J.B. SPEED SCHOOL OF ENGINEERING

TORNADO & HIGH WIND SHELTERING WITH MASONRY

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Learning objectives

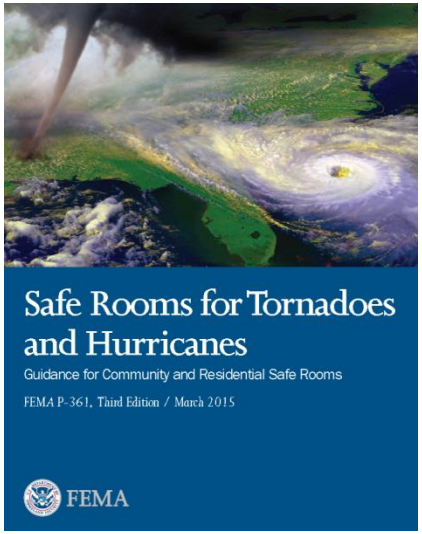
Become familiar with the ICC 500 requirements for storm shelter construction.

Gain an understanding of both the wind speed and missile testing criteria necessary to comply with the IBC 2015 and the ICC 500 requirements for tornado sheltering.

Gain an understanding of the masonry options available for tornado shelter design and construction.

Become familiar with the impact of the ICC 500 wind loads on building layout, design, and detailing.

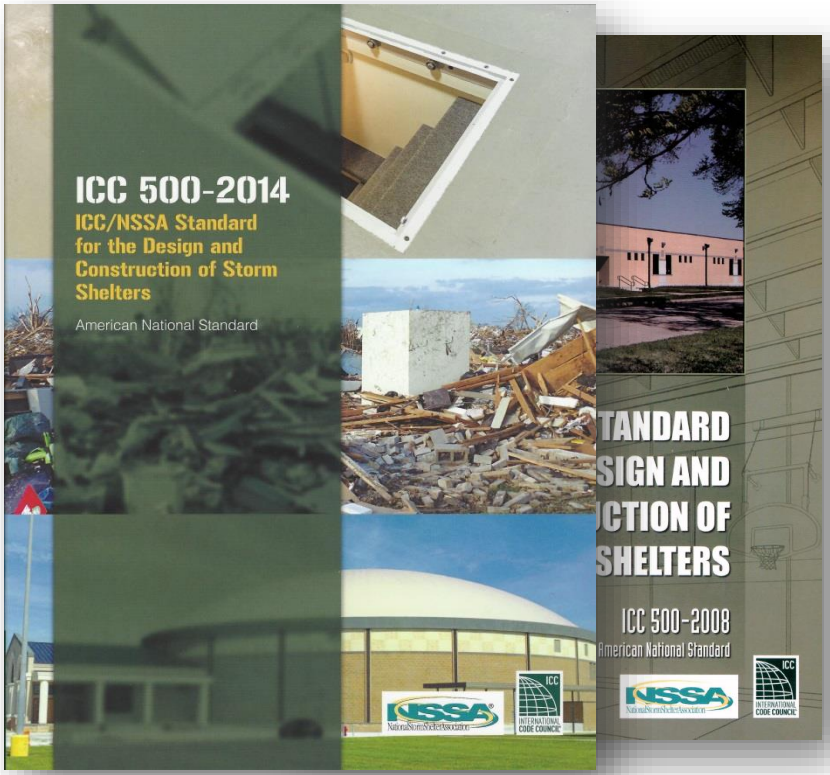
FEMA P-361 & ICC 500



FEMA P-361 is a FEMA document providing guidance for safe room design –
"There has not been a single reported failure of a safe room constructed to FEMA criteria."

ICC 500 is a standard for storm shelter design and construction and is adopted by reference in the IBC.

- ICC 500-2014 is referenced in the IBC 2015
- Update to previous ICC 500-2008
- Contains the requirements for storm shelters



ICC 500 – GENERAL INFORMATION

2015 IBC Requirements for Tornado Storm Shelters

- IBC 2015 has adopted ICC 500 which mandates storm shelters for certain geographic areas and certain building uses:
  - Critical facilities – 911 call stations, emergency operation centers, fire, rescue, ambulance and police stations.
  - Group E occupancies (SCHOOLS!) with aggregate occupant load of 50 or more:
    - Must be capable of housing total occupant load of the Group E occupancy
    - Exceptions: Group E day cares, occupancies accessory to places of worship.

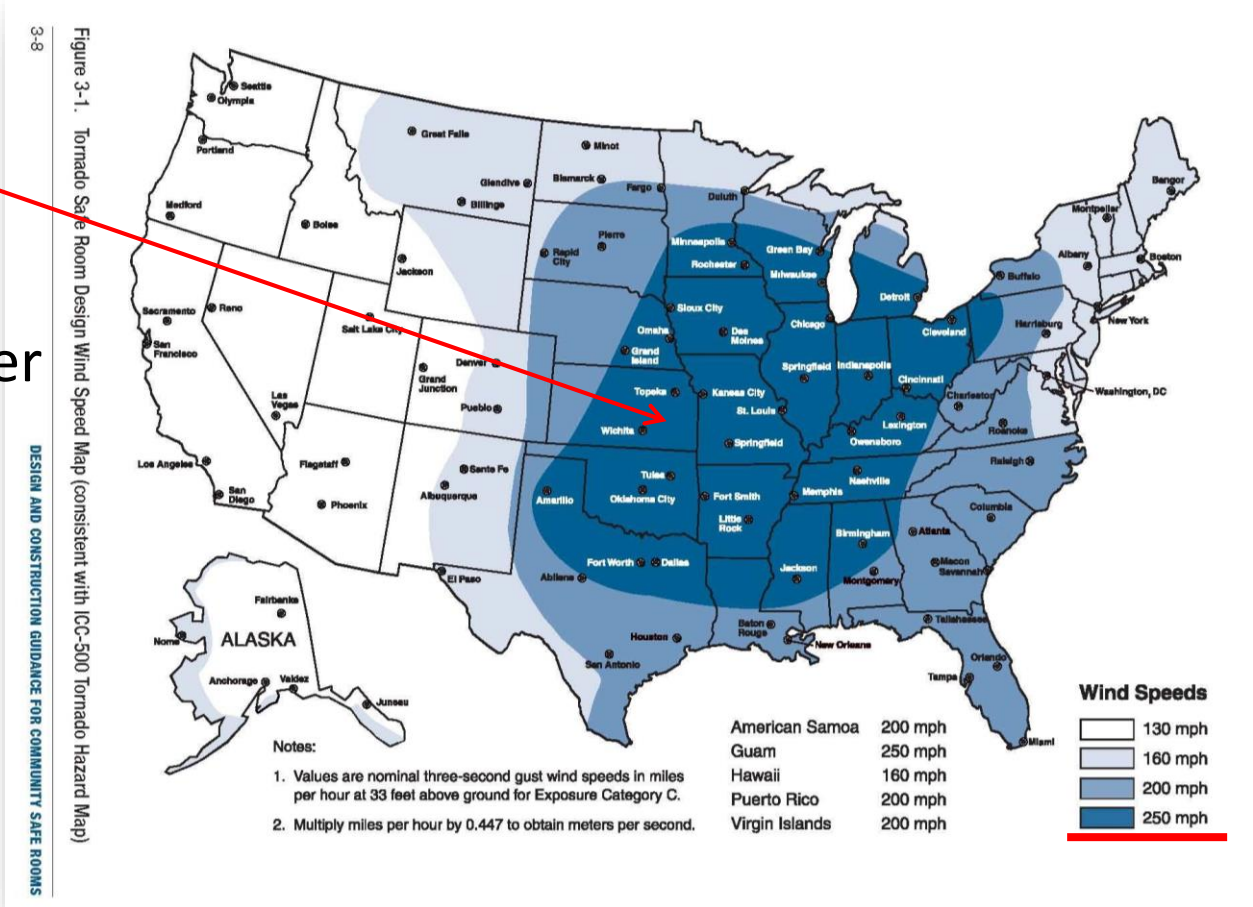
2015 IBC Requirements for Tornado Storm Shelters

- IBC 2015 was published in June 2014 and adoption will vary by state/local jurisdiction.
- Some state or local jurisdictions have mandated compliance with the ICC 500 requirements already.

ICC 500 & IBC 2015

Dark Blue

Locations required to comply with the ICC 500 storm shelter requirements per the IBC 2015.



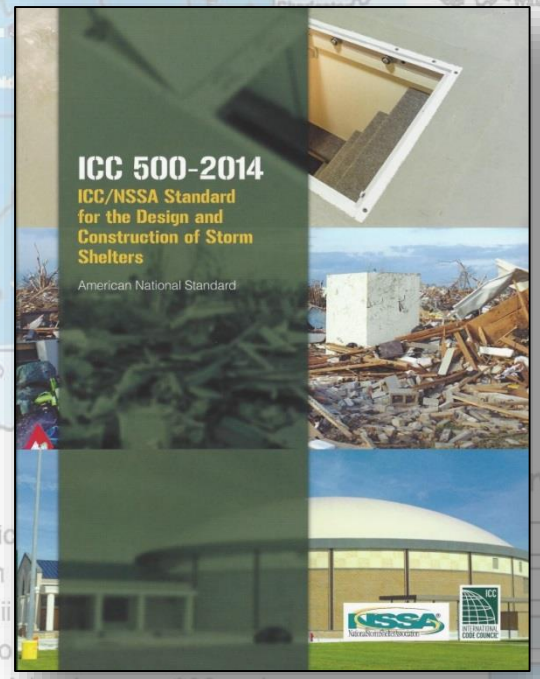
Once implemented, this new requirement will impact the majority of new school construction

Example: ICC 500 & ILLINOIS

Illinois Public Act 098-0883

26 (e-5) After the effective date of this amendatory Act of the 98th General Assembly, all new school building construction governed by the "Health/Life Safety Code for Public Schools" must include in its design and construction a storm shelter that meets the minimum requirements of the ICC/NSSA Standard for the Design and Construction of Storm Shelters (ICC-500),published jointly by the International Code Council and the National Storm Shelter Association. Nothing in this subsection (e-5) precludes the design engineers, architects, or school district from applying a higher life safety standard than the ICC-500 for storm shelters.

5/20/2014	**Senate**	**Third Reading - Passed; 043-014-000**
5/20/2014	House	Passed Both Houses
6/18/2014	House	Sent to the Governor
8/15/2014	House	Effective Date January 1, 2015
8/15/2014	House	Governor Approved
8/15/2014	**House**	**Public Act 98-0883**



ICC 500 Shelter Requirements

ICC 500 shelters have numerous requirements, including, but not limited to, the following highlights:

Architectural

- Peer Review by Independent Registered Design Professional
- > 5 sf per person of usable floor area
- 2-hour Fire Wall Separation at the Perimeter
- Mechanical or Natural Ventilation requirements
- Doors/Windows Designed for Debris Impact at designated wind speed
- 1 Emergency Escape Opening that opens inward and can be opened without a key
- Sanitation facilities within shelter
- Proper Signage and Labeling
- First Aid Kits
- Much more

ICC 500 Shelter Requirements

ICC 500 shelters have numerous requirements, including, but not limited to, the following highlights:

Structural

- Peer Review by Independent Registered Design Professional
- Shelter enclosure passes tornado missile test
- Shelter enclosure - 250 mph design wind speed
- Roof live load – 100 psf minimum
- Special Quality Assurance Plans and Inspections
- Inspection of Fabricators
- Structural Observation Report by Structural Engineer

ICC 500 Shelter Requirements

ICC 500 shelters have numerous requirements, including, but not limited to, the following highlights:

Mechanical, Electrical and Plumbing

- Peer Review by Independent Registered Design Professional
- Minimum Number of Toilets, etc.
- Automatic Shutoffs of Gas or other Hazardous Materials
- 2 hour minimum period of occupancy
- Ventilate 1 sf/1000 sf of floor area
- More

Civil

- Peer Review by Independent Registered Design Professional
- Must comply with Flood Elevation Criteria
- More

ICC 500 – Peer Review

Multi-discipline, Peer Review by Independent Registered Design Professional

Which shelters?

