

Approved Standard for Straw-Bale Construction

Note that the Straw-bale construction standard in Appendix S of the 2015 *International Residential Code* is a recognized alternative approved standard.

Straw-Bale Structures.

Section 101 - Purpose. The purpose of this document is to establish minimum prescriptive safety standards for the construction of structures which use baled straw as a load bearing or non-load bearing material.

Section 102 - Scope. The provisions of this chapter shall apply to all structures utilizing straw-bales in the construction of wall systems.

Section 103 - Definitions. For the purpose of this chapter, certain terms are defined as follows:

STRAW is the dry stems of cereal grains left after the seed heads have been removed.

BALES are rectangular compressed blocks of straw, bound by strings or wire.

FLAKES are slabs of straw removed from an untied bale. Flakes are used to fill small gaps between the ends of stacked bales.

LAID FLAT refers to stacking bales so that the sides with the largest cross-sectional area are horizontal and the longest dimension of this area is parallel with the wall plane.

LAID ON-EDGE refers to stacking bales so that the sides with the largest cross-sectional area are vertical and the longest dimension of this area is horizontal and parallel with the wall plane.

Section 104 - Materials

Section 104.1 Specifications for Bales.

Section 104.1.1 Type of Straw. Bales of various types of straw, including, but not limited to, wheat, rice, rye, barley, oats and similar plants, shall be acceptable if they meet the minimum requirements for density, shape, moisture content, and ties.

Section 104.1.2 Shape. Bales shall be rectangular in shape.

Section 104.1.3 Dimensions. Bales used within a continuous wall shall be of consistent height and width to ensure even distribution of loads within wall systems.

Section 104.1.4 Ties. Bales shall be bound with ties of either polypropylene string or baling wire. Bales with broken or loose ties shall not be used unless the broken or loose ties are replaced with ties which restore the original degree of compaction of the bale.

Section 104.1.5 Moisture Content. Moisture content of bales, at time of installation, shall not exceed 20% of the total weight of the bale. Moisture content of bales shall be determined by one of the following:

1. Field Method. A suitable moisture meter, designed for use with baled straw or hay, and equipped with a probe of sufficient length to reach the center of the bale, shall be used to determine the average moisture content of 5 bales randomly selected from the bales to be used.
2. Laboratory Method. A total of 5 samples, taken from the center of each of 5 bales randomly selected from the bales to be used, shall be tested for moisture content by a recognized testing lab.

Section 104.1.6 Density. Bales in load-bearing structures shall have a minimum calculated dry density of 7.0 pounds per cubic foot. The calculated dry density shall be determined after reducing the actual bale weight by the weight of the moisture content, as determined in Section 104.1.5. The calculated dry density shall be determined by dividing the calculated dry weight of the bale by the volume of the bale.

Section 104.1.7 Custom Size Bales. Where custom-made partial bales are used, they shall be of the same density, same string or wire tension, and, where possible, use the same number of ties as the standard size bales.

Section 105 - Construction and General Requirements

Section 105.1 General. Bale walls, when covered with plaster, drywall or stucco shall be deemed to have the equivalent fire resistive rating as wood frame construction with equivalent wall-finishing system.

Section 105.2 Wall Thickness. Nominal minimum bale wall thickness shall be 14 inches.

Section 105.3 Wall Height. Bale walls shall not exceed one story in height and the bale portion shall not exceed a height to width ratio of 5.6 : 1 (for example, the maximum height for the bale portion of a 23 inch thick wall would be 10 feet - 8 inches), unless the structure is designed by an Arizona Registrant.

Exception: In the non-load bearing exterior end walls of structures with gable or shed roofs, an approved continuous assembly shall be required at the roof bearing assembly level.

Section 105.4 Unsupported Wall Length. The ratio of unsupported wall length to thickness, for bale walls, shall not exceed 13:1 (for a 23-inch thick wall, the maximum unsupported length allowed is 25 feet), unless the structure is designed by an Arizona Registrant.

