

# Effects of Tension Reinforcement Ratio on Ductility of Mid-Rise Reinforced Concrete Structures

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## Abstract

Failure mode of reinforced concrete (RC) structures are classified according to tension reinforcement ratio of beam elements. To determine effect of tension reinforcement ratio on performance of RC structure, two planar RC structure were selected. One of them is 5 stories other of them is 7 stories. Two different concrete class, C20 and C25, were considered for analysis. Three tension reinforcement combinations were considered, three different tension reinforcement ratios were used. First case is the ratio of the tension reinforcement is lower than that of the compression reinforcement, second case is the ratio of the tension reinforcement is equal to the ratio of the compression reinforcement and third case is the ratio of the tensile reinforcement is higher than the compression reinforcement.

**Key words:** Reinforced concrete structures, tension reinforcement, fiber element, nonlinear static analysis

## 1. Introduction

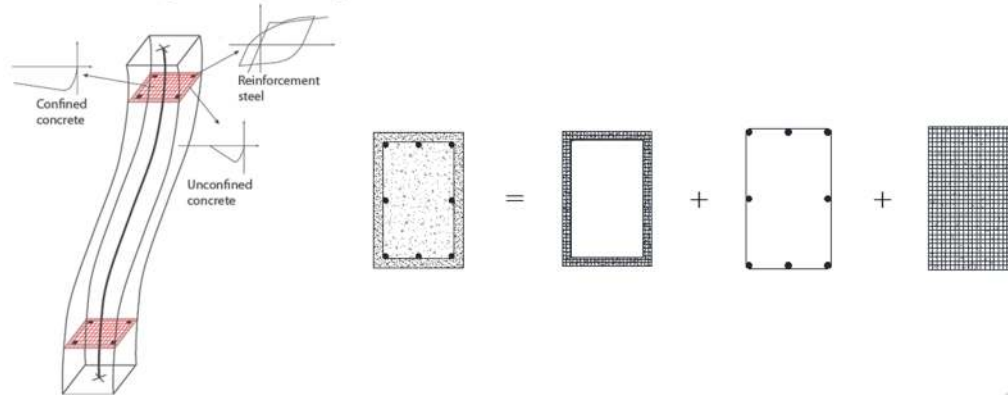
Tension or compression reinforcement ratio may change due to external effects such as corrosion and deterioration of rebars as reported by Theriaule and Benmokrane (1998) [1]. It was reported that two important parameters have influenced on performance of bar ratio change. One of them is propagated crack width, other of them is crack spacing. These two factors are restricted with tension reinforcement ratio [1]. Fantilli et al. (1999) investigated tension reinforcement ratio on structural performance on the base of bond-slip behavior [2]. Minimum steel bar ratio is affected by bar diameter. Thus, bond slip behavior is profoundly affected by bar diameter [2]. Ashour (2000) experimentally investigated tension reinforcement ratio on the high-strength beam behavior. Increasing compressive strength allowed beam to behave more flexible [3]. Lee and Pan (2003) investigated concrete confinement and spalling of concrete on the base of tension rebar ratio. Lee and Pan draw attention to fulfill ductility of structural members during design phase [4]. In this paper, it is aimed to investigate the effect of tension reinforcement ratio of beam on ductility of RC structures. For this purpose, two RC structure were selected. One of them is 5 stories and other of them is 7 stories. Two different concrete compressive strength were considered.

## 2. Numeric Model and Method

Both model in this study were defined with fiber element model which accounts plasticity. This plasticity is spread through to the cross-section and the length of the element. In this hinge model,

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the structural element is divided in three types of fibers: some fibers are used for modelling of longitudinal steel reinforcing rods; some of fibers are used to define nonlinear behaviour of confined concrete which consists of core concrete; and other fibers are defined for unconfined concrete which includes cover concrete. Also, for each fiber, the stress/strain field is determined in the nonlinear range by using constitutive laws according to defined materials. Figure 1 shows typical fiber modelling for a rectangular reinforced concrete section.



