CE 3115

REINFROCED CONCRETE - I

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RUET

Course Outline

CE 3115 Reinforced Concrete-I Credit: 3.00

Lecture: 3 hrs/ week

❖Fundamental behavior of reinforced concrete members

❖Introduction to WSD and USD methods.

❖Analysis and design of singly and doubly reinforced beams T-beams and one way slab according to WSD and USD methods.

❖Diagonal tension, bond and anchorage according to WSD and USD methods.

❖Design of Lintels, and staircases.

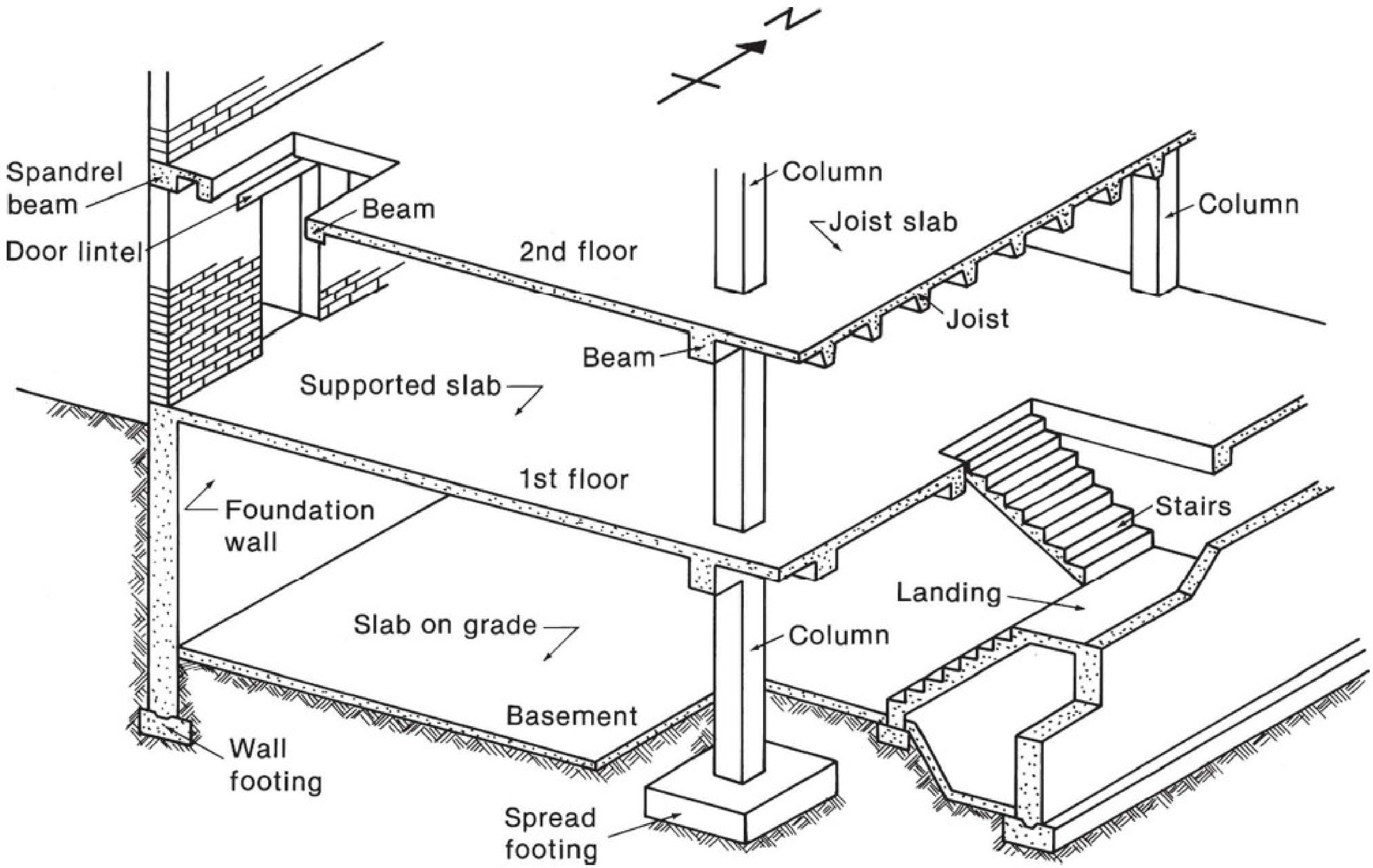
- ***Learning Objectives***
- Students will be able
- to understand and capture the behaviour of different reinforced concrete members
- to conceptualize different design philosophies
- to design and evaluate different types of reinforced concrete members according to WSD and USD methods of design

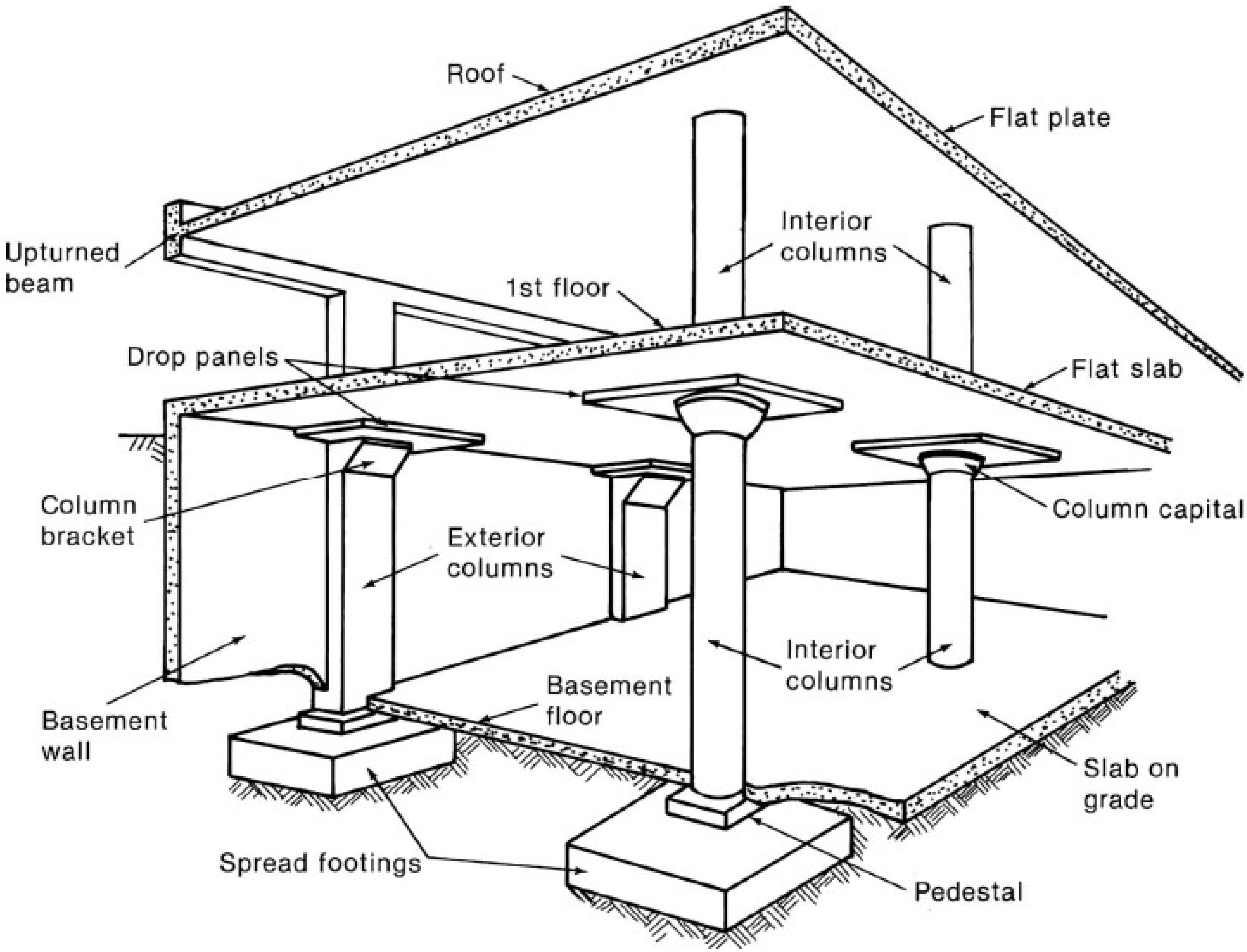
Learning Outcomes

- By the end of this course, the students would be able to:
- Understand the fundamental concept of reinforced concrete.
- Analyze and design singly and doubly reinforced concrete beams under flexure and shear and T-beams.
- Analyze and design structural concrete beams subjected to shear loading;
- Determine bond length, lap splice and detailing requirements for reinforced concrete members;
- Analyze and design one way slab under different support conditions; and
- Analyze and design stair and lintels.