Section 105.5 Allowable Loads. The allowable vertical load (live and dead load) on the top of bale walls shall not exceed 360 psf and the resultant load shall act at the center of the wall. Bale structures shall be designed to withstand all vertical and horizontal loads as specified in the *International Building Code* or the *International Residential Code*.

Section 105.6 Foundations. Foundations shall be sized to accommodate the thickness of the bale wall and the load created by the wall and roof live and dead loads. Foundation (stem) walls which support bale walls shall extend to an elevation of not less than 6 inches above adjacent ground at all points. The minimum width of the footing shall be the width of the bale it supports, except that the bales may overhang the exterior edge of the foundation by not more than 3 inches to accommodate rigid perimeter insulation. Footings shall extend a minimum of 12 inches below natural, undisturbed soil, or to frost line, whichever is lower.

Section 105.7 Wall and Roof Bearing Assembly Anchorage

Section 105.7.1 General. Vertical reinforcing bars with a minimum diameter of 1/2", shall be embedded in the foundation a minimum depth of 6 inches, and shall extend above foundation a minimum of 12 inches. These vertical bars shall be located along the centerline of the bale wall, spaced not more than 2 feet apart. A vertical bar shall also be located within 1 foot of any opening or corner, except at locations occupied by anchor bolts.

Section 105.7.2 Intersecting Walls. Walls of other materials intersecting bale walls shall be attached to the bale wall by means of one or more of the following methods or an acceptable equivalent:

1. Wooden dowels at least 5/8" in diameter of sufficient length to provide 12 inches of penetration into the bale, driven through holes bored in the abutting stud, and spaced to provide one dowel connection per bale.
2. Pointed wooden stakes, at least 12 inches in length and 1-1/2" by 3-1/2" at the exposed end, fully driven into each course of bales, as anchorage points.
3. Bolted or threaded rod connection of the abutting wall, through the bale wall, to a steel nut and steel or plywood plate washer, a minimum of 6 inches square and a minimum thickness of 3/16" for steel and 1/2" for plywood, in at least three locations.

Section 105.7.3 Anchor Bolts. Load bearing bale walls shall be anchored to the foundation by 1/2" diameter steel anchor bolts embedded at least 7 inches in the foundation at intervals of 6 feet or less. A minimum of two anchor bolts per wall shall be provided with one bolt located within 36 inches of each end of each wall. Sections of 1/2" diameter threaded rod shall be connected to the anchor bolts, and to each other, by means of threaded coupling nuts and shall extend through the roof bearing assembly and be fastened with a steel washer and nut. Bale walls and roof bearing assemblies may be anchored to the foundation by means of other methods which are adequate to resist uplift forces resulting from the design wind load. There shall be a minimum of two points of anchorage per wall, spaced not more than 6 feet apart, with one located within 36 inches of each end of each wall.

The dead load of the roof and ceiling systems will produce vertical compression of the bales. Regardless of the anchoring system used to attach the roof bearing assembly to the foundation, prior to installation of wall finish materials, bolts or straps shall be re-tightened to compensate for this compression.

Section 105.7.4 Moisture Barrier. A moisture barrier shall be used between the top of the foundation and the bottom of the bale wall to prevent moisture from migrating through the foundation into the bottom course of bales. This barrier shall consist of one of the following:

1. Cementitious waterproof coating;
2. Type 30 asphalt felt over an asphalt emulsion;
3. Sheet metal flashing, sealed at joints;
4. Other approved building moisture barrier. All penetrations through the moisture barrier, as well as all joints in the barrier, must be sealed with asphalt, caulking or an approved sealant.

Section 105.7.5 Stacking and Pinning. Bales in load-bearing walls shall be laid flat and stacked in running bond where possible, with each bale overlapping the two bales beneath it. Bales in non load-bearing walls may be laid either flat or on-edge and stacked in running bond where possible. For non-load bearing walls, bales may be laid either flat or on-edge. Bales in load bearing walls shall be laid flat and stacked in a running bond, where possible, with each bale overlapping the two bales beneath it. Overlaps shall be a minimum of 12 inches. Gaps between the ends of bales which are less than 6 inches in width can be filled by an untied flake inserted snugly into the gap.

