Zeitschrift: IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen

Band: 13 (1973)

Artikel: Behaviour of multi-storey reinforced concrete frames subjected to severe reversing loads

Autor: White, Richard N. / Chowdhury, Asadul H.

DOI: https://doi.org/10.5169/seals-13769

IV

Behaviour of Multi-Storey Reinforced Concrete Frames subjected to Severe Reversing Loads

Comportement de cadres à plusieurs étages en béton armé soumis à des charges alternées importantes

Verhalten mehrstöckiger Stahlbetonrahmen unter starker Wechselbelastung

Richard N. WHITE
Professor
Dept. of Structural Engineering

Asadul H. CHOWDHURY
Graduate Research Assistant
Dept. of Agricultural Engineering

Cornell University
Ithaca, N.Y., USA

There have been numerous experimental studies undertaken on reinforced concrete beams and other elements subjected to reversing loads. In recent years increasing attention has been given to more complex structural geometries under the same type of loadings, such as member-joint assemblages and portal frames. The present discussion proceeds one step further in that it treats the behavior of three-story, two-bay reinforced concrete frames subjected to a fixed level of gravity load and reversing lateral loads that simulate earthquake forces.

The study has been conducted utilizing small scale models. The difficulties and expense of loading large multistory frames made the model approach the only feasible way to study the problem within a limited budget of a normal research project. Although models have been highly successful in a number of research projects at Cornell University on the inelastic performance of reinforced concrete structures, it was felt necessary to further substantiate their ability to portray all levels of the complex behavior encountered in multi-story frames under reversing loads. Therefore, a preliminary study was undertaken to compare the results of seven 1/10 scale models with full-scale prototype tests for beam-column joints of a building (Fig. 1 shows the model dimensions). The prototypes (Ref. 1) represented the exterior beam-column joint of a high rise building between column inflection points and the beam inflection point. The prototypes and models were loaded with reversing bending of the beam according to the following schedule:

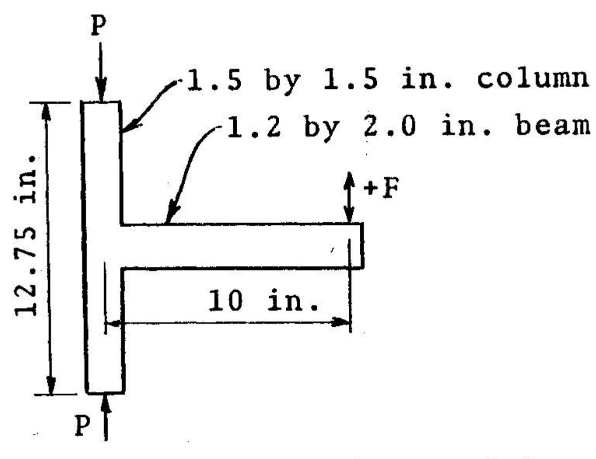


Fig. 1 - Beam-column model specimen geometry

Cycle:	1	2	3	4	5
D.F. :	3/4	2.5	4	3/4	3/4

Cycle:	6	7	8	9
D.F. :	3/4	5	5	5

where D.F. is the ductility factor, defined as the ratio of the total rotation at a length of one-half the beam depth from the critical section at maximum applied load to that at yield load. The column of each specimen was also subjected to simultaneous axial load.

The key to successful modeling of inelastic behavior of reinforced concrete structures is in meeting similitude requirements for model materials. Extensive development work was needed to obtain microconcretes with proper compressive and tensile strengths and stress-strain characteristics, and deformed model reinforcement with proper yield point and work hardening properties. Details on materials, as well as full reporting of model results, are given in Ref. 2.

