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A Methodology to Model Local Nonlinearities in a Slender Reinforced Concrete Member Subjected to Seismic Deformations

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ABSTRACT

A methodology is proposed for modeling local nonlinear behavior of slender reinforced concrete members. The nonlinearity is modeled by two orthogonal assemblages of nonlinear truss elements representing the nonlinear behavior of concrete and steel reinforcement. The trusses represent narrow strips of concrete to closely calculate the section neutral axis. This modeling procedure is computationally very efficient for seismic nonlinear dynamic analysis. Such a model is used to evaluate a critical column framing a door opening of a nuclear exhaust stack building subjected to seismic motions.

1 INTRODUCTION

When a slender reinforced concrete (RC) member is subject to end displacements/rotations due to dynamic motion of connected structural elements, yielding of reinforcement will usually occur in localized areas, while the rest of the member will behave linearly. The highest moments, which usually occur at the top or bottom of the RC member will cause local yielding of reinforcement (plastic hinge) which in turn will limit the amount of moment that could be passed through these hinges. Assuming that tension is primarily taken by reinforcement steel and compression is resisted by concrete section, it is essential that the model of the local nonlinear region of the slender member accurately represents the location of the neutral axis of the member for each time step. This requires using a large number of elements representing the cross section for the length of the plastic hinge. Representing the plastic hinge as solid elements with concrete material behavior are not computationally feasible for dynamic seismic analysis.

A computationally efficient methodology is proposed here for representing local nonlinear behavior of slender RC members. Such a model may be utilized to compute curvature ductilities in the plastic hinges and has been used in this study to seismically evaluate a critical column of a nuclear exhaust stack facility.

2 DESCRIPTION OF THE STRUCTURE

The RC column is placed in a wall of a room which is at the extreme edge of the

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stack building as shown in Figure 1. The column frames a 10 ft x 8 ft door. There is also a large 9.5 ft x 19.5 ft duct opening in this wall. Linear SSI analyses indicated that the responses in this wall is displacement driven from the massive stack building. The displacements resulted in large shears and moments in the RC pier and column which did not have enough capacity to resist these forces linearly. Upgrading the pier and column proved to be difficult, costly and requiring a long schedule. A detailed nonlinear dynamic analysis was, therefore, performed to show that the column has enough ductile capacity to resist the imposed motions.

3 ANALYSIS APPROACH

The SSI model, used for obtaining responses of the stack building, was linear and very large. To implement a nonlinear analysis with such a large model was not cost effective. This was resolved by a substructuring approach, whereby a modified equivalent linear elastic structural model was used in the SSI analysis to calculate relative displacements along the perimeter of the above-mentioned wall. These relative displacements were then imposed on a detailed nonlinear model of the wall to calculate the post yield gravity and seismic demand on the pier and column in the wall.

4 NONLINEAR MODEL

The detailed wall and column model is shown in Figure 2. The wall is modeled with quadrilateral linear elastic plate elements. The column and pier are modeled with linear elastic beam elements, which were connected to the wall plate elements by a nonlinear assemblage of elements, described below, to model the plastic hinges. This modeling procedure assumes that the only nonlinearity expected to develop in the wall is the plastic hinges at the top and bottom of the pier and column. This is a reasonable assumption to make because the column and pier will bend in double curvature and the maximum moments will occur at the two ends.

The plastic hinges at the top and bottom of the pier and column about each horizontal axis are modeled by an assemblage of nonlinear truss elements, as shown in Figure 3. Strips of concrete were modeled by nonlinear truss elements with compression only stress strain relations. Steel reinforcement in a strip is modeled by a nonlinear truss element with multi-linear stress strain relationship in tension and compression. These stress-strain curves are also shown in Figure 4. In order to capture the proper location of neutral axis of the plastic hinge, a large number of truss elements are used in two orthogonal directions. The shear transfer through the plastic hinge area is modeled by a linear beam element. End release conditions are specified for the beam element to avoid any moment and axial load transfer.

Before using the plastic hinge RC model, it was verified that the hinge produces the proper nonlinear moment-curvature relationship. For this purpose, the column section was input to the program RCCOLA (Mahin, 1977), which calculates the nonlinear moment-curvature relationship for any section. The plastic hinge model was then subjected to increasing moments and the curvature is computed using program ADINA (ADINA, 87). Figure 5 shows a good match-up of the curvatures.

