Plain & Reinforced Concrete-1

CE-314

Lecture # 2

Introduction

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Ultimate Strength Design (USD)/LRFD Method

Strength design method is based on the philosophy of dividing F.O.S. in such a way that **Bigger part** is applied on **loads** and **smaller part** is applied on **material strength.**

Applied Load x $F.O.S_1$ x $F.O.S_2$ ≤ Material Strength

Applied Load x $F.O.S_1$ ≤ {1 / $F.O.S_2$} Material Strength

$F.O.S_1$ = Overload Factor or Load Factor {greater than 1}

1/$F.O.S_2$ = Strength Reduction Factor or Resistance Factor {less than 1}

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Ultimate Strength Design (USD)/LRFD Method

(contd…)

$$U \leq \phi S_n$$

Where

S_n = Nominal Strength

ϕS_n = Design Strength

ϕ = Strength Reduction Factor

U = Required Strength, calculated by applying load factors

For a member subjected to moment, shear and axial load:

$$M_u \leq \phi M_n$$

$$V_u \leq \phi V_n$$

$$P_u \leq \phi P_n$$

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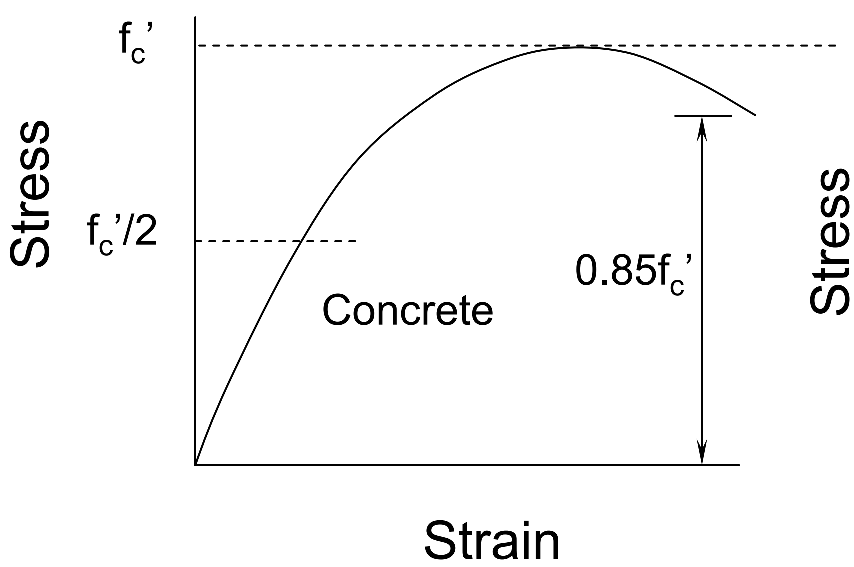
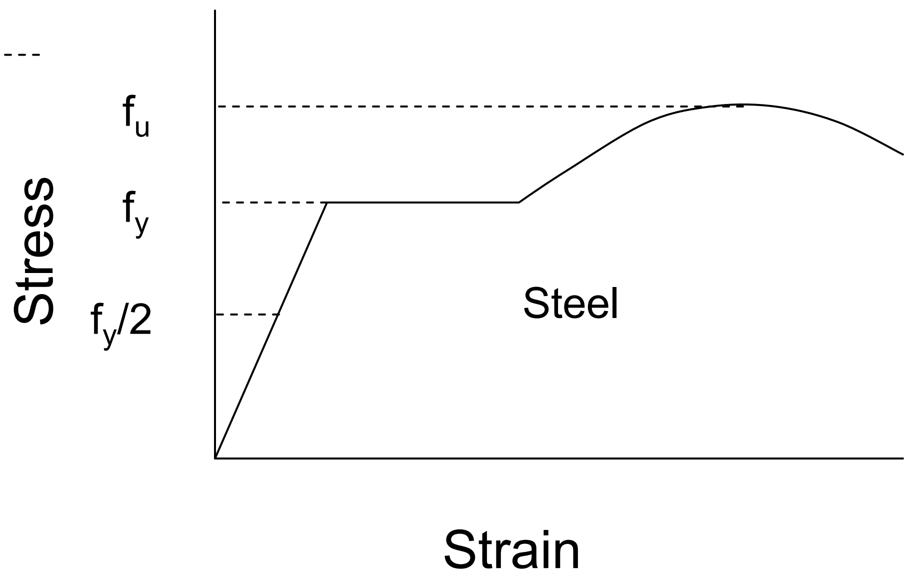
Allowable Strength Design (ASD)

