Multi-Hazard Design of Blast-Resistant Façades

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Learning Objectives

1. Become familiar with blast effects on façade components
2. Understand and apply government and industry multi-hazard criteria
3. Become familiar with the coordination process between blast design and other requirements
4. Recognize common conflicts and how to solve them with efficient detailing and project coordination
Blast-Resistant Design of Facades

Blast Load Basics

- **Common sources:**
  - High explosives (bomb, warhead…)
  - Vapor cloud explosions (from gas or chemical leak)

- **Definition:**
  - Energy that dissipates violently through shockwaves, projectiles, and thermal radiation
Blast Load Basics

- Shock waves are NOT like wind
  - Can not be redirected
  - Wind moves air particles, while shock propagates through air particles
  - Rare design event
    - Design goal is protection of people or critical systems
    - Dissipate energy through significant movement
    - Components may need to be replaced

Why design for blast loads?
Blast Effects

• Most injuries and occasionally a few fatalities that occur during a bombing event are associated with façade debris

• Façade hazards from high-velocity, flying debris:
  – Lacerations from glass shards
  – Blunt trauma from wall debris or entire window systems

Wall Hazards
Wall Hazard Mitigation

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Window Hazards

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Window Hazard Mitigation

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Door Hazards

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Door Hazard Mitigation

Severe Damage

Moderate Damage

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Multi-Hazard Façade
Design Loads

<table>
<thead>
<tr>
<th>Load Type</th>
<th>Load Duration</th>
<th>Design Codes &amp; Standards*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dead</td>
<td>always</td>
<td>IBC &amp; ASCE7</td>
</tr>
<tr>
<td>Wind</td>
<td>seconds</td>
<td>IBC &amp; ASCE7</td>
</tr>
<tr>
<td>Hurricane</td>
<td>seconds</td>
<td>ASCE7, ASTM E1886 &amp; E1996</td>
</tr>
<tr>
<td>Tornado</td>
<td>seconds</td>
<td>FEMA P361 &amp; ICC-500</td>
</tr>
<tr>
<td>Earthquake</td>
<td>minutes</td>
<td>ASCE7, ASCE 41, AISC Design Guide 22</td>
</tr>
<tr>
<td>Blast</td>
<td>milliseconds</td>
<td>Government (DoD UFC, VA, GSA/ISC, DoS) and Industry</td>
</tr>
</tbody>
</table>

*not an exhaustive list
Tornadoes and Hurricanes

• **Goal:** prevent loss of life and limit building damage due to high wind and impact loads

• **Available Criteria:**
  - Safe rooms for tornado and hurricane hazards
    • ICC-500 (2014) – storm shelter design for tornadoes
    • FEMA P361 (2015) – higher resistance than ICC-500, but based on that approach
  - Hurricane debris impact protection (costal areas)
    • ASCE 7-10 – for wind load design
    • ASTM E1996 (2014) and E1886 (2013) – for impact test methods and requirements

Design Methods:

- **Wind:** static analysis or testing
- **Debris Impact:** testing (and/or finite element modeling)

Tornado Debris Impact (200 lbs at 300 mph)
Earthquakes (Seismic Hazards)

- **Goal:**
  - Falling architectural façade components could present a hazard to building occupants
  - Components must be capable of resisting the forces (heavy facades increase seismic forces) and deformations associated with seismic loads

- **Available Criteria:**
  - ASCE 7-10 (Chap. 13) – design requirements for non-structural components
  - Generally architectural components in Seismic Category B are exempt for seismic provisions (unless specific of project)
  - ASCE 41 and AISC Design Guide 22 “Façade Attachment” also provide guidance

Earthquakes (Seismic Hazards)

- **Design Methods:**
  - Analysis
  - Testing
    - ICC-ES AC156
  - Experience data

Figure 1: Concrete panels falling from the J.C. Penney store, 1964 Alaska earthquake.
Figure 19: Glass damage in Mexico City earthquake, 1985. Note the extreme distortion of the first floor, but only a few glass panels were severely damaged. Even with the massive shaking, glass in the upper floors is undamaged.
Blast-Resistant Design Criteria

- **Government (Anti-Terrorism & Force Protection)**
  - Department of Defense (DoD UFC)
  - Veteran Affairs (VA)
  - General Services Administration (GSA ISC)
  - Department of State (DoS)
- **Industry**
  - Petrochemical (ASCE book)
  - Airports (FAA/TSA)
  - Energy and Industrial (Power)
  - Data Centers

**ATFP Design**

- **Goal**: prevent loss of life by allowing significant damage to the structure
- **Available Criteria**: well developed *design loads* and *response limits* for each government agency
ATFP Design