- Reference Books
- **Design of Concrete Structures**
- Arthur H. Nilson, David Dolan & Charles W. Dolan

- **REINFORCED CONCRETE - Mechanics and Design**
- **James K. Wight & James G. Macgregor**


N
Spandrel beam
Door lintel
Beam
2nd floor
Column
Joist slab
Column
Joist
Beam
Supported slab
1st floor
Foundation wall
Stairs
Landing
Slab on grade
Column
Basement
Wall footing
Spread footing


Roof
Flat plate
Upturned beam
Interior columns
1st floor
Drop panels
Flat slab
Column bracket
Exterior columns
Column capital
Interior columns
Basement floor
Basement wall
Slab on grade
Spread footings
Pedestal

Concrete

- Concrete is a stonelike material obtained by mixing cement, sand, gravel or other aggregate and water
- Concrete is being used for thousands of years starting with lime mortar from 12,000B.C.
- Its compressive strength is very high and primarily suitable for members subject to compression (e.g. Column)
- Its tensile strength is small compared its compressive strength
- So it is not economical to use concrete in members subject to tension fully (e.g. tie rods) or partially (such as beam)

Introduction

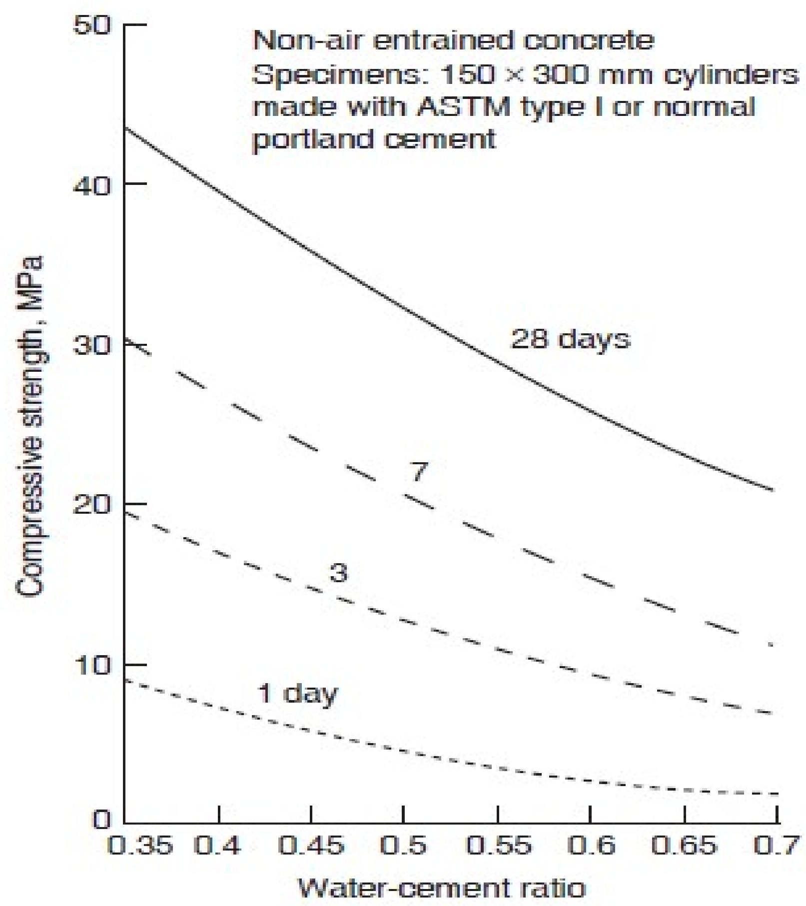
- Roughly 25 billion tonnes of concrete are manufactured globally each year.
- Over 3.8 tonnes of concrete per person in the world each year.

- Concrete is neither as strong nor as tough as steel, so why is it the most widely used engineering mtearial?

- There are at least three primary reasons
- First, concrete possesses excellent resistance to water
- The second reason for the widespread use of concrete is the ease with which structural concrete elements can be formed into a variety of shapes and sizes
- It is usually the cheapest and most readily available material on the job

Why is Strength the Property Most Valued in Concrete by Engineers?

- Strength is defined as the ability to withstand stress without failure.
- The strength of concrete is the property most valued by designers and quality control engineers
- Testing of strength is relatively easy compared to most other properties
- Many properties of concrete such as elastic modulus, impermeability and resistance to weathering agents are directly related to strength



Compressive strength of concrete is a function of the water-cement ratio and degree of cement hydration.

Factors Affecting Choice of Reinforced Concrete for Structure

- **1. Economy.**
- Frequently, the foremost consideration is the overall cost of the structure.
- This is a function of the costs of the materials and of the labor and time necessary to erect the structure.
- Concrete floor systems tend to be thinner than structural steel systems because the girders and beams or joists all fit within the same depth
- This produces an overall reduction in the height of a building compared to a steel building, which leads to (a) lower wind loads because there is less area exposed to wind and (b) savings in cladding and mechanical and electrical risers.

- **Suitability of material for architectural and structural function.**
- A reinforced concrete system frequently allows the designer to combine the architectural and structural functions.
- **Fire resistance.**
- The structure in a building must withstand the effects of a fire
- and remain standing while the building is being evacuated and the fire extinguished.
- A concrete building inherently has a 1- to 3-hour fire rating without special fireproofing or other details.
- Structural steel or timber buildings must be fireproofed to attain similar fire ratings.

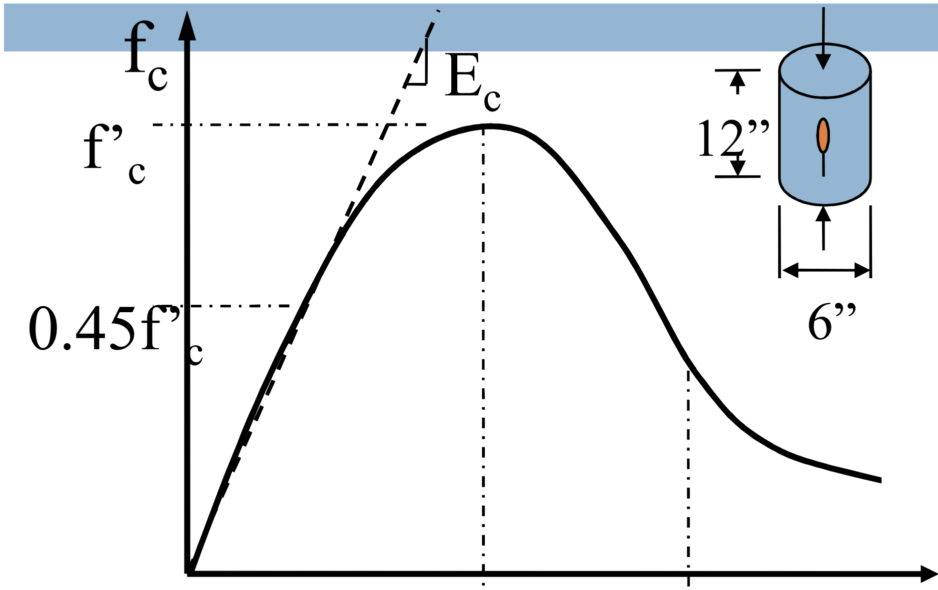
- **Rigidity -** The occupants of a building may be disturbed if their building oscillates in the wind or if the floors vibrate as people walk by. Due to the greater stiffness and mass of a concrete structure, vibrations are seldom a problem.
- **Low maintenance -** Concrete members inherently require less maintenance than do structural steel or timber members. This is particularly true if dense, air-entrained concrete has been used for surfaces exposed to the atmosphere and if care has been taken in the design to provide adequate drainage from the structure.
- **Availability of materials -** Sand, gravel or crushed rock, water, cement, and concrete mixing facilities are very widely available, and reinforcing steel can be transported to most construction sites more easily than can structural steel. As a result, reinforced concrete is frequently the preferred construction material in remote areas.

Factors that may cause one to select a material other than reinforced concrete.

- **Low tensile strength -** the tensile strength of concrete is much lower than its compressive strength ; hence, concrete is subject to cracking when subjected to tensile stresses.
- **Forms and shoring -** The construction of a cast-in-place structure involves three steps not encountered in the construction of steel or timber structures. These are (a) the construction of the forms, (b) the removal of these forms, and (c) the propping or shoring of the new concrete to support its weight until its strength is adequate.
- **Relatively low strength per unit of weight or volume. -**The compressive strength of concrete is roughly 10 percent that of steel, while its unit density is roughly 30 percent that of steel.

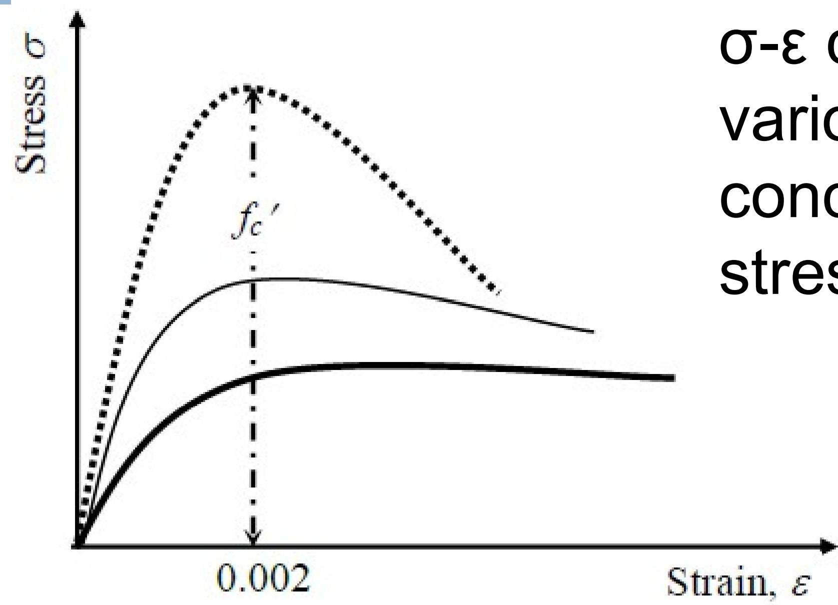
- Forms and Shoring (additional steps)
  - Construction of forms
  - Removal of forms
  - Fresh concrete requires support weight until strength is adequate.
  - Labor/Materials cost not required for other types of materials
- Time-dependent volume changes
  - Concrete & steel undergo similar expansion and contraction.
  - Concrete undergoes drying shrinkage, which may cause deflections and cracking.
  - Creep of concrete under sustained loads causes an increase in deflection with time.

