Reinforced Concrete

In the past, buildings were made from mud and stones and slabs are carried by walls. These bearing walls are of large dimensions and thickness which sacrify most of the space available.

Later when new stronger construction material became known, smaller cross-section for beam and column could safely carry loads and space is more efficiently used.

The most common construction materials are concrete, steel and wood. Every material has its own advantages and disadvantages. Among these three, reinforced concrete is more commonly used in constructing buildings, bridges, tunnels and tanks. Reinforced concrete is achieved by successful marriage of two materials namely concrete and steel and each of which has its duties and obligations to maintain a stable structures. This kind of marriage is susceptible to failure for different causes.

How to make a successful long lasting marriage and a friendly relationship between concrete and steel that is the theme of this course CE 315 / ARC 323.

Q1) Why concrete alone is not able to support load and form a structure?

A1) Because concrete is weak in tension and it will crack so it needs another partner to carry the tension force which itself can't carry. Therefore it needs steel to carry tension force and arrest crack. Once you add steel, one will have what is called reinforced concrete.

Q2) Why we need steel in reinforced concrete?

A2) We need it so as to help concrete in carrying tension force and to maintain a smaller cross section because steel is stronger than concrete.

Q3) How one would quantify strength of material in tension or compression?

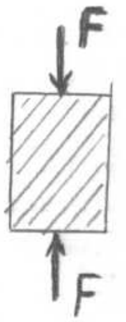
A3) Prepare a specimen or reasonable dimensions and apply tension or compression and increase the force until it fails, then calculate the corresponding stress by dividing force by area to yield stress. So strength is quantified by computing stress and not force.

$$f = F/A$$

F = force (N or 1b)

A = Area (m^2 or in^2)

f = stress (Pa or psi)



Q4) Why concrete structure would deteriorate?

A4) Concrete structures would deteriorate for two main causes:

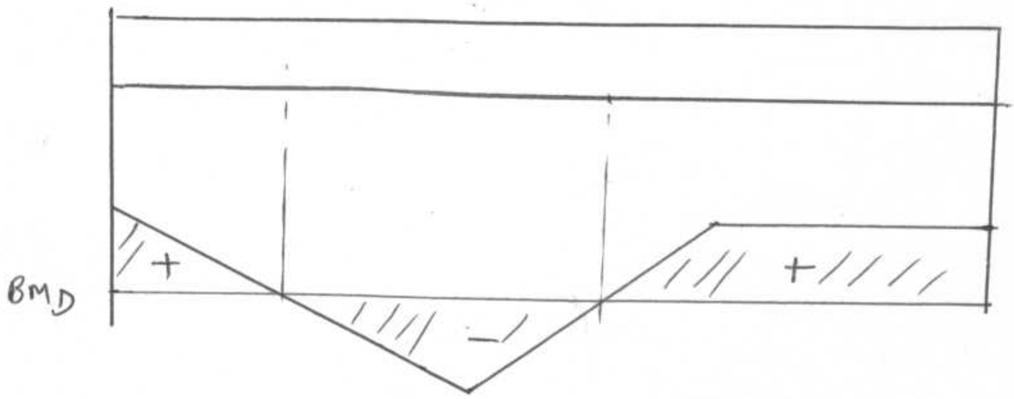
1) Externally by the effect of harsh environment where high humidity, temperature and salinity in the air would promote corrosion of reinforcement especially if concrete is poor and can't prevent aggressive species from attacking steel. Also the adverse conditions of temperature and moisture under which concrete is placed and cured could be a decisive factor in promoting early deterioration of reinforced concrete.

2) Internally by using one or more of the contaminated components in making concrete.

- not using sweet water
- using polluted sand or aggregate
- employing poor quality of cement

Q5) Given the bending moment diagram for a particular segment of structure, show proper location of steel along and across the depth of the beam. (Note that positive movement means tension in the bottom and compression means tension on top and vice versa.).

A5)



1) The most common construction materials used for buildings are wood, steel, and reinforced concrete.

