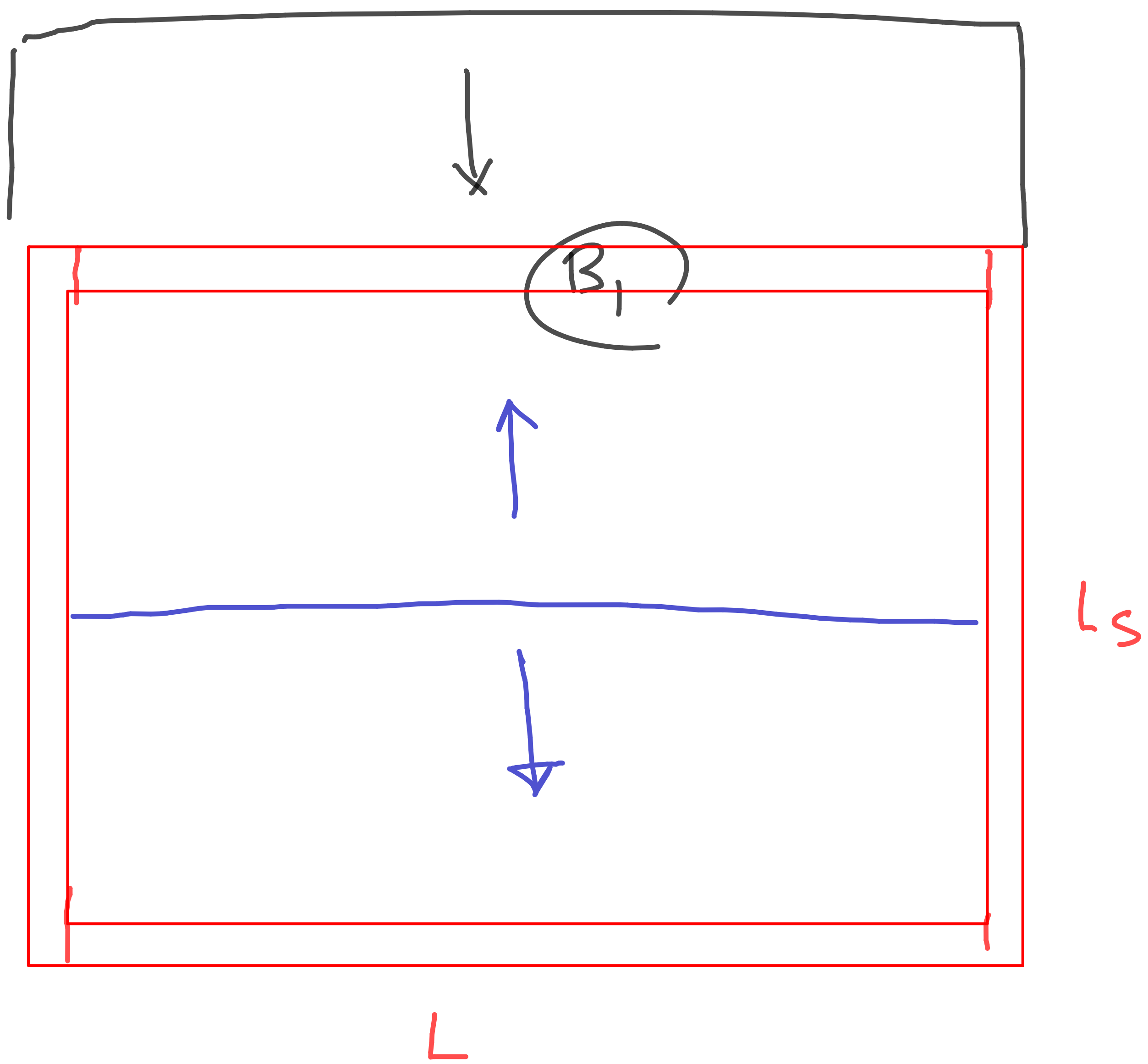
$w_{from,slab} = \Sigma w_{slab} (L_s/2) + w_{slab} (L_c)$

