

# 2 Chapter 2. MATERIALS

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## 2.1. Reading Assignment

Chapters 3, 4, and 5 of ACI 318

Chapter 2 of your text book

### 2.1.1. Cement (ACI 3.2)

Cement is a material which has adhesive and cohesive properties necessary to bond insert aggregates into a solid mass of adequate strength and durability.

#### 2.1.1.1 Portland cement

Portland cement was first patented in England in 1824 – comes in 94 lb bags. When cement is mixed with water to form a soft paste, it gradually stiffens until it becomes a solid. This process is known as *setting* or *hardening*.

- 14 days to reach sufficient strength that the forms of beams and slabs can be removed and reasonable load can be applied
- 28 days to reach design strength.

Different types:

1. ASTM type I – general purpose;
2. ASTM type II – sulfate resistant; drainage structures;
3. ASTM type III – high early strength
4. ASTM type IV – minimum heat generation
5. Special type: – severe sulfate resistance, white, masonry, etc.

### 2.1.2. Aggregate (ACI 3.3)

Aggregates occupy 70–75% of hardened mass by volume

1. Fine aggregate or sand – Sand and fine gravel – pass #4 sieve (4 holes/linear inch);

2. Coarse aggregate – Natural or crushed stone; unit weight varies about (140–152) lb/ft<sup>3</sup>

Section 3.3.2 of ACI code:

Nominal maximum size of coarse aggregate shall be not larger than :

- 1/5 of narrowest dimension between sides of forms, nor
  - 1/3 depth of slab, nor
  - 3/4 of minimum clear spacing between reinforcement
3. Special purpose aggregates
- a. light weight – expanded shales, clay, slates, fly ash...
    - low density; 50 lb/ft<sup>3</sup>
    - moderate strength; 60–80 lb/ft<sup>3</sup> and compressive strength 1000, 2500 psi
    - structural concrete; 90–120 pcf
  - b. Heavy weight (used for shielding against gamma, X-ray)
    - crushed iron; steel scrap
    - 200 - 230, pcf
    - up to 330 pcf if ores used for fines, steel for coarse aggregate.

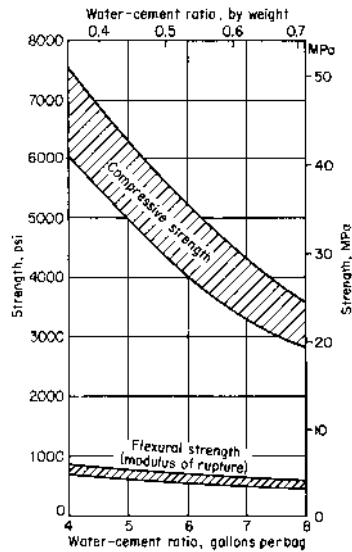
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### 2.1.3. Water (ACI 3.4)

Not necessary of drinking quality, clear, relatively free of suspended or dissolved solids; ph > 3.0  
(ACI 318 Sect. 3.4)

- Water cement ratio
  - Water cement ratio controls the strength of concrete
  - More water; workability increases, easier to move but strength will decrease; largervoids because of free water
- Slump test
  - Good measure of total water content in the mix; (2”–6”). Slump test is used to determine concrete consistency.

Testing the workability of concrete: (a) Slump Test, (b) Ball Test. The “ball” penetration is read on the graduated shaft.



Effect of water\*cement ratio on 28 day compression and flexural tensile strength

It is customary to define proportions of a concrete mix by volume, weight, or cement to sand to gravel such as 1:2:4 or 1 bag of cement (94 lbs) + 45lb of h<sub>2</sub>O, 230 lb of sand, and 380 lb of coarse aggregate.

## 2.1.4. Admixtures (ACI 3.6)

Used in almost all concretes in addition to the main components:

1. Air entraining agents – improve durability, workability, resistant to thawing and freezing;
2. Water reducing agents –
  - sometimes called superplasticizers, drastically increases slump with a given water content; for placement and compaction;
3. Retarder – delays setting of concrete;
4. Accelerator – speed initial set;
5. Workability agent – entrained air, pozzolans.

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## 2.1.5. Conveying

- ACI 5.9;
- problem with segregation.

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## 2.1.6. Placing

- ACI 5.10;
- compact by hand tools, or vibrators (clean before placing).