In allowable strength design the whole F.O.S. is applied on **material strength** and service loads (un-factored) are taken as they are.

Service Loads ≤ Material Strength / F.O.S.

In both Allowable strength design and Ultimate strength design analysis carried out in **elastic range**.





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Plastic Design

In plastic design, plastic analysis is carried out in order to find the behavior of structure near **collapse state**. In this type of design material strength is taken from **inelastic range**. It is observed that whether the failure is sudden or ductile. Ductile failure is most favorable because it gives an **warning** before the failure of structures

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Capacity Analysis

In capacity analysis size, shape, material and cross sectional dimensions are known and **maximum load carrying capacity** of the structure is calculated. Capacity analysis is generally carried out for existing structures.

Design of Structure

In design of structure load, span and material are known and **cross sectional dimension** and amount of **reinforcement** are to be determined.

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Objectives of Designer

There are two main objectives

1. **Safety**
2. **Economy**

Safety

The structure should be safe enough to carry all the applied throughout the life.

Economy

Structures should be economical. Lighter structures are more economical.

Economy α 1/self weight **(More valid for Steel Structures)**

In concrete Structures overall cost of construction decides the economy, not just the self weight.

General Design Flow Chart

1. Collect and list all the known data
2. Select trial section based on thumb rules and certain serviceability criteria
3. Perform strength checks
4. Perform serviceability checks
5. Accept section if all checks are satisfied, other-wise revise
6. Write final design results

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Load Combinations

To combine various loads in such a way to get a critical situation.

Load Factor = Factor by which a load is to be increased x probability of occurrence

1. $1.2D + 1.6L$
2. $1.4D$
3. $1.2D + 1.6L + 0.5L_r$
4. $1.2D + 1.6L_r + (1.0L \text{ or } 0.8W)$

Where

D = Dead load

L = Live load on intermediate floors

L_r = Live load on roof

W = Wind Load

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Strength Reduction Factor / Resistance Factor, Φ

Strength Condition	Strength Reduction Factor
Tension controlled section (bending or flexure)	**0.9**
Compression controlled section	
Columns with ties	**0.65**
Column with spirals	**0.75**
Shear and Torsion	**0.75**

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Shrinkage

"Shrinkage is reduction in volume of concrete due to loss of water"

Coefficient of shrinkage varies with time. Coefficient of shortening is:

- 0.00025 at 28 days
- 0.00035 at 3 months
- 0.0005 at 12 months

Shrinkage = Shrinkage coefficient x Length

Excessive shrinkage can be avoided by proper curing during first 28 days because half of the total shrinkage takes place during this period

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- An effective means of reducing shrinkage is to reduce the water content of the fresh concrete to a minimum maintaining the required workability.

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Creep

"creep is the slow deformation of material over considerable lengths of time at constant stress or load"

Creep deformations for a given concrete are practically proportional to the magnitude of the applied stress; at any given stress, high strength concrete show less creep than lower strength concrete.

Compressive strength	Specific Creep
(MPa)	%age per MPa
20	0.0145
30	0.0116
40	0.0080
55	0.0058

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Creep (contd…)

How to calculate shortenings due to creep?

Consider a column of 3m which is under sustained load for several years.

