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Response of an existing RC building including concrete crushing and bond slip effects

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ABSTRACT

The lateral capacity of a three storeys reinforced concrete (RC) building was assessed using pushover analysis. Several cases were studied to determine the effect of including concrete crushing, bond slip failure and beam-column joint shear deformation. The results showed the importance of including all failure modes to be able to assess the building behaviour. It showed also that the selected building behaviour is mainly affected by bond slip failure.

INTRODUCTION

In order to design the most appropriate rehabilitation system, the lateral load capacity and mode of failure of existing reinforced concrete (RC) buildings need to be evaluated. Existing structures may have inadequate lateral strength and/or ductility. Inadequate lateral strength results from the design according to earlier codes that either did not include seismic provisions or specified lower levels of seismic loads. Inadequate ductility results from the nonductile detailing which includes insufficient confinement and deficient lap splices. To assess the behaviour of an existing structure, the analytical model should be capable of representing all design and detailing deficiencies and potential failure modes. The objective of this study is to assess the behaviour of an existing RC building using a model that is capable of representing beam-column joint shear deformation, concrete crushing and bond slip failure.

MODEL DESCRIPTION

The developed model (Youssef and Ghobarah, 1999; Ghobarah and Youssef, 1999, Youssef and Ghobarah, 1998) is a macro model that accounts for beam-column joint shear deformations. Each member is represented using an elastic element and two inelastic elements. Each inelastic element consists of three concrete springs and three steel springs. The beam-column joint shear deformation is idealized using shear springs. The model is capable of idealizing the component failure due to cumulative concrete crushing, bond slip or beam-column joint shear failure. The developed model was verified using test results on specimens representing existing structures.

BUILDING DESCRIPTION

A three storey reinforced concrete office building was designed to represent existing nonductile buildings. The building was designed for gravity loads only according to the 1963 ACI code (ACI 318-63). The concrete strength is 21 MPa and the steel yield strength is 300 MPa. Typical floor plan, elevation and cross sections of the office building are shown in figure 1. Nonductile critical regions in the building include: beam bottom longitudinal reinforcement embedded 150 mm into the beam-column joint, widely spaced transverse reinforcement in beams and columns, column lap splices (20 bar diameter) located just above the floor level and no transverse reinforcement in the joints.

To evaluate the effect of various behavioral parameters and the potential mode of failure on the response of the building, a number of cases of three storey frames were analyzed. The effect of ignoring any of the failure criteria was studied. Ignoring bond slip softening was done by assuming the steel spring element to remain bilinear with the yield force calculated based on the bond slip behaviour. Concrete softening was ignored by assuming the degrading slope Z equal to zero. The three storey frame was analyzed six times, each case represents the effect of ignoring one or more of the joint shear deformation, concrete softening and bond slip softening. To differentiate between the different cases in the text and figures, the following symbols will be used, R for rigid joints; F for flexible joints (including joint shear deformation); B for including bond slip softening; NB for ignoring bond slip softening; S for including concrete softening and NS for ignoring concrete softening. For example, frame R-NB-S means that this frame was analyzed using rigid joints, bond slip softening was not included and concrete softening was included.

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PUSHOVER ANALYSIS

The purpose of the nonlinear pushover analysis was to identify the lateral strength of the structure and its behaviour under static load. The three storey frame was subjected to an increasing monotonic lateral load simulating the seismic base shear. The lateral load was distributed over the height of the building as shown in figure 1.

Overall displacements and drifts

Figure 2 shows the base shear-roof displacement relationships for the six cases studied. It is clear from the figure, that bond slip softening has major effect on the behaviour of this frame. The figure shows that the six cases are divided into two groups depending on whether bond slip softening was considered or not. Ignoring bond slip softening increased the ultimate load by about 24%. The effect of joint shear deformation and concrete softening on the overall displacement behaviour was minor especially after reaching the yield load. This could be attributed to the high deformation that developed due to the flexural behaviour in the columns.

Figures 3a and 3b shows the distribution of storey displacement and interstorey drift along the height of the building for cases in which bond slip softening was taken into account at load level of 234 kN. Figure 3a shows that the F-B-S case incurred the highest storey displacements followed by F-B-NS then R-B-NS then R-B-S. Figure 3b shows that the effect of concrete softening was higher than the effect of joint shear deformations.

Figure 4 shows the distribution of storey displacements and interstorey drift along the height of the building for cases in which bond slip softening was not taken into account at load level of 262.5 kN. The figure shows that in this particular frame design, the effect of the joint shear deformation on the overall behaviour was small.

