

# USE OF 500 GRADE STEEL IN THE DESIGN OF REINFORCED CONCRETE SLAB

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## **1.0 Introduction**

There is growing interest within the reinforced concrete industry in using higher strength reinforcing steel for certain applications. This interest is driven primarily by relief of congestion; particularly in buildings assigned a high seismic design category. There are also other areas where high strength bar can help improve construction efficiencies, or - combined with high strength concrete - allow reinforced concrete to be used in more demanding applications. Today, the vast majority of concrete design and construction uses Grade 60 steel, with occasional but increasing use of Grade 75 (Ref 1).

Most steel used for reinforcement is highly ductile in nature. Its usable strength is its yield strength, as this stress condition initiates such a magnitude of deformation (into the plastic yielding range of the steel), that major cracking will occur in the concrete. Since the yield strength of the steel is quite clearly defined and controlled, this establishes a very precise reference in structural investigations. An early design decision is that for the yield strength (specified by the Grade of steel used) that is to be used in the design work.

Several different grades of steel may be used for large projects, with a minimum grade for ordinary tasks and higher grades for more demanding ones. Cost increases generally for higher grades, so some feasibility studies must be made to see if the better steel in smaller quantities is really cheaper than a larger quantity of a lower grade. Actually, higher grades are often used to permit smaller concrete members, relating to the space problems for placement of the reinforcement.

Even though the steel ordinarily constitutes only a few percent of the total volume of reinforced concrete, it is a major cost factor. This includes the cost of the steel, the forming of the deformed bars, the cutting and bending required, and the installation in the forms. A cost-saving factor is usually represented by the general attempt to use the minimum reinforcement and the most concrete, reflecting typical unit costs for the two materials.

The use of different grades of steel in different building Codes and Standards and various design provisions of codes for the design of different structural members are discussed in details in the following articles.

## **2.0 Provision in Bangladesh National Building Code (BNBC-93) (Ref 2)**

5.3.2.1 - Deformed reinforcing bar shall conform to one of the following specification BDS 1313, ASTM A615, ASTM A706, BS 4461

5.3.2.2 - Deformed reinforcing bar with a specified yield strength  $f_y$  exceeding 410 N/mm<sup>2</sup> shall be permitted, provided  $f_y$  shall be the stress corresponding to a strain of 0.35 percent and the bars otherwise conform to one of the ASTM specification listed above.

6.1.2.5 - Yield strength of the reinforcement  $f_y$  shall not be taken more than  $550 \text{ N/mm}^2$ .

As per Art.8 of BDS 1313: 1991, (Ref 3) the tensile strength of any bar shall be greater than the actual yield strength measured in the tensile test by at least 15% for grades 250, 275, 350 and 400 and at least 10% for grade 500.

### 3.0 Provision in ACI Code (Ref 4)

The ACI Code allows the deformed reinforcement as given in Art 3.5.3 of the Code.

#### 3.5.3 — Deformed reinforcement

3.5.3.1 — Deformed reinforcing bars shall conform to the requirements for deformed bars in one of the following specifications,

- (a) Carbon steel: ASTM A615; (Ref 5)
- (b) Low-alloy steel: ASTM A706; (Ref 6)
- (c) Stainless steel: ASTM A955;
- (d) Rail steel and axle steel: ASTM A996. Bars from rail steel shall be Type R.

ASTM A615/ A615-96a specifies bars of three minimum yield levels: namely, 40,000 psi (300 MPa), 60,000 psi (420 MPa), and 75,000 psi (520 MPa), designated as Grade 40 [300], Grade 60 [420] and Grade 75 [520] respectively. The material, as represented by the test specimen, shall conform to the requirements for tensile properties prescribed in Table 1

Summary of minimum ASTM strength requirements (Table 1)

Product	ASTM Specification	Designation	Minimum Yield Strength, psi (MPa)	Minimum Tensile Strength, psi (MPa)
Reinforcing bars	A615	Grade 40	40,000 (280)	60,000 (420)
		Grade 60	60,000 (420)	90,000 (620)
		Grade 75	75,000 (520)	100,000 (690)
	A706	Grade 60	60,000 (420)	80,000 (550) <sup>a</sup>
			[78,000 (540) maximum]	
A996	Grade 40	40,000 (280)	60,000 (420)	
		Grade 50	80,000 (550)	
		Grade 60	90,000 (620)	

*a. But not less than 1.25 times the actual yield strength.*

3.5.3.2 — Deformed reinforcing bars shall conform to one of the ASTM specifications listed in 3.5.3.1, except that for bars with  $f_y$  exceeding 60,000 psi, the yield strength shall be taken as the stress corresponding to a strain of 0.35 percent. The values of  $f_y$  and  $f_{yt}$  used in design calculations shall not exceed 80,000 psi, except for prestressing steel and for transverse reinforcement in 10.9.3 and 21.1.5.4.

10.9.3 — Volumetric spiral reinforcement ratio,  $\rho_s$ , shall be not less than the value given by

$$\rho_s = 0.45 \left( \frac{A_g}{A_{ch}} - 1 \right) \frac{f'_c}{f_{yt}} \quad (10-5)$$

where the value of  $f_{yt}$  used in Eq. (10-5) shall not exceed 100,000 psi. For  $f_{yt}$  greater than 60,000 psi, lap splices according to 7.10.4.5(a) shall not be used.

21.1.5.4 — The value of  $f_{yt}$  used to compute the amount of confinement reinforcement shall not exceed 100,000 psi.