Compressive strength, fc′ = 28 MPa

Sustained stress due to load = 10 MPa

Specific creep for 28 MPa fc′ = 0.0116 % per MPa

Creep Strain = 10 x 0.0116 % = 0.116 %

Shortening due to creep = 3000 x 0.00116

= **3.48 mm**

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Specified Compressive Strength Concrete, fc′

"28 days cylinder strength of concrete"

According to ACI 5.6.2.4, the standard strength test means the average of the strengths of two 150 × 300 mm cylinders or at least three 100 × 200 mm cylinders, from the same sample, tested at 28 days age. Alternately, for the local conditions, this strength test may be taken identical to 80 % (75% is more safe value) of the average compressive strength of two 150×150×150 mm cubes (not an ACI provision).

ACI 5.1.5: For concrete designed and constructed in accordance with ACI code, fc′ shall not be less than 17 MPa (2500 psi)

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Cylinder Strength = (0.75 to 0.8) times Cube Strength

The apparent compressive strength of cubes is higher because of more restraining effect of platens of the machine. The local compressive stresses developed near the platens prevent the splitting of concrete.

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Concrete Cylinder

Concrete Cube

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Relevant ASTM Standards

- “Methods of Sampling Freshly Mixed Concrete” (ASTM C 172)
- Practice for Making and Curing Concrete Test Specimens in Field” (ASTM C 31)
- “Test Methods for Compressive Strength of Cylindrical Concrete Specimen” (ASTM C 39)

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Testing of Samples for Compressive Strength

Cylinders should be tested in moist condition because in dry state it gives more strength.

ACI 5.6.2.1: Samples for strength tests of each class of concrete placed each day shall be taken :

- Not less than once a day
- Not less than once for each 110 m^3 of concrete.
- Not less than once for each 460 m^2 of concrete.

Code allows the site engineer to ask for additional test samples if she/he considers it necessary to ensure quality.

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Acceptance Criteria for Concrete Quality

ACI : Strength level of an individual class of concrete shall be considered satisfactory if both of the following requirements are met:

- Every arithmetic average of any three consecutive strength tests equals or exceeds fc′.
- No individual strength test (average of two cylinders) falls below fc′
  - by more than 3.5 MPa (500 psi) when fc′ is 35 MPa (5000 psi) or less; or
  - by more than 0.10fc′ when fc′ is more than 35 MPa

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Acceptance Criteria for Concrete Quality (contd…)

Example

For Required fc′ = 20 MPa, if following are the test results of 7 samples:

- 19, 20, 22, 23, 19, 18, 24 MPa

  Mean 1 = (19 + 20 + 22) / 3 = 20.33 MPa
  Mean 2 = (20 + 22 + 23) / 3 = 21.67 MPa
  Mean 3 = (22 + 23 + 19) / 3 = 21.33 MPa
  Mean 4 = (23 + 19 + 18) / 3 = 20.00 MPa
  Mean 5 = (19 + 18 + 24) / 3 = 20.33 MPa

1. Every arithmetic average of any three consecutive strength tests equals or exceeds fc′.
2. Non of the test results fall below required fc′ by 3.5 MPa.

Considering these two points the quality of concrete is acceptable.

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Mix Design

- Ingredients of concrete are mixed together in order to get a specified Required Average Strength, f_{cr}' .

- If we use f_c' as target strength during mix design the average strength achieved may fall below f_c'.

- To avoid under-strength concrete f_{cr}' is used as target strength in-place of f_c'.

$$f_{cr}' > f_c'$$

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Mix Design (contd…)

ACI: Required Average Strength

Table -Required Average Compressive Strength when Data Are Available to Establish a Sample Standard Deviation

Specified Compressive Strength, f_c' (MPa)	Required Average Strength, f_{cr}' (MPa)
$f_c' \leq 35$	Larger of value computed from following Eqs. $f_{cr}' = fc' + 1.34\ S_s$ $f_{cr}' = f_c' + 2.33\ S_s - 3.5$
$f_c' > 35$	Larger of value computed from following Eqs. $f_{cr}' = fc' + 1.34\ S_s$ $f_{cr}' = 0.9fc' + 2.33\ S_s$

S_s = Standard deviation of at least 30 compressive strength tests

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Table 5.3.2.2-Required Average Compressive Strength when Data Are Not Available to Establish a Sample Standard Deviation