- Community shelters +50 occupant load
- Elementary Schools, secondary schools, daycares with occupant loads +16
- Risk Category IV

Who does this, what is done, who is it submitted to?

- Independent registered design professional (or several)
- Signed & Sealed Report
- Submitted with the Construction Documents to the Authority Having Jurisdiction

106.1.1 Peer review. A peer review shall be conducted by an independent registered design professional for compliance with the requirements of Chapters 3, 5, 6 and 7 for the following storm shelter types:

1. Community shelters with an occupant load greater than 50.
2. Storm shelters in elementary schools, secondary schools and day care facilities with an occupant load greater than 16.
3. Storm shelters in Risk Category IV (essential facilities) as defined in Table 1604.5 in the *International Building Code*.

106.1.2 Peer review report. Where a peer review is required by Section 106.1.1, a signed and sealed report shall be submitted to the authority having jurisdiction with the construction documents identified in Section 107 prior to issuance of a permit for construction. The report shall fully describe the items reviewed, their compliance or noncompliance with applicable codes and standards, and recommend acceptance or rejection of the storm shelter design or modifications to render the design acceptable.

* ICC 500 -2014

ICC 500 – Peer Review

Multi-discipline, Peer Review by Independent Registered Design Professional

What needs to be included?

- Structural design elements
- Occupancy, means of egress, accessibility,
- Fire safety
- Essential features (ventilation, sanitation facilities, backup power, etc.)
- Items defined in Chapters 3, 5, 6 and 7 of the ICC 500

ICC 500 – Inspection

Special Inspections

- Construction and installation of materials as required by the Authority Having Jurisdiction
  - Per Building Code
    - typical special inspections and submittals
  - Per ICC 500 Section 106.3
- Inspection of fabricators
  - Load-bearing or debris-impact-resistant components
- Special Cases
  - Alternatives to traditional materials
  - Unusual design/construction
  - Post installed anchors used for forming part of the shelter enclosure or foundation anchorage

ICC 500 – Quality Assurance Plan

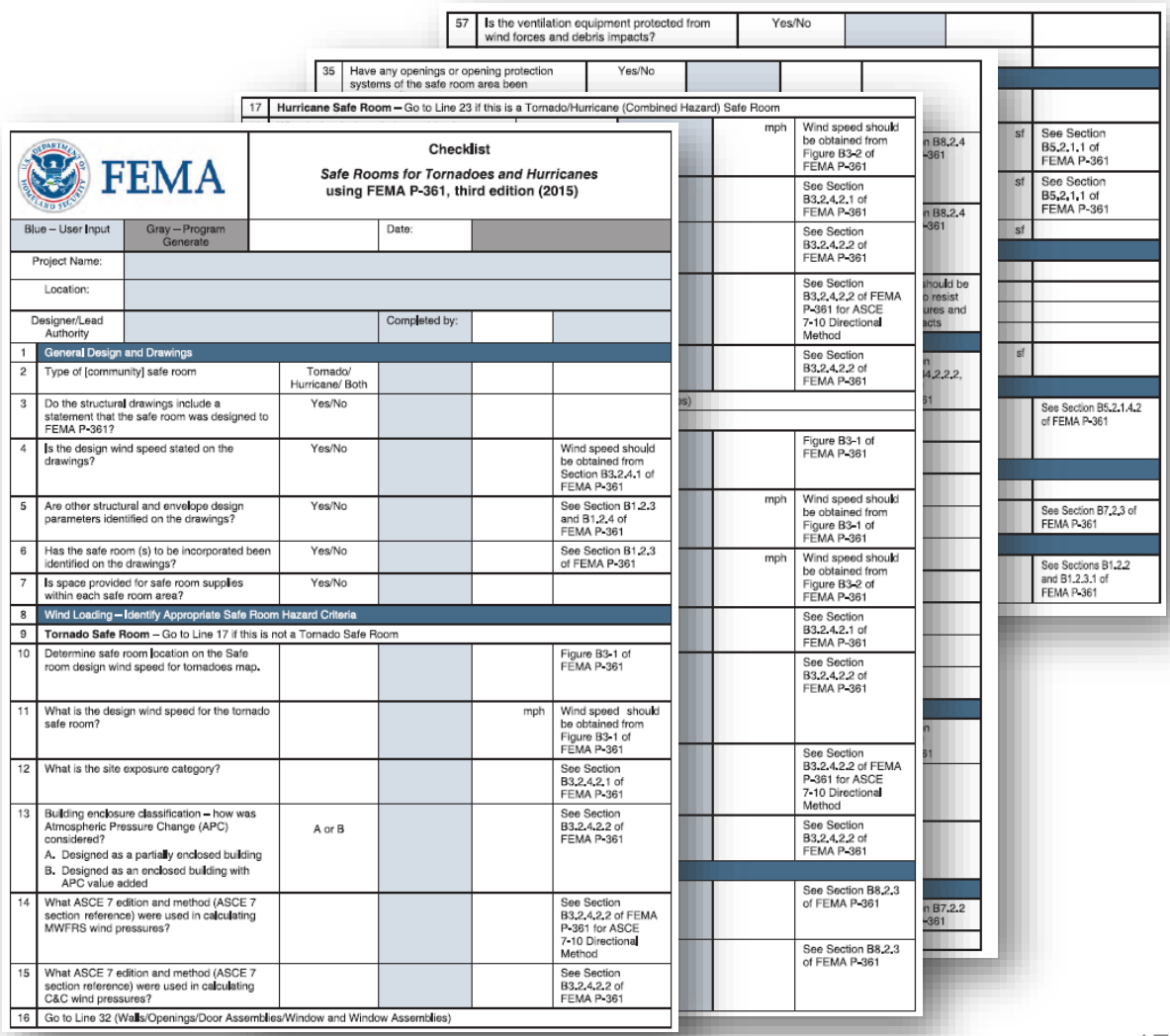
Quality Assurance Plan

- Prepared by registered design professional
- Detailed requirements in ICC 500 Section 107.3
- Contractors responsibility
  - Each contractor responsible for the construction, fabrication or installation of a main windforce-resisting system or any component must submit a written statement of responsibility to the AHJ, registered design professional and owner.

FEMA P-361 Designer Checklist

Designer Checklist

- Good starting point.
- Project specific needs also must be considered.
- Includes Hurricane and Tornado requirements so use appropriately.
- Appendix C to FEMA P361 – March 2015 edition which is available as free download: www.fema.gov.



FEMA

Checklist

Safe Rooms for Tornadoes and Hurricanes **using FEMA P-361, third edition (2015)**

Blue – User Input	Gray – Program Generate		Date:		
Project Name:					
Location:					
Designer/Lead Authority			Completed by:		
1	**General Design and Drawings**				
2	Type of [community] safe room	Tornado/ Hurricane/ Both			
3	Do the structural drawings include a statement that the safe room was designed to FEMA P-361?	Yes/No			
4	Is the design wind speed stated on the drawings?	Yes/No			Wind speed should be obtained from Section B3.2.4.1 of FEMA P-361
5	Are other structural and envelope design parameters identified on the drawings?	Yes/No			See Section B1.2.3 and B1.2.4 of FEMA P-361
6	Has the safe room (s) to be incorporated been identified on the drawings?	Yes/No			See Section B1.2.3 of FEMA P-361
7	Is space provided for safe room supplies within each safe room area?	Yes/No			
8	**Wind Loading – Identify Appropriate Safe Room Hazard Criteria**				
9	**Tornado Safe Room** – Go to Line 17 if this is not a Tornado Safe Room				
10	Determine safe room location on the Safe room design wind speed for tornadoes map.				Figure B3-1 of FEMA P-361
11	What is the design wind speed for the tornado safe room?			mph	Wind speed should be obtained from Figure B3-1 of FEMA P-361
12	What is the site exposure category?				See Section B3.2.4.2.1 of FEMA P-361
13	Building enclosure classification – how was Atmospheric Pressure Change (APC) considered? A. Designed as a partially enclosed building B. Designed as an enclosed building with APC value added	A or B			See Section B3.2.4.2.2 of FEMA P-361
14	What ASCE 7 edition and method (ASCE 7 section reference) were used in calculating MWFRS wind pressures?				See Section B3.2.4.2.2 of FEMA P-361 for ASCE 7-10 Directional Method
15	What ASCE 7 edition and method (ASCE 7 section reference) were used in calculating C&C wind pressures?				See Section B3.2.4.2.2 of FEMA P-361
16	Go to Line 32 (Walls/Openings/Door Assemblies/Window and Window Assemblies)				

57	Is the ventilation equipment protected from wind forces and debris impacts?	Yes/No			
35	Have any openings or opening protection systems of the safe room area been	Yes/No			
17	**Hurricane Safe Room** – Go to Line 23 if this is a Tornado/Hurricane (Combined Hazard) Safe Room				

* FEMA P-361

MASONRY WALL OPTIONS – TORNADO MISSILE TESTS

Today's Structural Focus

- Tornado sheltering in schools
- Structural
  - Shelter enclosure must pass tornado missile test (published).
  - Shelter walls must be engineered for 250 mph design wind speed.
  - Other structural requirements are not covered in detail in this seminar

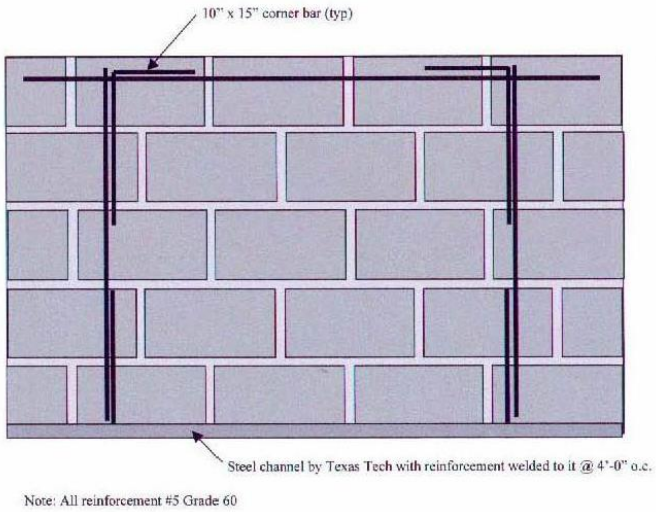
What is Tornado Missile Testing?

- Test to simulate wind born debris impact during a wind event such as a tornado.
- Firing, with an air cannon, a 15-pound 2x4 ‘missile’ at 100 mph at the wall specimen being tested.
- 3 missiles fired - no penetration to the shelter interior to pass.

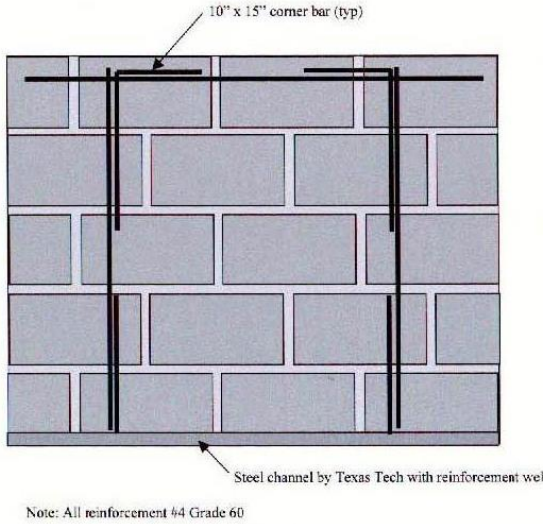
Tornado Missile Tests on Masonry

- Published masonry wall options that pass the tornado missile tests:
  - Solid grouted masonry options – previous testing both clay brick and CMU.
  - Partially grouted & reinforced cavity wall options – newer testing completed in June 2014.