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## 2.1.7. Curing

- ACI 5.11;  
maintenance of proper condition during the time when concrete is reaching its 28 day  
freezing reduces strength by 50%;  
keep moisture for 7 to 14 days.

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## 2.1.8. Modulus of Elasticity

*ACI Sect. 8.5.1.  $\rightarrow E_c = 57,000\sqrt{f'_c}$  where  $f'_c$  is in psi*

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## 2.1.9. Creep, and Fatigue

Sect. 3.9.7 of text

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## 2.2. Quality Control

See Section 3.5 of text

See ACI 318 Sections 5.1 through 5.7.

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## 2.3. Estimating compressive strength for a trial mix using the specified compression strength

The compressive strength for which the trial mix is designed is not the strength specified by the designer. The mix should be over designed to assure that the actual structure has concrete with specified minimum compressive strength. The extent of mix overdesign depends on the degree of quality control available in the mixing plant.

ACI 318 specifies a systematic way to determine the compressive strength for mix designs using the specified compressive strength,  $f'_c$ . The procedure is presented in a self-explanatory flowchart 5.3 of code. The cylinder compressive strength  $f'_c$  is the test result at 28

days after casting normal-weight concrete. Mix design has to be based on an adjusted higher value  $f'_{cr}$ . This adjusted cylinder compressive strength  $f'_{cr}$  for which a trial mix design is calculated depends on the extent of field data available.

1. No cylinder test records available. If field-strength test records for the specified class (or within 1,000 psi of the specified class) of concrete are not available, the trial mix strength  $f'_{cr}$  can be calculated by increasing the cylindrical compressive strength  $f'_c$  by a reasonable value depending on the extent of spread in values expected in the supplied concrete. Such a spread can be quantified by the standard deviation values represented by the values in excess of  $f'_{cr}$  in Table 5.3.2.2. Section 5.4 should be used for proportioning without field experience or trial mixtures.

2. Data available on more than 30 consecutive cylinder tests. If more than 30 consecutive test results are available, Equations (5-1) and (5-2) if  $f'_c \leq 5000 \text{ psi}$  or Equations (5-1) or (5-3) if  $f'_c > 5000 \text{ psi}$  and (A) can be used to establish the required mix strength,  $f'_{cr}$ , from  $f'_c$ . If two groups of consecutive test results with a total of more than 30 are available  $f'_{cr}$  can be obtained using Equations (5-1) and (5-2) if  $f'_c \leq 5000 \text{ psi}$  or Equations (5-1) or (5-3) if  $f'_c > 5000 \text{ psi}$  and (B).

3. Data available on fewer than 30 consecutive cylinder tests. If the number of consecutive test results available is fewer than 30 and more than 15, Equations (5-1) and (5-2) if  $f'_c \leq 5000 \text{ psi}$  or Equations (5-1) or (5-3) if  $f'_c > 5000 \text{ psi}$  and (A) should be used in conjunction with Table 5.3.1.2. Essentially, the designer should calculate the standard deviation  $s$  using Equation (A) multiplied the  $s$  value by a magnification factor provided in Table 5.3.1.2, and use the magnified  $s$  in Equations (5-1) and (5-2) or (5-3). In this manner, the expected degree of spread of cylinder test values as measured by the standard of deviation  $s$  is well accounted for.

### **2.3.1. Recommended proportion for concrete strength $f'_{cr}$ .**

Once the required average strength  $f'_{cr}$  for mix design is determined, the actual mix can be established to obtain this strength using either existing field data or a basic trial mix design.

**ACI 5.3.3.1.** Use of field data. Field records of existing  $f'_{cr}$  values can be used if at least 10 consecutive test results are available. The test records should cover a period of time at least 45 days. The materials and conditions of the existing field mix data should be the same as the ones to be used in the proposed work.

**ACI 5.3.3.2.** Trial mix design. If the field data are not available, trial mixes should be used to establish the maximum water/cement ratio or minimum cement content for designing a mix that produces a 28-day  $f_{cr}'$  value. In this procedure the following requirements have to be met:

- (a) Materials used and age of testing should be the same for the trial mix and the concrete used in the structure.
- (b) Trial mixtures with a range of proportions that will produce a range of compressive strengths encompassing  $f_{cr}'$  and meet the durability requirements of Chapter 4 of ACI.
- (c) Trial mixtures shall have slumps with the range specific for the proposed work.
- (d) For each trial mixture, at least two 6 by 12 in. or three 4 by 8 in. cylinders shall be made and cured in accordance with ASTM C192. Cylinders shall be tested at 28 days or at test age designated for  $f_c'$ .
- (e) The compressive strength results, at designated test age, from the trial mixtures shall be used to establish the composition of the concrete mixture proposed for the Work.