5 ANALYSIS AND RESULTS

The nonlinear analysis is performed using the ADINA code, and is implemented in two stages. The first stage calculated the gravity forces by applying the relevant relative displacements at the wall boundaries from the gravity analysis of the entire building. The second stage is to impose seismic relative displacement time histories to the periphery of the wall. A dynamic nonlinear analysis was performed using direct step-by-step integration method with full Newton-Raphson convergence compliance check at every five steps. Figure 6 presents the curvature ductility time history for the column at the plastic hinge. Ductility values below 1.0 indicate that the column is within its elastic capacity for the combined moment and axial force demand values. The two pulses that develop plastic hinges require very small curvature ductilities compared to the available ductility. The maximum ratio of demand to available ductility is 0.3.

6 CONCLUSIONS

The following conclusions can be drawing from this study:

(1) The assemblage of nonlinear truss systems properly represents the plastic behavior of a RC column end section and is a cost-effective, numerically efficient approach to model such local nonlinearities.

(2) A modified substructuring approach, which utilized a global model to obtain boundary displacements in a local area and then used a local detailed nonlinear model subjected to these boundary displacements to obtain localized nonlinear stresses, is a cost-effective way to handle localized nonlinearities.

REFERENCES

Mahin, S.A., et. al. (1977), RCCOLA: A Computer Program for Reinforced Concrete Column Analysis, University of California, Berkeley.

ADINA R&D, Inc. (1987), ADINA: A Finite Element Program for Automatic Dynamic Incremental Nonlinear Analysis, Watertown, Massachusetts.

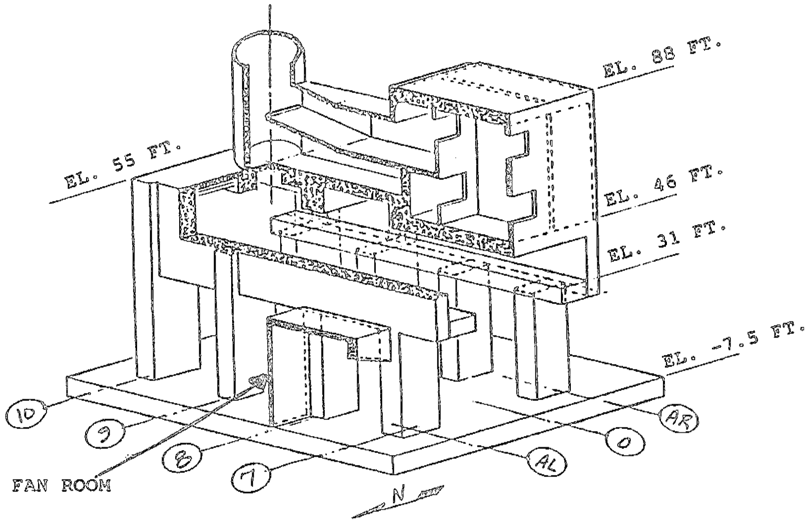
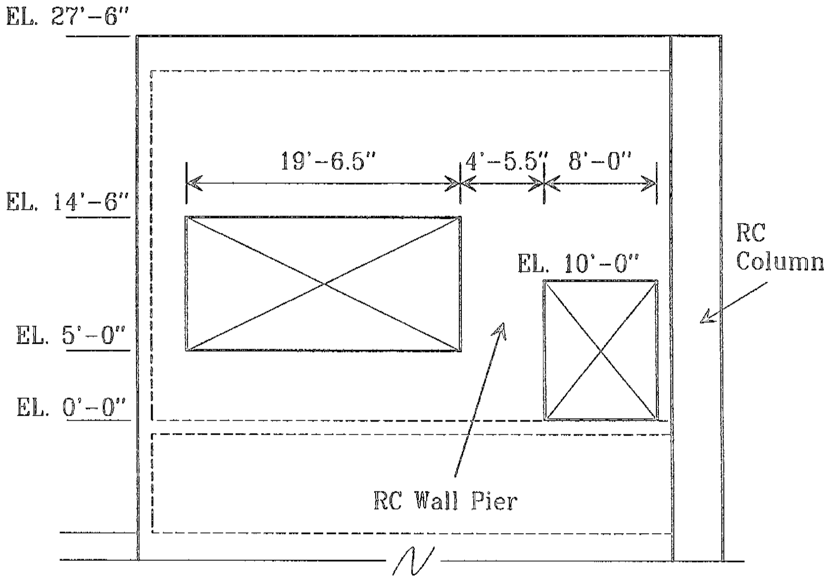
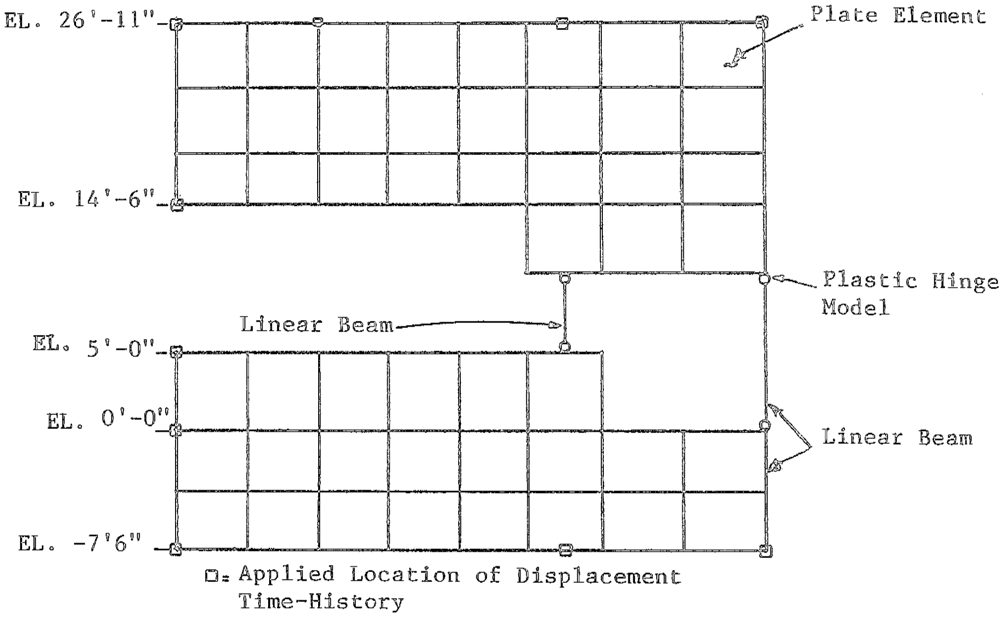