The first course of bales shall be laid by impaling the bales on the vertical bars or threaded rods, if any, extending from the foundation. When the fourth course has been laid, #4 rebar pins, or an acceptable equivalent, long enough to extend through all four courses, shall be driven down through the bales, two in each bale, located so that they do not pass within six inches of, or through the space between the ends of any two bales. The layout of these pins shall approximate the layout of the vertical bars extending from the foundation. As each subsequent course is laid, two such pins, long enough to extend through the course being laid and the three courses immediately below it, shall be driven down through each bale. This pinning method shall be continued to the top of the wall. In walls seven or eight courses high, pinning at the fifth course may be eliminated.

Only full-length bales shall be used at corners of load bearing walls, unless exceptions are designed by an Arizona Registrant.

Vertical #4 rebar pins, or an acceptable alternative, shall be located within 1 foot of all corners or door openings.

Staples, made of #3 or larger rebar formed into a “U” shape, at least 18 inches long with two 6 inch legs, shall be used at all corners of every course, driven with one leg into the top of each abutting corner bale. In lieu of staples, corner bales may be tied together, by a method approved by the building official.

Section 105.7.5.1 Alternative Pinning Method. When the third course has been laid, vertical #4 rebar pins, or an acceptable equivalent, long enough to extend through all three courses, shall be driven down through the bales, two in each bale, located so that they do not pass within 6 inches of, or through the space between the ends of any two bales. The layout of these rebar pins shall approximate the layout of the rebar pins extending from the foundation. As each subsequent course is laid, two such pins, long enough to extend through that course and the two courses immediately below it, shall be driven down through each bale. This pinning method shall be continued to the top of the wall.

Section 105.7.6 Roof Bearing Assembly. Load bearing bale walls shall have a roof bearing assembly at the top of the wall to bear the roof load and to provide a means of connecting the roof structure to the foundation. The roof bearing assembly shall be continuous along the tops of structural walls.

An acceptable roof bearing assembly option consists of two double 2” X 6”, or larger, horizontal top plates, one located at the inner edge of the wall and the other at the outer edge. Connecting the two doubled top plates and located horizontally and perpendicular to the length of the wall shall be 2” X 6” cross members spaced no more than 72 inches center to center, and as required to align with the threaded rods extending from the anchor bolts in the foundation. The double 2” X 6” top plates shall be face nailed with 16d nails staggered at 16 inches on center, with laps and intersections face nailed with four 16d nails. The cross members shall be face nailed to the top plates with four 16d nails at each end. Corner connections shall include overlaps nailed as above or an acceptable equivalent such as plywood gussets or metal plates. Alternatives to this roof bearing assembly option must provide equal or greater vertical rigidity and provide horizontal rigidity equivalent to a continuous double 2 by 4 top plate.

The connection of roof framing members to the roof bearing assembly shall comply with the appropriate sections of the *International Residential Code* or *International Building Code* local amendments.

Section 105.7.7 Openings and Lintels. All openings in load bearing bale walls shall be a minimum of one full bale length from any outside corner, unless exceptions are designed by an Arizona Registrant.

Section 105.7.7.1 Openings. Openings in exterior bale walls shall not exceed 50 percent of the total wall area, based on interior dimensions, where the wall is providing resistance to lateral loads, unless the structure is designed by an Arizona Registrant.

Section 105.7.7.2 Lintels. Wall and/or roof load present above any opening shall be carried, or transferred to the bales below by one of the following:

1. A structural frame.
2. A lintel (such as an angle-iron cradle, wooden beam, wooden box beam). Lintels shall be at least twice as long as the opening is wide and extend at least 24” beyond either side of the opening. Lintels shall be centered over openings, and shall not exceed the load limitations of Section 105.5 by more than 25 percent.