Specified Compressive Strength, f_c' (MPa)	Required Average Strength, f_{cr}' (MPa)
$f_c' < 21$	$f_{cr}' = f_c' + 7$
$21 \leq f_c' \leq 35$	$f_{cr}' = f_c' + 8.5$
$f_c' > 35$	$f_{cr}' = 1.1f_c' + 5$

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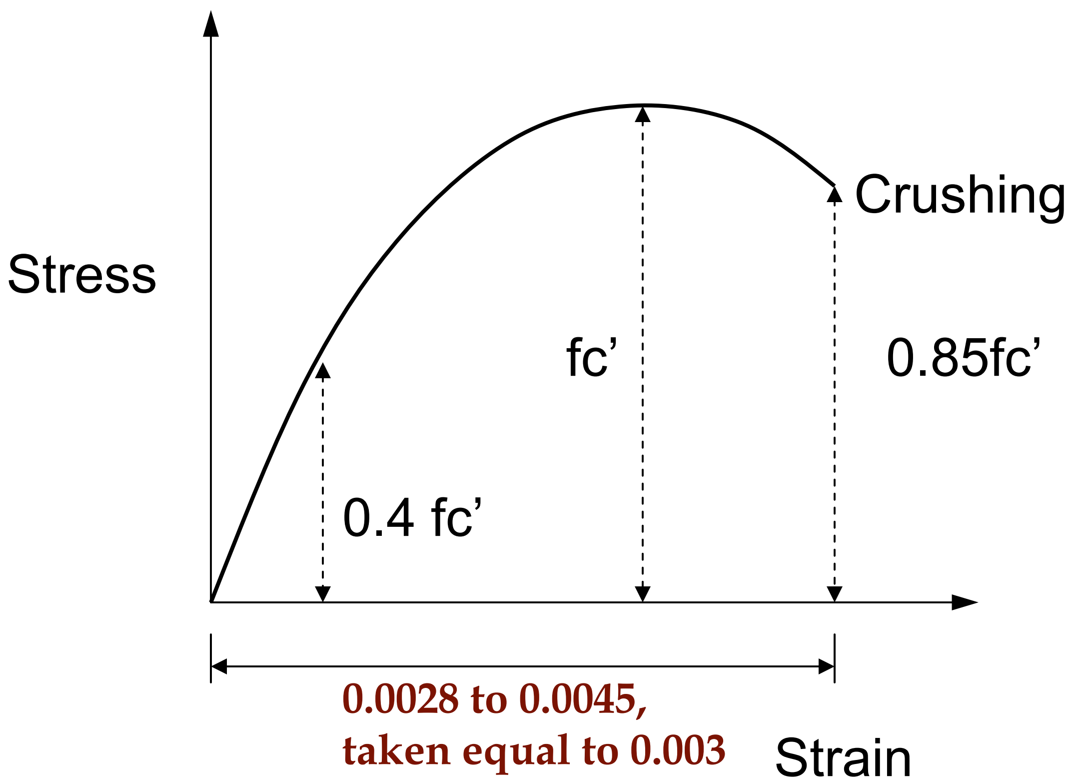
Stress Strain Curve of Concrete



- The first portion of curve, to about 40% of the ultimate strength f_c', can be considered linear.
- The lower the strength of concrete the greater will be the failure strain