FIGURE 1 ISOMETRIC VIEW OF 105-K STACK BUILDING AND FAN ROOM



a) Fan Room North Wall Elevation



b) Fan Room North Wall Model

FIGURE 2 FAN ROOM NORTH WALL NONLINEAR ANALYSIS

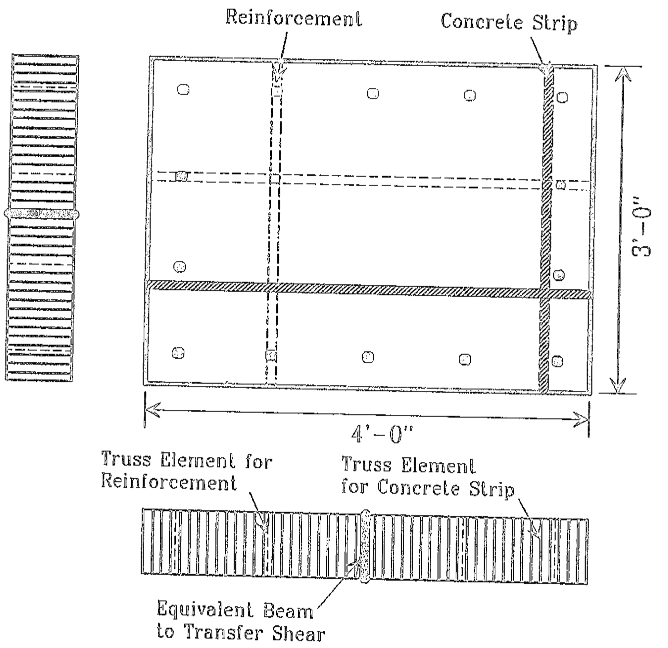
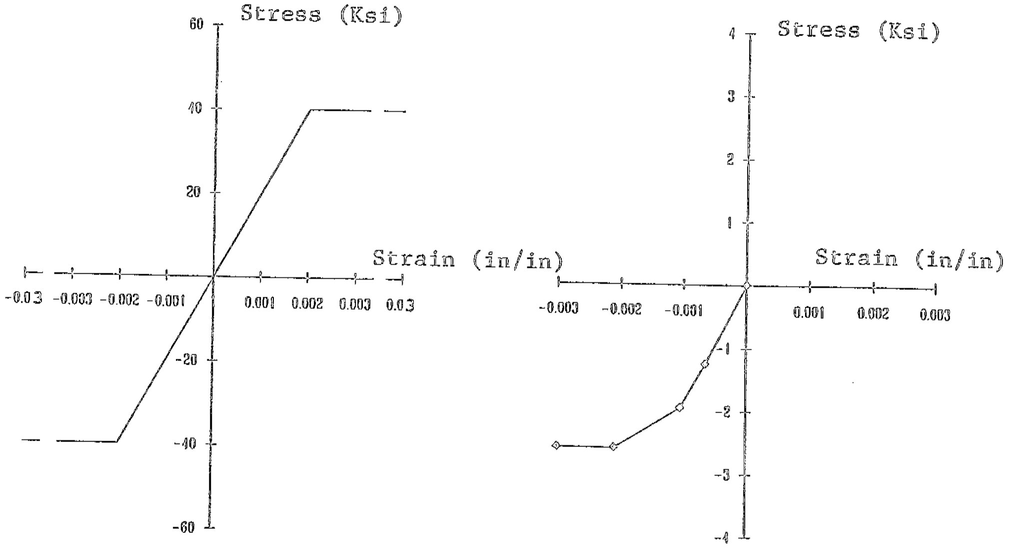


