

# Comparative Study of Steel Requirements

Using 40, 60 & 72.5 ksi Deformed Reinforcing Bars  
For a Commercial Building

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## *Abstract*

*M/s mushtaq & bilal (M&B) Consulting Engineers* have conducted a comparative study to evaluate steel requirements of three different types of reinforcing bars, produced locally, for a commercial building.

The analysis was, therefore, carried out by designing a 12 storied office building, as per ACI Code 318-2005, using steel reinforcement conforming to:

- *ASTM A615-08*                      having yield strength ( $f_y$ ) = 40 ksi
- *ASTM A615-08*                      having yield strength ( $f_y$ ) = 60 ksi
- *BS 4449-2005*                      having yield strength ( $f_y$ ) = 72.5 ksi

All these grades of steel are permitted by the Code to be used in moderate seismic regions like Karachi and Lahore.

### **A. 12 Storied Building:**

The analysis and design of the typical office building with typical spans of 20 feet, where, *the concrete sections were kept constant for all options so that a reasonable comparison can be made*, indicate the following results:

- a. **Comparison between reinforcement conforming to BS 4449-2005 with  $f_y = 72.5$  ksi and ASTM A615-08 with  $f_y = 60$  ksi:**
  - 13% saving in quantum of steel.
  - 15% saving in cost.
  
- b. **Comparison between reinforcement conforming to BS 4449-2005 with  $f_y = 72.5$  ksi and ASTM A615-08 with  $f_y = 40$  ksi:**
  - 36% saving in quantum of steel.
  - 29% saving in cost.

### **B. Typical Slab of larger span:**

A typical slab of larger span (27'-6" c/c grid) was also analyzed and the results are as follows:

**a. Comparison between reinforcement conforming to BS 4449-2005 with  $f_y = 72.5$  ksi and ASTM A615-08 with  $f_y = 60$  ksi:**

- 17% saving in quantum of steel.
- 19% saving in cost.

**b. Comparison between reinforcement conforming to BS 4449-2005 with  $f_y = 72.5$  ksi and ASTM A615-08 with  $f_y = 40$  ksi:**

- 40% saving in quantum of steel.
- 34% saving in cost.

### **C. Deflections and crack width**

The concrete sections were selected on the basis of commonly used 60 ksi steel. The deflections and crack widths were therefore checked and found to be within the Code prescribed limits.

The study results, therefore, clearly indicate that the use of higher stress bars of  $f_y = 72.5$  ksi is considerably economical in terms of quantity of steel as well as cost of structures as compared to commonly used steel of  $f_y = 60$  ksi.

## ***Introduction***

The production of 500 MPa High Strength Deformed Bars (G500) conforming to the Specifications BS 4449-2005 with yield stress of 72.5 ksi has started in Pakistan. The usual steel reinforcement conforming to ASTM A615 with yield stress of 60 and 40 ksi has been produced since long. The price of steel bars with higher yield stress (G500) is, at present, lower than the price of commonly used steel reinforcement with yield stress of 60 ksi.

*M/s M&B* have compared the quantum of steel required for usual RCC building construction using three types of steel reinforcement available in the market. Accordingly, a typical 12 storied office building located in Karachi was designed using steel reinforcement conforming to BS-4449-05 with yield stress of 72.5 ksi and with ASTM A615 with yield stress of 40 and 60 ksi.

Complete structural analysis and design were carried out for the selected building as per ACI Code 318-2005. *The concrete sections were kept constant for all options so that a reasonable comparison can be made.* Additionally, a typical slab of larger span was also analyzed for comparison.

The ACI Code allows the use of higher stress bars in flexure and compression. As far as shear design is concerned, stress in ties is limited to 60 ksi, even for ties made of bars having higher yield stress.

