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Nonlinear Modeling of Reinforced Concrete Beam

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Abstract

The aim of this study is to model a reinforced concrete beam by using materially nonlinear constitutive models. In the modeling, two approaches are used. In the first approach, the concrete and reinforcement are modeled as 4-noded quadrilateral elements. In the second approach, the reinforcement is assumed to be uniformly distributed throughout the beam. So, the beam is modeled as a single composite element by increasing the modulus of elasticity of concrete by considering the reinforcement ratio. For these two approaches, elastic- perfectly plastic stress-strain relationship is used. Also, tension is considered. Tension zone of concrete is modeled by using different stress-strain relationship proposed in the literature. For the analysis, a computer program is coded in MATLAB. The results obtained from different cases are presented in terms of load-displacement curves.

Keywords: *RC Beam, Nonlinear Analysis, Tension Region, Stress-Strain Relationship*.

1 Introduction

Cracking of the concrete, plasticity of the reinforcement and plasticity of the compression concrete are the main reasons of nonlinear behavior. Bond between concrete and steel, dowel action of reinforcing steel, shrinkage and temperature

change are also the reason for nonlinear behavior of reinforced concrete structures. In order to determine complex response of concrete, failure or fracture criterion described in terms of stress invariants and stress-strain relationships determined from experimental studies are used.

The stress-strain relationship is not clear for concrete structures. In order to obtain true response of concrete, many constitutive models are proposed by researchers. They used different stress-strain relationships. Kwak and Kim (2001) used Hognestad stress-strain model in nonlinear analysis of shear walls. Wang and Hsu (2001) presented a new constitutive model in concrete structures by using softening coefficient in compressive and linear ascending branch up to cranking strain in pre-peak tension and different descending branches in post-peak tension. Wong (2002) described the stress-strain relationships according to compression pre-peak response, compression post-peak response, tension pre-peak response and tension post-peak response. Dede et al. (2006) presented a study to show some stress-strain relationship such as Popovics, Hognestad, Hoshikuma, Popovics-Mander, Popovics-Saenz, Kent-Park, Saenz, and Desayi-Krishnan.

The aim of this study is to investigate the nonlinear analysis of a reinforced concrete beam under different stress-strain relationships and different modeling of composite material consists of concrete and steel bars. Two stress-strain relationships for tensile stress and one stress-strain model are used to model reinforced concrete finite elements and two approaches are used to assemble the reinforced concrete finite element.

2 Material Modes

In this study, two approaches are used to model the composite reinforced concrete elements. In first approach, concrete elements are modeled by using 4-noded quadrilateral finite element. The reinforcing bars embedded in the concrete elements are represented by an equivalent steel element. The material matrices of concrete and steel element are given as:

$$[D_c] = \frac{E_c}{1-\nu_c^{\,2}} \begin{bmatrix} 1 & \nu_c & 0 \\ \nu_c & 1 & 0 \\ 0 & 0 & (1-\nu_c)/2 \end{bmatrix} \tag{1}$$

$$[D_s] = \begin{bmatrix} \rho_x E_s & 0 & 0 \\ 0 & \rho_y E_s & 0 \\ 0 & 0 & 0 \end{bmatrix} \tag{2}$$

where D_c and D_s are material matrices of concrete and equivalent reinforcing bar elements, E_c and E_s are modulus of elasticity of concrete and steel materials, respectively. ν_c is Poisson's ratio of concrete, ρ_x and ρ_y are the reinforcement ratios in global directions of the x and y axes , respectively.

The stiffness matrix of the composite reinforced concrete finite element is created by superposition of the concrete and reinforcing steel stiffness matrices. This is achieved as

$$[K_{el}] = [K_{el}]_{concrete} + \sum_{i=1}^{n} [K_{el}]_{steel} \tag{3}$$

$$[K_{el}] = \int_{v} [B]^T \left\{ [D_c] + \sum_{i=1}^{n} D_s \right\} [B] dV \tag{4}$$

where n is number of reinforcing bars embedded in the concrete element.

