The CenterCore technique of reinforcing unreinforced masonry (URM) walls was developed with the aid of a National Science Foundation Grant in 1984. The strengthening system of full height reinforced/grouted vertical cores centered in the masonry walls has been utilized in more than 100 projects to strengthen Earthquake Hazardous buildings. From experiences with these projects, many lessons have been learned and improvements made in the CenterCore technique.

Rehabilitation Option for

CenterCore Strengthening System for Seismic Hazard Reduction of Unreinforced Masonry Bearing Wall Buildings

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Masonry Walls

"...testing included in-plane shear and out-of-plane bending..."

Background and History

The concept of placing reinforcing steel in an existing unreinforced masonry wall is not new. Engineers have intuitively thought it would be the obvious, most logical way to provide strength and ductility for an existing brick wall. In 1969, an attempt was made to place post-tensioning strand in an unreinforced masonry wall of the Audubon High School in Los Angeles. The placement of the strand was accomplished, but the post-tensioning was not effective because of the inability of the wall to maintain tension in the reinforcing strand, thus failing to provide an effective compression in the masonry.

Other strengthening concepts that have been used to stabilize and strengthen unreinforced masonry walls include:

- Adding reinforced concrete (shotcrete) to one or both sides of the walls to increase the walls' capacity to resist in-plane shear and attempt to resist out-of-plane bending with a "basketing" or membrane action;
- Placing reinforced concrete "ribs" within the wall by saw-cutting vertical slots in the bearing walls and joining the vertical ribs with a horizontal bond beam at the diaphragm(s);
- Placing steel braced frames alongside the walls to replace the vertical and lateral load carrying capacity of the unreinforced masonry; and
- Bonding a reinforced fiber composite to one or both sides of the walls to provide a tension capacity to the wall assembly.

The scope of the NSF grant provided for full-scale testing of the CenterCore technique on a one-story unreinforced masonry building in Long Beach, California. The building was scheduled for demolition prior to the 1984 Los Angeles Olympic Games. The testing included in-plane shear and out-of-plane bending using a variety of grouts while varying the reinforcing steel and core diameter.

The test results were significantly higher for the polyester and epoxy grouts. The demolition of tested wall sections revealed a migration of the grout far beyond expectations, and far beyond the vicinity of the core. It was concluded that the high test values for both in-plane shear and out-of-plane bending was a result of the grout migration together with its excellent bond capacity, developing a fairly large and somewhat uniform composite section for the full height of the grouted core.

Based upon the results of the NSF Report, the City of Long Beach permitted the use of the CenterCore System on buildings in the City of Long Beach. The first owner that requested use of the technique was the First Congregational Church of Long Beach. Built in 1914 and somewhat damaged in the 1933 Long Beach earthquake, the church is a beautiful, two and three-story 44,000 square foot building with a full basement.

The sanctuary has a large balcony/choir loft on three sides, and a steel truss roof system. A total of 4,400 lineal feet of reinforced core was placed in the unreinforced masonry walls that were anchored to strengthened diaphragms.

Out-Of-Plane Stability

A common failure of unreinforced masonry buildings subjected to earthquake ground motions is the separation of the walls from the roof and wall diaphragms. In addition to providing a good wall-to-diaphragm anchorage, the walls require flexural capacity to resist out-of-plane forces to remain in place for support of the building's vertical loads.

The first objective for the stabilization of URM bearing walls is to secure the overburden and give the walls flexural capacity for out-of-plane forces. With the use of conventional reinforcing steel in a well-bonded grout assembly, CenterCore provides a stable and predictable flexural capacity. This flexural capacity, in addition to the arching action capacity, keeps the wall in place to carry the building's vertical loads. The design strength of CenterCore for out-of-plane flexure is based upon yielding of the steel prior to any crushing of the masonry, using a conservative value of fm. The force developing the moment vs. the flexural strength of the CenterCore System will determine the spacing of the cores, similar to the design of new reinforced masonry walls. The sample calculation in Figure 1 demonstrates that a 6" diameter core with #7 bar (#22 metric) reinforcing steel at 6'-0" on center, and a value of fm equal to 300 psi for the masonry, will provide about 8 foot-kips capacity. The resulting capacity is approximately 1.3 times the design moment.

(Note: Calculations are based on an imperical approach to test results. Strength design approaches would comply with IBC 2000 & ASCE 7.)

