Department of Homeland Security HPBD-E Project

Structural Committee

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Overview

- Address structural requirements for both conventional and protective design loading
- Develop appropriate range of Demands, Benchmarks, Metrics and Outcomes
- Consider various building structure and envelope system combinations, and their interaction with other Attributes

Structural Committee Attributes

- Security – Protective design related loading
  - Sub-attributes
    - Blast
    - Ballistic
- Safety – Natural hazard related loading
  - Sub-attributes
    - Seismic
    - Wind
    - Flood
    - Fire

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Performance Based Model Development

- Demands
- Benchmarks/Metrics
- Interactions
- Ranges

Blast Demands

- Demands
  - Size of blast
  - Standoff distance
  - Size of building/ extent of damage

Range	Charge Weight		
	425	2,500	15,000
100ft	99	350	1310
300ft	30	103	360
1000ft	-	29	99

Range	Charge Weight		
	Low	Medium	High
100ft	M	H	Out of Range
300ft	L	M	H
1000ft	Out of Range	L	M

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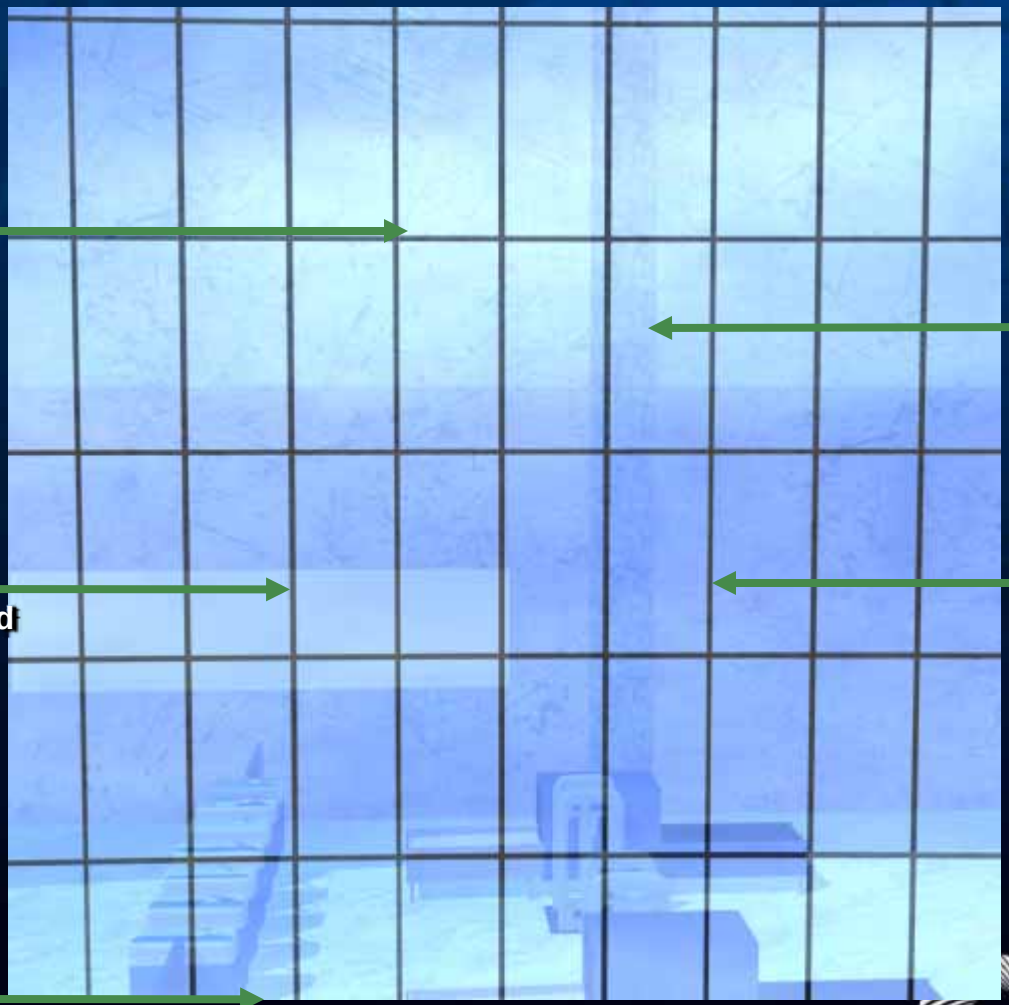
Blast Resistant Façade