Section 105.7.8 Moisture Protection. All weather-exposed bale walls shall be protected from water damage. An approved building moisture barrier shall be used to protect at least the bottom course of bales, but not more than the lower one-third of the vertical exterior wall surface, in order to allow natural transpiration of moisture from the bales. The moisture barrier shall have its upper edge inserted at least 6 inches into the horizontal joint between two courses of bales, and shall extend at least 3 inches below the top of the foundation. Bale walls shall have special moisture protection provided at all window sills. Unless protected by a roof, the tops of walls shall also be protected. This moisture protection shall consist of a waterproof membrane, such as asphalt-impregnated

felt paper, polyethylene sheeting, or other acceptable moisture barrier, installed in such manner as to prevent water from entering the wall system at window sills or at the tops of walls.

Section 105.7.9 Wall Finishes. Interior and exterior surfaces of bale walls shall be protected from mechanical damage, flame, animals, and prolonged exposure to water. Bale walls adjacent to bath and shower enclosures shall be protected by a moisture barrier.

Cement stucco shall be reinforced with galvanized woven wire stucco netting or an acceptable equivalent. Such reinforcement shall be secured by attachment through the wall at a maximum spacing of 24 inches horizontally and 16 inches vertically.

Where bales abut other materials, the plaster/stucco shall be reinforced with galvanized expanded metal lath, or an acceptable equivalent, extending a minimum of 6 inches onto the bales.

Earthen and lime-based plasters may be applied directly onto the exterior and interior surface of bale walls without reinforcement, except where applied over materials other than straw. Weather-exposed earthen plasters shall be stabilized.

Lime based plasters may be applied directly onto the exterior surface of bale walls without reinforcement, except where applied over materials other than straw.

Section 105.7.10 Electrical. Type NM or UF cable may be used, or wiring may be run in metallic or nonmetallic conduit systems. Electrical boxes shall be securely attached to wooden stakes driven a minimum of 12 inches into the bales, or an acceptable equivalent.

Section 105.7.11 Plumbing. Water or gas pipes within bale walls shall be encased in a continuous pipe sleeve to prevent leakage within the wall. Where pipes are mounted on bale walls, they shall be isolated from the bales by a moisture barrier.

Section 106 - Patio/Landscape Walls

Section 106.1 General. This section covers freestanding or attached bale patio or landscape walls, not exceeding 6 feet in height, from final grade to top of wall. Bales may be stacked either flat or on-edge. Alternate methods, other than those listed in this section, may be approved by the building official.

Section 106.2 Foundations. The minimum foundation shall consist of an 8 inch thick reinforced concrete stem wall, over an approved footing. Minimum width of the stem wall shall be equal to the width of the bottom bale. Stem walls shall have continuous horizontal reinforcement consisting of two #4 bars with 24 inches minimum lap at splices.

Section 106.2.1 Reinforcement. Vertical reinforcing bars, a minimum 3/8" in diameter, shall be placed in the center of the stem wall, two per bale, and extend up a minimum of 24 inches, and be embedded a minimum of 4 inches into the concrete stem wall. Bales shall be pinned, using two 3/8" diameter bars per bale, and use pins long enough to provide at least one vertical bar from stem wall to top of wall, with a minimum of one full bale overlap where not continuous.

For the purpose of attaching stucco mesh to the wall, 12d or larger galvanized common double-headed nails shall be embedded in the concrete a minimum of 1 inch below the top of the stem wall, with the heads embedded a minimum of 2 inches into the concrete, and the points extending a minimum of 3/4" from the face of the stem wall, and spaced a minimum of 6" on center on both sides of the wall.

Section 106.2.2 Moisture Barrier. A moisture barrier shall be used between the top of the stem wall and the first course of bales. A moisture barrier shall also be used to protect the tops of bales at the top of walls, and shall extend 6 inches down on either side of the wall.

Section 106.2.3 Stucco Mesh. Stucco mesh, 20 gauge or heavier, shall be attached by means of clinching the embedded nails on one side of the wall, stretching a continuous piece of netting tightly over the top of the wall, and fastening the netting in the same manner on the opposite side of the wall.

Section 106.2.4 Wall Finish. Walls shall be finished with cement stucco, or stabilized mud plaster, with a minimum thickness of 7/8".