APPENDIX M

STRAW-BALE STRUCTURES

SECTION M101
PURPOSE

M101.1 Minimum standards. The purpose of this appendix chapter is to establish minimum prescriptive standards of safety for the construction of structures that use baled straw as a load-bearing or nonload-bearing material.

SECTION M102
SCOPE

M102.1 Applicability. The provisions of this chapter shallapply to single family detached structures and relate accessory structures as defined in Section M103, utilizing straw bales in the construction of wall systems.

SECTION M103
DEFINITIONS

M103.1 General. For the purpose of this chapter, certain terms are defined as follows:

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

FLAKES. 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.

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

LOAD BEARING The use of straw bale walls as structural load-bearing walls supporting the roof and resisting lateral loads.

NONLOAD BEARING. A structure where straw bales are used to in-fill between the supporting structural members. The exterior straw bale in-fill wall sections collect lateral loads resulting from wind or seismic activity and transfer these loads to the primary structure for resistance.

IN-FILL WALL. The nonbearing section between vertical supports.

SECTION M104
MATERIAL SPECIFICATIONS

M104.1 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.

M104.2 Shape. Bales shall be rectangular in shape.

M104.2.1 Dimensions. Bales used within a continuous wall shall be of consistent height and width to ensure even distribution of loads within wall systems.

M104.2.2 Wall thickness. Nominal minimum bale wall thickness shall be 14 inches (356 mm).

M104.2.3 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.

M104.3 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.

M104.4 Moisture content. Moisture content of bales, at time of installation and just prior to applying exterior weather protection such as stucco, shall not exceed 20 percent of the total weight of the bale. Bales that become wet or exceed 20-percent moisture content shall be replaced with dry bales or allowed to dry and be retested. Bales that exceed 20-percent moisture content shall be replaced. Special inspection of the moisture content of bales shall be performed using one of he following methods:

M104.4.1 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 five bales randomly selected from the bales to be used.

M104.4.2 Laboratory method. A total of five samples, taken from the center of each of five bales randomly selected from the bales to be used, shall be tested for moisture content by a recognized testing lab.

M104.5 Density. Bales in load-bearing structures shall have a minimum calculated dry density of 7.0 pounds per cubic foot (1.10 kN/m^3). The calculated dry density shall be determined after reducing the actual bale weight by the weight of the moisture content, as determined in Section M104.5. The calculated dry density shall be determined by dividing the calculated dry weight of the bale by the volume of the bale.

SECTION M105
FOUNDATION REQUIREMENTS

M105.1 Foundations. Foundations shall comply with Chapter 4. Foundations shall be sized to accommodate the thickness of the bale wall and support the imposed live and dead loads from walls and roofs. 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 (76 mm) to accommodate rigid perimeter insulation.

M105.2 Wall reinforcement embedded in foundation. Vertical reinforcing bars with a minimum diameter of $^1/_2$ inch (12.7 mm), shall be embedded in the foundation a minimum depth of 6 inches (153 mm), and shall extend above the foundation a minimum of 12 inches (304.8 mm). These vertical bars shall be located along the centerline of the bale wall, spaced not more than 2 feet (610 mm) apart. A vertical bar shall also be located within 1 foot (305 mm) of any opening or corner, except at locations occupied by anchor bolts.

M105.3 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. Cementious waterproof coating;
2. Type 30 asphalt felt over an asphalt emulsion;
3. Sheet metal flashing, sealed at joints; or
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 M106
WALL CONSTRUCTION

M106.1 General (fire resistance). Bale walls, when covered with plaster or stucco shall be deemed to be fire resistive.

A straw bale covered with plaster or stucco having a minimum thickness of $^7/_8$ inch (22.4 mm) on both sides maybe used between a dwelling and attached garage as required in Section R309.2.

M106.2 Allowable Loads. The allowable vertical load (live and dead load) on the top of load-bearing bale walls shall not exceed 360 pounds per square foot (psf) [23 inches divided by 12 inches by 360 pounds = 690 pounds per linear foot (plf)] 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 Chapter 3 and the *Oregon Structural Specialty Code*, Chapter 16. Increases in stress and reductions of live loads specified in *Oregon Structural Specialty Code* Chapter 16 may be applied.