Failure mechanisms

Several investigations have been conducted on the modeling and behaviour of reinforced concrete (RC) buildings. However, the definition of failure is still a deficiency in most available models. Near collapse, it is often difficult to distinguish between numerical instability and structural instability (Ghobarah, 1998). In frame analysis, failure is defined by most researchers as steel yielding and using this concept plastic hinge distribution is defined. This is a crude assumption as concrete sections can carry loads after steel yielding.

Figure 5 shows the failure mechanism for the six studied cases. For cases with bond softening, the failure mechanism is a soft first storey. For cases without bond softening, failure is a combination of concrete crushing and excessive steel yielding. The failure in the frames shown in figure 5 are concentrated in the columns. Also, that bond slip softening is concentrated in the columns despite the fact that beam lap splices are shorter than column lap splices. This could be attributed to the fact that flexural capacities of the beams are higher than those of the columns. Failure in beams was limited to those beams connecting to exterior columns due to the high demands on those beams relative to the interior ones.

CONCLUSIONS

Results from the pushover analysis on the three storey frames indicated that the failure mode is mainly due to bond slip failure. Concrete softening and beam-column joint shear deformation did not affect the lateral strength. This means that the joint capacities are sufficient to transmit the shear forces without failure. Considering concrete softening, it is expected that it will have a major effect if the section is over reinforced or subjected to high axial loads. But most importantly, considering concrete softening is necessary to define the failure mechanism which will help in defining a suitable rehabilitation technique.

The results demonstrate the importance of including all potential modes of failure due to concrete crushing, bond slip and beam-column joint shear in the seismic assessment of structures. This is particularly important in the analysis of existing buildings with recognized inadequate lateral load resistance and poor detailing. The lateral load carrying capacity and the failure mode of the building can be obtained using the pushover analysis.

Finally, it should be mentioned that the presented results are based on a limited number of analyses on a specific frame. To establish general conclusions concerning the behaviour of gravity load designed frames, a more comprehensive study is needed.

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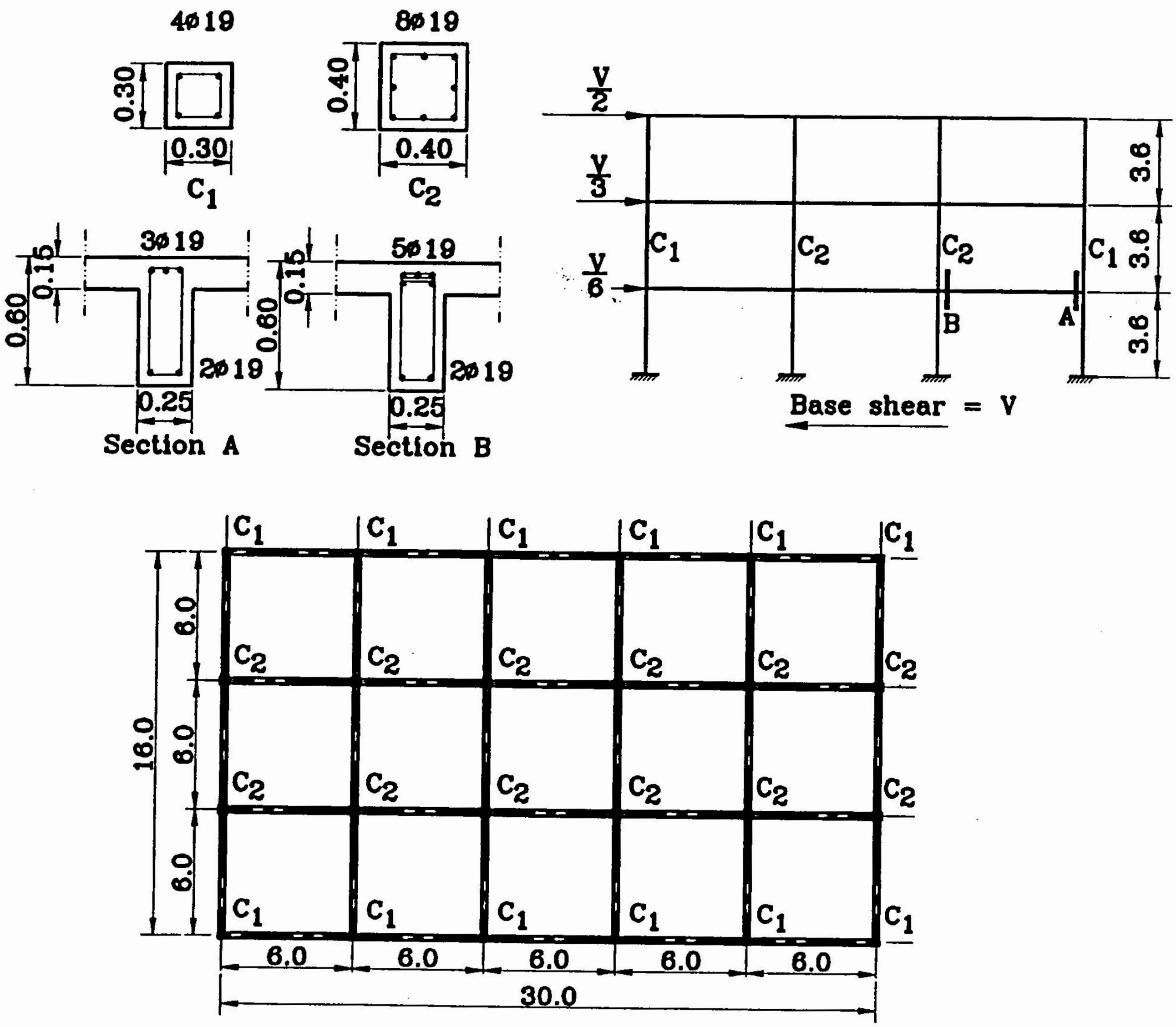

