A HUFF, AND A PUFF, AND… IT BLEW THE CHIMNEY DOWN

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Abstract
This paper will present case studies and assessment of collapses of tall, free standing residential masonry chimneys resulting from windstorms in North Texas. The case studies will outline the assessment of the causes of the collapses and a discussion of design and/or construction defects.

A review of limited and highly lacking documentation on design, construction and code requirements governing the architectural and structural "design" and construction of residential chimneys will be conducted. The paper will provide a discussion of the lack of design standards and poor construction practices used for residential load-bearing masonry chimneys.

This paper will illustrate how the lack of design, construction, and code requirements results in chimneys lacking sufficient capacity to resist below design wind loads leading to unsafe conditions. It is only a matter of time before the collapse of one of these elevated masonry chimney "missiles" results in severe injury or death of an inhabitant.

Introduction

The majority of residential structures being built throughout the country today rely on construction requirements outlined within the International Residential Code (IRC). The IRC provides a prescriptive outline of minimum requirements that must be met during the construction of one and two-family dwellings, not exceeding three stories in height. In today's typical residential construction, a minimal amount of actual engineering of the structure and structural components is performed. In fact, according to the IRC, only those structural components exceeding or not conforming to the empirical design specifications as set forth in the IRC require design by a professional engineer.

Masonry chimneys are prevalent in residential construction in North Texas with tall, slender chimneys rising above rooftops almost anywhere you turn. The minimum required height that a chimney must extend above a roof has been consistent across different building codes as far back as the 1980's. Codes have and still require a chimney to extend a minimum of 2 feet above any adjacent construction located within 10 feet of the chimney. Steep roof pitches are common in North Texas which leads to taller chimneys. However, the overall required height of the masonry chimney is ultimately regulated by the sizing and subsequent ability for air to properly flow through the flue. The three basic elements of residential chimney design are: the area of the fireplace opening, the area of the flue, and the height of the chimney. The size of the fireplace opening is directly proportional to the height and area of the flue. In essence, the larger the fireplace opening gets the taller the chimney becomes.

As the chimneys extend past the roof line, no lateral resistance is provided and they act as cantilevered masonry elements. In fact, residential construction is typically not designed by a structural engineer and the code does not require lateral support for the chimney in low seismic zones; therefore, any lateral resistance provided by the framing of the house is undetermined and not designed and therefore, should not be relied upon.

Lateral Resistance

In North Texas, design of structures for lateral forces is typically governed by the forces imparted by wind due to the low seismic activity in the region. The design wind speed in the area is 90 mph (3-second gust). As the chimneys increase in height above the roof line, the moment induced on the masonry assembly from the cantilevered section increases as well. The moment at the base of a chimney extending ten feet above the second story roof can be as much as 11 times greater than at a chimney extending only three feet above the same roof line. As these lateral forces increase, the amount of available resisting force must increase as well. Resistance to overturning from lateral force is typically provided by the installation of vertical reinforcement within the masonry assembly since unreinforced masonry construction is extremely weak in tension.

Previous building codes, such as the Uniform Building Code (UBC) and Building Officials and Code Administrators International, Inc. (BOCA), required a minimum amount of vertical reinforcement for masonry chimneys located in seismic zones 2, 3, and 4; however, no minimum amount of reinforcement was specified due to forces from wind. No specific minimum reinforcing requirements were provided within versions of the Standard Building Code (SBC).

As stated above, design for lateral forces is typically governed by wind in North Texas. Due to the lack of clear empirical direction for required amounts of vertical reinforcement in masonry chimneys, coupled with the fact that the chimneys are typically erected using unskilled labor, masonry chimneys erected in North Texas are built with little to no vertical reinforcement and rely on the weight of the masonry to provide the resistance to wind loads. This lack of reinforcing severely reduces the chimneys' ability to resist lateral forces.

In addition to the lack of design, defects in chimney construction have been identified which contribute to a decrease in the chimneys' ability to resist external loading, including: improper installation of metal flashing at the roof intersection, lack of roof crickets at the upslope side of the chimney, improper/incomplete installation of mortar at bed and head joints, lack of masonry unit interlock between the core and veneer of the chimney, and the lack of horizontal joint reinforcement.

