Resiliency of Reinforced Structural Clay Unit Masonry Construction

By Steven G. Judd, S.E.

It is common to overlook Structural Clay Units (SCU) as a viable, and often more desirable, solution during discussions of structural masonry. It seems that the default solution to most structural masonry design challenges is Concrete Masonry Units (CMU). Unfortunately, in many instances, this is due to lack of information. There are some areas of the U.S. and Canada, and some individual practitioners, who are unfamiliar with SCU as a viable structural solution. If properly evaluated, practitioners may find that SCU is the best structural masonry solution to satisfy the design criteria/demand.

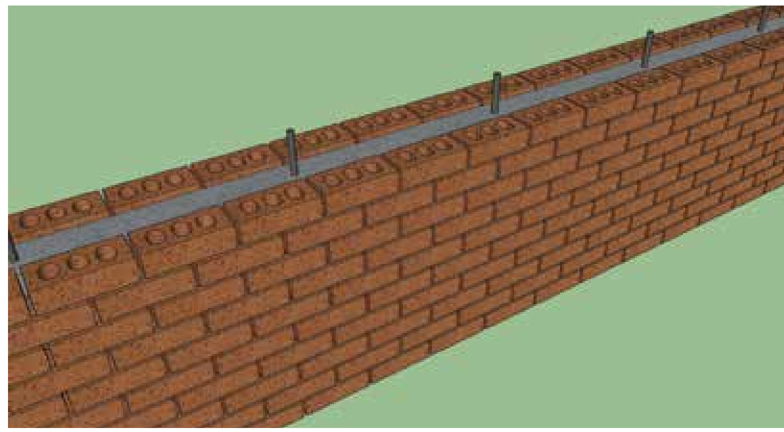

Figure 1. Reinforced cavity wall.

History

Reinforced clay masonry use dates to the 1800s where it was typically used to hold large ornate Terra Cotta pieces onto masonry buildings. In 1813, reinforcement was proposed by Mark Isambard Brunel to reinforce a masonry chimney which was under construction in England at the time. Its first significant use was the Brunel-designed Thames Tunnel which began in 1825 – a successful construction of a 30-inch-thick (762 mm), 50-foot-diameter (15.24 m) tube buried 70 feet deep (21 m) under the famous river that bisects London, England.

Another early use came in 1875 with the construction of the seven-story Palace Hotel in San Francisco, California. The hotel was comprised of three-foot-thick solid brick walls with iron bands spaced every few feet, forming a "basket" that completely encircled the facility. The hotel is one of the very few large buildings that survived the 7.9 (Richter) magnitude (est.) 1906 San Francisco earthquake.

It was not until the 1920s and 1930s that serious research was performed (initially in India, and later in the United States) on the properties of loadbearing, grouted, and reinforced clay brick masonry and engineering procedures were developed to create thinner masonry elements. The first reinforced clay brick systems used reinforced cavity construction; two wythes separated by a grouted and reinforced cavity space (*Figure 1*). The international use of reinforced masonry in the early 20th century was initially driven by the lack of suitable (ductile) structural steel and the cost of wood (for forming reinforced concrete). Reinforced masonry became the standard material for construction of public and important private buildings, plus bridges, retaining walls, storage bins, and chimneys (back to the original proposed use).

In 1952, the Structural Clay Products Institute (SCPI) developed the "Structural Clay Research" (SCR) brick. This brick was intended to be used as a loadbearing wall replacement to wood framing. This was unreinforced clay masonry, common before the introduction of seismic codes in the 1970s. In response to many large west coast seismic events up through the 1970s, building codes in California and the western United States changed to mandate that all loadbearing masonry buildings be reinforced and tied to the foundation and the roof. The concept of a two-wythe reinforced cavity wall coupled with SCR brick led to the development of hollow reinforceable brick, which is the principal reinforced SCU used today: two brick faces separated by reinforced grout cells – a scaled-down version of the grouted cavity wall (*Figure 2*).

