EARTHQUAKE STABILITY OF INTERIOR NON-BEARING HOLLOW CLAY TILE PARTITIONS

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SUMMARY

This paper presents findings of an earthquake strengthening study for an older building. This three story reinforced concrete frame building, constructed in Santa Barbara, California, in 1924, was damaged from nearby earthquakes in 1925, 1940, 1952, and 1978. As part of the study, in-place tests to destruction were performed on panels of plastered hollow clay tile partitions with static loads of 0.82G maximum applied normal to wall surface. Studies indicate that with conventional construction, these partitions have substantial inherent earthquake resistance, deflecting 4" to 5" at collapse, and they may not require strengthening if story drift is properly controlled.

INTRODUCTION

Thousands of large "fireproof" multi-story buildings have been constructed in California and other earthquake prone areas in the United States and elsewhere with interior non-bearing partitions of plaster on hollow clay tile (HCT). Many of these reinforced concrete and steel frame buildings have experienced damage to HCT partitions during past earthquakes. (Ref. 1 and 2) Strengthening of these older buildings to resist earthquakes must deal with possible replacement, strengthening, or isolation of this special form of unreinforced masonry.

Constantly, the practicing engineer is required to make decisions affecting life-safety and large expenditures of money when he has insufficient factual knowledge about how building elements such as HCT actually respond to earthquake ground shaking. He commonly makes simplifying assumptions which at the time seem rational and reasonable. At times, these assumptions are far from the truth.

This paper presents the author's efforts to determine by in-place field tests what, if anything, should be done about plastered hollow clay tile (HCT) walls and partitions in an existing building. While crude by laboratory standards, the tests were extremely helpful in making a tentative decision not to strengthen these walls.

It is hoped that other practicing engineers and investigators will undertake similar studies so a body of factual knowledge can be accumulated before major earthquake strengthening programs are undertaken in the thousands of buildings containing hollow clay tile walls and partitions.

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THE STUDY

The primary reason for studying this building was to identify substantial earthquake hazards and to develop a strengthening scheme that would materially increase life safety and reduce the risk of injury to persons in or around the building. The building is home and school for developmentally handicapped persons, their teachers, and staff.

Discussion of the study will be limited to strengthening considerations and those aspects of the study directly related to hollow clay tile exterior walls and interior partitions. The building and framing details are shown in Figure 1.

STRENGTHENING CONCEPTS

Most people will try to leave the building during an earthquake. It is essential that they have a safe pathway through, out, and away from the building, free of falling hazards at stairways and exit doors.

1. The HCT exterior walls and interior partitions probably represent the most significant hazard other than building collapse, thus load tests should be made on isolated panels to provide a better understanding of their strength, deflection characteristics and mode of failure.

2. Partitions surrounding stairways and exterior walls that could fall onto normal exit paths are unacceptable and should be removed and replaced with steel studs and plaster.

3. Reasonably closely spaced concrete (gunite) shear walls at the exterior of the building are compatible with the HCT walls because:

a) they limit story drift, minimize floor and roof diaphragm deflections, and the need for collector members. They also allow use of existing columns as shear wall chord members.

b) they provide substantial in-line stiffness to minimize participation of and subsequent damage to HCT exterior walls.

c) construction operations are far less costly if they can be largely confined to outside of the building.

d) shear walls can be built by removing the outer course of HCT and using the inner course, stiffened by properly cushioned strong-backs, as a form for a 9" reinforced concrete (gunite) shear wall.

HOLLOW CLAY TILE WALLS AND PARTITIONS

Construction

The walls and partitions use 12" x 12" individual units that are built tight to concrete columns, beams, spandrels, and slabs. Sometimes bricks are used at the top of walls to fill small spaces. The top and end mortar joints are wedged up to existing concrete.

Exterior walls consist of two interconnected 3" thick walls with a 6" space between and are about 10'-8" high. They are interconnected with cross tiles on edge, somewhat randomly placed.

Interior partitions are 3" thick, weigh 30 pounds per square foot, and are 10'-4" to 11'-8" high. Walls rest on a full bed of mortar set on the rough concrete slab. Tile are laid with rather full 1/2" thick bed and head joints. Workmanship and mortar quality are good.

Tests

Two load tests of wall panels 24" and 27" wide were made by saw cutting through them for the wall full height. (See Figure 2.) These closet walls terminated a few inches above the metal lath and plaster ceiling, thus the top of the wall was restrained horizontally only by the plaster. Bottom restraint was naturally provided by a hardwood floor on 2x2 sleepers built tight to the wall.