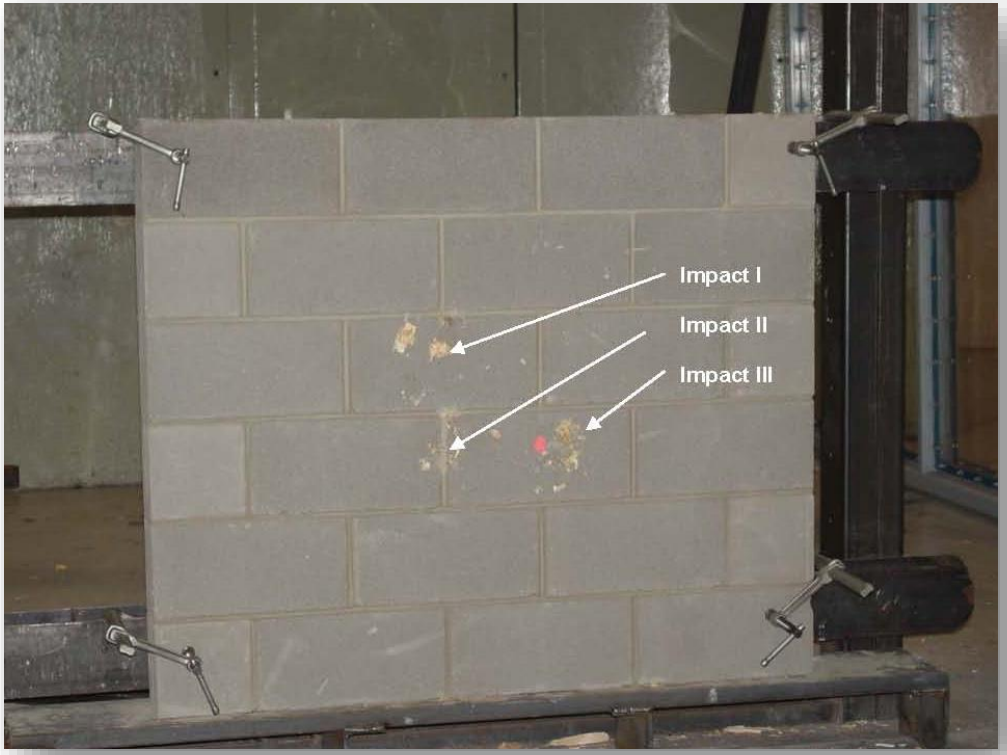
Tornado Missile Tests - Solid Grouted Masonry



8-inch CMU panel

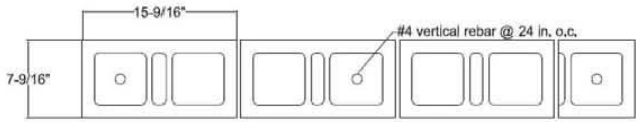


6-inch CMU panel

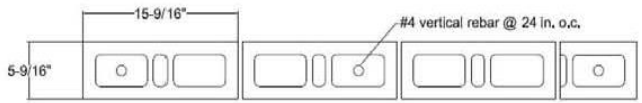


Images from TTU test report.
Testing sponsored by NCMA.

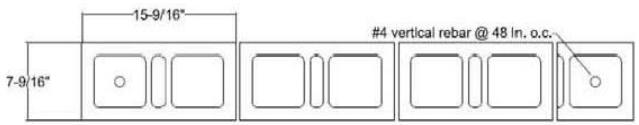
Tornado Missile Tests - Solid Grouted Brick



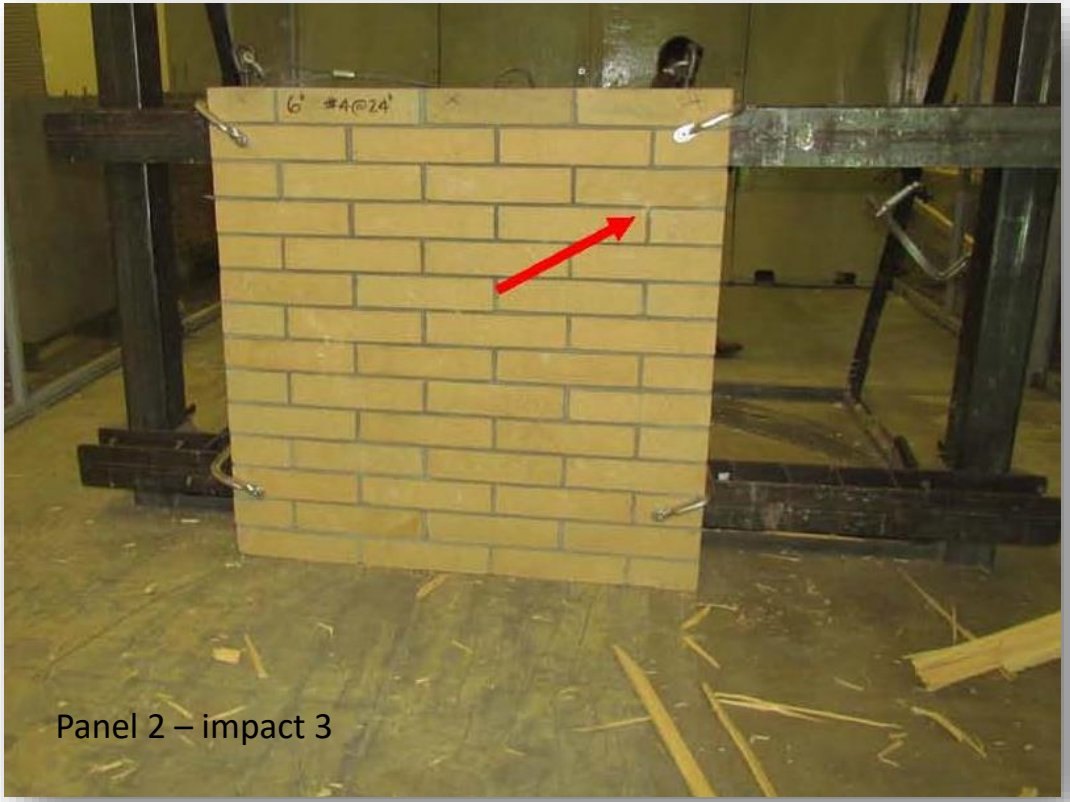
8”x 4” x 16” panel - #4 bars @ 24”o.c.



6” x 4” x 16” panel - #4 bar @ 24”o.c.



8”x 4” x 16” panel - #4 bar @ 48”o.c.



Panel 2 – impact 3

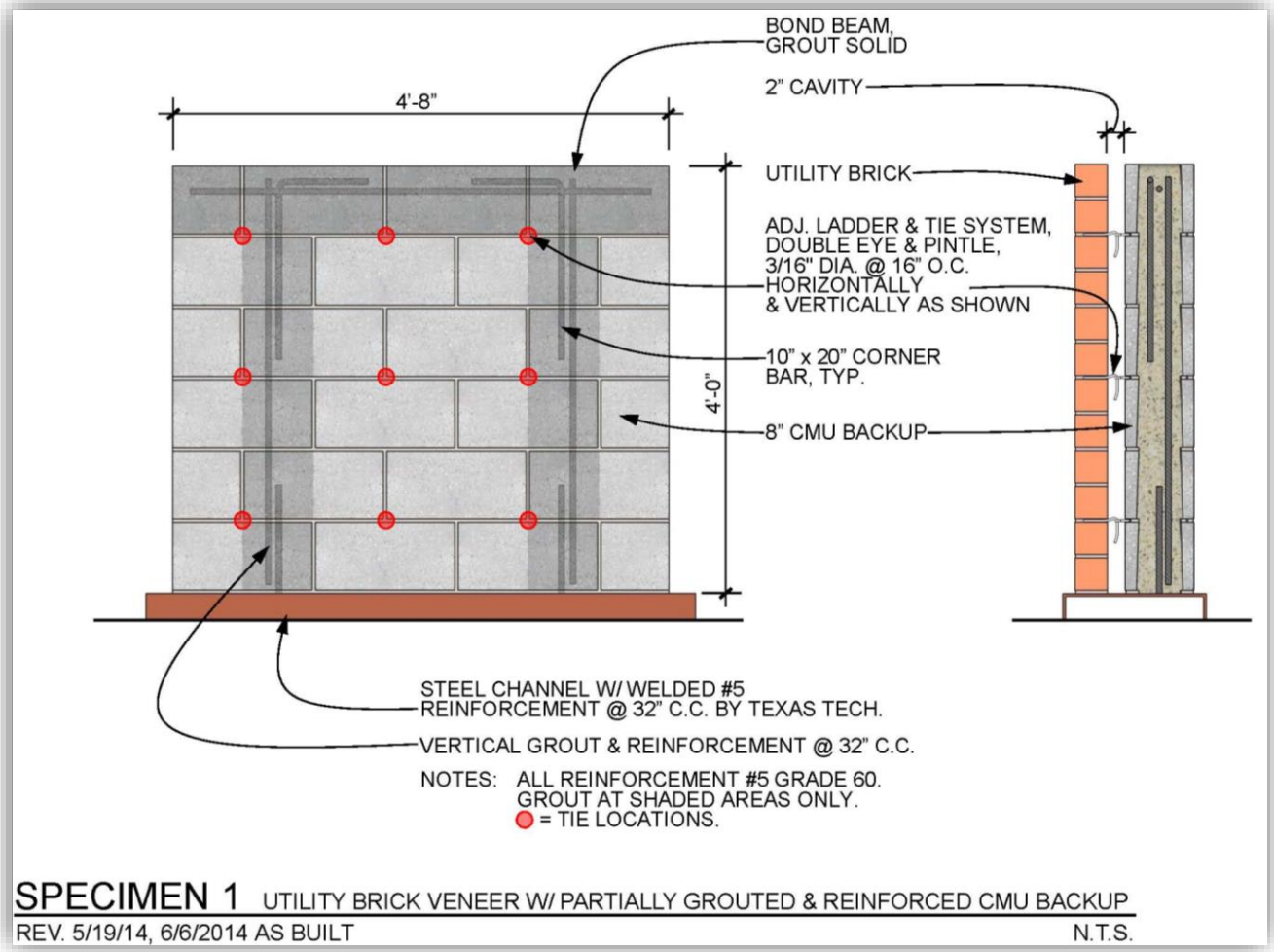
Images from TTU test report.
Testing sponsored by Western States Clay Products.

Brick & Block Cavity Wall Tests

- Brick veneer with partially grouted & reinforced CMU cavity wall is a common system of construction for schools (and other emergency facilities).
- No tests reported for a masonry cavity wall system.
- Advantage for masonry if a cavity wall with partially grouted & reinforced CMU back-up and brick veneer passes the tornado missile test.
- Possible retrofit applications?
- So, will a cavity wall built with a brick veneer and a partially grouted & reinforced CMU cavity wall pass the tornado missile test?