The ACI Commentary states that, *ASTM A615 includes provisions for Grade 75 bars in sizes No. 6 through 18. The 0.35 percent strain limit is necessary to ensure that the assumption of an elasto-plastic stress-strain curve in 10.2.4 will not lead to unconservative values of the member strength.*

### 3.1 ACI Code Provisions for Minimum Slab Thickness.

ACI code 9.5.2.1 specifies the minimum thickness of the non-pre-stressed one-way slabs using Grade 60 reinforcement as given in Table 9.5(a).

9.5.2.1 — Minimum thickness stipulated in Table 9.5(a) shall apply for one-way construction not supporting or attached to partitions or other construction likely to be damaged by large deflections, unless computation of deflection indicates a lesser thickness can be used without adverse effects.

**TABLE 9.5(a) — MINIMUM THICKNESS OF NONPRESTRESSED BEAMS OR ONE-WAY SLABS UNLESS DEFLECTIONS ARE CALCULATED**

	Minimum thickness, $h$			
	Simply supported	One end continuous	Both ends continuous	Cantilever
Member	Members not supporting or attached to partitions or other construction likely to be damaged by large deflections			
Solid one-way slabs	$\ell/20$	$\ell/24$	$\ell/28$	$\ell/10$
Beams or ribbed one-way slabs	$\ell/16$	$\ell/18.5$	$\ell/21$	$\ell/8$
Notes: Values given shall be used directly for members with normalweight concrete and Grade 60 reinforcement. For other conditions, the values shall be modified as follows: a) For lightweight concrete having equilibrium density, $w_c$ , in the range of 90 to 115 lb/ft <sup>3</sup> , the values shall be multiplied by $(1.65 - 0.005w_c)$ but not less than 1.09. b) For $f_y$ other than 60,000 psi, the values shall be multiplied by $(0.4 + f_y/100,000)$ .				

9.5.3.2 — For slabs without interior beams spanning between the supports and having a ratio of long to short span not greater than 2, the minimum thickness shall be in accordance with the provisions of Table 9.5(c) and shall not be less than the following values:

- (a) Slabs without drop panels .....5 in.  
 (b) Slabs with drop panels.....4 in.

9.5.3.3 — For slabs with beams spanning between the supports on all sides, the minimum thickness,  $h$ , shall be as follows:

- (a) For  $\alpha_m$  equal to or less than 0.2, the provisions of 9.5.3.2 shall apply;  
 (b) For  $\alpha_m$  greater than 0.2 but not greater than 2.0,  $h$  shall not be less than

$$h = \frac{\ell_n \left( 0.8 + \frac{f_y}{200,000} \right)}{36 + 5\beta(\alpha_{fm} - 0.2)} \quad (9-12)$$

and not less than 5 in.;

- (c) For  $\alpha_m$  greater than 2.0,  $h$  shall not be less than

$$h = \frac{\ell_n \left( 0.8 + \frac{f_y}{200,000} \right)}{36 + 9\beta} \quad (9-13)$$

and not less than 3.5 in.;

- (d) At discontinuous edges, an edge beam shall be provided with a stiffness ratio  $\alpha_m$  not less than 0.80

**TABLE 9.5(c)—MINIMUM THICKNESS OF SLABS WITHOUT INTERIOR BEAMS\***

$f_y$ , psi†	Without drop panels‡			With drop panels‡		
	Exterior panels		Interior panels	Exterior panels		Interior panels
	Without edge beams	With edge beams§		Without edge beams	With edge beams§	
40,000	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$	$\ell_n/36$	$\ell_n/40$	$\ell_n/40$
60,000	$\ell_n/30$	$\ell_n/33$	$\ell_n/33$	$\ell_n/33$	$\ell_n/36$	$\ell_n/36$
75,000	$\ell_n/28$	$\ell_n/31$	$\ell_n/31$	$\ell_n/31$	$\ell_n/34$	$\ell_n/34$

\*For two-way construction,  $\ell_n$  is the length of clear span in the long direction, measured face-to-face of supports in slabs without beams and face-to-face of beams or other supports in other cases.  
 †For  $f_y$  between the values given in the table, minimum thickness shall be determined by linear interpolation.  
 ‡Drop panels as defined in 13.2.5.  
 §Slabs with beams between columns along exterior edges. The value of  $\alpha_f$  for the edge beam shall not be less than 0.8.

or the minimum thickness required by Eq. (9-12) or (9-13) shall be increased by at least 10 percent in the panel with a discontinuous edge.

Term  $l_n$  in (b) and (c) is length of clear span in long direction measured face-to-face of beams. Term  $\beta$  in (b) and (c) is ratio of clear spans in long to short direction of slab.

### 3.2 ACI Code Provisions for Minimum Reinforcement.

10.5.4 — For structural slabs and footings of uniform thickness,  $A_s$ , min in the direction of the span shall be the same as that required by 7.12.2.1. Maximum spacing of this reinforcement shall not exceed three times the thickness, nor 18 in.

7.12.2.1 — Area of shrinkage and temperature reinforcement shall provide at least the following ratios of reinforcement area to gross concrete area, but not less than 0.0014:

(a) Slabs where Grade 40 or 50

deformed bars are used .....0.0020

(b) Slabs where Grade 60

deformed bars or welded wire

reinforcement are used.....0.0018

(c) Slabs where reinforcement

with yield stress exceeding 60,000 psi measured at a yield strain of

0.35 percent is used .....  $\frac{0.0018 \times 60,000}{f_y}$

7.12.2.2 — Shrinkage and temperature reinforcement shall be spaced not farther apart than five times the slab thickness, nor farther apart than 18 in.

