P 10.5 On the performance of brick and concrete masonry in windstorms

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1. Introduction

It is common for people to check their property for damage after a windstorm. Sometimes, they find cracks and separations in masonry walls and think this distress is due to the storm. In order to determine whether wall distress was caused or aggravated by wind, it is important to understand how wind affects masonry. This paper summarizes the types of distress wind can produce in brick and concrete masonry walls.

2. Components of masonry walls

Modern bricks are made by mixing clay and water then formed into the desired shapes and sizes. Various chemicals are added to the mix for color and to improve physical properties. The bricks are dried then fired in a kiln. Firing adds strength to the brick and helps resist moisture intrusion.

A concrete masonry unit (CMU) is made by mixing Portland cement, aggregate, and water. Individual units are formed in molds with hollow cells to aid in hydration and reduce weight. The units are cured in a special drying chamber.

Mortar bonds the stacked bricks or CMUs and is a mixture of Portland cement, lime, sand, and water. Lime increases workability of the mix. A common pattern for laying masonry is a "running bond" where each successive course is offset half its length. Sometimes, bricks are stood on their ends as a decorative feature to finish the top of the wall, known as a soldier course.

Brick and CMU walls can be load bearing, supporting the weight of the roof as well as live loads such as wind pressure, rain, and snow. Brick masonry also is installed as a veneer that does not carry roof loads. Brick veneer walls should be attached to a structural wall with metal ties. An air cavity between the brick veneer and structural wall, alleviates moisture build up. In addition, small slots (weep holes) are provided along the bases of walls to assist drainage.

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3. Wind damage to masonry walls

Wind blowing against a building deflects over and around it. As a result, positive (inward) pressures develop on windward walls while negative (outward) pressures form on side and leeward walls. However, wind pressures are not uniform (Fig. 1). Wind speed increases with height above the ground and stagnates in the upper portion of the windward wall generating maximum positive pressures. High outward pressures occur at windward wall corners while negative pressures (suction) results on the leeward wall.

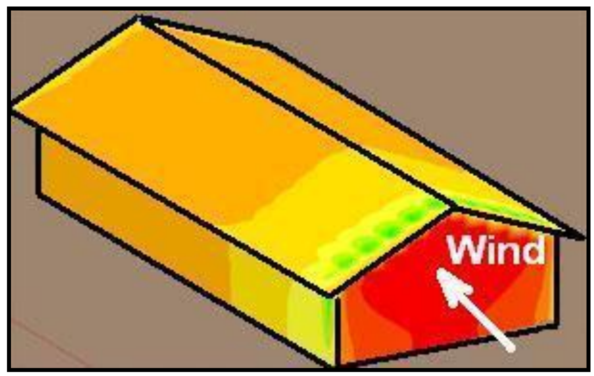

Figure 1. Numerical simulation of relative wind pressures on the windward face of a building with gable roof (after Sambolt, 2006). The red color indicates maximum positive pressures whereas the green color indicates maximum negative pressures.

Masonry walls are susceptible to wind-caused damage especially when subjected to high internal pressures. Internal pressures result when doors or windows are breached on the windward side of the building (Fig. 2). The combination of positive pressures on the interior sides of perimeter walls and negative pressures on exterior sides can lead to wall failure. As shown by Marshall et al. (2008a and b), masonry walls that fail in the wind frequently rotate along horizontal hinge lines at the bases of the walls and separate along vertical joints at window and door openings. Window and door openings interrupt continuity and bridging action, thereby weakening walls.


Figure 2. Failure of the garage doors led to internal pressures that helped topple the: A) brick wall and B) concrete masonry unit wall.

Masonry chimneys are susceptible to toppling in the wind since they extend above the roof where wind speed is higher. Failures of chimneys usually occur along mortar joints as the joints have little tensile strength to resist lateral or uplift loads. Leaning masonry chimneys result from foundation movement due to uneven bearing on the underlying soil, and are not wind-caused.

Marshall and Robinson (2006) showed that gable ends of masonry walls were susceptible to toppling in strong winds. Lateral wind loads caused the masonry to fail along horizontal hinge lines at the bases of the gables. Sometimes when load bearing masonry walls fail, it can result in the partial collapse of the roof or total collapse of the structure. Such wall failures have been documented by Blaney (1994) after Hurricane Andrew in Florida and by Schultz et al. (2002) after tornadoes in Minnesota. Both load bearing and non-load bearing masonry walls should be designed in accordance with local building codes. In the United States, design wind loads vary from 40 to 67 ms^{-1} as a three-second gust in open terrain.

