MASONRY INSIGHTS

Masonry Storm Shelters

Tornadoes and hurricanes produce extreme meteorological conditions and forces on buildings during such weather events with unpredictable outcomes. Providing safe structures for people during storm events requires many specific design provisions not typically needed for a standard building that must be coordinated with the entire design team. Masonry is a great option due to the inherent strength, durability, and fire resistance of the material as well as being largely available throughout the U.S.

Design Standards and Definitions

A significant change in IBC-2015 is the adoption of ICC-500, requiring storm shelters for specific geographic areas and certain building uses (Critical facilities and Group E occupancies including schools). For projects under IBC 2015 that fall within these categories, storm shelter design is no longer an option and is mandatory.

- IBC 2015 Section 423
- ICC 500 (2014 - Second Edition)
- FEMA P-361 (2015 - Third Edition)
- FEMA P-320 (2014 - Fourth

Storm Shelter: a building or structure (full or portion) designed and constructed per ICC 500 designated for use during a tornado or hurricane
Safe Room: an interior room or an entire building designed and constructed per FEMA 361 or 320 to provide *near absolute* life-safety *protection* for its occupants from tornadoes or hurricanes
Residential Storm Shelter: a safe room or storm shelter serving occupants of dwelling units and having an occupant load not exceeding 16 people
Community Storm Shelter: any safe room or storm shelter not defined as a residential safe room or storm shelter

The main difference between the ICC and FEMA documents is that FEMA provides best practices and recommended criteria as guidance for design and construction of safe rooms while ICC presents a codified document which has undergone the consensus standard vetting process. FEMA P-361 provides design criteria and commentary for community and residential structures (which are more stringent than ICC) while FEMA P-320 covers prescriptive solutions for homes and small businesses. FEMA P-361 (2015) includes a matrix in its appendix to compare the ICC-500 and FEMA P-361 requirements.

Structural Design Considerations

During a tornado or hurricane, there are many special load cases that must be considered during the design phase for a storm shelter or safe room. The first of the two main load cases are the high direct lateral wind loads based on maximum ultimate winds speeds of 250mph for tornadoes and 220mph for hurricanes using ASCE 7-10 load cases. Since wind pressures are based on the square of the wind speed, tornado loads, for example, will be 4.7 times higher than the standard design wind load in the 115mph area for most of the U.S.

Figure 1: ICC 500-14 Figure 304.2(1)
Shelter Design Wind Speeds for Tornadoes

Figure 2: ICC 500-14 Figure 304.2(2)
Shelter Design Winds for Hurricanes

Discussions with the design team are critical when determining whether a shelter is enclosed or partially enclosed. Enclosed shelters have specific requirements that must be met involving penetrations and venting whereas partially enclosed shelters do not. Therefore, best practices per FEMA P-361 Chapter B8 recommend the use of the internal pressure coefficient for partially enclosed buildings. In addition, the design team must be aware that corner wind pressures often exceed the tested capacity of the fabricated opening elements, thus openings at the corners should be minimized or avoided.

TABLE 305.1.1
SPEEDS FOR 15-lb SAWN LUMBER 2 × 4 MISSILE FOR TORNADO SHELTERS

DESIGN WIND SPEED	MISSILE SPEED AND SHELTER IMPACT SURFACE
130 mph	80 mph Vertical Surfaces 53 mph Horizontal Surfaces
160 mph	84 mph Vertical Surfaces 56 mph Horizontal Surfaces
200 mph	90 mph Vertical Surfaces 60 mph Horizontal Surfaces
250 mph	100 mph Vertical Surfaces 67 mph Horizontal Surfaces

The second major loading is the force due to impact from flying debris. All perimeter walls, roofs, and materials covering openings must be strength tested to withstand the force of a 2x4 projectile at various high speeds depending on the requirements for the specific region in which the shelter or safe room is located. Refer to ICC-500 (2014) Table 305.1.1.

For these strong storms, many other load cases need to be considered as well. Heavy dense debris can land on the shelter roof, thus minimum roof live loads are required (100 psf for tornadoes and 50 psf for hurricanes). Shelters below ground could experience hydrostatic, flood, and buoyancy loads. It is important to consider proximity to taller buildings, above ground power lines, radio antennas, and even parking lots. The wind forces are strong enough to turn vehicles into projectiles that can go through walls or land on the roof.