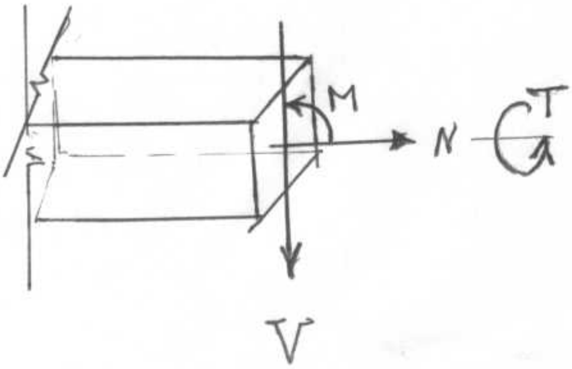
2) Many structures are built of reinforced concrete including

bridges	retaining wall	conduits
viaducts	tunnels	
buildings	tanks	

3) Reinforced concrete is dealing principally with design and investigations (analysis) of reinforced concrete members subjected to:

axial force,	N
bending moment,	M
shear force,	V
torsion,	T

or combination of the above.



CONCRETE

Plain concrete = cement + aggregate + water + admixtures

Strength of concrete depends on two major factors: one is the proportion of ingredients and the other is the condition of temperature and moisture under which it is placed and cured.

(1) Cement:

Cement is a material, which has adhesive and cohesive property, and composed of silicates, aluminate, and clay which chemically react when water added to form a paste. The reaction is called "hydration" and the cement itself is called "hydraulic cement". The cement used in normal concrete is called "Portland Cement" because of its resemblance when hardened to Portland stone found near Desert in England.

Type of Portland Cement

Type	Function
I	Ordinary cement for general purpose construction
II	For moderate sulfate resistance (concrete with contact with soil)
III	High early strength for the removal of formwork soon
IV	Low heat of hydration for massive concrete construction
V	Severe sulfate resistance

(2) Aggregates:

There are two types of aggregate; one is fine aggregate (sand) and the other is called coarse aggregate. Fine aggregate are those materials which passes the No. 4 sieve [i.e. less than 3/16 in or (5 mm)]. Coarse aggregate those which are larger than 6/16 in (5 mm). Aggregate should be clean, hard, and well graded (contain different sizes). The quantity of aggregate is very important since they make up 60-75% of these volumes of concrete.

The quantity and strength of aggregate will determine the type of concrete and its unit weight. There are three kinds of concrete:

1) light weight concrete (70-115 pcf)
2) normal concrete (145 pcf)
3) heavy weight concrete (250 pcf)

Normal concrete is made using sand and stones but light weight concrete can be made using industrial by-products such as expanded slag or clay. The normal concrete conforming to ASTM C33 has a unit weight [145 pcf (lb/ft^3) or 2320 kg/m^3] whereas light weight concrete conforming to ASTM C330 has a unit weight [70-115 pcf or 1120-1840 kg/m^3]. The heavy weight – light weigh density concrete contain a specially made aggregate and its unit weight is 200-350 pcf. Such concrete is used for shielding against radiation as the concrete used for nuclear reactor or places where x-ray is used in the hospital.

(3) Admixtures:

Admixtures are chemicals which are added to the concrete mix to achieve special purposes or to meet certain construction conditions. There are basically four types of admixtures.

- air-entraining agents
- workability agents
- retarding agents
- accelerator agents

Air-Entraining Agents:

Those are used for concrete exposed to freeze-thaw cycles. Billions of tiny air bubbles of 1 mm or smaller in size are deliberately mixed with concrete to provide interconnected pathway so water near the surface will escape as it expand. Also air bubbles improve workability of the mix.

Workability Agents:

Through the use of these agents, one can use less water and have the same workability. Plasticizers fly ash (by-products of the burning of coal) is an example. Superplasticizers are relatively new and they are responsible for the development of high strength concrete in excess to 15,000 psi.

Retarding Agents:

They are to slow down the setting time especially for large masses of concrete where concrete need to stay in plastic state for long time so as not to form what is called "cold joint" where two patches of concrete may arrive at different time and form discontinuity between them.

Accelerator Agents:

Accelerators serve to increase the rate of strength gain and to decrease the setting time. The best known accelerator is "calcium chloride".