The following was in ACI318-05.

- (b) At least three water/cement ratios or three cement contents should be tried in the mix design. The trial mixes should result in the required  $f_{cr}'$ . Three cylinders should be test for each w/c ratio and each cement content tried.
- (c) The slump and air content should be with  $\pm 0.75$  in, and 0.5% of the permissible limits.
- (d) A plot is constructed of the compressive strength at the designated age versus the current cement content or w/c ratio, from which one can then choose the w/c ratio or the cement content that can give the average  $f_{cr}'$  value required.

Read

- ACI 5.6.** Evaluation and Acceptance of Concrete
- ACI 5.6.1.** Frequency of testing
- ACI 5.6.2.3** Acceptance criteria 1.

### 2.3.2. Example: Calculation of design strength for trial mix

Calculate the average compressive strengths  $f'_{cr}$  for the design of a concrete mix if the specified compressive strength  $f'_c$  is 5000 psi such that

- (a) the standard of deviation obtained using more than 30 consecutive tests is 500 psi;
- (b) the standard of deviation obtained using 15 consecutive tests is 450 psi
- (c) records of prior cylinder test results are not available.

#### 2.3.2.1. Solution

(a) using Eq. (5-1)

$$f'_{cr} = f'_c + 1.34s$$

$$\begin{aligned} f'_{cr} &= 5,000 + 1.34 \times 500 \\ &= 5,670 \text{ psi} \end{aligned}$$

Using Eq. (5-2)

$$f'_{cr} = 5000 + 2.33 \times 500 - 500 = 5,665 \text{ psi}$$

Hence the required trial mix strength  $f'_{cr} = 5,670$  psi

(b) The standard of deviation,  $s$ , is 450 psi in 15 tests. From Table 5.3.1.2, the modification factor for  $s$  is 1.16.

Hence the value of standard of deviation to be used in Eqs. (5-1) and (5-2) is  $1.16 \times 450 = 522$  psi. Using Eq. (5-1)

$$f'_{cr} = 5,000 + 1.34 \times 522 = 5,700 \text{ psi}$$

Using Eq. (5-2)

$$f'_{cr} = f'_c + 2.33s - 500$$

$$f'_{cr} = 5,000 + 2.33 \times 522 - 500 = 5,716 \text{ psi}$$

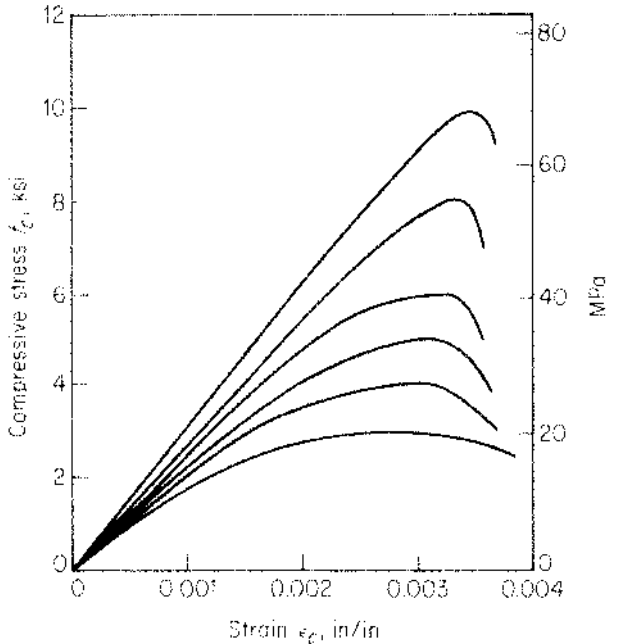
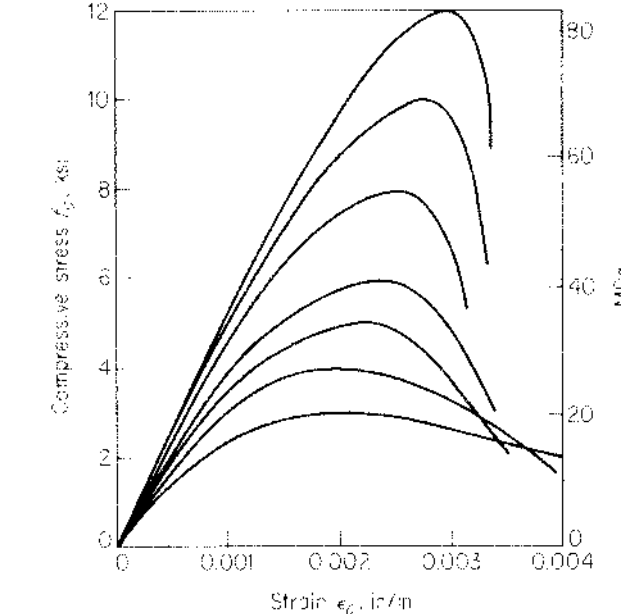
Hence the required trial mix strength  $f'_{cr} = 5,716$  psi.