Façade System: Engineered to Take Advantage of inherent Flexibility

Laminated Glazing to restrain debris and develop membrane resistance

Façade Frame: Designed to withstand maximum loads transferred by the glazing

Glazing Adhered to Mullion With Structural Silicone Sealant to Transfer Collected Loads to Frames

Anchorage: Designed to transfer loads to Structure

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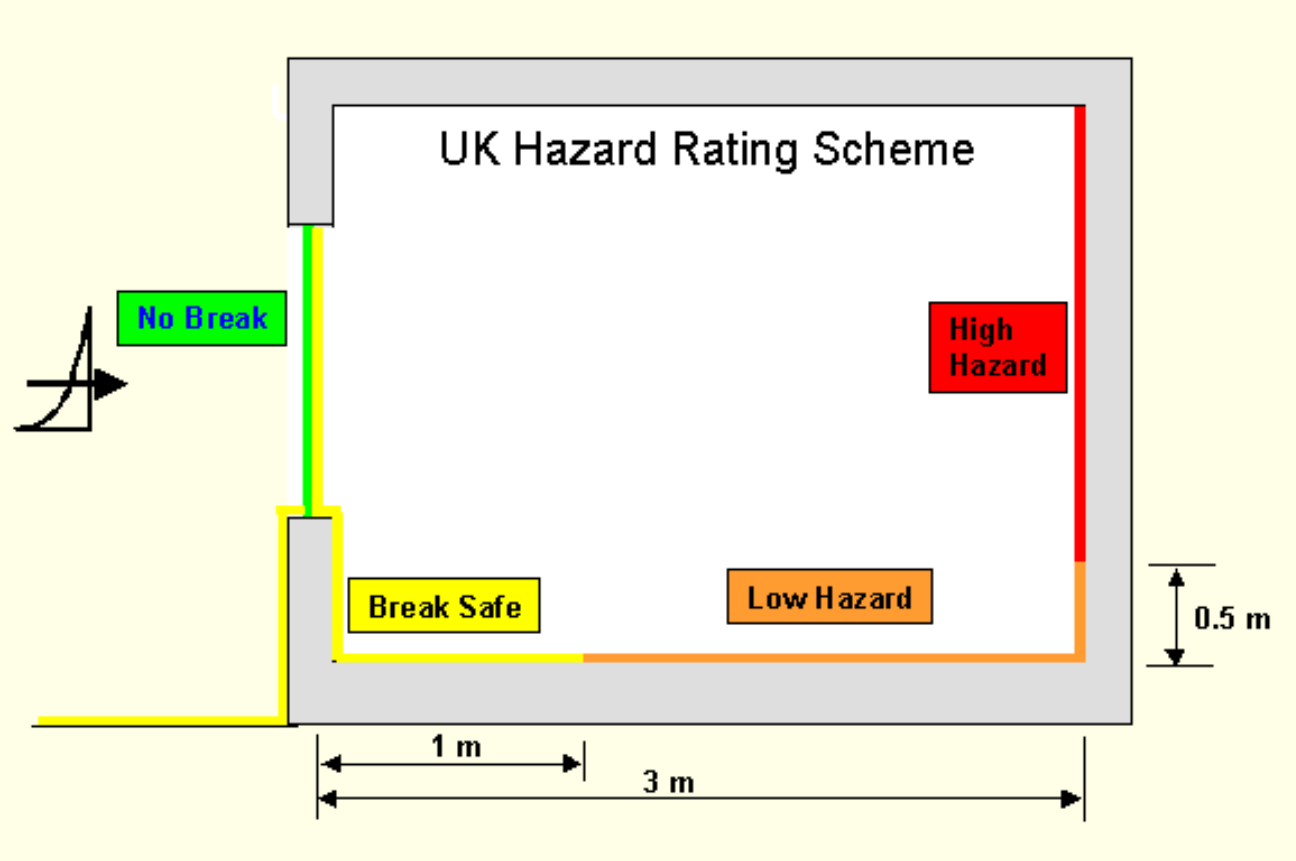
Blast Benchmarks