$= 9.5 \times (4/2) + 0$

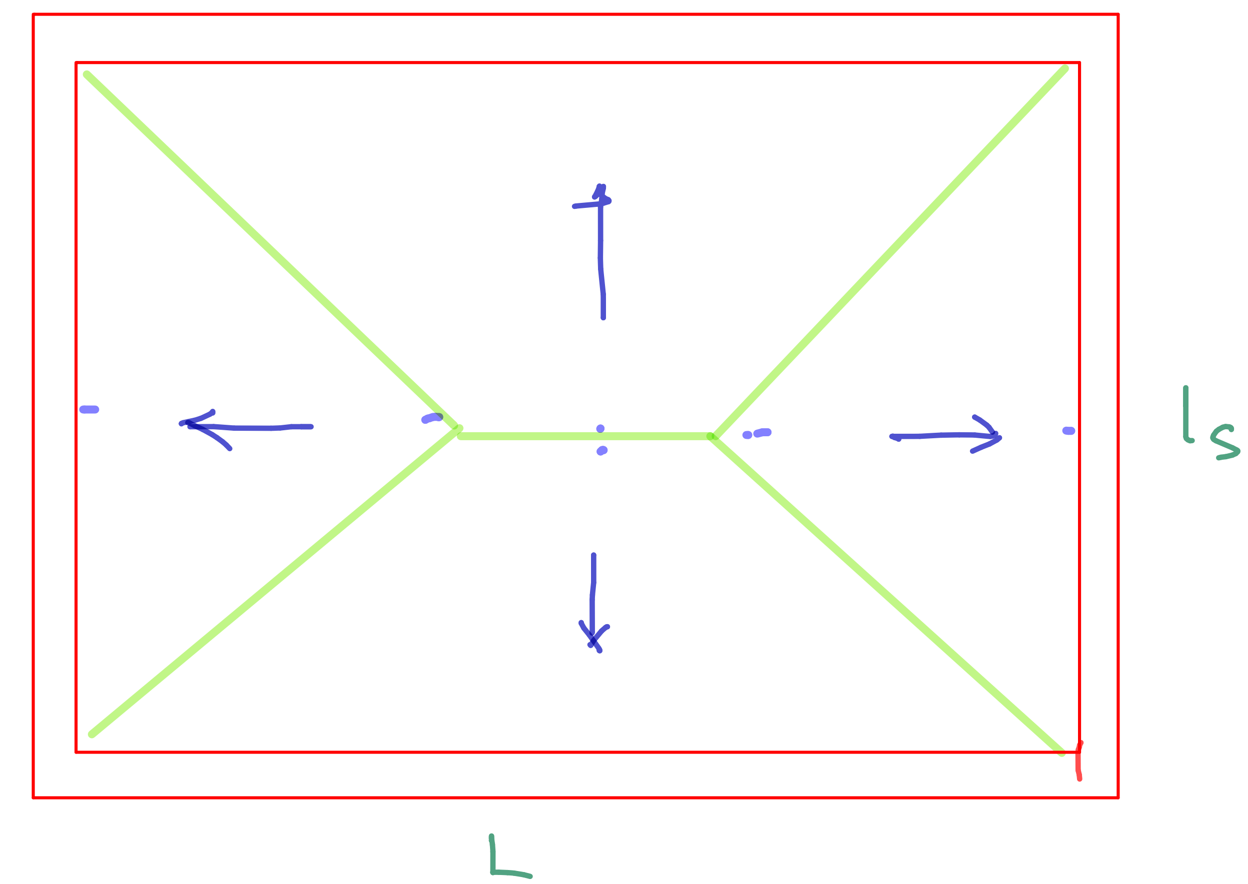
$= 19 \text{ kN/m}$



$w_{beam} = 3.75 + 7.5 + 19 = \underline{30.25} \text{ kN/m}$



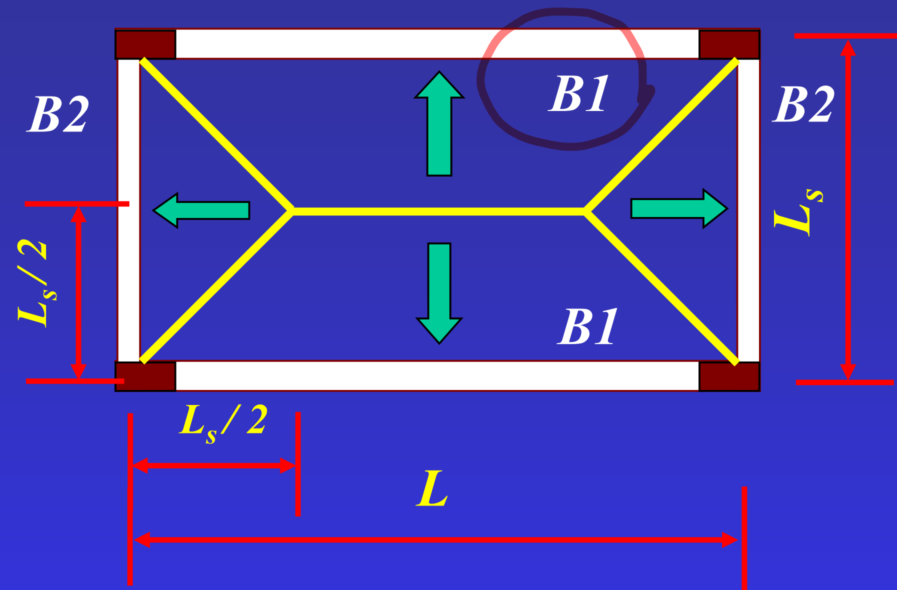
$L / L_s \geq 2$ one way slab



$L / L_s < 2$ two slab

Next → two way slab

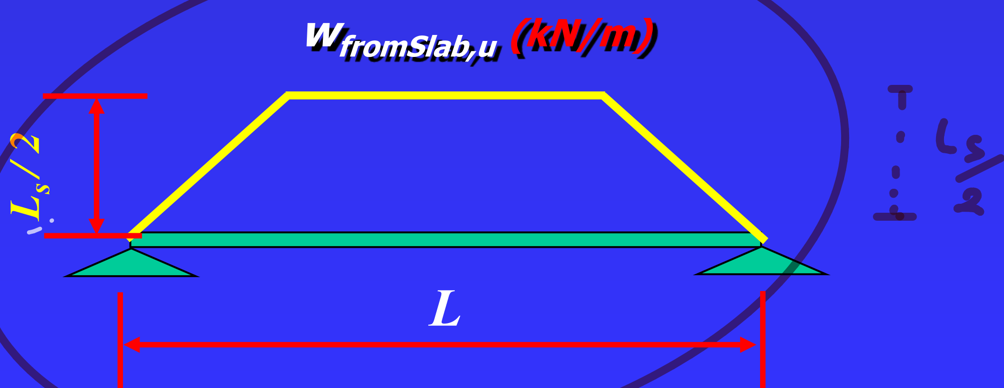
Two-Way Slabs



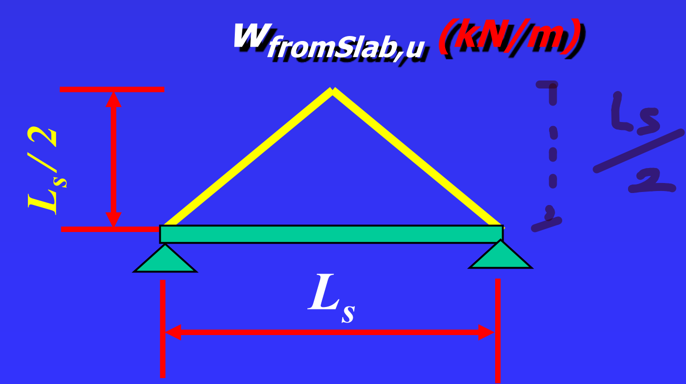
Two-Way Slabs ($L / L_s < 2$)

$L/L_s < 2$

- **Slab Ultimate load transferred to beam**



BEAM (B1)



BEAM (B2)