In the second approach, composite reinforced concrete element is modeled with an equivalent concrete element. The modulus of elasticity is increased according to reinforcement ratio. This is achieved as

$$E_c = E_{concrete} + \rho E_{steel} \tag{5}$$

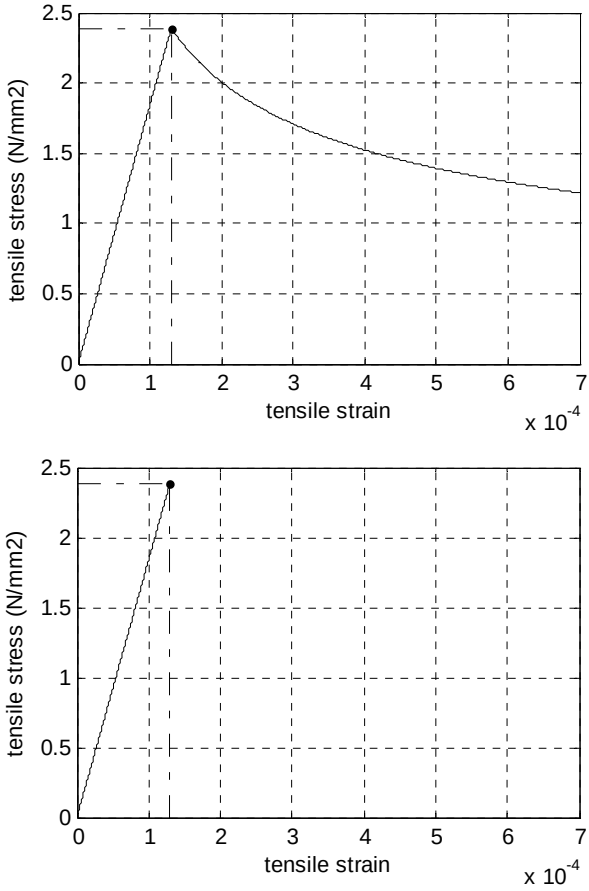
2.1 Concrete in tension

In this study, two different tensile stress-strain relationships (tension model 1 and 2) are used to model concrete elements subjected to tensile stresses. Tension model 1 shown in Figure 1(a) has an ascending and a descending branch. Descending branch is generally named "tension softening". Equations for this model are given as (Wang and Hsu, 2001):

$$\sigma_1 = E_c \varepsilon_1 \qquad if \qquad \varepsilon_1 \le \varepsilon_{cr} \tag{6}$$

$$\sigma_1 = f_{cr} \left(\frac{\varepsilon_{cr}}{\varepsilon_1} \right)^{0.4} \quad if \qquad \varepsilon_1 > \varepsilon_{cr} \tag{7}$$

where f_{cr} is the cracking stress of concrete, ε_1 is the first principal strain, ε_{cr} is the cracking strain of concrete and σ_1 is the first principal stress.



Figuer 1. Stress-strain relationships (a) tension model 1 and (b) tension model 2.

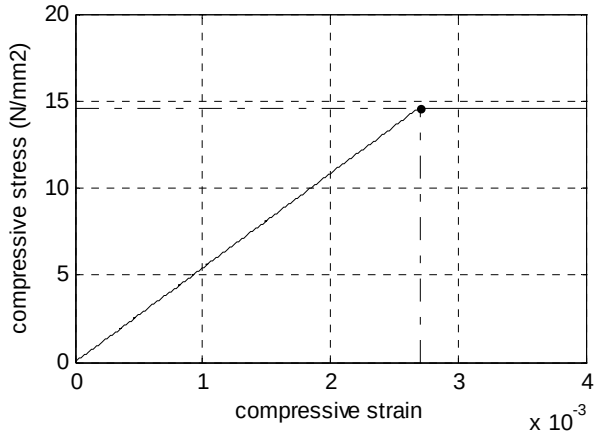
In tension model 2 shown in Figure 1(b), the descending branch is not taken in to account. It is assumed that the concrete is full cracked if it is reaches to the peak tensile stress.

