Study on Grade 75 and 60 Reinforcement in RC design

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Abstract

In civil construction a variety of materials are in competition and this is initiating a continuous technological innovation. This innovation not only concerns the improvement of the materials themselves, but also results in the introduction of new technologies and methods for fabrication, joining and construction. At present Grade 75 (75 ksi, 525 MPa) steel is available for structural construction. In structural design the common practice is to use Grade 60. It is necessary to know about the advantages and disadvantages of Grade 75 steel over Grade 60. A structural engineer should have adequate knowledge about effect of Grade 75 steel in reinforced concrete design for an efficient and economical design. In this paper comparative study has been performed between Grade 75 and 60 steel for column and beam design. Column interaction diagrams and moment curvature diagrams have been drawn for same steel area for Grade 75 and 60 steel and with different concrete strength. Ultimate moment capacity of a beam section has been compared for Grade 75 and 60 steel. Design charts have been produced for Grade 75 and 60 steel with different steel ratio to have a clear idea about nominal moment capacity of rectangular section. From the serviceability point of view deflection controls the cross section area of a member. Deflection of a simply supported beam designed with Grade 75 and 60 steel has been compared. Development length of Grade 75 and 60 steel for different bar diameter have also been compared. Force-displacement characteristics of a structure are important for structural behavior under seismic load. Nonlinear pushover analysis has been performed for a portal frame designed with Grade 75 and 60 steel. A comparative study have been performed using Grade 75 and 60 steel to find the economical advantage, if any. It can be concluded that Grade 75 steel gives higher moment capacity thus reducing reinforcement requirement but at the same time deflection criterion must be taken care of. Ductility is less in higher grade steel than the lower grade. Concrete strength more than 4 ksi is recommended to get the full advantage of using Grade 75 steel.

Key words: Grade 75 and 60 steel, interaction diagram, moment curvature relation, ductility

1. Introduction

Steel has been established for more than 100 years as a construction material and the Eiffel Tower in Paris is a world-wide recognized example demonstrating not only impressively the merits of steel but also its impact on architectural creativity.

Probably the most relevant innovation for steel construction within the last century came with the introduction of welding as the major joining technology. Furthermore, the application of high strength steels supported the economics and the elegance of steel as well as reinforced steel concrete constructions. High rise buildings, car park decks, offshore platforms, ocean vessels, bridges, etc. demonstrate the widespread penetration of steel into concrete construction engineering.

In civil construction a variety of materials are in competition and this is initiating a continuous technological innovation. This innovation not only concerns the improvement of the materials themselves, but also results in the introduction of new technologies and methods for fabrication, joining and construction.

At present Grade 75 (75 ksi, 525 MPa) steel is available for structural construction. In structural design the common practice is to use Grade 60. It is necessary to know about the advantages and disadvantages of Grade 75 steel over Grade 60. A structural engineer should have adequate knowledge about effect of Grade 75 steel in reinforced concrete design for an efficient and economical design. In this paper comparative study has been performed between Grade 75 and 60 steel for column and beam design.

Column interaction diagrams and moment curvature diagrams have been drawn for same steel area for Grade 75 and 60 steel with different concrete strength. Ultimate moment capacity of a beam section has been compared for Grade 75 and 60 steel. Design charts have been produced for Grade 75 and 60 steel with different steel ratio to have a clear idea about nominal moment capacity of rectangular section. From the serviceability point if view deflection controls the cross section area of a member. Deflection of a simply supported beam designed with Grade 75 and 60 steel has been compared. Development length of Grade 75 and 60 steel for different bar diameter has also been compared. Force-displacement characteristic of a structure is important for structural behavior under seismic load. Nonlinear pushover analysis has been performed for a portal frame designed with Grade 75 and 60 steel. A comparative study have done for Grade 75 and 60 steel to find the economical advantage achieved from Grade 75 steel, if any.

2. Objectives

The main objectives of this study are

(i) to compare the column interaction diagrams constructed using Grade 75 and 60 steel with varying the concrete strength,

(ii) to find out the effect of Grade 75 steel over Grade 60 in beam moment capacity and deflection,

(iii) to compare the ductility between the two Grades.

3. Methodology

In this study ACI 2002 has been used code for every analysis. Deflection calculation is based on assumption that section is cracked transformed. Moment curvature relationship and nonlinear pushover analysis have been performed using finite element analysis software named, OPENSEES (ver.1.7.5). Development length for different bar diameter has been calculated using formula given in ACI 2002. The column design for the portal frame to investigate economical benefit has been done with PCACOLUMN (ver. V2.2) software.

4. Materials

Material constitutive laws that have been used in the OPENSEES analysis are shown in Figures 1 and 2. Parameters that have been used for various analyses are given in Table 1.