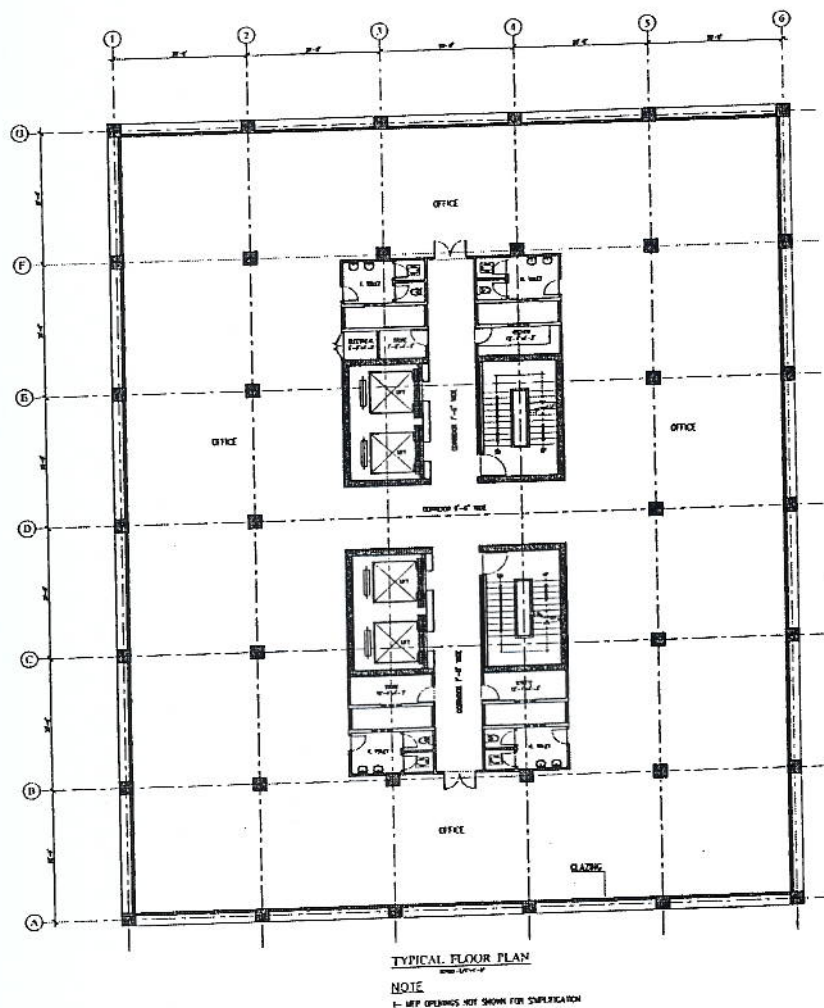
Selected samples of bars of higher strength, to be used for flexural/ compression design were tested at NED University of Engineering and Technology, Karachi to determine the stress at 0.35% strain.

The data used for the evaluation study including description of the building, typical loading, load combinations, properties of reinforcing bars etc. are subsequent part of this report.

## Building Description

The building used for comparison is a 12 storied RCC office building with central core containing elevators and stairs surrounded by office space. Major structural features of the buildings are as follows:

- Flat slab 6" thick
- Drop 6" thick
- Columns 24" square
- RCC shear walls 12" thick on typical floors.
- Floor area 12,445 sq. ft on all floors
- Total covered area 149,340 sq. ft
- Additionally a typical office building slab with 27'-6" span has been designed for comparison.



## Typical Loading

Following loadings were used for analysis:

### Dead Load

Self Weight of structure as per sectional sizes.

### Superimposed Dead Load

Floor Finishes	30 psf
Air-conditioning/False Ceiling	25 psf
Partition	30 psf
Peripheral Wall Load (8" thick)	90 lb/ft

### Live Load

Office floors 50 psf

\* Live Load reduction is done as per ANSI/ASCE7-88

### Lateral Loads

Wind Load

Forces auto-generated by software, wind speed set to 100 mph.

Seismic Load

Forces auto-generated by software for Zone 2B

## Load combinations

Following load combinations were used for analysis:

- 1-  $1.4D+1.7L$
- 2-  $1.2D+1.0L\pm 1.6W$
- 3-  $1.2D\pm 0.8W$
- 4-  $0.9D\pm 1.6W$
- 5-  $1.2D+1.0L\pm 1.0E$
- 6-  $0.9D\pm 1.0E$

Where:

D = Dead Load

L = Live Load

W = Wind Load

E = Earth quake load

## Reinforcement bars used for comparison

The reinforcing bars, manufactured locally, used for study are as follows:

- 1) As per ASTM A 615 with yield stress of 40 ksi, costing RS. 68,000/metric ton as on April 2012.
- 2) As per ASTM A 615 with yield stress of 60 ksi, costing RS. 77,500/metric ton as on April 2012.
- 3) As per BS 4449-05 with yield stress of 72.5 ksi, costing RS 75,500/metric ton as on April 2012.

