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Displacement Controlled Analysis of RC Columns by M-φ Technique

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1. Introduction

Research for the analysis of reinforced concrete structures is being carried out by using different complicated methods (e.g. 2-D or 3-D Analysis) with distributed crack, smeared crack approach, etc. These approaches generally consume lot of computational time. In this paper, simple analytical method using sectional property of moment-curvature relationship is used to developed an algorithm for the analysis of reinforced concrete members. Displacement control algorithm with inelastic material properties is implemented. This program[1] was used successfully in simulating members without having axial load. In this paper steel stress-strain diagram is modified to get better convergence to successfully simulate the members behavior with axial load. This program is applied to compare with experimental results of a cantilever RC column[2] that had Pre-cast Panels(PPC) used as form work. The PPC panels were made of high strength concrete (50N/mm^2) whereas the core was made of normal strength concrete(24N/mm^2). Analysis of members with and without axial load cases are presented.

2. The Material Properties

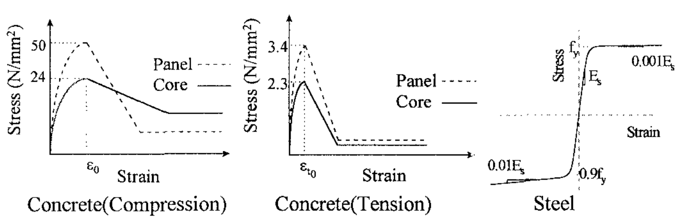

Fig. 1: Material properties for concrete and steel

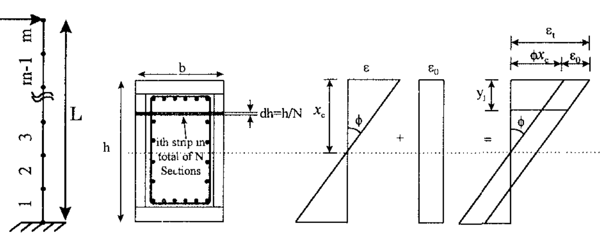

Fig. 2: Element and its Details

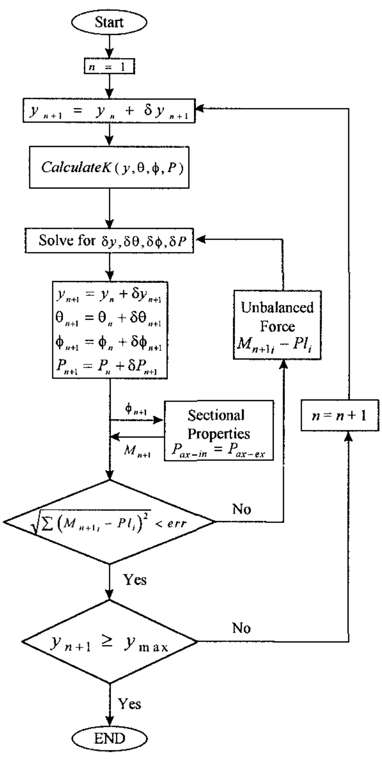

Fig.3: Program Flowchart

For concrete, two different material properties were used as shown in Fig. 1. Perfect bond between PPC panel and core concrete has been assumed. For the PPC panel concrete, compression stress-strain diagram with less ductility is assumed whereas for the core concrete, compression stress-strain diagram with higher ductility is assumed. For reinforcement in tension, lower apparent yield strength ($f_y' = 90\%$ of the actual yield stress) and higher post peak slope (0.01E$_s$) has been assumed[3] to take care of tension stiffening effect. In order to make continuity in pre-peak and post peak lines, smooth curve has been applied[3] at the discontinuity as shown in Fig. 1. This makes program running for axial load case. In compression nominal slope (0.001E$_s$).is assumed after yield stress in tension, for stability in the analysis.

3. Analysis using Sectional Properties

Column, as shown in Fig. 2, of height L is divided into *m* elements. Element cross-section has been divided into N number of strips. On each i^{th} node, deflection y_i, slope θ_i, curvature ϕ_i and bending moment M_i are to be calculated. For ϕ_i, M_i can be calculated from M-φ property of the cross- section. It is assumed that plain section remains plain before and

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after bending. Displacement control program is implemented, with displacement applied at the top of the column.