Compressive Strength

The strength of concrete is controlled by the proportioning of cement, coarse and fine aggregates, water, and admixtures. Concrete strength is measured by compression test of a standard test cylinder (12″ in height and 6″ in diameter) at 28 days of curing after casting. In some part of the world, a cube of concrete is used instead of cylinder. These cubes are 200×200×200 mm or 150×150×150 mm. The concrete strength is denoted by f_c' and the cube strength gives higher value than cylinder of the same concrete.

$$f_c' \text{ of cylinder } = 83\% \,(f_c' \text{ of cube of } 200)$$
$$= 80\% \,(f_c' \text{ of cube of } 150)$$

The single most important indicator of strength is the ratio of water used compared to cement by weight [it is called (water-cement ratio)]. The higher the w/c ratio the lower the strength, see Fig. below. A typical value of w/c ratio is 0:4 – 0:6.

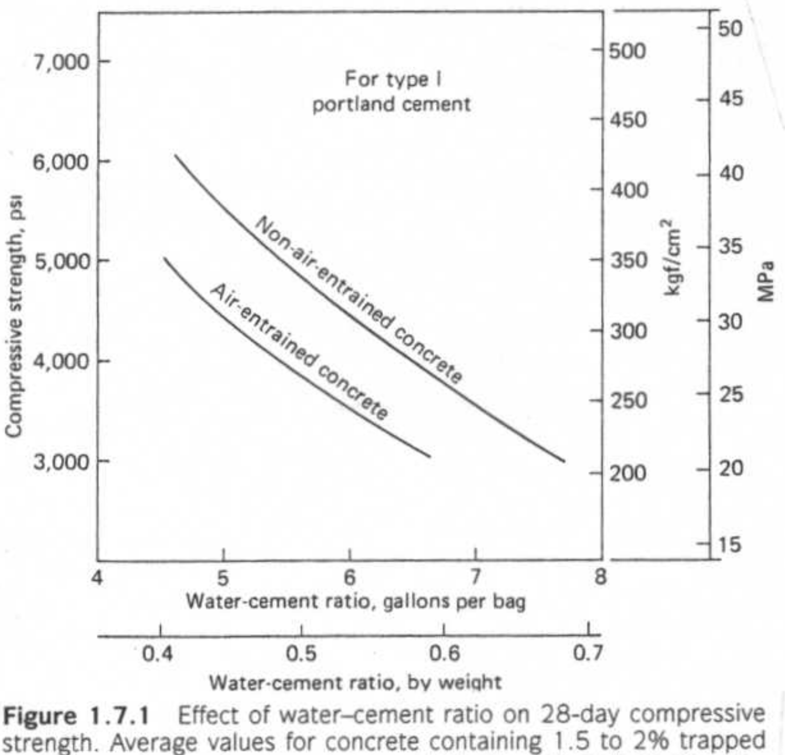


Figure 1.7.1 Effect of water–cement ratio on 28-day compressive strength. Average values for concrete containing 1.5 to 2% trapped air for non-air-entrained concrete, and No More Than 5 to 6% Air for Air-Entrained Concrete (curves drawn from data in Ref. 1.43, Table 6.3.4a).

A good indicator of water content of the mix (or workability) is obtained by having a "standard slump test".

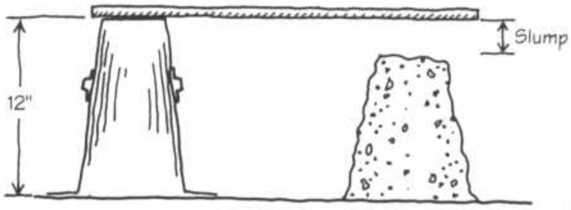
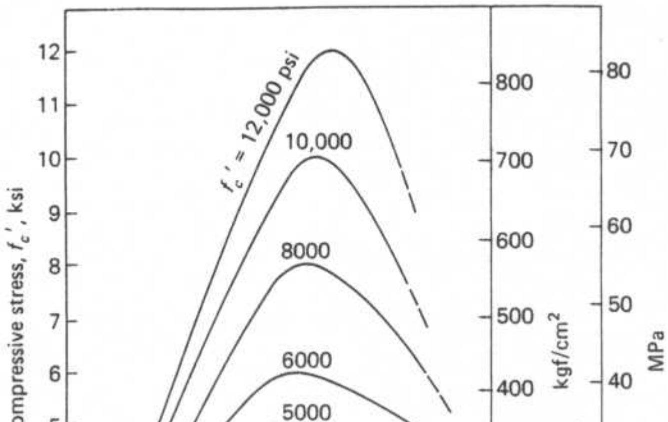


FIGURE 2.4 Slump test.