Selected results are given in Figs. 2 and 3. Fig. 2 gives prototype and scaled model moment-rotation response for prototype specimen I-A for cycles 1, 2, 3, and 7. A comparison of major

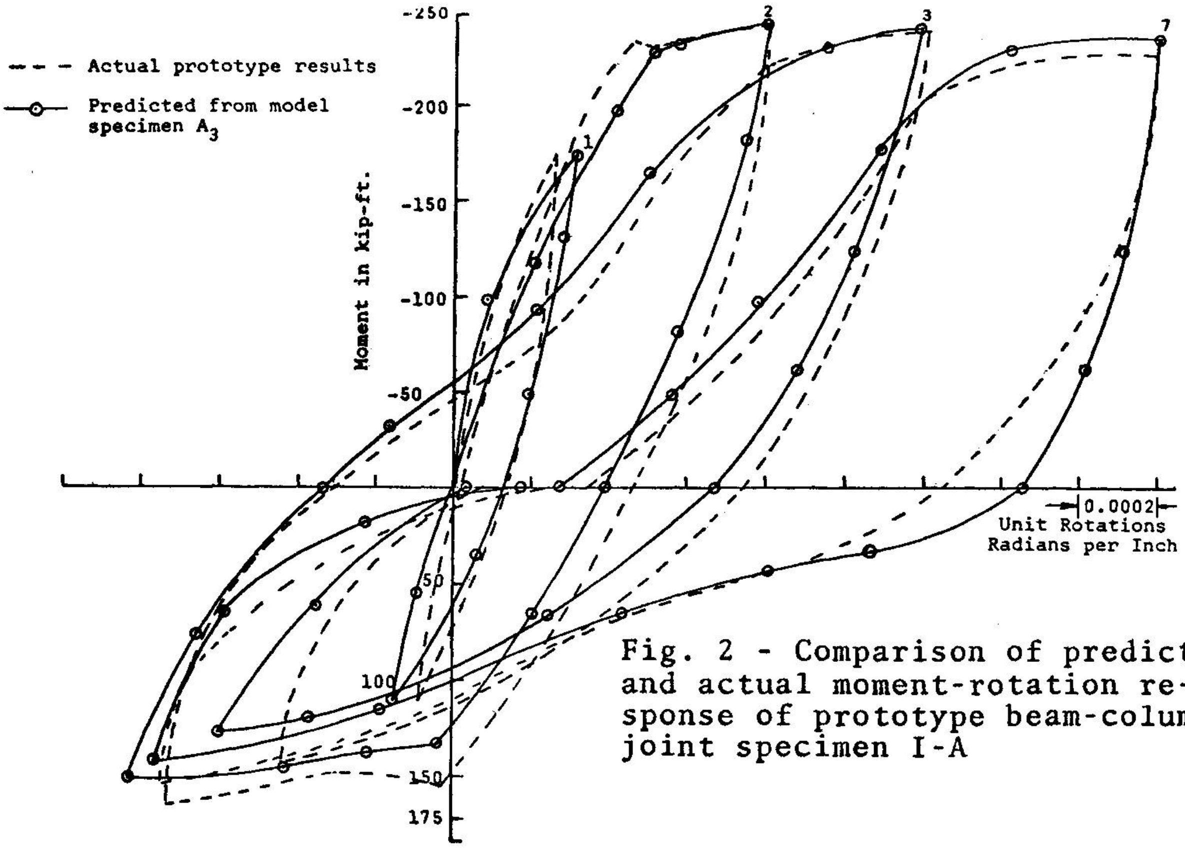


Fig. 2 - Comparison of predicted and actual moment-rotation response of prototype beam-column joint specimen I-A

cracking patterns for the same specimen is shown in Fig. 3; a remarkably similar pattern of cracking is evident in model and prototype. Model and prototype beam deflection correlations were equally good. These correlations are considered to be excellent in that identical prototype specimens would not be expected to compare any more favorably. Model predictions for beam and column reinforcing steel stresses and for other prototype specimen designs were also good to excellent. Diagonal cracking in the columns of some models was not modeled properly; in each case the model concrete compressive strength was some 15-20% higher than that of the prototype specimen. It is absolutely essential that the model material similitude requirements be met as closely as