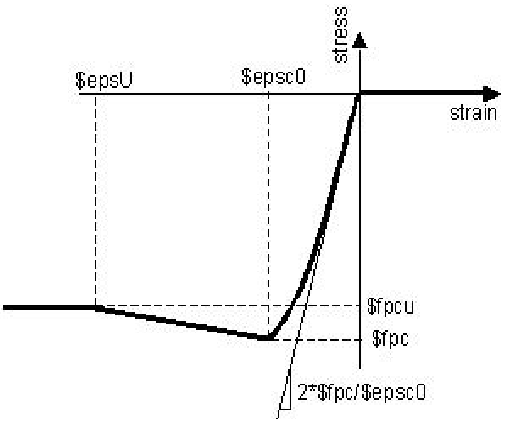


Figure 1 Constitutive law for concrete

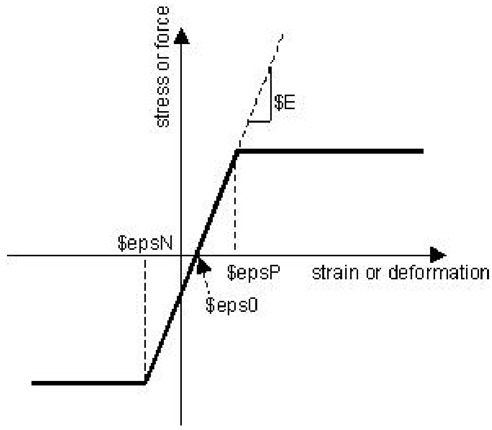


Figure 2: Constitutive law for steel

Table 1: Parameters used for the analysis.

Material	f'c(ksi)	ε_c	fu(ksi)	ε_u
Concrete	3	0.002	1.05	0.003
	3.5	0.002	1.225	0.003
	4	0.002	1.4	0.003
	5	0.002	1.75	0.003
	7	0.002	2.45	0.003

Material	Grade	fy (ksi)	E (psi)
Steel	60	60000	29000000
	75	75000	29000000

5. Results

5.1 Column Interaction diagrams

Column interaction diagrams have been plotted for the material properties given in Table 1. Column interaction diagrams of Grade 75 and Grade 60 steel is shown in Figure 3(a) for 3, 5 and 7 ksi concrete.

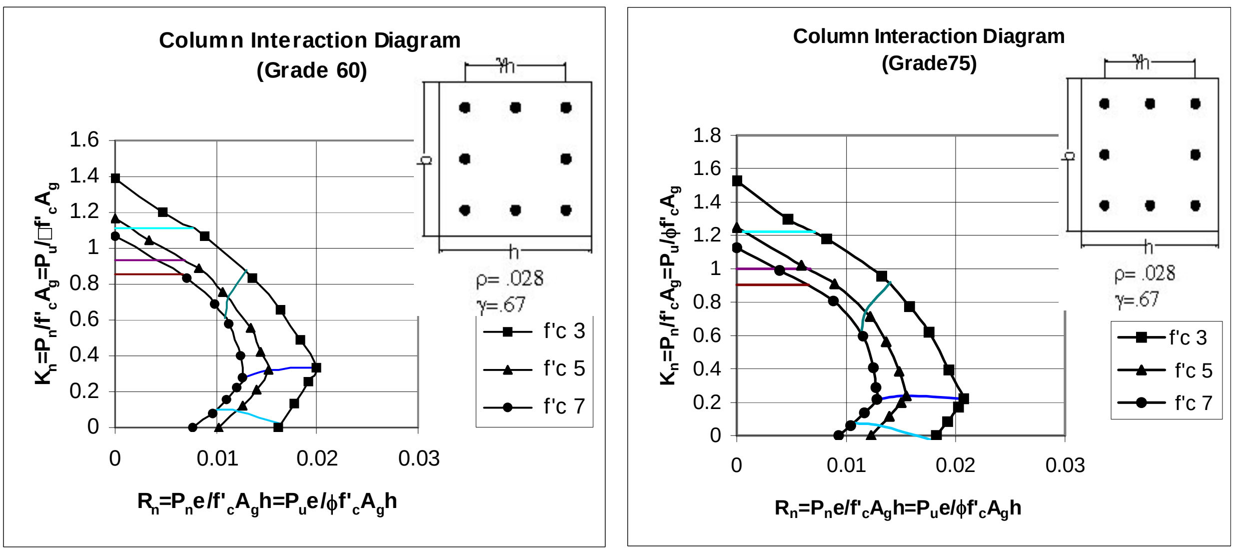


Figure 3 (a): Column interaction diagrams for Grade 75 and 60 reinforcement

Designers need uni-axial column interaction curves for column design. Currently no column interaction diagrams are available for Grade 75 steel. In this paper efforts have been made to prepare some column interaction charts for designers. Some typical design charts for uni-axial column design are given below (Figure 3(b)). Complete charts will be published in next publication.