Example (3)- In class Activity

- **Given:**

t_s = 0.14 m

F.C. = 1.5 kN/m²

w_L = 1.5 kN/m²

Beam sec = 0.3 x 0.65 m

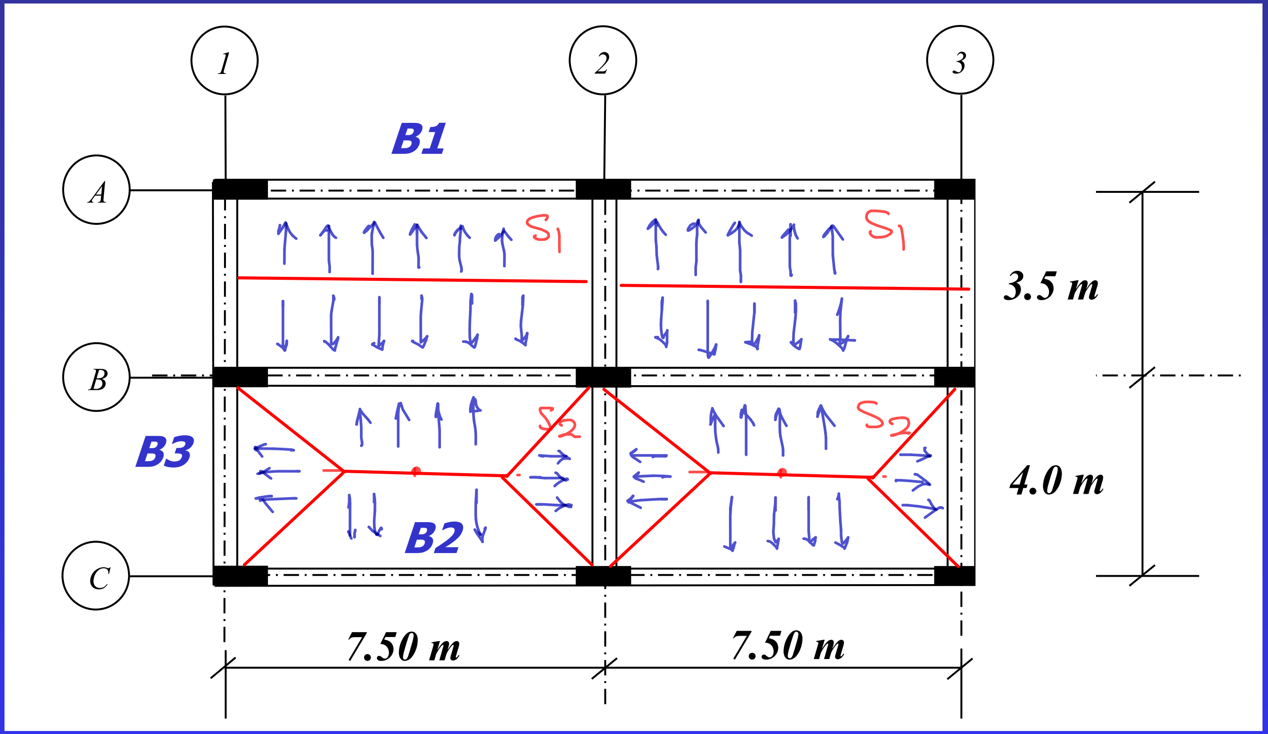
γ_c = 25 kN/m³

Wall density = 10 kN/m³

wall height = 3 m

Wall thickness = 0.25 m

Columns sec. = 0.3 x 0.5 m



For $S_1 \Rightarrow \frac{7.5}{3.5} > 2 \Rightarrow$ one way slab

For $S_2 \Rightarrow \frac{7.5}{4} < 2 \Rightarrow$ two way slab

- **Required:**

Calculate Ultimate Load carried by beams B1, B2, and B3

Solution Guidelines

STEP 1: Draw tributary areas for beams on plan

STEP 2: Draw Statical System of the beam showing its tributary area

STEP 3: Calculate slab ultimate load transferred to beam

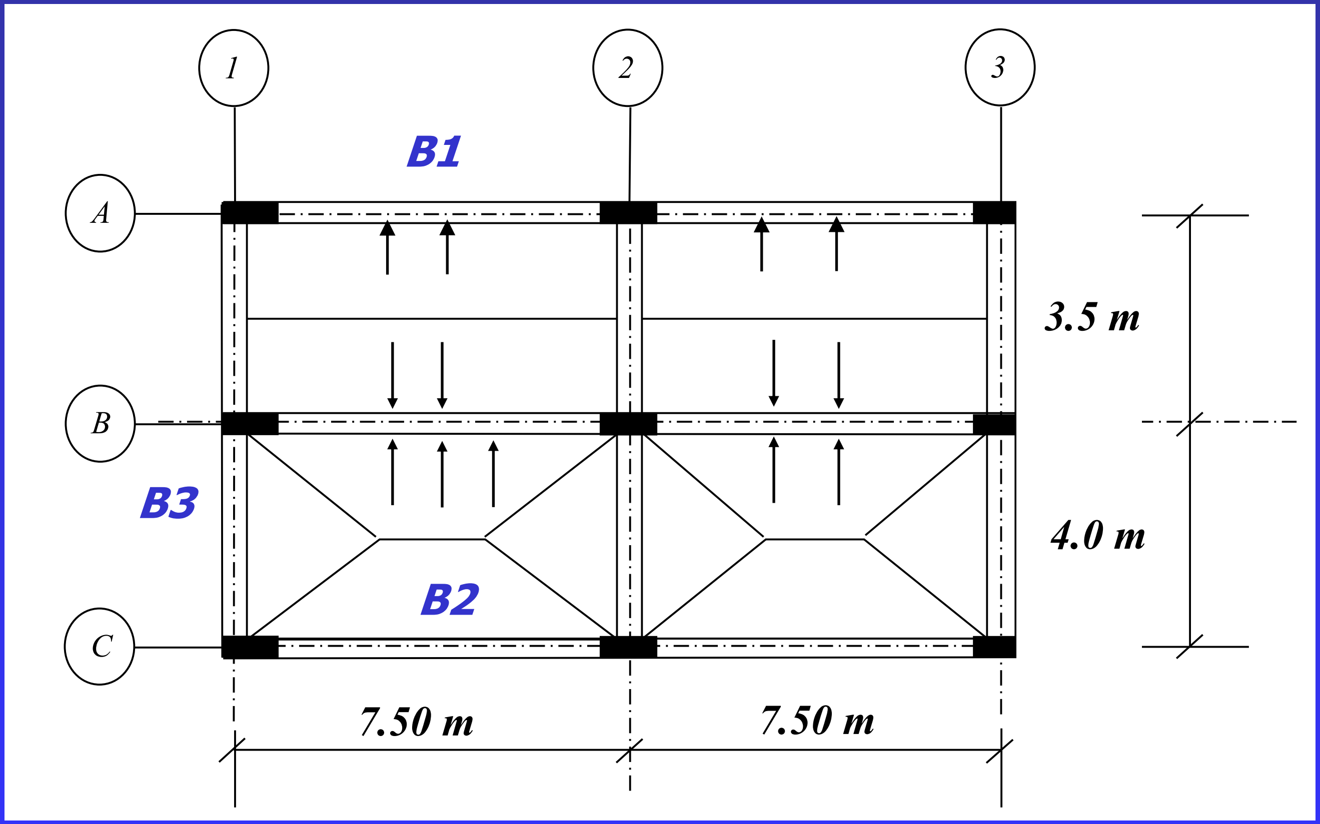
STEP 4: Calculate ultimate beam own weight (dead load)

STEP 5: Calculate ultimate wall weight carried by the beam (dead load)