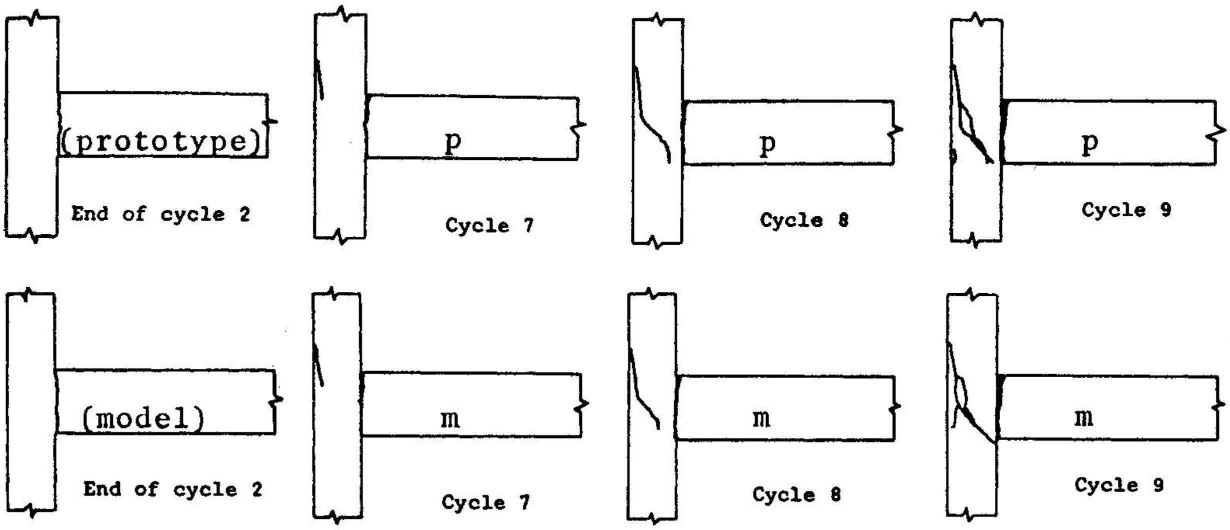


Fig. 3 - Crack patterns for Prototype I-A and model A3 at peak downward loadings (major cracks only)

possible for small scale modeling of complex inelastic reversing load effects.

The second part of this paper treats the behavior of 1/10 scale, three-story, two-bay reinforced concrete model frames subjected to combined gravity and lateral loads. One frame was loaded with 1.4 specified gravity load and a monotonically increasing lateral load up to failure. The second frame has the same gravity load and cyclic, reversing lateral loads of varying intensity. Defining the lateral load factor (LLF) as the ratio of applied lateral load to the design lateral load, the loading history is summarized on the next page. The model frame dimensions are given in Fig. 4.