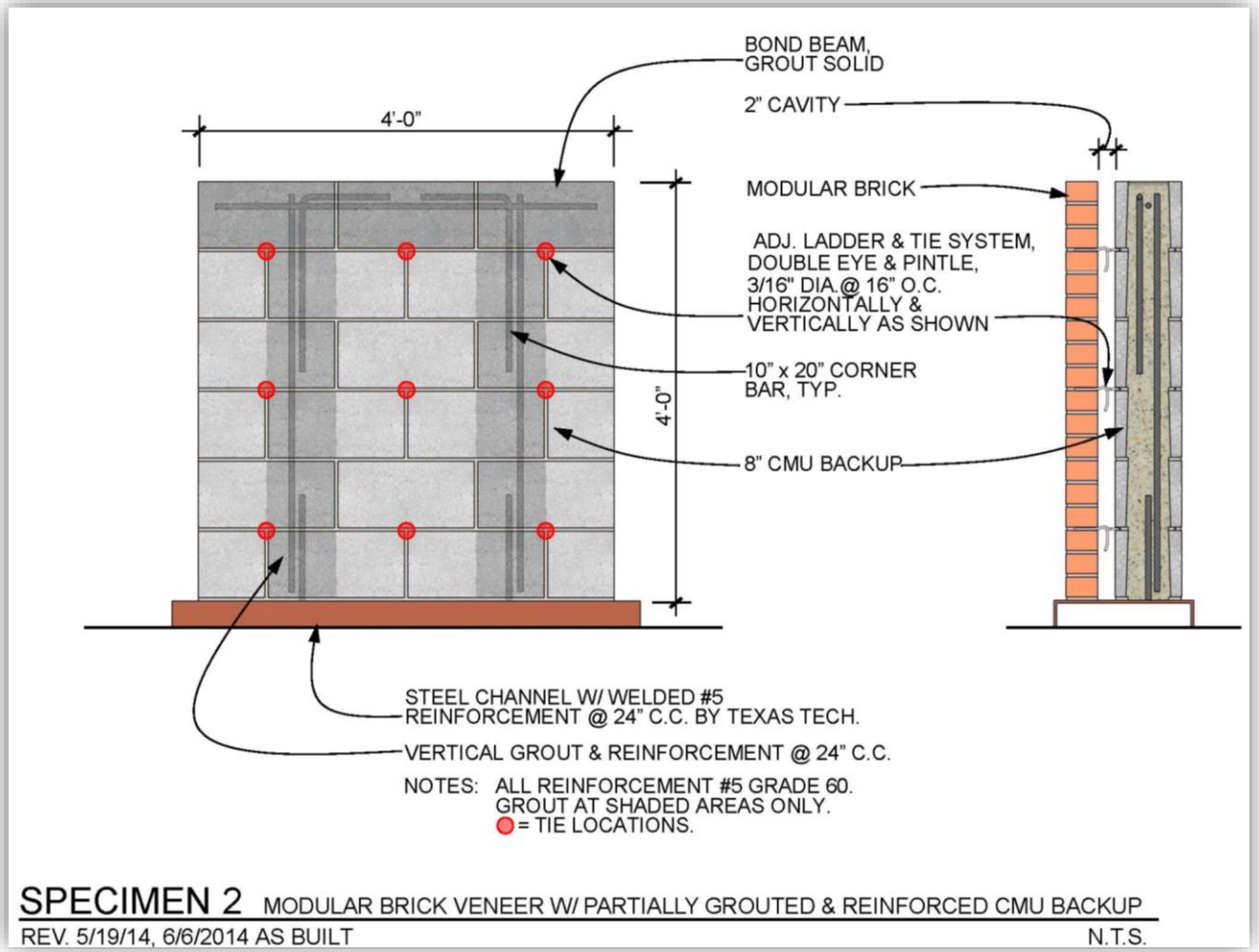
Tornado Missile Testing – Masonry Cavity Walls (Specimen 1)

Clay brick, utility size; 2″ cavity;
8″ CMU back-up partially grouted & reinforced at 32″c/c.



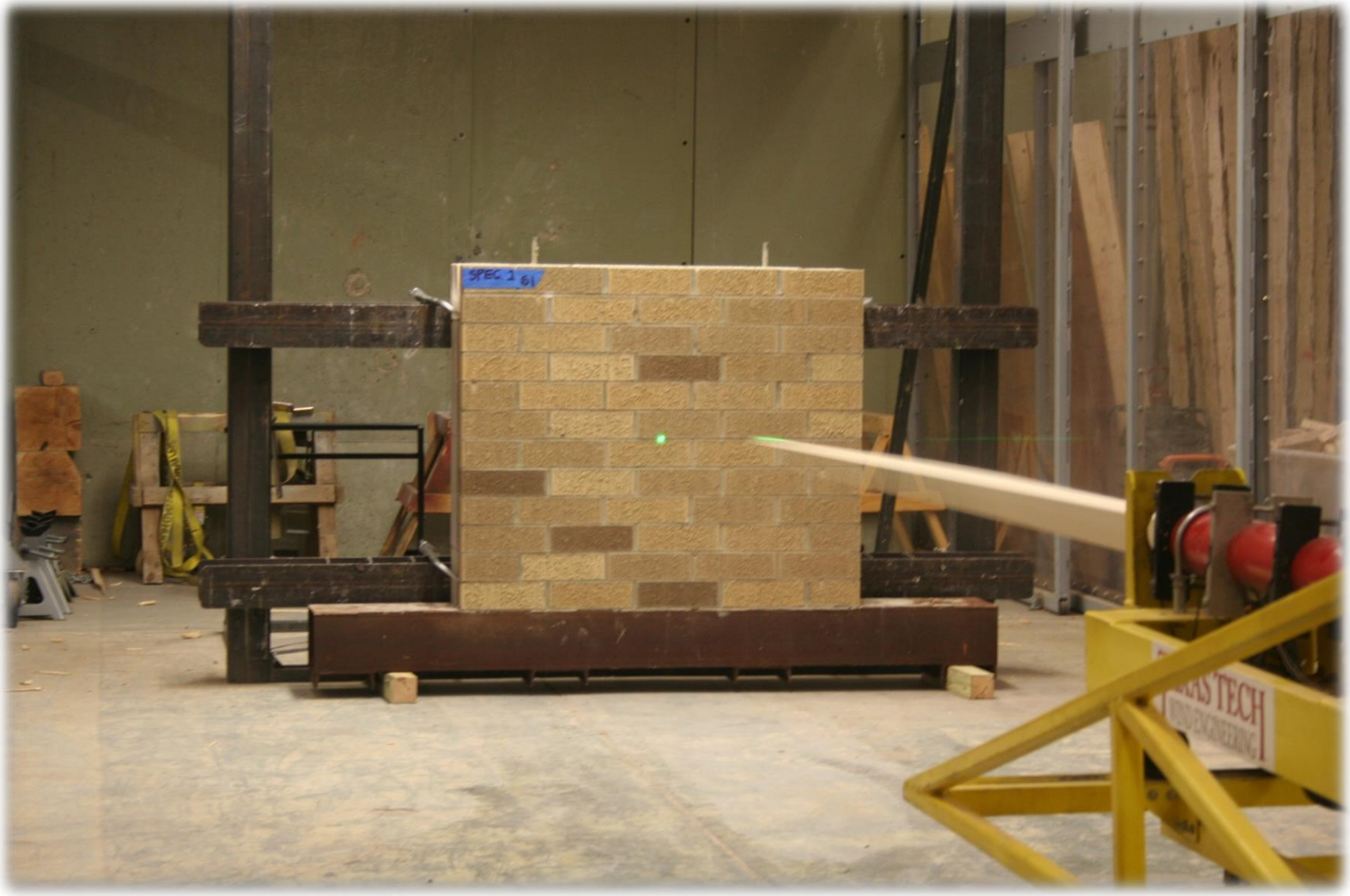
Tornado Missile Testing – Masonry Cavity Walls (Specimen 2)

Clay brick, modular size; 2" cavity;
8" CMU back-up partially grouted & reinforced at 24"c/c.



Tornado Missile Testing Video

Firing the First Missile



Impact of the First Missile

After Impact – Exterior Veneer

After Impact – Interior Face Undamaged

Link to posted Texas Tech report: http://www.depts.ttu.edu/nwi/research/DebrisImpact/

ICC 500 - STRUCTURAL CONSIDERATIONS

Today's Structural Focus

- Tornado sheltering in schools
- Structural
  - Shelter enclosure must pass tornado missile test (published).
  - Shelter walls must be engineered for 250 mph design wind speed.
  - Shelter roofs must be engineered for 100 psf min roof live load.
  - Other structural requirements are not covered in detail in this seminar

Continuous Load Path - General

Continuous load path required for gravity loads but also for lateral and uplift forces generated by tornadic winds.

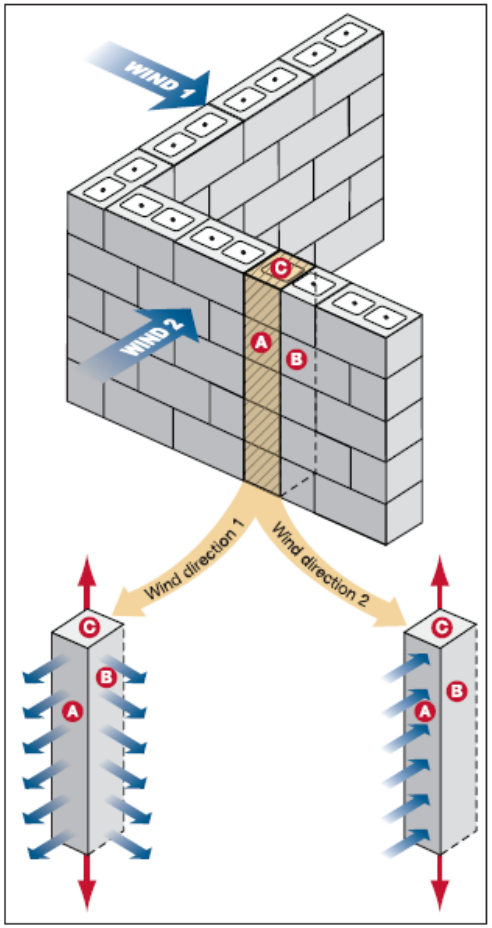


Figure B3-4. MWFRS combined loads and C&C loads acting on shelter wall section*

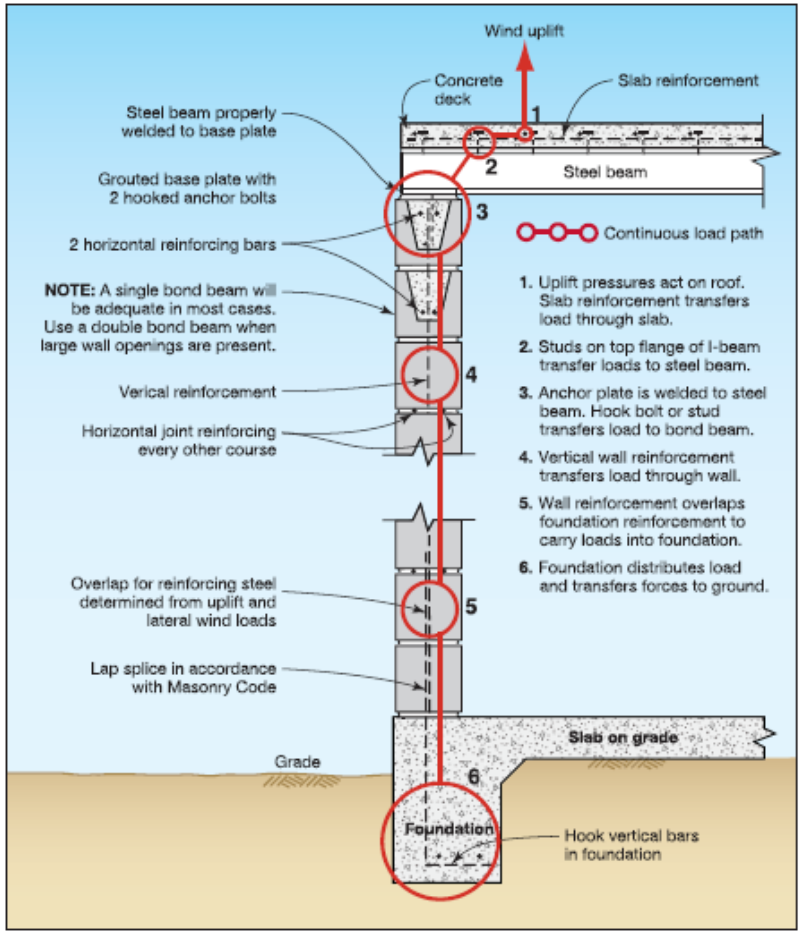


Figure B3-6. Continuous Load path in a reinforced masonry building with a concrete roof deck*

* FEMA P-361

Continuous Load Path - Connections

B3.2.4.3.1 Anchorages and Connections*

A common problem during extreme wind events is the failure of connections between building elements. This failure is often initiated by a breach in the building envelope, such as broken doors and windows or partial roof failure, which allows internal pressures with the building to increase rapidly. This phenomenon is illustrated in the schematic in Figure B3-7, which shows the forces acting on the buildings when a breach occurs.