(c) Records of prior test results are not available. Using Table 5.3.2.2,

$$\begin{aligned} f'_{cr} &= f'_c + 1200 \quad \text{for 5,000 psi concrete} \\ &= 6,200 \text{ psi} \end{aligned}$$

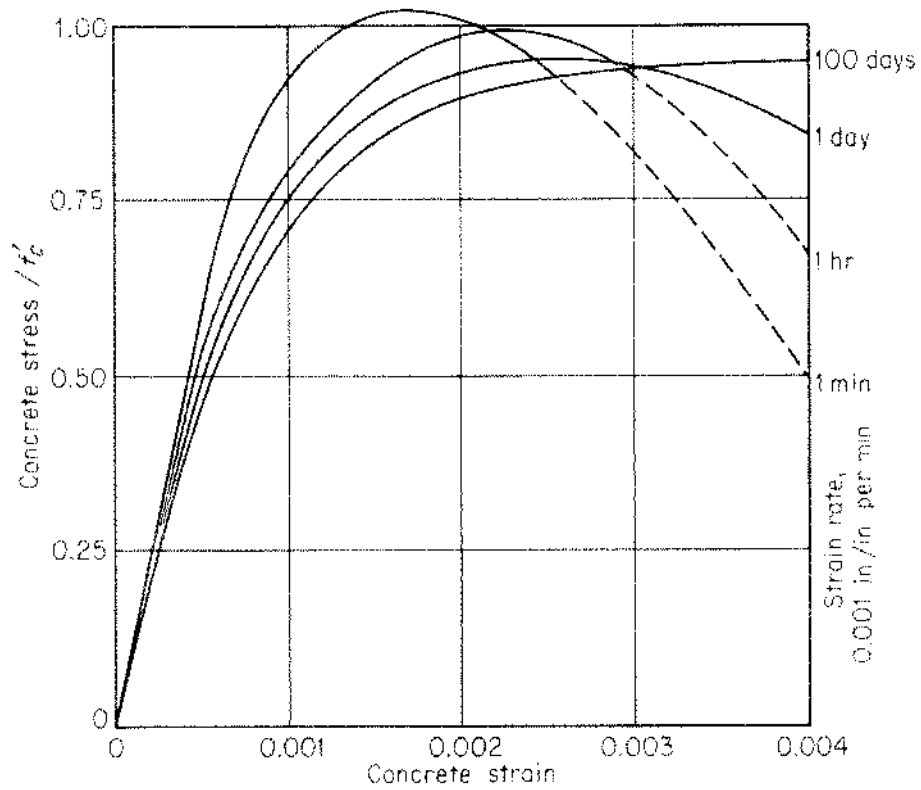
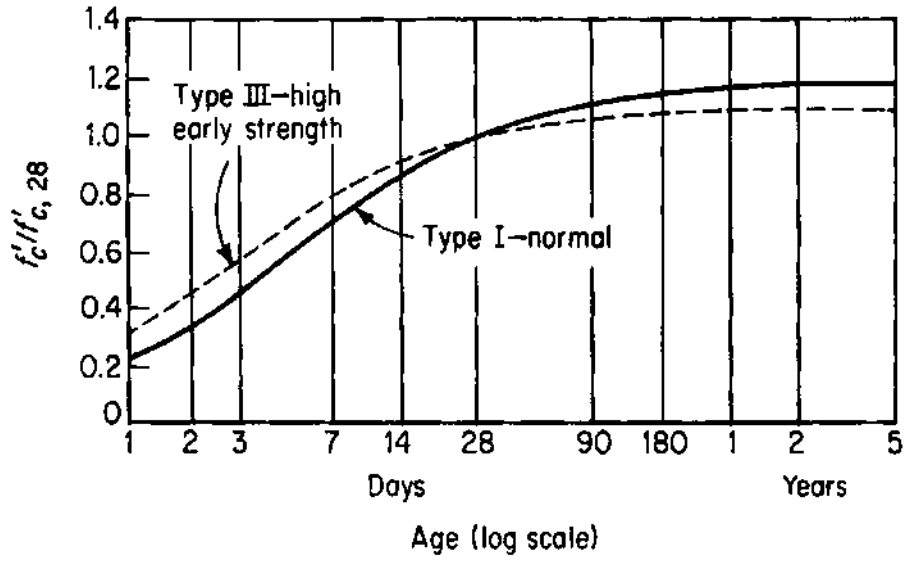
It can be observed that if the mixing plant keeps good records of its cylinder test results over a long period, the required trial mix strength  $f_{cr}'$  can be reduced as a result of such quality control, hence reducing costs for the owner.