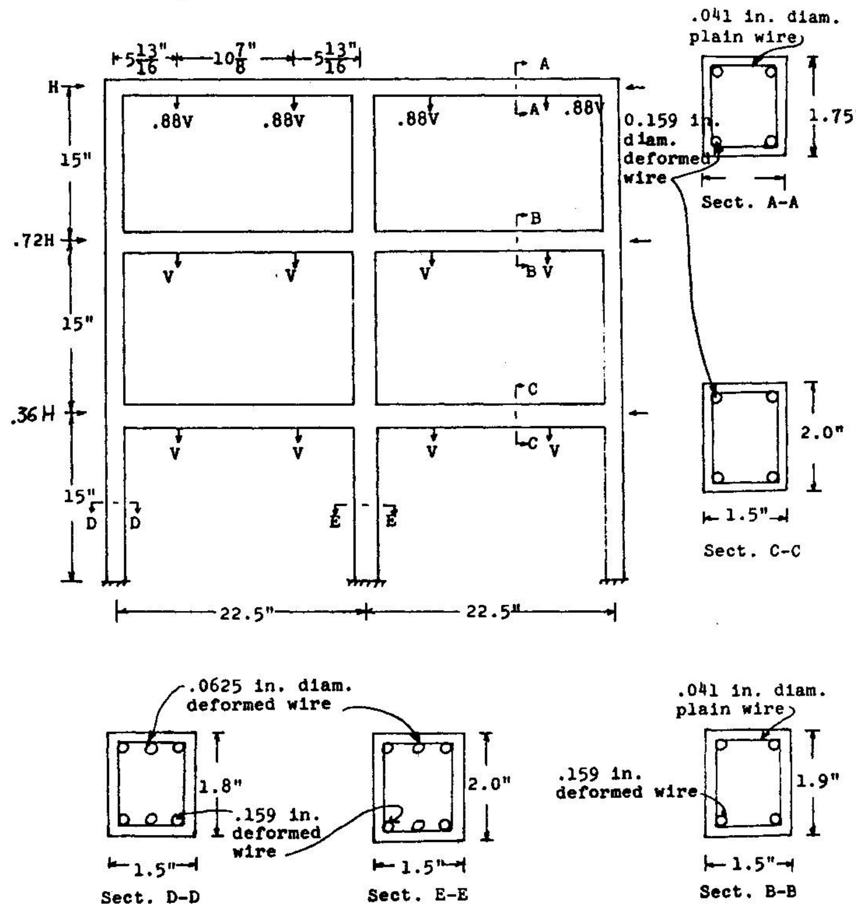


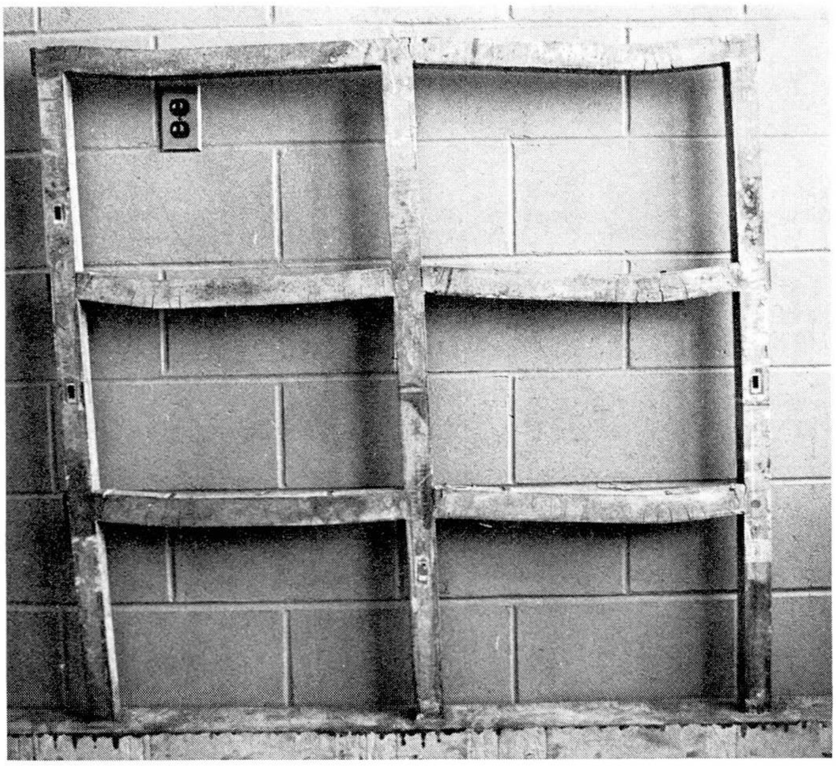
Fig. 4 - Frame details

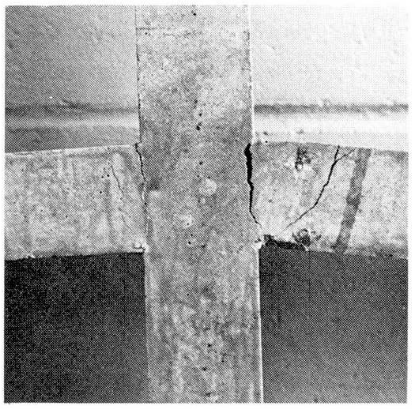
Cycle:	1	2	3	4	5	6	7	8	9
LLF:	1	3	3	3	3	5	5	5.5	6

The frames were designed to conform in all details to the requirements of the Structural Engineers Association of California Recommendations for Seismic Design. Selected results presented here include comparisons between the monotonically loaded and cyclically loaded frame, and comparisons with theory.