Most concrete mixes have slumps of 2 – 5 in.

Remark 3: Modern concrete contains cementitious material beside cement. Therefore instead of water cement ratio it should be water to cementitious material ratio which include cement and other admixtures.

A more useful relation for concrete is the stress-strain curves which show the whole history of loading. Different concrete mixes will give different strength and different stress-strain curves. (See Fig. below)



One important point is that the lower the strength, the greater the ductility (or deformability).

The maximum stress is reached at a strain range (0.002 – 0.005). The ultimate strain at crushing of concrete is about 0.003.

* It has been found from experiments that modulus of elasticity (the initial slope of the stress-strain curve) is a function of concrete strength and its unit weight according to the following:

$$E_c = 33\ \omega^{1.5}\sqrt{f_c'}$$

which for concrete of $\omega = 145$ pcf gives

$$E_c = 57000\sqrt{f_c'} \qquad \text{psi}$$

or $$E_c = 4700\sqrt{f_c'} \qquad \text{MPa}$$

or $$E_c = 15000\sqrt{f_c'} \qquad \text{kg/cm}^2$$

There are two properties of concrete and designer should consider. These are **creep** and **shrinkage**.

Creep: is the property of concrete by which it continue to deform with time at a constant load. See Fig. below.

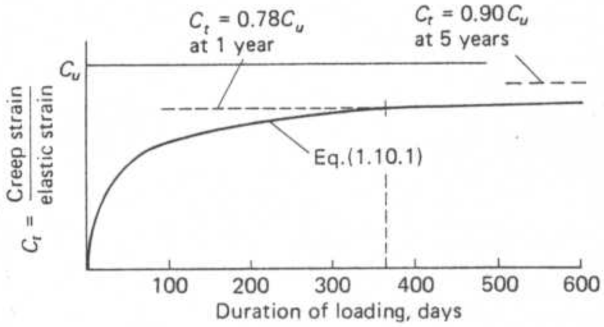


Figure 1.10.2 Standard creep coefficient variation with duration of loading (for 4 in. or less slump, 40% relative humidity, moist cured, and loading age of 7 days).

<u>Shrinkage:</u> It is basically the volume change or reduction in volume as concrete dry. See Fig. below.

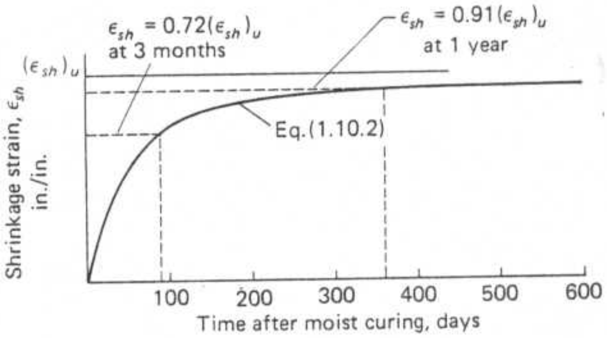


Figure 1.10.4 Standard shrinkage strain variation with time after moist curing (for 4 in. or less slump, 40% ambient relative humidity and minimum thickness of member 6 in. or less, after 7 days moist cured).