M106.3 Insulation. Exterior walls using straw bales shall be considered to meet the wall insulation requirements of Path 1 as described in Section N1104. All other exterior wall components shall comply with Section N1104. For the purpose of calculating thermal performance using Table N1104.1.2, the insulation of straw bale walls can assume to be R=2.1 per inch [a 23-inch (584 mm) bale would be R-48 or U-0.021].

M106.4 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 $^5/_8$ inch (16 mm) in diameter, of sufficient length to provide 12 inches (305 mm) of penetration into the bale, driven through holes bored in the abutting wall stud, and spaced to provide one dowel connection per bale.
2. Pointed wooden stakes, at least 12 inches (305 mm) in length and $1^1/_2$ inch by $3^1/_2$ (38.1 mm by 88.9 mm) 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 (153 mm) square and a minimum thickness of $^3/_{16}$ inch (4.8 mm) for steel and $^1/_2$ inch (12.7 mm) for plywood, in at least three locations.

SECTION M107
LOAD-BEARING WALLS

M107.1 Anchor bolts. In addition to vertical reinforcement bars required in Section M105.2, load-bearing bale walls shall be anchored to the foundation by $^1/_2$-inch (12.7 mm) diameter steel anchor bolts embedded at least 7 inches (178 mm) in the foundation at intervals of 6 feet (1829 mm) or less. A minimum of two anchor bolts per wall shall be provided with one bolt located within 36 inches (914 mm) of each end of each wall. Sections of $^1/_2$-inch (12.7 mm) 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 (1829 mm) apart, with one located within 36 inches (914 mm) 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, straps or cables shall be retightened to compensate for this compression after the actual dead load of the roof framing and roofing have been applied.

M107.2 Load-bearing wall height. Load-bearing straw 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 (584 mm) wall would be 10 feet, 8 inches (3251 mm)].

M107.3 Unsupported wall length. The ratio of unsupported wall length to thickness, for load-bearing bale walls, shall not exceed 13:1 [for a 23-inch (584 mm) thick wall, the maximum unsupported length allowed is 25 feet (7620 mm)].

M107.4 Openings and lintels. All openings in load-bearing bale walls shall be a minimum of one full bale length from any outside corner.

M107.4.1 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.

Door and window frames (rough bucks) shall be stabilized with $^1/_2$-inch (12.7 mm) diameter hardwood dowels extending 12 inches (305 mm) into every adjacent bale or by means of a continuous metal lath applied to both the interior and exterior, extending a minimum of 12 inches (305 mm) onto adjacent bales, installed prior to the application of plaster or stucco.

M107.4.2 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 inches (610 mm) beyond either side of the opening. Lintels shall be centered over openings, and shall not exceed the load limitations of Section M106.2 by more than 25 percent.
3. A roof-bearing assembly designed to act as a rigid beam over the opening.

M107.5 Stacking. 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 nonload-bearing walls may be laid either flat or on-edge and stacked in running bond where possible. Overlaps shall be a minimum of 12 inches (305 mm). Gaps between the ends of bales which are less than 6 inches (153 mm) in width may be filled by an untied flake inserted snugly into the gap. Only full-length bales shall be used at corners of load-bearing walls.

M107.5.1 Pinning. 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, No. 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 6 inches (153 mm) of, or through the space between the ends of any two bales. The layout of these pins shall approximate the layout of the vertical rebars 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.

M107.5.1.1 Corners and openings. Vertical No. 4 rebar pins, or an acceptable alternative, shall be located within 1 foot (305 mm) of all corners or door openings.

M107.5.1.2 Staples at corners. Staples made of No. 3 or larger rebar formed into a "U" shape, at least 18 inches (457 mm) long with two 6-inch (153 mm) legs, shall be used at all corners of every course, driven with one leg into the top of each abutting corner bale.

M107.6 Gable end walls. In load bearing exterior walls with gable or shed roofs, a continuous assembly as described in Section M110.1 shall be provided that continues through the gable end walls.

SECTION M108
NONLOAD-BEARING WALLS

M108.1 General. A nonload-bearing wall is part of a structural system where the primary frame is an approved system complying with this code or *Oregon Structural Specialty Code* Chapter 16. The straw bales are used as in-fill between structural members or framing.