Details of the entire study, including the modeling techniques employed, are given in References 2, 3, and 4. Gravity loads were applied with gravity load simulators that allowed free translation of the frame. Lateral loads were applied with mechanical jacks that permitted rather precise control of the loading, even in the later cycles when behavior was highly inelastic.

The final cracking pattern of the frame subjected to nine cycles of lateral loading with a maximum lateral load factor of 6 is shown in Fig. 5 below. Each of the six beams in the frame has four crack forming regions (two positive and two negative moments). Fig. 5a shows the final cracking pattern of the bottom story interior beam-column joint. At the peak of the first cycle, with LLF = 1, no flexural cracking was visible in the joint. For the first half of the second cycle (LLF = 3), when the lateral loads were applied from the left side of the frame, the top of the left beam yielded and a wide flexural crack was visible. On unloading, the crack narrowed but remained visible. In the second half of this cycle, cracks appeared in the right beam due to the yielding of the top bars, and the cracks in the left beam widened. At the completion of cycle 2, with LLF = 0, the cracks in both beams closed partially but remained visible.





(a)

Fig. 5 - Cyclically loaded frame

The sequence of crack formation and crack widening in other critical sections of the frame was similar to that described above. It is recognized that fewer cracks are visible in the model than in the prototype, but extensive modeling studies have shown that this does not produce any measurable differences in the moment-rotation and load-deflection characteristics of the model structure.

First visible cracking at the bases of the columns was observed at the sixth cycle (LLF = 5). Column crack widths increased substantially in subsequent cycles.

The application of cyclic loads produces alternating diagonal tension forces in the joint regions of the frame. These forces may produce deterioration of reinforcement anchorage, yielding of shear reinforcement, additional yielding of beam steel, and shear failure of the joint itself. In order to prevent these inelastic deformations of the joint area, and to avoid shear failure and other non-ductile behavior, proper reinforcement detailing must be followed in the joint areas and other regions with high shear and anchorage forces. As shown in Fig. 5 , no cracks appeared in any joints in the frame designed and detailed according to earthquake resistant design specifications which give major emphasis to the details of transverse reinforcement and anchorage lengths in the joint regions.

Fig. 6 shows the top story lateral load vs. the rotation of the bottom story beam. A comparison between the curves for the cyclically load and unidirectionally loaded frames shows that properly designed frames do not deteriorate significantly under