• **Design Methods:**
  – Dynamic analysis
    • Single-degree-of-freedom (SDOF) analysis
    • Finite element analysis (FEA)
  – Dynamic testing
    • Replicate field application
    • Any deviations from test must be analyzed
  – Design connections using static analysis

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ATFP Design

• **Available Criteria:**
  – Unified Facilities Criteria (UFC) 4-010-01 DoD Minimum Antiterrorism Standards for Buildings (October 2013)
  – Department of State (DoS) Overseas Building Operations-International Code Supplement (OBO-ICS)
### ATFP Design – DoD/UFC

**Design Highlights:**
- Blast engineer is **required**
- **Occupancy level important**
- **Site plan is important** – design blast load based on applicable explosive weights (CWI or CWII) at the actual standoff distances
  - Check for a controlled perimeter (CWI apply)
  - Nearest roadways and parking (CWII apply)
- Design wall, window, door, and roof components to meet applicable LOP for applicable blast loads
  - Check conventional construction standoff distance and parameters for wall and roof designs
  - **Must** design windows and doors

### ATFP Design – VA PSDM

**Design Highlights:**
- Physical security specialist **required**
- Based on **Life Safety or Mission Critical** designation
- **Set minimum design load** of
  - GP1 with minimum 25-ft standoff (LS)
  - GP2 with minimum 50-ft standoff (MC)
  - **Independent site layout**
- Design wall, window, door, and roof components for specified response criteria
**ATFP Design – GSA/ISC**

- **Design Highlights:**
  - Blast engineer **required** for 100,000 GSF projects (new or renovations) or larger
  - Based on **Facility Security Level** (FSL)
  - Blast load based on Design Basis Threat at closest point to protected set back
    - **Site layout important**
  - 90% of façade must meet performance requirements
    - 10% can fail for given load scenario

- **Goal:** Prevent loss of life and allow for continued operations (shelter-in-place), thus less damage allowed

- **Available Criteria:** response limits minimally developed for a narrow class of facades/structures, however loads must be determined from site studies
  - Shelter-in-place requires doors, louvers, penetrations special design and equipment
Energy and Industrial Hazards

- **Goal:** prevent loss of life and allow for continued operations (shelter-in-place), thus less damage allowed

- **Available Criteria:**
  - Specialized loads case by case – vessel burst, reactive vessel burst, vapor cloud explosion, pool fire
  - Can utilize response limits from petrochemical design resources

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Airports

- **Goal:**
  - Life safety and collapse prevention – landside
  - Shelter in place - airside

- **Available Criteria:**
  - FAA/TSA
  - Process incorporates site specific vulnerability assessment and local acceptance of risk
Data Centers

- **Goal**: allow for continued operations (shelter-in-place), thus minimal damage allowed
- **Available Criteria**:
  - Loads case by case – often located in industrial (Class “B/C”) areas; envelope design includes forced entry, impact, blast (roadway incidents) and ballistic protection
  - Can utilize response limits from petrochemical or ATFP design resources
  - Critical that power and cooling stay operational; often requires secondary protection of power and HVAC feeds
  - Typically little or no glazing

## Multi-Hazard Façade Design Loads Comparison

<table>
<thead>
<tr>
<th></th>
<th>Traditional Loads</th>
<th>Blast Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Design Load Type</strong></td>
<td>Static Pressure</td>
<td>Dynamic Pressure-Impulse</td>
</tr>
<tr>
<td><strong>Load Combinations</strong></td>
<td>IBC/ASCE7</td>
<td>Independent Load Case</td>
</tr>
<tr>
<td><strong>Design Methods</strong></td>
<td>Static (LRFD, ASD)</td>
<td>Dynamic (Ultimate)</td>
</tr>
<tr>
<td><strong>Allowable Response</strong></td>
<td>Elastic</td>
<td>Inelastic / Plastic</td>
</tr>
<tr>
<td><strong>Material Strengths</strong></td>
<td>Lower Bound*</td>
<td>Expected (SIF and DIF)</td>
</tr>
</tbody>
</table>
Multi-Hazard Façade
Common Design Approach

- Blast Design
  - Size Members
    - Check ductility, \( \mu \)
    - Check rotation, \( B \)
  - Design Connections
    - Dynamic plastic member capacity
  - Revise Blast Design

- Wind & Gravity Design
  - Size Members
    - Check strength
    - Check serviceability
  - Check Connections
    - Verify details meet wind and gravity requirements

- Seismic Design
  - Size Members
    - Check strength
    - Detailing requirements
  - Check Connections
    - Verify details meet drift and strength requirements

Grouping by task rather than by discipline
Multi-Hazard Façade
Potential Design Conflicts

1. Façade mass
2. Member strength and stiffness
3. Impact resistance requirements
4. “Non-structural” components
5. Accommodating movement
6. Incomplete Specifications