## 2.4. Stress and Strain Curves for Concrete





## 2.5. Time Dependent Properties of Concrete

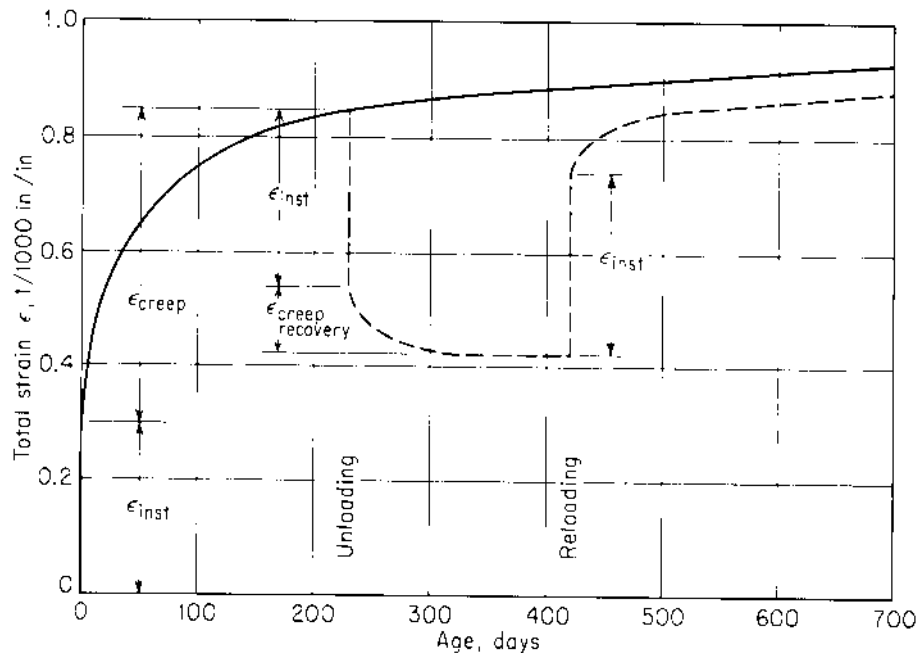


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## 2.6. Creep

Amount of creep depends on:

- Humidity
- Time of first loading
- Strength of Concrete
- etc.



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## 2.7. Reinforcing Steel for Concrete

The useful strength of ordinary reinforcing steels in tension as well as compression, i.e. yield strength, is about 15 times the compressive strength of common structural concrete, and well over 100 times its tensile strength. On the other hand, steel is a high-cost material compared with concrete. It follows that the two materials are best used in combination if concrete is made to resist the compressive stresses and the steel the tensile stresses. Thus, in reinforced concrete beams, the concrete resists the compressive force, longitudinal steel reinforcing bars are located close to the tension face to resist the tension force, and usually additional steel bars are so disposed that they resist the includes tension stresses that are caused by shear force in the beams. However, reinforcing bars are also used to resist compressive forces where it is desired to reduce the cross-sectional dimensions and compression members, as in the lower-floor of columns of multistory buildings.