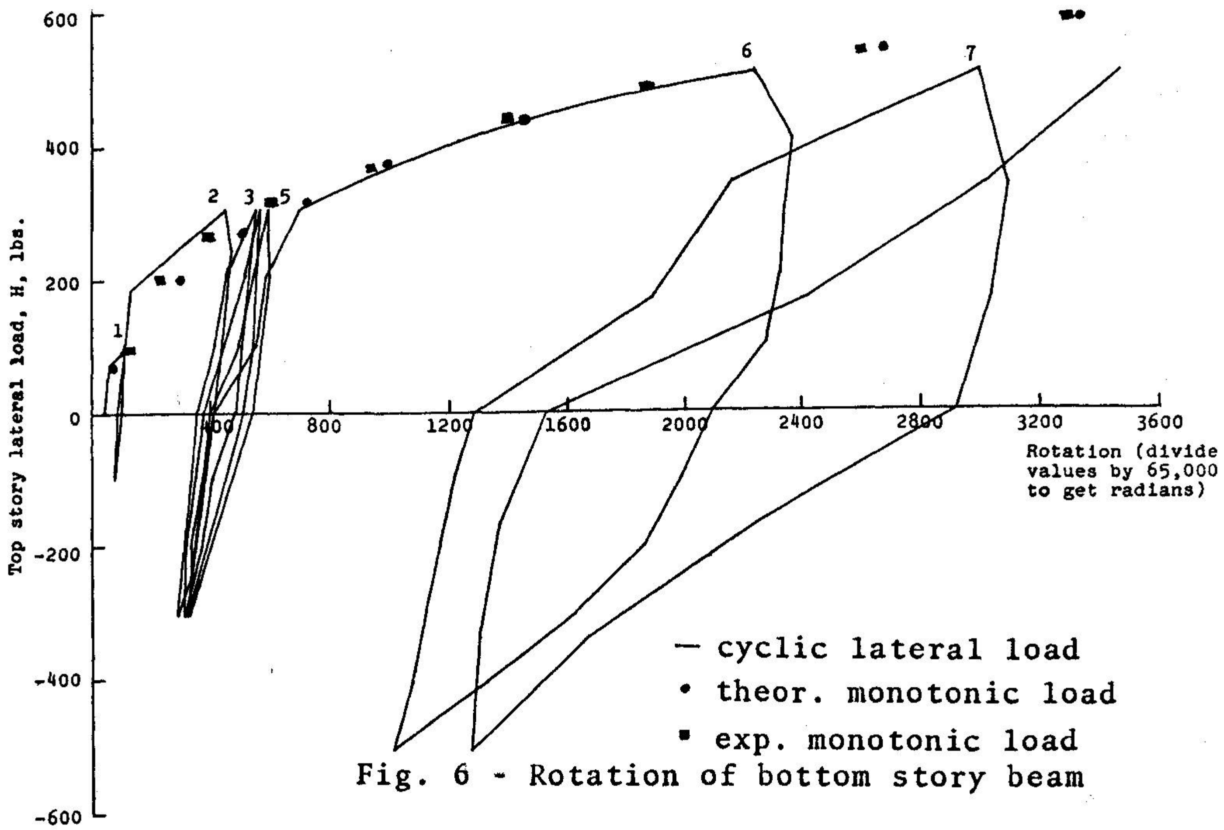


Fig. 6 - Rotation of bottom story beam

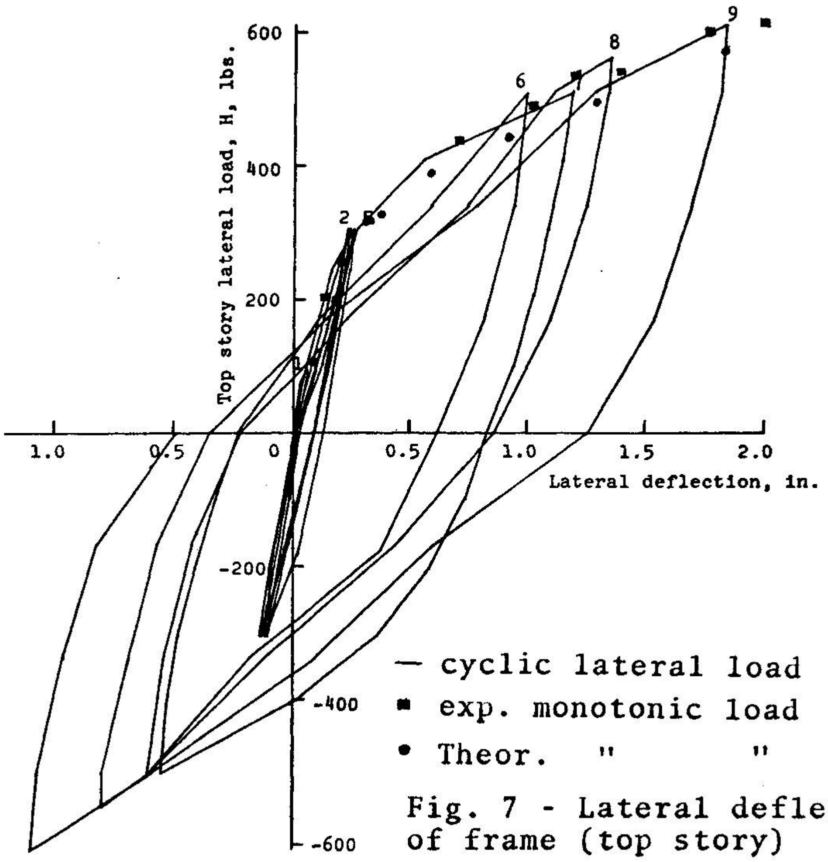


Fig. 7 - Lateral deflection of frame (top story)

severe cyclic loads. The load-deflection characteristics of the two frames (Fig. 7) also supports this conclusion. The indispensable role of compression reinforcement and closely spaced ties in providing toughness and ductility is apparent from these tests.

Acknowledgment: Partial support for this study was provided by the National Science Foundation (Grant GK-13992).

References:

1. Hanson, N.W. and Conner, H.W., "Seismic Resistance of Reinforced Concrete Beam-Column Joints," Journal of the Structural Division, ASCE, Vol. 93, October 1967, p. 533.

2, Chowdhury, A.H., "Inelastic Behavior of Small Scale Reinforced Concrete Beam-Column Joints Under Severe Reversing Loads," Department of Structural Engineering Report #342, Cornell University, October 1971.

3. Chowdhury, A.H., White, R.N., and Scott, N.R., "Multi-Story Reinforced Concrete Frame Models," Meeting Preprint 2002, ASCE National Structural Engineering Meeting, San Francisco, California, April 1973.

4. Chowdhury, A.H., "An Experimental and Theoretical Investigation of the Behavior of Reinforced Concrete Multi-Story, Multi-bay Frame Models Subjected to Simulated Seismic Loads ," A Ph.D. thesis to be submitted to the Graduate School of Cornell University, Ithaca, New York, September, 1973.

SUMMARY