Anchorage and connection failures can lead to the failure of the entire safe room and loss of life. *Therefore, whenever feasible, it is best practice for the design of anchorages and connections to be based on the C&C loads calculated from ASCE 7.* All effects of shear and bending loads at the connections should be considered.

BEST PRACTICE

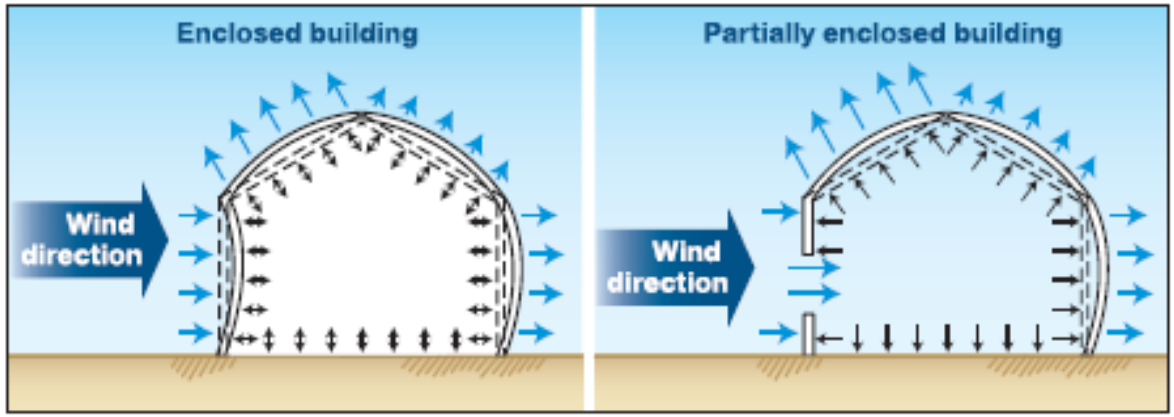


Figure B3-7. Internal pressurization and resulting building failure due to design winds entering an opening in the windward wall.

* FEMA P-361

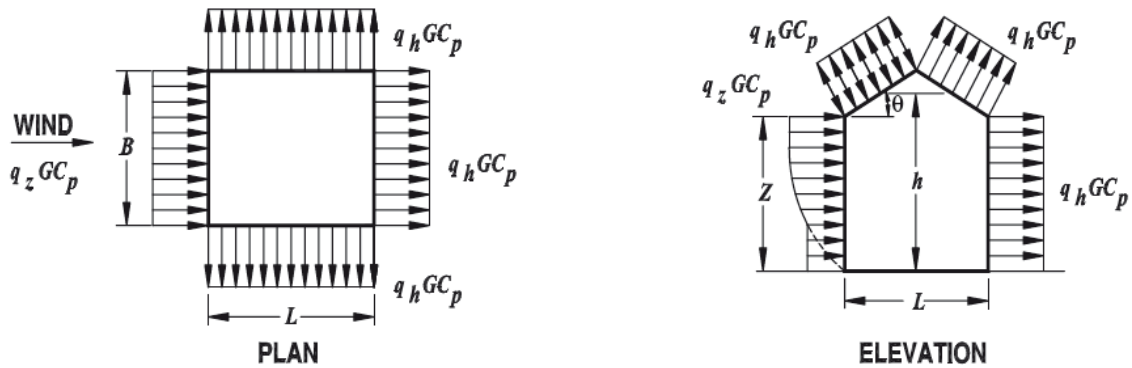
Continuous Load Path - Connections

It's all about Load Path & Connections

- Foundation to wall
  - Full development not just dowels
  - Masonry foundation walls – continuity and better connection options over concrete stem walls.
- Wall to roof
  - Bond beams and anchorage
- Doors and windows to walls
  - Critical so no breach of the envelope
- Veneer to structural wythe
  - If both used for impact resistance

Wind Loads MFRS – ASCE 7

Main Wind Force Resisting System – Part 1		All Heights
Figure 27.4-1	External Pressure Coefficients, C_p	Walls & Roofs
Enclosed, Partially Enclosed Buildings		



GABLE, HIP ROOF

V=130 mph to 250. Shelter designs typically in the 250 mph zone.

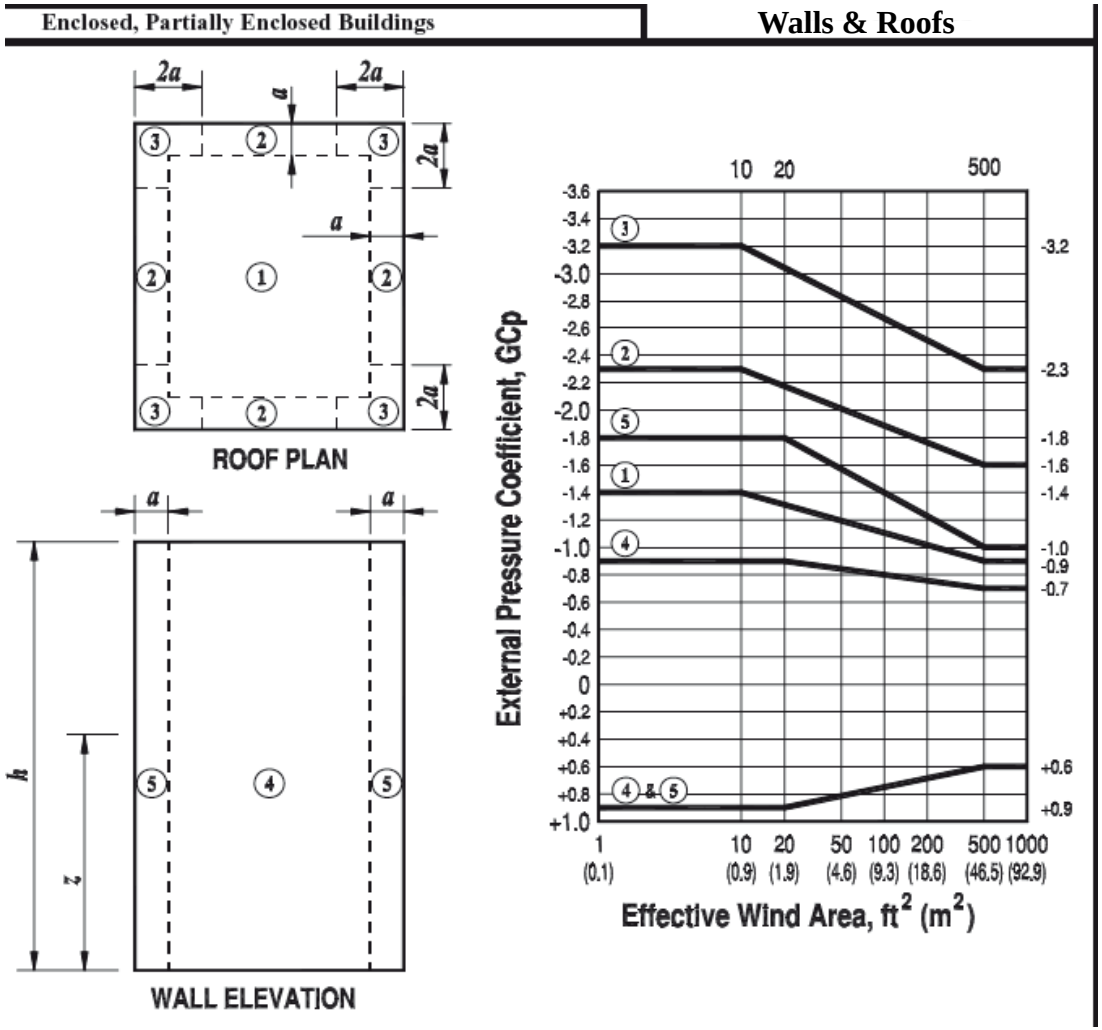
$$q = 0.00256 * K_z * K_{zt} * K_d * V^2 \text{ (ASCE -10)}$$

Directional Procedure – $p = q*GC_p - q*GC_{pi}$

But any method allowed: Note K_d =1.0, (Exposure C always), $K_{zt} \leq 1.0$

Gc_{pi}= +/- 0.18 when APC (atmospheric pressure change) venting
or = +/- 0.55 other wise

Wind Loads C & C – ASCE 7 Components and Cladding



$$p = q*GC_p - q_i*GC_{pi}$$

Gc_{pi}= +/- 0.18 when APC venting or = +/- 0.55 other wise

Remember connections designed for max A_t = 10 ft^2

Figure for heights greater than 60 ft (h < 60 ft below similar)

Example later

ICC 500 - ADDITIONAL CONSIDERATIONS

Usable Floor Area – ICC 500

Calculation of usable floor area

- Concentrated furnishings or fixed seating
  - Reduce gross floor area of shelter by 50% minimum
- Unconcentrated furnishings and without fixed seating
  - Reduce gross floor area of shelter by 35% minimum
- Areas of Open Plan Furnishings and without fixed seating
  - Reduce gross floor area of the shelter by 15% minimum

Alternative Calculation of usable floor area

- Subtract from the gross floor area, the floor area of:
  - Partitions and walls,
  - Columns, and
  - Fixed or movable objects, furniture, equipment or other features that under probable conditions cannot be removed.

- ***As a best practice, once all unusable areas have been subtracted from the gross floor area, an additional 15 percent should be subtracted to account for egress.***

BEST PRACTICE

* FEMA P-361

Wall & Roof Openings – ICC 500

Doors

- Missile impact and pressure testing per ICC 500
- Exception for alcove or baffled entry systems

Windows and Glazed Openings

- Missile impact testing and pressure testing per ICC 500
- Missile impact testing not required if protected by rated impact-protective system

Impact-protective Systems

- Missile impact testing per ICC 500
- Designed for specified wind loads
- Permanently affixed
- Operable systems manually operable from inside shelter

More: Anchorage, door undercut, joints, gaps, etc.