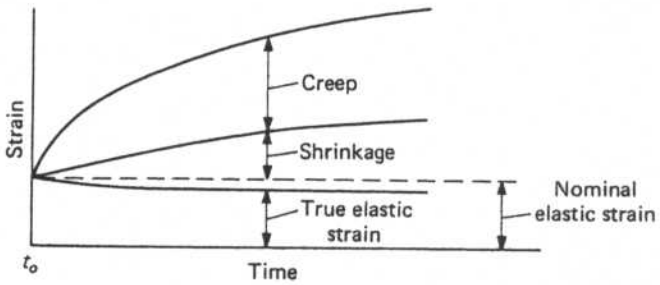


Figure 1.10.1 Change in strain of a loaded and drying specimen; t_0 is the time of application of load.

STEEL REINFORCEMENT

Steel reinforcement may consists of bars, welded wire fabric, or wires. For usual construction bars are used. Deformed bars are common used which they have lugs or protrusions to enhance bond with concrete.

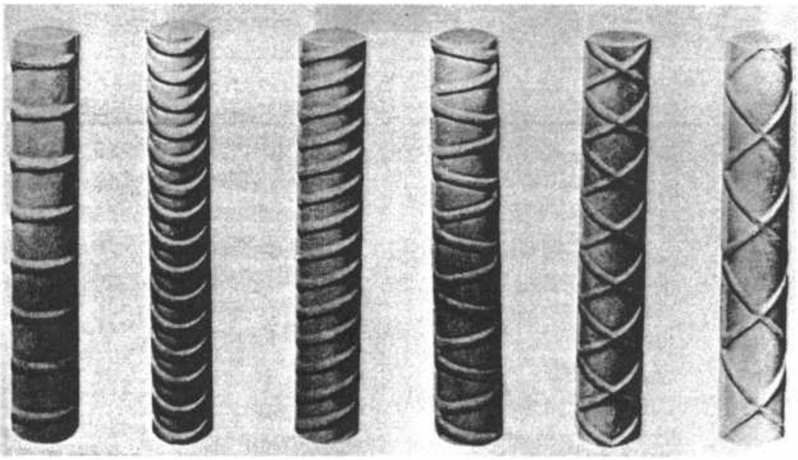
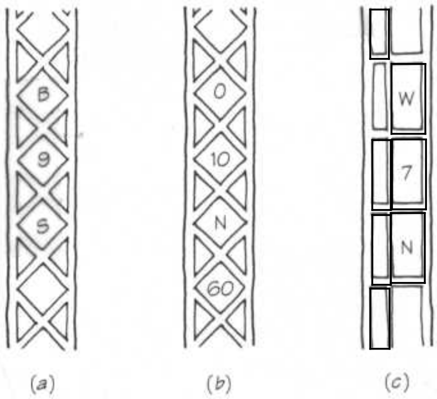


Figure 1.12.1 Deformed reinforcing bars. (Courtesy of Concrete Reinforcing Steel Institute.)



Typical reinforcing bar

According to ASTM (American Steel Testing Materials) bars are denoted by numbers and these numbers go from 3 to 18.

1) Bar numbers from 3-8 represent the number of the eighths of an inch as normal dominator.

Examples:

3 has diameter of 3/8 in

7 has diameter of 7/8 in

8 has diameter of 8/8 = 1 in

2) Bars No. 9 to No. 11, they are:

9 ~ area = 1 in^2

10 ~ area = 1 1/8 in^2

11 ~ area = 1 ¼ in^2

3) No. 12 and # 13.

4) # 14 and # 18 are equal to square of size 1 ½ and 2 respectively.

Table 1.12.1 Standard Reinforcing Bar Dimensions and Weights (Bars in Inch–Pound Units According to ASTM A615 [1.84], A616 [1.85], A617 [1.86], and A706 [1.87])

BAR NUMBER	NOMINAL DIMENSIONS				WEIGHT	
	DIAMETER		AREA			
	(in.)	(mm)	(sq in.)	(cm^2)	(lb/ft)	(kg/m)
3	0.375	9.5	0.11	0.71	0.376	0.559
4	0.500	12.7	0.20	1.29	0.668	0.994
5	0.625	15.9	0.31	2.00	1.043	1.552
6	0.750	19.1	0.44	2.84	1.502	2.235
7	0.875	22.2	0.60	3.87	2.044	3.041
8	1.000	25.4	0.79	5.10	2.670	3.973
9	1.128	28.7	1.00	6.45	3.400	5.059
10	1.270	32.3	1.27	8.19	4.303	6.403
11	1.410	35.8	1.56	10.06	5.313	7.906
14	1.693	43.0	2.25	14.52	7.65	11.38
18	2.257	57.3	4.00	25.81	13.60	20.24