After considering all of the possible load cases, a critical part of the structural design is ensuring a continuous load path through the structure (see Figure 3). Providing adequate vertical reinforcement in the wall will not suffice if appropriate laps or connections are not provided to transfer all tension, compression, and moment through the full cross section from roof to foundation. Missing connections would be detrimental to the performance of the structure during an event. The contract documents must clearly detail all aspects of the load path. Following the load path, sliding and overturning of the structure must be reviewed. Due to the magnitude of the uplift forces, special inspection shall be performed on all post-installed anchors. Fortunately, the weight of the solid masonry aids greatly with overturning and sliding resistance, but a close look at holddown connections to the foundation is still critical.

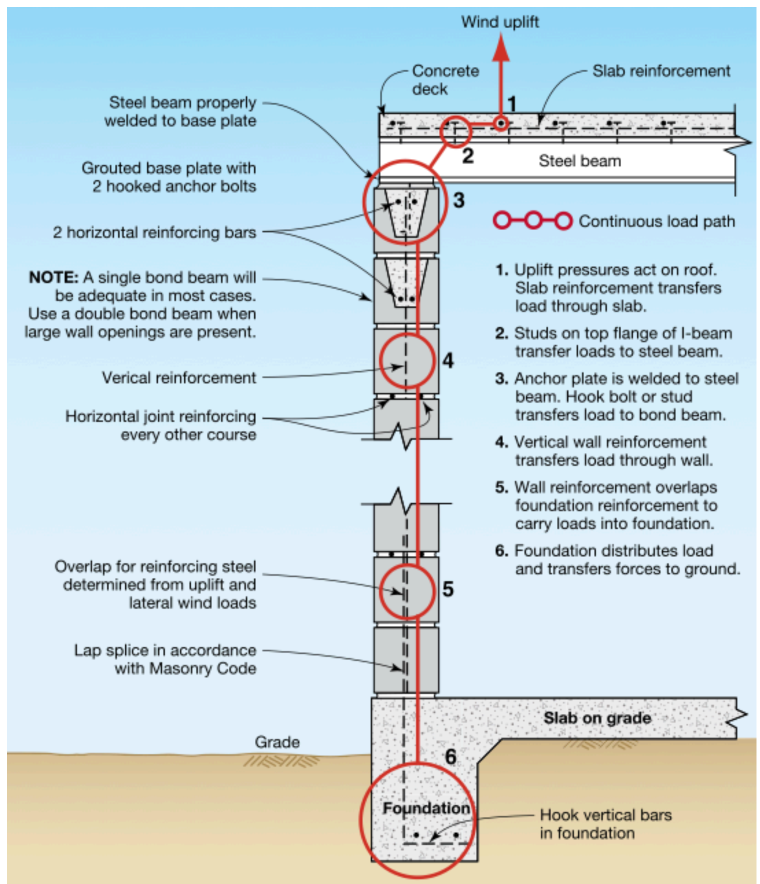

Figure 3: FEMA P-361 Figure B3-6
Continuous Load Path

The final step of the design process is to have a peer review of the design completed by an independent licensed engineer experienced in the design of storm shelters or safe rooms to ensure all critical design requirements have been properly addressed.

Architectural Design Considerations

The architectural design of storm shelters and safe rooms has many requirements beyond the impact testing material requirements of the exterior door and window openings of the structural envelope. There are numerous human factors to consider, which include but are not limited to:

- Three design phases:
  - Pre-event: opening shelter, getting occupants inside, locking
  - Event: structural envelope, deter people from opening protective devices
  - Post-event: evacuation, treatment of injuries, return shelter to original condition for daily use
- Entrances/Exiting/ADA
- Free standing vs. connected to non-shelter structures
- Proximity to taller structures, adjacent structures with roof-top equipment, overhead power lines, radio towers, parking lots, etc.
- Flooding and flood zones
- Storm design duration
  - tornadoes = 2 hours,
  - hurricanes = 24 hours
- Occupancy Density
  - Emergency power
  - Storage for water, food, and other supplies

Additional Resources:
- ➡ NCMA Storm Shelter Design Guide 2015
- ➡ NCMA Storm Shelter Case Study Design Commentary 2015
- ➡ https://www.wbdg.org/resources/wind-safety-building-envelope