DUCTILITY BEHAVIOUR OF REINFORCED CONCRETE FRAMES

L.R. Gupta[I] and Brijesh Chandra[II]

SUMMARY

This paper presents an approach of nonlinear analysis of reinforced concrete frames subjected to combined vertical and lateral loads. Both material and geometrical nonlinearities have been included in the analytical model. The analysis also includes the effect of confinement in steel binders. Deflection ductility factor of a frame is defined here on the basis of lateral deflection at working load.

Three different categories of single bay one storeyed reinforced concrete frames - strong column weak beam, column and beam of comparable sections and weak column - strong beam, initially designed for vertical loads alone, have been considered in the present investigation. The study indicates that strong column - weak beam design concept is more suitable for earthquake resistant design.

ANALYTICAL MODEL

In order to develop an analytical model to find the lateral load deflection relation of a frame under the constant vertical load, the following assumptions are made in addition to the usual assumptions in the analysis of reinforced concrete frames.

1. The plastic hinges are formed at the ends of the members and yielded length is approximately 1/5th of the member length.
2. Axial and shear deformations in the beam and column are considered.
3. Ultimate strain in concrete cover is 0.003.
4. Ultimate strain in confined concrete is assumed as given by Corley (2), and its stress-strain curve is as represented by Vallenas, et al.(5).
5. Strain variation over the cross section is linear.
6. Tensile steel has strain hardening in its stress-strain curve, while strain hardening in case of compression steel is not considered.
7. The reduction in frame stiffness due to vertical loads and changes in geometry is approximated by the use of a consistent geometrical stiffness matrix which includes the $P - \Delta$ effect.

SECOND ORDER ELASTIC ANALYSIS

In this analysis, the stiffness matrix $[k]$ of an element is given as

$$[k] = [k_1] + [k_2] \qquad \ldots (1)$$

I Senior Research Fellow
II Professor

Department of Earthquake Engineering, University of Roorkee, Roorkee, U.P., INDIA

where $[k_1]$ is the first order local stiffness matrix, and

$[k_2]$ is the nonlinear local geometrical stiffness matrix based on an assumed cubic displacement pattern (1).

The remaining analysis proceeds along conventional lines adopted for plane frames.

CROSS SECTIONAL ANALYSIS

Considering the known values of moment and axial force from the elastic analysis, strain distribution over the section is established. The procedure of the cross-sectional analysis to obtain resultant axial force and moment is similar to that adopted by Kroenke, et al. (3) except that stress-strain relationship (5) for the confined concrete as shown in Fig.1 and the shape of the steel stress-strain curve (4) as shown in Fig.2 are considered.

COMPUTATION PROCEDURE

The lateral load-deflection curve of a reinforced concrete frame is obtained in successive steps of lateral loads upto collapse. The second order elastic analysis and the cross-sectional analysis are coupled together and an iterative procedure is followed to achieve the requirment of equality of the determined forces in the elastic and the cross sectional analysis.

DUCTILITY FACTOR

There are several definitions of ductility factors based on deflection, curvature or strain. In the present study, the deflection ductility factor is defined as the ratio of acceptable lateral deflection (corresponding to first yield) to the lateral deflection at working load.

EXAMPLES

The following three types of single bay, one storeyed reinforced concrete frames, initially designed for vertical loads alone and based on Indian Standard Specifications are considered.

1. Strong column - weak beam (SCWB)
2. Column and beam of comparable section (CBC)
3. Weak column - strong beams (WCSB)

Geometric and material properties of each frame are listed in Table 1.

RESULTS AND DISCUSSION

For a structural analyst, it is easier to determine safe working load rather than the load deflection curve. Hence in this study, the definition of deflection ductility factor based on working load has been suggested. The deflection ductility factor for the three different frames are shown in Table 2. Lateral load carrying capacity at first yield for the three frames are also given in the same table. Results of this analysis show that SCWB type frame has ductility 37% less while lateral load carrying capacity is 76.8% more than the values for WCSB type frame, and CBC type frame has ductility 35.2% less while lateral load carrying capacity is only46% more than the values for WCSB frame.

CONCLUSIONS

In connection with the restoring force characteristics, which is the basis of the aseismic design of frames, the behaviour of frames under varying horizontal loads in addition to the constant vertical load has been investigated. Definition of ductility factor based on safe working load is suggested which is easier to be employed by a structural designer. A strong column - weak beam type frame gives the best results for lateral load carrying capacity while a weak column strong beam type frame gives the best results for ductility. However, on the whole, strong column - weak beam design concept is more appropriate than any other type of frame.

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REFERENCES

1. Aas - Jakobsen, K. and Grenacher, M., 1974, Analysis of Slender Reinforced Concrete Frames, IABSE, Vol. 34-I, pp.1-17.

2. Corley, W.G., 1966, Rotational Capacity of Reinforced Concrete Beams, Journal of the Structural Division, ASCE, 92, No.ST 5, pp.121-146.

