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CenterCore seismic hazard reduction system for URM buildings

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ABSTRACT: The CenterCore technique of reinforcing unreinforced masonry walls was develop with the help of a National Science Foundation grant in 1984. The CenterCore strengthening syste consists of a reinforced grouted core placed in the center of an existing unreinforced masonry wa The core is provided by coring a vertical hole from the top continuously through the wall into t existing footing. The drilling is a dry process with debris removal handled by a vacuum and filt system that controls the debris collection and keeps the dust to a minimum. Reinforcing steel is plac in the center of the hole, usually a #6 to #9 bar, and a polyester-sand grout is placed to bond t assembly. The migration and strong bonding of the grout to the inner and outer wythes of bri provides a "homogeneous" structural element to resist both in-plane shear and out-of-plane bending.

1.0 BACKGROUND AND HISTORY

The concept of placing reinforcing steel in an existing unreinforced masonry wall is not new. Engineers have all 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.

Another strengthening concept that has been used to retrofit an unreinforced masonry wall is the addition of reinforced concrete to one or both sides of the wall to increase the wall's capacity to resist in-plane shear and to resist out-of-plane bending with a "basketing" or membrane action. The significant benefit of the CenterCore technique is that there is no disturbance to the interior or exterior side of the wall. The appearance of the building is not altered in any way by the presence of CenterCore and the occupant may remain in the building during construction.

In 1983 a National Science Foundation Grant was provided by the United States Government. The work of this grant provided for full-scale testing of the CenterCore technique on a one-story unreinforced masonry building in Long Beach, California that 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. So 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 that developed a fairly large, and somewhat uniform composite section for the full height of the grouted core.

Based upon the test results of the National Science Foundation Report, the City of Long Beach permitted the use of the CenterCore System on buildings in the City of Long Beach. The first building that requested use of the CenterCore technique was the First Congregation Church of Long Beach. This Church was constructed in 1913 and 1914. It is a beautiful, two and three-story building with a full basement and a total area of approximately 44,000 square feet. The sanctuary has a large balcony on three sides with a steel truss roof system. The 115-foot-high bell tower is a steel framed structure with brick infill. Immediately adjacent to the west wall of the sanctuary is a two-story parlor area and offices of the church with their own, somewhat separate basement structure.

All these components together form a structure of a difficult configuration and a challenge to a strengthening system of any type. Fortunately for our office, the leaders in the church had maintained the plans over the years, including the plans of the repair work after the March, 1933 Long Beach earthquake. This was a great help, not just from a field measuring standpoint, but with the repair plans it could be seen what areas of the building performed without damage while the actual repaired areas identified a previous weakness as well as a potential future weakness. A total of 4400 lineal feet of reinforced core was placed in the unreinforced brick of the Church walls. This strengthening of the bearing walls plus anchoring the walls to strengthened floors and the roof greatly enhanced the structure's ability to resist ground shaking during future earthquakes.

2.0 IN-PLANE SHEAR

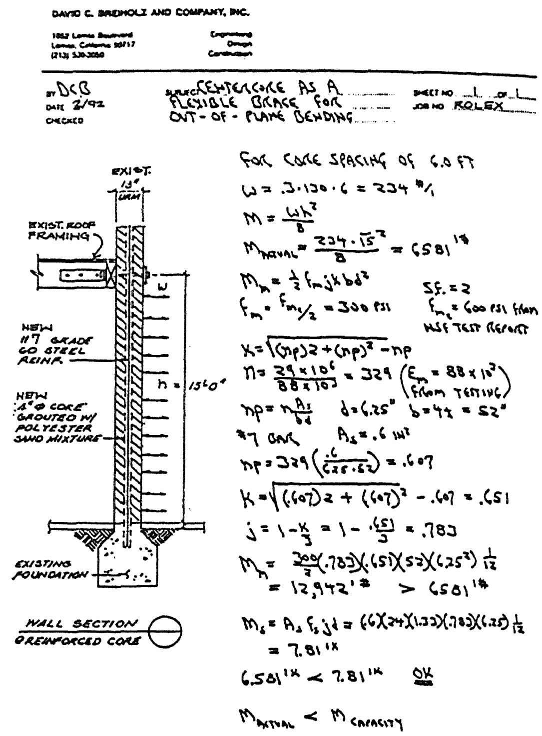
Of the unreinforced masonry buildings my engineering office has analyzed for seismic hazard mitigation, it is the in-plane shear forces on walls with openings that are usually critical and control the design. In-plane shear tests since the Long Beach National Science Foundation testing have verified 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 affected by the grout, it is my opinion that wherever confinement of unreinforced masonry units can be provided, such as the areas of wall between grouted cores, the in-plane shear capacity is very predictable and certainly made more dependable by this confinement and the full-height anchoring of the wall to the footing.