**Figure 1.** Typical fiber model of a RC element [5]

### **2.1. Description of Numeric Model**

Numeric models were modelled with 5 storeys and 7 storeys RC frame. Both of the RC frames have 5 bays and width of the bay is 5m. Two different concrete compressive strength were considered C20 and C25 and yield strength of rebar 420 MPa. Columns were not jacket in this study. One of the models was presented in Figure 2. Each floor was 3.0 m constant story height. The dimensions for columns were selected as 40cm/40cm for 5 story building and 50cm/50cm for 7 story building. Moreover, dimensions of beams were selected as 30/50 for both buildings. The nonlinear static analyses of the buildings were performed indicated in Turkish Seismic Code (TSC) [6]. The building importance coefficient is assumed as 1.0 for the existing building. Boundary condition of the building was supposed as fixed support. Also, the soil differences and damping properties accordance with soil were not considered. For nonlinear analyses, SeismoStruct [7] program was used which is able to simulate the inelastic structural systems response.

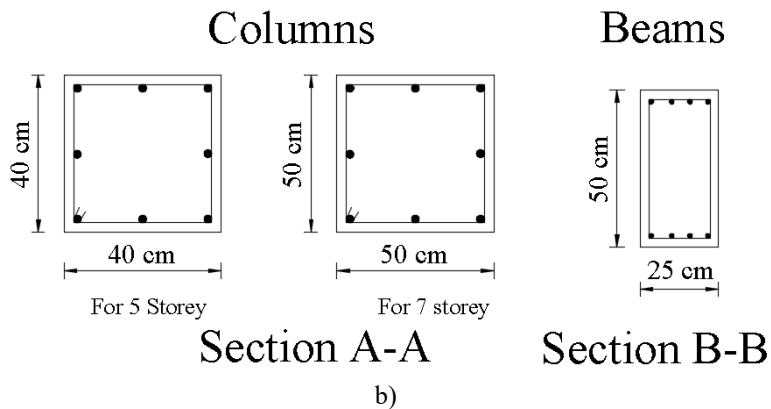
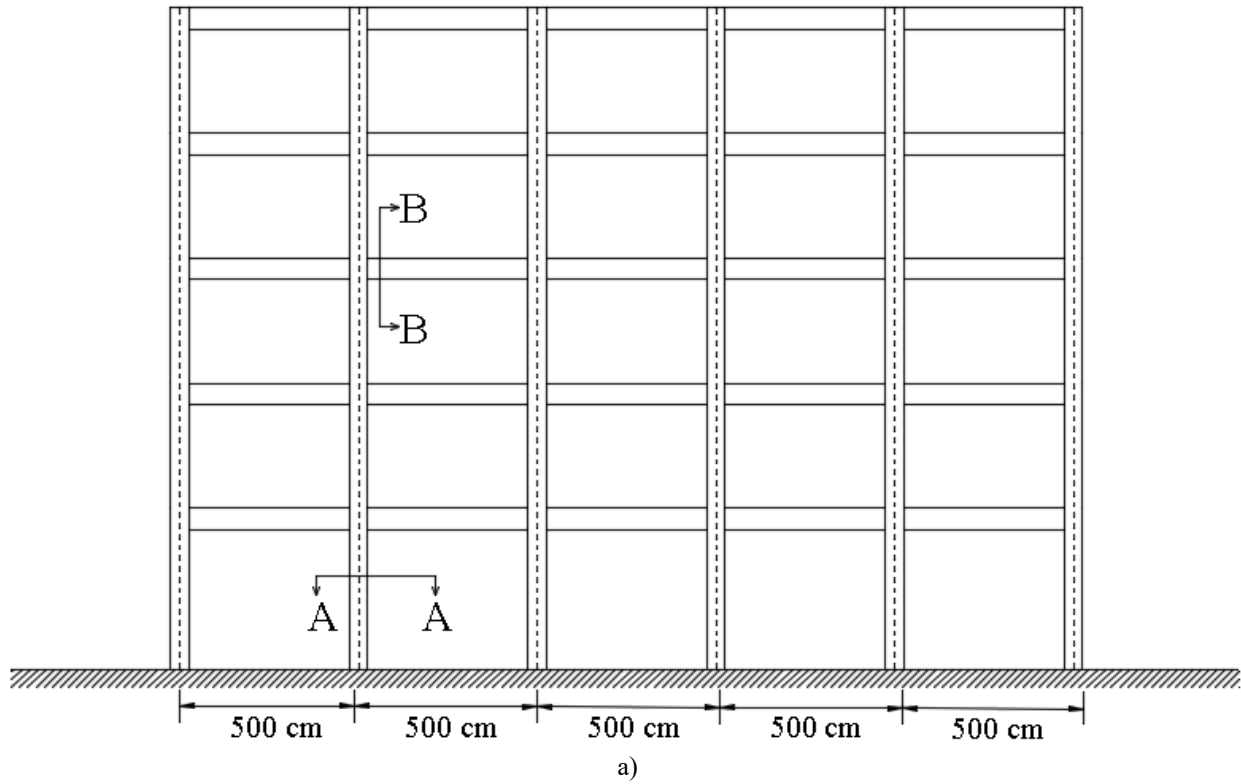
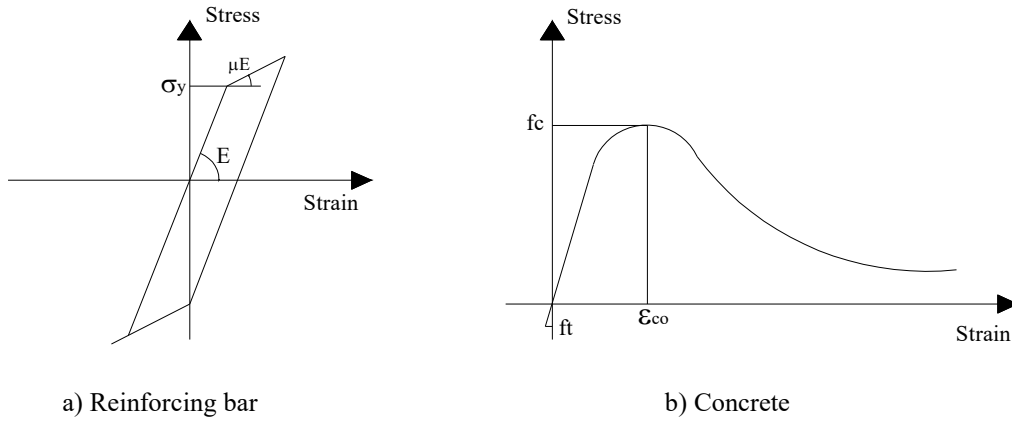