Concrete Properties



- Concrete strain at max. compressive stress, ε_u
  - ε_u varies between 0.0015-0.003
  - For normal strength concrete, $\varepsilon_u \sim 0.002$
- Maximum useable strain, ε_u
  - ACI Code: $\varepsilon_u = 0.003$
  - Used for flexural and axial compression

Stress-strain Curve of Concrete



σ-ε curves are different for various ultimate strengths of concrete, particularly the peak stress and ultimate strain.

The tensile strength $f_t' = 6\sqrt{f_c'}$.

Concrete Properties

The standard strength test generally uses a cylindrical sample. It is tested after 28 days to test for strength, $f_c^{/}$. The concrete will continue to harden with time and for a normal Portland cement will increase with time as follows:

Age	7 days	14 days	28 days	3 months	6 months	1 year	2 years	5 years
Strength ratio	0.67	0.86	1.0	1.17	1.23	1.27	1.31	1.35

Concrete Properties

- Compressive Strength, $f_c^{/}$
  - Normally use 28-day strength for design strength
- Poisson's Ratio, ν
  - $\nu \sim 0.15$ to 0.20 Usually use $\nu = 0.17$
  - Modulus of Elasticity For normal weight concrete ($w_c \cong$ 150 pcf)

$$E_c\ (psi) = 57{,}000\sqrt{f'_c\ (psi)}$$

$$E_c\ (psi) = 33\ w^{1.5}\sqrt{f'_c\ (psi)}$$

Concrete Properties

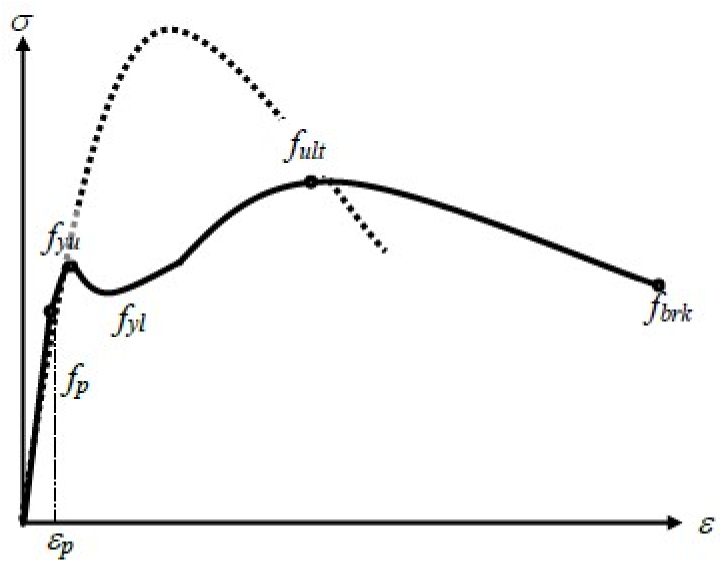
- <u>Exercise:</u>

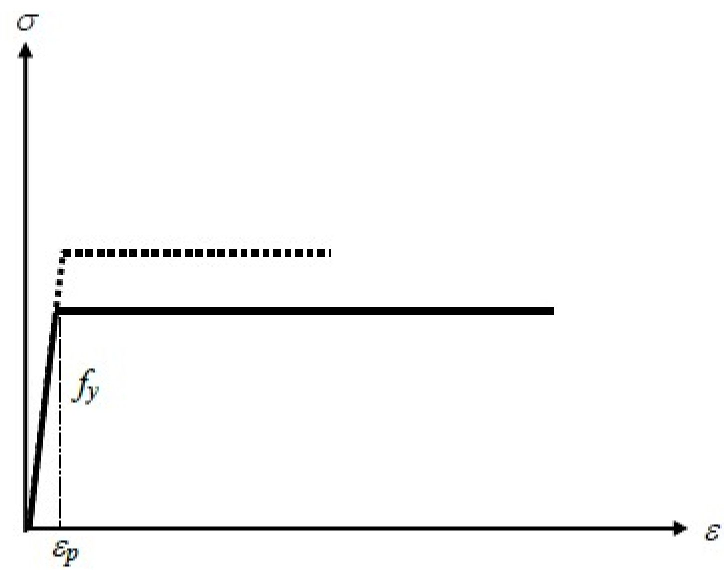
  Compute E_c for f'_c = 4500 psi for normal weight (145 pcf) concrete using both ACI equations:

$$E_c\,(psi) = 33\,w^{1.5}\sqrt{f'_c\,(psi)}$$

$$E_c\,(psi) = 57{,}000\sqrt{f'_c\,(psi)}$$

Steel Properties





The elastic-perfectly-plastic (EPP) model for steel assumes the stress to vary linearly with strain up to yield point (f_y) *and remain constant beyond that.*

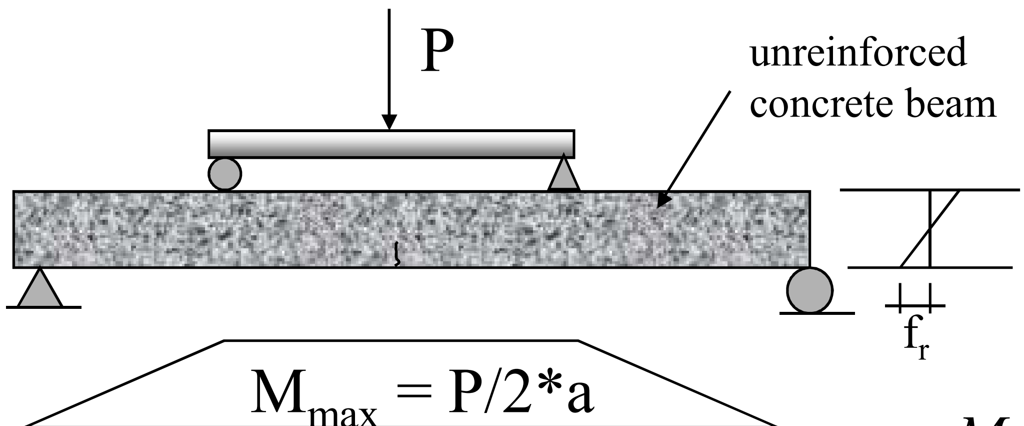
Concrete Properties

- **2. Tensile Strength**
  - Tensile strength ~ 8% to 15% of f'_c
  - Modulus of Rupture, f_r
    - For deflection calculations, use:

$$f_r = 7.5\sqrt{f'_c\ (psi)}$$

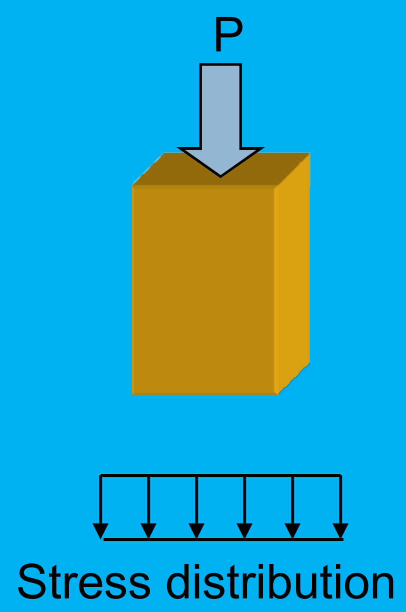
ACI Eq. 9-9

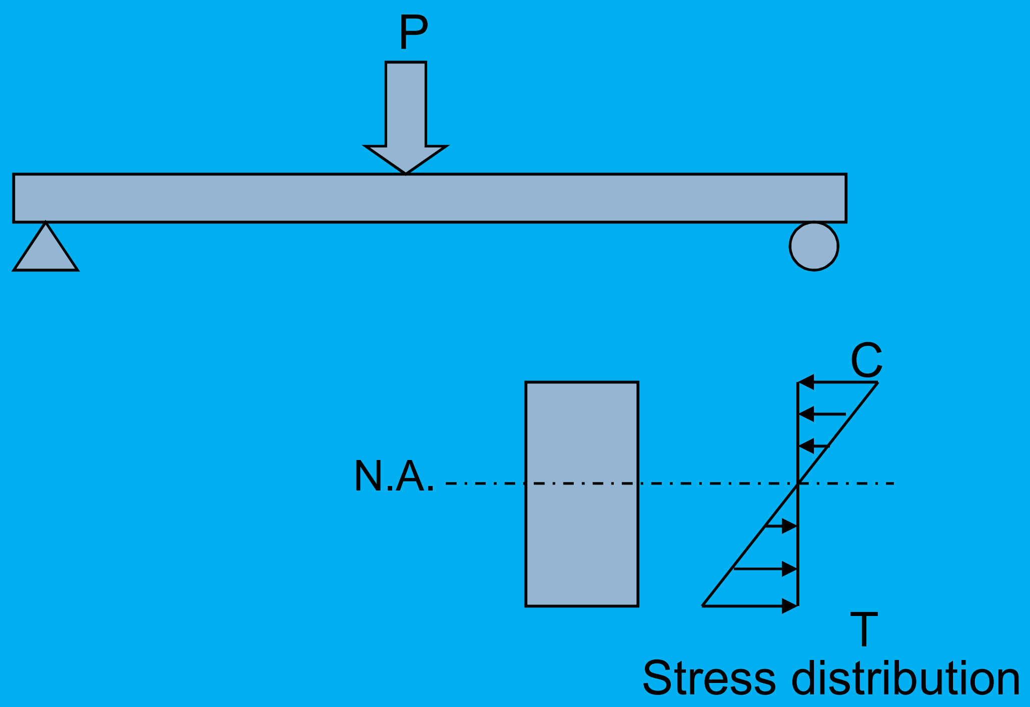
  - Test:



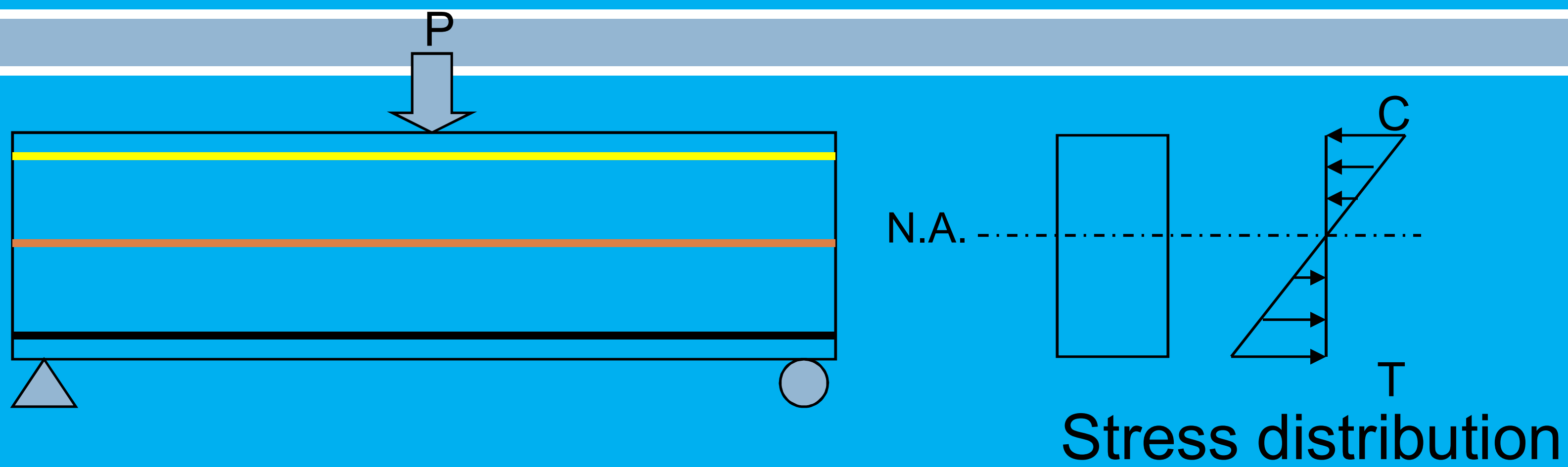
$$f_r = \frac{Mc}{I} = \frac{6M}{bh^2}$$