The seismic design force to the Church walls was based upon 13% of the mass of the building as a lateral force applied in two orthogonal directions resisted entirely by the walls in line with the direction of the load. Although shear tests were performed on the existing mortar resulting in a relatively high average net shear of 89 psi, the in-plane shear design utilized only the CenterCore test results, with appropriate safety factors, and ignored the tested capacity of the existing mortar.

3.0 OUT-OF-PLANE BENDING

The purpose of strengthening for out-of-plane forces is obviously to prevent the wall from falling in or falling out. Once a good wall-to-diaphragm anchorage is accomplished, the reinforced core at the center of the section provides flexural capacity in addition to the arching action capacity to keep the wall in place and in position to carry the building's vertical loads and prevent collapse. The design strength of CenterCore for out-of-plane flexure is based upon a yielding of the steel prior to any crushing of the masonry using a conservative value of f_m (allowable compressive strength of masonry). The force developing the moment vs. the flexural strength of the CenterCore System will determine the spacing of the cores.

The following sample calculation demonstrates that a 4" diameter core with 7/8" ϕ reinforcing steel at 6'-0" on center and a conservative value of f_m of 300 psi for the masonry, will provide a moment capacity of about 8 foot-kips which is approximately 1.2 times the actual design moment.


DAVID C. BREIHOLZ AND COMPANY, INC.

BY DCB
DATE 2/92
CHECKED
SUBJECT CENTERCORE AS A FLEXIBLE BRACE FOR OUT-OF-PLANE BENDING
SHEET NO. 1 OF 1
JOB NO. ROLEX

FOR CORE SPACING OF 6.0 FT

$w = .3 \cdot 130 \cdot 6 = 234$ #/'

$M = \frac{wh^2}{8}$

$M_{ACTUAL} = \frac{234 \cdot 15^2}{8} = 6581$ '#

$M_m = \frac{1}{2} f_m jk bd^2$ S.F. = 2

$f_m = f_{m_t}/2 = 300$ PSI $f_{m_t} = 600$ PSI from NSF TEST REPORT

$k = \sqrt{(np)2 + (np)^2} - np$

$n = \frac{29 \times 10^6}{88 \times 10^3} = 329$ ($E_m = 88 \times 10^3$ from TESTING)

$np = n\frac{A_s}{bd}$ d = 6.25" b = 4t = 52"

#7 BAR $A_s = .6$ IN²

$np = 329\left(\frac{.6}{6.25 \cdot 52}\right) = .607$

$k = \sqrt{(.607)2 + (.607)^2} - .607 = .651$

$j = 1 - \frac{k}{3} = 1 - \frac{.651}{3} = .783$

$M_m = \frac{300}{2}(.783)(.651)(52)(6.25^2)\frac{1}{12}$
$= 12{,}942$ '# > 6581 '#

$M_s = A_s f_s jd = (.6)(24)(1.33)(.783)(6.25)\frac{1}{12}$
$= 7.81$ 'K

6.581 'K < 7.81 'K OK

$M_{ACTUAL} < M_{CAPACITY}$

4.0 IMPROVEMENTS SINCE FIRST PROJECT OF 1986

4.1 Coring

The improvements with coring bits have made dry coring a better option than wet coring. There is no longer a sacrifice in speed with the dry coring system. The multiple bit used for dry coring cuts the core as well as mulches the debris so that, 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. The core created in the wall without water is clean and dry and does not need brushing for removal of brick paste or drying prior to grouting.

