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

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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).

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.

Design/material Provision in Bangladesh National Building Code (BNBC-93) (Ref 2,3)

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

Deformed reinforcing bar with a specified yield strength fy exceeding 410 N/mm2 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. (Art 5.3.2.2)

Yield strength of the reinforcement fy shall not be taken more than 550 N/mm^2. (Art 6.1.2.5)

The ultimate 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, as per Art.8 of BDS 1313: 1991 (Ref 3).

Limitations on materials for Seismic design:

Concrete in members resisting earthquake induced forces, fc' shall be not less than 20 N/mm^2

And reinforcing steel in members resisting earthquake induced flexural and axial forces in frames and wall boundary members shall comply with ASTM A706, ASTM A615 and BDS 1313. Reinforcement with fy = 275N/mm2 and fy = 410N/mm2 are allowed in these members if the following two conditions are satisfied.

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Actual fy $\leq$ specified fy + 125 N/mm2

$$\frac{\text{Actual ultimate tensile stress}}{\text{actual fy}} \geq 1.25$$

Provision for Materials in ACI Code (Ref 4)

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

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

(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 75000 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

Table 1 : Summary of minimum ASTM strength requirements

Product	ASTM Specification	Designation	Minimum Yield Strength, psi (MPa)	Minimum Tensile Strength, psi (MPa)
Reinforcing bars	A615	Grade 40 Grade 60 Grade 75	40,000 (280) 60,000 (420) 75,000 (520)	60,000 (420) 90,000 (620) 100,000 (690)
	A706	Grade 60	60,000 (420) [78,000 (540) maximum]	80,000 (550)[a]
	A996	Grade 40 Grade 50 Grade 60	40,000 (280) 50,000 (350) 60,000 (420)	60,000 (420) 80,000 (550) 90,000 (620)

a. But not less then 1.25 times the actual yield strength.

Deformed reinforcing bars shall conform to one of the ASTM specifications listed in 3.5.3.1, except that for bars with fy 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 (Art 3.5.3.2).

Limitation on Materials:

A minimum specified concrete compressive strength fc' of 3000 psi and a maximum specified reinforcement yield strength fy of 60,000 psi are mandated. These limits are imposed as reasonable bounds on the variation of material properties, particularly with respect to their unfavorable effects on the sectional ductilities of members in which they are used. A decrease in the concrete strength and an increase in the yield strength of the tensile reinforcement tend to decrease the ultimate curvature and hence the sectional ductility of a member subjected to flexure.

Chapter 21 requires that reinforcement for resisting flexure and axial forces in frame members and wall boundary element be ASTM A706 grade 60 low alloy steel, which is intended for application where welding or bending, or both, are important. However, ASTM A615 billet steel bars of grade 40 or 60 may be used in these members if the following two conditions are satisfied.

$$\text{Actual } f_y \leq \text{specified } f_y + 18{,}000 \text{ psi}$$

$$\frac{\text{Actual ultimate tensile stress}}{\text{actual } f_y} \geq 1.25$$

The first requirement helps to limit the magnitude of the actual shears that can develop in a flexural member above that computed on the basis of specified yield value when plastic hinges form at the ends of a beam. The second requirements in intended to ensure steel with a sufficiently long yield plateau.

In the “strong column-weak beam” frame intended by the code, the relationship between the moment strengths of columns and beams may be upset if the beams turn out to have much greater moment strengths than intended. Thus, the substitution of Grade 60 steel of the same area for specified Grade 40 steel in beams can be detrimental. The shear strength of beams and columns, which is generally based on the condition of plastic hinges forming at the ends of the members, may become inadequate if the moment strengths of member ends should be greater than intended as a result of the steel having a substantially greater yield strength than specified.

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).

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 (Art 9.5.3.2)

(a) Slabs without drop panels ....5 in.

(b) Slabs with drop panels...................................4 in.

For slabs with beams spanning between the supports on all sides, the minimum thickness, h, shall be as follows (Art 9.5.3.3)

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

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

and not less than 5 in.;

(c) For α_m greater than 2.0, h shall not be less than

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^3, 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 $(0.4 + f_y/100{,}000)$.

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

and not less than 3.5 in.;

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, ℓ_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 α_f for the edge beam shall not be less than 0.8.

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

BS Standard contains provision for 3 steel grades such as B500A, B500B & B500C all of 500MPa characteristic yield strength, but different ductility characteristics. The code pr EN 10080 allows Grade 500 steel.