### 3.3 ACI Code Provisions for Seismic Resistance.

21.1.4.2 — Specified compressive strength of concrete,  $f'_c$ , shall be not less than 3000 psi.

21.1.4.3 — Specified compressive strength of lightweight concrete,  $f'_c$ , shall not exceed 5000 psi unless demonstrated by experimental evidence that structural members made with that lightweight concrete provide strength and toughness equal to or exceeding those of comparable members made with normal weight concrete of the same strength.

21.1.5.2 — Deformed reinforcement resisting earthquake- induced flexural and axial forces in frame members, structural walls, and coupling beams, shall comply with ASTM A706. ASTM A615. Grades 40 and 60 reinforcement shall be permitted in these members if:

(a) The actual yield strength based on mill tests does not exceed  $f_y$  by more than 18,000 psi; and (b) The ratio of the actual tensile strength to the actual yield strength is not less than 1.25.

21.1.5.4 — The value of  $f_{yt}$  used to compute the amount of confinement reinforcement shall not exceed 100,000 psi.

21.1.5.5 — The value of  $f_y$  or  $f_{yt}$  used in design of shear reinforcement shall conform to 11.4.2.

11.4.2 — The values of  $f_y$  and  $f_{yt}$  used in design of shear reinforcement shall not exceed 60,000 psi, except the value shall not exceed 80,000 psi for welded deformed wire reinforcement.

ACI commentary states that - *Limiting the values of  $f_y$  and  $f_{yt}$  used in design of shear reinforcement to 60,000 psi provides a control on diagonal crack width. In the 1995 Code, the limitation of 60,000 psi for shear reinforcement was raised to 80,000 psi for welded deformed wire reinforcement. Research has indicated that the performance of higher-strength steels as shear reinforcement has been satisfactory. In particular, full-scale beam tests described in Reference 11.19 indicated that the widths of inclined shear cracks at service load levels were less for beams reinforced with smaller-diameter welded deformed wire reinforcement cages designed on the basis of a yield strength of 75 ksi than beams reinforced with deformed Grade 60 stirrups.*

#### 4.0 Provision in British/European Standard BS-4449/prEN-100800 (Ref 7)

##### 4.1 Properties of Reinforcement in British/European Standard BS/EN

Current British Standards for reinforcement are BS 4449:1988 (bars) and BS 4483:1985 (welded fabric). It is envisaged that when EN 10080 (currently in draft form as pr EN 10080) is published Grade 500 (bars and fabric) will supersede Grade 460. The differences between the current British Standards and pr EN 10080 are summarized in Table 2.

**Table 2:** differences between the current British Standards and pr EN 10080

Property	BS 4449 and BS 4483	prEN 10080
Specified characteristic yield strength	Grade 460 N/mm <sup>2</sup> Grade 250 N/mm <sup>2</sup>	500 N/mm <sup>2</sup> not included
Bond strength for: Ribbed bars/wires Indented wires Plain bars/wires	Deformed Type 2 Deformed Type 1 Plain rounds	High bond Not included Not included
Ductility class (now defined as elongation at maximum load and ultimate to yield strength ratio)	Not covered	Class H or Class N (this may be deleted in the final version) (see note)

*NOTE All ribbed bars and all Grade 250 bars may be assumed to be Class H. Ribbed wire welded fabric may be assumed to be available in Class H in wire sizes of 6 mm or over. Plain or indented wire welded fabric may be assumed to be available in Class N. In design where plastic analysis or moment distribution over 15 % is used, it is essential to specify ductility class (H) as defined in prEN 10080 since this parameter is not covered by BS 4449 and BS 4483.*

## 4.2 Provision for Column in EN Code (Ref 7)

The Code provisions for column design are given below:

### 5.4.1 Columns

This clause deals with columns for which the larger dimension  $b$  is not greater than 4 times the smaller dimension  $h$ .

#### 5.4.1.1 Minimum dimensions

(1) The minimum permissible transverse dimension of a column cross-section is:

- |200 mm| for columns of solid section, cast in situ (vertically)
- |140 mm| for precast columns cast horizontally.

#### 5.4.1.2 Longitudinal and transverse reinforcement

##### 5.4.1.2.1 Longitudinal reinforcement

(1) Bars should have a diameter of not less than 12 mm.

(2) The minimum amount of total longitudinal reinforcement  $A_{s,min}$  should be derived from the following condition:

$$A_{s,min} = \frac{0.15 N_{Sd}}{f_{yd}} \leq |0.003| A_c$$

where:

$f_{yd}$  is the design yield strength of the reinforcement

$N_{Sd}$  is the design axial compression force

$A_c$  is the cross-section of the concrete

(3) Even at laps, the area of reinforcement should not exceed the upper limit |0.08  $A_c$ |.

(4) The longitudinal bars should be distributed around the periphery of the section. For columns having a polygonal cross-section, at least one bar shall be placed at each corner. For columns of circular cross-section the minimum number of bars is |6|.

##### 5.4.1.2.2 Transverse reinforcement

(1) The diameter of the transverse reinforcement (links, loops or helical spiral reinforcement) should not be less than |6 mm| or |one quarter| of the maximum diameter of the longitudinal bars, whichever is the greater; the diameter of the wires of welded mesh fabric for transverse reinforcement should not be less than |5 mm|.

(2) The transverse reinforcement should be adequately anchored.