2.1 Concrete in compression

Concrete elements subjected to the compressive stress are modeled by using the elastic-perfectly plastic stress-strain relationship.

$$\sigma_1 = E_c \varepsilon_1 \qquad if \qquad \varepsilon_1 \le \varepsilon_{co} \tag{8}$$

$$\sigma_1 = f_c \qquad if \qquad \varepsilon_1 > \varepsilon_{co} \tag{9}$$



Figuer 2. Stress-strain relationships for elastic perfectly plastic material.

where f_c is the maximum compressive stress of concrete and ε_{co} is the concrete strain at maximum compressive stress.

3 Nonlinear Solution Method

In this study, incremental Newton-Raphson technique (Zienkiewics and Taylor, 1989) is used in the nonlinear solution process. In this technique, the external nodal forces, F, is divided into the number of load increment determined by user. Then, for each load increment, the iteration process is started. If convergence is achieved, the next load increment is carried out. At each iteration, the unbalanced forces are calculated by the following equation.

$$F_{unbalenced} = F_{external} - F_{ixternal} \ . \tag{10}$$

The internal or equivalent nodal forces are obtained as,

$$F_{ixternal} = \sum \int [B]^T [D] \varepsilon \, dv \tag{11}$$

where, ε, is the strain calculated for each element. After each iteration, the unbalanced nodal forces should become small enough to meet the convergence criterion.

4 Numerical Example

A reinforced concrete beam (under-reinforced) is analyzed using two finite element meshes, two approaches and two tensile stress-strain models. This simply supported beam is tested by Shayanfar et al. (1997) with two concentrated third-point loads. The details of the reinforcement and the dimensions of the beams are shown in Figure 3 and finite element modelings for 20 and 80 element are given in Figure 4.

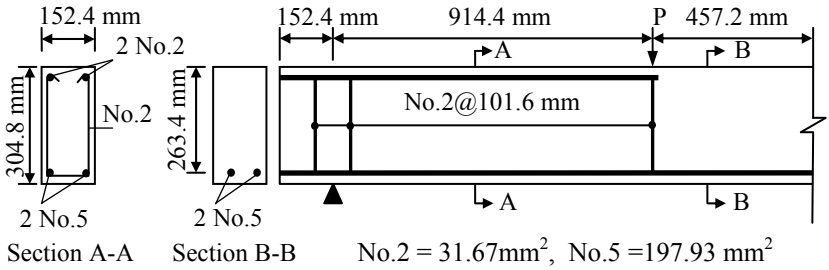


Figure 3. Details of Reinforced Concrete Beam.

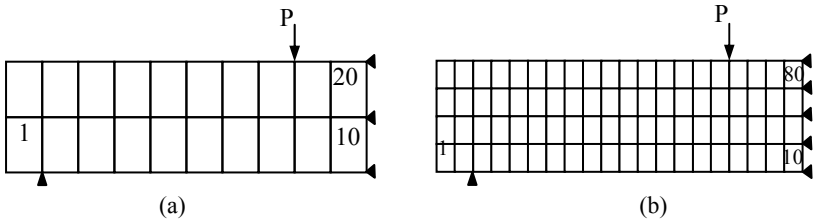


Figure 4. Finite Element Modeling of RC Beam for (a) 20 element, (b) 80 element.

Material properties of beam are: Maximum compressive stress of concrete f_c' = 14.62 N/mm^2, modulus of elasticity of concrete E_o = 18095.93 N/mm^2, maximum compressive strain of concrete ε_{co} = 0.0027, ultimate compressive strain of concrete ε_{cu} = 0.004, maximum tensile stress of concrete = 2.39 N/mm^2, Poisson's ratio of concrete v = 0.17 and modulus of elasticity of steel E_s =7308.7 N/mm^2.

The load-displacement curves obtained from this study are given in Figure 5. The ultimate load capacity of this beam obtained from this study and the theoretical and experimental results given by Shayanfar et al. (1997) are given in Table 1.