FIGURE 3 COLUMN SECTION AND PLASTIC HINGE MODEL



a. Steel Truss Element

b. Concrete Truss Element

FIGURE 4 STRESS-STRAIN CURVES FOR CONCRETE AND STEEL TRUSS ELEMENTS

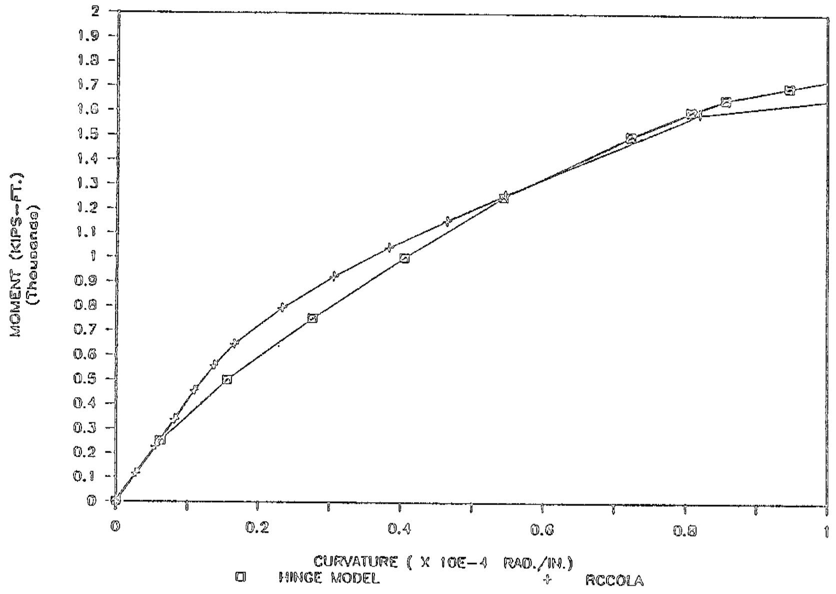


FIGURE 5 COMPARISON OF MOMENT-CURVATURE RELATIONSHIPS GENERATED BY ADINA HINGE MODEL AND RCCOLA SECTION MODEL

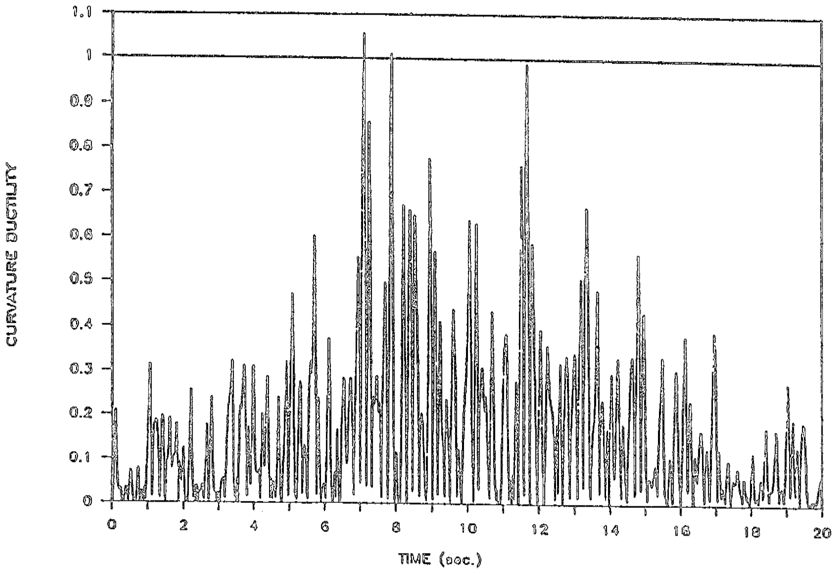


FIGURE 6 FAN ROOM COLUMN CURVATURE DUCTILITY