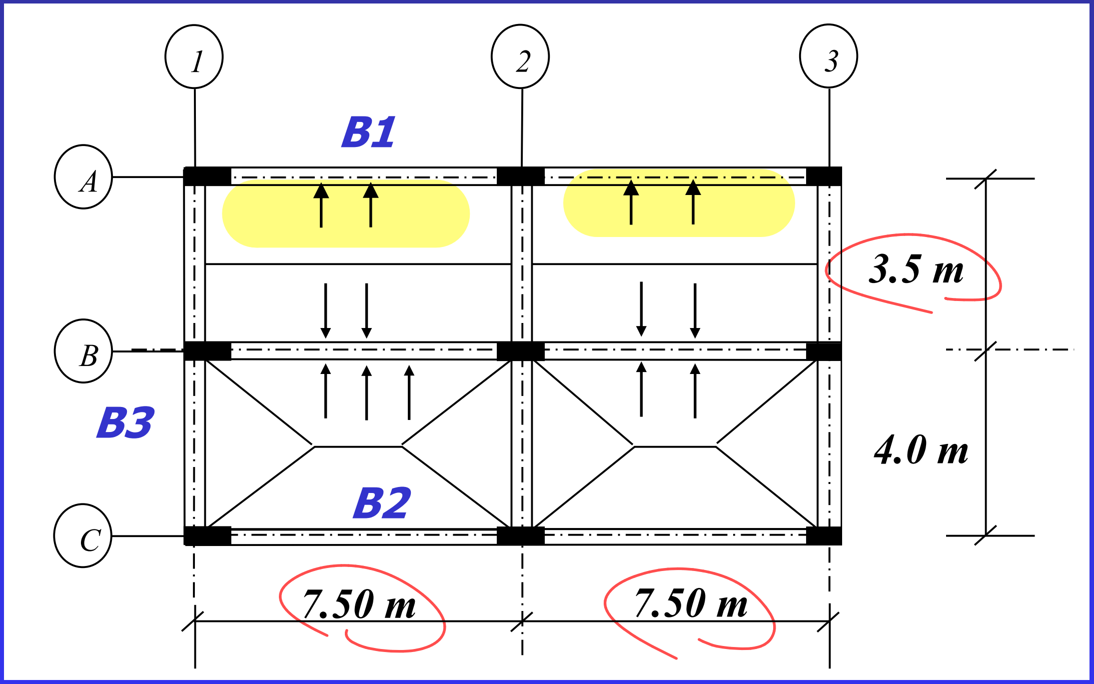
STEP 6: Draw Statical System of the beam showing all ultimate loads