Provisions for Cast in Situ Solid Slabs in EN code.

For a solid slab, the absolute minimum thickness is |50 mm|. (Art 5.4.3.1)

The maximum spacing of the bars is as follows (Art 5.4.3.2).

- For the principal reinforcement, |1.5h $\leq$ 350 mm|, where h denotes the total depth of the slab;
- For the secondary reinforcement, |2.5 h $\leq$ 400 mm|.

Provisions 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.

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.(Art 7.1)

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, *Min*, N/mm1	415.0	500.0	550.0
ii)	Elongation, percent, Min, on gauge length 5.65 *I/AT* where *A* is the cross sectional area of the test piece	14.5	12.0	8.0
iii)	Tensile strength, *Min*	10 percent more than the actual 0.2 percent proof stress but not less than 485 N/mm2	8 percent more than the actual 0.2 percent proof stress but not less than 545 N/mm2	6 percent more than the actual 0.2 percent proof stress but not less than 585.0 N/mm

Provisions of Minimum Reinforcement in Indian Standard:

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

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. (Art 26.5.2.1)

The diameter of reinforcing bars shall not exceed one eight of the total thickness of the slab. (Art 26.5.2.2)

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

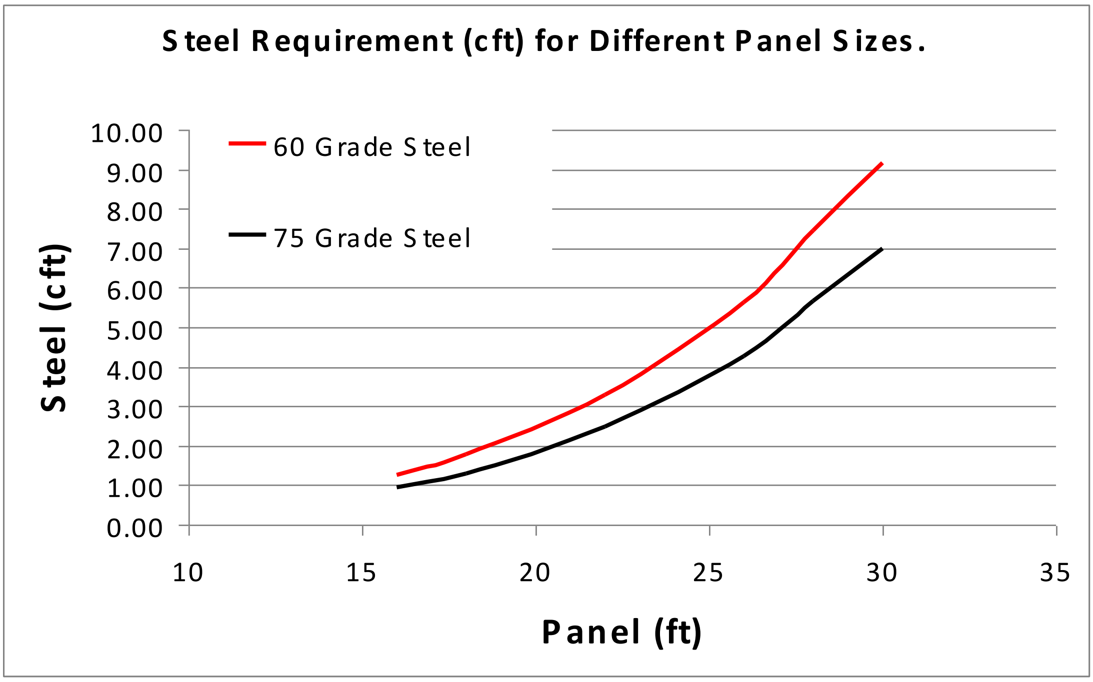
For estimation purpose of total steel, negative reinforcements at column strips are provided up to 0.3L from column supports and 25% of total negative steel are assumed continuous for seismic resistance. Negative reinforcements at middle strips are provided up to 0.22L from column supports.