Why RCC

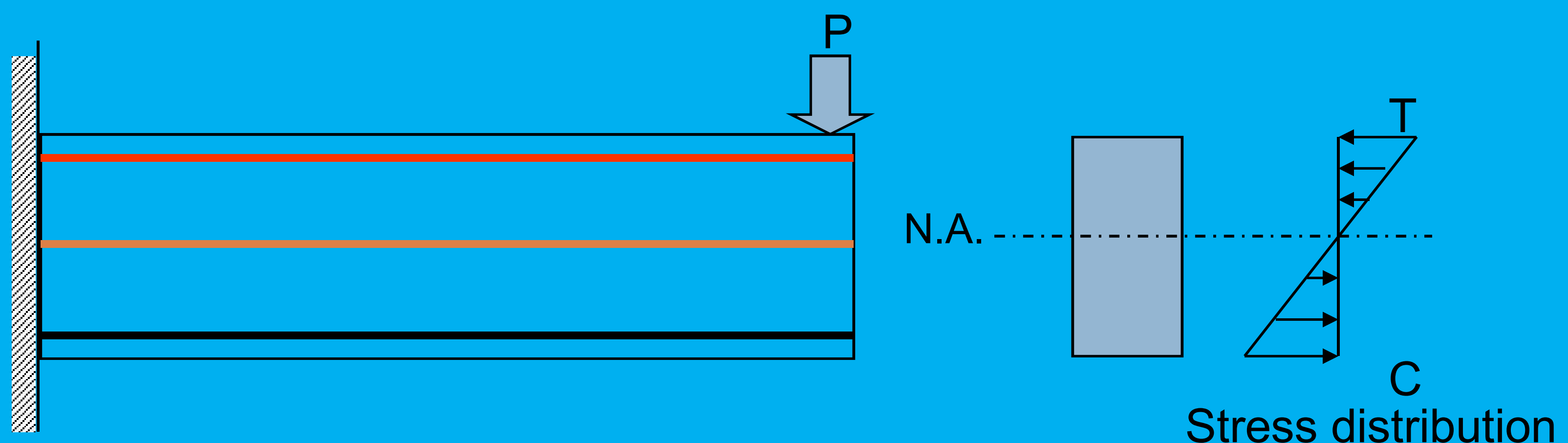




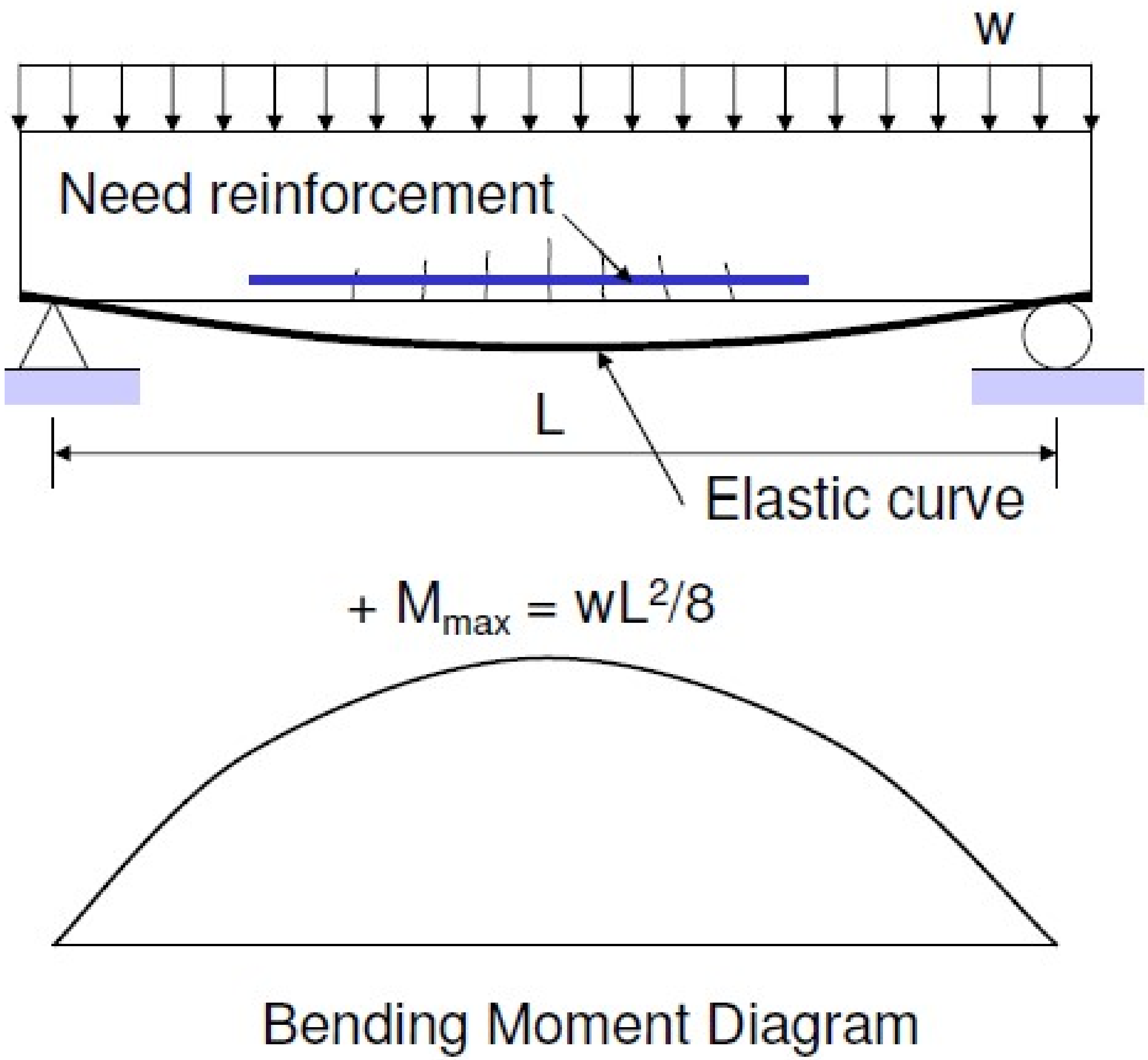
Why RCC

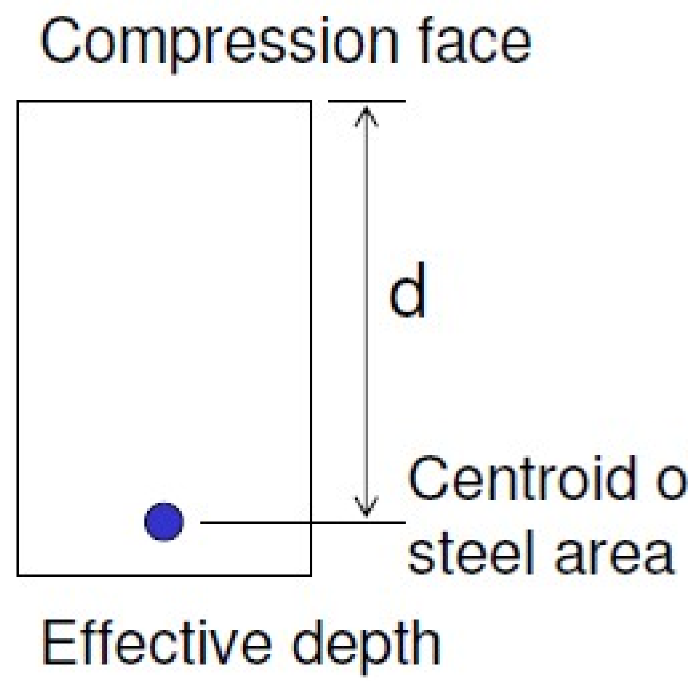


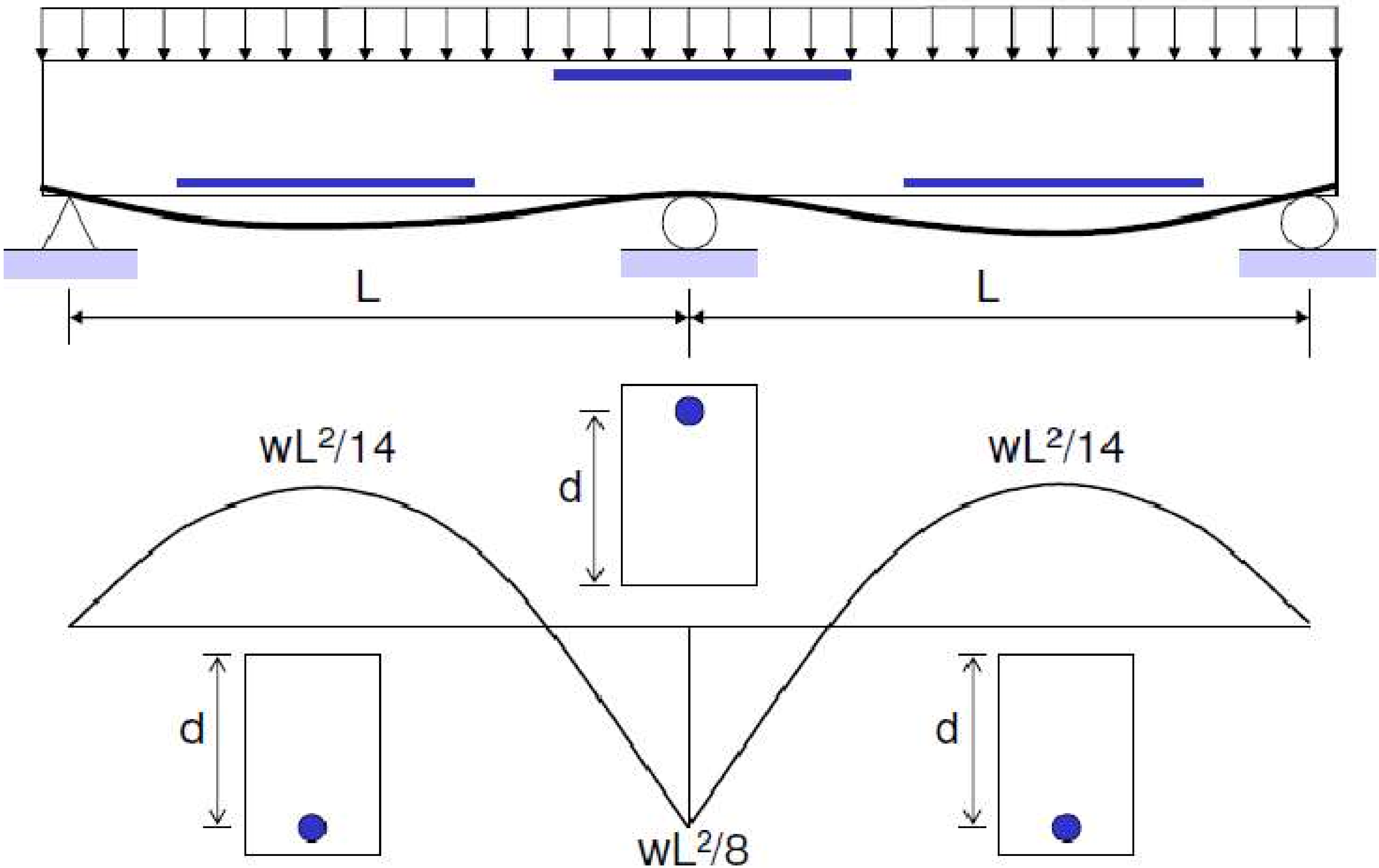
Cantilever Beam



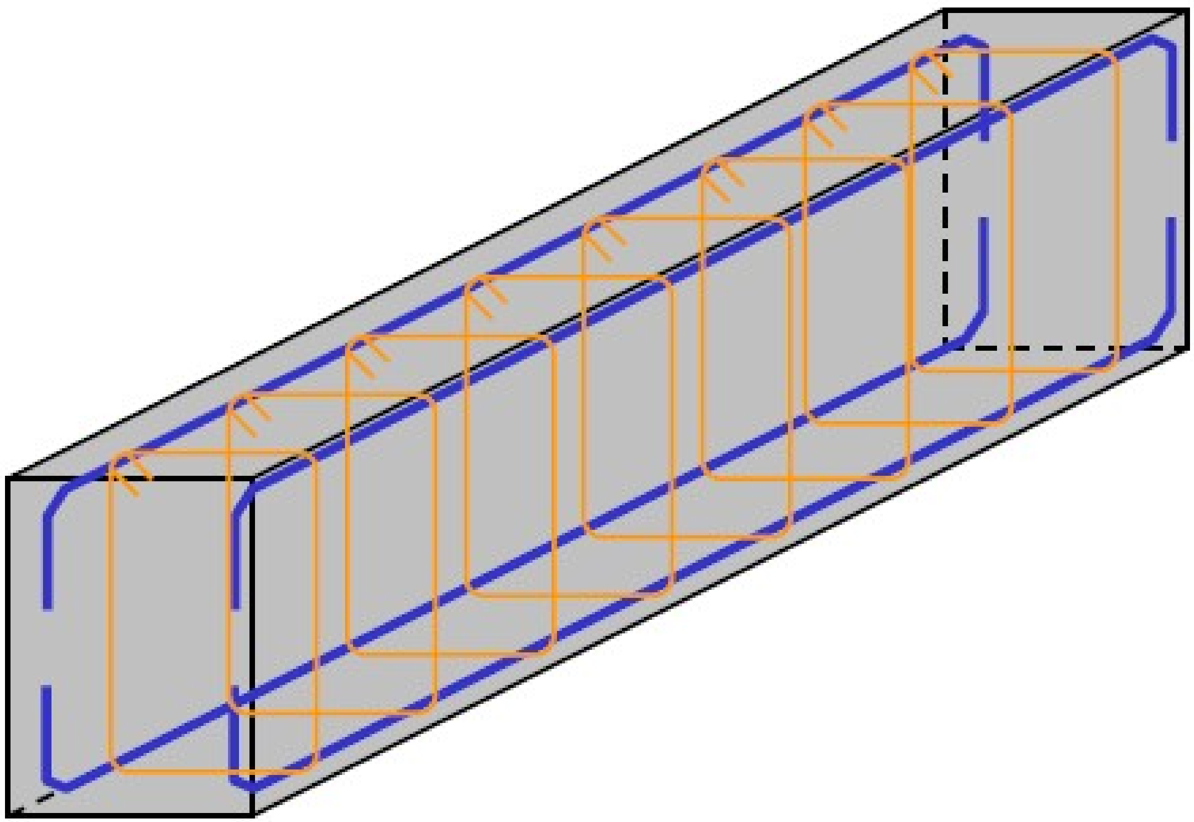
Tension Steel Position in Beam

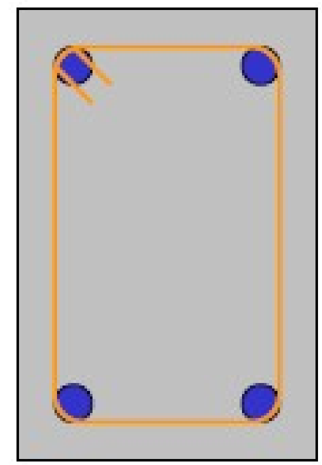






L
L
wL²/14
d
wL²/14
d
d
wL²/8





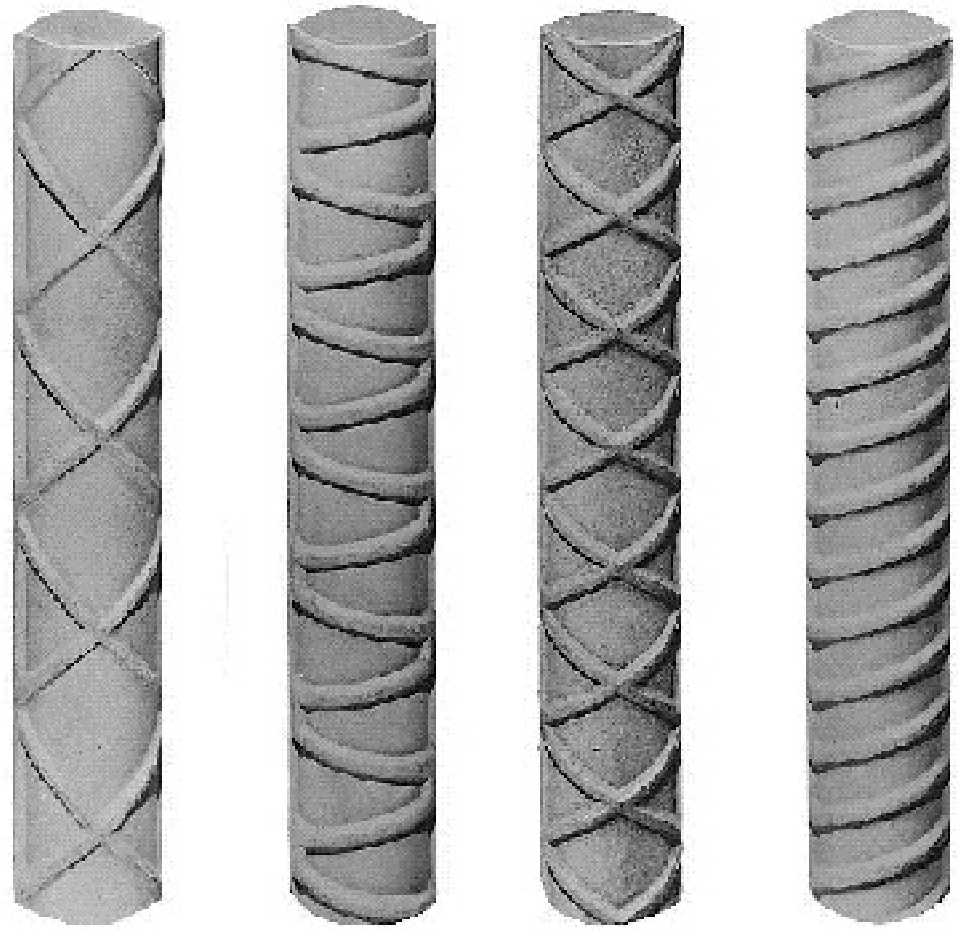
Why is Mild Steel Reinforcing Bar

- In reinforced concrete beams, concrete resists compressive forces, longitudinal reinforcing bars resist the tension forces
- For most effective reinforcing action, it is essential that steel and concrete deform together, i.e. the bond between concrete and reinforcing bars be sufficiently strong

Why is Mild Steel Reinforcing Bar

- The thermal expansion coefficient of concrete and steel (6.5×10^{-6} vs 5.5×10^{-6})are sufficiently close to resist undesirable differential thermal deformation
- Corrosion resistance of bare steel is poor where as concrete possesses excellent corrosion resistant >> together use minimizes corrosion problem and maintenance cost
- Thermal conductivity of concrete is relatively low and provides insulation for steel rebars

Reinforcing Bars (Deformed Bars)



The available bar sizes available in the market are designated by diameters proportional to 1/8-in or millimeters and have the following areas

d (No.)	2	3	4	5	6	7	8	9	10
A_s (in^2)	0.05	0.11	0.20	0.31	0.44	0.60	0.79	1.00	1.27
d (mm)	8	10	12	16	19	22	25	28	31
A_s (in^2)	0.08	0.12	0.18	0.31	0.44	0.59	0.76	0.95	1.17

ACI Building Codes

It is understandable that the analysis for strength of a reinforced concrete member has to be partial empirical although rational.

These semi-rational principles and methods are being constant revised and improved as a result of theoretical and experimental research accumulate.

The American Concrete Institute (ACI), serves as clearing house for these changes, issues building code requirements.

Uncertainties in analysis, design and construction of RC Structures

1) Actual load ≠ Assumed load
2) Load distribution may differ
3) Simplification of analysis