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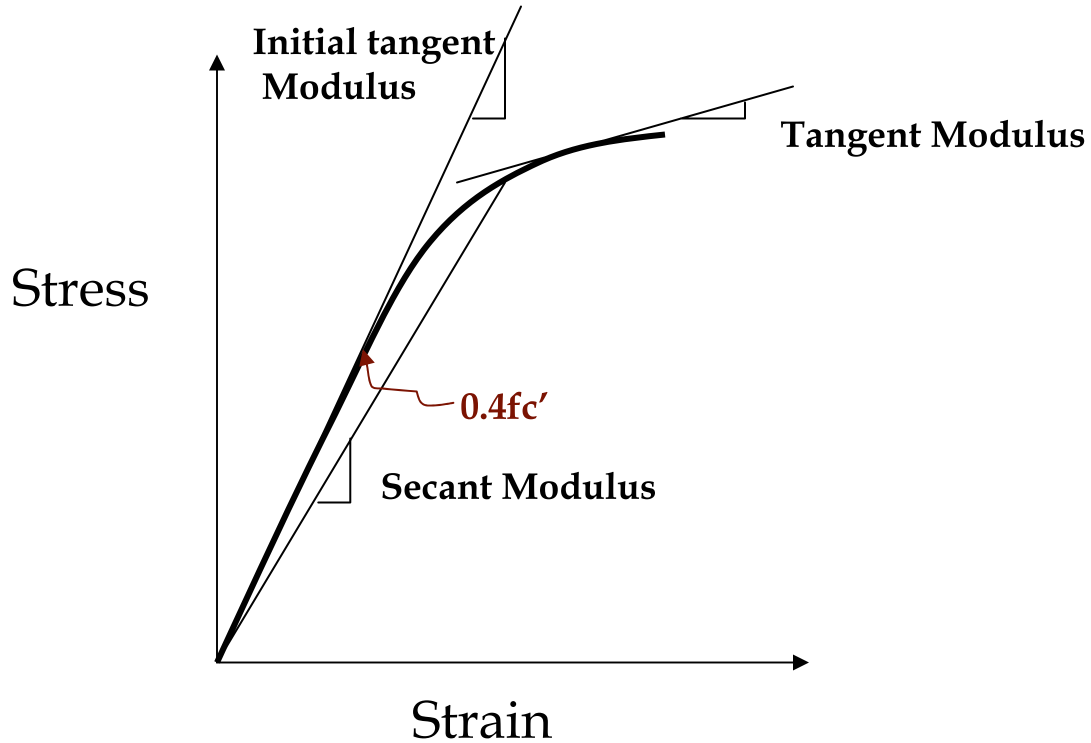
Modulus of Elasticity

Concrete is not an elastic material therefore it does not have a fixed value of modulus of elasticity



Tangent and Secant Moduli of Concrete

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Modulus of Elasticity (contd…)

Initial tangent modulus (E_c) is the one which is common in design.

$$Ec = 0.043\, w_c^{1.5}\sqrt{fc'}$$

w_c = density of concrete in kg/m^3

fc′ = specified cylinder strength in MPa

For normal weight concrete, say w_c = 2300 kg/m^3

$$Ec = 4700\sqrt{fc'}$$

Table 1.3. Grades of Concretes.				
Grade	f_c' (MPa)		*Grade*	f_c' (MPa)
C10	10		C30	30
C12	20		C35	35
C15	15		C40	40
C18	18		C45	45
C20	20		C50	50
C22	22			
C25	25			
C28	28			

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Reinforcing Steel

Steel bars are:

- **Plain**
- **Deformed** (currently in use)

Deformed bars have longitudinal and transverse ribs. Ribs provide a good bond between steel and concrete. If this bond fails steel becomes in effective.

The most important properties for reinforcing steel are:

- **Young's modulus, E (200 GPa)**
- **Yield strength, f_y**
- **Ultimate strength, f_u**
- **Size and diameter of bar**

