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HYSTERETIC MOMENT ROTATION MODELLING OF REINFORCED CONCRETE ELEMENTS UNDER TIME VARYING AXIAL LOADS

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1. INTRODUCTION This paper presents an analytical model for predicting hysteretic moment-rotation relation of the cross section as well as RC members under time varying moments and also axial loads based on generalized material stress-strain models, as a part of long-term experimental and analytical studies of RC structures under seismic excitation.

2. METHOD OF ANALYSIS AND ASSUMPTIONS The beam theory and fiber representation of element materials (Fig.1) are the basis of the model proposed herein for the analysis of RC plane structures. Plane cross section remains plane after the deformations, which leads to the linear strain variation with the depth. Members are composed of discrete segments, with linear variation of bearing capacity between appropriately selected cross sections(Fig.2(a)). Stress-strain models of confined, unconfined and steel material are based on the experimental results derived from the uniaxial tests of sample specimens under generalized cyclic loads.

3. MULTI SECTION FIBER ELEMENT MODEL The instentaneous tangent element stiffness matrix is defined by inversion of the element flexibility matrix which can be estimated by integration of the cross section flexibility along the element. The cross section flexibility matrix is obtained by inversion of the cross section stiffness matrix which is defined by sumation of the current tangent fiber stiffnesses. The shape functions relating cross section deformations to element displacement are derived from the current section and element flexibilities.

3.1. <u>Cross Section Stiffness and Flexibility Matrix:</u> The strain of any fiber i can be expressed as $\varepsilon_i = \varepsilon_a + \Phi y_i$....Eq.(1) (where ε_a:strain at reference point, Φ:curvature and y_i:distance from the reference point). The tangent stiffness of the fiber is the slope of the stress-strain curve for the given strain, which is derived taking into consideration of the previous strain history. By using section equilibrium equations, the incremental section forces can be related with incremental section deformations. Eq.(2) or Eq.(3), (where $[K]_s$:current cross section tangent stiffness matrix). Corresponding cross-section tangent flexibility matrix is given by inversion of section stiffness matrix, Eq.(4)

$$\begin{Bmatrix}\Delta M\\ \Delta N\end{Bmatrix}_s = \begin{bmatrix}\Sigma A_i E_i Y_i^2 & \Sigma A_i E_i Y_i\\ \Sigma A_i E_i Y_i & \Sigma A_i E_i\end{bmatrix}\begin{Bmatrix}\Delta\Phi\\ \Delta\varepsilon_a\end{Bmatrix}_s \;...(2)\quad \{\Delta F\}_s=[K]_s\{\Delta r\}_s \;...(3)\quad [F]_s=[K]_s^{-1}...(4)\quad \{\Delta r\}_s=[F]_s\{\Delta F\}_s....(5)$$

3.2. <u>Element Flexibility and Stiffness Matrix:</u> For the element, Fig.2.(a), the two end rotations along with axial displacement constitute the three local degree of freedom (θ_i, θ_j, and δ_l) associated with two end moments (M_i, M_j) and axial load (N). Assuming linear variation of flexibility between appropriate selected cross sections the element flexibility can be calculated by closed form of integration along the length of the element. The first step is to relate the cross section forces $[S]_s$ to the member end forces $[S]_m$, Eq.(6), by implementing equilibrium equations through $[b]$ matrix. If flexibility matrix of any section $[F(x)]_s$ is calculated by linear interpolation, the element flexibility matrix (3x3) is obtained by intergration, Eq.(7). The element stiffness matrix can be obtained by inversion of the element flexibility matrix and relation between incremental element end forces and element end deformations is defined, Eq. (8)

$$\begin{Bmatrix}M\\ N\end{Bmatrix}_s = \begin{bmatrix}-1+x/L & x/L & 0\\ 0 & 0 & 1\end{bmatrix}\begin{Bmatrix}M_i\\ M_j\\ N\end{Bmatrix} \;...(6)\quad [F]_e=\int_0^{\ell}[b(x)]^T[F(x)]_s[b(x)]dx \;..(7)\quad \begin{Bmatrix}\Delta M_i\\ \Delta M_j\\ \Delta N\end{Bmatrix} = \begin{bmatrix}K_{11} & K_{12} & K_{13}\\ K_{21} & K_{22} & K_{23}\\ K_{31} & K_{32} & K_{33}\end{bmatrix}\begin{Bmatrix}\Delta\Phi_i\\ \Delta\Phi_j\\ \Delta\delta_\ell\end{Bmatrix}....(8)$$

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3.3 Hysteretic Moment-Curvature Relation of Section and Moment-Rotation Relation of a Member: Following the incremental solution approach, the hysteretic moment curvature relation for single cross-section of RC member can be derived by implementation of Eq.(2) under time varying moment and axial force. Similarly, the nonlinear relation between member end forces and member end deformations can be calculated by incremental solution of Eq(8) for the given time varying end moments and axial force.