Steel types designated by their grades and grade represent the initial yield stress, for example:

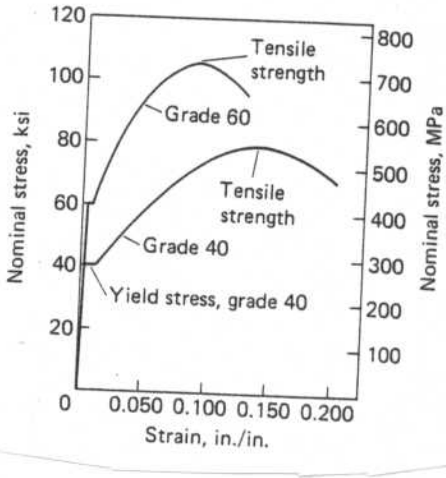
Steel grade 40 has a yield stress = 40 ksi

Steel grade 60 has a yield stress = 60 ksi

Grade 60 steel is the primary reinforcement material. However Grade 40 steel is used for smaller bars as # 3 and # 4 which are used as stirrups.

Also welded wire fabric (WWF) is used in thin slabs and shells. These consist of cold-drawn wire in orthogonal pattern squares or rectangular.

WWF6×8 = is a welded wire fabric mesh that has 6″ spacing in one direction and 8″ spacing in the other direction.



Design Methods & Requirements

The ACI CODE

The American Concrete Institute (ACI) based on Detroit, Michigan (USA) is an organization of design professionals. One of its function is to promote the safe and efficient design and construction of concrete structures.

The ACI has numerous publications to assist designers and builders, some of which are:

* Building Code Requirements for Reinforced Concrete and Commentary (produced by the Committee 318 of ACI).

* Strength Design Handbook vol. 1 & 2

* ACI Detailing Manual (SP-66)

Strength Design and Working Stress Design Methods

There are two philosphies of design:

(I) Working stress design method, or
allowable stress design, or
service load design.

The method is based on forcing the stress resulted from the serice loads using elastic mechanics ($\sigma = \frac{Mc}{I}$, $\tau = \frac{VQ}{Ib}$) to be not exceeding a specified value (this value is called allowable stress)

$$f \le f_{all}$$

f: computed using elastic mechanics

f_{all}: from stress-strain curve.

$f_{all}^{con.} = 0.4 f_c'$

$f_{all}^{stee} = 0.5 f_c'$

This method is regarded limited as dead load and live load are treated equally and creep and shrinkage is not taken into account in the elastic analysis.

(load → internal moment → internal forces → stress f) $\le f_{all}$

(II) Strength Design Method

This method is formely is called "Ultimate strength method". The method is based on imagining the structure at failure. Then calculating the theortical capacity of the member at failure and forcing it to be greater than the required internal strength to carry the factored loads.

failure ⟶ factored loads

strength provided (Theoritical capacity of the section at	$\geq$	The required internal strength to carry the [redacted]

Safty Provisions

The purpose of safty is to limit the failure probability and yet permit an economical structure. Therefore, structural member must be designed to carry some reserved load above what is expected under normal conditions.
This could happen due to overloading situations and / or understrength material. where actual strength is less than that is computed.

Overloading : Due to change of the use of the building

understrength factors : variation in material strength
unproper workmanship.
less dimensions
less degree of supervision

ACI has divided the safty provisions into two parts :

U factors to account for overloading
ϕ factors to account for understrength.