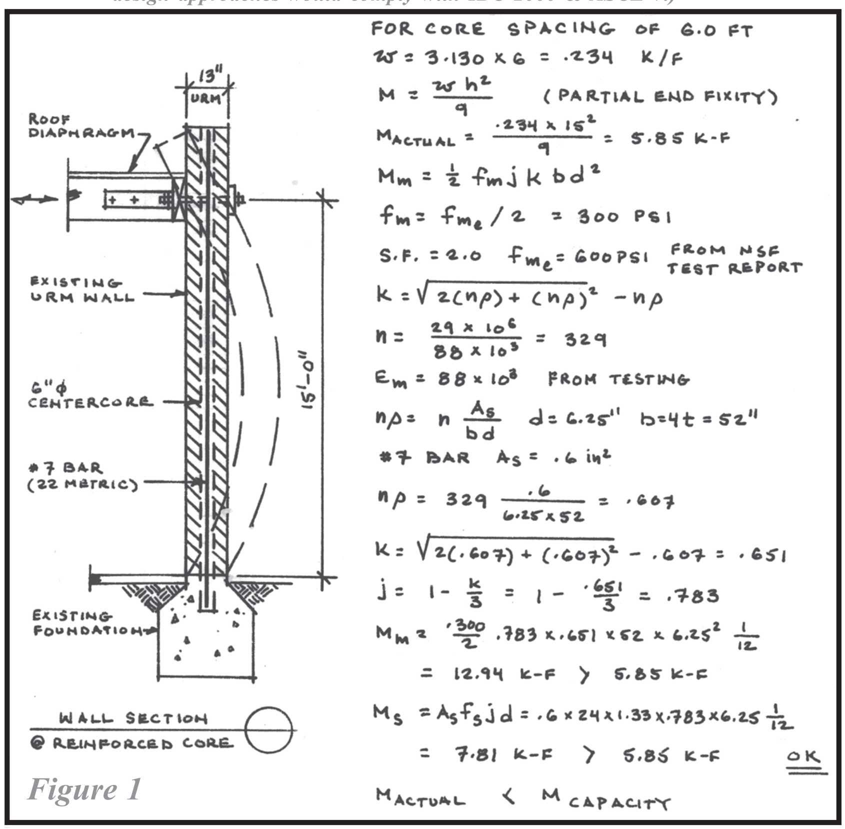

Figure 1

The above calculation clearly demonstrates that the force developing the moment vs. the flexural strength of the CenterCore system will determine the spacing of the cores. The strengthening approach is not to over-reinforce the wall thus creating a potential for compression failure, but to allow the steel to yield as the preferred failure mode. Unlike cementicious grouts, the resin-sand grout, has its own tension capacity, but is neglected in the masonry assembly.

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Pictured on previous page: Top - CenterCore Retrofit (274 cores; 5,000 lineal feet). US Customs House, San Francisco, 1991. URS Consultants; Middle - First CenterCore Project. First Congregational Church, Long Beach, CA, 1987. David C. Breiholz & Co., Inc.; Bottom - CenterCore Retrofit. City of Los Angeles, Lincoln Heights Library, 1991. Wheeler & Gray

"...in-plane shear capacity is greatly enhanced..."

In-Plane Shear Strength

Typical unreinforced masonry buildings with wall openings lack shear capacity to resist in-plane forces. So, in many cases, the retrofit of the unreinforced masonry wall is controlled by in-plane shear.

In-plane shear tests, subsequent to the Long Beach National Science Foundation testing, have verified that in-plane shear capacity is greatly enhanced by the presence of the polyester grout. In addition to the high shear strength for the masonry units directly influenced by the grout, it is widely accepted that wherever confinement of unreinforced masonry units can be provided, such as the areas of wall between grouted cores, the push test values would certainly be more dependable by this horizontal confinement and the full-height securing of the overburden.

An accepted standard for measuring the shear capacity of a brick wall is the "push test" found in codes for the seismic retrofit of existing buildings (such as the Uniform Code for Building Conservation (UCBC) or FEMA 356 Draft). This materials test determines the actual shear capacity of the weakest link of the unreinforced masonry assembly – the mortar bed joint. The empirical formula of the "codes" for shear allow masonry shear to be one-tenth of the value of the in-plane shear test. The basis for this conservative 10% of the tested value is the assumption of diagonal shear cracks in the wall, as well as the unpredictable nature of the overburden.

The presence of a bonded assembly of full height reinforced cores in the wall secures the overburden for its overall height, and effectively confines the brick-mortar matrix horizontally between cores. With this confinement, the expected strength of the overall in-plane shear capacity would be very near 100% of the push test results. A recommended design value, or Ø factor, is 75% vt without using any shear capacity of the actual reinforcement, which is significant. Therefore, the engineer can utilize 75% of the tested average of vt when the tested wall area is confined. A wall area is considered confined when reinforced cores are spaced not more than 75% of the story height as shown in Figure 2.