(3) The spacing of the transverse reinforcement along the column should not exceed the lesser of the following three distances:

- 12 times the minimum diameter of the longitudinal bars;
- the least dimension of the column;
- 300 mm

- (4) The spacing should be reduced by a factor |0.6|:
  - i) in sections located above and below a beam or slab over a height equal to the larger dimension of the column cross-section;
  - ii) near lapped joints, if the maximum diameter of the longitudinal bars is greater than |14 mm|.
- (5) Where the direction of the longitudinal bars changes, (e.g. at changes in column size), the spacing of transverse reinforcement should be calculated, while taking account of the lateral forces involved.
- (6) Every longitudinal bar (or group of longitudinal bars) placed in a corner should be held by transverse reinforcement.
- (7) A maximum of |5| bars in or close to each corner can be secured against buckling by any one set of transverse reinforcement.

## 4.2 Design Provision for Beams in EN code.

### 5.4.2.1 Longitudinal reinforcement

#### 5.4.2.1.1 Minimum and maximum reinforcement percentage

(1) The effective cross-sectional area of the longitudinal tensile reinforcement should be not less than that required to control cracking (see 4.4.2), nor less than:

$$|0.6| b_t d / f_{yk} \leq |0.0015| b_t d \quad (f_{yk} \text{ in N/mm}^2) \quad \text{-----} \quad 5.14$$

Where  $b_t$  denotes the mean width of the tension zone; for a T-beam with the flanges in compression, only the width of the web is taken into account in calculating the value of  $b_t$ . Sections containing less reinforcement than that given by Equation (5.14) should be considered as unreinforced.

(2) The cross-sectional areas of the tension reinforcement and of the compression reinforcement should not be greater than |0.04  $A_c$ |, other than at laps.

## 4.3 Design Provision for Cast in Situ Solid Slabs in EN code.

### 5.4.3.1 Minimum thickness

(1) For a solid slab, the absolute minimum thickness is |50 mm|.

### 5.4.3.2 Flexural reinforcement

#### 5.4.3.2.1 General

(1) For the detailing of the main reinforcement, 5.4.2.1 applies.

(2) Secondary transverse reinforcement should be provided in one-way slabs generally, this secondary transverse reinforcement should be at least |20 %| of the principal reinforcement.

(3) 5.4.2.1.1(1) and (2) give the minimum and the maximum steel percentages in the main direction.

(4) The maximum spacing of the bars is as follows:

— For the principal reinforcement, |1.5h ≤ 350 mm|, where h denotes the total depth of the slab;

— For the secondary reinforcement,  $[2.5 h \leq 400 \text{ mm}]$ .

#### 5.4.3.2.2 Reinforcement in slabs near supports

(1) In slabs, half the calculated span reinforcement should continue up to the support and be anchored therein.

(2) Where partial fixity occurs along one side of slab, but is not taken into account in the analysis, the top reinforcement should be capable of resisting not less than one quarter of the maximum moment in the adjacent span; this reinforcement should be provided along a length of not less than 0.2 times the adjacent span measured from the inner face of the support.

#### 5.4.3.2.3 Corner reinforcement

(1) If the detailing arrangements at a support are such that lifting of the slab at a corner is restrained, suitable reinforcement should be provided.

#### 5.4.3.2.4 Reinforcement at the free edges

(1) Along a free (unsupported) edge, a slab should normally contain longitudinal and transverse reinforcement generally arranged as shown in Figure 5.16.

(2) The normal reinforcement provided for a slab may act as edge reinforcement

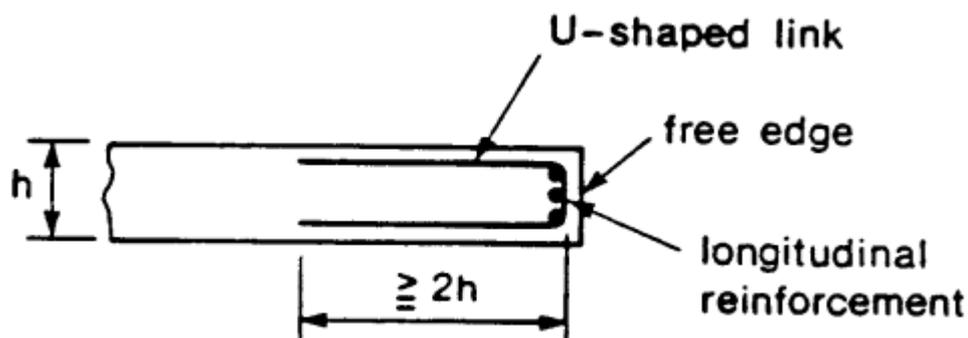


Figure 5.16 — Edge reinforcement for a slab

#### 5.4.3.3 Shear reinforcement

(1) A slab in which shear reinforcement is provided should have a depth of at least  $[200 \text{ mm}]$ .

(2) In detailing the shear reinforcement, 5.4.2.2 applies except where modified by the following rules.

Where shear reinforcement is required, this should not be less  $[60 \text{ %}]$  of the values in Table 5.5 for beams.

(3) In slabs if  $V_{Sd} \leq 1/3 V_{Rd2}$ , (see 4.3.2), the shear reinforcement may consist entirely of bent-up bars or of shear assemblies.

(4) The maximum longitudinal spacing of successive series of links is given by Equations 5.17 to 5.19 neglecting the limits given in mm. The maximum longitudinal spacing of bent-up bars is  $s_{\max} = d$ .