Small scale models are shown to be an excellent approach for investigation of reversing load phenomena in reinforced concrete. Three-story, two-bay frames were tested under simulated seismic loads and reached lateral force levels of 6 times the design values for both unidirectional and cyclic lateral loadings. Properly designed frames (closely spaced ties, compressive reinforcement, and adequate anchorage lengths) do not deteriorate significantly under severe cyclic lateral loadings.

RESUME

Les modèles à petite échelle s'avèrent très intéressants pour l'étude du phénomène des charges alternées dans les structures en béton armé. Des portiques multiples à trois étages et doubles travées soumis à des charges sismiques simulées et à des forces latérales dont l'intensité atteint six fois la valeur de dimensionnement ont été testés à la fois pour des charges latérales uni-directionnelles et pour des charges cycliques. Les portiques correctement dimensionnés (armatures peu espacées, armatures de compression, longueurs d'encrage adéquates) ne sont pas particulièrement endommagés même soumis à des charges cycliques latérales importantes.

ZUSAMMENFASSUNG

Es wird gezeigt, dass Modelle in kleinem Massstab eine sehr gute Annäherung an die Wirklichkeit für die Untersuchung von Lastumkehr-Phänomenen in Stahlbeton darstellen. Dreistöckige Rahmen mit 2 Oeffnungen wurden unter simulierter seismischer Belastung untersucht; die horizontale Kraft erreichte eine Grösse, die bis zu sechs mal den Bemessungswerten für gleichgerichtete und zyklische horizontale Belastung entspricht. Sauber bemessene Rahmen (engliegende Anker, Druckarmierung, genügende Verankerungslängen) verschlechtern sich nicht wesentlich unter starker horizontaler zyklischer Belastung.

Leere Seite
Blank page
Page vide