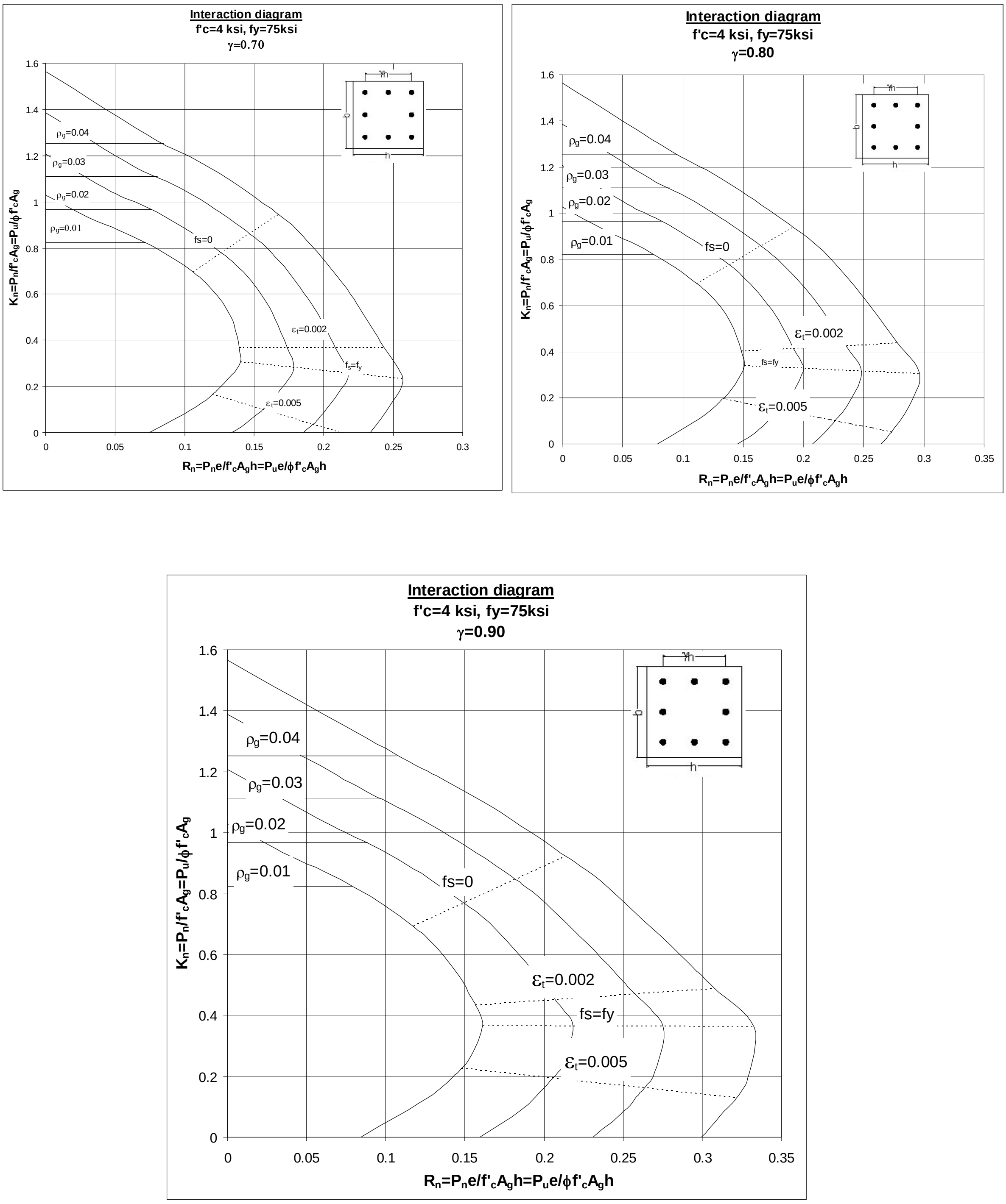
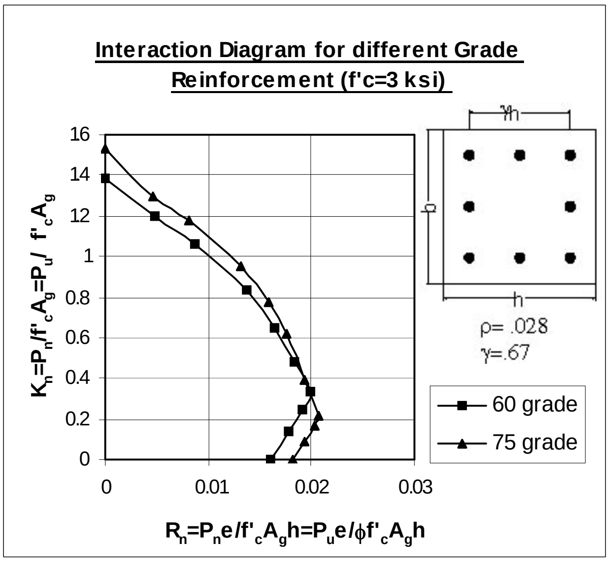
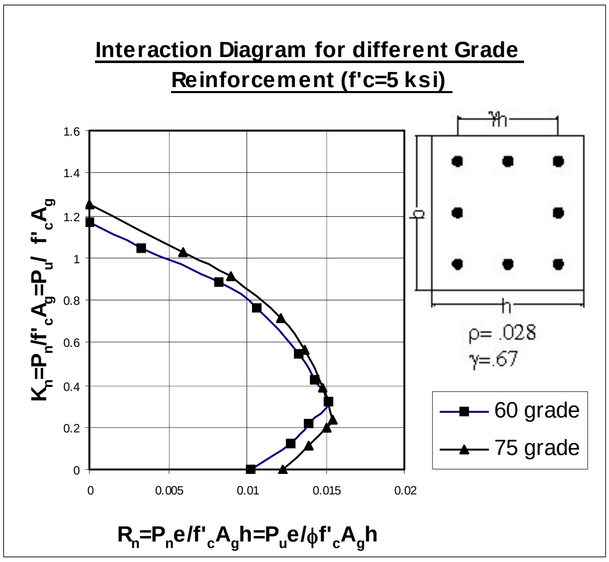


