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SUMMARY OF FINDINGS OF CYCLIC SHEAR TESTS ON MASONRY PIERS

by

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Atkinson-Noland & Associates

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conducted by:

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PREFACE

This report was prepared in support of research Category 3.0, Task 3.1(a) of the U.S. Coordinated Program for Masonry Building Research. The report summarizes findings of Earthquake Engineering Research Center, Berkeley, CA from research conducted on reinforced masonry piers subjected to in-plane loadings both static and cyclic.

Dr. John C. Scrivener prepared the report while on sabbatical leave from the University of Melbourne, Australia. The work was supported by NSF Grant ECE-8421234.

Any opinions, findings, and conclusions or recommendations expressed in this document are those of the author and do not necessarily reflect the views of the National Science Foundation.

J. L. Noland
June 1987

The report summarizes the findings of the Earthquake Engineering Research Center (EERC) reports dealing with the test behavior of reinforced masonry piers subjected to in-plane loadings (both static and dynamic cyclic). It considers reports 76/8 and 76/16 on double piers; 78/27, 78/28, 79/12 on single piers; and 81/10 on seismic design provisions.

The effect of horizontal reinforcing on pier behavior, in particular shear ductility, is considered in more detail.

EERC MASONRY RESEARCH PROGRAM

In 1972, the EERC at the University of California, Berkeley, commenced a program on the seismic resistance of masonry. Early work reviewed the literature and it was concluded that shear walls penetrated by openings (Fig. 1) were the most frequently damaged structural elements in earthquakes. The vertical piers were singled out for investigation and the first tests (EERC 76/8 and 76/16) were on 17 double piers (see Fig. 2). This represented a departure from the single cantilever wall tests previously conducted elsewhere but the double pier tests were adopted as they gave realistic boundary conditions.

Unfortunately, the double pier test results were not conclusive and they demonstrated the need for more extensive tests to establish definite parametric relationships. The cost in time and money of double pier

tests precluded their further use so 80 single pier tests (EERC 78/27, 78/28, and 79/12) were conducted (Fig. 3).

The single piers were not the cantilever walls of earlier researchers but again "fixed-fixed" as the double piers. The top and bottom beams simulate the action of the spandrel beams in an actual building; they are connected by two steel columns which prevent rotation of the top beam and thus provide approximate fixed end conditions throughout the test.

This setup creates an additional vertical compressive load as lateral displacements are imposed on the top beam by the hydraulic actuators, the constraint provided by the side columns forcing the top beam to move in a circular arc. The vertical component of this motion is opposed by the axial stiffness of the pier resulting in a compressive load, cyclically varying, being applied to the pier. This additional load forces the piers to fail in the shear mode even though they may exhibit a flexural type of behavior. The effect may be greatest on the hysteresis loops. It is interesting to note that two unreinforced walls tested in this setup failed in shear as the additional vertical load prevented sliding and rotation of the top and bottom of the piers thus permitting the horizontal load to increase until a shear failure occurred.

Accordingly for some later tests the setup has been modified (Fig. 4) by replacing the steel columns by vertical actuators which impose forces of equal value but opposite sign at the two sides of the pier. The magnitude of the forces is selected to maintain the point of inflection of the deformed pier at mid-height (EERC 81/10). The results of these test are awaited.

The tests were conducted on storey height specimens with different aspect ratios and used:

Hollow concrete blocks (HCBL) of standard 2-core and nominal 6" thickness,

Hollow clay bricks (HCBR) of standard 2-core and nominal 8" thickness,

Double wythe grouted clay bricks (CBRC) of two wythes of solid bricks, nominal 4" thickness, 3" wide cavity.

SUMMARY OF TEST RESULTS

Tables 2.3, 2.4 and 2.5 of pp. 23-25 EERC 81/10 give the actual results of both series of pier tests.

Table 1 (of this report) summarizes qualitatively all the EERC results and the results of other researchers - where there is conflict it is pointed out. The table gives the effect of various parameters on various aspects of the pier behaviors. A column headed "overall inelastic behavior" is included as ductility should not be considered in isolation when evaluating the inelastic performance of masonry, e.g., the maximum displacement that can be withstood by the piers is also important. "Desirable inelastic behavior" is discussed qualitatively (pp. 68-70 EERC 76/8) and there it is pointed out that the relative desirability of force-deflection relationships depend on the intensity of the expected earthquake.

DUCTILITY RATIO

"Ductility ratio" is defined as the ratio of the maximum displacement at which the maximum load can no longer be maintained to the displacement at which the yield load is just attained.

The range of ductility ratios obtained in the EERC tests and by other researchers is:

In the flexural mode of failure; 2 to 4

--but significantly improved with 1/8" thick plates in mortar beds at the top and bottom of the piers (hereafter called Priestley plates after the originator)

In the shear mode of failure; 1 to 2

--but significantly improved with increase of horizontal reinforcement.