ACI 318 -05 permits the design using steel reinforcement with a yield strength defined as the stress corresponding to a strain of 0.0035 (see ACI Code Requirement Table below), but not to exceed 80 ksi (552 MPa). The exception is transverse reinforcement where use of yield strength up to 100 ksi (690 MPa) is permitted, but may only apply to the requirements for confinement in compression members and not to requirements for shear, torsion, flexure or axial strength (Section 10.9.3, ACI 318-05).

Hence, design is done for grade 40 and 60 reinforcement used as flexure, compression, shear and torsion reinforcement, whereas the design with grade 500 steel (72.5 ksi) reinforcement is carried out using it for flexure and compression reinforcement. Stress in steel for shear is kept limited to 60ksi for Grade 500 steel (72.5 ksi).

The physical characteristics of the bars are as follows:

Physical Properties	ASTM A 615	BS 4449-2005	Grade 500 Steel <sup>1</sup>
$f_y$	60 ksi (min.)	72.5 ksi	72.5 ksi
$f_t$	90 ksi (min.)		
$f_t/f_y$	-	>1.15, <1.35	1.15-1.3
Elongation	60 ksi, 7-9% ; 75 ksi, 6-7%	min. 6-7.5%	11.5 to 16%*

\*Elongation at Max. Force measured after fracture.

### ACI Code Requirement:

ACI CODE REQMT	
MODERATE SEISMIC	DEFORMED BARS COMPLYING WITH A615 EXCEPT IF $F_y > 60$ , STRESS TO BE TAKEN AS .35% OF STRAIN
HIGH SEISMIC	A706 TO BE USED OR A615 IF, ACTUAL $F_y$ IS NOT EXCEEDING DESIGN $F_y$ BY MORE THAN 18KSI AND ACTUAL TENSILE TO YIELD STRENGTH RATIO IS GREATER THAN OR EQUAL TO 1.25

<sup>1</sup> Obtained from NED test results.

## *Analysis*

The analysis of the selected office building was carried out using ETABS (Extended Three Dimensional Analysis of Building Systems) version 9.1.6.

The critical output values are as follows:

1- Total dead load of structure	=	44,100 kips
2- Total Base Shear	=	3,294 kips
3- Max. Column Load	=	1,780 kips
4- Min. Column Load	=	412 kips
5- Bearing Capacity assumed (working)	=	2 tons/sft
6- Raft thickness	=	39 inch
7- Column reinforcement	=	1.4% max.

Since the concrete sections were selected on the basis of commonly used 60 ksi steel, the deflections and crack width were therefore checked and found to be within the Code prescribed limits.

## Quantities of Steel Reinforcement

The quantities were taken out for all the structural members and the results are tabulated below:

Items	Steel in Tons			Percentage Reduction <sup>2</sup>		
	40 ksi	60 ksi	72.5 ksi	40 ksi- 72.5 ksi	60 ksi - 72.5 ksi	40 ksi – 60 ksi
Slab	511	332	278	45.6%	16.3%	35%
Foundation	148	113	91	38.5%	19.5%	23.6%
Beams	75	54	51	32%	5.5%	28%
Columns	71	74	76	-7%	-2.7%	-4.2%
Walls	141	115	105	25.5%	8.7%	18.4%
<b>Total Steel</b>	<b>946</b>	<b>688</b>	<b>601</b>	<b>36.5%</b>	<b>12.6%</b>	<b>27.3%</b>
<b>Kgs/sq.foot</b>	<b>6.33</b>	<b>4.61</b>	<b>4.02</b>			
<b>Total Cost</b>	<b>Rs. 64.33 million</b>	<b>Rs. 53.30 million</b>	<b>Rs. 45.38 million</b>	<b>29.46%</b>	<b>14.86%</b>	<b>17.15%</b>
<b>Cost / sq.ft</b>	<b>Rs. 430.76</b>	<b>Rs. 356.90</b>	<b>Rs.303.87</b>	<b>29.46%</b>	<b>14.86%</b>	<b>17.15%</b>

