Project Report on

Missile Perforation Threshold Speeds
for
Straw Bale Wall Construction with a Stucco Finish

Research and Development Performed by

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Date Submitted

March 17, 1999

INVESTIGATION OF WIND-BORNE DEBRIS RESISTANCE OF STRAW BALE WALL CONSTRUCTION WITH A STUCCO FINISH

Overview of Project

The Wind Engineering Research Center (WERC) at Texas Tech University continually attempts to evaluate and develop combinations of common, new, and alternative materials for construction. This research is used in developing and implementing design and construction practices focusing on wind damage mitigation and providing occupant protection from wind forces and wind-borne debris (missiles). As new or alternative materials take their place alongside traditional construction materials, basic research must be performed on the alternative material to determine its strengths and weaknesses. This research allows designers to use the best material for the design purpose in modern composite construction techniques.

The tornado missile testing that has been conducted is due to the proliferation of straw bales as a construction material in the Central and Southwest United States and the use of other straw products throughout Europe and Asia. The missile criterion used for the tests was a 15 pound 2x4 in. wood board traveling along the board's longitudinal axis, striking the wall perpendicular to the wall face. The tornado test criteria uses this missile traveling at 100-mph which corresponds to a 250-mph wind and is the criterion used in designing for occupant protection. In 99 percent of the tornadoes that have occurred in the U.S., wind speeds are less than 250-mph: in 90 percent, maximum wind speeds are less than a 150-mph. Additional factors of safety are inherent in the criterion since there is a very small probability that a missile will be traveling along its axis and will strike a wall perpendicular to its surface.

Tests Conducted

The WERC tested typical straw bale construction with a stucco finish by impacting the bales with the design missile. The bales were 14x24x48 in. weighing approximately 65-lb. The bales were stacked in a running bond with the 14-in. dimension as the height of the course and the 24-in. dimension as the width of the course. The assembly tested used five courses of bales. The bales were placed on a footing with ½-in. steel rebar spaced 2-ft. on center to act as anchorage for the first course of bales. The rebar extended 14-in. from the footing to develop a full transfer of structural and impact forces imparted from rebar driven from the top through all the courses of straw bales to the wall footing. The bales were pushed together to make the construction as tight as possible and to better simulate a longer wall. The use of rebar to tie the courses of bales together is the common construction process for most types of straw bale wall construction. The bales were then covered front and back with stucco. The stucco was applied over two different types of wire mesh. The first type of mesh was the older chicken wire type. The second mesh was light gage expanded metal. Both types of mesh were attached to 1x4 in lumber that was tied to the bales at 4 ft on center. The mesh was then tied to the bales by passing baling wire

through the bale and tying it to the mesh on the other side. The mesh was attached every 12 in on center vertically and horizontally. Stucco was then applied over the mesh and pushed into the straw bales. The stucco consisted of 18 parts brick sand, 2 parts portland cement, 1 part type S masonry cement, and 1 cup of 1 in plastic fiber. The bales were covered in three layers of stucco. The finish layer did not contain the plastic fiber. The thickness of the stucco varied from 1 ½ in to 3 in, confirmed during the dismantling of the target. The bales were then impacted at the approximate center of a bale. The points of impact were chosen based on previous test experience for critical points in construction to determine the net effect of the mesh and stucco finish. The specifics about each test and results follow.

View of Impact Surface of Straw Bale Wall

Shot I – 91.96 f/s (63 mph)

The missile impacted near the seam between the bales. The mesh was the wire type. The missile penetrated the wall 13 in. The missile impact caused small radial cracks in the stucco on the non-impact surface.

Shot I – Impact Surface

Shot I – Non-impact Surface

Shot II – 103.46 f/s (71 mph)

The missile impacted near the seam between the bales. The mesh was the wire type. The missile penetrated the wall 21 in. The missile impact caused spalling of the stucco on the non-impact surface. There was no damage to the wire mesh.

Shot II – Impact Surface

Shot II – Non-impact Surface

Shot III – 123.14 f/s (84 mph)

The missile impacted just above the seam between the bales. The mesh was the wire type. The missile perforated the wall 15 in. The missile impact caused large pieces of stucco to spall from the non-impact surface.

Shot III – Impact Surface

Shot III – Non-impact Surface

Shot IV – 147.84 f/s (101 mph)

The missile impacted just above the seam between the bales. The mesh was the expanded metal type. The missile penetrated the wall 13 in. The missile impact caused large pieces of stucco to spall from the non-impact surface. There was no damage to the expanded metal mesh.

Shot IV – Impact Surface

Shot IV – Non-impact Surface

Shot V – 133.85 f/s (91 mph)

The missile impacted near the seam between the bales. The mesh was the expanded metal type. The missile totally perforated the wall. The missile impact caused no spalling of the stucco on the non-impact surface except that at the exit point of the missile.

Shot V – Non-impact Surface

Shot V – Non-impact Surface Viewed From Side

Conclusions

The perforation threshold velocity of straw bale construction depends on many variables.

The variables are the:

density of straw.
length of straw.
density of the bale.
quality of the bale.
orientation of the straw relative to the impact.
weight that is compressing the bales.
location of impacted bale in the wall.
quality of construction.
type of mesh used in stucco
quality of stucco

Previous tests indicated that the missile would push the baling machine compressions out of the bale. The compressions slide relative to one another. This is due to the way the baler gathers and compresses the straw. The use of wire mesh and stucco improved the response of the system to impact. The mesh and stucco unified the bales so that they behave more as a whole and not as individual compression zones of straw. The mesh and stucco also worked like a net to contain the pushed straw and missile causing the system to absorb the energy of the impact.

From these preliminary tests the type of mesh used does not appear to significantly affect the missile perforation threshold value of this type of construction. The quality of the stucco and its application are more likely to cause great variations in the threshold value no matter what type of mesh is used.

This is just the beginning of the testing that would be required to conclusively qualify and quantify the variables that effect the response of straw bale construction to missile impact.