U - factors

$$U = 1.4D + 1.7L$$
$$U = 0.75(1.4D + 1.7L + 1.7W)$$
$$U = 0.9D + 1.3W$$
$$U = 0.75(1.4D + 1.7L + 1.7(1.1)E$$
$$U = 0.9D + 1.3(1.1)E$$
$$U = 1.4D + 1.7L + 1.7H$$
$$U = 0.9D + 1.7H$$
$$U = 1.4D + 1.4F + 1.7L$$
$$U = 0.9D + 1.4F$$
$$U = 0.75(1.4D + 1.4T + 1.7L)$$
$$U = 1.4(D + T)$$

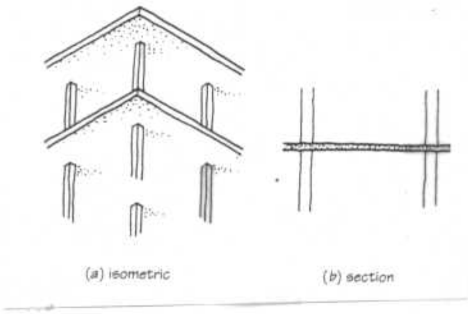
Strength Reduction factors ϕ

	ϕ Factors
1. Flexure, with or without axial tension	0.90
2. Axial tension	0.90
3. Shear and torsion	0.85
4. Compression members, spirally reinforced	0.75*
5. Compression members, other	0.70*
6. Bearing on concrete	0.70
7. Plain concrete: flexure, compression, shear, and bearing	0.65

The total required nominal (theoritical) strength to be provided in design is U/ϕ

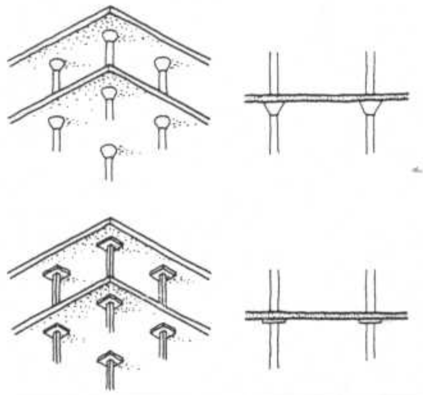
Structural Systems

	System	Functionality	Advantage or disadvantage
I	FLAT PLATE	Good for short spans and light loading such as apartments and motels.	May suffer from punching shear especially for over-loading



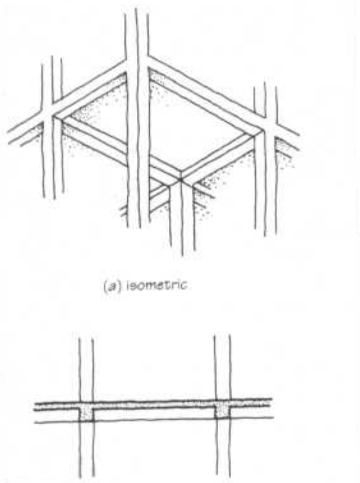
Span (ft)	Thickness (in)
12	5
15	6
18	7
20	8

	System	Functionality	Advantage or disadvantage
II	FLAT SLAB WITH SHEARHEADS	For large spans and heavy loads such as industrial buildings and offices.	No punching shear because of the drop panel. Efficient with square column. Drop pane size 1/3 of span length. One may offset location of column by 20% of span.

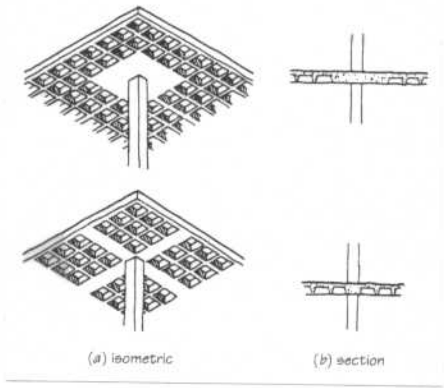


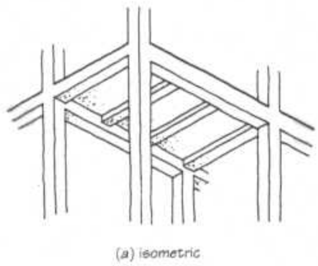
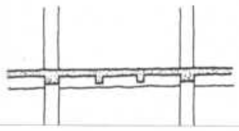
Span (ft)	Slab thickness (in)	Total thickness of drop panel (in)
16	6	8
20	8	11
24	10	14
28	12	17