Figure 3 (b): Column interaction diagrams for Grade 75 and 60 reinforcement

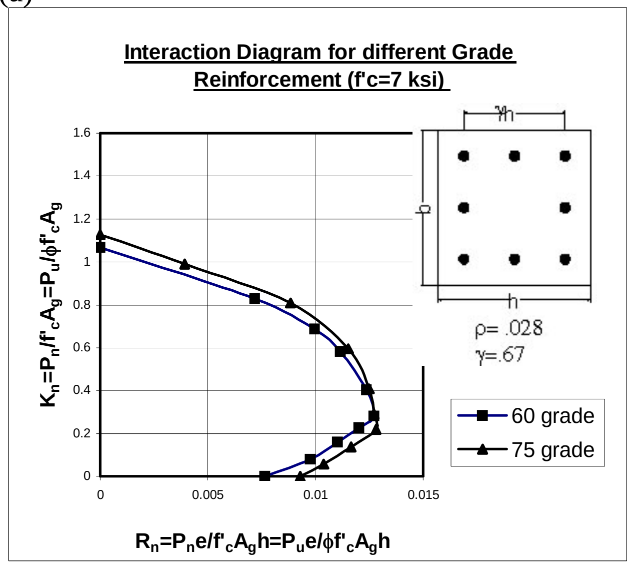
Same interaction diagram have been redrawn to compare the difference between Grade 75 and Grade 60 steel for a particular concrete strength. Capacity of column increases if Grade 75 steel is used (Figure 4). From these figure very little benefit will be derived if the column has been design near the balanced steel ratio.



(a)



(b)



(c)

Figure 4: Variation of column interaction diagram for Grade 75 and 60 reinforcement using different concrete strength

5.2 Congestion relief

So far, the main demand for high strength reinforcing steel has been in seismic areas on the West Coast of USA where congestion (Figure 5) issues, especially at beam-column intersections continue to plague rebar placing and design. A recent 31-story condominium project in Seattle proved the potential benefits of 100 ksi reinforcing steel in just such a situation. "Typical spacing of the confinement steel in the columns is 4 to 5 inches using standard Grade 60 #4 bars," says Brian Booth of Harris Rebar Seattle Inc., Tacoma, Wash. "This creates severe congestion issues at the intersection areas. By switching to #5 bars made of Grade 100 steel, the spacing increased to between 8 to 12 inches, allowing faster construction and easier placement of the concrete."

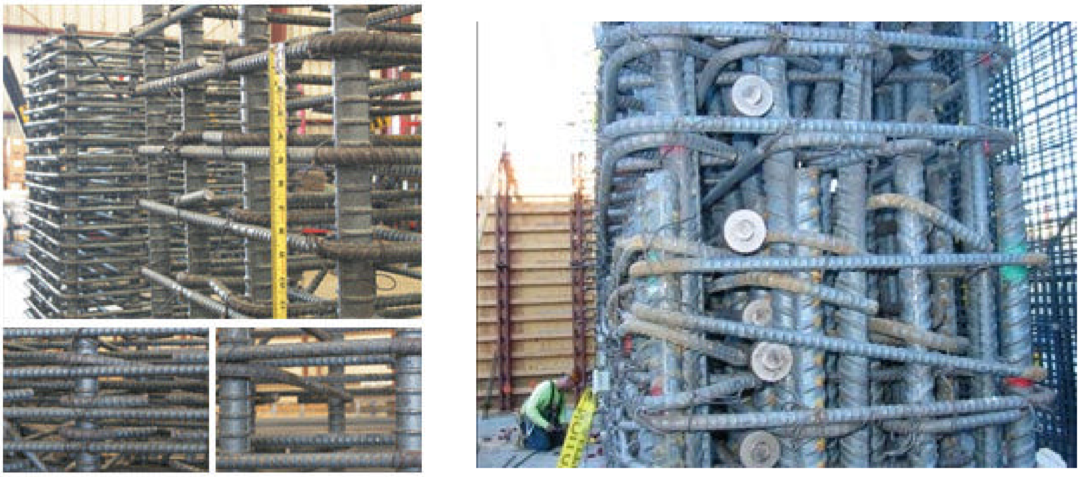


Figure 5: Reinforcement congestion relief

5.3 Moment Capacity

Variation of Moment capacity has also been computed using Grade 75 and 60 steel. Figure 6 shows the ultimate moment capacity of rectangular beam designed with different grade steel and different concrete strength. It has been found that moment capacity is increased significantly.

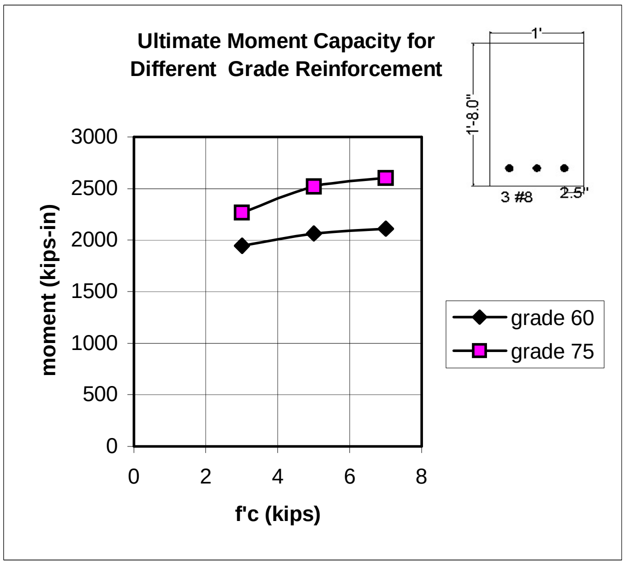


Figure 6: Moment capacity for rectangular beam using Grade 75 and 60 reinforcement

From Figure 7 it can be observed that for same percentage of steel beam with Grade 75 gives higher **R** value than Grade 60 steel, which will eventually reduce the steel requirement if the depth of the beam kept constant. It has been observed that due to less steel area requirement the deflection may increase.