4) Actual structure behavior not known perfectly
5) Actual dimension may differ
6) Steel position may not proper
7) Actual material strength may differ

Design Philosophy

Two philosophies of design have long prevalent.
Working Stress Design method focuses on conditions at service loads.

Ultimate Strength Design method focusing on conditions at loads greater than the service loads when failure may be imminent.

The strength design method is deemed conceptually more realistic to establish structural safety.

Strength Design Method

In the strength method, the service loads are increased sufficiently by factors to obtain the load at which failure is considered to be "imminent/close to occur". This load is called the ***factored load*** or ***factored service load***.

$$\text{strength provided} \geq \begin{bmatrix} \text{strength required to} \\ \text{carry factored loads} \end{bmatrix}$$

Strength Design Method

Strength provide is computed in accordance with rules and assumptions of behavior prescribed by the building code and the strength required is obtained by performing a structural analysis using factored loads.

The “strength provided” has commonly referred to as “ultimate strength”. However, it is a code defined value for strength and not necessarily “ultimate”. The ACI Code uses a conservative definition of strength.

Advantage of USD over WSD

1) Consider mode of failure
2) Nonlinear behavior of concrete
3) More realistic F.S.
4) Ultimate load prediction 5%
5) Saving (lower F.S.)

Safety Provisions

Structures and structural members must always be designed to carry some reserve load above what is expected under normal use.

There are three main reasons why some sort of safety factor are necessary in structural design.

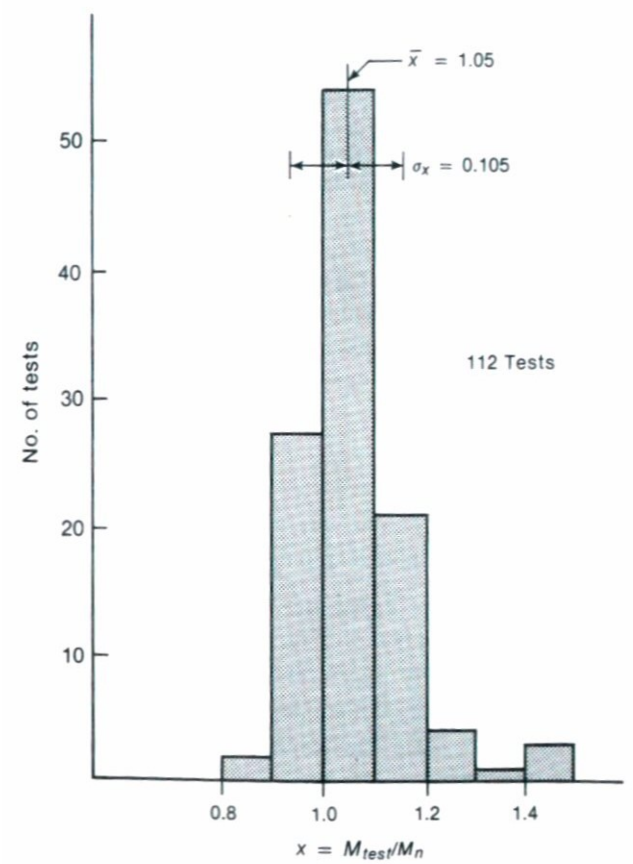
- Variability in resistance.
- Variability in loading.
- Consequences of failure.

Variability in resistance

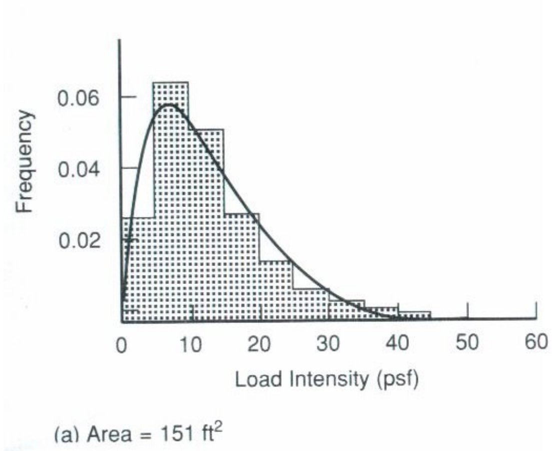
- Variability of the strengths of concrete and reinforcement.
- Differences between the as-built dimensions and those found in structural drawings.
- Effects of simplification made in the derivation of the members resistance.