Egress Requirements – ICC 500

Doors

- Number per normal occupancy but if only one – emergency escape opening
- Direction of swing per normal occupancy
- Operable from inside without keys or special knowledge or effort

Emergency Escape Opening

- Additional door or opening min. 5.7 sf in area min. height 24” and min, width 20”
- Operable from inside without tools or special knowledge
- If more than 44” above finished floor then stairs or ladder required
- Location requirements

Other

- Accessible route required per ICC A117.1
- Consider ingress requirements as well as egress

Egress Requirements – ICC 500

Alcove or baffled entries

- No missile testing requirement if 2 impact surfaces prior to opening
- Doors subject to rebound impact reduced missile impact requirement

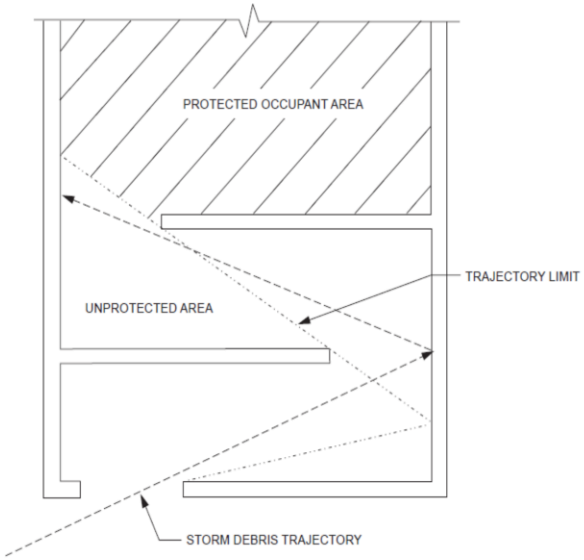


FIGURE 804.9.7
ALCOVE/BAFFLED ENTRY SYSTEM

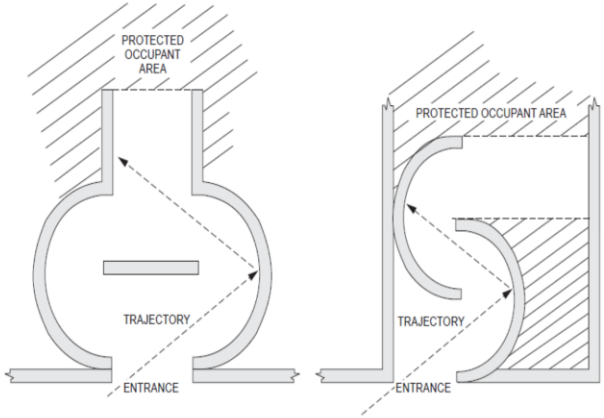


FIGURE 804.9.7.1
ALCOVE/BAFFLED ENTRY SYSTEMS FOR WHICH NO DOOR IS REQUIRED

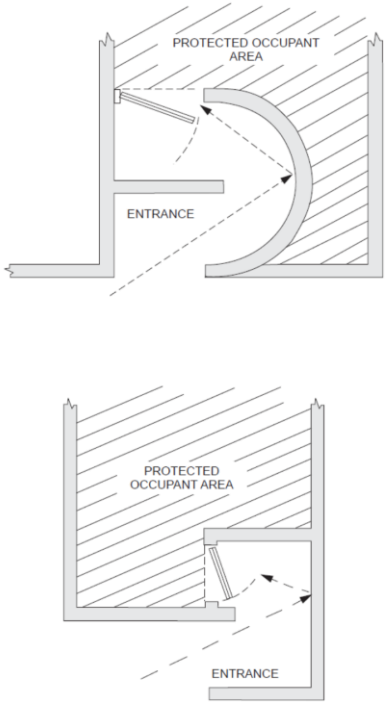


FIGURE 804.9.7.2
DOORS SUBJECT TO REBOUND IMPACT

Fire Safety – ICC 500

Fire Separation

- Fire barriers and horizontal assemblies separating shelters must have minimum fire-resistance rating of 2 hours.

Fire Extinguishers

- Required within shelter
- Meet NFPA 10

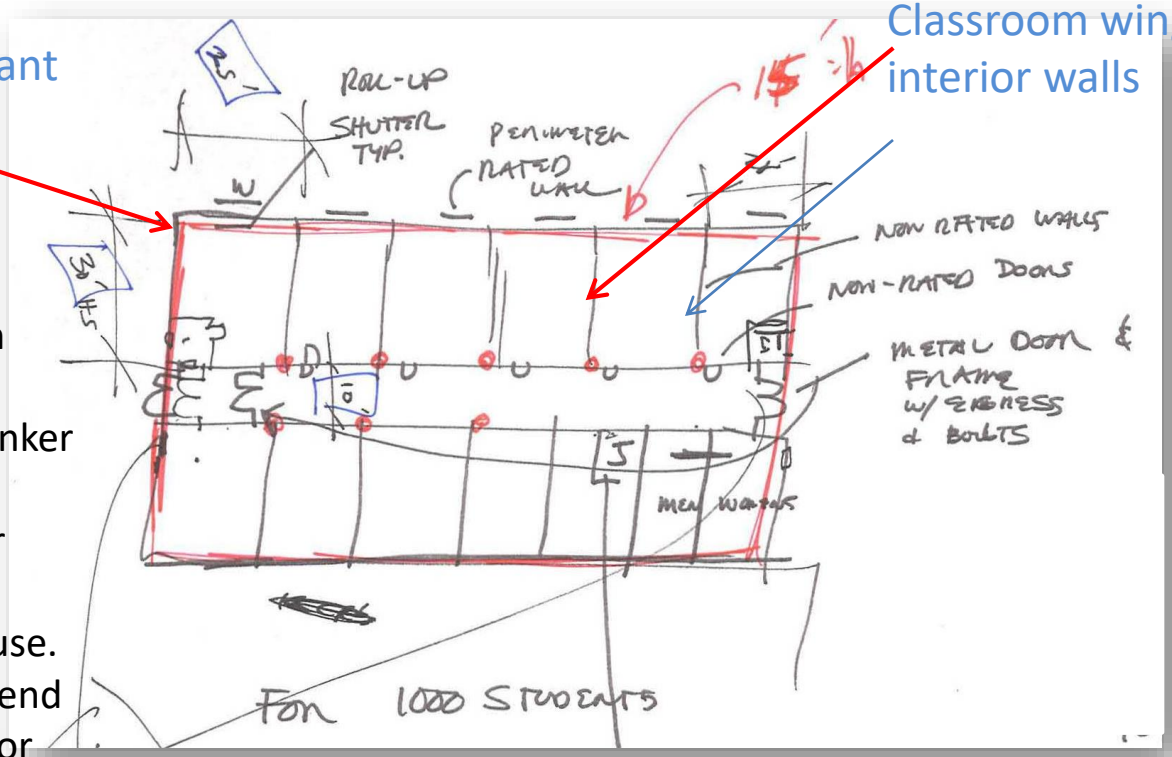
SHELTER DESIGN EXAMPLE - MASONRY WALLS

ICC 500 Shelter Concept

Classroom wing as Shelter

Classroom wing – shelter impact resistant walls (in red)

Classroom wing – typical interior walls (in grey)



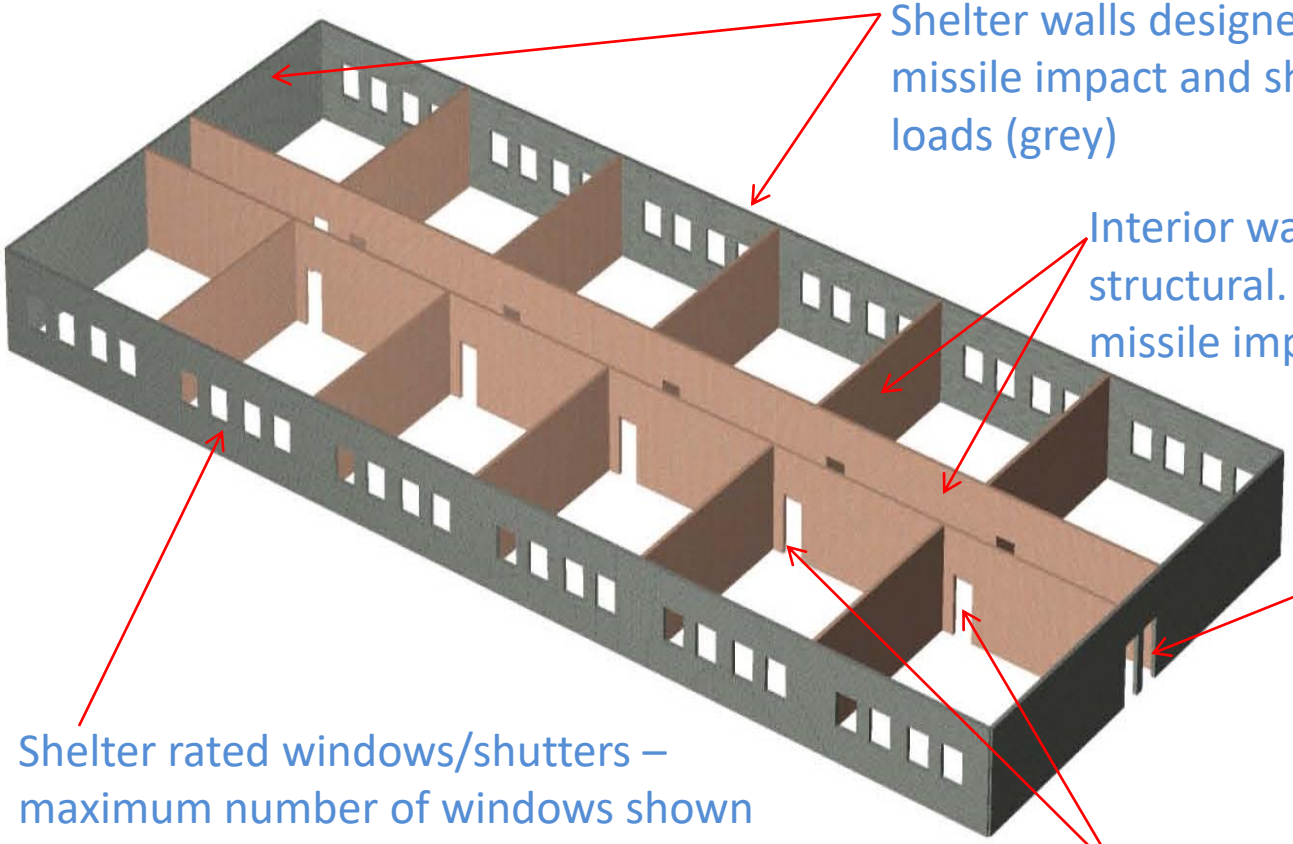
Benefits

- Student comfort from familiar classroom appearance (not a bunker for example).
- Sheltering in place for many.
- Cost effective, multi-use.
- Storm rated doors at end of each corridor not for each classroom.
- Restrooms incorporated.
- More

School wing or first story of multi-story school

ICC 500 Shelter Concept

Classroom wing as Shelter



Shelter walls designed for both missile impact and shelter wind loads (grey)

Interior walls – partitions or structural. No requirement for missile impact resistance (beige)

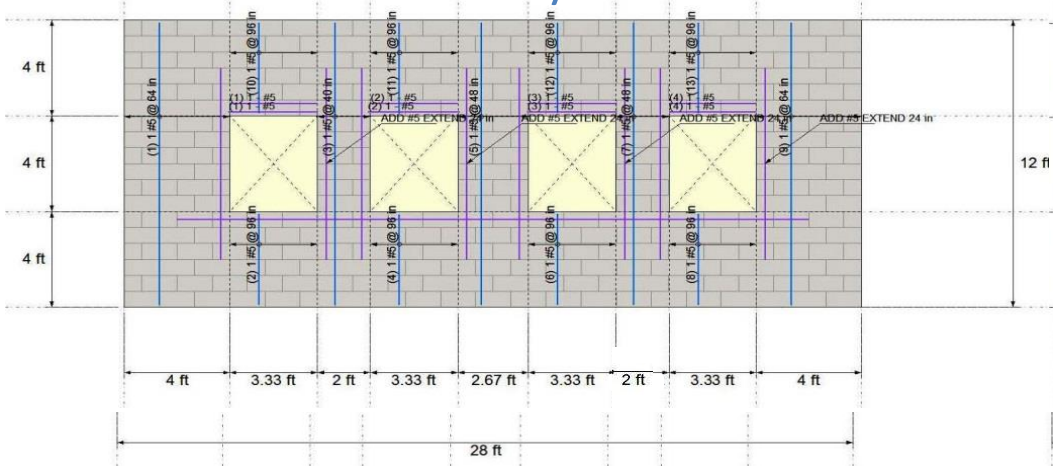
Shelter rated doors (recessed at end of corridor – alcove not shown but required)