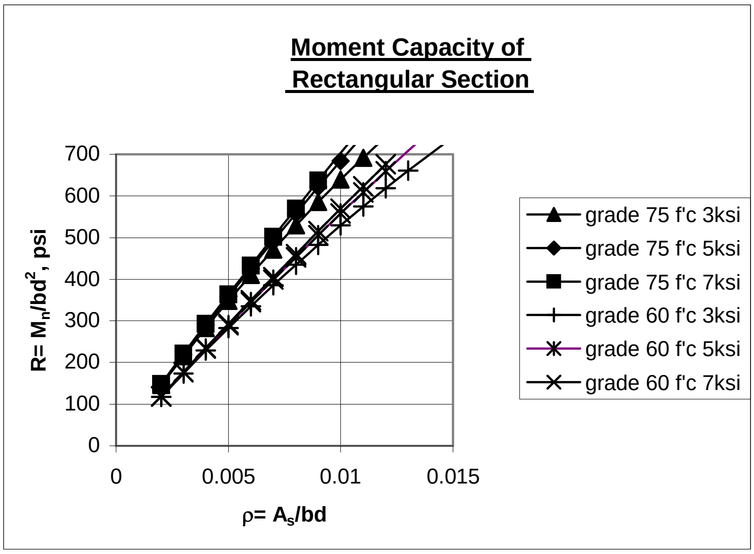


Figure 7: **R** value for Grade 75 and 60 reinforcement

5.4 Deflection of Beam

For the beam shown in Figure 8 deflection at ultimate stage has been calculated using OPENSEES. The simply supported beam has been used for calculate deflection. Figure 9 shows the variation of deflection for Grade 75 and Grade 60 steel. The comparison shows that deflection is higher when Grade 75 steel is used.

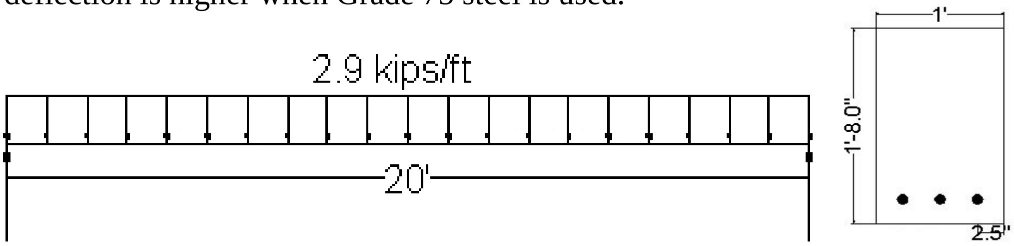


Figure 8: Schematic of beam used for deflection calculation

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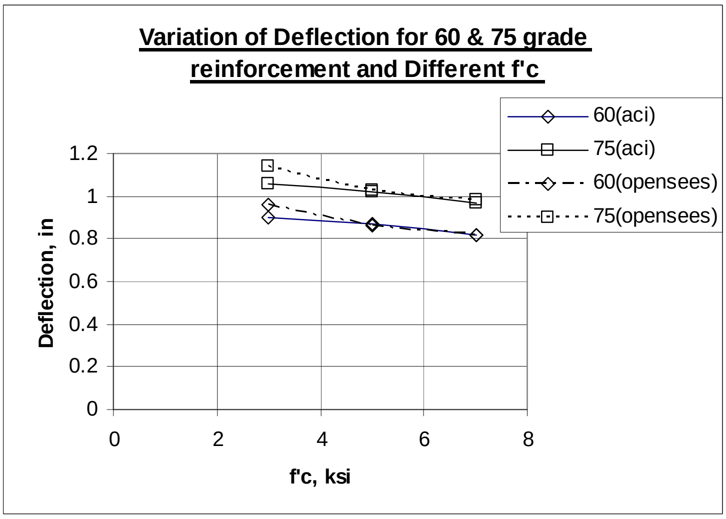


Figure 9: Beam deflection

5.5 Pushover analysis

Pushover analysis is very important for performance based design. Pushover analysis has been performed for a simple portal frame (Figure 10) using Grade 75 and Grade 60 steel. Result of the pushover analysis has been given in Figure 11. It can be seen from the figures that Grade 75 produces larger lateral deformation for Grade 75 steel than Grade 60 steel. It can be concluded that strength and stiffness both decreased with the introduction of Grade 75 steel.