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Steel Bars

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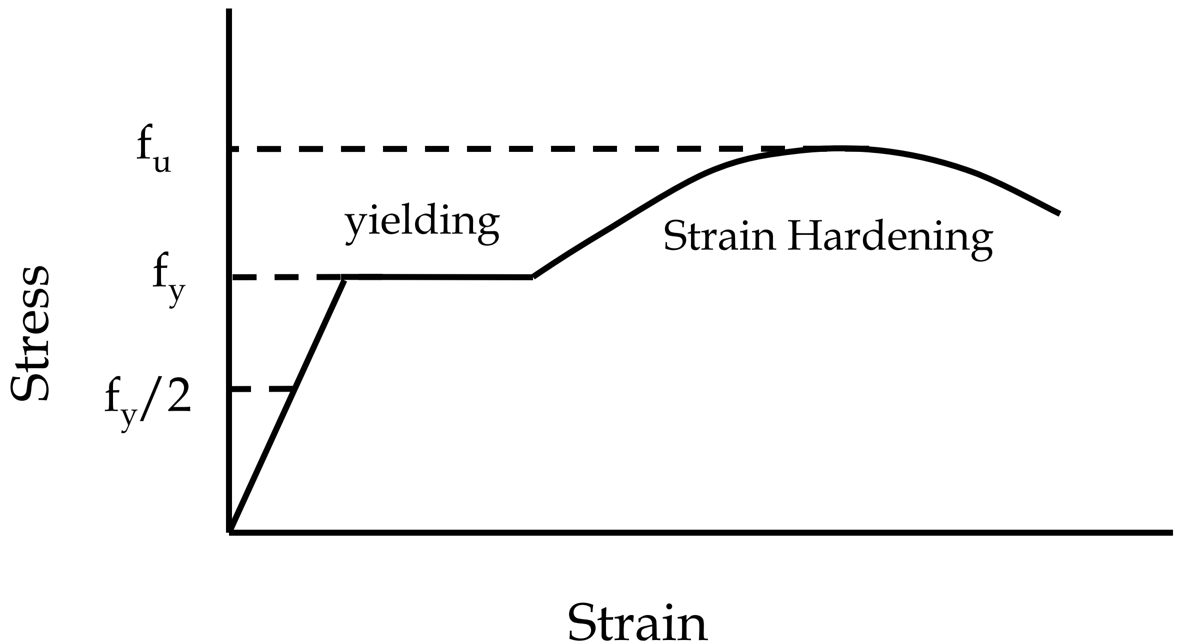
Reinforcing Steel (contd..)

Stress Strain Curve for Steel



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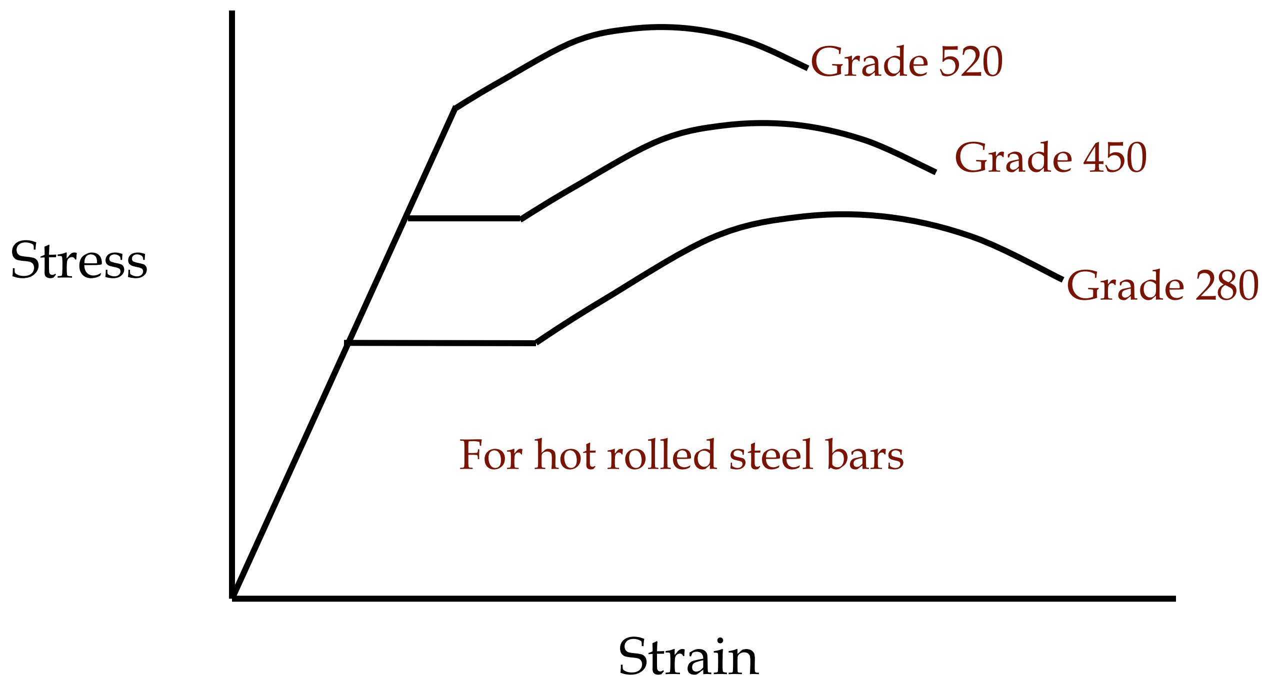
Reinforcing Steel (contd…)