M108.2 Primary frame. The primary frame (such as post and beam or pole building) shall comply with this code or *Oregon Structural Specialty Code* Chapter 16. Structural calculations showing compliance shall be submitted with plans and application for building permits.

M108.2.1 Anchorage to foundation. The primary frame shall be anchored to the foundation in accordance with Chapters 4 and 6 of this code or *Oregon Structural Specialty Code* Chapter 16.

M108.3 Wall anchorage to foundation. Vertical reinforcing bars with a minimum diameter of $^1/_2$ inch (12.7 mm) shall be embedded in the foundation a minimum depth of 6 inches (153 mm), and shall extend above the foundation a minimum of one-and-one-half bales.

M108.3.1 Location. The vertical bars shall be located along the centerline of the bale wall, spaced not more than 2 feet (610 mm) apart and a minimum of two per bale.

M108.3.2 Corners and openings. A vertical bar shall be located within 1 foot (305 mm) of any opening or corner, except at locations occupied by anchor bolts.

M108.4 Wall connections to primary frame. The straw bale in-fill walls shall be securely anchored to all adjacent structural members to sufficiently resist lateral displacement of the straw bale in-fill walls.

M108.4.1 Anchors. Anchors shall be placed at every horizontal joint or one per bale along the vertical member and a maximum of 24 inches (610 mm) on the center along horizontal members at the top of the straw bale wall beginning not more than 12 inches (305 mm) from each end of the in-fill.

M108.4.2 Metal lath. At all points where the straw bales are butted against a different material (wood, concrete, steel, etc.), metal lath shall be used to cover the junction. Expanded metal lath shall extend a minimum of 6 inches (153 mm) over the edge of the straw bales and shall be securely fastened to the straw bales.

M108.5 Stacking and pinning. Nonbearing straw bale walls shall be stacked and pinned as described in Section M107.5

M108.6 Openings and lintels. The limitations of the openings relative to wall area is controlled by the design of the primary frame.

M108.7 Wall Height. Nonload-bearing walls shall not exceed 12 feet (3658 mm) in height.

M108.7.1 Gable end walls. In the nonload-bearing exterior wall with gable or shed roofs, a continuous assembly as described in Section M110.1 shall be provided that continues through the gable end wall or shall meet the requirements of Section R601.2.

SECTION M109
WALL FINISHES

M109.1 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 (153 mm) into the horizontal joint between two courses of bales, and shall extend at least 3 inches (76 mm) 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.

A vapor barrier paint having a 1-perm dry cup rating or less shall be applied to the interior wall finish of straw bale walls which separate heated and nonheated spaces and exterior walls for compliance with Section N1104.9.1.

M109.2 Protection. Interior and exterior surfaces of bale walls shall be protected from mechanical damage, flames, animals, and prolonged exposure to water or snow. Bale walls adjacent to bath and shower enclosures shall be protected by a moisture barrier.

M109.2.1 Stucco. 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 (610 mm) horizontally and 16 inches (406 mm) vertically, using a method approved by the building official.

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 (153 mm) onto the bales.

M109.2.2 Plasters. 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 Portland cement stabilized using methods of application approved by the building official.

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 M110
ROOF TO WALL CONNECTION

M110.1 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 load bearing bale walls.

M110.1.1 Assembly option. An acceptable roof-bearing assembly option consists of two double 2 × 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 × 6 cross members spaced no more than 72 inches (1829 mm) center to center, and as required to align with the threaded rods extending from the anchor bolts in the foundation. The double 2 × 6 top plates shall be face nailed with 16d nails staggered at 16 inches (406 mm) 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 shall provide equal or greater vertical rigidity and provide horizontal rigidity equivalent to a continuous double 2 × 4 top plate.

The connection of roof framing members to the roof bearing assembly shall comply with the appropriate sections of this code.

SECTION M111
ELECTRICAL, PLUMBING AND MECHANICAL

M111.1 Electrical. All wiring within or on bale walls shall meet the electrical provisions in this code. Type NM or UF4 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 (305 mm) into the bales, or an acceptable equivalent.

M111.2 Plumbing. Water or DWV 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.

M111.3 Mechanical. 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.