4.2 Grout

Improved quality control measures for the grout components (sand, polyester resin, and catalyst) have provided a more predictable product in terms of handling and final strength as well as control of gel time. Bagged silica sand is used with a premixed, catalyzed resin for a uniform mix in a mechanical mixer. Viscosity can now be easily controlled without giving up bond strength.

5.0 COST

The strengthening of the walls of an unreinforced masonry building is a significant part of the total seismic retrofit work; however; there are obviously other building elements to be addressed, mainly the roof and floor diaphragms and wall anchors tying the walls to the diaphragms. The cost of the CenterCore technique, which covers all wall-strengthening costs, is $95.00 per lineal foot of core in place. The total number of cores is determined by the required design strengthening of the building.

An approximate cost per square foot of wall would be $12.00 with cores at 8' on center in a 12' high wall. A representative cost per square foot area for the above wall condition would be $8.60 for a 50' x 100' building.

6.0 NEEDED RESEARCH

The utilization of CenterCore since 1986 has identified needs for future testing and research. Following are some areas where further research would enhance the technique and add to the practical benefits of the process:

1. In-plane Shear - A testing program should be developed to determine the optimum spacing of cores for confinement of the unreinforced masonry between cores. To simplify the design procedure the allowable shear stress should be expressed in terms of percentage of tested mortar shear strength and the core spacing.

2. Out-of-Plane Bending - Flexural capacities of CenterCore strengthened walls should be tested to verify the safe allowable compression on the existing brick or stone assembly. The design objective for flexural capacity of the wall is to achieve tensile yielding of the steel prior to compressive crushing of the masonry. At this point in time we are using a conservative 300 psi for an allowable compression in the masonry assembly based upon the full scale flexural test results of 1984. The most dependable test to establish f_m for a particular building (or wall) is the flat-jack test. This test is performed in the field and can be applied to a specific accessible wall and provides real valves for the actual masonry assembly.

3. Stress Behavior - An instrumentation program of placing strain gages on reinforcing steel within the cores at strategic locations in the walls and footings as well as on wall anchors connecting the roof and floor(s) to the cores should be developed. Knowing the real stress on critical structural elements responding to real ground motions would be very enlightening to the Earthquake Safety Community and advance the Science of seismic hazard reduction.

4. Quality Control - Development of specialized grout mixing and placing equipment such as a fiber reinforced plastic tremie that serves as both a passive mixer and a conduit to place the grout as well as the tensile reinforcing for the core. This FRP tremie could simply be abandoned in the grouted core which would reduce the clean-up chores and enhance the quality control of placing the grout.

7.0 RECOMMENDATIONS

The reinforced core and the surrounding masonry that is influenced by the core and the grout migration constitutes a vertical element of a frame that is an integral part of the wall. Since this frame is a homogeneous part of the wall it cannot move independently of the surrounding "infill". The effect of a reinforced core attracting and carrying a shear force in the plane of the wall is a direct transfer of this in-plane force from the core to the adjacent "infill". Although the infill is confined by the next adjacent reinforced core, if it was permitted to move, its failure mode would be diagonal tension "x-cracking". The x-cracks that may develop are interrupted by the influence of the next adjacent core. The core spacing to assure that a 45 degree x-crack would be interrupted by a vertical core is a spacing less than the story height. For example, if a potential x-crack develops at the roof level and travels down to the floor diapragm level it would hit the influence of the core frame before it got to the ledger. A conservative spacing of the CenterCore reinforcement for resisting in-plane forces would be .75 times the story height. Tests have demonstrated that the effective influence of the grouted core is at least one brick length beyond the edge of the core. With a four inch diameter core, the effective width of the core influence is two feet, so with a core spacing of .75h a diagonal crack could only develop a horizontal projected length of .75h, - 2 feet.