— if $V_{Sd} \leq 1/5 V_{Rd2}$ : $s_{\max} = 0.8 d \nlessgtr 300 \text{ mm}$	(5.17)
— if $1/5 V_{Rd2} < V_{Sd} \leq 2/3 V_{Rd2}$ : $s_{\max} = 0.6 d \nlessgtr 300 \text{ mm}$	(5.18)
— if $V_{Sd} > 2/3 V_{Rd2}$ : $s_{\max} = 0.3 d \nlessgtr 200 \text{ mm}$	(5.19)

(for  $V_{Rd2}$ , see Section 4.3.2.4 Equations 4.25 and 4.26)

(5) The distance between the inner face of a support, or the circumference of a loaded area, and the nearest shear reinforcement taken into account in the design should not exceed  $d/2$  for bent-up bars. This distance should be taken at the level of the flexural reinforcement; if only a single line of bent-up bars is provided, their slope may be reduced to  $30^\circ$ . [Figure 5.17 b)]

(6) It may be assumed that one bent-up bar takes up the shear force over a length of  $2d$ .

(7) Only the following reinforcement may be taken into account as punching shear reinforcement:

- Reinforcement located in a zone bounded by a contour line situated at a distance not exceeding  $[1.5 d \text{ or } 800 \text{ mm}]$ , whichever is the smaller, from the periphery of the loaded area; this condition applies in all directions;
- bent-up bars passing over the loaded area [Figure 5.17 b)] or at a distance not exceeding  $[d/4]$  from the periphery of this area [Figure 5.17 c)].

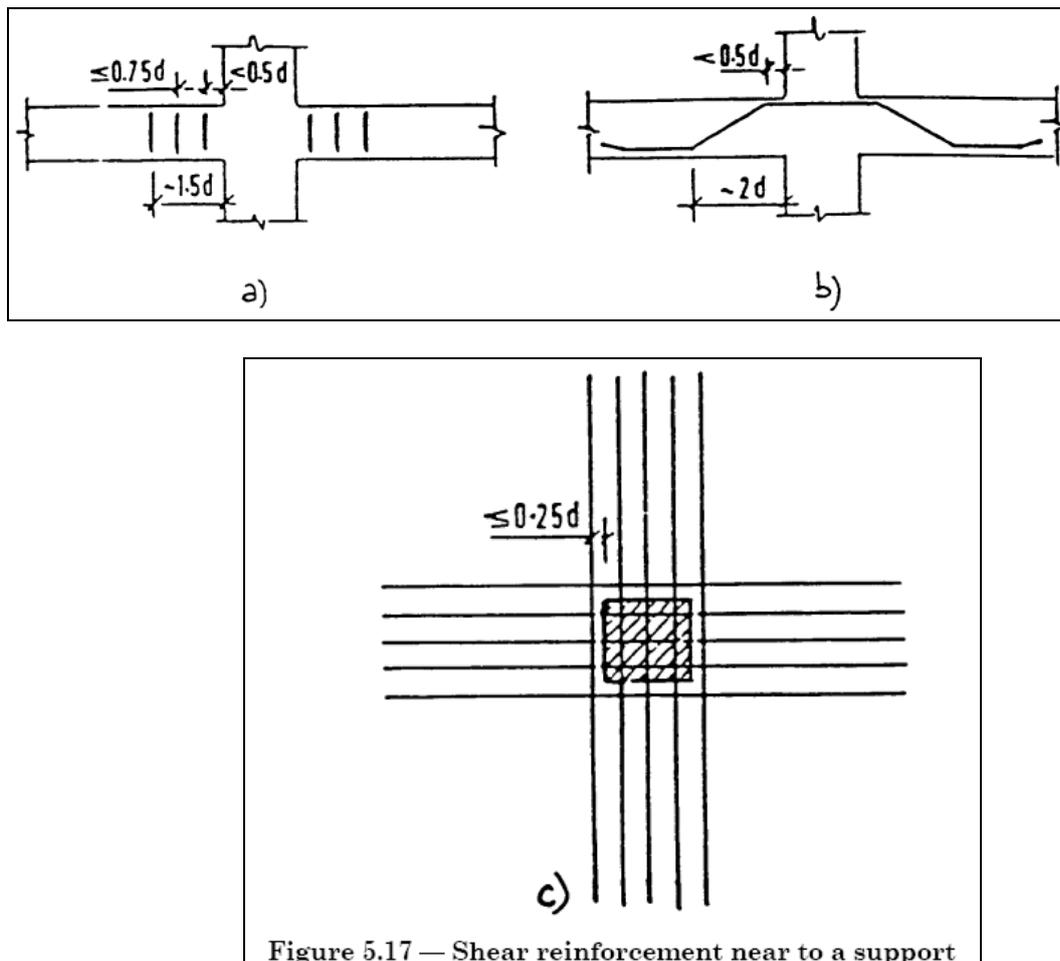


Figure 5.17 — Shear reinforcement near to a support

## 5.0 Design Provision in Indian Standard IS 456 : 2000 (Ref 8)

The reinforcement shall be any of the following:

- a) Mild steel and medium tensile steel bars conforming to IS 432 (Part 1).
- b) High strength deformed steel bars conforming to IS 1786 (Ref 9)
- c) Hard-drawn steel wire fabric conforming to IS 1566.
- d) Structural steel conforming to Grade-A of IS 2062.

In IS-1786 the physical properties of the high strength deformed bars are given in Art 7.1.

Art 7.1 Proof stress, percentage elongation and tensile strength for all sizes of deformed bars/wires determined on effective cross-sectional area (see 5.3) and in accordance with 8.2 shall be as specified in Table 3.

