INELASTIC RESPONSE OF STEEL FRAMES SUBJECT TO MULTICOMPONENT EARTHQUAKES

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SUMMARY

A numerical method for the analysis of three dimensional frames loaded dynamically into the inelastic range is developed in this study. The elasto-plastic force-deformation behaviour at the ends of the frame members is represented by an equation which corresponds essentially to the inverse of the Ramberg-Osgood representation. The system stiffness matrix is formulated as a tangent stiffness by taking into account P-Δ effect.

STRUCTURAL MODEL DESCRIPTION

The three dimensional rigid frame model which is considered in this study has prismatic straight members attached together by rigit connection at the joints. A typical joint in this frame has six degrees of freedom which are constituted three joint rotations about each reference axis and three joint deflections along each reference axis.

METHOD OF ANALYSIS

Member and System Tangent Stiffness Formulation

The strain-stress relation for the material is defined by following equation ;

$$\sigma = \frac{E\varepsilon}{\left(1+\left|\frac{E\varepsilon}{\sigma_o}\right|^b\right)^{1/b}} \qquad (1)$$

in which E= modulus of elasticity; b= constant defining shape of the stress strain relationship; σ= unit stress; ε= unit strain; σ= ultimate stress.

The members of the space frame are represented by a model which is elastic everywhere but at its ends where the nonlinear material behaviour is concentrated. Since loads are assumed to be applied only at nodes, these are the sections at which maximum bending moments occur.

For a member subjected only to bending about one of the principal axes of its cross section, the moment at the node is assumed to be expressed by a relationship similar to Eq.1

$$M = \frac{K\theta}{\left(1+\left|\frac{K\theta}{M_p}\right|^n\right)^{1/n}} \qquad (2)$$

in which K= elastic member end stiffness; M_p =plastic moment capacity of the member end; θ= effective member end deformation which can be expressed for i end of ij member of the frame, about one of the principal axes of its cross section, as follows ;

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$$\theta_i = \psi_i + \frac{1}{2}\psi_j \qquad (3)$$

in which ψ_i is the elastic rotation of the element at i and, ψ_j is the elastic rotation of the element at j end of the member.

Since for the space rigid frame loaded dynamically into the inelastic range, several loading-unloading behaviour may take place; hysteresis loop and corresponding functional relationships between member end forces and member end deformations must be defined. Such a hysteresis loop and corresponding functional relationships are given in Fig.3. In this figure the curve between Q-O and O-P represents the skeleton curve and corresponding functional relationship can be expressed by Eq.2. The branch curve is represented by the curves between Q-K, K-P and Q-N, N-P and corresponding functional relationship can be expressed similar to Eq.2 as follows ;

$$M = M^{(o)} + \frac{K(\theta-\theta^{(o)})}{\left(1+\left|\frac{K(\theta-\theta^{(o)})}{2M_p}\right|^n\right)^{1/n}} \qquad (4)$$

Since, the tangent stiffness of the structure will be used for step-by-step solution procedure, it is necessary to express Eq.2 and Eq.4 in incremental form as follows

$$\Delta M = \frac{K\Delta\theta}{\left(1+\left|\frac{K\theta}{M_p}\right|^n\right)^{\frac{1+n}{n}}} \qquad (5)$$

$$\Delta M = \frac{K\Delta\theta}{\left(1+\left|\frac{K(\theta-\theta^{(o)})}{2M_p}\right|^n\right)^{\frac{1+n}{n}}} \qquad (6)$$

where $M^{(o)}.\theta^{(o)}$ are the coordinates of the point at which the moment is reversed.

Similar expressions can be derived for axial force and axial deformations. By employing these expressions the tangent stiffness matrix of the elasto-plastic member which relates six independent member end deformation increments to six independent member end force increments is defined in local coordinate system.

The Direct Stiffness Method has been used in generating system tangent stiffness matrix by employing the tangent stiffness matrices of the elasto-plastic members. Similar way has been followed in generating system geometric stiffness matrix.

Inelastic Interaction Effects

In this study the interaction effects for space frame members are accounted for by the use of interaction relationships developed by Tebedge and Chen [1]. In their work, Tebedge and Chen approximated the yield surface of H columns by nondimensional equations as shown in Fig.2. In this figure N_p denotes plastic axial force capacity and M_{1p} ; M_{2p} denote the plastic moment capacity about 1-1 and 2-2 axes of the cross section.

In order to achieve stiffness modification due to the inelastic interaction effects, an efficient iterative procedure has been developed [2].

Numerical Integration Procedure

The constant average acceleration method is employed to integrate the incremental motion equation. This method has been shown to be unconditionally stable for any magnitude of Δt time increment [3].

COMPUTER PROGRAM

The method proposed in this study was programmed in Fortran IV (G1) for IBM 370/168 type computer at University of Missouri, Rolla.

NUMERICAL EXAMPLES

Although several examples have been run; due to the limited space, only the most informative two examples are presented in this paper. As the first example, a two-story one bay building frame subjected to the first 5 sec of all the three components of the 1940 El Centro Earthquake was analyzed by taking damping into account. The time history of U(t) translations for elastic and elasto-plastic cases are shown in Fig.3. As the second example, an eight-story one bay space frame shown in Fig.4 was analyzed dynamically to illustrate the inelastic behaviour of larger structures. Dynamic response to the first 5 sec of all the three components of the 1940 El Centro Earthquake for elasto-plastic case is shown in Fig.4. An instability arose suddenly at the point shown in this figure. The time increment used in this example was $\Delta t = 0.01$ sec and the solution took 15 min on the IBM 370/168 computer.