Figure 1 Details of the three storey building and lateral load distribution for pushover analysis

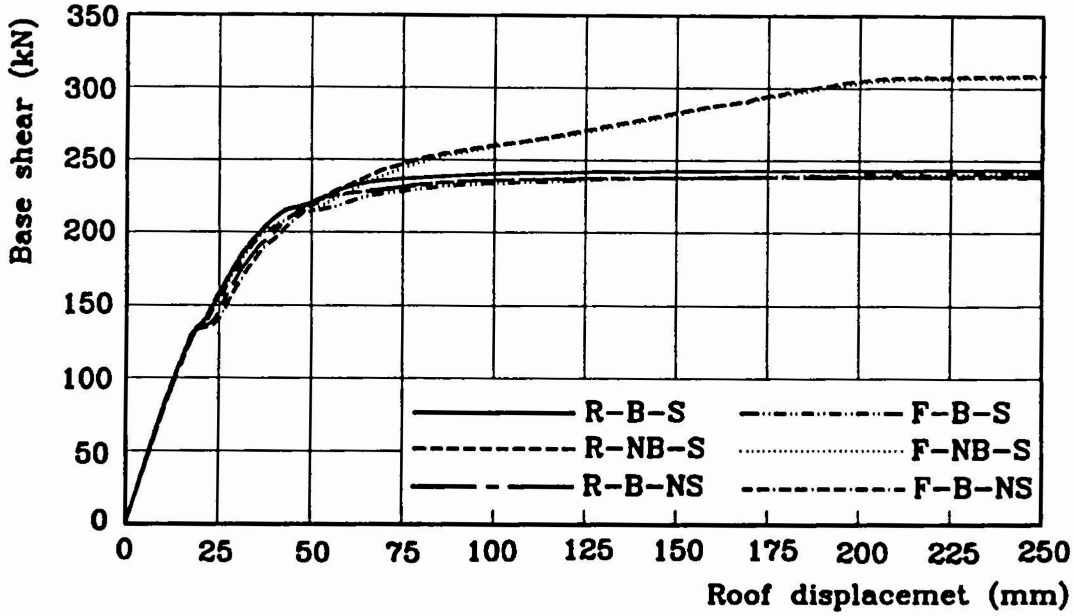

Figure 2 Base shear-roof displacement relationship from pushover analysis.