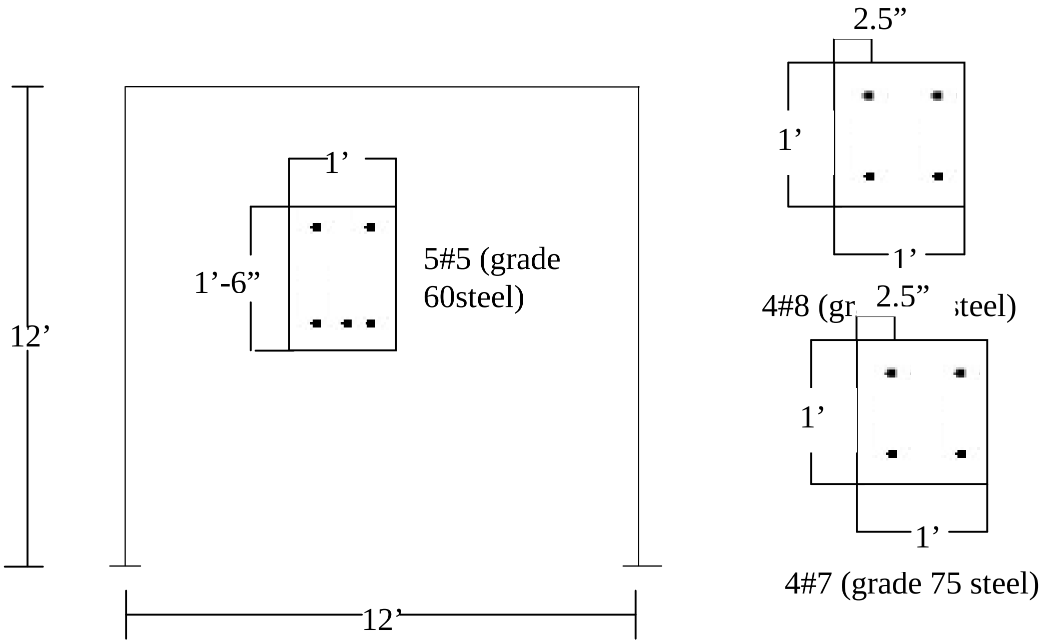
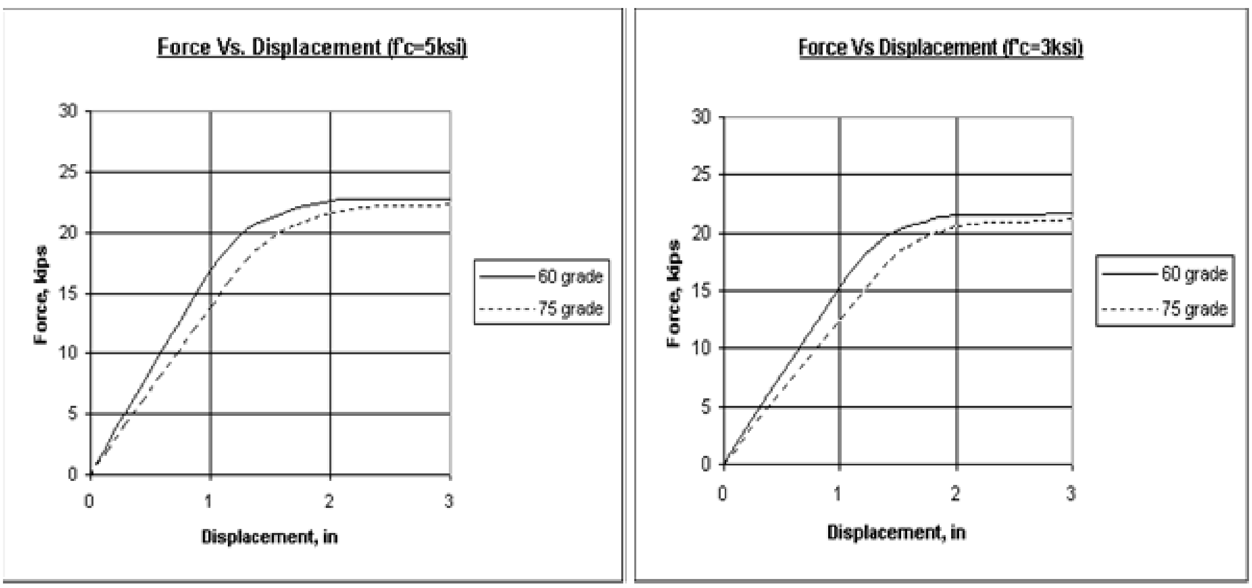