Figure 2. a)Generic 5 storey model, b) Cross sections

## 2.2. Adopted Material Models and Properties

The bilinear elastic plastic material model which includes kinematic strain hardening is used for the reinforcing bar. Concrete material is defined by the uniaxial confinement concrete model (Figure 3) [8, 9]. The confinement effect is calculated by using Mander model [10]. Reinforced concrete parameters related to structural elements are illustrated in Table 1.



**Figure 3.** Material models for reinforcing bar and concrete

**Table 1.** Reinforced concrete parameters related to structural elements.

Structural Elements		Longitudinal reinforcement	Section	Transverse reinforcement spacing (cm)
Column (50/50 and 40/40)	Confinement zone of column	8Ø16	A-A	15
	Central zone of column		A-A	15
Beam (25/50)	Confinement zone of beam	Top reinforcement 2Ø12	B-B	20
	Central zone of beam	Bottom reinforcement 4Ø12		

Model-I represents  $\frac{\rho}{\rho'} = \frac{1}{2}$ , Model-II represents  $\frac{\rho}{\rho'} = 1$ , Model-III represents  $\frac{\rho}{\rho'} = \frac{3}{2}$ . Where  $\rho'$  represents rebar area of compression reinforcement,  $\rho$  represents rebar area of tension reinforcement.