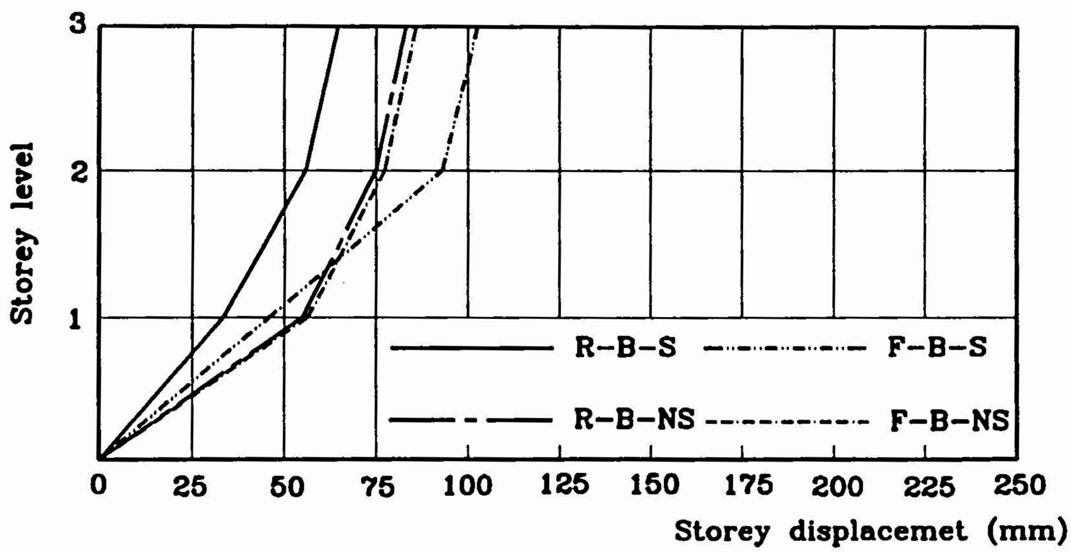

Figure 3a Storey displacement at load level 234 kN of the pushover analysis.

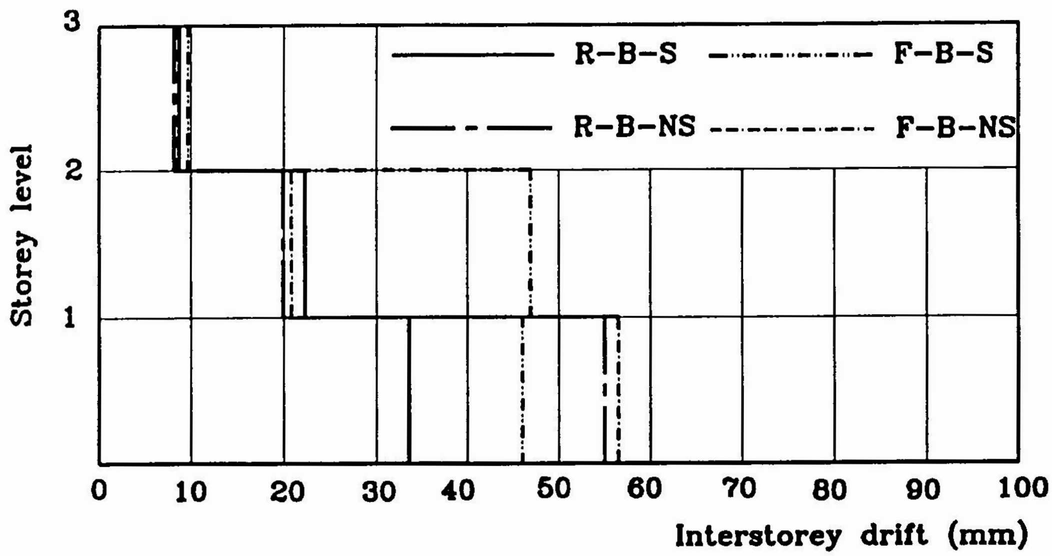

Figure 3b Interstorey drift at load level 234 kN due to the pushover analysis.

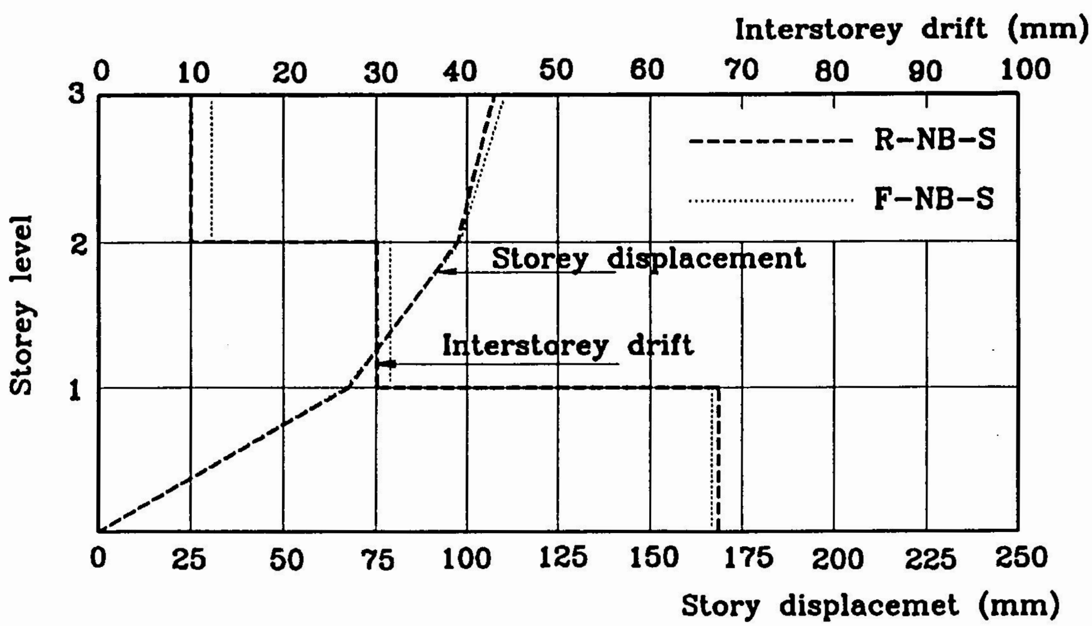

Figure 4 Storey displacement and interstorey drift at load level 262.5 kN of the pushover analysis.