<b>Total Covered Area</b>	149,340 sq. ft
<b>Concrete Volume</b>	172,770 cft, kept constant for all options
<b>Rate of 40 ksi Steel</b>	RS. 68,000 - April, 2012
<b>Rate of 60 ksi Steel</b>	RS. 77,500 - April, 2012
<b>Rate of 72.5 ksi Steel</b>	RS. 75,500 - April, 2012

The above comparison clearly indicates the advantages of using higher stress bars over the lower stress bars as anticipated. The major reduction is found in flexural members particularly with clear savings of the following order:

When Grade 500 is compared with Grade 40 steel:

- 36 % saving in the quantity
- 29% saving in the cost

When Grade 500 is compared with Grade 60 steel:

- 13 % saving in the quantity
- 15% saving in the cost

<sup>2</sup> Reduction in steel quantity and cost from use of steel of lower strength to steel of higher strength.

In addition, another typical slab with larger spans was also analyzed to compare reinforcing requirements using higher stressed bars conforming to BS 4449-05 ( $f_y = 72.5$  ksi) and the results demonstrate following clear savings:

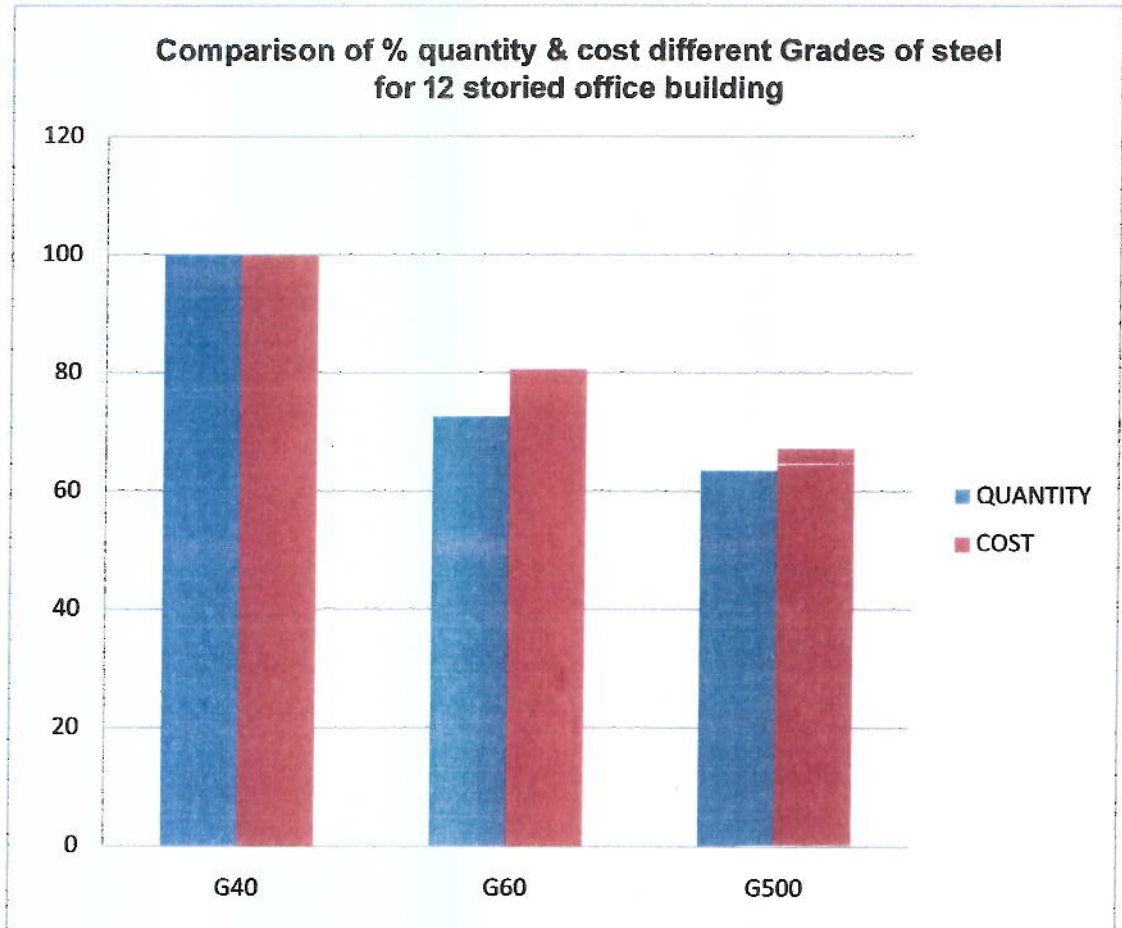
When Grade 500 is compared with Grade 40 steel:  
 40% saving in the quantity  
 34% saving in the cost