A horizontal load was applied by a manually operated hydraulic jack and 1" diameter ram with an in-line calibrated gauge.

A steel shim plate and wall width piece of 2x8 was placed against the wall so as not to concentrate the applied load at a horizontal mortar joint.

Wall deflections were measured by a steel tape with 1/16" gradations.

Test panel #1 with plaster each face was loaded by increments to 237 pounds. (See Figure 3.) When this load was released, a 1/8" permanent deflection was noted. Loads were then reapplied. The ultimate failure load of 316 pounds was applied for about 20 seconds as slow yielding occurred and the wall finally collapsed.

At collapse, the actual deflection of these walls was about 4" to 5", likely due to restraint at bottom of wall provided by the finish wood floor construction.

Test Observations

No movement or crushing of ceiling plaster was observed. No movements or crushing of wood floor was observed. Just prior to failure, a vertical trending crack occurred on the loaded (compression) face of the tile as large deflections produced a rocking-like condition at the horizontal mortar joint. (See Figure 2.)

DISCUSSION

Do the tests model a real earthquake? No. The actual movements of a partition are likely very complex and depend upon the degree and type of restraint at top, bottom, and ends as well as intersecting walls. The most unrestrained movement will likely occur within panels most distant from ends and intersecting walls..

The top and bottom of a partition are dynamically driven by the motions of the floor above and the one upon which it rests. Forces developed are dependent upon firmness of connection to each floor.

Future testing should include dynamic tests out-of-plane, after walls have diagonal cracks from in-plane racking tests. These would most simulate actual conditions in a building during an earthquake.

Tests

The deflections produced in the elastic range of 5/8" and 3/4" seem reasonable and compatible with current story drift limitations of about 0.60".

The restraint provided by the finished wood floor system was unanticipated, but welcome, because it permitted very large wall deflections before final collapse. At collapse, the wall was completely broken through at the mortar joint at point of load. It had separated into two pieces. The upper one-half of the wall "leaned" against the sides of the metal lath and plaster and could not fall out vertically until the lower half moved out from under it.

The lower half of the wall has moment restraint provided at the bottom by its "embedment" below the hardwood floor and cannot fall until it works its way out of the hole through the wood floor. The simple force diagram on Figure 2 depicts this condition.

Cement or terrazzo floor finishes are common and will provide some confinement and restraint at bottom while the top of the wall is customarily wedged against beam or slab above. Lefter (Ref. 3) states that tests by Wilton and Gabrielson (Ref. 4) showed that unreinforced masonry walls develop significant resistance to out-of-plane forces if arching action is developed in the wall when compressive forces are developed in the plane of the wall due to the resistance of the wall supports to in-place deformation of the wall. It is important that in-place field tests be made to verify this wedging action.

Load Deflection Diagrams

Test #1 diagram shows deflection proportional to load up to yielding at 19/32" [5/8"$^{(-)}$] with a load of 316 pounds. The reason for the temporary yielding at load increments 4 and 5 is not clear.

Test #2 diagram shows larger deflections for a given load that are not directly proportional to load. Wall started final yielding @ 3/4" with a load of 237 pounds.

This difference in performance may be explained by the differences in test panels. Plaster was removed from the loading (compression) face for Test #2. This unsymetrical cross section has a smaller moment of inertia, thus larger deflections would be anticipated. The shape of the load deflection diagram suggests that some relatively non-uniform yielding began at load increment #3 (119 pounds).

Possible Strengthening

The primary strength of HCT partitions to resist out-of-plane forces is likely provided by the tensile capacity of the lime plaster. Calculations by classical methods indicate maximum tensile stresses in the plaster of about 120 lbs. per sq. in. for both test panels. Tensile capacity at tile and mortar bed joints is dependent upon very good workmanship and thus usually unreliable. Plaster is far more uniform. Essentially, the plastered wall is composite construction.

Strengthening of HCT walls can be achieved by:

1. Isolating them from the structural columns because most damage occurs due to in-plane forces. This could be simply done by removing the vertical mortar joint at columns and installing a flexible caulking. The capacity to transfer in-plane earthquake forces at interface with underside of beam or slab appears to be very limited, thus if isolated, the wall functions as a vertical cantilever off the floor where it usually has substantial resistance to sliding or positive resistance can be provided.