Figure 10: Portal frame used for pushover analysis

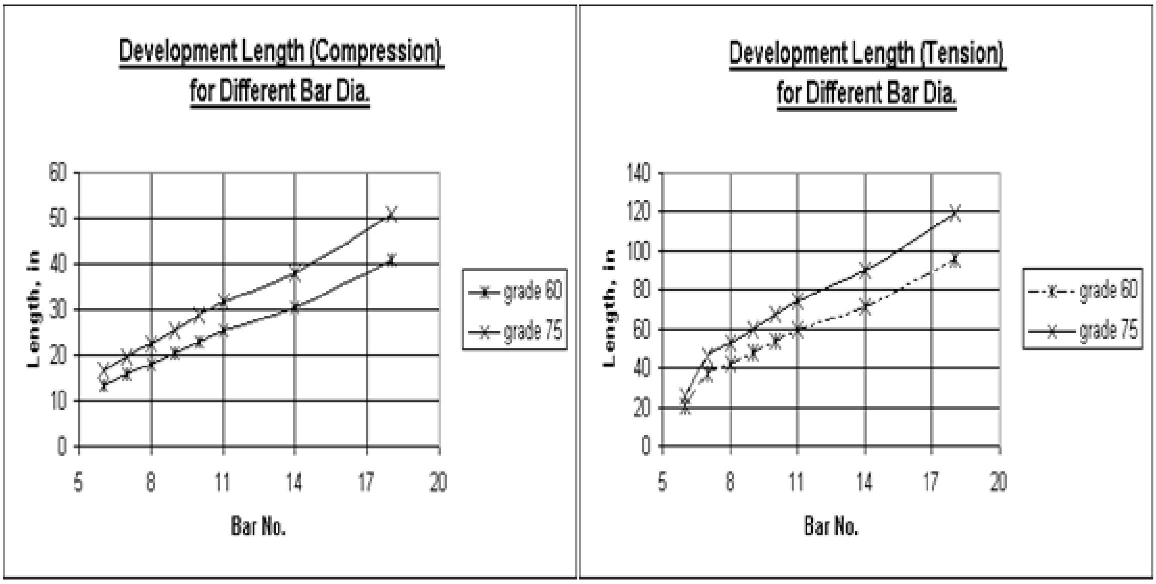


(a) (b)

Figure 11: Force deflection curves from pushover analysis

5.6 Development Length

Figure 12(a) and Figure 12(b) show the difference in development length for Grade 75 and 60 steel having different bar diameter. Development length for Grade 75 steel is higher than development length for Grade 60.



(a) (b)

Figure 12: Development length diagrams for Grade 75 and 60 reinforcement

5.7 Moment Curvature Relationship

Moment curvature relationship (Figure 13) for a particular cross section is very important because information of ductility can be inferred from that. It can be said from the figure that ductility increases with the increase of concrete strength. Low grade concrete behaves poorly with high grade steel.

