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Insurance Institute for Business & Home Safety (IBHS) Research Center performed a high-wind test of commercial masonry structures to determine design and construction best practices. High winds caused roof up-lift, pulling bond beam from top of unreinforced wall, leaving no horizontal support.

Research confirms resiliency of structural masonry in major wind events

Best Practice Lateral bracing at top of wall provides critical connection

Don Beers, PE

Masonry can be the best wall system available for resisting high winds and preventing damage to structures. The weight and stability of the concrete masonry unit (CMU) or structural brick combined with the grouted rebar connections throughout the wall give masonry a unique ability to stand up to high wind pressures, even pressures far in excess of the calculated design loads. For masonry, and any other type of wall, one of the essential requirements for resistance to horizontal wind load is support by a roof or elevated floor at the top of the wall (referred to as diaphragm action). Walls with lateral support at the top and the bottom are called *simply supported* as opposed to *cantilevered* walls, which have no horizontal support at the top.

The tall, unsupported cantilevered wall acts as a lever creating torque (high bending forces at the bottom) which tries to push the wall over, or if the connection to the foundation is strong enough, tries to overturn the foundation. This torque at the base is referred to by engineers as an *overturning moment*. The *moment* being simply a rotational force. This *moment* action has to be resisted by a large foundation with enough weight to resist the overturning and creates excessive bending moment in the lower area of the wall. The bending moment in a cantilevered wall is four times the bending moment in a wall of equivalent height braced (*simply supported*) at the top for horizontal (*lateral*) wind loads.

Structural engineers and builders understand

- masonry walls taller than 4' or 5' must be designed as cantilevers or be supported at both the top and bottom.
- cantilevered walls taller than 8' usually require special oversized foundations and additional vertical reinforcement at the base of the wall.
- walls above 15' in height are not usually cantilevered because of very large foundation and heavy reinforcement necessary to handle the overturning and bending moment.



Upon reading the article you will be able to:

- 1 Explain the importance of lateral support at the top of walls in commercial and residential structures.
- 2 Identify code requirements for exterior wall support and designer responsibility in meeting requirements.
- 3 Compare the performance of commonly-built structures and those built using best practices for resisting high wind loads

IBHS Testing Gives Graphic Illustration of the Impact of Side Wall Connection

The Insurance Institute for Business & Home Safety (IBHS) is dedicated to research and training as related to the evaluation of residential and commercial construction materials and systems. Research performed at their test center is used to justify revisions to building codes and practices toward more resiliency in the built environment and a reduction of the cost to the public in both lives and property lost as a result of natural disasters.

In an effort to compare and contrast performance of typical commercial strip mall-type construction with that of construction using best practices, IBHS tested two 30' x 20', single-story structures side by side in their wind tunnel facility in Chester County, South Carolina. Associations affiliated with the building envelope (including walls, roof and doors) were consulted.

Best Practice vs Common Practice. Because of their experience with masonry structures in high wind, both in theory and practice, IBHS approached the Masonry Association of Florida and the National Concrete Masonry Association (NCMA) for help in designing masonry walls for the two side-by-side commercial buildings. One of the buildings (called *Common*) was to contain the most common practices of masonry construction, many of which include doing things as they have always been done. The second building (called *Stronger*) was to be built according to best practices and current design code

Photo courtesy of Masonry Association of Florida



While this wall was well reinforced, there was no tie in between the vertical wall reinforcement and the bond beam. When the winds of Hurricane Andrew blew, both roof and wall failed and the building's interior was demolished.

requirements. The assembled design team agreed on four key differences in the two wall designs (see table page 38).

The virtual lack of continuity of the wall vertical reinforcement into the bond beam and poor connection to the roof in the *common* building was the primary failure area. Indeed, the *Common* building failed in the wind test in the exact mode I have seen played out in wind storms across Florida. The vertical reinforcement in the wall of the *Common* building lacked adequate connection to the bond beam. Consequently, the net roof up-lift of approximately 45 to 50 psf pulled the bond beam away from the top of the wall leaving no horizontal support for the wall. It had little capacity since it was not designed to act as a cantilevered wall and thus had little means to resist the approximately 35 psf of wall net wind pressure.

The top wind gust during the test was 136 mph, or the equivalent of a 97 mph one-minute sustained wind speed. All wind speeds are referenced to standard open country conditions at an elevation of 10m (33') (Exposure C in wind code terms).

Results indicate that proper reinforcement and detailing significantly reduce structural damage, which in turn, protects occupants and property.

This is especially important to the insurance industry as their research indicates that one in four businesses that close during a disaster does not repair their facilities and reopen. This can have disastrous repercussions on the economy, as small businesses are vital, occupying 30-50% of all commercial space and accounting for 54% of all sales in the US, according to the Small Business Administration.

Portions of the test can be online seen at disastersafety.org/high_winds/commercial-high-wind-test-resources/. Of all the masonry building designs I have ever been involved with, this is the only one that was built to be blown down!

