MIXED FORMULATION OF RC BEAM ELEMENT WITH SHEAR-AXIAL FORCE AND FLEXURE INTERACTION

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1. INTRODUCTION

Shear critical elements appear frequently in structures that are subjected to earthquake excitations. These are often used in metallic energy dissipating devices, but are also present in shear deficient column of older reinforced concrete buildings. The purpose of this study is to develop a beam element that accounts for the nonlinear material response under the interaction of shear, axial force and bending moment.

2. DESCRIPTION OF PROPOSED FORMULATION

A beam finite element is proposed with the assumptions of the Timoshenko shear beam theory for the displacement field. The element is based on a three-field variational formulation according to the Hu-Washizu principle with interpolation functions for the internal forces that satisfy exactly the equilibrium equations of the problem. Consequently, no displacement interpolation functions are required and difficulties with shear locking in slender beams do not arise. The force-displacement relation of the element is based on the integration of the section response at several monitoring stations along the axis (Gauss or Gauss-Lobatto integration points). The section response is, in turn, derived from the integration of the nonlinear material response at a number of monitoring stations across the section. The nonlinear material response accounts for the coupling between normal and shear stress. The transverse strain field is determined from the satisfaction of transverse equilibrium between the concrete stress field and the stress in the transverse reinforcing steel. The concrete stress field is described by an orthotropic nonlinear material model that is based on the modified compression field theory [1], even though alternative formulations of the same type can be easily explored. A bilinear uniaxial model is used for the longitudinal and transverse reinforcing steel.

Additional assumptions of the proposed model and the underlying concrete constitutive relation are: (a) perfect bond between reinforcing steel and concrete is assumed, (b) the dowel action of reinforcement is is neglected, (c) the concrete constitutive model is based on the assumption of smeared cracking, without the possibility of accounting for a discrete crack, (d) tension stiffening effects and compression softening behavior under transverse tensile strain follow the relations of the original modified compression field theory [1], and (e) a rotating crack model is used with principal stress directions assumed to coincide with the principal strain directions.

3. RESULTS

The proposed model exhibits the efficiency, accuracy and numerical robustness that is characteristic of beam elements based on the force formulation. The results have first been validated with available experimental data from the hysteretic response of short and long shear links in eccentrically braced steel frames. More recently, simulations of the shear beam tests by Bresler and Scordelis [2] shows significant promise. The proposed model represents the salient features of the response and the final shear compression failure of specimen A1 very well. It is worth noting that a single beam element with five

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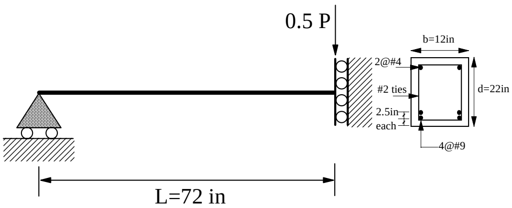
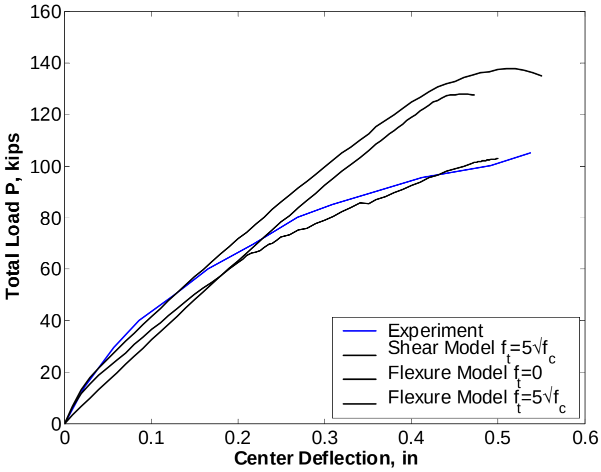
Gauss integration points is used, as is evident from the crack and stress distributions in the figure. The load-displacement response shows clearly the effect of shear on this specimen, because a beam model with only flexure overestimates the ultimate strength by 40%.

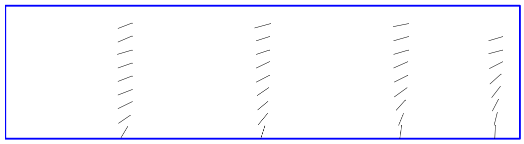
At the present time studies are under way to investigate the numerical robustness of alternative material model descriptions for concrete and to survey available constitutive relations for cyclic biaxial response. Moreover, shear critical beams with widely spaced stirrups need to be investigated by introducing concepts from fracture mechanics and discrete crack element formulations.



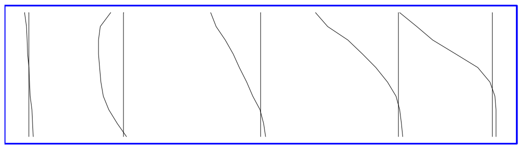
Model of ½ of Bresler-Scordelis Beam A1



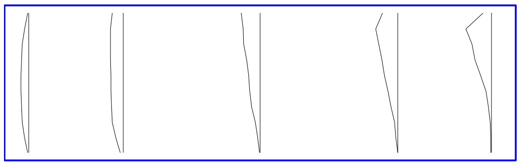
Analytical results without shear with and without tensile strength, with shear and tensile strengths vs. experiment



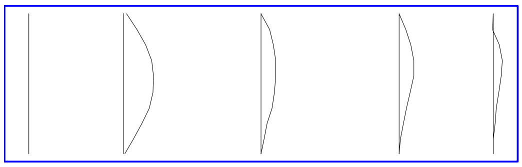
Crack distribution at peak load



Normal stress distribution at peak load



Shear stress distribution at peak load



Shear strain distribution at peak load

4. REFERENCES

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5. KEYWORDS

Reinforced concrete, shear, beam element, mixed formulation