### **2.7.1. Reinforcing Bars**

The most common type of reinforcing steel is in the form of round bars, often called “rebars” available in diameters ranging from  $\frac{3}{8}$  to  $1 \frac{3}{8}$  in (Nos 3 through 11) for ordinary applications and in two heavy bar sizes of about  $1 \frac{3}{4}$  and  $2 \frac{1}{4}$  in (Nos 14 and 18). The numbers are arranged such that the unit in the number designation corresponds closely to the number of  $\frac{1}{8}$  in of diameter size. For example a No. 5 bar has a nominal diameter of  $\frac{5}{8}$ . These bars have surface deformations for the purpose of increasing resistance to slip between steel and concrete.

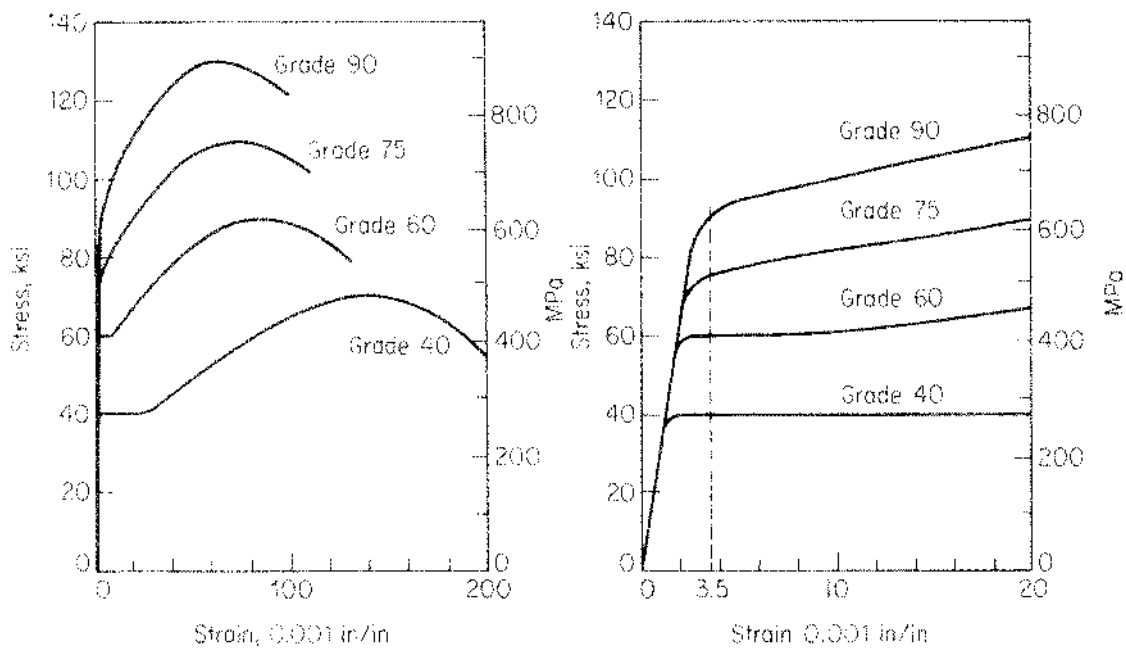
### **2.7.2. Grades and Strength**

Reinforcing bars with 40 ksi yield stress, almost standard 20 years ago, have largely been replaced with 60 ksi yield stress because they are more economical and their use tends to reduce congestion of steel in forms.

### 2.7.3. Stress–Strain Curves for Reinforcing bars

Low-carbon steels show an elastic portion followed by a “yield plateau,” – a horizontal portion of the curve where strain continues to increase at constant stress. For such steels the yield point is that stress at which the yield plateau establishes itself. With further strains the stress begins to increase again – a process called “strain-hardening.” The curve flattens out when the tensile strength is reached, it then turns down until fracture occurs.

Higher-strength carbon steels, with 60 ksi yield stress or higher, either have a yield plateau of much shorter length or enter strain-hardening immediately without any continued yielding at constant stress. In the latter case the ACI Code specifies that the yield stress  $f_y$  be the stress corresponding to strain of 0.0035 in/in.



# MATERIAL SPECIFICATIONS FOR REINFORCING BARS (Cont.)

## IDENTIFICATION MARKS\*—ASTM STANDARD REBARS

The ASTM specifications for billet-steel, rail-steel, axle-steel and low-alloy reinforcing bars (A 615, A 616, A 617 and A 706, respectively) require identification marks to be rolled into the surface of one side of the bar to denote the producer's mill designation, bar size, type of steel, and minimum yield designation. Grade 60 bars show these marks in the following order.