### 3. Results and Discussion

Results of the performed analysis were presented with two different graphs. One of the graphs was performance graphs contains base shear and roof displacement, other of them is interstorey drift versus floor number. Capacity curves of the 7 storey and 5 storey models were presented in Figure 4 a) and Figure 4b) respectively.

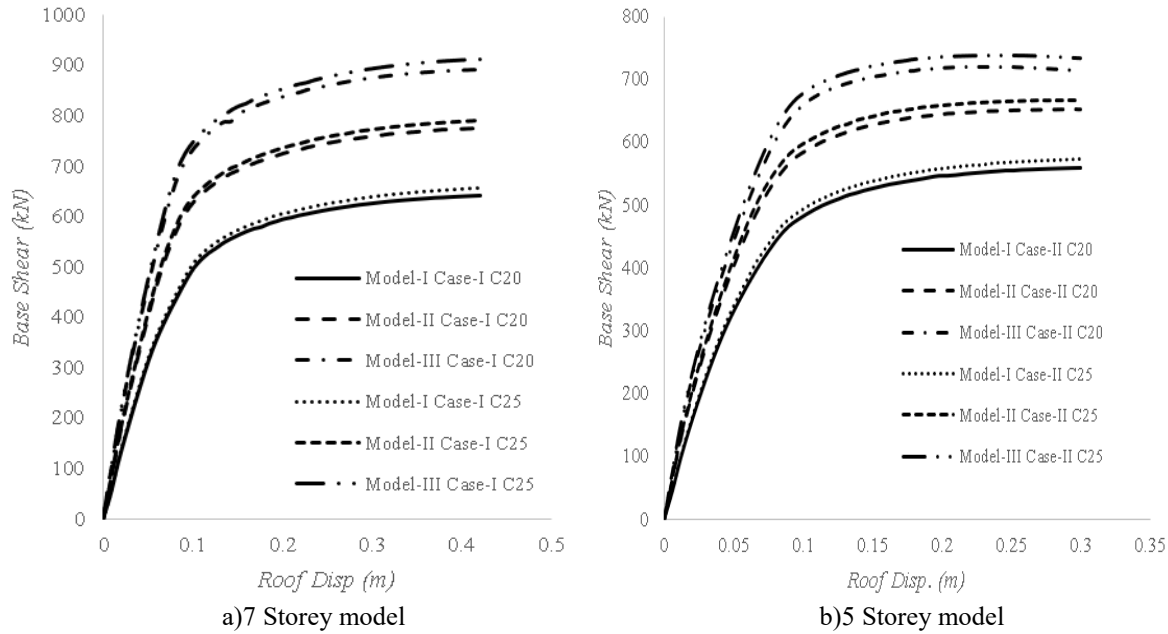


Figure 4. Capacity curves of the two models

Figure 4 presents capacities of the two models according to performed analysis. After performed analysis, obtained maximum values were tabulated in Table 2.

Table 2. Maximum base shear and maximum roof displacements.

	5 Storey						7 Storey					
	Model-I		Model-II		Model-III		Model-I		Model-II		Model-III	
	C20	C25	C20	C25	C20	C25	C20	C25	C20	C25	C20	C25
Max. Base Shear (kN)	560	573	653	667	720	737	641	656	775	791	891	912

As seen from Table 2, increasing concrete compressive strength 5 MPa contributes overall structural performance around 2.38% for both models. However, increasing compression rebar area with constant tension rebar increases overall structural lateral resistance 16% while compared Model-II with Model-I. Moreover, this increase ratio decreased to 10% while compared Model-III and Model-II. This contribution ratios are common for two different storey structural system, i.e. 5 storey and 7 storey. After performing analysis, interstorey drifts were evaluated on the base of TSC 2007 [11] by using Equation 1 and Equation 2.

