Strawbale Construction and Its Evolution in Building Codes

By David Eisenberg and Martin Hammer

Strawbale construction—a wall system using baled straw as large, stackable blocks—was invented in the United States more than 130 years ago. Though its original heyday was in the early 20th century, a vigorous revival began in the late 1980s and continues today. The result is thousands of strawbale buildings spread across 49 states—more than 500 in California alone—and many thousands more in over 45 countries around the world.[1]

Fig.1. Simonton House. Nebraska—1908

In 1880, Josiah Leeds of Indiana was granted a U.S. Patent for a load-bearing strawbale building system, made possible by the earlier invention of baling machines. No less than five patents using strawbales as a building material followed during the next five decades, from practitioners in Wisconsin, Missouri and New York. Strawbale construction was especially popular in Nebraska (Fig. 1) where it originated, and many of Nebraska's early buildings, some more than 100 years old, are

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Fig. 2. A contemporary strawbale building. Ridge Winery, California, 2002. Interior before plaster, exterior finished. Freebairn-Smith & Crane Architects.

PHOTOS COURTESY TIM OWEN-KENNEDY, VITAL SYSTEMS

still in service. The practice was abandoned in the post-war 1940s, but the rediscovery and modern revival that began in the American southwest in the 1980s spread rapidly as the owner-builder friendliness, resource and energy efficiency, and aesthetic qualities were recognized.

Today, strawbale buildings include residences, schools, office buildings, retail stores, wineries (see Fig. 2), multi-story buildings, and both load-bearing structures and others using strawbale shear walls, even in areas of high seismic risk. Strawbale buildings have been constructed up to 20,000 square feet in size. Building styles range from modern and high-tech to rustic, with most finished with plaster, though other cladding systems have been used.

Materials

Straw is an agricultural by-product remaining after the harvest of grains such as rice, wheat, barley, oat and rye. It is baled at a moisture content of less than 20 percent using mechanical baling equipment. Two- and three-string bales are commonly used for building (see Fig. 3). Braided polypropylene is now used nearly universally as baling twine. Typical bale densities are 7-8 pounds per cubic foot (pcf), resulting in a three-string bale weighing 75-80 pounds.

Plaster on strawbale walls uses binders of clay, lime or cement-lime, applied either by hand or machine, with or without mesh, depending on structural demands. Mesh of galvanized steel, high-density polypropylene, nylon or natural fiber has been used.

Testing and Research

The challenge of obtaining building permit approvals led to initial structural, fire, and thermal-resistance testing in the early 1990s. This testing led to the development of the first strawbale codes in New Mexico (1996) and in Tucson and Pima County, Ariz., (1996).

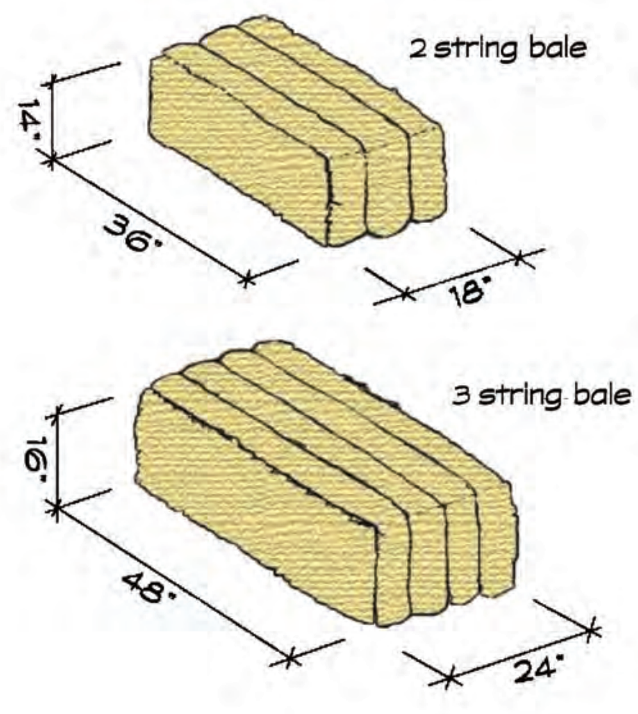

Fig. 3. Two-string and three-string bales

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Fig. 4. Shake table test at the University of Nevada, Reno, 2009.

