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

Yoshikazu YAMADA (I), Hirokazu IEMURA (II), ○Danilo RISTIĆ (III)

1. INTRODUCTION

During the recent catastrophic earthquakes (Japan, USA, Yugoslavia, Algeria, Italy etc.), large number of structures with basic RC structural system (buildings, bridges etc.) have been severely damaged, which caused very high economical losses. In order to reduce expected economical losses in future earthquakes, without significant increase of construction cost, it is extremely needed to minimize or exclude damages of basic RC structural systems through improvement of seismic design codes as well as better understanding of actual dynamic behavior of structures during the severe earthquakes, in which case it is unreasonable to expect it to remain in elestic domain. From the above facts, the authors conducted long term experimental and analytical investigation of the RC structural elements under simultaneous time varying shear and axial loads in order to investigate resistance, deterioration process as well as to find what can be damage and failure criteria of these structures. 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 with further posibilities for complete and the most accurate basic RC structural system modeling.

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 with one dimensional members. 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. An approach with incremental solution is applied for response computation of the cross section, elements and structural systems under time varying loads.

3. MULTI SECTION FIBER ELEMENT MODEL

The instantaneous 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. Cross Section Stiffness and Flexibility Matrix

Using the assumption of plane section, the strain of a fiber can be expressed $\varepsilon_i = \varepsilon_a + \Phi y_i$ ....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)

$$\begin{Bmatrix}\Delta M\\ \Delta N\end{Bmatrix}_s = \begin{bmatrix}\Sigma A_i E_i Y_i^2 & \Sigma A_i E_i Y_i\\ \Sigma A_i E_i Y_i & \Sigma A_i E_i\end{bmatrix}\begin{Bmatrix}\Delta\Phi\\ \Delta\varepsilon_a\end{Bmatrix}_s \quad ...(2)$$

$$\{\Delta F\}_s=[K]_s\{\Delta r\}_s \quad ...(3) \qquad [F]_s=[K]_s^{-1} \quad ...(4) \qquad \{\Delta r\}_s=[F]_s\{\Delta F\}_s \quad ....(5)$$

3.2. Element Flexibility and Stiffness Matrix

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)

$$\begin{Bmatrix}M\\ N\end{Bmatrix}_s = \begin{bmatrix}-1+x/L & x/L & 0\\ 0 & 0 & 1\end{bmatrix}\begin{Bmatrix}M_i\\ M_j\\ N\end{Bmatrix} \quad ...(6) \qquad [F]_e=\int_0^{\ell}[b(x)]^T[F(x)]_s[b(x)]dx \quad ..(7)$$

$$\begin{Bmatrix}\Delta M_i\\ \Delta M_j\\ \Delta N\end{Bmatrix} = \begin{bmatrix}K_{11} & K_{12} & K_{13}\\ K_{21} & K_{22} & K_{23}\\ K_{31} & K_{32} & K_{33}\end{bmatrix}\begin{Bmatrix}\Delta\Phi_i\\ \Delta\Phi_j\\ \Delta\delta_{\ell}\end{Bmatrix} \quad ....(8)$$

(I) Professor and (II) Associate Professor,Structural Earthquake Engineering Laboratory,School of Civil Engineering,Kyoto University,Kyoto 606 Japan ,Member of JSCE
(III) Monbusho Scholar,Assistant Professor,Institute of Earthquake Engineering and Engineering Seismology, University "Kiril and Metodij" Skopje, Yugoslavia ,Member of JSCE

3.3. Hysteretic Moment-Curvature Relation of Section

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.

3.4. Moment-Rotation Relation of Members

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 of stress-strain relations of materials under generalized cyclic loading, 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

This paper presents summary of the analytical model proposed for predicting hysteretic moment-curvature relation of the cross-section as well as RC members under time varying moments and axial loads, as a part of long-term experimental and analytical study of hysteretic behavior of RC structures under seismic exitation.

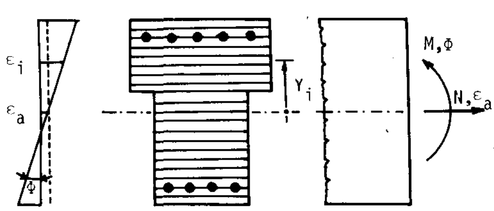

Fig.1.Typical cross section fiber model (CSFM)

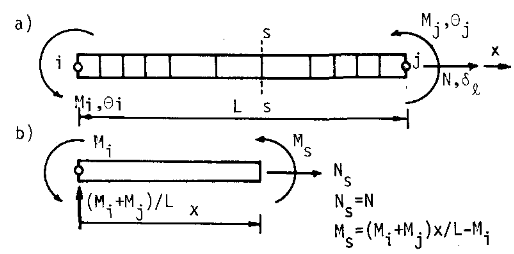

Fig.2.Beam element in local coordinate system. Local degrees of freedom and element forces (a),relating section forces to element forces (b)

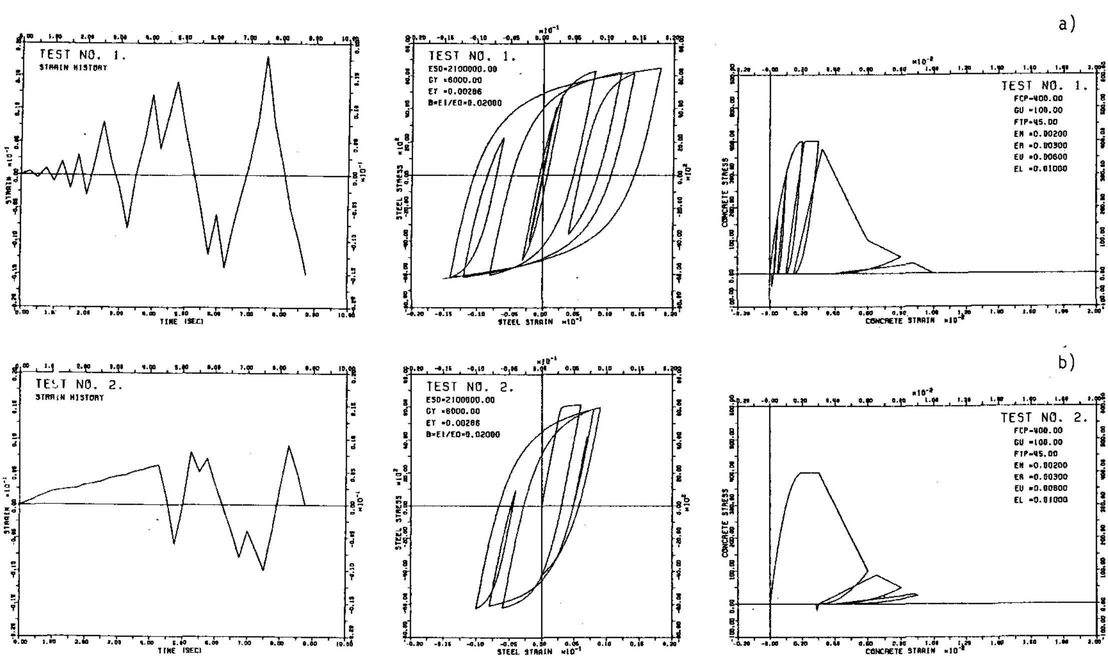

Fig.3.Behavior of proposed concrete and steel stress-strain models under arbitrary strain time hystories a)Test number 1., b)Test number 2.