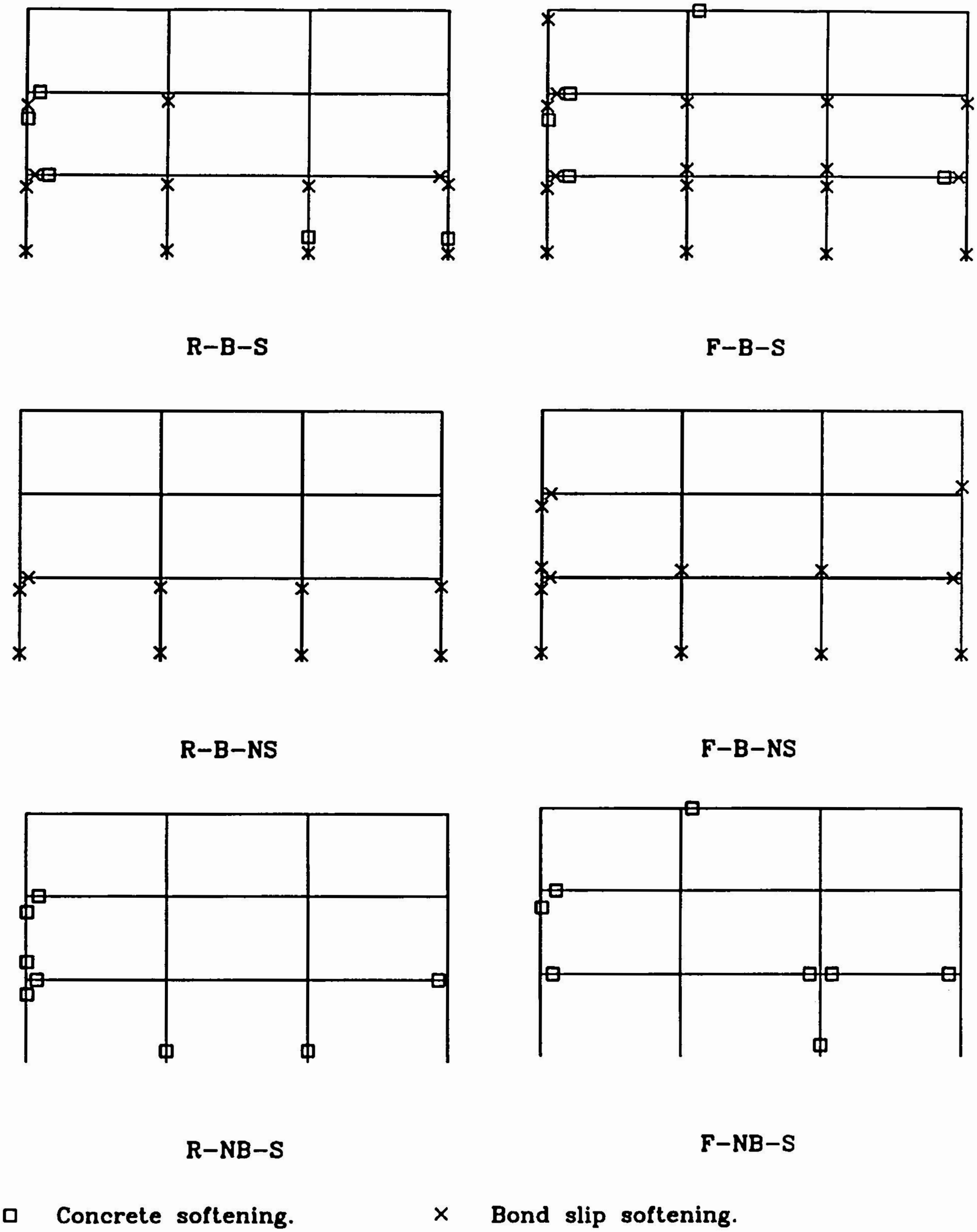

Figure 5 Failure mechanism from the pushover analysis.