PHOTO COURTESY OF MARTIN HAMMER, PAKSBAB.

Since that time, extensive research, testing and development, coupled with the collective experience of architects, engineers and builders, have resulted in more widespread use and acceptance, as well as an evolution in strawbale building codes.

A variety of wall specimen and component structural tests have been performed since 1993. These include vertical load-bearing, reversed in-plane cyclic, monotonic and out-of-plane wall specimen tests, as well as component tests on bales, plasters and mesh anchorage. Most tests have occurred in university or laboratory settings. A successful full-scale shake table test of a small house using a low-tech, low-cost wall system tailored to post-earthquake Pakistan was conducted in 2009 at the University of Nevada (see Fig. 4).

Guarded hot box thermal tests at Oak Ridge National Laboratory and other labs have shown plastered strawbale walls to have thermal resistance of R-30 for a typical wall. ASTM E-84 tests in 2000 indicated a flame spread index of 10 and a smoke developed index of 350 for strawbales, each less than respective IBC maximums of 25 and 450 for both concealed and exposed insulation. In 2006, ASTM E-119 fire tests were conducted, including hose stream tests, indicating fire-resistance ratings for strawbale wall assemblies with clay plaster and cement-lime plaster of 1-hour and 2-hour, respectively.

Click here for testing and research reports, and analyses of wall system behavior regarding structure, moisture, fire-resistance and thermal-resistance.

Wall System Anatomy and Structural Performance

Strawbale walls are typically plastered inside and out using clay, lime, or cement-lime plasters, with or without reinforcing mesh, depending on the plaster type and structural demands. The bales, plaster and mesh work together to create a composite structural system, similar in concept and performance to a structural insulated panel (SIP). The plaster and its reinforcement form a skin that is strong, stiff and durable, bonding to the softer bales and protecting them from moisture, fire and wear, while the bales brace the plaster skins against buckling. Plastered strawbale walls have substantial structural capacity when properly detailed, both as load-bearing and in-plane lateral load resisting systems.

There are many variations of strawbale wall systems used throughout the world. Strawbale walls are either

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load-bearing or post and beam with strawbale infill, and are used as shear walls, or the building relies on another lateral force resisting system. Most buildings to date have been one-story, but two-story buildings are not unusual. Typical wall sections are illustrated for one-story load-bearing (see Fig. 5) and two-story post-and-beam with strawbale shear walls (see Fig. 6).

Testing has shown load-bearing walls capable of supporting service loadsof 800 pounds per foot for "hard" plasters (cement lime, soil-cement) and 400-500 pounds per foot for "soft" plasters (clay, lime). In-plane tests indicate allowable shears for strawbale shear walls, from 140 pounds per foot for reinforced clay plaster walls to 680 pounds per foot for cement-lime plaster walls, depending on plaster thickness, mesh, mesh attachment, and top and bottom plates. These values reflect factors of safety of 2.75 to 3.9 relative to the ultimate loads in the tests. In all structural strawbale walls, the primary load path is through the plaster skins, the stiffest element in the system. As such, it is important that detailing delivers roof or floor loads into the skins at the top of the wall, and that the bottom plaster edges are supported at floors and foundations.

In structural walls, it is also important that plasters bond with the strawbale core, so the system acts as a composite. Therefore, no sheet barrier (moisture or