TABLE 3 MECHANICAL PROPERTIES OF HIGH STRENGTH  
DEFORMED BARS AND WIRES

Sr No	PROPERTY	GRADE		
		Fe 415	Fe 500	Fe 550
(1)	(2)	(3)	(4)	(5)
i)	0.2 percent proof stress/ yield stress, <i>Min</i> , N/mm <sup>1</sup>	415.0	500.0	550.0
ii)	Elongation, percent, <i>Min</i> , on gauge length 5.65 <i>l</i> / <i>A</i> <i>T</i> where <i>A</i> is the cross sectional area of the test piece	14.5	12.0	8.0
iii)	Tensile strength, <i>Min</i>	10 percent more than the actual 0.2 percent proof stress but not less than 485 N/mm <sup>2</sup>	8 percent more than the actual 0.2 percent proof stress but not less than 545 N/mm <sup>2</sup>	6 percent more than the actual 0.2 percent proof stress but not less than 585.0 N/mm

## 6.0 Design Provision of Minimum Reinforcement in Indian Standard IS:

In IS 456-2000, the minimum requirements of reinforcements for slabs are given in Sec 26.5.2.

### 26.5.2 Slabs

The rules given in 26.5.2.1 and 26.5.2.2 shall apply to slabs in addition to those given in the appropriate clauses.

26.5.2.1 Minimum reinforcement.

The mild steel reinforcement in either direction in slabs shall not be less than 0.15 percent of the total cross sectional area. However, this value can be reduced to 0.12 percent when high strength deformed bars or welded wire fabric are used.

26.5.2.2 Maximum diameter

The diameter of reinforcing bars shall not exceed one eight of the total thickness of the slab.

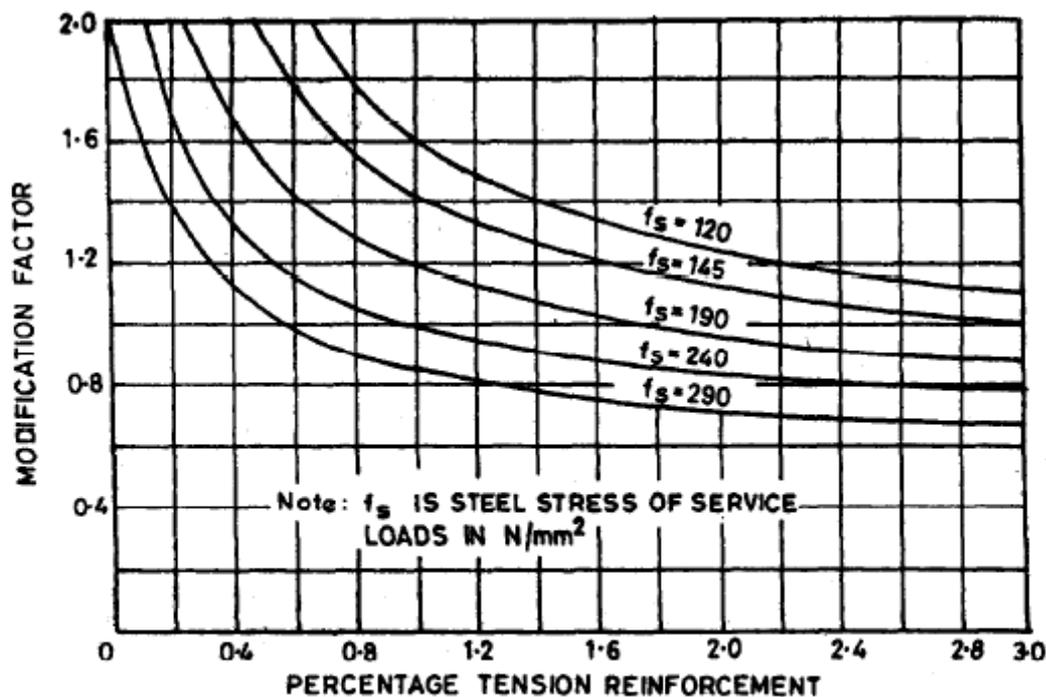
23.2.1 The vertical deflection limits may generally be assumed to be satisfied provided that the span to depth ratios are not greater than the values obtained as below:

a) Basic values of span to effective depth ratios for spans up to 10 m:

Cantilever	7
Simply supported	20
Continuous	26

b) For spans above 10 m, the values in (a) may be multiplied by  $l_0/\text{span}$  in meters, except for cantilever in which case deflection calculations should be made.

c) Depending on the area and the stress of steel for tension reinforcement, the values in (a) or (b) shall be modified by multiplying with the modification factor obtained as per Fig 4.



$$f_t = 0.58 f_y \frac{\text{Area of cross-section of steel required}}{\text{Area of cross-section of steel provided}}$$

FIG. 4 MODIFICATION FACTOR FOR TENSION REINFORCEMENT

c) Depending on the area of compression reinforcement, the value of span to depth ratio be further modified by multiplying with the modification factor obtained as per Fig. 5.