Façade Mass

Seismic  Blast

Low  High

Design loads are proportional to weight

\[ F_p = 0.4 S_{DS} I_e W_p \]

Inertial resistance is proportional to weight

\[ R = M a \]
Façade Mass

**Structural Engineer (Seismic)**

**Light façade mass**

Provide EIFS on CFSS

Reaction at diaphragm…

\[ F_p = 0.4S_{DS}l_e W_p \]
\[ F_p = 0.4(0.6)(1.25)(50\text{ plf}) \]
\[ F_p = 15\text{ plf} \]

**Heavy façade mass**

Provide 4-in. brick on CFSS

Reaction at diaphragm…

\[ F_p = 0.4S_{DS}l_e W_p \]
\[ F_p = 0.4(0.6)(1.25)(400\text{ plf}) \]
\[ F_p = 120\text{ plf} \]

800% INCREASE
**Façade Mass**

**Blast Engineer**

**Case A:**
Gr. 50 Steel Studs with EIFS
Supported Weight ~10psf
Required studs for CWII at 50-ft and LLOP
600S200-97 at 16 in O.C
Connection forces: 16kip!!

**Case B:**
Gr. 50 Steel Studs with 4-in Brick
Supported Weight ~40psf
Required studs for CWII at 50-ft and LLOP
600S200-54 at 16 in O.C
Connection forces: 3kip

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**Member Strength & Stiffness**

- **Blast**
  - Low
  - Plastic design and resistance through ductility
  - Ductile LFRS – High EQ

- **Seismic**
  - Depends
  - Elastic design and serviceability requirements
  - Non-Ductile LFRS – Low EQ

- **Wind**
  - High

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Member Strength & Stiffness

Particularly for long-span slender members…
- Wind serviceability requirements govern stiffness
- Unnecessarily strong sections result
- Blast reactions quickly become excessive due to “capacity design”

Impact Resistance

Particularly in coastal regions, wind-borne debris impact resistance is required…
- Heavy laminated or polycarbonate systems are required for missile impact
- Blast reaction forces necessitate heavy connections and/or additional support framing
Impact Resistance

- 72”x48” with 0.03pvb
- 72”x48” with 0.09pvb

Supporting Frame

Coupled Glazing Analysis

- Can help reduce reactions…
“Non-Structural” Components

Components detailed by the Architect that are required to resist significant lateral loads for blast.

• Architectural knee walls
• Non-loadbearing stud walls
• Etc.

“Non-Structural” Components

Cantilever Knee Walls
“Non-Structural” Components

Non-Load-Bearing Stud Walls

Accommodating Movement

- Façade elements must accommodate the relative displacements of the structure
- May be required to prevent load transfer (ex: “wind only” connections)
- Potential sources of movement:
  - Seismic lateral drift
  - Wind deformations
  - Live load deflections
  - Thermal movements
  - Etc.
Accommodating Movement

Examples of connection with vertical and horizontal slots to accommodate movement:

- **Vertical Slots to Prevent Gravity Load Transfer**
- **Horizontal Slots to Allow Lateral Sway Displacement**

Potential issues when allowing for movement in a connection:

- Decreased edge distances
- Increased or variable eccentricities
- Reduced sections at slots
- Larger connections
- Etc.
Incomplete Specifications

• Architectural components are typically addressed through delegated design
  – Window systems
  – Doors
  – Cold formed steel stud walls or roof trusses
  – Precast panels
• Requires adequate performance based or prescriptive specifications

Incomplete Specifications

• What to look for or include:
  – Applicable design loads
  – Allowed methods of analysis or testing
  – Acceptance criteria
  – Specialty requirements
    • hurricane impact, ballistic, forced entry…
  – Defined submittal requirements
    • Shop drawings + calculations and/or test reports
  – Experience requirements for subcontractors
Tips for Blast Design

• Recommend dynamic analysis for façade component design
  – Most economic solution for blast
  – Blast loads do not always control
• Design connections statically for flexural capacity of component
  – Blast reactions typically control
  – Properly accommodate movement
Complex Façade Design

• Finite element analysis for blast

Complex Façade Design

• Finite element analysis for wind-borne debris impact
Conclusions

• There are many government and industry criteria available for design of envelope components against blast loads
  – Generally less defined criteria results in more restrictive design requirements
• Coordinate early and understand all the applicable requirements of your project
  – Impact, seismic, blast, etc.

Conclusions

• Group work design by task not discipline
  – Accommodate serviceability requirements before designing for strength
  – Different load cases will control different aspects of the design
• Complex facades require advanced analysis tools or testing
  – Take advantage of dynamic analysis for blast
  – Account for coupled response in design
Questions?

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