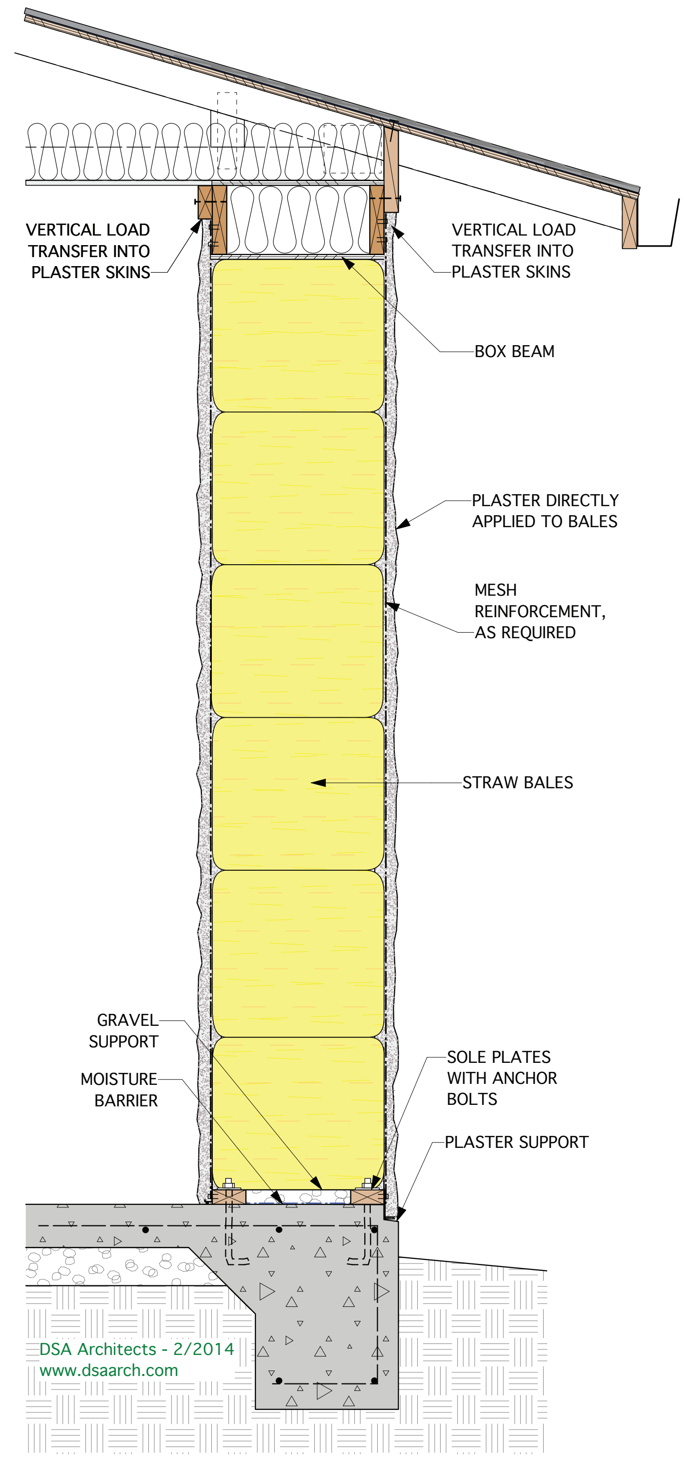

Fig. 5. One-story load bearing strawbale wall.
ILLUSTRATION COURTESY OF DSA ARCHITECTS