Steel Grade Designation

	FPS
Grade 280, fy = 280 MPa	Grade 40
Grade 420, fy = 420 MPa	Grade 60
Grade 520, fy = 520 MPa	Grade 75

For hot rolled steel bars (FPS Grade 40, Grade 60, Grade 75)



Cold twisted steel bars are available in grade 420

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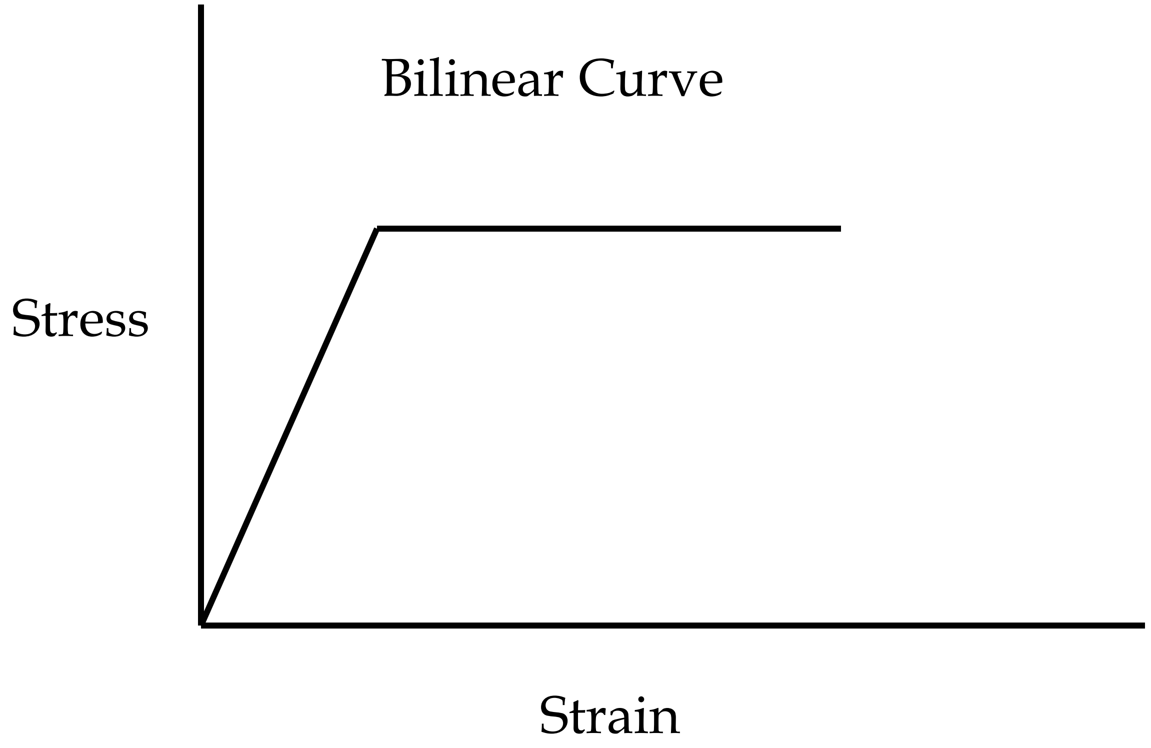
Reinforcing Steel (contd..)

For simplification the stress strain diagram is considered bilinear because after yielding excessive cracks appear.



Concluded