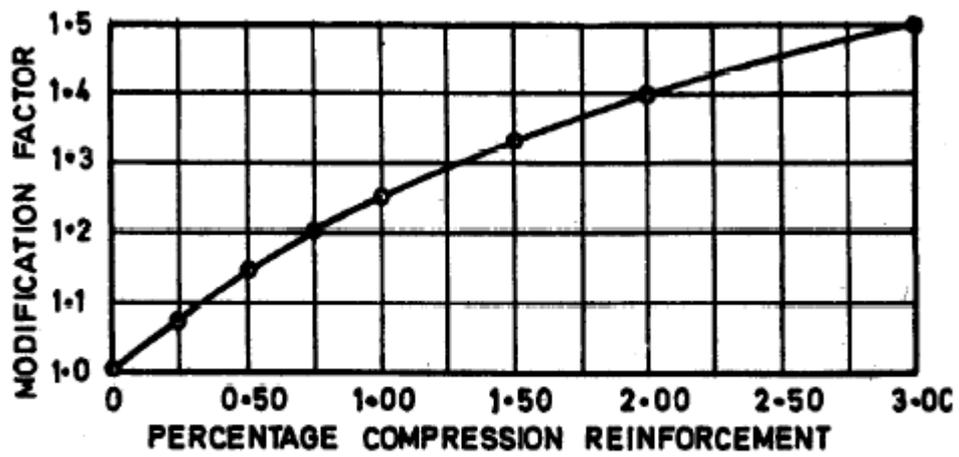


FIG. 5 MODIFICATION FACTOR FOR COMPRESSION REINFORCEMENT

## 7.0 Determination of Concrete and Steel Volume for Flat plate slab (Using ACI Code)

For estimation purpose of total steel, negative reinforcements at column strips are provided up to 0.3L from column supports and 25% of total negative steel are assumed continuous for seismic resistance. Negative reinforcements at middle strips are provided up to 0.22L from column supports.

<b>INTERIOR PANEL</b>				
	<b>Panel Size 18'-0"X18'-0" Column Size (24"X24")</b>		<b>Panel Size 26'-0"X26'-0" Column Size (24"X24")</b>	
<i>Sr No</i>	<i>60 Grade</i>	<i>75 Grade</i>	<i>60 Grade</i>	<i>75 Grade</i>
Slab Thickness (in)	6	6.5	9	9.5
Floor Finish (psf)	25	25	25	25
Partition Wall (psf)	50	50	47.5	47.5
Live Load (psf)	60	60	60	60
$W_u$ (psf)	276	283.5	318	325.5
$M_0$ (kip-ft)	158.98	163.3	595.3	609.34
Column Strip				
+M (kip-ft/ft)	3.71	3.81	9.62	9.846
-M (kip-ft/ft)	8.612	8.846	22.33	22.846
+As (in <sup>2</sup> /ft)	0.194	0.143	0.298	0.229
-As (in <sup>2</sup> /ft)	0.451	0.332	0.6916	0.53
Middle Strip				
+As (in <sup>2</sup> /ft)	0.1293	0.0953	0.199	0.153
-As (in <sup>2</sup> /ft)	0.1503	0.1107	0.256	0.177
As minimum (in <sup>2</sup> /ft)	0.1296	0.1092	0.1944	0.1596
Total Steel (cft)	1.6421	1.2404	4.446	3.8125
Total Steel (kg/sft)	1.1263	0.851	1.462	1.253
Total Concrete (cft)	162	175.5	507	535.16
Savings in Steel (%)	24.46		14.25	
Extra Concrete (%)	8.33		5.6	

## 8.0 Determination of Concrete and Steel Volume for Two Way slab (Using ACI Code)

For estimation purpose of total steel, positive reinforcements are assumed alternately cranked at supports and additional bars are provided up to 0.3L from supports for negative reinforcement.

<b>INTERIOR PANEL (CASE-2)</b>				
	<b>Panel Size 18'-0"X18'-0" Beam Size (12"X20") Column Size (24"X24")</b>		<b>Panel Size 26'-0"X26'-0" Beam Size (12"X24") Column Size (24"X24")</b>	
<i>Sr No</i>	<i>60 Grade</i>	<i>75 Grade</i>	<i>60 Grade</i>	<i>75 Grade</i>
Slab Thickness (in)	5	5.25	7	7.5
Floor Finish (psf)	25	25	25	25
Partition Wall (psf)	50	50	47.5	47.5
Live Load (psf)	60	60	60	60
+M (kip-ft/ft)	1.057	1.071	2.335	2.398
-M (kip-ft/ft)	2.297	2.332	5.039	5.218
+As (in <sup>2</sup> /ft)	0.101	0.077	0.1482	0.1124
-As (in <sup>2</sup> /ft)	0.219	0.1672	0.3212	0.2446
As minimum (in <sup>2</sup> /ft)	0.108	0.088	0.1512	0.126
Total Steel (cft)	0.81	0.63	2.448	1.9103
Total Steel (kg/sft)	0.556	0.432	0.805	0.628
Total Concrete (cft)	120.42	126.44	364.6	390.6
Savings in Steel (%)	22.3		22.0	
Extra Concrete (%)	5.0		7.1	

## 9.0 Determination of Concrete and Steel Volume for One Way slab (Using ACI Code)

For estimation purpose, panel dimensions 10' X 25' and 15' X 35' are considered for one-way slab. The slabs are assumed continuous on both sides. For other conditions, these values will be different.