Solution – Tributary Areas

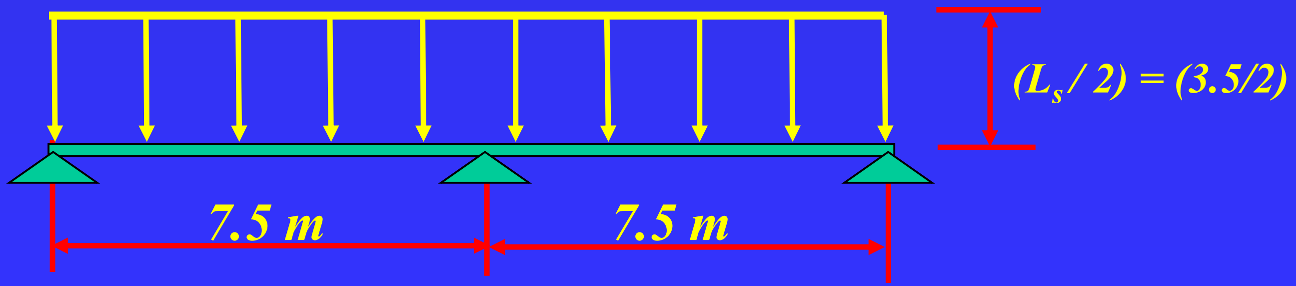
Tributary areas for beams on plan



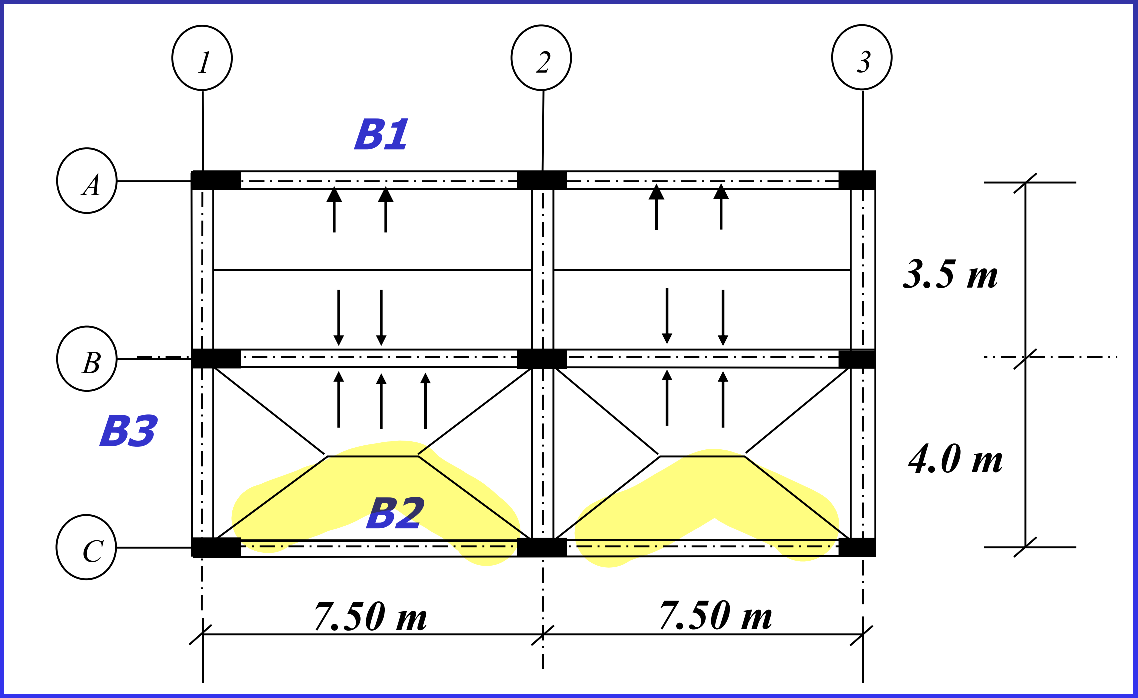
Solution – Beam B1



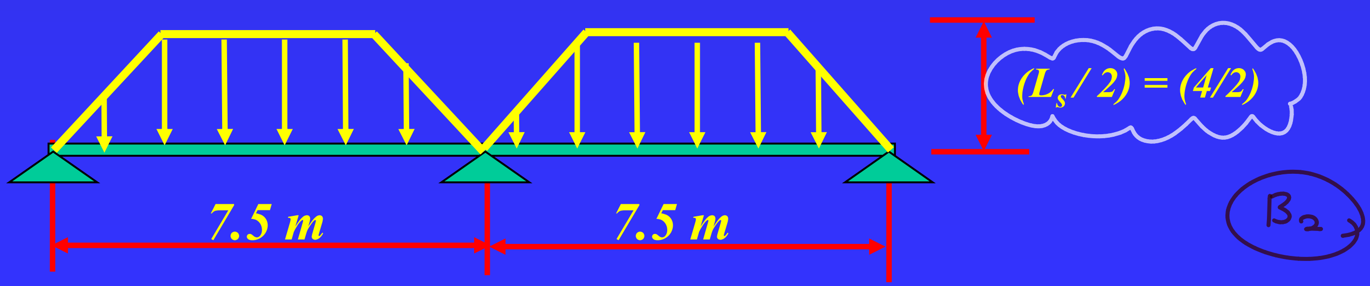
Beam B1



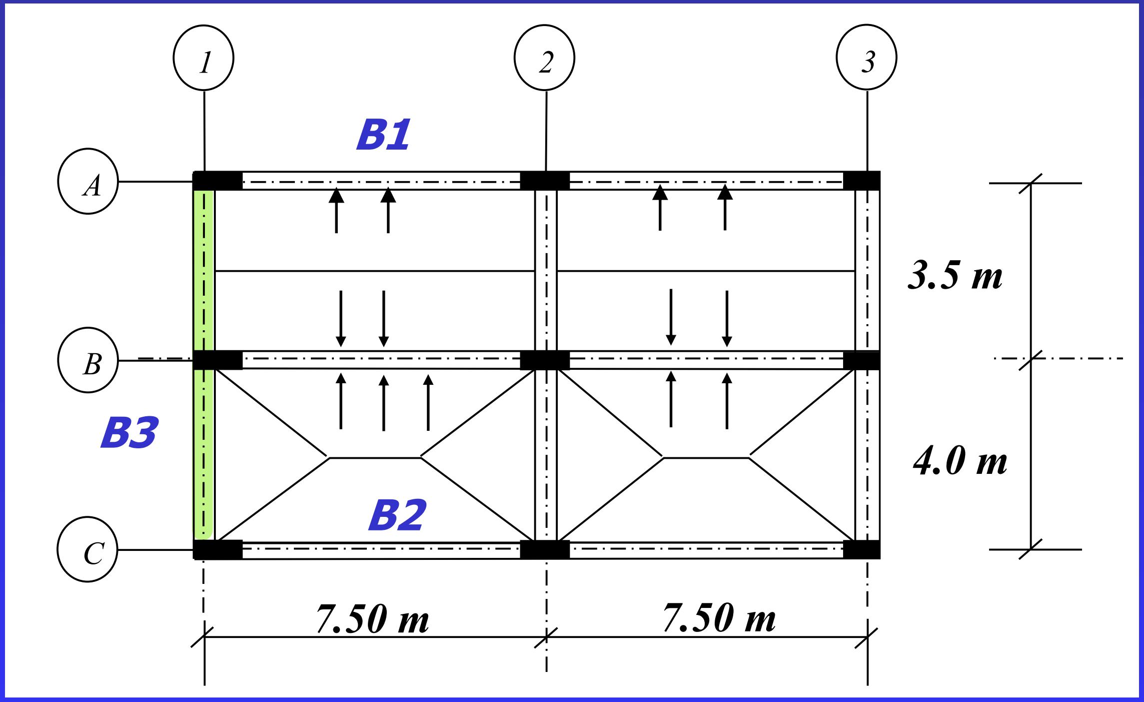
Solution – Beam B2



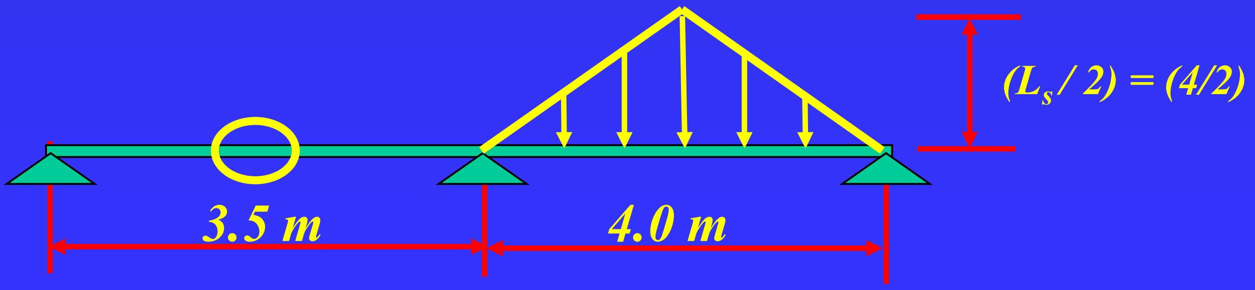
Beam B2



Solution – Beam B3



Beam B3



Example (4) In class Activity

- **Given:**

t_s = 0.14 m

F.C. = 1.5 kN/m^2

w_L = 1.5 kN/m^2

Beam sec = 0.3 x 0.65 m

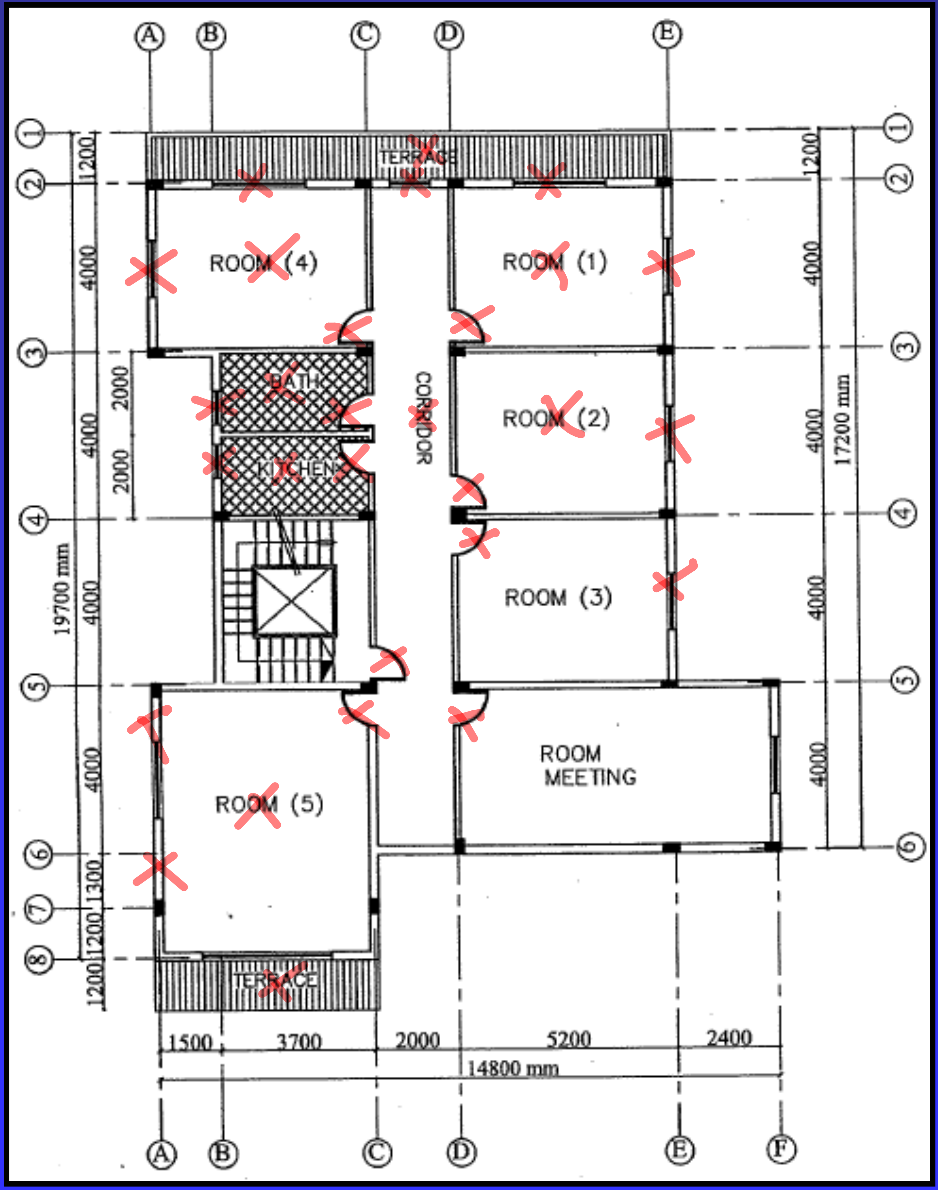
γ_c = 25 kN/m^3

Wall density = 10 kN/m^3

wall height = 3 m

Wall thickness = 0.25 m

Columns sec. = 0.3 x 0.5 m



Example (4) In class Activity

- **Required:**

The figure shows an architectural plan of a typical story of a building. It is required to:

a- Propose a structural system of the floor as a slab-beam type system.

b- Calculate the Load carried by the beams on axes D, E, and 2.