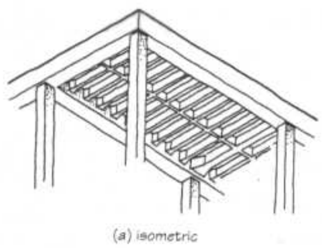
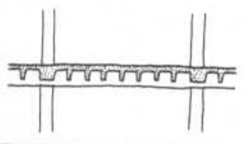
	System	Functionality	Advantage or disadvantage
III	FLAT SLAB WITH BEAMS	For spans larger than 24 ft.	No punching shear. Beams provide moment of interaction with column which help to resist lateral loads - for up to 5 floor. No need for shear walls.



Span (ft)	Thickness of slab (in)	Beam depth (in)
20	7	16
24	9	20
28	11	25
30	13	28

<table>
<tr><th></th><th>System</th><th>Functionality</th><th>Advantage or disadvantage</th></tr>
<tr><td>V</td><td>WAFFLE SLAB

Two ways of transferring shear to column</td><td>The system can span up to 50 ft.

24-50 ft
<table><tr><th>Span (ft)</th><th>Slab Thicknes s</th><th>Total Thicknes s</th></tr><tr><td>25</td><td>3</td><td>12</td></tr><tr><td>30</td><td>3</td><td>15</td></tr><tr><td>35</td><td>4</td><td>19</td></tr><tr><td>40</td><td>5</td><td>29</td></tr></table></td><td>The system is architecturally handsome. Easy to make holes in the slab for mechanical purposes.</td></tr>
<tr><td>V</td><td>ONE WAY SLAB

</td><td>The most frequently used for any concrete systems when bay ratio is 3/2 and greater primary steel is placed in the shortest direction and temperature and shrinkage is place in perpendicular direction.</td><td>Smaller beams depth.

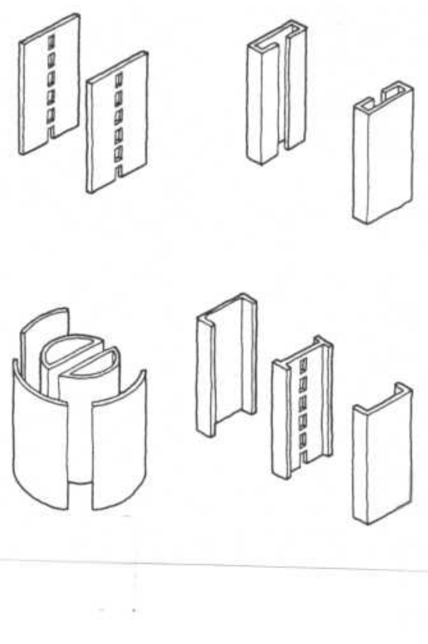
Span 10-16 ft.</td></tr>
<tr><td>VI</td><td>PAN JOIST

</td><td>Used for heavy load application such as storage or industrial facilities. Rib or joist is spaced 18-30 in center to center and spans 18-28 ft. The system has visual directionality and therefore it uses bridging at mid span of joist similar to diaphragm ⊥ to joist.
<table><tr><th>Span joist × beam</th><th>Total Joist depth</th><th>Total Beam Depth</th></tr><tr><td>18×28</td><td>9</td><td>22</td></tr><tr><td>20×32</td><td>11</td><td>26</td></tr><tr><td>24×36</td><td>14</td><td>28</td></tr><tr><td>28×40</td><td>17</td><td>32</td></tr></table></td><td>Having smaller beams depth especially when joist run in the shorter direction.</td></tr>
</table>

SHEAR WALLS

Shear Walls : are reinforced concrete walls as very deep narrow cantilever beams sticking out of the ground.

Function: To prevent loss of stability in terms of overturn or sliding and to minimize drift displacement.

Used: In tall buildings to account for resisting wind and earthquake building movement.



System Selection

The selection of a particular system would depend on functionality. Larger spans would suggest the use of pan system whereas for residential spaces with short span and light load, flat plate is recommended.

It is very essential that the designer should be aware of the coordination of the

- structural system
- circulation system
- mechanical system
- clarity movement of people virtually and horizontally.