4. STRESS-STRAIN MODELS FOR CONCRETE AND STEEL The accurate prediction of the mechanical behavior of the structure, elements, and cross sections during earthquake exitations depends on the development of reliable analytical models which describe the hysteretic behavior of the critical regions of the structure. Based on the past experimental studies, the stress-strain models for concrete and steel fibers are formulated including main parameters influencing these relations. The stress-strain model for concrete fiber includes concrete confinement levels, tension stresses, crack openings, crush of concrete etc., while the steel stress-strain model includes Bauschinger effect, isotropic strain hardening etc.. In Fig.3 are presented behaviors of proposed concrete and steel fiber models under arbitrary strain time history, from which general pattern of proposed models based on experimental data can be recognized.

5. CONCLUSIONS Analytical model proposed herein for predicting hysteretic moment--curvature relation of the cross-section as well as RC members under time varying moments and axial loads, can be implemented for complete and the most accurate RC structures modelling under seismic excitation.

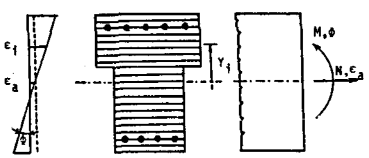

Fig.1.Typical cross section fiber model (CSFM)

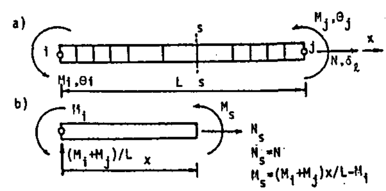

Fig.2.Beam element in local coordinate system. Local degrees of freedom and element forces (a),relating section forces to element forces (b)

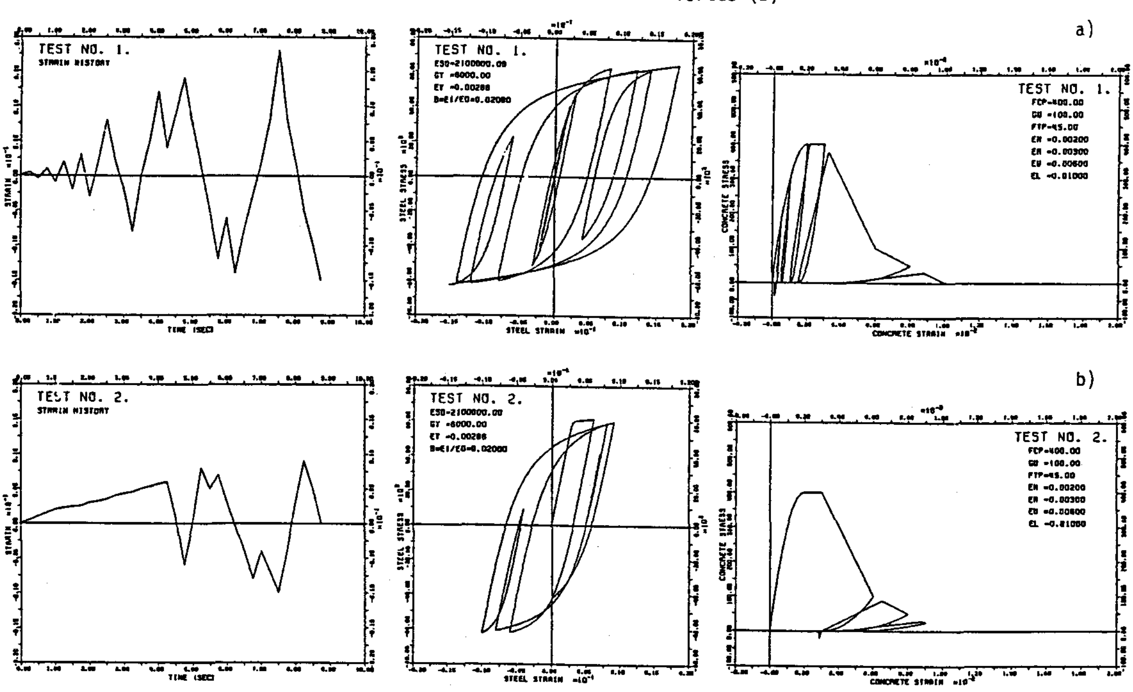

Fig.3.Behavior of proposed concrete and steel stress-strain models under arbitrary strain time hystories a)Test number 1., b)Test number 2.