C- Calculate the Load carried by the columns at the intersections of the following axes:

a) 2 and E

b) 3 and D

c) 6 and F

Solution Guidelines

STEP 1: Draw tributary areas for beams and columns on plan

STEP 2: Draw Statical System of the beam and column showing their tributary areas

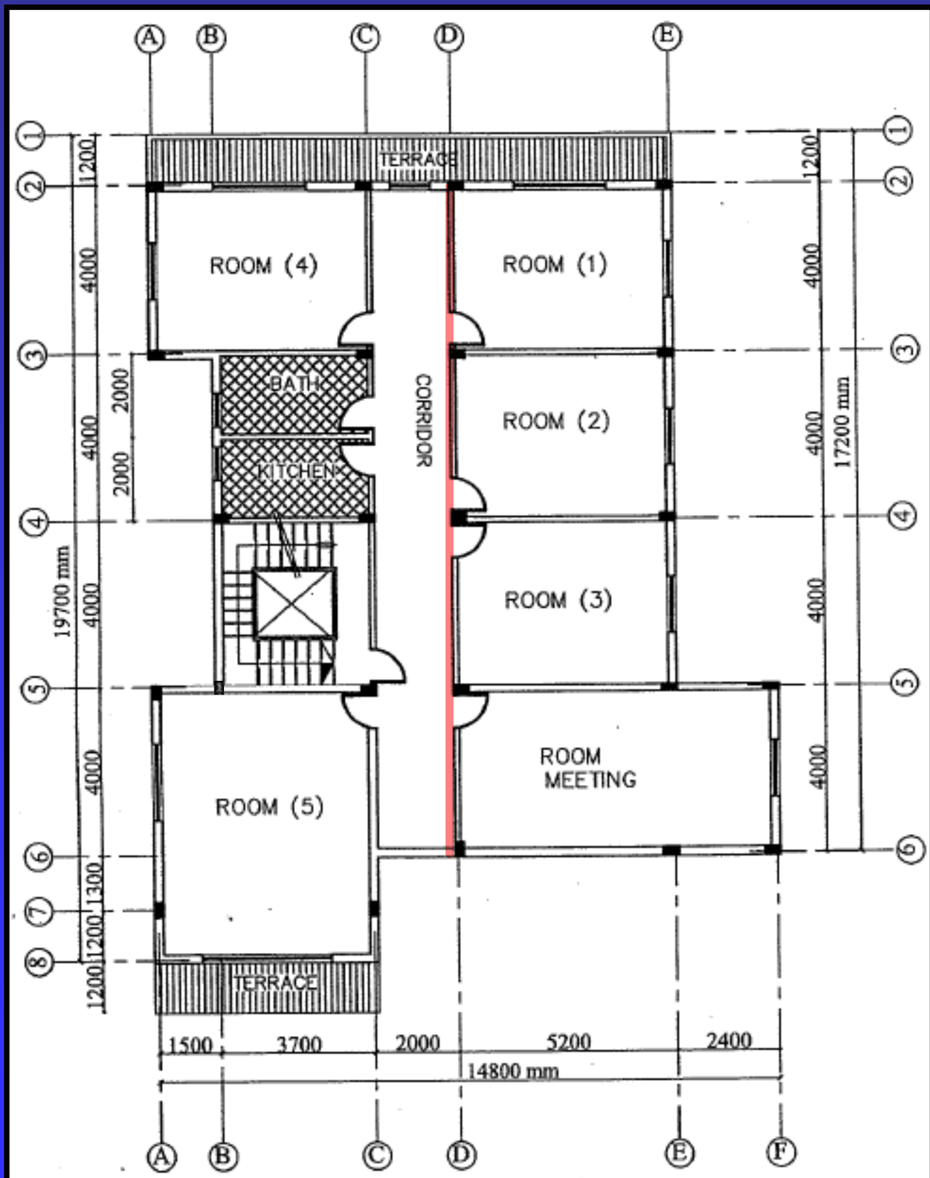
STEP 3: Calculate slab ultimate load transferred to beam and column

STEP 4: Calculate ultimate beam and column own weight (dead load)

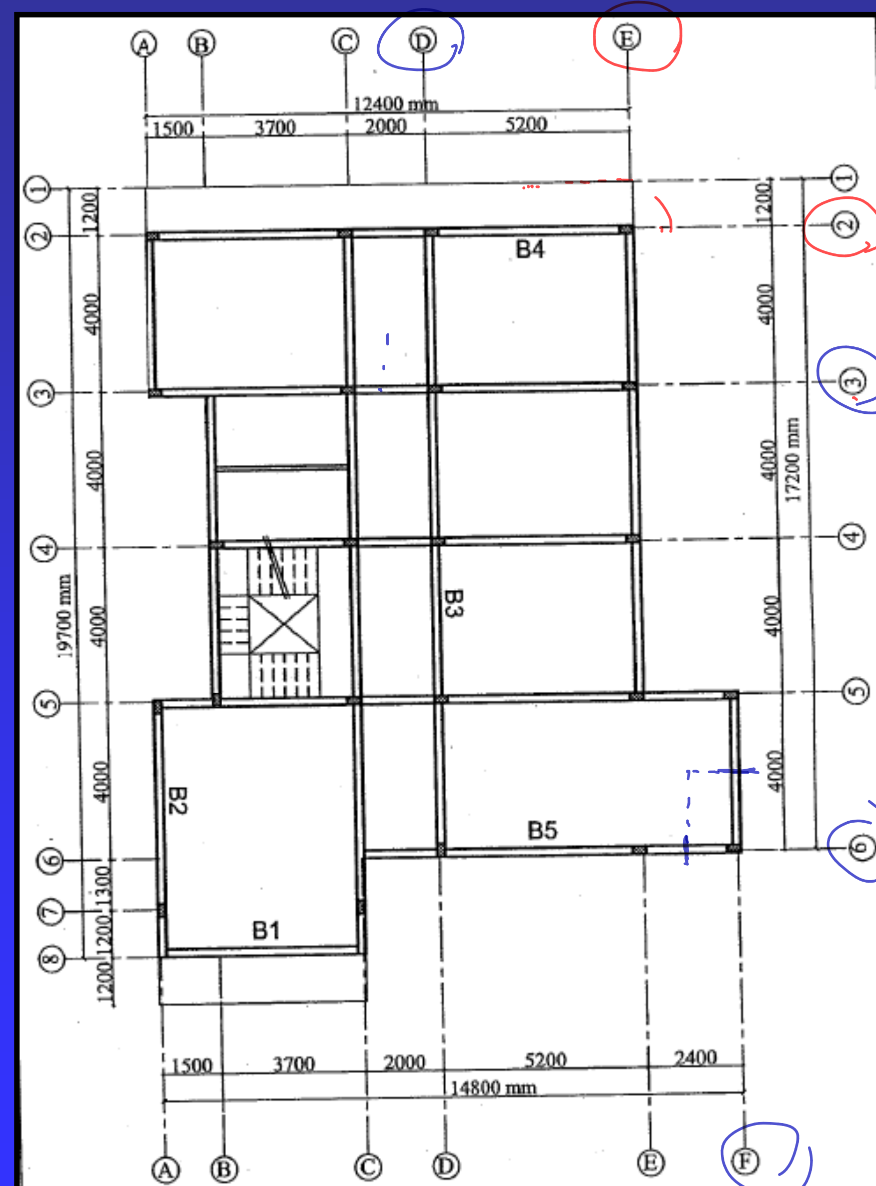
STEP 5: Calculate ultimate wall weight carried by the beam and column (dead load)