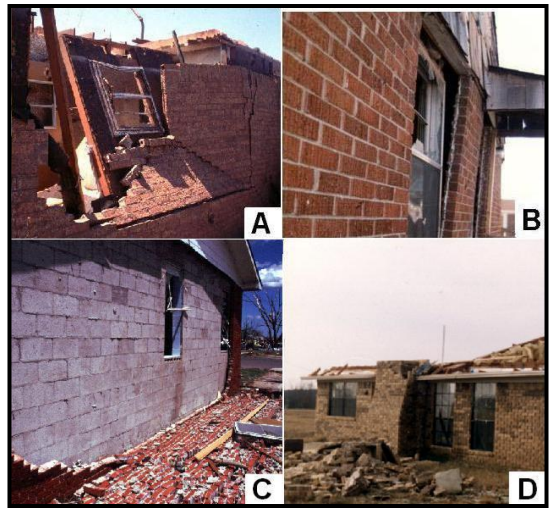
Figure 3. Failure of masonry in the wind: A) windward wall toppled inward around a window, B) leeward wall leaned outward around a window, C) toppled wall along a hinge line at the base of the wall, and D) a broken chimney at roof level.

Brick veneer walls should have steel ties to anchor them to the underlying structure. The ties typically are zinc-coated (galvanized) steel. The zinc helps protect the steel from rust and corrosion but is water soluble. Moisture-laden salts can erode the zinc, leading to deterioration of the ties. Typically, brick ties are installed 40.7 cm apart horizontally and spaced 25 to 45 cm vertically. The authors have encountered many buildings that did not have ties or did not have them bent properly to engage the masonry. These walls could be flexed easily when pushed by hand. The walls were not "loosened" by the wind; they never were anchored. The extent of wall flexing will depend on the amount of mortar droppings wedged in the air cavity. Brick veneer walls, without engaging metal ties, are free standing and high wind loads can topple them (Fig. 4).

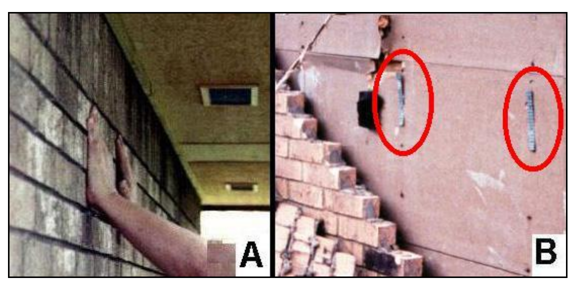
Figure 4. Brick veneer not properly attached to the structural wall: a) could be flexed by hand, and b) wall failure revealed wall ties (circled) did not engage the masonry.

4. Inspection procedure

A detailed visual inspection of masonry walls involves measuring and diagramming each elevation and identifying the locations of distress (Fig. 5). According to Grimm (1988), some characteristics of masonry cracks worth noting are: 1) the direction (pattern), 2) the extent (where it begins and where it ends), the width (uniform or tapered), the depth, the alignment (in plane or out of plane), the sharpness (rough or rounded), and cleanliness (presence of paint, cobwebs, etc.). Occasionally, an inspector will use a mason's bubble level to measure the plumbness of the walls. A plumb bob can be used to check vertical wall alignment.

An inspector should examine wall openings around window and door frames. These openings become stress concentration points when the walls move. Masonry cracks frequently develop at corners around window and doors. Close examination can reveal whether the cracks resulted from cyclic thermal expansion and contraction, differential foundation movement, wind, or other causes. A high intensity flashlight and magnifying lens can be used to peer inside the cracks to see if they are of recent origin.

Caulked joints around windows and doors should be examined to see if they have separated. The conditions of the joints, whether they contain paint or dirt, can indicate the age of any distress. Windows and doors can be opened or closed to determine if they operate properly. Look for evidence of wear on door and window frames and note any prior adjustments of door striker plates.

Locate and examine control joints in the walls. Masonry walls expand and contract with changes in temperature. Therefore, sizeable walls must have control joints to accommodate thermal strains and reduce cracking. A control joint is a vertical or horizontal gap constructed in the masonry wall that should contain a foam type backer rod or neoprene pad covered by an elastomeric sealant. According to the Brick Institute of America (BIA, 2006a and b), control joints should be placed every 20 feet or so along walls to minimize cracking due to volumetric changes.

Identify dissimilar materials that butt against or penetrate the masonry. Wood, steel and aluminum expand and contract at rates different from that of masonry, resulting in distressed joints. Check joints around piping penetrations for relative movement.

Wood frieze boards typically extend around the tops of masonry walls. Examine joints in the frieze boards, especially at wall corners. Rotation or gaps in the frieze boards may indicate a leaning wall. Exposed portions of the frieze boards should be checked for the presence of paint, cobwebs, or patches that may indicate prior movement (Fig. 6).

Walk around the building and check the slope of the terrain as well as drainage conditions. Ground surfaces should slope away from the bases of masonry walls. There should be sufficient soil to cover all but the top few centimeters of the foundation grade beams. Note where downspouts empty water adjacent to the foundation and where trees and other vegetation grow near the foundation. Plant growth can cause moisture variations in the soil and result in wall distress, especially if the soils are expansive.