Most Vulnerable Structures

Churches, gymnasiums, box retail stores, warehouses and other structures with walls above 10' in height and a single span roof system are at increased risk from high winds. Where cast-in-place floors and roofs lock in the exterior walls, the problem is much less likely. However, every exterior wall must be properly connected into the structure at the top and bottom for best performance.

After Hurricane Andrew made landfall in Florida in 1992, we observed some classic failures due to lack of connection. Large doors are vulnerable in high winds. If the large door fails on the windward side, increased pressure develops inside the building and may blow out the side wall, particularly with a lack of connection between the wall and pre-stressed roof.

This type of collapse would likely completely demolish the interior of the structure.

We encountered a church structure exposed to winds in the Category 2 hurricane range (96-100 mph sustained wind

speeds). The collapsed wall was connected to the roof structure with a cut nail every 48", which was obviously provided during – and for – construction, not for lateral support.

Pictured is an endwall of a warehouse structure. While the wall was very well reinforced, there was no tie in between the vertical wall reinforcement and the bond beam (sound familiar?)

One in four businesses closed due to disaster does not repair facilities and reopen

LATERAL BRACING TOP OF WALL

	Common Building	Stronger Building
Amount of Vertical Reinforcement	Contained #4 vertical reinforcement on both sides of openings and in the corners	Added #4 vertical reinforcement at maximum spacing of 8' on center along all walls
Connection of the bond beam to the vertical wall steel (Primary failure area)	No hook bars extended into the bond beam. Vertical bars were allowed to extend into the bottom of the bond beam ¼"	90° hook bars extended fully into the bond beam and extended down into the wall to lap with vertical wall steel
Corner bars for continuity of reinforcement in bond beams around corners	No corner bars were used in bond beams	Corner bars in bond beams were used to fully connect walls together at the top corners
Bond Beam Depth	Used an 8" deep bond beam at the top of the wall	Bond beam depth was increased to 16" (two courses). Both courses contained (2) #4 bars in top of each course

IBHS research construction practice criteria used in erecting Common and Stronger buildings for high wind testing.

Best Practices Both the IBC and the MSJC call for lateral support at the top of the wall. Section 1.7.4.1 of TMS 402-08 states, "Walls, columns and pilasters shall be designed to resist loads, moments and shears applied at the intersections with horizontal members". The location and number of these structural elements are obviously left up to the designer, but their presence is essential, as we have seen, to the wind load resistance of the structure.

Communication. Early and regular collaboration and communication between members of the design team, construction team and inspectors can reinforce the importance of proper connection to structural elements to prevent lateral connections from being overlooked.

Detailing. Designers often have a floor or roof near the top of the wall to act as lateral support (diaphragms). Without one, solutions are not immediately obvious. For some large open structures with tall walls, I have gone to the extent of creating horizontal trusses spanning between the bearing walls. In other cases, long tall walls may require regular vertical pilasters spanning between the foundation and roof diaphragm with the wall spanning horizontally between these members.

Another common oversight happens when the engineer of record assumes that the wall to roof connection is being detailed by roof supplier. Again, this can be resolved by early and open communication between parties.

The Big Picture. Bearing wall connections to the roof are generally not where the issue arises, because there has to be some type of connection to hold the roof in place. Not so for the non-bearing walls. Special brackets or odd connectors attaching the roof and top of the endwall (non-bearing) may be ignored simply as a cost-saving effort without clear understanding of how critically important to the survival of the structure the connectors are. **The IBHS study showed, however, that while a building may perform acceptably under normal conditions without those connections, the time and cost of re-building after a storm or earthquake is exponentially more expensive than the original savings were worth. And you run the risk of human injury or loss of life as a result.** Acting on the big picture, for the long term, is always better than a short-term savings.

Checks and Balances. Without some foreknowledge by the inspector on the importance of proper roof-to-wall detailing, he may miss checking for this when work is in progress. After construction, the connection areas may not be obvious or be hidden from view, especially if 20' or 30' off the ground, so verifying their placement may be difficult after the fact. Again, early communication and planning can help ensure not only that the work is being executed properly, but that it will be inspected for accuracy and verified.

Is Residential Exempt? Unbraced gable endwalls in smaller, single-family homes fair no better than their

commercial counterparts. A standard failure mode is wind on the leading edge of the roof pries up decking, trusses progressively collapse into the structure, and the endwall, with no lateral bracing, collapses into the structure also. It is instructive to note that during the development of the Florida wind codes, the arguments over the proper bracing of the gable end were the most contentious and animated. Subsequent wind storms have ended the argument. Bracing of the gable endwall is essential! The solution is either adequate bracing of the gable endwall back into the roof structure or balloon framing where the end-wall spans from the foundation all the way up to the underside of the roof decking (roof diaphragm including proper connection).

The Answer Masonry design has made incredible advances in both design codes and computerization. Real-life failures are often from a simple omission. Not providing lateral support at the top of all walls is an easy-to-understand and easily correctable mistake, not only in masonry construction but in all construction types. Sadly, it is also the most common and unnecessary masonry failure mode I have seen from Florida hurricanes and tornados. ■



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Acting on the big picture is always better than a short-term savings.