Typical doors (all classrooms)

Shelter rated windows/shutters – maximum number of windows shown but <u>probably won't want to include that many</u> as they need to be shuttered or debris-rated (see next slide)

Comparison - Exterior Wall in Ohio

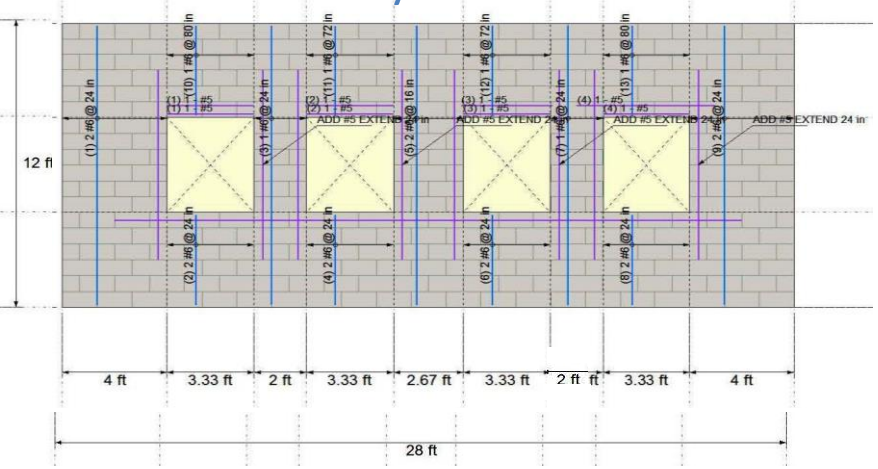
Non-shelter masonry wall



8” CMU Partially Grouted – Optional Veneer
#5 bar ea. jamb /#5 @ 64”c/c
Joist roof option
Foundation lap = 6” min.
L-bar at top bond beam recommended
Joint reinforcing 16” x 24”

Window layout –
Shown with minimum spacing between windows that worked structurally. Note that shutters must also be considered when laying out window openings.

Shelter masonry wall



8” CMU Partially Grouted with Veneer[1]

OR

8” CMU Solidly Grouted – Optional Veneer[2]
#6 bar ea. jamb / #6 @ 24” c/c
‘Heavy’ roof/second floor or uplift
Foundation lap = fully developed (~40”)
L-bar or fully developed bar detail at top bond beam required
[1]3/16” joint reinforcing 16” c/c vert. & hor.

OR

[2] Typical 9 ga. joint reinforcing 16” x 24”

Example for illustration only, not for construction

Windows – A Short Discussion

Shelter masonry wall

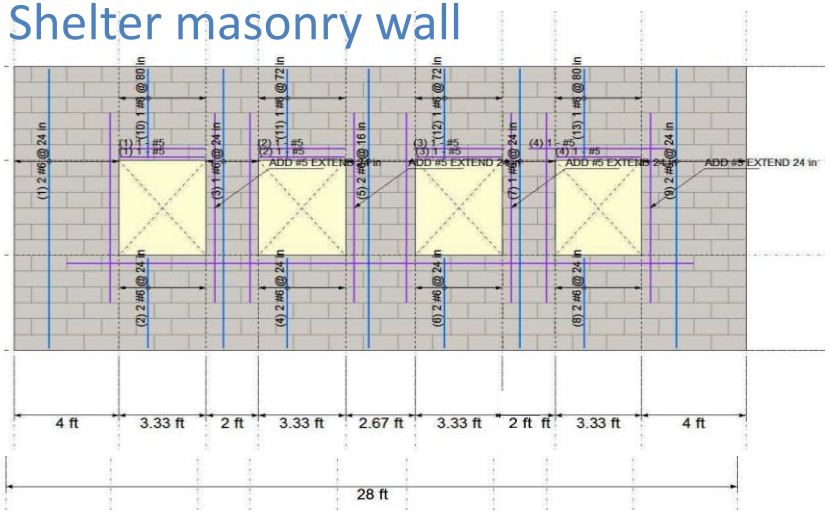


Figure A4-5. Interior operated safe room shutters in multi-purpose classroom/safe room. Image on left is normal usage; image on right shows shutters in 'lock down' position where they are closed and latched

* FEMA P-361

Window layout

- The spacing between window openings shown on the computer model, shown on the left, is the closest that would work structurally for this project.
- Often this many windows may not be included in the project, but there may be cases when this is desired as in the photo of a school shelter shown on the right.
- Note that the dimensions of the shelter-rated shutters, if used, must also be considered when laying out window openings.

Example for illustration only, not for construction

ICC 500 Shelter Concept

Gymnasium as Shelter

Architectural:

- > 5 sf per person of usable floor area
- 2 hour fire wall separation at the perimeter
- Doors/Windows designed for debris impact at designated wind speed
- Sanitation facilities within shelter

Structural:

- Shelter enclosure passes tornado missile test
- 250 mph design wind speed
- Roof live load – 100 psf minimum

Discussion:

- More open space/fewer deductions for furniture, etc.
- Usually fairly simple to accomplish.
- Typically fewer windows than classrooms. Door locations should be carefully considered.
- Locker rooms can provide this – their enclosure must be designed as part of the shelter.
- No more difficult than classroom enclosure.
- More difficult structurally to handle the taller walls and potentially more expensive.
- More difficult structurally to handle the longer spans and potentially more expensive.

ICC 500 Shelter Concept

Gymnasium as Shelter

- Familiar location for school occupants but not sheltering in place for most.
- Sanitation requirements met through locker room spaces but must be accessible within the shelter enclosure.
- Few windows to shutter/protect and permits more options for glazing in non-shelter areas.
- Few doors but double doors may be difficult.
- Concern over tall wall /long roof span collapse – key to anchor to foundation and roof.
- Roof live loads are high and spans may be long – precast double tees can provide missile impact resistance and could be a structural option. May limit architectural roof profiles or they become secondary and potentially sacrificial.
- Walls are very tall – again structurally more difficult to engineer and anchor. Consider:

  Thicker walls

  Horizontally spanning walls

  Muti-wythe walls using both wythes structurally

  Intermediate support inside shelter enclosure - room walls, running tracks, pilasters…

  Intermediate support exterior – must be shelter-rated.

Comment – Potentially less foot print to shelter, but bigger structural hit

PARTIALLY GROUTED MASONRY CAVITY WALL EXAMPLE

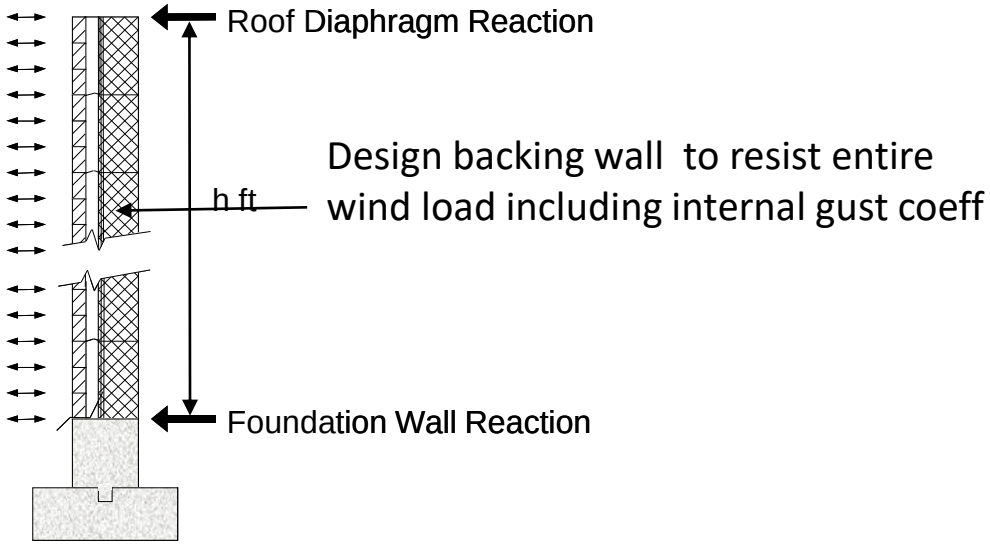
Partially Grouted Cavity Wall Example

With partially grouted cavity wall option, both the structural wythe and the veneer must be engineered to withstand the 250 mph design wind speed required by the ICC 500-2014 criteria.

BACK-UP WYTHE ONLY RESISTS THE MISSILE IMPACT (Solid grouted back-up) – Prescriptive veneer requirements of TMS 402 can be used.

VENEER RESISTS MISSILE IMPACT AS WELL AS BACK-UP WYTHE (Partially grouted back-up)- Prescriptive veneer requirements of TMS 402 cannot be used as the velocity pressures exceed limits of TMS 402.

- Engineer the veneer for C&C wind loads
- Suction typically governs
- Veneer will likely crack near mid-height at design loads – Allowed by code



Example for illustration only, not for construction

Partially Grouted Cavity Wall Example

For example – Cavity wall 8" CMU 4 " Clay brick veneer – 250 MPH (assume a 15' building mean roof height and use Components and Cladding loading with an effective wind area of 100 SF - Chapter 30 of ASCE 7-10):

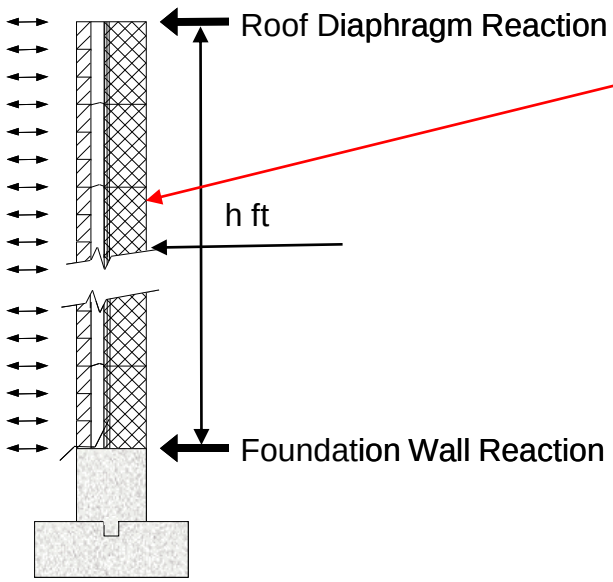
$q = 0.00256*0.85*1.0*1.0*250^2 = 136.0$ psf.

$p_{corner\ zone} = 136.0*0.82-136.0*(-0.18) = 136.0$ psf or

$p_{corner\ zone} = 136.0*(-1.05)-136.0*0.18 = -167.3$ psf

$p_{general\ field} = 136.0*0.82-136.0*(-0.18) = 136.0$ psf or

$p_{general\ field} = 136.0*(0.92)-136.0*0.18 = -149.6$ psf

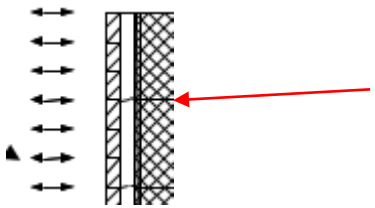


Design backing wall to resist entire wind load including internal gust coeff.

Note the above components and cladding wind loads were determined based on an effective wind area of 100 ft^2 and are for illustration only. This area will vary. The wind code would suggests the loads should be determined using a wind area no lower than the $span^2/3$. The effective wind area is used to determine the components and cladding pressure coefficients and thus the wall pressures. These pressures are then applied over the actual tributary area.