Resiliency

To understand the resiliency provided by reinforced SCU masonry, one must understand the manufacturing process of the clay units. Brick is a natural product principally comprised of clay, shale, and sand in various proportions. Other minerals (barium, chromate, manganese) are added to modify/broaden the color palette and which also, consequently, modify the strength. Water is added to the pulverized dry clay mix to create a stiff plastic consistency, similar to modeling clay, so that the clay mix can be pushed through dies or pressed into molds. After the clay is extruded through the die and trimmed to size, the column of brick is cut to the pre-fired size. In some facilities, the clay is dried in a separate process to help reduce stress cracking from the firing process. Whether pre-dried or not, the clay units are then fired in kilns at temperatures around 2100°F (1149° C), near the vitrification temperature of clay, creating a very hard, strong, durable, mostly inert product. As fired, the net unit compressive strength ranges from 9,000 psi (62 MPa) upwards of 18,000 psi (124 MPa), depending on the clay mix, the unit profile, and the firing process. As one can see, the clay units are many times stronger than CMU units that are generally around 2,500 psi (17.2 MPa) to 3,500 psi (24.1 MPa), perhaps up to 6000 psi (41.4 MPa) for high strength CMU concrete mixes.

The high strength of the clay units used in grouted and reinforced walls produce a very high-strength, resilient wall system. This SCU wall system can accomplish many goals and accommodate many design challenges, including resistance to fire exposure, extreme wind, wind-driven projectiles, ballistic impact, and seismic forces.

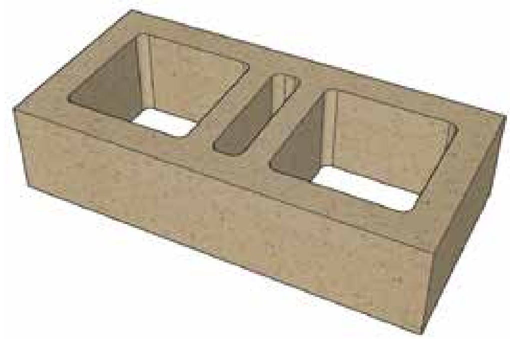

Figure 2. Structural Clay Unit.

Fire Resilience

The kiln temperatures used to fire the brick are higher than the temperature used to fire-test reinforced SCU wall assemblies for fire resistance. The UL-935 rating requires wall assemblies to be preloaded in compression and held at a temperature of 2000° F (1093° C) for four hours, then sprayed with water at 45 psi (2.16 kPa) for 5 minutes. Eight-inch (203 mm) reinforced SCU walls (unreinforced vertical cells filled with grout or insulation) are UL 935 rated for 4-hour fire resistance. Thinner walls, or partially unfilled walls, meet shorter fire duration ratings. Fire-rated walls used for safe rooms, property-line walls, fire-rated demising walls, and building separation walls are ideal uses for reinforced SCU.

In the past several years, two different multi-family, multi-story apartment buildings caught fire in Winnipeg, Manitoba. In the first case, the building was a typical multi-level wood framed facility. The fire started in one unit and spread to all the units, displacing around a dozen families. In the second case, the multi-story apartment facility was constructed of SCU and the fire was contained in one unit, displacing only one tenant. Homes and other residential buildings have a distinct advantage in consideration of accidental fires and wildfires. According to an article written by Christopher Williams for THE NEST website, houses with brick or masonry construction are often less expensive to insure than wood-framed houses, due, in part, to their increased capacity to resist fire.

Extreme Wind Resilience

Large areas of the United States can have tornado driven winds as high as 250 mph (402 kph). This equates to service-level-design wall pressures of around 117 psf (5.6 kPa) for single-story facilities. Reinforced SCU walls can efficiently resist this intensity of direct pressure. As an example: a 6-inch-thick (152 mm), 12-foot-tall (3.6 m) reinforced SCU wall, supporting 1500 plf (2232 kg/m) roof loads at a 1.5-inch (38 mm) eccentricity, can resist the 117 psf (5.6 kPa) direct wind design pressure perpendicular-to-face. A similar height CMU wall would have to be 8 inches (204 mm) thick to provide the equivalent axial and bending wall capacity. This example shows that reinforced SCU walls save space and use less grout (due to smaller grout cells), which can save construction cost and increase leasable space.

FEMA grants are often used by small communities to fund construction of storm shelters. FEMA grants will not cover the cost of aesthetic enhancements, like brick veneer, but FEMA will cover the cost of reinforced SCU used as the primary structure. This approach maintains the brick aesthetics with costs covered by the FEMA storm shelter grant (75% FEMA/25% local jurisdiction). SCU walls can solve design challenges in tornado and hurricane-prone areas. Potential SCU uses include essential facilities, hospitals, schools, fire stations, police stations, emergency generator enclosures, hardened spaces, and tornado and hurricane shelters as good uses for reinforced SCU.