Steel lintels should be examined for rust and associated cracks in the mortar joints. Steel lintels expand and contract at rates different from that of masonry. Also, rusting steel expands and can drive apart the mortar joints. Look for sagged lintels and improperly constructed headers over windows and doors that can result in wall distress.

If the cause of masonry wall distress is claimed to be wind, check for collateral damage around the area such as downed trees, fences, and roof damage. Determine the magnitude and direction of the wind and compare that to the location and extent of wall distress. Look for signs of impact on the walls from falling trees or flying debris. Wall distress caused by impacts will be localized. As Mehta and Minor (1986) point out, unreinforced masonry is relatively weak and vulnerable to collapse due to lateral pressure. It is a brittle material and collapses without any significant redistribution of load.

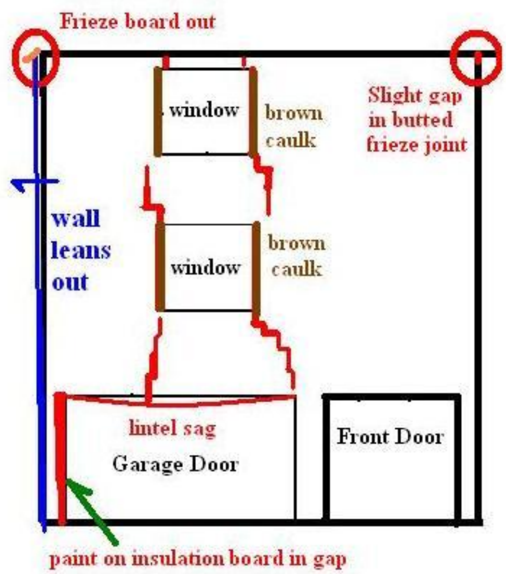

Figure 5. Crack mapping on a three story building face. Cracks resulted from deflection of the steel lintel above the garage and foundation settlement at the left side of the wall, not by wind.

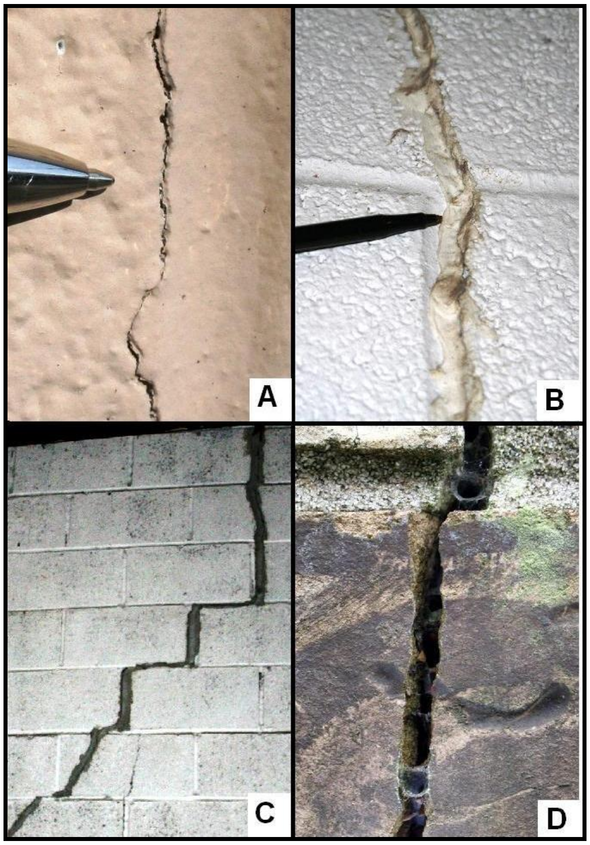

Figure 6. Close inspection revealed old cracks in masonry walls that contained: a) paint, b) caulk, c) mortar, and d) cobwebs.

5. Summary

In this paper, we described how wind damages brick and concrete masonry walls. Examples were presented showing that masonry walls are susceptible to failing in the wind when subjected to high internal pressures. Internal pressure results when a breach occurs in the windward side of a building. Common breaches in windstorms are a failed door or window. Masonry walls adjacent or opposite the breach can topple outward, pivoting about its base. Masonry chimneys and gable ends are also susceptible to wind damage. Chimneys are prone to failure at roof level while gable ends fail at the tops of the walls.

Detailed examinations of masonry walls can determine whether wall distress resulted from wind or a combination of manufacturing, installation, and in-service conditions. Typically, when wind damages masonry, there is collateral damage to other items on and around the property. Trees, fences, satellite dishes, air conditioners, and roofing components and cladding are all susceptible to wind damage. The direction and magnitude of the wind should be compared to the locations and extent of wall distress.

A procedure on how to conduct a visual examination of masonry has been presented. The procedure includes mapping the distress on each elevation and examining interiors of cracks and gaps. Patterns and characteristics of the distress can yield clues whether wind damaged the walls or not.

ACKNOWLEDGEMENTS

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