Example for illustration only, not for construction

Partially Grouted Cavity Wall Example



Design veneer to span between ties – Conservatively simple spans

It can be argued that the internal building pressures are not applied to the veneer wythe and the pressures on the veneer could be reduced by (1-.18) = 0.82.
In addition, the wind load provisions would require that the connectors (ties) be designed for the actual tributary area. Since loads are the same for areas below 10 ft^2, this can conservatively be used for effective wind area. Loads in the wall field are then 149.6 psf and 190.4 psf in the corner.

Vertical Span:
In the general field.

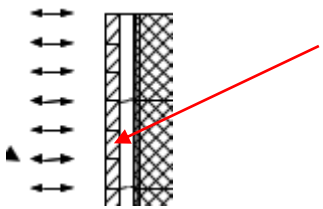
$$\phi f_{tv} = 0.60 \times 80.0 \text{ psi} = \frac{M_u}{S} = \frac{\dfrac{1.0 \times 149.6 \text{ psf} \times (L_v)^2}{8} \times 12 \text{ in.}/\text{ft}}{\dfrac{12 \text{ in.}(3.63 \text{ in.})^2}{6}} \Rightarrow L_v = 2.37 \text{ ft} = 28.5 \text{ in.}$$

At the corners

$$\phi f_{tv} = 0.60 \times 80.0 \text{ psi} = \frac{M_u}{S} = \frac{\dfrac{1.0 \times 190.4 \text{ psf} \times (L_v)^2}{8} \times 12 \text{ in.}/\text{ft}}{\dfrac{12 \text{ in.}(3.63 \text{ in.})^2}{6}} \Rightarrow L_v = 2.10 \text{ ft} = 25.2 \text{ in.}$$

Example for illustration only, not for construction

Partially Grouted Cavity Wall Example



Design veneer to span between ties – Conservatively simple spans

Horizontal Span:

In the General Field:

$$\phi f_{th} = 0.60 \times 160\,\text{psi} = \frac{M_u}{S} = \frac{\dfrac{1.0 \times 149.6\,\text{psf} \times (L_h)^2}{8} \times 12\,\text{in.}/\text{ft}}{\dfrac{12\,\text{in.}(3.63\text{in.})^2}{6}} \Rightarrow L_h = 3.36\,\text{ft} = 40.3\text{in.}$$

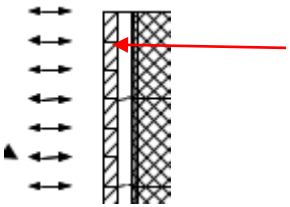
At Corners:

$$\phi f_{th} = 0.60 \times 160\ \text{psi} = \frac{M_u}{S} = \frac{\dfrac{1.0 \times 190.4\,\text{psf} \times (L_h)^2}{8} \times 12\,\text{in.}/\text{ft}}{\dfrac{12\,\text{in.}(3.63\ \text{in.})^2}{6}} \Rightarrow L_h = 2.98\ \text{ft} = 35.7\ \text{in.}$$

These distances are the maximum spans for the veneer under the design wind loads, and represent the maximum spacing between tie systems. (Ignore self-weight.)

Example for illustration only, not for construction

Partially Grouted Cavity Wall Example



Upper section of veneer designed as cantilever

Vertical Span:

In the General Field:

$$\phi f_{tv} = \frac{\dfrac{149.6\,\text{psf} \times \left(L_{v\ revised}\right)^2}{2} \times 12\ \text{in.}/\text{ft}}{\dfrac{12\ \text{in.}(3.63\ \text{in.})^2}{6}} = 0.60 \times 80\ \text{psi} \Rightarrow L_{v\ revised} = 1.19\ \text{ft} = 14.2\ \text{in.}$$

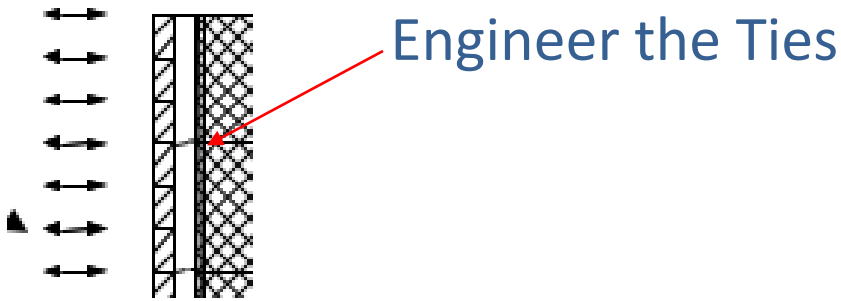
At Corners:

$$\phi f_{tv} = \frac{\dfrac{190.4\,\text{psf} \times \left(L_{v\ revised}\right)^2}{2} \times 12\ \text{in.}/\text{ft}}{\dfrac{12\ \text{in.}(3.63\ \text{in.})^2}{6}} = 0.60 \times 80\ \text{psi} \Rightarrow L_{v\ revised} = 1.05\ \text{ft} = 12.6\ \text{in.}$$

Crack isolation is not likely in the horizontal direction.

Example for illustration only, not for construction

Partially Grouted Cavity Wall Example



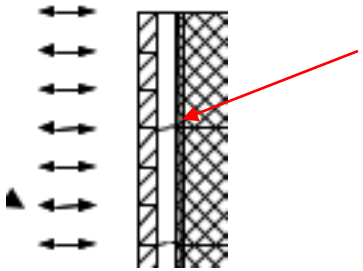
- If ties are reasonably ductile you get load re-distribution and thus can distribute loads w.r.t. tributary area.

- Backing wall MUST be stiff as well. CMU back-up is relatively stiff compared to the veneer.

- Flexible backing, such as studs, is problematic. Masonry veneer over stud back-up does not pass the missile tests and cannot be used as shelter walls. The tributary width distribution may not be used for this application

Example for illustration only, not for construction

Partially Grouted Cavity Wall Example



Engineer the Ties

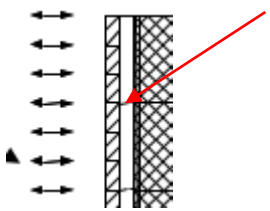
- Little code guidance for ties design. TMS 402 allows anchor test data to establish nominal strengths in Section 9.1.6.2.

- Try Canadian CSA A 370 (Connectors for Masonry).

- Those provisions require that the nominal capacities of the ties (determined based on tests or analysis), when reduced by a capacity-reduction factor of 0.9 for material failures and 0.6 for anchorage or buckling failures, equal or exceed the factored design loads. The tie minimum capacity in each direction (tension or compression) is considered to govern.

Example for illustration only, not for construction

Partially Grouted Cavity Wall Example



Engineer the Ties

If ties are reasonably ductile you get a uniform load distribution and thus can distribute loads w.r.t. trib. area.

Using a typical tie allowable load = 200 lb.

Maximum tie tributary area in the general field of the wall:

$$= \frac{200\,\text{lb}}{149.6 \text{ x } 0.6\,\text{lb}/\text{ft}^2} = 2.22\ \text{ft}^2$$

Maximum tie tributary area at the corners of the wall:

$$= \frac{200\,\text{lb}}{190.4 \text{ x } 0.6\,\text{lb}/\text{ft}^2} = 1.75\ \text{ft}^2$$

Example for illustration only, not for construction

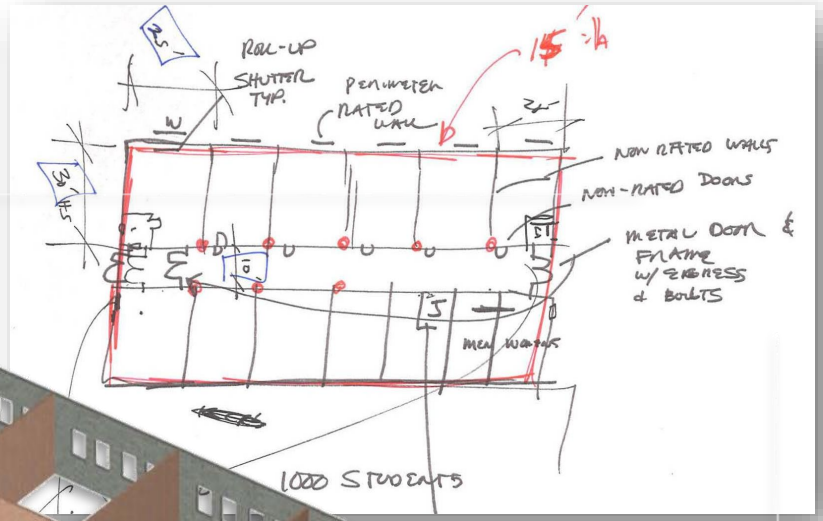
SUMMARY – HIGH WIND SHELTERING WITH MASONRY

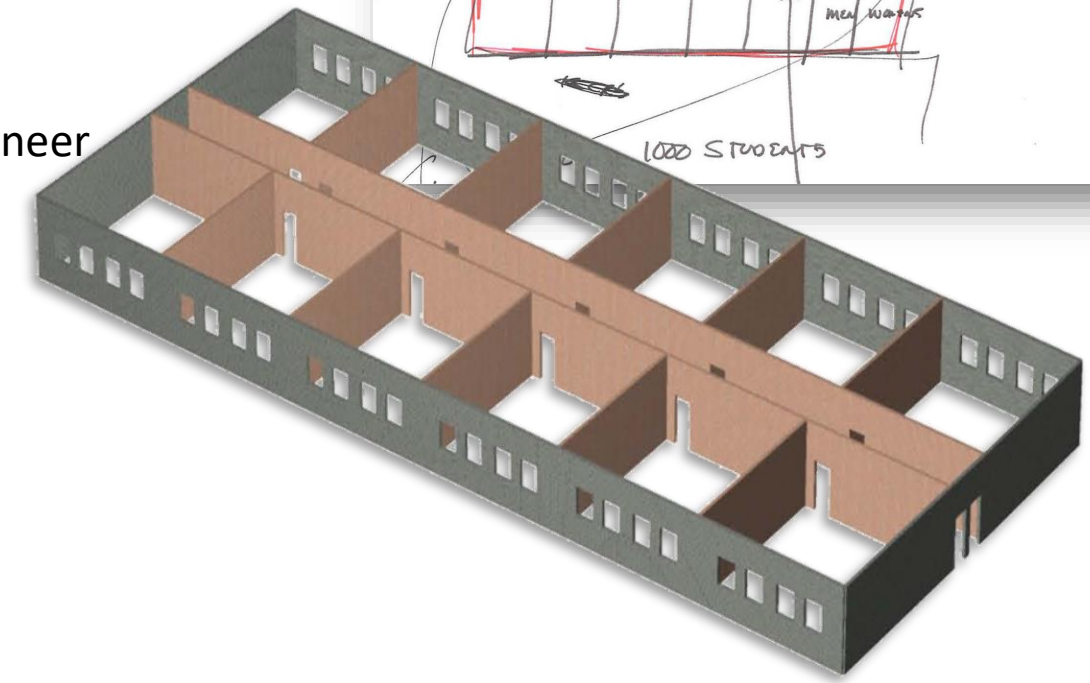
Sheltering with Masonry - Cost Impact

Classroom wing as Shelter

Masonry Changes:

- Anchorage to roof
- Foundation dowels to full laps
- Vertical rebar size or spacing
- Possible
  - Joint reinforcement size and/or spacing decrease
  - Grouting
  - Engineering the veneer





Summary

- With masonry, design options exist – both in solid grouted or partially grouted walls.
- Masonry shelter walls are cost effective – our typical designs are 'almost there'.
- The construction detailing required for high wind sheltering with masonry isn't new -- some/all has been done and much won't change.
- What is new is that high wind sheltering will be mandated by code:
  - FEMA P361 has been available for storm shelters,
  - ICC 500 tornado shelters will be mandated for most schools and more in the 2015 IBC.

J.B. SPEED SCHOOL
OF ENGINEERING

THANK YOU !

QUESTIONS?

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