Projectile Resilience

Tests have shown that 6-inch (152 mm) and 8-inch (203 mm) solid grouted SCU walls effectively resist penetration of projectiles, unlike typical brick veneer walls. The standard tornado projectile test – a 15-pound (6.8 kg), 10-foot-long (3.0 m) 2x4 (51mm x 102mm) traveling at 100 mph (161 kph) – results in the projectile shattering when striking the face of a reinforced and grouted SCU wall, leaving no discernable damage (*Figure 3, page 18*). This projectile resistance capacity complies with the prescribed criteria for tornado shelters for community and residential safe rooms as contained in FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes*. An added benefit is that the high strength, reinforced SCU wall system can more easily develop high capacities for fasteners used to secure window frames, door frames, and louvers. Due to these two factors, tornado shelters, hurricane shelters, and hardened rooms are good uses for reinforced SCU.

Ballistic Impact Resilience

The high kiln-firing temperatures of the clay produce materials that come close to becoming an impermeable fused mass, like igneous rock.

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Figure 3. Shattered projectile after hitting SCU wall.

Self-performed preliminary ballistic testing proves grouted SCU is an effective barrier to ballistic impact. In general, typical handgun munitions only pock the surface of the brick. Rifle munitions can do more damage, but, up to certain large calibers, do not penetrate the wall. This capability to resist ballistic impact can be effective in protecting occupants in schools, libraries, workspaces, and many other at-risk facilities.

Seismic Resilience

Typical high-strength clay units can produce a very strong and resilient wall for resistance to high in-plane shear loads and high axial loads, at a higher capacity than the same thickness CMU wall systems. Typical design prism strengths for CMU range from 1900 psi to 2500 psi; typical design prism strengths for SCU range from 3500 psi to 4000 psi. This higher prism strength means thinner walls of SCU can be used to generate the capacities/resistance needed as compared to CMU. This capability makes reinforced SCU a good choice for primary lateral force resisting masonry systems – bearing wall and shear wall buildings. In some ways, reinforced SCU can be considered as "left-in-place concrete formwork," providing high in-plane wall strength with a durable, classic finished surface. Unlike structural clay tile, which is restricted for use in some high seismic areas, structural clay brick can be used in any seismically active region.

The Los Angeles Police Department, Devonshire Station, is a reinforced SCU facility that survived the 6.7 (Richter) magnitude 1994 Northridge California Earthquake intact and was reportedly used as an emergency service coordination center immediately after the temblor. The facility is located 3.0 miles (4.8 km) from the epicenter of that event.

Blast Resilience

Blast resistant reinforced SCU exterior walls were used for the United States Federal Courthouse in Covington, Kentucky. Reinforced SCU walls produce almost infinite redundant load paths, which is essential for providing the capacity to withstand blast damage without total collapse. Reinforced structural walls tend to arch over openings and redistribute load paths as a natural consequence of their construction. The high strength associated with reinforced SCU allows embedded items (connections) to develop high strength in the wall system, which is essential for blast resistant connection design of the wall to the primary structure. These characteristics make reinforced SCU an excellent choice for facilities that require blast resistance, such as judicial facilities, embassies, emergency response facilities, high-value diplomat residences, and military facilities.

Other Considerations

When compared to reinforced CMU, a reinforced SCU wall can be constructed higher for any given wall thickness and applied load, or can generally be thinner for a given wall height and applied load. Thus, reinforced SCU provides for more efficient space use; less space is devoted to the wall system. Interior 10-inch (254 mm) SCU bearing walls (f´m = 4000 psi [27.58 MPa]) have been designed with heights up to 44 feet [13.4 m] (without bracing or pilasters). A CMU wall (f´m = 2500 psi [17.24 MPa]) would have to be 12 inches [305mm] thick to work with the same amount of reinforcement as that 10-inch [254 mm] SCU wall. Consequently, less interior space may be required for the structural wall using SCU, making it a good choice for large volume spaces such as garages, pools, auditoriums, ballrooms, and water treatment plants.

The firing process drives out all latent moisture from the clay, so clay masonry does not shrink after it is fired. Clay masonry will expand over time, to a small degree, as the clay absorbs ambient atmospheric moisture. Clay masonry wall systems tend to "tighten up," enhancing moisture impermeability over time.

In addition to the resiliency discussed above, grouted SCU provides: good sound transmission control; the benefits of thermal mass (thermal dampening and temperature lag); and a finished brick face without the need for adding brick veneer.

Reinforced SCU should be considered a versatile, resilient, and high performing structural wall system to apply to many structural design challenges.▪

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