2. Providing tensile capacity to resist in-plane and out-of-plane forces. Adding a coat of metal lath and plaster to each side appears practical, functional, and economical. It may not need to be carried above the ceiling to the top of the wall.

The economic impact of HCT walls and partitions on proposed earthquake strengthening is considerable. The study building has about 65,000 sq. ft. of HCT representing an in-place value of about $700,000. Protecting such an investment along with materially improving life-safety is a real challenge.

CONCLUSIONS

1. Plastered HCT walls and partitions have substantial strength to resist out-of-plane forces due to restraint naturally provided by ceiling and floor construction. The floor restraint may be sufficient to permit unusually large deflections.

2. In-place load tests are a practical way to evaluate strength and deflection characteristics of HCT construction in individual buildings.

3. More laboratory and field load tests, both static and dynamic, should be performed to accumulate the necessary body of knowledge needed to minimize the hazards of HCT walls in earthquake prone areas.

4. Practical, economical, and trustworthy in-place strengthening methods should be developed before professional engineers as a group undertake large scale strengthening of existing buildings.

REFERENCES

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3. Lefter, James, and Colville, James, "Reinforcing Existing Buildings to Resist Earthquake Forces," Proc. of the U.S. National Conference on Earthquake Engineering, 1975.

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THE BUILDING

Structural Frame

The reinforced concrete structural frame consists of columns, foundation walls, and footings supporting roof and floor framing systems of beam, joist, and slab construction. The primary resistance to lateral forces is provided by the non-ductile moment resisting frame at the exterior walls and the interior non-bearing HCT partitions.

Past Earthquake Damage

Historical records indicate severe damage to several brick bell towers and numerous cracks in HCT walls and partitions from the 1925 Magnitude 6.3 earthquake with epicenter about 12 miles away. No damage was observed to columns or beams. The following nearby earthquakes caused additional cracking in HCT and/or reopening of old repairs: 1940 Magnitude 6.0, epicenter at $15^{\pm}$ miles; 1952 Magnitude 7.6, epicenter at 50 miles; 1978 Magnitude 5.7, epicenter at 8 miles.

Wall and partition cracks were typically diagonal trending at corners of openings with some "X" patterns. Patched plaster clearly shows past damaged areas. No evidence was found of replacement of large sections of wall, thus the HCT walls appeared to have withstood past earthquakes reasonably well. No evidence was found to indicate any exterior walls had fallen out and away from the building.