STEP 6: Draw Statical System of the beam and column showing all ultimate loads

Solution

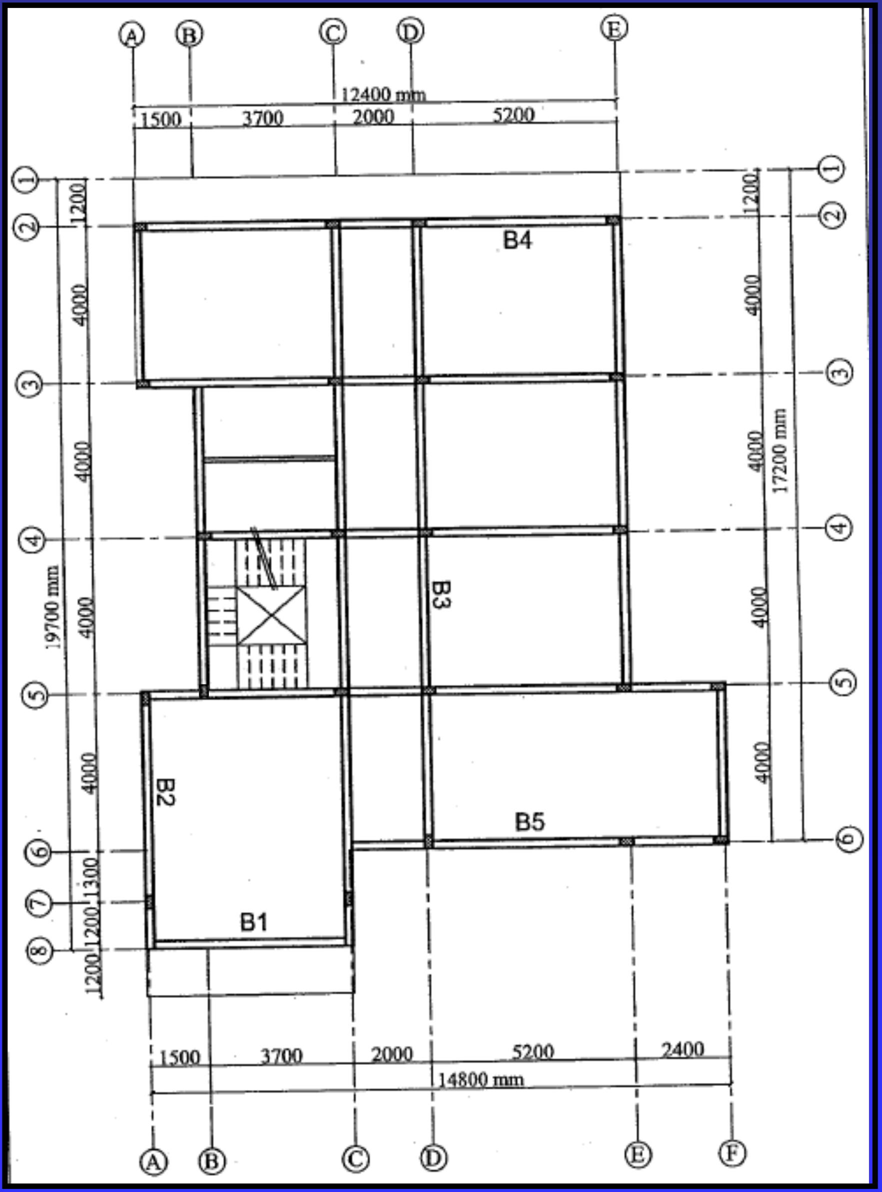


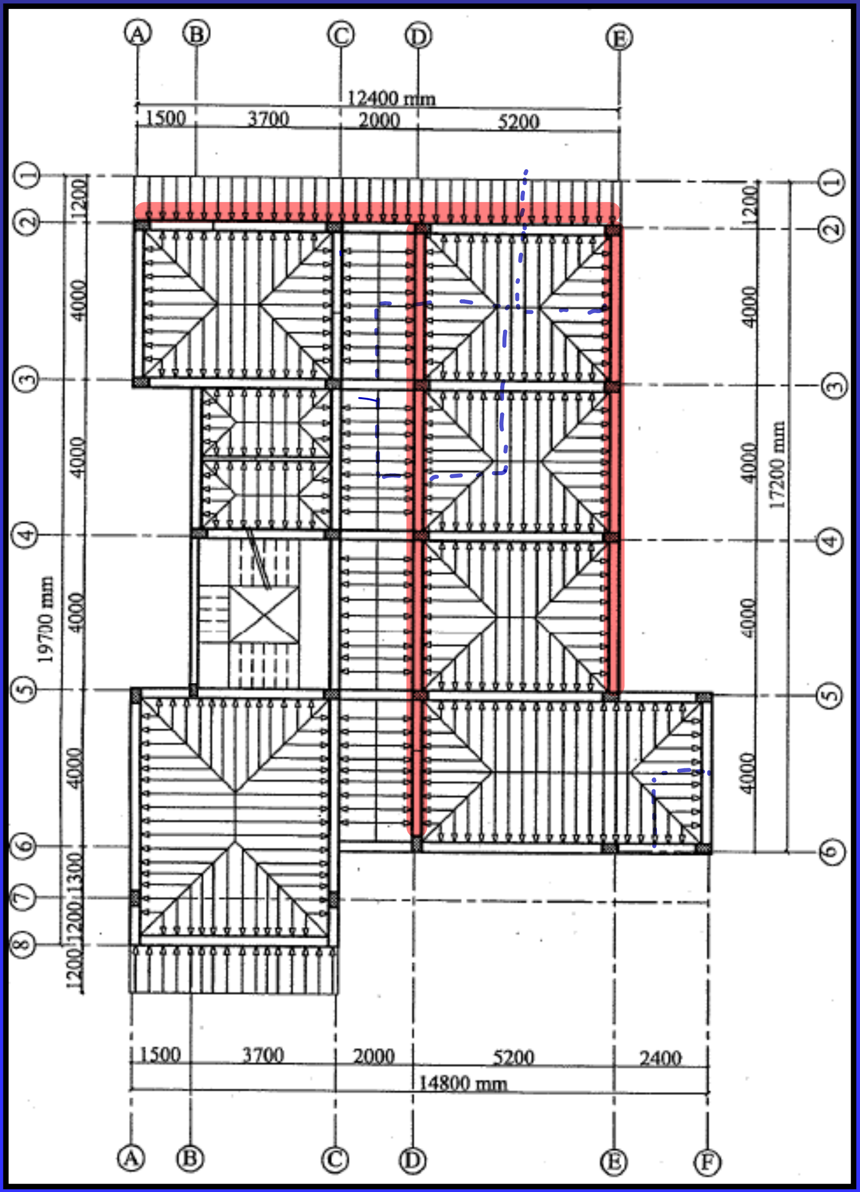
TERRACE
ROOM (4)
ROOM (1)
BATH
CORRIDOR
ROOM (2)
KITCHEN
ROOM (3)
ROOM MEETING
ROOM (5)
TERRACE
19700 mm
17200 mm
14800 mm
1500
3700
2000
5200
2400



