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Effect of Steel Strength on Sectional Ductility and Moment Capacity of Reinforced Concrete Section

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ABSTRACT

Frequent occurrence of recent earthquakes in South Asian region has inspired the civil engineers to become more concern about earthquake resistant building design. In order to construct a building in a high seismic zone, the flexural members like beams, must have adequate ductility along with enough strength. Ductility is a solid material's ability to deform under tensile stress. To evaluate the flexural ductility, it is necessary to conduct non-linear moment-curvature experiment or numerical analysis. Moment curvature is a method to determine the load-deflection behavior of a concrete section using nonlinear material stress-strain relationship. As experimental analysis is time consuming and costly, a quicker and cheaper approach numerical analysis can be performed. In this paper, results of a numerical program conducted on sectional ductility behavior of a rectangular concrete beam are presented. Eighteen cross sections, with three different reinforcement ratio (0.007, 0.010 and 0.013), two different yield strength of reinforcement (400MPa-nominal strength steel and 500MPa-high strength steel) and three different concrete compressive strengths (25MPa, 30MPa and 35MPa) have been built and analyzed. An effort is made to order the performance of the samples according to moment capacity and ductility. From the program it has been observed that, moment capacity is higher in highly reinforced section. But more ductility is obtained from a lower reinforced high strength steel beam. The use of higher strength steel helps to maintain minimum level of flexural ductility along with higher flexural strength. It also leads to reduce construction cost by reducing dimension of a concrete section and by reducing steel requirement.

Introduction

The most fundamental requirement in predicting the moment-curvature behavior of a member is the knowledge of the behavior of its constituents [1, 2]. With the increasing use of higher-grade concretes, the ductility of which is significantly less than normal concrete [3], it is essential to confine the concrete. Ductility may be defined as the ability to undergo deformations without a substantial reduction in the flexural capacity of the member [4]. This deformability is influenced by some factors such as the tensile reinforcement ratio, the amount of longitudinal compressive reinforcement, the amount of lateral tie and compressive strength of concrete reinforced concrete members [7, 8, 9, 10]. Design offices will be faced more and more with the need of predicting the deformation capacity of concrete members. A general approach to account for confinement of concrete and predicting the flexural behavior of concrete member is needed. Many experiments were conducted on predicting moment curvature behavior of steel [11, 12, 13, 14, 15, 16]. But all of them are expensive and lengthy. So numerical analysis is preferable to determine moment curvature and ductility of reinforced concrete member section. The results of a numerical analysis on eighteen sections, with three different reinforcement ratio, two different yield strength of reinforcement and three different concrete strengths have been built and analyzed. The main objective was to compare moment-curvature behavior of both high strength and nominal strength steel from numerical analysis. An optimum steel ratio, steel strength and compressive strength of concrete is also suggested through this paper in order to achieve a minimum level of ductility and flexural strength.

Software Program

Response 2000 software developed by Evan C. Bentz [17] was used in this study. Eighteen beam sections (300mmx375mm) were modeled for three different compressive strength of concrete of 25 MPa, 30 MPa and 35 MPa. Also two different type of yield strength of longitudinal and transverse steel was evaluated as 400MPa (in cases of nominal strength steel) and 500Mpa (in cases of high strength steel). Three different reinforcement ratios (0.007, 0.010 and 0.013) were also selected. Clear cover of beam section was kept constant as 25mm. Spacing of transverse reinforcement

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were set aside as 150 mm. For longitudinal compressive reinforcement and transverse reinforcement, 10 mm diameter reinforcing bar were utilized.

Result Analysis

Moment-curvature curves of the beam sections programmed are plotted through Figures 1 to 3. It can be observed that the moment-curvature curves are almost linear before the peak moment is reached and there is a quite long yield plateau at the post-peak phase. From moment-curvature relation information about flexural strength, flexural stiffness and more importantly flexural ductility can be extracted. Numerical results may be used for further analysis as experiment conducting is always not feasible and also costly.

Moment Capacity

From figures 1 to 3 it is found that, for a fixed concrete strength, the moment capacity and flexural stiffness is higher for a high strength steel beam section than nominal strength steel beam section. Maximum moment capacity or flexural stiffness (around 180 kN-m) was obtained from highest steel ratio 0.013 and high strength steel (fy=500 MPa) section for compressive strength 35 MPa of concrete (Figure 3(f)). Minimum moment capacity or flexural stiffness (around 90 kN-m) was achieved from lowest steel ratio 0.007 and nominal strength steel (fy=400 MPa) section for compressive strength of 25 MPa of concrete (Figure 1(a)). In cases of particular compressive strength, more flexural strength was obtained from high strength steel (Figures 1(a) and 1(d), 1(b) and 1(e), 1(c) and 1(f), 2(a) and 2(d), 2(b) and 2(e), 2(c) and 2(f), 3(a) and 3(d), 3(b) and 3(e), 3(c) and 3(f)). The initial slope of moment curvature curve is steeper in cases of lower steel ratio.