3.1 Stiffness Matrix Formation:

The strain in j_{th} strip of a section is

$$\delta\varepsilon_j = \delta\varepsilon_{t_i} - y_j\delta\phi_i \quad (1)$$

Applied axial force P_{ax} is assumed to be constant.

$$P_{ax} = \sum_{j=1}^{N}\sigma_j A_j \Rightarrow \delta P_{ax} = \sum_{j=1}^{N}\delta\sigma_j A_j = 0 \Rightarrow \sum_{j=1}^{N}\frac{\partial\sigma}{\partial\varepsilon_j}\delta\varepsilon_j A_j = 0 \quad (2)$$

$$\Rightarrow \delta\varepsilon_t = \left(\sum_{j=1}^{m}\frac{\partial\sigma_j}{\partial\varepsilon_j}A_j\delta y_j \Big/ \sum_{j=1}^{m}\frac{\partial\sigma_j}{\partial\varepsilon_j}A_j\right)\delta\phi_i \quad (3)$$

From equilibrium of bending moment, we get

$$\delta M_i = \sum_{j=1}^{m}\delta\sigma_i A_j\left(\frac{h}{2}-y_j\right) = \sum_{j=1}^{m}\frac{\partial\sigma_j}{\partial\varepsilon_j}A_j\left(\frac{h}{2}-y_j\right)\delta\varepsilon_i \quad (4)$$

by substituting, Eq 1 and Eq 3 into Eq 4, we can simplify to $\delta M_i = B_i\delta\phi_i$. The balance of external and internal moments at the section($M_i = Pl_i$) in incremental form can be written as

$$\delta M_i - \delta Pl_i = B\delta\phi_i - \delta Pl_i = 0 \quad (5)$$

The deflection y, rotation θ and curvature ϕ in incremental form can be related as

$$\delta y_{i+1} - \delta y_i - \frac{\Delta l}{2}(\delta\theta_{i+1} + \delta\theta_i) = 0 \quad (6)$$

$$\delta\theta_{i+1} - \delta\theta_i - \frac{\Delta l}{2}(\phi_{i+1} + \phi_i) = 0 \quad (7)$$

Eq 5,6 and 7 are used to formulate the stiffness matrix. Fig . 3 shows the flow chart of the program. We get y_i, θ_i, ϕ_i at each node as nodal variables and applied P as a global variable. Internal bending moments M_i can be calculated at each node for the calculated curvature ϕ_i based in internal equilibrium of axial force(Eq 2). Since this internal moment is calculated based on non-linear material properties, unbalanced moment is taken as input for further iteration till the convergence between internal and external moment is achieved as shown in the flowchart(Fig. 3).

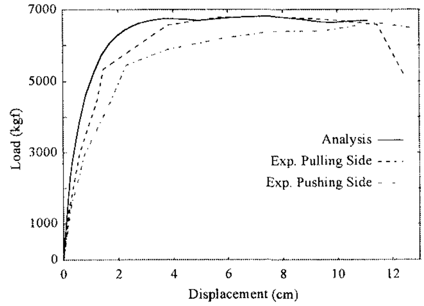

Fig. 4: Comparison of analysis and experimental results without axial load

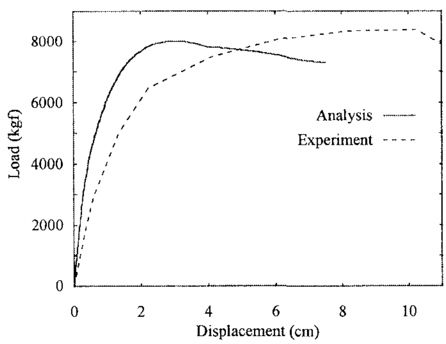

Fig. 5: Comparison of analysis and experimental results with axial load

3.2 Comparison with Experimental results

Experimental results[2] of the columns of height 275cm and cross section of 45.0cm x 30.0cm casted with 3cm thick PPC panels as form work are used to compare with the analytical result. The axial load of $1.85 N/mm^2$ is applied. Cyclic displacement was applied at the tip of the column specimen. Comparison of analytical results with envelop curve obtained from the experiments without and with axial load are shown in Fig. 4 and 5 respectively. It can be seen that for no axial load(Fig. 4), the analytical result matches well with the experimental results but in axial load case the peak load is matching but displacements are not so promising. The possible reason can be the amount of displacement due to the pull out effect. Further work is going on to improve the results for axial cases.

4. Conclusion

Analysis of the RC column has been done using cross-sectional property of M-ϕ relationship. Using displacement controlled algorithm, program has been made incorporating phenomena like confinement of concrete and tension-stiffening effect. The analytical results of specimens without and with axial load are compared with experimental results. It can be seen that analytical results of the specimen without axial load has nice matching with experimental results but for the case of specimen with axial load the peak load is matching but displacements are not so promising. Further work is going on to improve the results for specimen with axial load.

References

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