Load Bearing Masonry

When built according to the empirical methods set forth in current and previous editions of the building code, a masonry chimney may not support any additional structural load unless it has been specifically designed and constructed to do so. Therefore, unless the chimney has been designed by a structural engineer, the walls of the chimney are not permitted to be used as a bearing wall for floor or roof framing.

Vertical loads from the self weight and any additional building dead and live loading must be transferred into the foundation below. Many of the researched building codes provide a minimum footing thickness of 12 inches for conventionally reinforced concrete foundation construction. The concentration of vertical and overturning loads imparted on the foundation by these full height masonry chimneys must be accounted for by residential foundation designers. This is particularly important in the North Texas region where the high shrink/swell potential of soils creates the need for specialized foundation systems such as pier and beam and post-tensioned concrete slabs-on-grade. As illustrated in Case Study B, foundation designers do not always account for the lateral loads from the chimney in their foundation designs.

Case Studies

Two individual case studies are presented below which exhibit failure of the chimneys from wind due to the lack of structural design combined with poor quality of construction and construction defects.

Case Study A: In the early morning hours of April 10, 2008, a line of severe thunderstorms moved through North Texas producing large hail, tornadoes, and damaging straight-line winds. The straight-line winds were recorded at up to 87 miles per hour in the vicinity of the subject site.

The subject chimney was constructed of brick masonry. Based on pre-storm photographs, the overall height of the masonry chimney was estimated to be over 35 feet above grade with an extension of approximately 12 to 15 feet above the eave. The chimney was measured to be 6 feet wide by 1 foot 8 inches in depth at the base; however, the top portion of the chimney was corbelled for aesthetic appeal and was wider than the supporting base. This effectively created a large elevated mass at the top of the chimney and resulted in a top-heavy condition.

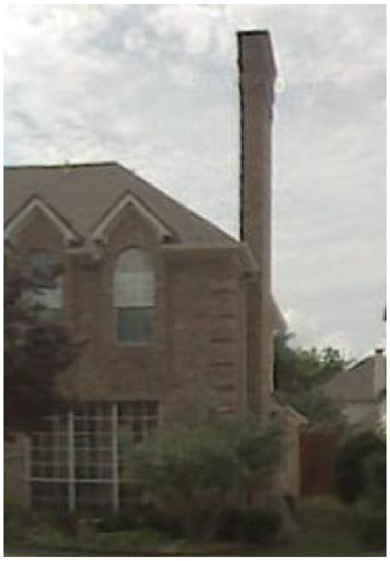

Figure 1. Pre-storm Chimney at Case Study A (Google Maps Street View)

The addition of the solid masonry core at the top of the chimney contributed to the overturning moment and subsequent collapse of the chimney. The top portion of the chimney is visible in Figures 2 and in the left side of Figure 3 below. The bottom section of the masonry chimney was erected such that hollow cavities existed on each side of the flue. These hollow cavities terminated approximately 4 feet from the top where the solid masonry core began as shown in Figure 2.

Figure 2. Solid Masonry Core Formerly at Top of Chimney

Due to the lateral forces imparted on the chimney by high winds, (but still less than the required 90 mph design wind speeds), the cantilevered portion of the masonry chimney failed, falling into and causing significant damage to the structure below.

Figure 3 below shows the collapsed masonry chimney as well as the detached top portion of masonry that punctured through the roof deck and framing. The second floor ceiling and wall framing stopped the detached section of masonry from crashing into the bedroom below where two young girls were sleeping at the time of the chimney collapse.

Figure 3. Collapsed Section of Chimney Above Children's Bedroom

Investigation of the remaining chimney shaft revealed the following deficiencies which most likely contributed to the failure:

- Continuous vertical reinforcement had not been installed within the masonry.
- A roof cricket had not been installed at the upslope side of the chimney.
- Metal flashing had been installed in place of the cricket and penetrated through the full width of the mortar bed (Figure 4). The full penetration of flashing effectively broke the masonry bond, creating a weak joint in the chimney construction.