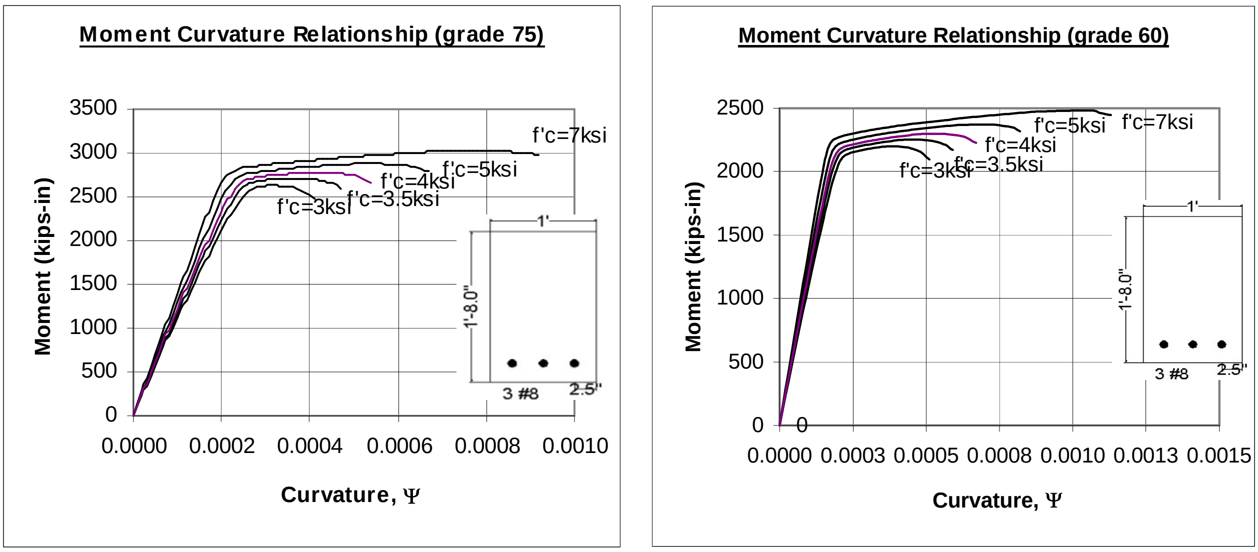


Figure 13: Moment curvature diagrams for Grade 75 and 60 reinforcement

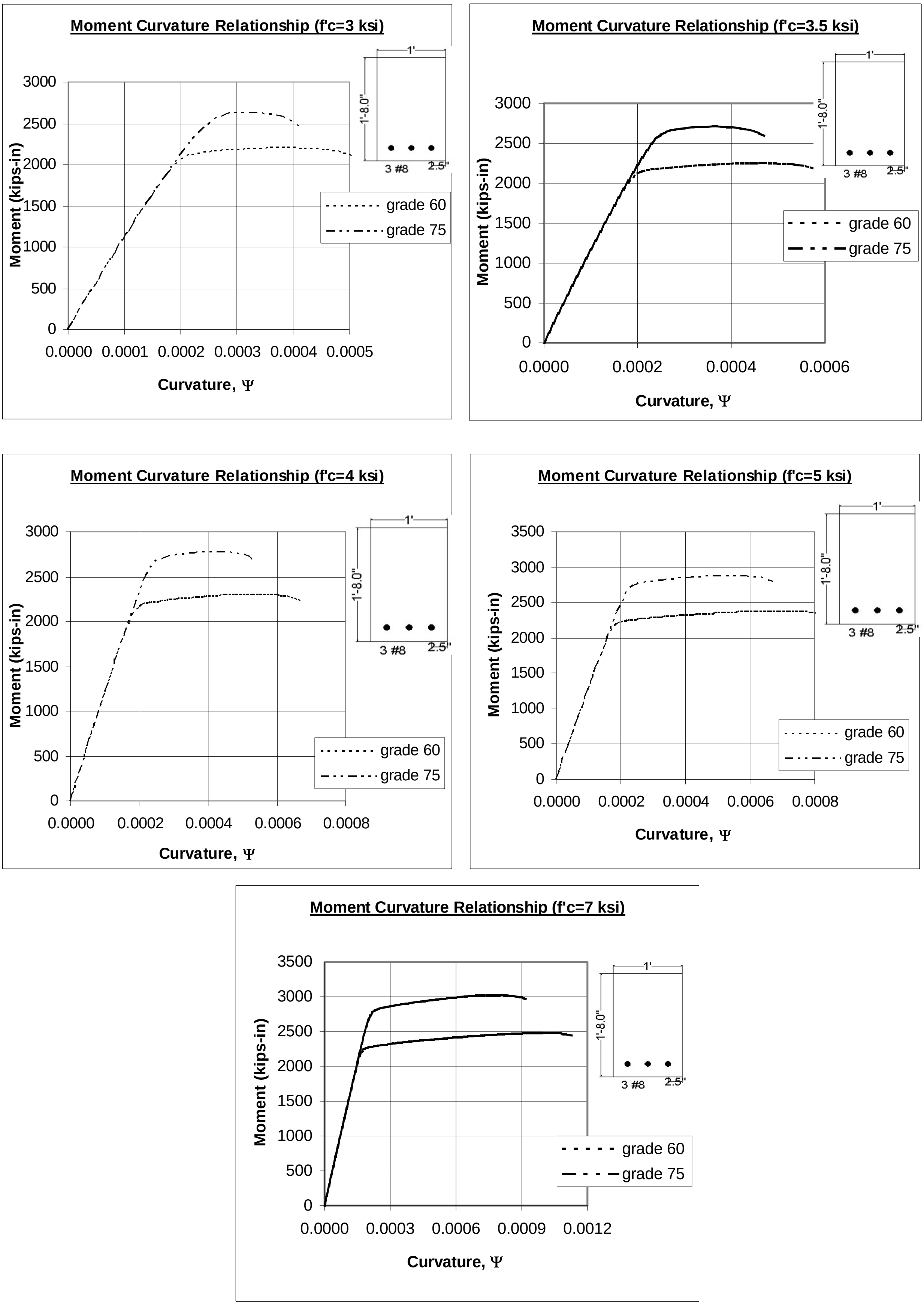


Figure 14: Moment curvature diagrams for Grade 75 and 60 reinforcement

From Figure 14 it can be said that for any concrete grade, high grade steel (Grade 75) gives lower ductility than low grade steel (Grade 60).

5.8 Economic Benefit

5.8.1 Column

To investigate economic benefit from Grade 75 steel, a column section having dimension of 12x12 in has been designed for factored moment M_u =30 kips-ft and a factored load P_u = 330 kips with both Grade 75 and 60 steel. The steel requirement has been found 4#8 bar for Grade 60 steel and 4#7 bar for Grade 75 steel (Figure 15)

Figure 15: Cross section used for beam design

The ratio of reinforcement required by Grade 75 to 60 = (.79*4/.6*4)

= 0.76 =76%

i.e. steel required by Grade 75 is 76% of steel required by Grade 60 steel.

5.8.2 Beam

For a beam it is known that, $M_n = A_s * f_y * (d-a/2)$

Beam with Grade 60 steel,

$M_n = A_{s60} * f_{y60} * (d-a/2)$ (1)

Beam with Grade 75 steel,

$M_n = A_{s75} * f_{y75} * (d-a/2)$ (2)

From Equation (1) and (2)

$A_{s75} = (f_{y60/} f_{y75}) * A_{s60}$

$A_{s75} = 0.8*A_{s60}$

It can be said ignoring all other requirement, only from flexural requirement 20% steel can be saved by using Grade 75 steel.

6. CONCLUSIONS

It has been found that Grade 75 steel have some advantages over Grade 60 steel except in development length and deflection of beam and ductility. Economy may also be achieved by using Grade 75 steel. Main advantage of using Grade 75 steel is to remove the steel congestion at beam column joint. To get maximum benefits from Grade 75 steel good engineering judgments are required. Steel is a very versatile material for construction. With increasing yield strength of material cost reductions can be achieved for high rise buildings. Low rise buildings may not produce cost reduction using Grade 75 steel. Another important factor is concrete strength. Concrete strength more 4 ksi is recommended to achieve the added benefit by introducing the Grade 75 steel. Proper supervision in the concrete construction site is required for these purposes. These benefits can be applied only if the construction is safe. Actual design codes allow safety considerations to avoid brittle fracture based on fracture mechanics and using small test samples.