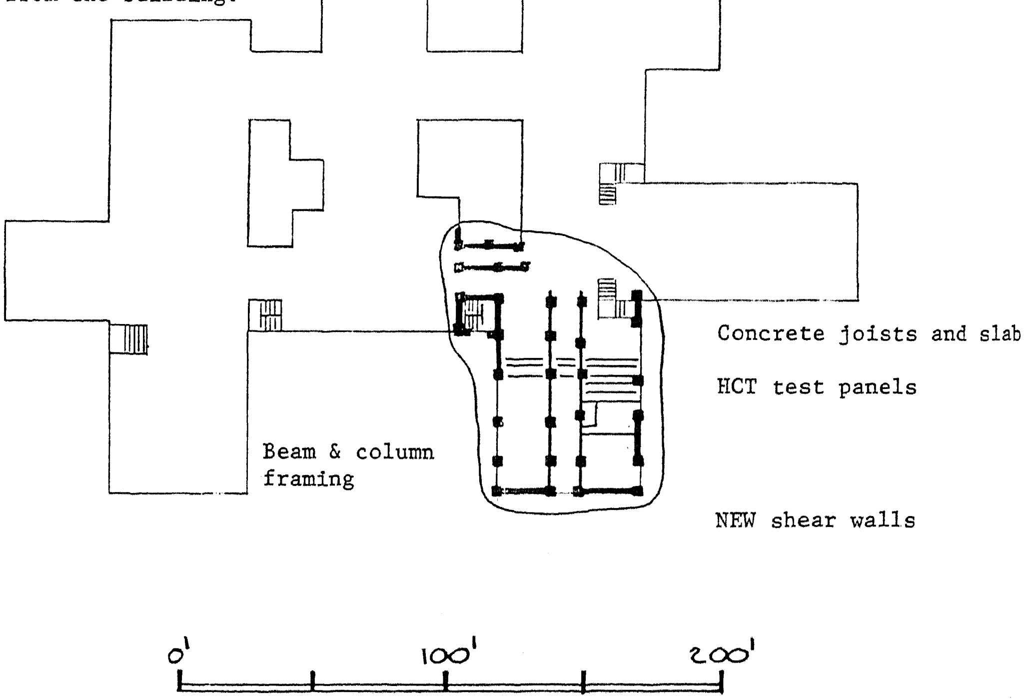
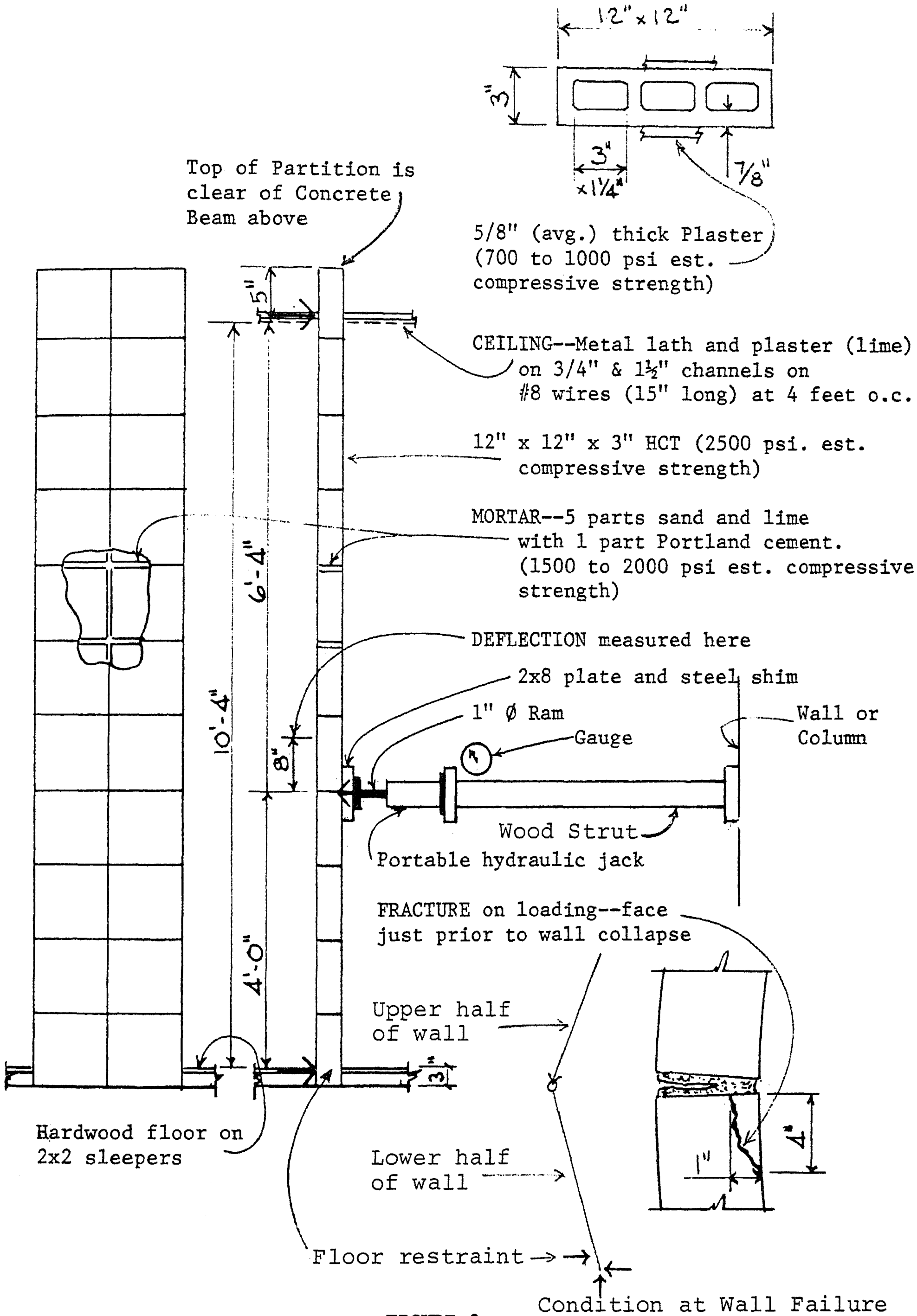