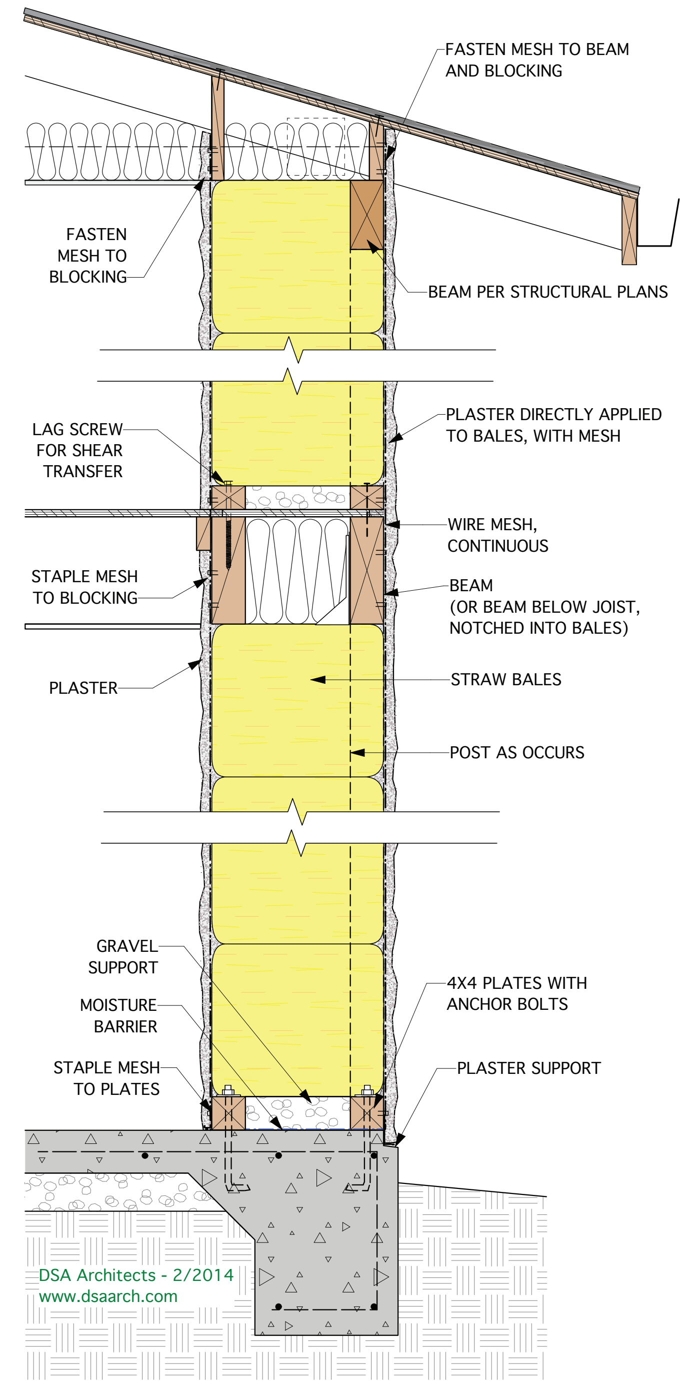

Fig. 6. Two-story post and beam with strawbale shear walls.
ILLUSTRATION COURTESY OF DSA ARCHITECTS

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wind barrier) should be used between plaster and straw. Though counter to code requirements for other wall systems, testing and extensive field experience in a variety of climates have shown that the wall system without a moisture barrier manages moisture very effectively without damage to the straw. This is attributed to straw's ability to store modest amounts of moisture, and then release it though vapor permeable plasters when environmental conditions permit.

Out-of-plane tests on strawbale walls show them to be highly resistant to buckling under load. This is due to their wide footprint and composite behavior.

Strawbale Construction and U.S. Building Codes

The first permitted strawbale building was a retreat center in Kortright, N.Y., in 1989 (see Fig. 7). The permit was issued to the owner at the building inspector's dining room table. Since then, most strawbale buildings have been permitted under the "Alternative Materials and Methods" section of the building code. Only New Mexico (1996), Oregon (2000), and North Carolina (2011) have adopted statewide strawbale codes. In 1995, California legislated strawbale construction guidelines for voluntary adoption by local jurisdictions. Those guidelines (in California's Health and Safety Code) were revised in 2002. Since 1997, nine cities or counties in four other states have adopted strawbale building codes.

Fig. 7. First permitted strawbale building. A retreat center in Kortright, N.Y., 1989. Finished with gunite.
PHOTO COURTESY OF CATHERINE WANEK

Most strawbale building codes in the United States were derived from the strawbale code created for and

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adopted by the city of Tucson and Pima County, Ariz. in 1996. Extensive experience, testing, research and engineering analyses since then have shown these codes to be out-of-date and deficient. In some aspects, they are too restrictive; in others, not restrictive enough, and they are silent on many important issues.

In January 2013, a code change proposal was submitted for an appendix on strawbale construction for the 2015 *International Residential Code*® (IRC). The proposal was approved 9-1 by the IRC Building Committee at the ICC Committee Action Hearings in April 2013. In October 2013, the proposal received final approval at ICC's Public Comment Hearings. The approved appendix, reflecting current understanding of strawbale construction, is tailored to the format and requirements of the IRC and will appear in the 2015 *International Residential Code*. **bsj**

[1] See the International Straw Bale Building Registry

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