<b>Both End Continuous</b>				
	<b>Span Length 10'-0"</b>		<b>Span Length 15'-0"</b>	
<b>Sr No</b>	<b>60 Grade</b>	<b>75 Grade</b>	<b>60 Grade</b>	<b>75 Grade</b>
Slab Thickness (in)	4.5	5.0	6.5	7.5
Floor Finish (psf)	25	25	25	25
Partition Wall (psf)	50	50	47.5	47.5
Live Load (psf)	60	60	60	60
+M (kip-ft/ft)	1.811	1.865	4.557	4.725
-M (kip-ft/ft)	2.817	2.90	7.088	7.35
+As (in <sup>2</sup> /ft)	0.124	0.089	0.193	0.136
-As (in <sup>2</sup> /ft)	0.193	0.138	0.300	0.211
As minimum (in <sup>2</sup> /ft)	0.097	0.084	0.1404	0.126
Total Steel (cft)	0.6524	0.434	2.092	1.60
Total Steel (kg/sft)	0.58	0.386	0.886	0.677
Total Concrete (cft)	93.75	104.17	284.375	328.125
Savings in Steel (%)	33.44		23.6	
Extra Concrete (%)	11.11		15.38	

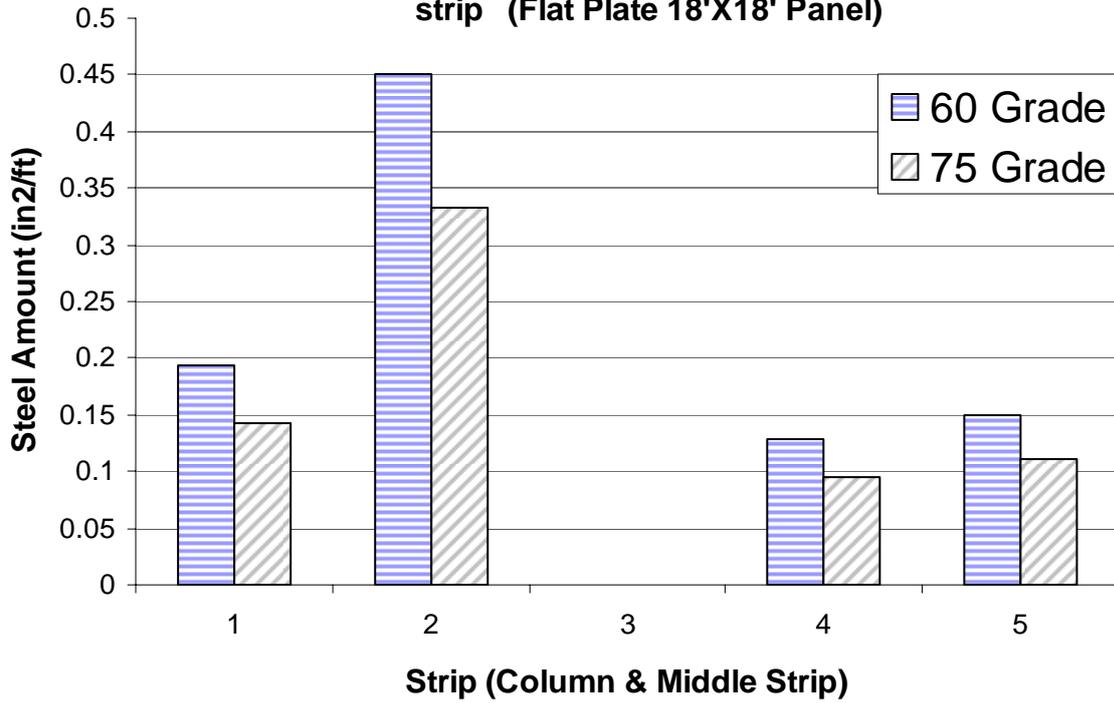
## 10. Concluding Remarks

Despite the potential benefits of higher strength reinforcement, there are still a number of important questions that have to be answered from design and production to fabrication and placement. From a design standpoint, all the current codes limit the allowable design strength to 80 ksi. By using higher strength steel in a number of different applications, overall project costs can be further reduced. By specifying 75 ksi rebar instead of conventional 60 ksi rebar in flat plate slabs, two-way slabs and one-way slabs, less steel is required. While the cost of the higher strength steel may be more than the conventional weaker bar, the steel savings offset the additional cost.

## References

1. Bob R. and Scott H., *High-Strength Reinforcing Steel: Next Generation or Niche?* Concrete Construction Magazine, January, 2008.
2. Bangladesh National Building Code (BNBC). HBRI & BSTI. December, 1993
3. Bangladesh Standard, *Specification for Steel bars and wires for The Reinforcement of Concrete*. Bangladesh Standard and Testing Institution. 116-A, Tejgaon Industrial Area. Dhaka-1208, Bangladesh. October 1992.
4. ACI Committee 318, *Building Code Requirements/or Reinforced Concrete*, ACI Standard 318-08; and the *Commentary on Building Code Requirements for Reinforced Concrete*, American Concrete Institute, Deemed to satisfy ISO 19338:2007(E)
5. American Society for Testing and Materials, *Standard Specification for Deformed and Plain Billet-Steel Bars for Concrete Reinforcement*, A 615/A 615M-96a, ASTM, Philadelphia, 1980, pp. 588-599.
6. American Society for Testing and Materials, *Standard Specification for Low-Alloy Steel Deformed Bars for Concrete Reinforcement*, A706-79, ASTM, Philadelphia, 1980, pp. 755-760.
7. Eurocode 2: *Design of concrete structures- Part 1: General rules and rules for buildings (Together with United Kingdom National Application Document)* DD ENV 1992-1-1:1992
8. IS 456 : 2000, Indian Standard, *Plain And Reinforced Concrete - Code Of Practice*, (Fourth Revision )
9. IS :1786 - 1985 (Superseding IS : 1139-1966, Rent Timed 1990), *Indian Standard Specification for High Strength Deformed Steel Bars and Wires for Concrete Reinforcement* (Third Revision), Third Reprint APRIL 1992

**Fig 1: Steel requirement (in<sup>2</sup>/ft) for Column and Middle strip (Flat Plate 18'X18' Panel)**



**Fig 2: Steel requirement (in<sup>2</sup>/ft) for Column and Middle strip (Flat Plate 26'X26' Panel)**