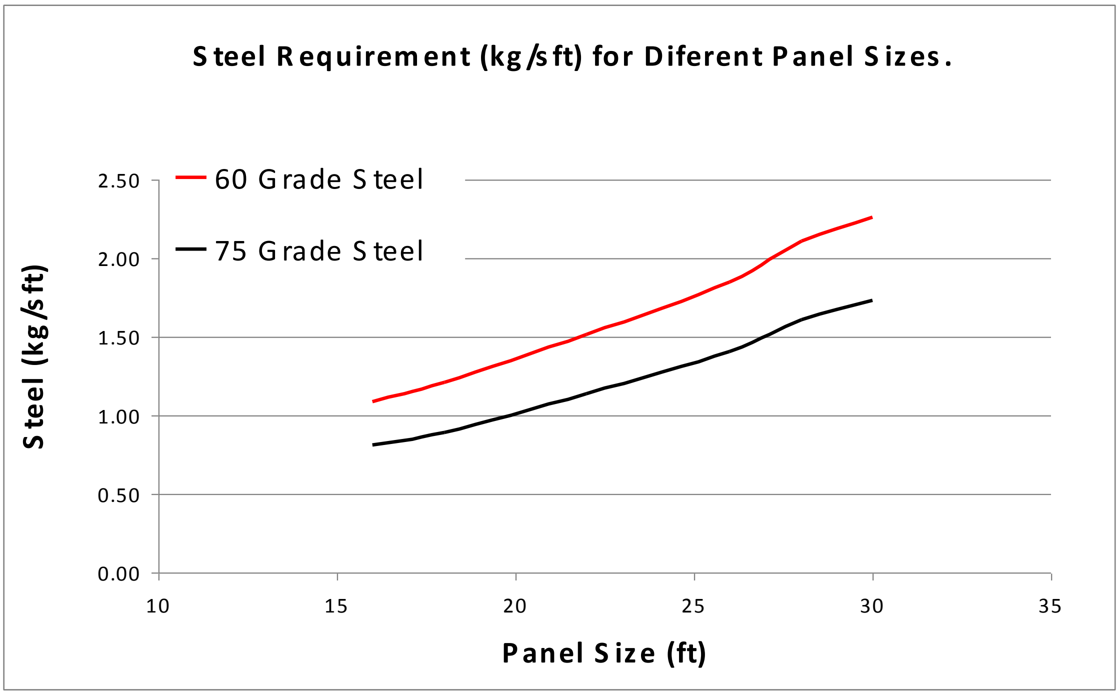
FLAT PLATE (60 Grade Steel)

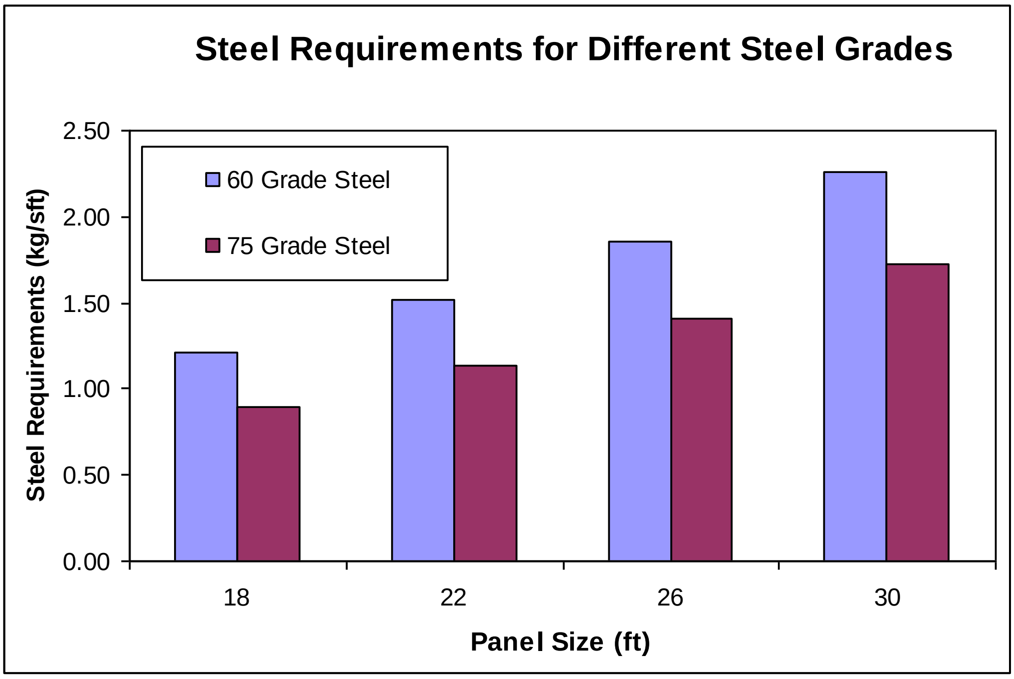
PANEL(ft)	STEEL(cft)	CONCRETE(cft)	STEEL(kg/sft)
16	1.25	110.75	1.09
18	1.77	160.23	1.21
22	3.30	299.20	1.52
26	5.63	501.37	1.85
28	7.45	613.22	2.11
30	9.14	778.36	2.26