- 1st — Producing Mill (usually a letter)
- 2nd — Bar Size Number (#3 through #18)
- 3rd — Type of Steel: **S** for Billet (A 615)

**I** for Rail (A 616)

**I R** for Rail meeting Supplementary Requirements S1 (A 616)

**A** for Axle (A 617)

**W** for Low-Alloy (A 706)

- 4th — Minimum Yield Designation

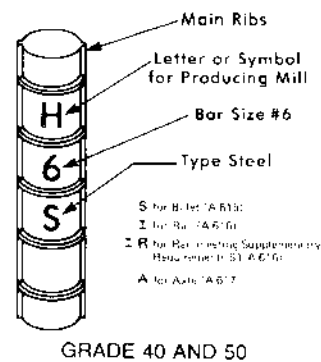
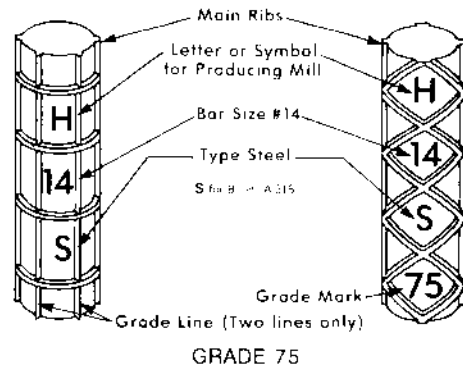
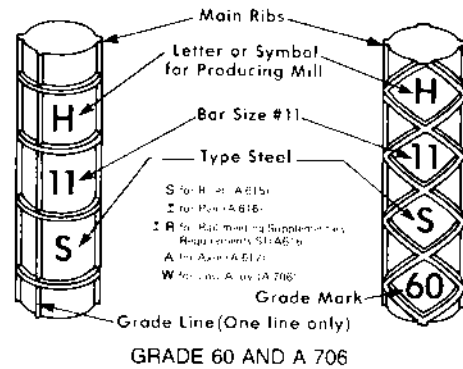
Minimum yield designation is used for Grade 60 and Grade 75 bars only. Grade 60 bars can either have one (1) single longitudinal line (grade line) or the number 60 (grade mark). Grade 75 bars can either have two (2) grade lines or the grade mark 75.

A grade line is smaller and is located between the two main ribs which are on opposite sides of all bars made in the United States. A grade line must be continued through at least 5 deformation spaces, and it may be placed on the side of the bar opposite the bar marks. A grade mark is the 4th mark on the bar.

Grade 40 and 50 bars are required to have only the first three identification marks (no minimum yield designation).

**VARIATIONS:** Bar identification marks may also be oriented to read horizontally (at 90° to those illustrated).

Grade mark numbers may be placed within separate consecutive deformation spaces to read vertically or horizontally.



## ACI BUILDING CODE – REQUIREMENTS FOR REINFORCING BARS

The current ACI Building Code requires billet-steel reinforcing to conform to the ASTM A 615 specification.

Rail-steel reinforcing bars must meet A 616 including supplementary requirement (S1). As shown in the mechanical requirements table on page 1-2, the supplementary requirement (S1) prescribes more-restrictive bend tests. S1 also requires that A 616 reinforcing bars fur-

nished to these supplementary requirements must be designated for type of steel by the symbol "R", in addition to the rail symbol.

The ACI Code does not have special requirements for axle-steel (A 617) and low-alloy (A 706) reinforcing bars, nor take any exceptions to the ASTM specifications for these bars.

\*See Appendix A for complete identification marks of concrete reinforcing bars produced by all U.S. manufacturers. The marks, listed alphabetically by producing mill, include the identification requirements of ASTM and the deformation pattern used by each mill.

# U.S. MANUFACTURERS OF CONCRETE REINFORCING BARS

## IDENTIFICATION OF U.S. REINFORCING BARS

ASTM and AASHTO Specifications require that all reinforcing bars be identified by permanent, mill imprinted markings. See page 1-3.