Figure 4. Full Penetration of Metal Flashing

The lack of continuous vertical reinforcement effectively limited the tensile forces that the chimney could resist. In this case, the addition of a top-heavy masonry "missile" aided in the chimney collapse. Wind forces laterally displaced the chimney, creating an eccentric loading condition from the solid masonry top section and a subsequent moment that exceeded the tensile strength of the as-built masonry construction. The chimney collapsed at the base of the cantilevered section and into the structure. Fortunately, the roof framing absorbed enough of the chimney's kinetic energy for the second floor ceiling and wall framing to stop the masonry "missile's" further decent into the structure; otherwise, the two young girls sleeping in the bedroom below may have been severely injured or even killed.

<u>Case Study B:</u> The masonry chimney outlined in this case study failed due to winds with significantly less intensity than the design wind speed for the region or those recorded in Case Study A. The recorded wind speed at the time of collapse was only 39 mph (3-second gust). Wind speeds of this magnitude and higher are frequent in the North Texas area.

Figure 5. Pre-storm Chimney at Case Study B (Google Maps Street View)

The design and construction for the structure was based on the 1997 UBC with a seismic zone classification of 0 and a 70 mph design wind speed. The chimney was constructed of generally un-mortared, rubble-type construction and was clad with a fieldstone and brick veneer. The height of the chimney was approximately 40 feet above grade; almost half of which stood laterally unsupported above the roof line. This can be seen in Figure 5 above. The shape of the chimney was unusual and transitioned above the roof line from a single rectangle to a pair of parallel rotated squares. The shape transition required the flue to not only offset, but to rotate 45 degrees as well. Information provided indicates that the driving force for the unusual shape and height of the chimney was purely architectural in nature.

Failure of the chimney occurred at the roof line, allowing for the full cantilevered portion to overturn and fall into the structure below as seen in Figure 6. The collapsed chimney fell through the second floor bedroom and into the first floor dining room. Review of the construction documents indicated specific portions of the structure were required to be designed by a structural engineer; however, the design of the chimney was not included in the structural requirements. Additionally, the post-tensioned foundation did not account for the additional weight imparted by the solid core masonry chimney at that location and did not account for the lateral wind loads acting to overturn the chimney.

Figure 6. View of Collapsed Chimney

Further investigation of the post-collapse debris revealed that no vertical or horizontal reinforcement had been installed. Additionally, the brick masonry core had been poorly constructed and did not have proper continuous mortar bedding for the bricks. Much of the brick within the masonry core appeared to have been laid loosely with no structure or organization as seen in Figure 7 below. No interlock was observed between the brick core and veneer, allowing for subsequent delamination from the core during collapse. Debris, including aluminum cans, was observed within the rubble of the collapsed chimney.

Figure 7. Lack of Mortar and Interlock at Masonry Core

In addition to the lack of continuous vertical reinforcement, the narrowing of the chimney section and transition from a rectangular section to two separate rotated square-shaped flues aided in the chimney's inability to resist lateral forces. As stated previously, the chimney failed from wind forces far less than those outlined in the building code. Similar to Case Study A, the chimney collapsed above a second floor bedroom; however, in this scenario, the ceiling framing was not able to retard the masonry's decent into the structure. In addition, potential injury and/or death were averted simply because the occupant of the bedroom below the chimney was away at school and another occupant had recently left the room at the time of the collapse after investigating a strange bumping sound (likely the chimney swaying prior to collapse).

Conclusion

The two case studies presented above showcase some of the poor construction associated with non-engineered freestanding masonry chimneys in North Texas. In addition, the lack of clear empirical direction for the construction of brick masonry chimneys contributes to the erection of structures with deficient load resisting capability. In both case studies, the collapsed chimneys fell on bedrooms. Thankfully, no one was injured associated with either of these collapses; however, it is only a matter of time before someone is injured or killed when a tall freestanding masonry chimney collapses due to inadequate design and/or construction.

The authors of this paper strongly recommend that the requirements for the structural design of free-standing chimneys in no or low seismic regions be strengthened immediately in order to reduce the potential for injury and/or loss of life. This includes strengthening the requirements for the design of the foundation systems supporting these chimneys as well as the requirements for continuous vertical reinforcing. The authors further recommend that the requirements for the inspection of the quality of construction by the design professionals also be strengthened and that homeowners with free-standing masonry chimneys have their chimneys evaluated for possible deficiencies and concerns for safety.

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