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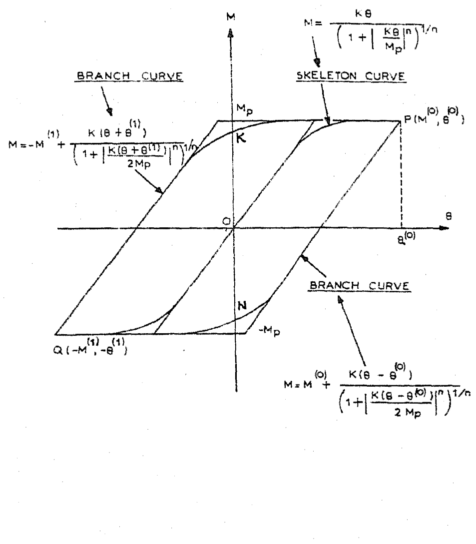


FIGURE 1 HYSTERESIS CURVES FOR MOMENT-EFFECTIVE ROTATION RELATIONS

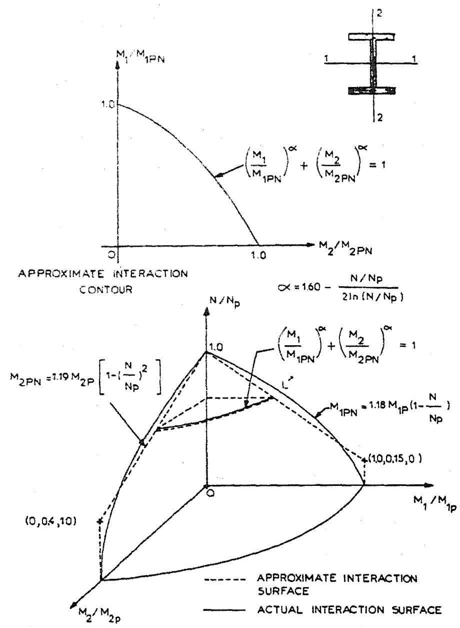
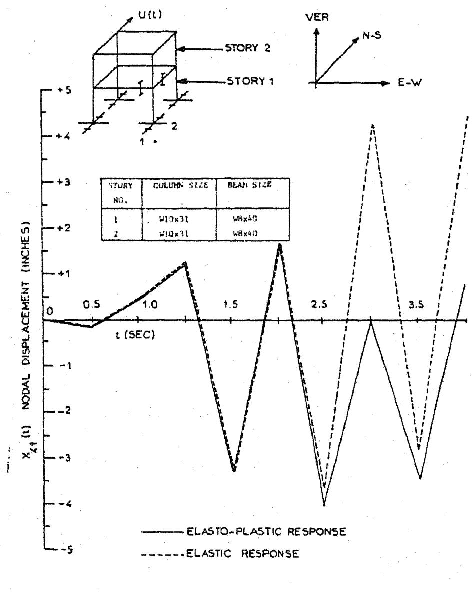
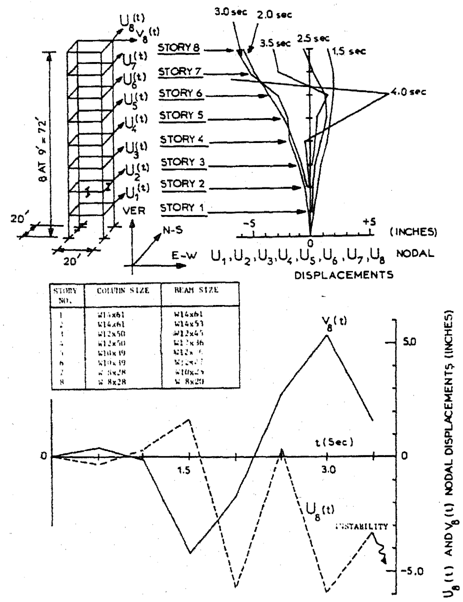


FIGURE 2 APPROXIMATE INTERACTION SURFACE AND INTERACTION CONTOUR



STORY NO.	COLUMN SIZE	BEAM SIZE
1	W10x31	W8x40
2	W10x31	W8x40

FIGURE 3 DYNAMIC RESPONSE OF TWO-STORY SPACE FRAME SUBJECTED TO 1940 EL CENTRO EARTHQUAKE (N-S, E-W & VERTICAL COMPONENTS)



STORY NO.	COLUMN SIZE	BEAM SIZE
1	W14x61	W14x61
2	W14x61	W14x53
3	W12x50	W12x45
4	W12x50	W12x36
5	W10x39	[illegible]
6	W10x39	[illegible]
7	W 8x28	W10x25
8	W 8x28	W 8x20

FIGURE 4 DYNAMIC RESPONSE OF EIGHT-STORY SPACE FRAME SUBJECTED 1940 EL CENTRO EARTHQUAKE (N-S,E-W, VERTICAL COMPONENTS)