When Grade 500 is compared with Grade 60 steel:  
 17% saving in the quantity  
 19% saving in the cost

The below table shows the quantity of steel in a floor slab of larger span (27'-6" c/c span).

Item	Steel in tons			Comparison		
	40 ksi	60 ksi	72.5 ksi	72.5 ksi- 40 ksi	72.5 ksi- 60 ksi	60 ksi- 40 ksi
Quantity of Steel in Slab	736.2	530.6	439.5	40.3%	17.2%	28%
Total Cost	Rs. 50.06 million	Rs. 41.12 million	Rs. 33.18 million	33.72%	19.31%	17.86%

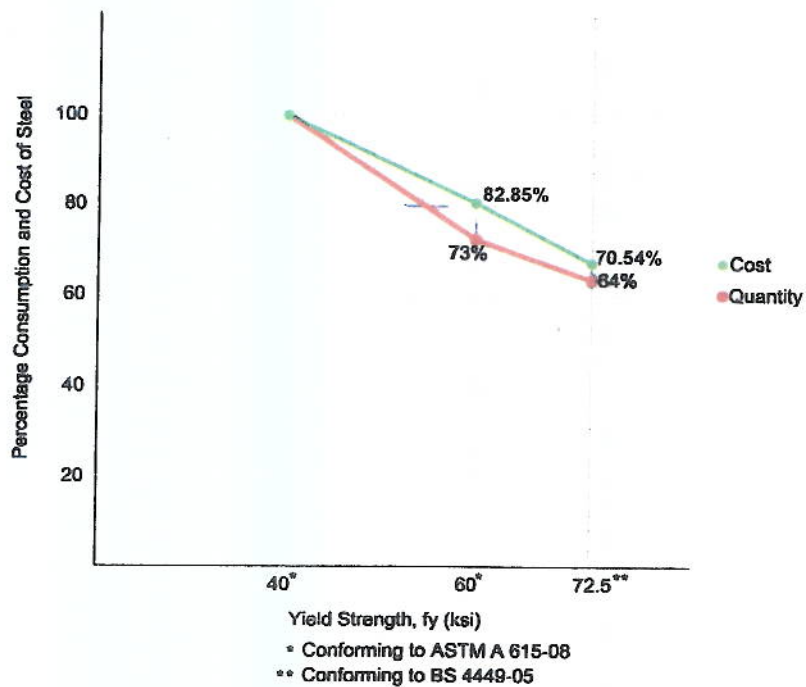
The following chart is illustrating the comparison results for quantity and cost when different types of grades are used for the same building configuration:



### **Conclusion**

The study for a 12 - storied RCC building, in which all concrete sections were kept uniform, clearly indicates that the use of higher stress bars of Grade 72.5 as permitted by the ACI Code, results in considerable savings in the quantities as well as the unit cost of structure as compared to commonly used steel of Grade 60 and 40 ksi. Savings of material and cost between the use of Grade 60 and 72.5 is likely to be in the range of 10-15%.

The following graph illustrates the comparison results for quantity and cost.



**COMPARISON OF QUANTITY AND COST  
USING VARIOUS GRADES OF STEEL  
FOR A 12- STORIED OFFICE BUILDING**

The concrete sections were based on the requirements of Grade 60 steel. The deflection and crack width were found to be within Code specified limits for all grades of steel for the span used.