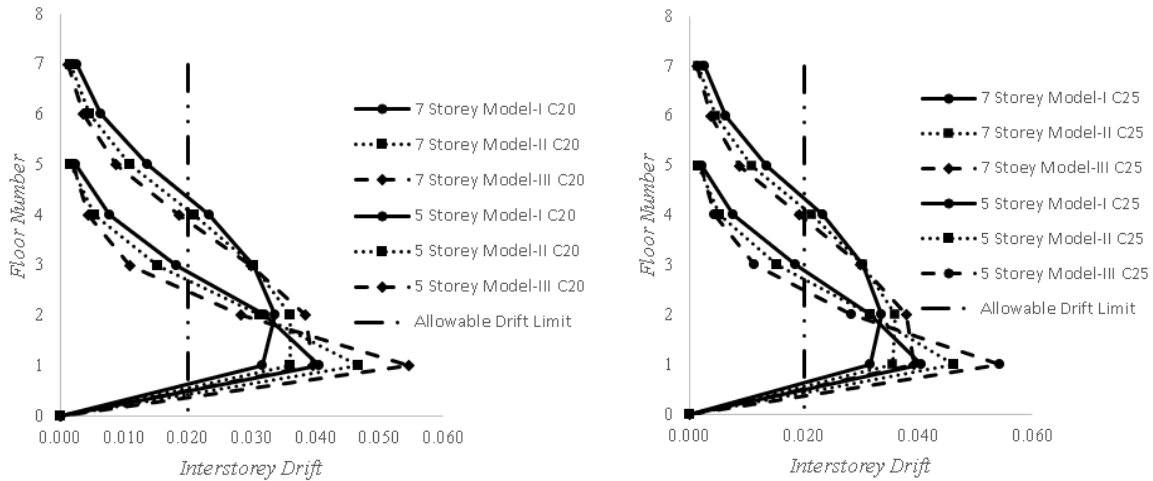
$$\delta_i = R * \Delta_i \tag{1}$$

Where  $\Delta_i$  is the obtained lateral displacement,  $R$  is the global behaviour factor of structural system,  $\delta_i$  is the effective lateral displacement.

$$\frac{(\delta_i)_{max}}{h_i} \leq 0.02 \tag{2}$$

$h_i$  is the story height of the investigated structure. Result of Equation 2 is should be lower than

0.02.



a) Drift results for two model with C20

b) Drift results for two model with C25

Figure 5. Drift results for all models with two different compressive strength test results

Interstorey drift is one of the most important criteria to see structural response under any type of loading. For this purpose, Figure 5 was plotted to observe structural behavior under varying conditions. Table 3 was tabulated to see maximum interstorey drift in percent.

Table 3. Maximum interstorey drifts and code limitation.

	5 Storey						7 Storey					
	Model-I		Model-II		Model-III		Model-I		Model-II		Model-III	
	C20	C25	C20	C25	C20	C25	C20	C25	C20	C25	C20	C25
Max. Interstorey drift (%)	3.4	3.4	3.6	3.6	4.0	3.9	4.1	4.1	4.7	4.6	5.5	5.4

As seen from the Figure 5 and Table 3, Storey number 1 and 2 have not provided allowable limits of TSC 2007 at 5 storey building model. In addition, storey number 1, 2, 3 and 4 have not satisfied 2.0% allowable limit as presented TSC 2007. Since, concrete compressive strength was increased from 20 MPa to 25 MPa 3<sup>rd</sup> storey of 5 storey building was satisfied. However, 5 MPa compressive strength increase has not enough for 7 storey building.

### Conclusions

In this paper, it is aimed to investigate the effect of tension reinforcement ratio of beam on ductility of RC structures. For this purpose, two RC structure were selected. One of them is 5 stories and other of them is 7 stories. Two different concrete compressive strength were considered, i.e. 20 MPa and 25 MPa. Nonlinear static analysis was performed on the models to see structural response. According to results, increasing tension reinforcement of beam elements has not any effect on maximum roof displacement. Whereas, tension reinforcement increases decreased interstorey drift ratio. However, this ratio has not reached expected level. 5 MPa compressive strength increase retained only one storey of structural system at 5 storey building model. This increase has not

prevented drift level as expected level at 7 storey building.

**Examples:**

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