### 1 A.B. STEEL MILL, INC.



#3 and #4 bars only  
Grade mark line used for #3

### 1 A.B. STEEL MILL, INC.



Bars #5 through #10 only

### 2 ARMCO INC. (Midwestern Steel Division)



#3 and #4 bars only  
Grade mark line on opposite side

### 3 ATLANTIC STEEL COMPANY



Coiled bars (#3 through #5 only)

### 3 ATLANTIC STEEL COMPANY



Straight bars (#3 through #11 only)

### 3 ATLANTIC STEEL COMPANY

MILL	BAR SIZES
Cartersville .....	#3 through #7 only
Atlanta .....	#8 through #11 only

### 4 AUBURN STEEL COMPANY, INC.



Bars #3 through #5 only

### 4 AUBURN STEEL COMPANY, INC.



Bars #6 through #11 only

### 5 BAYOU STEEL CORPORATION



Bars #4 through #6 only  
Grade mark line on opposite side

### 6 BIRMINGHAM STEEL CORPORATION (Barbary Coast Steel Corporation)



### 6 BIRMINGHAM STEEL CORPORATION (Illinois Division)



Bars #4 through #11 only

### 6 BIRMINGHAM STEEL CORPORATION (Mississippi Steel Division)



### 6 BIRMINGHAM STEEL CORPORATION (Norfolk Steel Corporation)



Bars #4 through #11 only

### 6 BIRMINGHAM STEEL CORPORATION (Salmon Bay Steel Division)



Bars #3 through #9 only

### 6 BIRMINGHAM STEEL CORPORATION (Salmon Bay Steel Division)



Bars #10 through #18 only

### 6 BIRMINGHAM STEEL CORPORATION (Southern United Steel Division)



Bars #5 through #11 only

### 7 BORDER STEEL MILLS, INC.

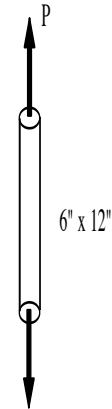


## 2.8. Tension Strength

### 2.1.2 Direct tension test.

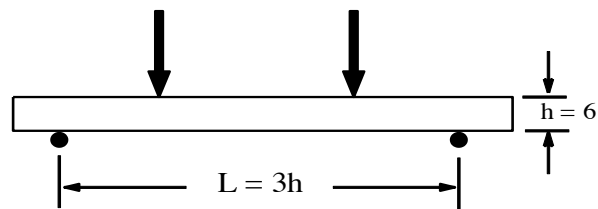
- seldom used
- not very accurate

misalignment or stress concentration in gripping devices; because the specimen water surface evaporates and middle stays rather wet which causes internal stresses and generates cracks at surface of specimen.



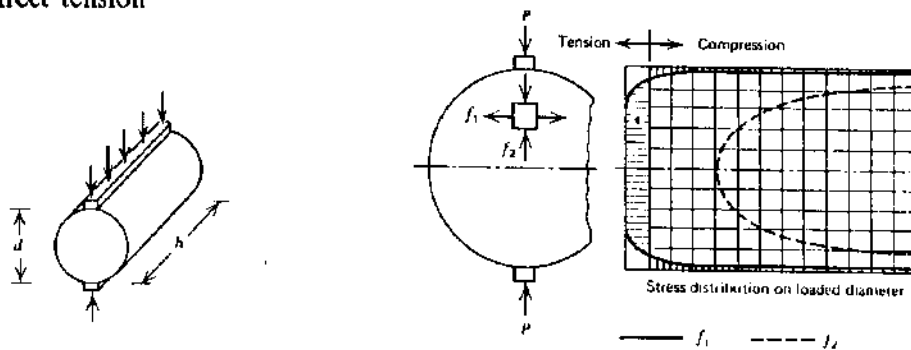
### 2.1.3 Flexure test

based on elastic theory (not good, because failure happen in nonlinear range)



### 2.1.4 Splitting test (ASTM C496-71)

indirect tension



in general  $f_r > f_{sp} \approx f_t$

for normal weight

for sand\*light weight ( $0.85 \times 7.5 = 6.4$ )

for all\*light weight ( $0.75 \times 7.5 = 5.6$ )

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## 2.2 Homework Set 2

A concrete production facility has test records of 40 consecutive concrete cylinders. The cylinders were tested in axial compression 28 days after casting. The result of the tests is summarized below. Compressive strength is listed in *psi*.

5240	5235	4870	5100
4190	5300	5460	5280
5120	5980	4800	4290
4700	5910	4750	4100
4500	5250	4230	5920
3510	4100	4390	5050
4540	5790	5100	6180
5590	5830	4250	4190
4090	5600	5260	5340
4380	5000	4020	4750

Determine the average compressive strength  $f'_{cr}$  for the design of a concrete mix if the specified compressive strength  $f'_c$  is 5000 *psi*. Use a spreadsheet to perform your calculations.

*Answer:*

$$f'_{cr} = ? \text{ psi}$$