SHEAR DUCTILITY

In general, an increase in horizontal reinforcement increases the ductility of a pier, improves the crack pattern and increases the pier's deformation capacity. However, the form of the relationship between reinforcement amount and improvement amount is not apparent. Furthermore, the rate of strength degradation after ultimate strength is reached appears to be independent of the horizontal reinforcement. And the favourable influence of horizontal reinforcement holds for HCBL and HCBR but is minimal for CBRC piers.

Priestley and Bridgeman demonstrated that horizontal steel is approximately three times as efficient as vertical steel in carrying shear force across a diagonal crack, and in contrast with earlier findings that a larger quantity than 0.3 percent bd of shear steel is effective in improving the ultimate shear capacity of masonry. For this larger quantity of shear reinforcement to be effective, they stated that the quantity (preferably horizontal) should be sufficient to resist the full ultimate flexural lateral load, so that a flexural mode of failure

is induced. However, according to Priestley's design method, the shear capacity of two of the EERC double piers should have been close to the $A_{hs}f_y$ capacity of the horizontal reinforcement. This was not the case, and because of this discrepancy and the lack of consistency of other test results, the effect of horizontal reinforcement in the shear mode of failure was studied extensively in the single pier test program. Regrettably, the single pier test results were over-ridden by the additional vertical compressive force applied.

Hopefully the modified test setup will give definitive information on shear ductility and the effect of horizontal reinforcement.

TABLE 1: QUALITATIVE SUMMARY OF TEST RESULTS

EFFECT ON → EFFECT OF ↓	Mode of Failure	Ultimate Strength	Ductility	Stiffness Degradation	Energy Dissipation Ratio	Overall Inelastic Behavior
Increase of vertical reinforcement	Flexural strength increases which may result in shear failure	Increase in flexural strength (except with single piers with additional vertical load)	←— Less desirable —→ if shear failure			
Increase of horizontal reinforcement	Assists in changing mode from shear to flexure	Increase for HCBL (not substantiated by other research). Small increase for HCBR; no change for CBRC. Inconclusive	Increase	No increase after ultimate strength attained. Inconclusive	Increase for HCBL and HCBR Inconclusive	More desirable for HCBL and HCBR
Increase of bearing stress	-	Increase	Inconclusive	Increase	-	Inconclusive -probably less desirable
Increase of loading rate	-	Dynamic strength ≤ pseudo static strength	-	Increase	-	-
Change from full grouting to partial grouting	-	Increase for HCBL - decrease for HCBR	←— No difference in HBCL—→ Lower with HCBR. Inconclusive	Higher with HCBR. Inconclusive	Lower with HCBR	Less desirable with HCBR
Inclusion of Priestley plates	-	Increase if flexural failure	Increase	Decrease	-	Increase
Increase of height/width	Increases chance of flexural failure	Decrease for HCBL & HCBR – no change for CBRC	←— More desirable —→ if shear failure			