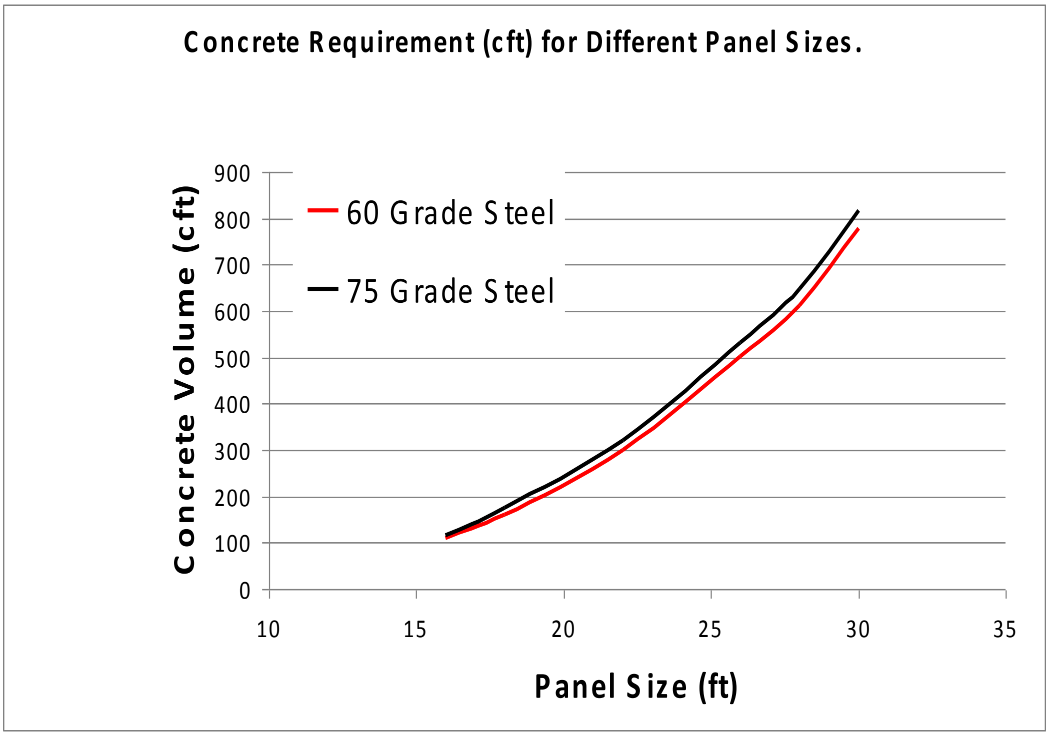
FLAT PLATE (75 Grade Steel)

PANEL(ft)	STEEL(cft)	CONCRETE(cft)	STEEL(kg/sft)
16	0.94	116.40	0.81
18	1.30	174.20	0.89
22	2.47	320.19	1.14
26	4.28	530.89	1.41
28	5.66	647.67	1.61
30	7.01	817.99	1.73


Steel Requirement (cft) for Different Panel Sizes.
60 Grade Steel
75 Grade Steel
Steel (cft)
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
10
15
20
25
30
35
Panel (ft)


Steel Requirement (kg/sft) for Diferent Panel Sizes.
60 Grade Steel
75 Grade Steel
Steel (kg/sft)
2.50
2.00
1.50
1.00
0.50
0.00
10
15
20
25
30
35
Panel Size (ft)


Steel Requirements for Different Steel Grades
Steel Requirements (kg/sft)
2.50
2.00
1.50
1.00
0.50
0.00
60 Grade Steel
75 Grade Steel
18
22
26
30
Panel Size (ft)


Concrete Requirement (cft) for Different Panel Sizes.
Concrete Volume (cft)
900
800
700
600
500
400
300
200
100
0
60 Grade Steel
75 Grade Steel
10
15
20
25
30
35
Panel Size (ft)