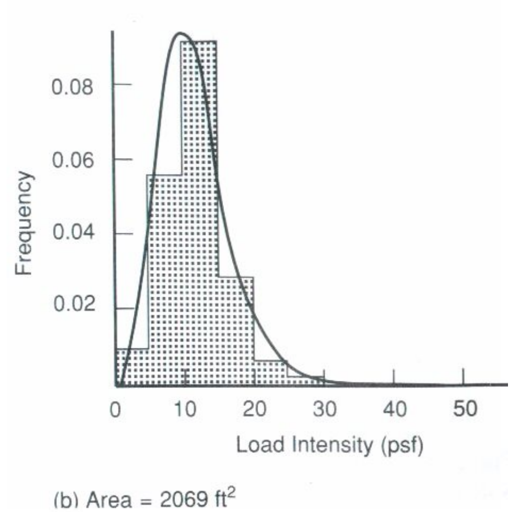
Variability in Resistance

Comparison of measured and computed failure moments based on all data for reinforced concrete beams with $f_c > 2000$ psi.



Variability in loading





Consequences of Failure

A number of subjective factors must be considered in determining an acceptable level of safety.

- Potential loss of life.
- Cost of clearing the debris and replacement of the structure and its contents.
- Cost to society.
- Type of failure warning of failure, existence of alternative load paths.

Loading

***1.* SPECIFICATIONS**

- BNBC (Bangladesh National Building Code),

other building codes such as :

ACI American Concrete Institute

Uniform Building Code (UBC)

Indian Standard (IS)

~~*Basic Building Code (BOCA)*~~

~~*Standard Building Code--rarely*~~

Dead Loading

- Weight of all permanent construction
- Constant magnitude and fixed location

Dead Loads

Examples:

- Weight of the Structure
  (Walls, Floors, Roofs, Ceilings, Stairways)
- Fixed Service Equipment
  (HVAC, Piping Weights, Cable Tray, Etc.)

Can Be Uncertain….

- pavement thickness
- earth fill over underground structure

Live Loads

Loads produced by use and occupancy of the structure
Maximum loads likely to be produced by the intended use
Not less than the minimum uniformly distributed load given by Code.

See Table 2-1 from *ASCE 7-95*

Stairs and exitways:	100 psf
Storage warehouses:	125 psf (light)
	250 psf (heavy)

Minimum concentrated loads are also given in the codes

Live Loads

TABLE 2–1 Typical Live Loads Specified in ASCE 7–95

Apartment buildings	
Residential areas and corridors serving them	40 psf
Public rooms and corridors serving them	100 psf
Office buildings	
Lobbies and first-floor corridors	100 psf
Offices	50 psf
Corridors above first floor	80 psf
File and computer rooms shall be designed for heavier loads based on anticipated occupancy	
Schools	
Classrooms	40 psf
Corridors above first floor	80 psf
First-floor corridors	100 psf
Stairs and exitways	100 psf
Storage warehouses	
Light	125 psf
Heavy	250 psf
Stores	
Retail	
Ground floor	100 psf
Upper floors	75 psf
Wholesale, all floors	125 psf

Source: Based on *Minimum Design Loads for Buildings and Other Structures*, ASCE Standard ASCE 7–95, with the permission of the publisher, the American Society of Civil Engineers.

Environmental Loads

- Earthquake
- Tsunami
- Wind
- Soil Pressure
- Ponding of Rainwater
- Temperature Differential
- Snow Loadss

Wind Loads

- Wind pressure is proportional to Velocity ^{2}
- Wind velocity pressure = q_z

$$q_z = 0.00256\, K_z\, k_{zt}\, V^2\, I$$

where

0.00256 reflects mass density of air and unit conversions.

V = Basic 3-second gust wind speed (mph) at a height of 33 ft. above the ground in open terrain. (1:50 chance of exceedance in 1 year)

k_z = Exposure coefficient (bldg. ht., roughness of terrain)

k_{zt} = Coefficient accounting for wind speed up over hills

I = Importance factor

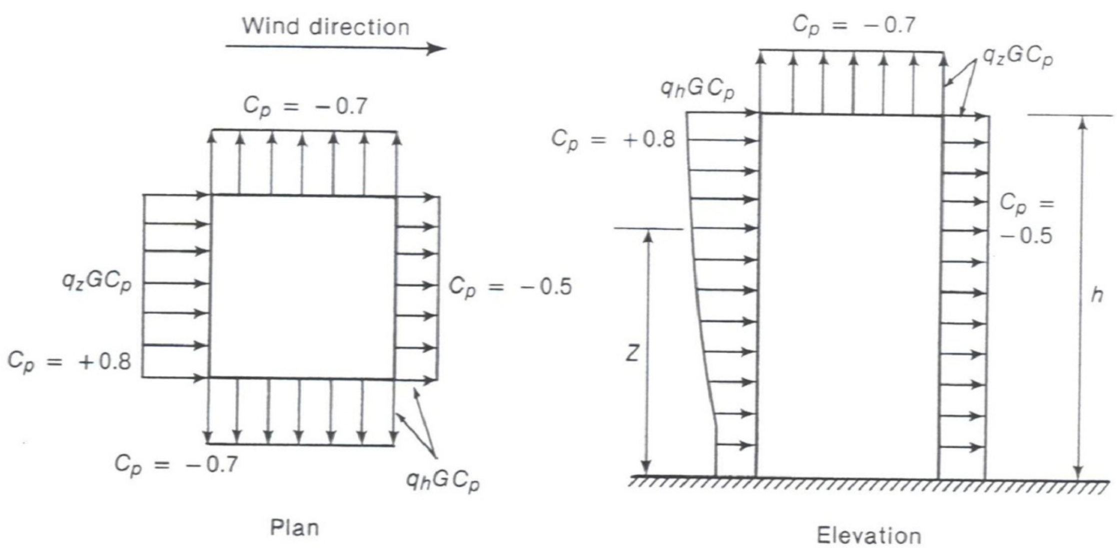
Wind Loads

Design wind pressure,

$$p = q_z * G * C_p$$

G = Gust Response Factor

C_p = External pressure coefficients (accounts for pressure directions on building)



Earthquake Loads

Inertia forces caused by earthquake motion

$$(F = m * a)$$

- Distribution of forces can be found using equivalent static force procedure (code, not allowed for every building) or using dynamic analysis procedures
- Equivalent Static Force Procedure for example, in ASCE 7-95:

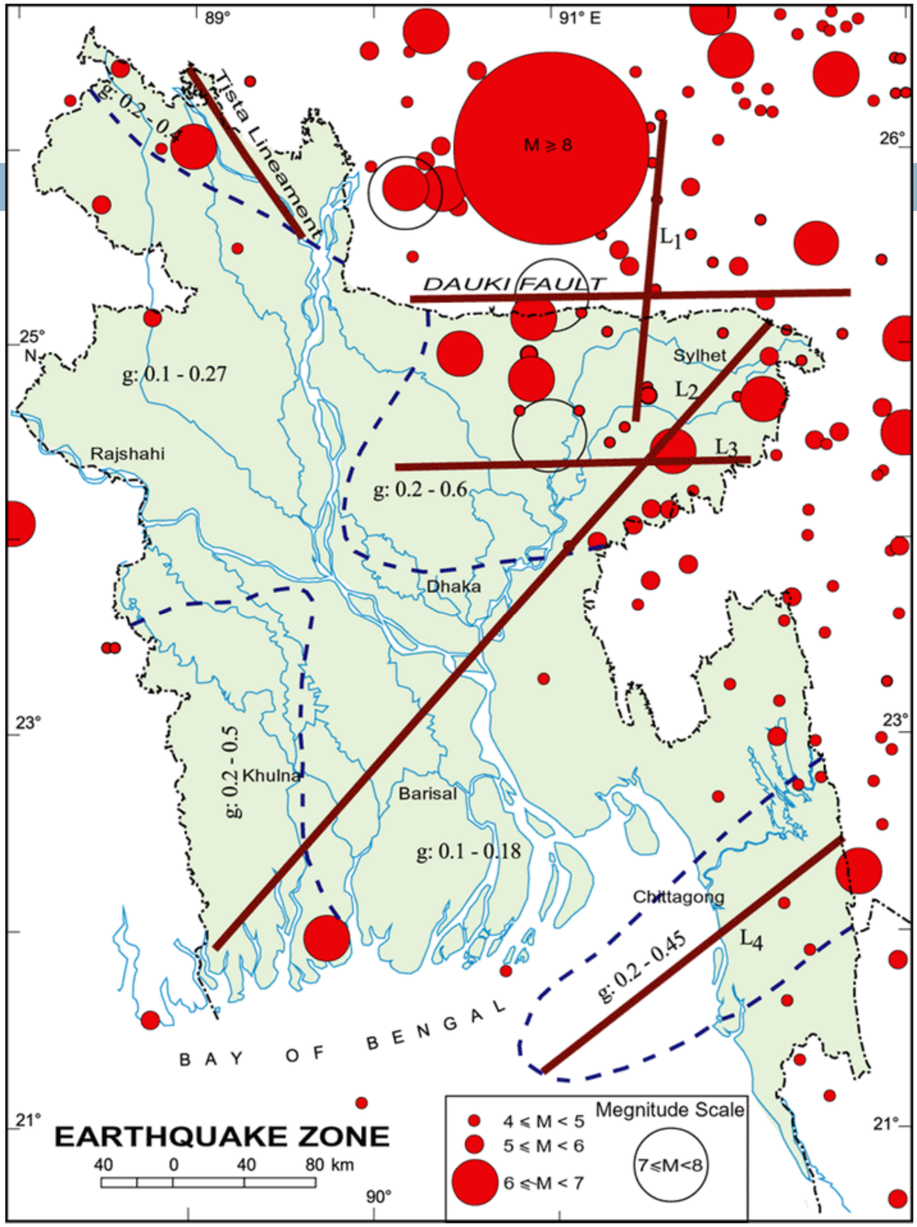
$$V = C_s * W$$

where

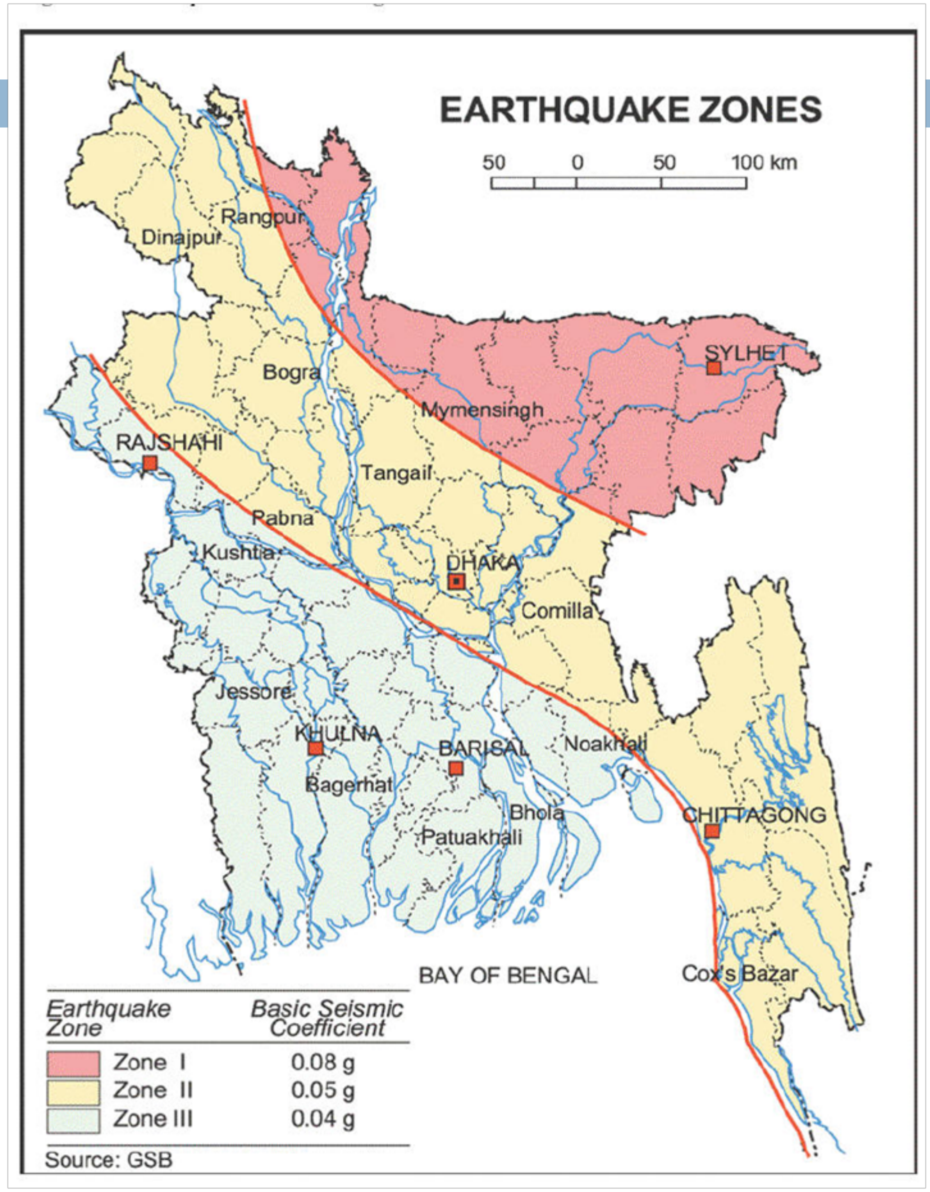
V = Total lateral base shear

Cs = Seismic response coefficient

W = Total dead load


EARTHQUAKE ZONE
89°
91° E
26°
25° N
23°
21°
90°
M ≥ 8
Tista Lineament
DAUKI FAULT
Sylhet
Rajshahi
Dhaka
Khulna
Barisal
Chittagong
g: 0.2 - 0.4
g: 0.1 - 0.27
g: 0.2 - 0.6
g: 0.2 - 0.5
g: 0.1 - 0.18
g: 0.2 - 0.45
L1
L2
L3
L4
BAY OF BENGAL
40 0 40 80 km
Megnitude Scale
4 ≤ M < 5
5 ≤ M < 6
6 ≤ M < 7
7≤M<8

Earthquake Map



Roof Loads

- Roof loads are in addition to snow loads
- Minimum loads for workers and construction materials during erection and repair
- Ponding of rainwater
  - Roof must be able to support all rainwater that could accumulate in an area if primary drains were blocked.
  - Ponding Failure:

    → Rain water ponds in area of maximum deflection

    → increases deflection

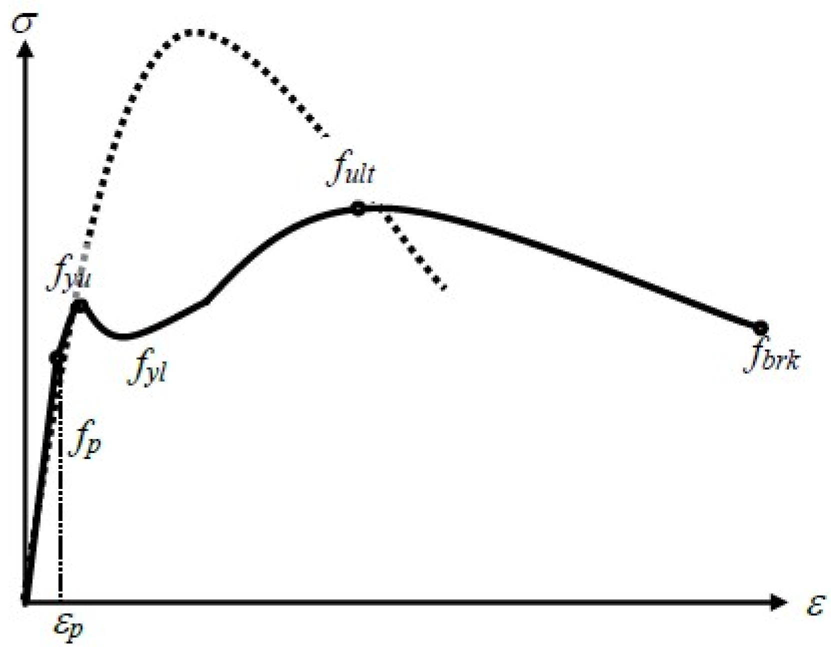
    → allows more accumulation of water → cycle continues…

    → potential failure

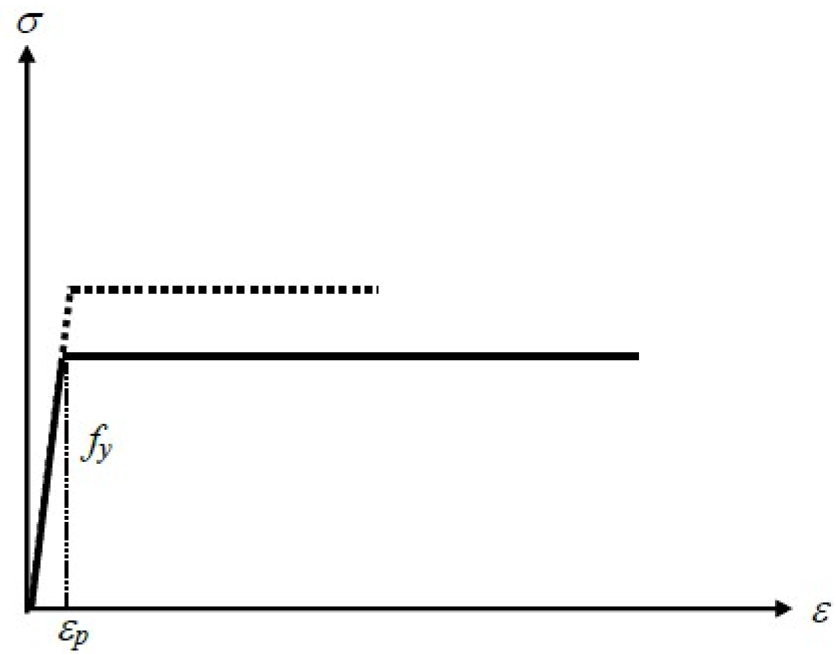
Construction Loads

- Construction materials
- Weight of formwork supporting weight of fresh concrete

Stress-strain Curve of Steel



Actual Stress- Strain Curve



Idealized stress-strain curve (Elastic perfectly plastic

Advantages of Concrete Structures

- Low Maintenance
- Availability of Materials
  - Sand, gravel, cement, H_20 & concrete mixing facilities widely available
  - Reinforcement - easy to transport as compared to structural steel

Disadvantages of Concrete Structures

- Low tensile strength - ~ 0.1 f_c cracking if not properly reinforced →