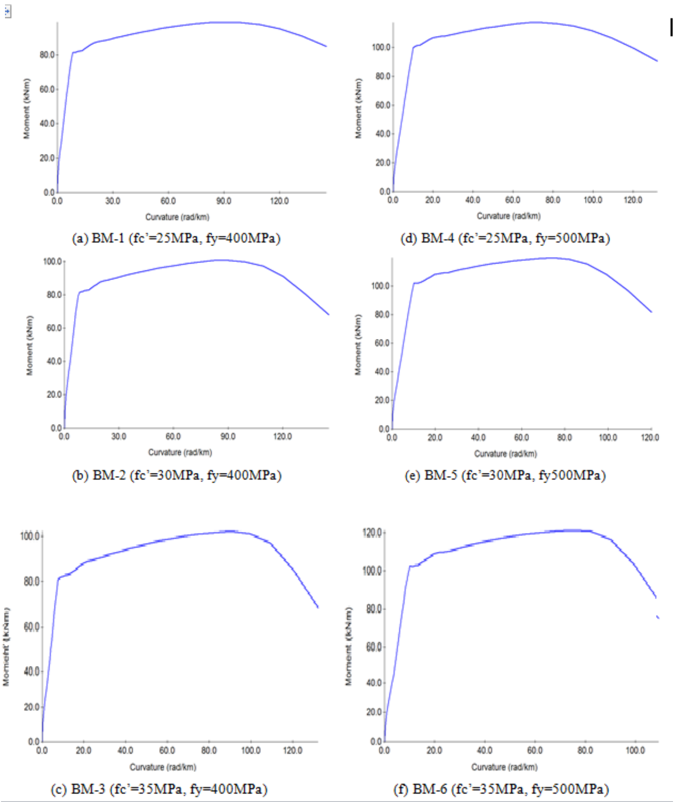

Figure 1. Moment Curvature of Beam Sections for Steel Ratio ρ= 0.007

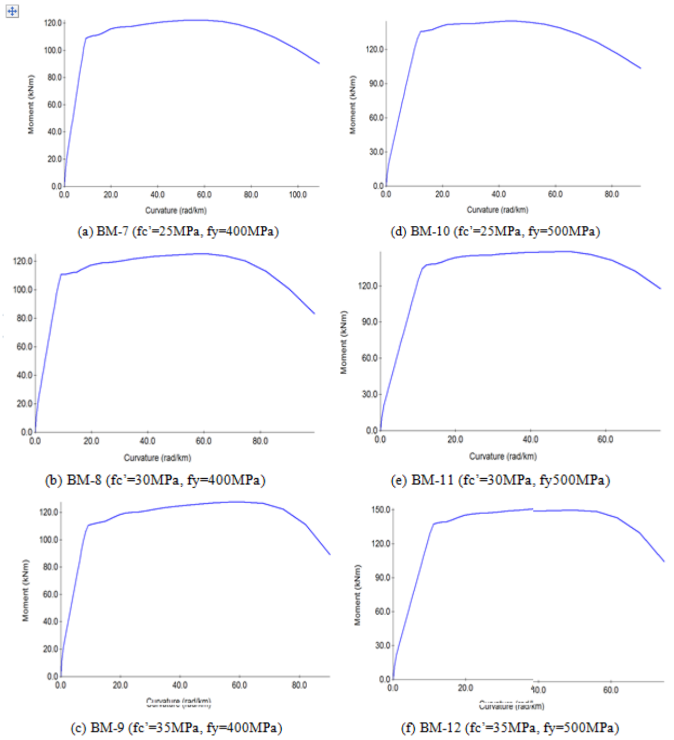

Figure 2. Moment Curvature of Beam Sections for Steel Ratio ρ= 0.010

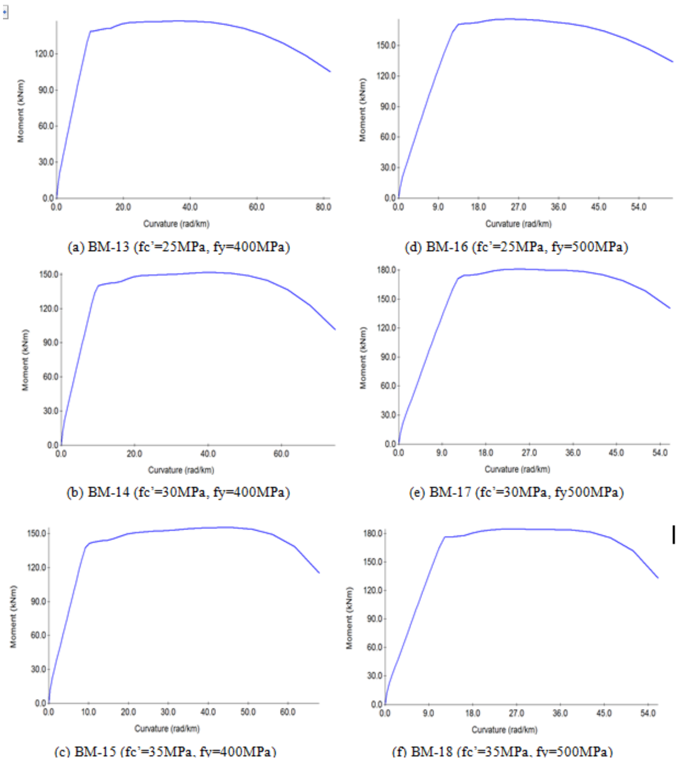

Figure 3. Moment Curvature of Beam Sections for Steel Ratio ρ= 0.013

Change in compressive strength of concrete has also significant effect on moment capacity. Effect of concrete strength and steel strength on moment capacity is presented in Table 1. Around 6-33%, 22-56% and 44-100% increase in moment capacity was found from sections having steel ratio 0.007, 0.010 and 0.013, respectively. Comparisons were made with control section having steel ratio 0.007, yield strength of steel of 400 MPa and concrete compressive strength of 25

MPa (lowest steel ratio and minimum steel and concrete strength).

Ductility

Figure 4 shows variation in ductility ratio obtained from different type of beam sections. As no significant change in ductility was observed (Figures 1 to 3) due to change in concrete compressive strength, effect of compressive strength was neglected here. In cases of nominal strength steel, maximum ductility was found from steel ratio 0.010. For high strength steel, maximum ductility was yielded from steel ratio 0.007. Table 2 shows percent increase or decrease in ductility ratio with respect to the control section having steel ratio 0.007 and yield strength of steel 400 MPa and concrete compressive strength of 25 MPa (lowest steel ratio and minimum steel and concrete strength). About 35% more ductility is obtained from the section having steel ratio 0.007 and yield strength of steel 500 MPa. About 14% more ductility is obtained from the section having steel ratio 0.010 and yield strength of steel 400 MPa. All other cases show lower ductility ratio. Maximum ductility was yielded from high strength steel section having steel ratio 0.007.

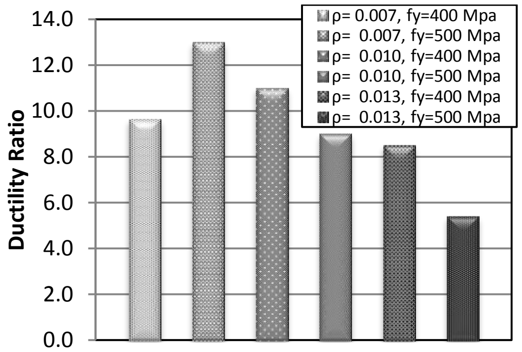

Figure 4. Ductility ratio obtained from different beam sections

List of Notations

fc'= Concrete compressive strength
fy = Yield strength of reinforcement steel
M = Moment
ρ=Steel ratio

Table 1. Percent increase in moment capacity with respect to steel ratio=0.007, f_y=400 Mpa, concrete strength 25 MPa