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

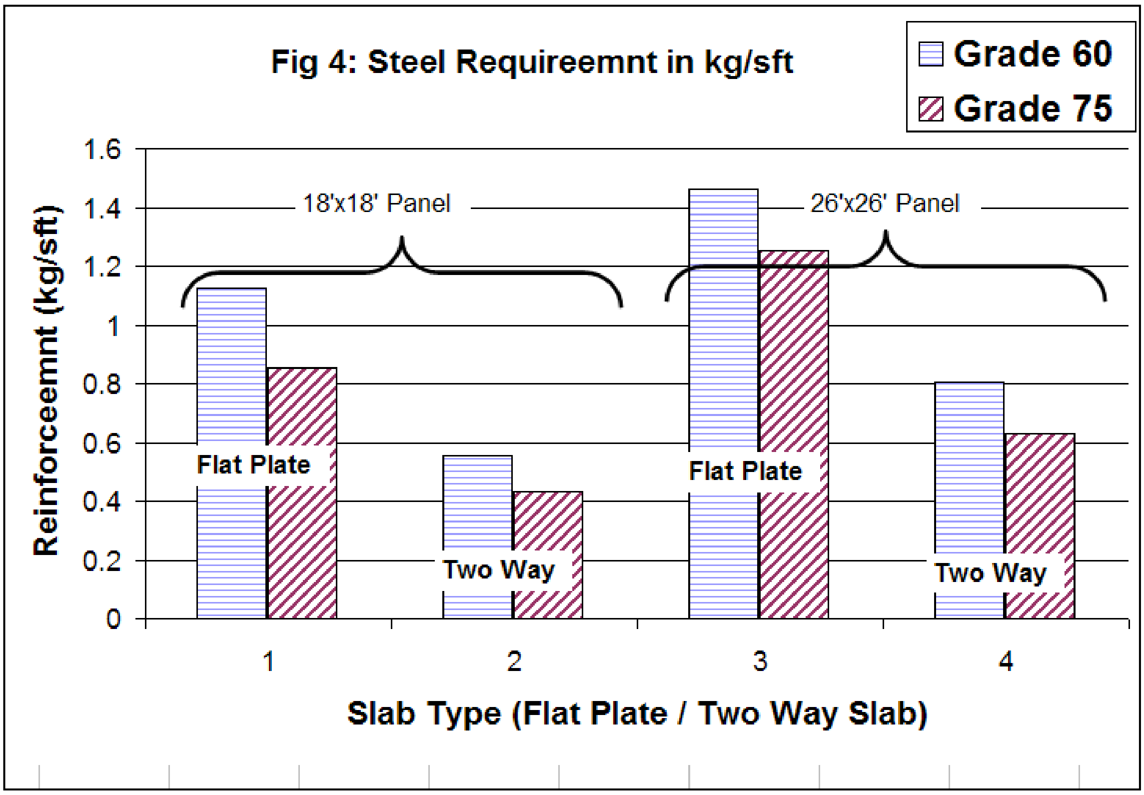
For estimation purpose of total steel, positive reinforcements are assumed alternately cranked at supports and additional bars are provided up to 0.3L from supports for negative reinforcement.

TWO WAY SLAB (18'X18' Panel)

Total Steel (cft)	*0.81*	*0.63*
Total Steel (kg/sft)	*0.556*	*0.432*
Total Concrete (cft)	*120.42*	*126.44*
Savings in Steel (%)	***22.3***	
Extra Concrete (%)	***5.0***	

TWO WAY SLAB (26'X26' Panel)

Total Steel (cft)	*2.448*	*1.9103*
Total Steel (kg/sft)	*0.805*	*0.628*
Total Concrete (cft)	*364.6*	*390.6*
Savings in Steel (%)	22	
Extra Concrete (%)	7.1	



Concluding Remarks

It has been found that Grade 500 steel is allowed as reinforcing bar in all national and international building codes and standards. From a design standpoint, all the current codes limit the allowable design strength of reinforcement to 80 ksi (550 MPa). Using Grade 500 steel instead of commonly available Grade 415 bars in the market, economy can also be achieved. Main advantage of using Grade 500 steel is to remove the steel congestion at beam column joint and in the foundation mat. However development length for Grade 500 steel is higher than development length for Grade 415 steel. To get maximum benefits from Grade 500 steel, higher strength concrete and good engineering judgments are required.

References

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