12400 mm
1500
3700
2000
5200
B4
B3
B2
B5
B1
19700 mm
17200 mm
14800 mm
2400

Solution


12400 mm
1500
3700
2000
5200
1200
4000
4000
4000
4000
1300
1200
1200
19700 mm
17200 mm
B4
B3
B2
B5
B1
2400
14800 mm


12400 mm
1500
3700
2000
5200
19700 mm
17200 mm
2400
14800 mm

ACI 318 Load Combinations

ACI Code Section 9.2 gives the load combinations to be used in reinforced concrete design

The ACI load combinations deal with load effects, not loads

ACI 318 Load Combinations

$$U = 1.4\left(D + F\right)$$

$$U = 1.2\left(D + F + T\right) + 1.6\left(L + H\right) + 0.5\left(L_r \text{ or } S \text{ or } R\right)$$

$$U = 1.2D + 1.6\left(L_r \text{ or } S \text{ or } R\right) + \left(1.0L \text{ or } 0.8W\right)$$

$$U = 1.2D + 1.6W + 1.0L + 0.5\left(L_r \text{ or } S \text{ or } R\right)$$

$$U = 1.2D + 1.0E + 1.0L + 0.2S$$

$$U = 0.9D + 1.6W + 1.6H$$

$$U = 0.9D + 1.0E + 1.6H$$

ACI 318 Load Combinations

D -> dead load
L -> live load
L_r -> roof live load
F -> weight or pressure created by fluids
T -> temperature, creep, shrinkage, differential settlement
S -> snow load
W -> wind load
E -> seismic load
H -> lateral earth pressure, groundwater pressure or pressure from bulk materials

Example.5

The compressive gravity axial load for a building column are: L = 300 k, D = 150 k and L_r = 60 k. The compressive axial force in the column due to other loads are: wind = 70 k, seismic = 50 k. Tensile axial force in the column due to other loads are: wind = 60 k, seismic = 40 k. Determine the critical design loads based on the ACI load combinations . Compressive loads are positive (this is an arbitrary choice).

Example.5

$$(9-1) \quad U = 1.4(150\text{ k} + 0\text{ k}) = 210\text{ k}$$

$$(9-2) \quad U = 1.2(150\text{ k} + 0\text{ k} + 0\text{ k}) + 1.6(300\text{ k} + 0\text{ k}) + 0.5(60\text{ k}) = 690\text{ k}$$

$$(9-3a) \quad U = 1.2(150\text{ k}) + 1.6(60\text{ k}) + 1.0(300\text{ k}) = 576\text{ k}$$

$$(9-3b) \quad U = 1.2(150\text{ k}) + 1.6(60\text{ k}) + 0.8(70\text{ k}) = 332\text{ k}$$

$$(9-3c) \quad U = 1.2(150\text{ k}) + 1.6(60\text{ k}) + 0.8(-60\text{ k}) = 228\text{ k}$$

$$(9-4a) \quad U = 1.2(150\text{ k}) + 1.6(70\text{ k}) + 1.0(300\text{ k}) + 0.5(60\text{ k}) = 622\text{ k}$$

$$(9-4b) \quad U = 1.2(150\text{ k}) + 1.6(-60\text{ k}) + 1.0(300\text{ k}) + 0.5(60\text{ k}) = 414\text{ k}$$

Example.5

$$(9-5a)\quad U = 1.2(150\text{ k}) + 1.0(50\text{ k}) + 1.0(300\text{ k}) + 0.2(0\text{ k})$$
$$= 530\text{ k}$$

$$(9-5b)\quad U = 1.2(150\text{ k}) + 1.0(-40\text{ k}) + 1.0(300\text{ k}) + 0.2(0\text{ k})$$
$$= 440\text{ k}$$

$$(9-6a)\quad U = 0.9(150\text{ k}) + 1.6(70\text{ k}) + 1.6(0\text{ k}) = 247\text{ k}$$

$$(9-6b)\quad U = 0.9(150\text{ k}) + 1.6(-60\text{ k}) + 1.6(0\text{ k}) = 39\text{ k}$$

$$(9-7a)\quad U = 0.9(150\text{ k}) + 1.0(50\text{ k}) + 1.6(0\text{ k}) = 185\text{ k}$$

$$(9-7b)\quad U = 0.9(150\text{ k}) + 1.0(-40\text{ k}) + 1.6(0\text{ k}) = 95\text{ k}$$

Slab load

- one way: $L_L / L_s \geq 2$
- two way: $L_L / L_s < 2$

W_D — W_L (given)

$$W_D = t_s \cdot \gamma_c + SDL \text{ (given)}$$

t_s: thickness; SDL: cover — Super Imposed

$$W_{slab} = W_D + W_L \quad (kN/m^2)$$

Walls

$$O.W_{wall} = b_w \, h_w \, \gamma_w \quad kN/m$$

(D.L)

Beam

- $o.w,\ beam$ (D.L)
- $o.w,\ wall$
- $\sum W_{slab} * (L_s)$

$$o.w,\ beam = b_b \, h_b \, \gamma_c$$

$$W_{beam} = b_b \, h_b \, \gamma_c + b_w \, h_w \, \gamma_w + \sum W_{slab} * L_{slab} \quad kN/m$$

Column loads

$$o.w\ Column + \sum o.w_{beam} \cdot L_{beam} + \sum o.w_{wall} \cdot L_{wall} + W_{slab} \times A_{slab}$$

$$= b_{col} \, t_{col} \, h_{col} \, \gamma_c$$