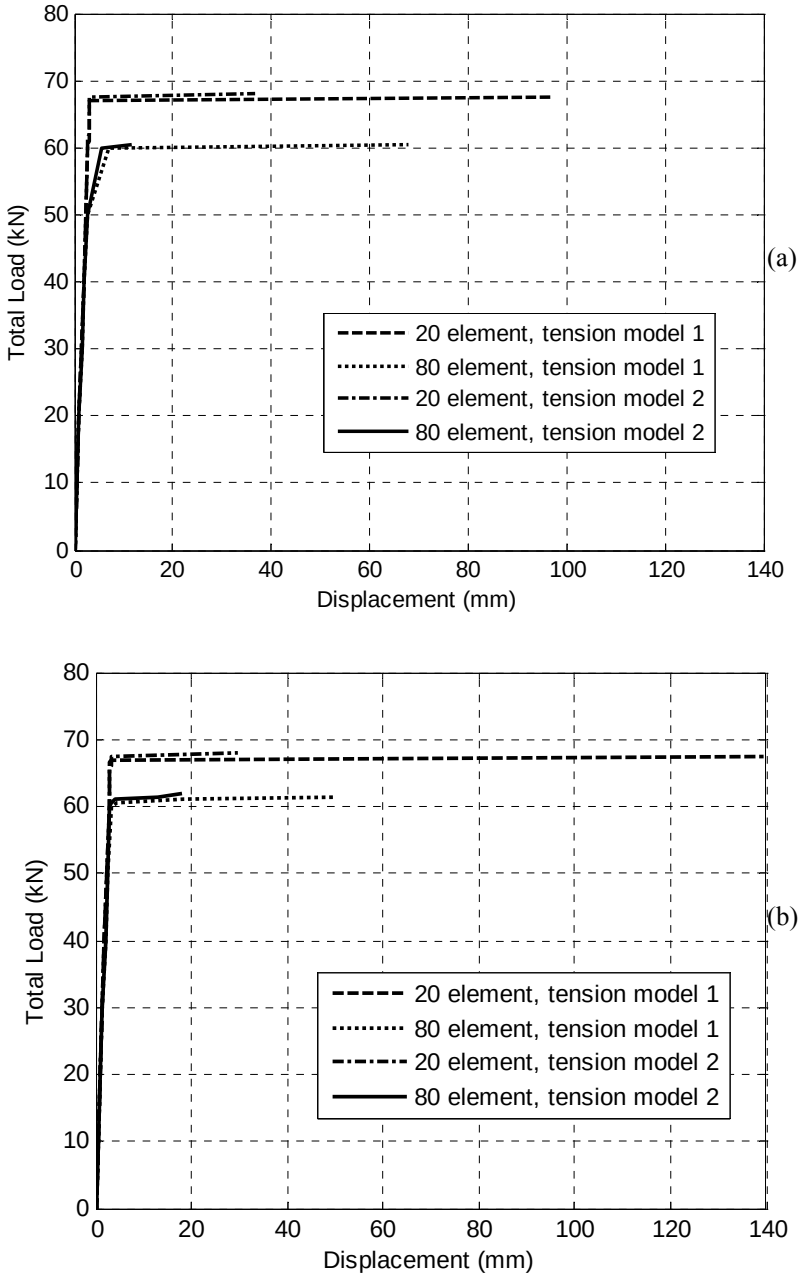


Figure 5. Load-displacement curve at mid-span of beam for (a) the first approach and (b) the second approach (ε_{tu}=0.0007, ε_{cr}=0.00013)

Table 1. Analysis results of RC beam (units: Newton)

Number of element	This study				Shayanfar et al. (1997)	
	First approach		Second approach			
	Tension model 1	Tension model 2	Tension model 1	Tension model 2	Theoretical	Experimental
20	67500	68000	675000	68000	62272	69682.37
80	60500	60500	615000	62000	60048	

As seen from Figure 5 and Table 1 the load capacities of the two different tension models used in this study are almost the same, but the maximum displacement obtained by using these two tension models are different. The maximum displacement obtained using model 1 consisting of tension softening is larger than that of model 2 not consisting of tension softening. As also seen from this figure and table, the ultimate load capacities of the two different approaches are also almost the same. These results show that the approaches and models considered in this study can be effectively be used in the non-linear analyses of RC beams.

5 Conclusions

In this study, different modeling of RC finite element and different tension stress-strain relationship are used. It is concluded that the results obtained in this study are in agreement with the result given in the literature. These results show that the approaches and models considered in this study can be effectively be used in the non-linear analyses of RC beams.

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