8.0 CONCLUSION

Both the National Science Foundation and the City of Long Beach deserve credit for taking a progressive step with the testing and first acceptance of the CenterCore System.

This initial step has provided many benefits with the most important being earthquake safety for a significant number of buildings (see project list). Another benefit of CenterCore development is for the practicing engineer who is given the task of strengthening the next unreinforced masonry building. He now has a viable alternative for seismic hazard reduction from a structural and economic sense. The engineer now has a way to add stability and strength to a building where the strength is expected -- in the bearing walls.

CenterCore has given some hope to the owner who may be ordered by the government to strengthen or demolish his building. The owner is the ultimate responsible party to provide a safe building. With CenterCore, the owner has a strengthening option that should be cost effective and will have less of an impact on his tenants than conventional methods of structural rehabilitation.

For the preservationist, and all of us with any interest in our cultural heritage, when it comes to buildings, CenterCore can be applied to a distinguished old building and when the work is complete, we have a safer building that still is attractive. The structural engineer is the practical unsung hero to many building projects. When he or she can apply CenterCore so structural rehabilitation, the preservationist must consider this engineer as the lead hero. I think we all know the importance of saving attractive landmarks. As the motto of the National Trust for Historic Preservation says, "Old Friends Are Worth Keeping."

The final benefit of utilizing CenterCore is being able to occupy the building during construction. With some harmony in the combination of the four benefits above, the agency, the engineer, the owner and the preservationist, CenterCore strengthening allows the occupant to remain in the building while providing a much safer place to live and work and also providing an extension of life for the building.

9.0 LIST OF CENTERCORE PROJECTS 1984 TO PRESENT

Project/Location	Description
Full Scale Testing 325 Pine Ave. Long Beach, CA. 1984	One-story jewelry store
1st Congregational Church 3rd & Cedar Ave. Long Beach, CA 1986-1987	44,000 sq. ft one and two story with basement. URM infill bell tower. Historic building
Bank of America 115 Pine Ave. FullLong Beach, CA Office Building over La Opera Restaurant 1987	Six-story offices over retail. basement. CenterCore with braced frames & moment frames 77 cores 55'-80' long. Historic building
South Hall University of California at Berkeley 1987	University classroom building
Zietans Market* The Toledo withLong Beach,CA	One-story URM grocery store attached wood frame apartment
Office of Naval Research * 1030 E. Green St. Pasadena, CA. 1988	35,000 sq. ft. 2-story offices over partial basement. Historic building
Paramount Chevrolet Paramount, CA 1988	One-story automobile showroom/repair
Far West Savings 5116 East 2nd St. Belmont Shores, CA 1986	One-story bank building
Our Lady of Help Catholic Church 1989	4 cores for bell tower
Sacred Heart 2200 Sichel St. Los Angeles,CA 1989-1990	53 - 6" diameter cores 40' - 70' long Historic Building
Gatewood Elementary School Seattle, WA 1990	47 - 4" diameter cores 62' long Historic school building
St. Mary's Church 500 S. Central Blvd. Glendale, CA 1990	10 cores, repair of Whittier Narrows Earthquake Damage
Welge/Wells Fargo 5209-11 2nd Street Long Beach, CA 1990	One & two story Offices over retail 5500 sq. ft.
Japanese American National Museum 1st & Central Avenue Los Angeles, CA 1990-1991	One & three-story Assembly/Museum Historic building
Chancellor's Residence University of California Berkeley, CA 1991	University Residence Historic building
Motley Building #1 Malaga Cove Palos Verdes Estates, CA 1992	2-story URM Historic building Offices over bank and retail sales.
FHP Senior Health Center 628 Alamitos Blvd Long Beach, CA 1991	CenterCore in lieu of gunite for property line wall
Lincoln Heights Library* 2430 Workman Street Los Angeles, CA 1991	One and two Story Historic library
U.S. Customs House* 555 Battery San Francisco, CA 1991	274 cores 5000 lineal feet Historic building

* Designed, not constructed

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