FIGURE 1



12" x 12"
3"
3"
x 1¼"
7/8"
Top of Partition is clear of Concrete Beam above
5/8" (avg.) thick Plaster (700 to 1000 psi est. compressive strength)
5"
CEILING--Metal lath and plaster (lime) on 3/4" & 1½" channels on #8 wires (15" long) at 4 feet o.c.
12" x 12" x 3" HCT (2500 psi. est. compressive strength)
MORTAR--5 parts sand and lime with 1 part Portland cement. (1500 to 2000 psi est. compressive strength)
6'-4"
10'-4"
DEFLECTION measured here
2x8 plate and steel shim
1" Ø Ram
Gauge
Wall or Column
8"
Wood Strut
Portable hydraulic jack
FRACTURE on loading--face just prior to wall collapse
4'-0"
Upper half of wall
3"
4"
1"
Hardwood floor on 2x2 sleepers
Lower half of wall
Floor restraint
Condition at Wall Failure

FIGURE 2

LOAD INCREMENT	LOAD (LBS.)	DEFLECTION (INCHES)	REMARKS
	TEST #1 -- 24" WIDE PANEL - PLASTER EACH SIDE		
		Wt. = 620#	- 10'-4" high
1	79	3/32	First crack in plaster on tension face.
2	118.5	4/32	
3	158	5/32	
4	197.5	7/32	Slight drop in load.
5	197.5	10/32	Reapplied load and deflection continued.
6	237	11/32	Continued load and deflection.
7	0	5/32	Load released. Permanent deflection.
8	79	9/32	Reapplied load--permanent deflection.
9	197.5	13/32	
10	237	15/32	
11	276.5	17/32	
12	316	19/32	Wall yielding.
13	316	1-23/32	Wall yielding.
14	316	5±	Wall collapsed to floor.
	TEST #2 -- 27" WIDE PANEL - PLASTER REMOVED FROM LOADING FACE		
		Wt. = 697#	- 10'-4" high
1	39.5	--	No recorded deflection.
2	79	5/32	
3	118.5	8/32	
4	158	12/32	
5	197.5	20/32	
6	237	24/32	
7	237	4±	Wall collapsed to floor.

Test #1: I = 152.0 $in.^4$, S = 71.5 $in.^3$, E = 2.12 x 10^5 #/sq.in.

Test #2: I = 100.8 $in.^4$, S = 61.0 $in.^3$, E = 1.49 x 10^5 #/sq.

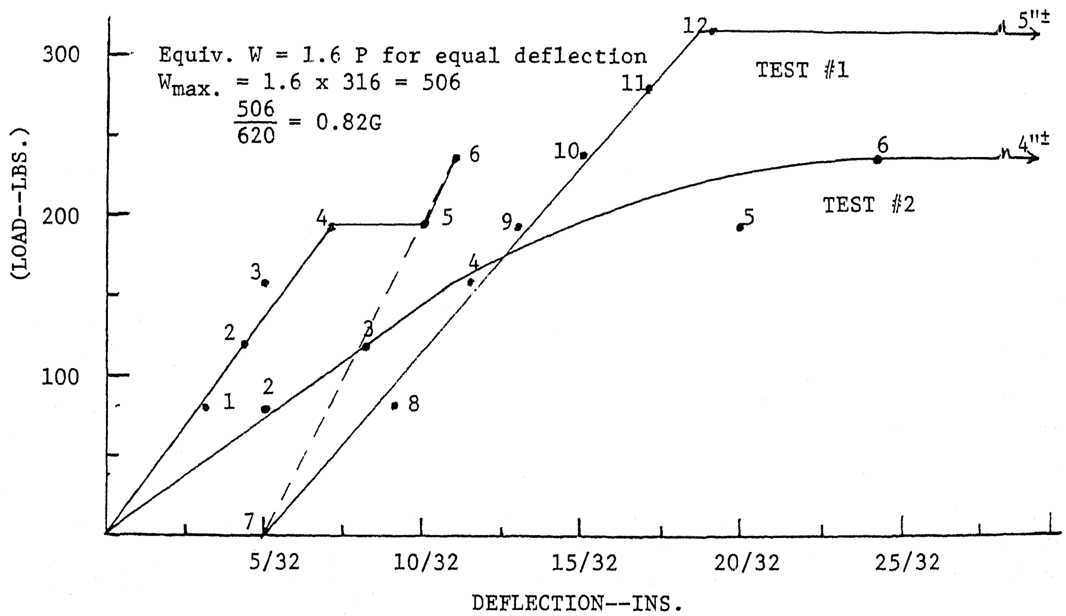


FIGURE 3