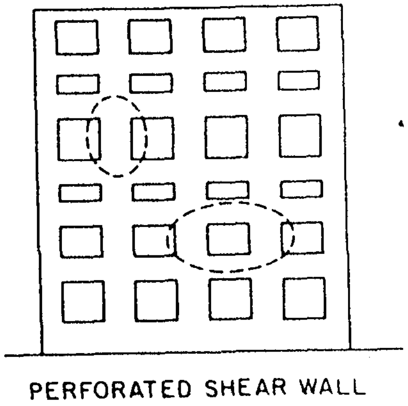

FIG. 1 TYPICAL SHEAR WALLS

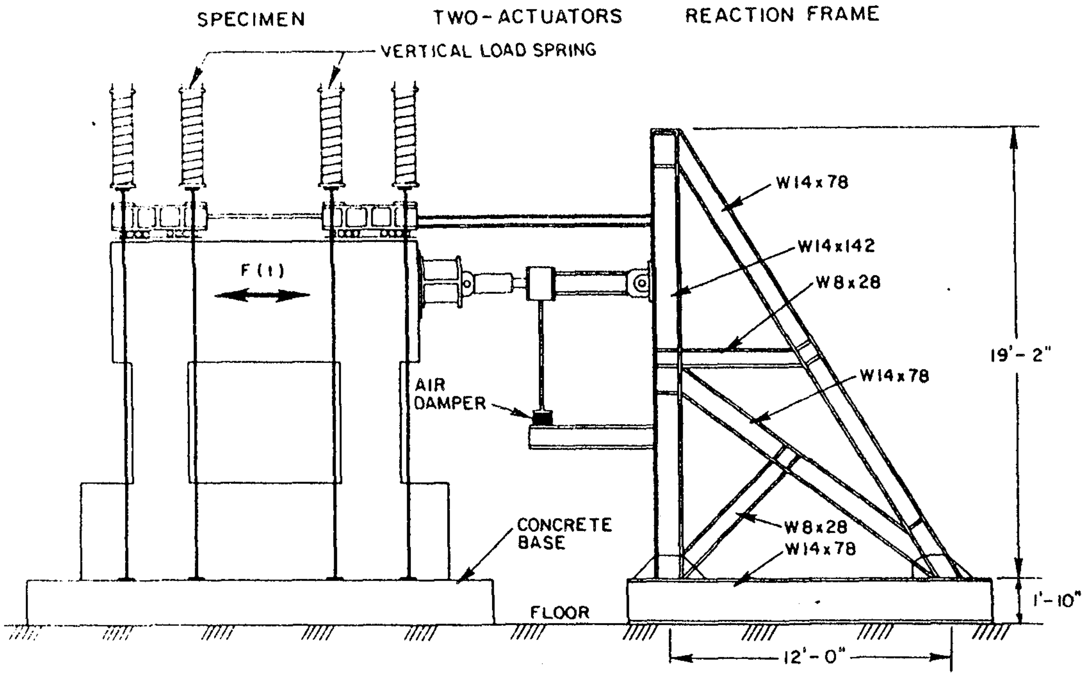

FIG. 2 DOUBLE PIER TEST SETUP

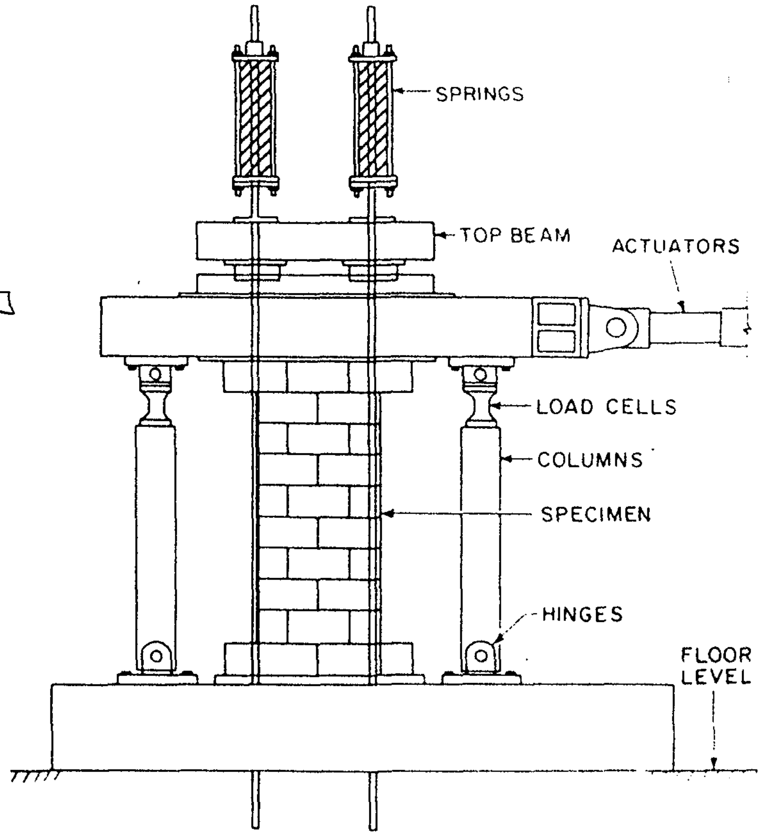

FIG. 3 SINGLE PIER TEST SETUP

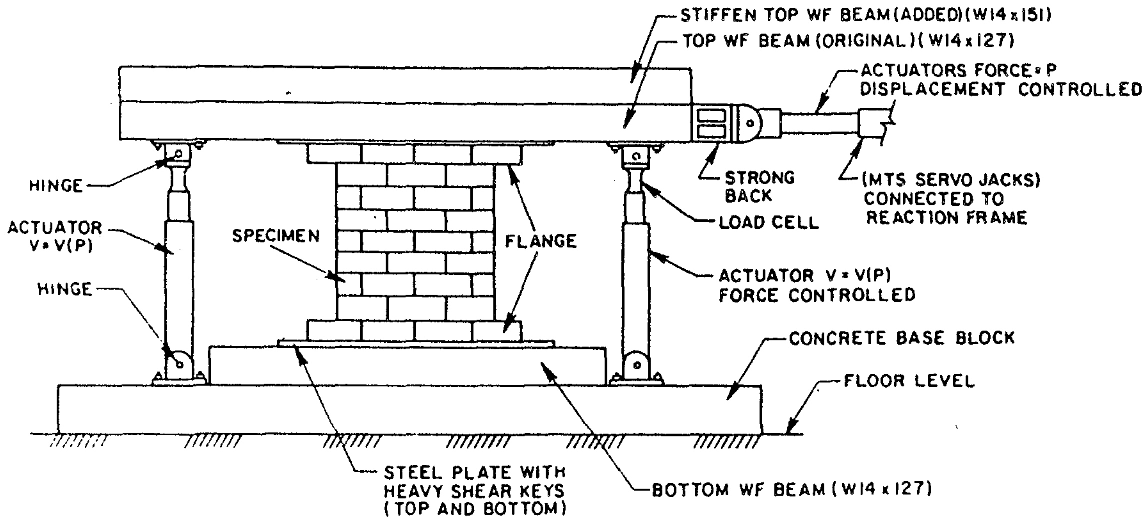

FIG. 4 MODIFIED SINGLE PIER TEST SETUP