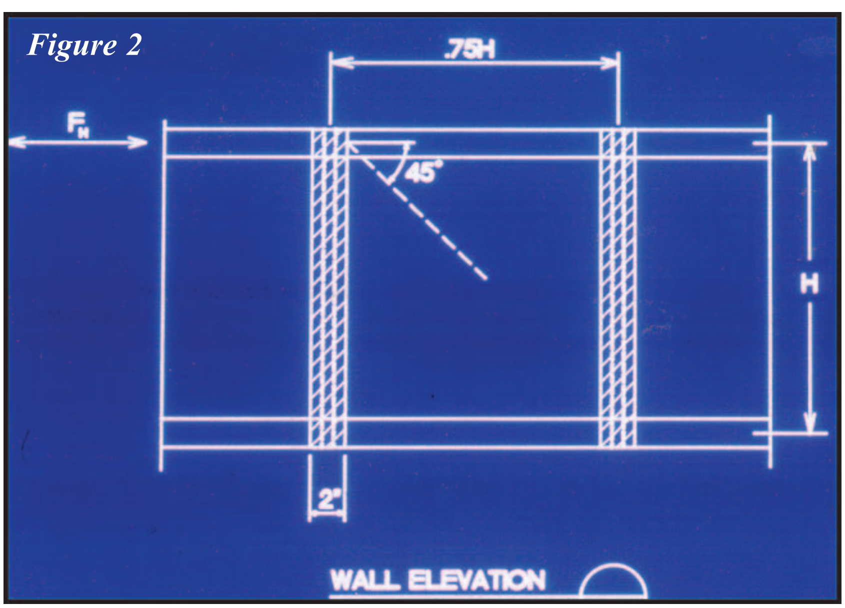
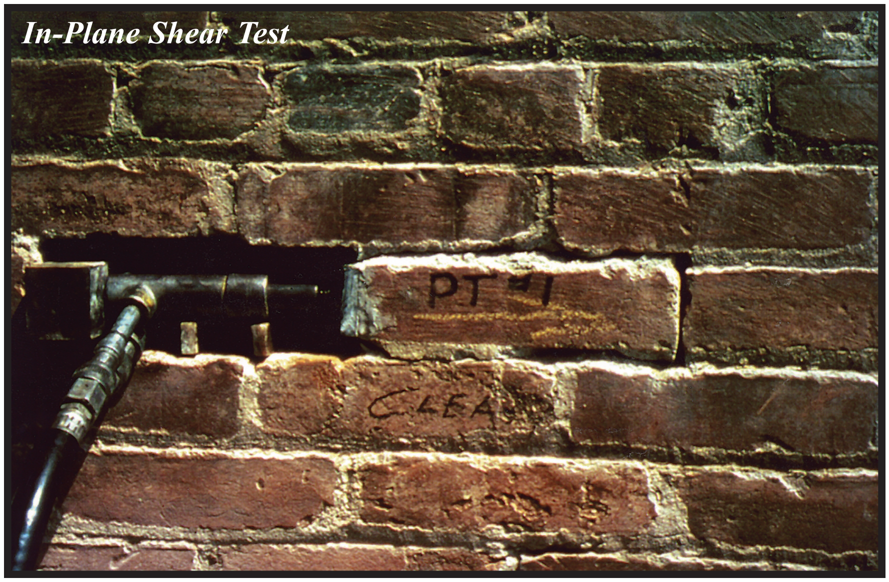


Figure 2



In-Plane Shear Test

"...the core created in the wall is clean and dry..."

The Coring

State of the art coring bits have made dry coring a best option. The multiple bit cuts the core, as well as mulches the debris. Instead of extracting brick rubble from the core, a positive and negative air system simply vacuums the brick dust directly to a filtered, dust-controlled container for removal from the site. By eliminating the use of water, the core created in the wall is clean and dry and does not need brushing for removal of brick paste or drying prior to grouting.

The Grout

Improved quality control measures for the grout components (sand, polyester resin and catalyst) have provide a more predictable grout in terms of handling and final strength, as well as control of gel time. The grout mix preparation is approximately 2 to 1 of bagged silica sand with a pre-mixed, catalyzed resin for a uniform mix in a mechanical mixer. Viscosity can be easily controlled without giving up bond strength.

The Cost

The in-place cost of a reinforced grouted core is approximately $125.00 per lineal foot. Considering the area of unreinforced masonry wall that is stabilized as a function of core spacing, the CenterCore technique is cost effective and structurally more desirable than other rehabilitation options. Most other wall stabilizing/wall strengthening options require displacement of occupants or tenants.

Conclusion

The initial progressive steps taken by the National Science Foundation and The City of Long Beach have given the structural engineer a viable alternative for seismic hazard reduction of unreinforced masonry buildings. We now have a technique to provide stability and predictable strength to a building where the strength is expected – in the bearing walls.

The world inventory of seismically hazardous unreinforced masonry buildings is large. The CenterCore technique can play a significant role in reducing the seismic hazard and extending the life of these buildings.