Steel Ratio	Compressive strength of concrete (MPa)	Yield Strength of Steel (MPa)	Percent increase or decrease in moment capacity
0.007	25	500	6
	30	400	11
		500	22
	35	400	28
		500	33
0.010	25	400	22
		500	28
	30	400	33
		500	39
	35	400	50
		500	56
0.013	25	400	44
		500	56
	30	400	67
		500	89
	35	400	94
		500	100

Table 2. Percent change in ductility ratio with respect to steel ratio=0.007, f_y=400 Mpa, concrete strength 25 MPa

Steel Ratio	Yield Strength of Steel (MPa)	Percent increase or decrease in ductility ratio
0.007	500	35
0.010	400	14
0.010	500	-7
0.013	400	-12
0.013	500	-44

Conclusion

A number of high-strength reinforcing steels are currently available for the design and construction of reinforced concrete flexural members. Higher strength steel permits a higher flexural strength and stiffness at the same time as maintaining the same minimum level of flexural ductility if steel ratio is properly selected. On the other hand, the use of a higher strength steel allows smaller steel area for a given flexural strength requirement to save the amount of steel needed and so the design becomes conservative. So earthquake resistant building can be designed with high strength steel in order to ensure a minimum level of ductility with lower steel area which is also a cost effective structural solution. From this numerical analysis it was found that, lowest steel ratio (0.007) and high strength steel (500 MPa), 35% better ductility performance was obtained than similar section having nominal strength steel for all compressive strength. Conversely, 14% more ductility is obtained from the section having steel ratio 0.010 and yield strength of steel 400 MPa.

Four major findings found from this work are:

- Higher flexural strength/stiffness/moment capacity was obtained from concrete section with more compressive strength
- Higher stiffness and moment capacity was ensured with high strength steel for higher steel ratio.
- Higher ductility is obtained from high strength steel than nominal strength steel only when steel ratio is lower
- No significant effect of compressive strength of concrete on ductility was observed

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