3. Kroenke, Wayne C., Gutzwiller, Martin J. and Lee, Robert H., 1973, Finite Elements for Reinforced Concrete Frame Study, Journal of the Structural Division, ASCE, Vol. 99, No.ST 7, pp. 1371-1390.

4. Park, R. and Paulay, T., 1975, Reinforced Concrete Structures, John Wiley and Sons, New York, pp.229-230.

5. Vallenas, J., Bertero, V.V. and Popov, E.P., 1977, Concrete Confined by Rectangular Hoops and Subjected to Axial Loads, Earthquake Engg. Research Center, Univ. of California, Berkeley, Report No.UCB/EERC-77/13.

TABLE 1 - GEOMETRIC AND MATERIAL PROPERTIES

Frame	Beam to Column Stiffness	Nominal Dimensions							
		Span	Height	Beam			Column		
		L cm	h cm	b cm	t cm	d cm	b cm	t cm	d cm
SCWB	0.2276	700	350	30	50	46	30	65	59.8
CBC	1.185	700	350	30	60	55.8	30	45	40.5
WCSB	4.0	700	350	30	60	55.8	30	30	25.5

Frame	Longitudinal Bars (Percentage of Steel)							
	Beam				Column			
	End Section		Mid Section		Top		Bottom	
	Outer	Inner	Outer	Inner	Outer	Inner	Outer	Inner
SCWB	1.422	1.422	0.711	1.067	1.094	1.094	0.448	0.448
CBC	0.721	0.135	0.48	1.073	1.717	1.717	0.776	0.776
WCSB	0.375	0.135	1.126	1.261	3.157	3.157	1.232	1.232

Frame	Lateral Ties and Stirrups					
	Beam				Column	
	Near Ends		Mid Span			
	Dia.(cm)	Spacing(cm)	Dia.(cm)	Spacing(cm)	Dia(cm)	Spacing(cm)
SCWB	1.0	8.0	.6	25	.8	25
CBC	1.0	9.5	.6	25	.6	25
WCSB	1.0	10.0	.6	25	.8	25

Material Properties (same for all the three frames)

γ kg/m^3	σ_c' kg/cm^2	E_c kg/cm^2	E_s kg/cm^2	σ_y kg/cm^2	σ_u kg/cm^2	ϵ_{SH}/ϵ_y	ϵ_u %
2400	120	1.125×10^5	2.1×10^6	2600	4200	12	23

γ : Unit weight of concrete, σ_c' : Cylinder strength of concrete
E_c : Modulus of elasticity of concrete, E_s: Modulus of elasticity of steel
σ_y : Yield strength of mild steel, σ_u : Ultimate strength of steel,
ϵ_{SH} : Strain at onset of strain hardening, ϵ_y: Yield Strain, ϵ_u: %age elongation.

TABLE - 2

Frame	Deflection Ductility Factor	Lateral Load Carrying Capacity w.r.t. First Yield (kg)
SCWB	2.15	9900
CBC	2.21	8175
WCSB	3.41	5600

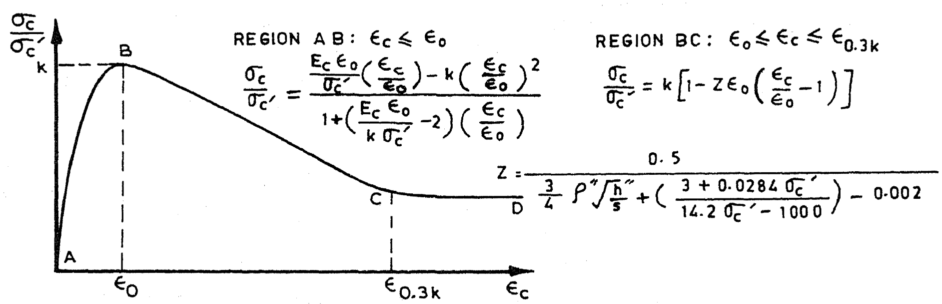

Fig. 1_ Stress strain curve for confined concrete(5)

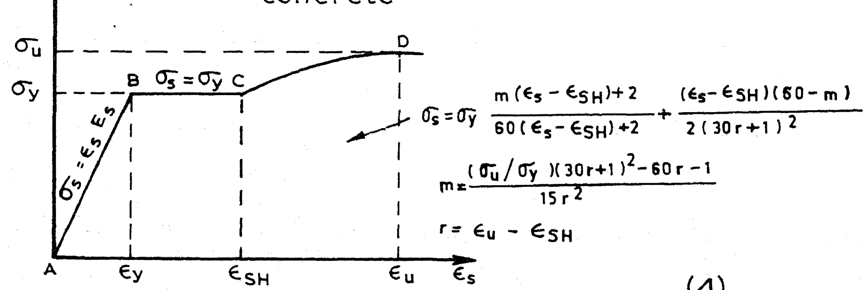

Fig. 2_ Stress-strain curve for steel(4)