- Benchmarks: Level of damage that will occur during a blast event ranging from major damage to minor/superficial damage.
- Metrics
  - Qualitative – Level of Damage and Continuity of Operations
  - Quantitative – Glass Hazard Level and Component Ductilities and End Rotations

Glazing Hazard



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Blast Benchmarks

- ReB – No blast protection
  - Hazardous failure of envelope
  - Not economically repairable
  - Not operational
  - Glazing Hazard = High
  - End Rotations > 6°
- Re+ – Major Damage
  - Large deformations of envelope
  - Not economically repairable
  - Not operational
  - Glazing Hazard = Low
  - End Rotations < 4°

Blast Benchmarks

- Re++ – Medium Damage
  - Components deform beyond elastic limit
  - Some repair/replacement required
  - Portions of building operational
  - Glazing Hazard = Minimal
  - End Rotations < 2°
- Hre – Minor Damage
  - No permanent deformations
  - Minor repairs only
  - Operational
  - Glazing Hazard = None
  - Ductility < 1

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Ballistic Demands/Benchmarks

- Benchmarks: The benchmark for ballistic performance is that the glazing or other envelope component stops the threat bullet in accordance with the UL 752 standard
- Demands/Metrics
  - Qualitative – Weapon component is capable of resisting
  - Quantitative – # of shots, weight, caliber and velocity of round

Ballistic Benchmarks

- ReB – No ballistic protection
- Re+ – UL Level I
- Re++ – UL Level III
- Hre – UL Level VIII

- At each level component must be replaced, but building is mostly operational

Seismic Demands

- The Seismic Design Category (SDC) is the expression used in the demand model to measure an earthquake hazard in a particular region, and categorize the associated seismic risk to building envelope components.
- The building envelope should accommodate deformation and response of the structure, characterized by defined peak seismic interstory drift.

SDC A	A	Low
SDC B	B	Medium-Low
SDC C	C	Medium-High
SDC D	D	High
SDC E/F	E/F	Very High

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Seismic Benchmarks

- Benchmarks: Level of damage that will occur during a seismic event ranging from major damage to minor/superficial damage.
- Metrics
  - Qualitative – Extent of Damage and Continuity of Operations from a Design Basis Earthquake (10% Probability of Exceedance in 50 Years)
  - Quantitative – Glass Hazard and Envelope Deformation Corresponding to Seismic Building Interstory Drift and Acceleration Forces

Seismic Benchmarks

- ReB – Baseline (Non-Compliant)
  - Hazardous nonstructural and structural conditions may exist.
  - Disengagement of cladding from building structure.
  - Fracturing of glass and glass fallout may occur
  - May not be economically repairable
  - Not operational

- Re+ – Life Safety/Code Compliant
  - Major, systemic damage to cladding may occur, but cladding remains anchored to building structure.
  - Displacement and out-of-plane movements may occur. Seals and gaskets may tear/fallout and ability to provide weather protection is globally compromised.
  - Occupancy not expected until repairs are performed.

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Seismic Benchmarks

- Re++ – Reduced Damage
  - Moderate damage to cladding may occur but cladding remains anchored to building structure.
  - Seals and gaskets may tear and ability to provide weather protection is locally compromised.
  - Glass breakage is mitigated. Glass edge damage may occur and glazing may fall off of setting blocks.
  - The building remains safe to occupy; repairs are minor.

- HRe – Continued Operations
  - Negligible structural and nonstructural damage.
  - Minimal damage to cladding, seals remain intact, gaskets maybe loosened. No glass breakage is expected.
  - The building envelope system components remain operational with little or no repair or replacement.

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Wind Demands

Demand Levels:

Low: 30 to 50 PSF

Medium = 50 to 90 PSF

High = 90+ PSF + WBDR

Special Case: Tornado

	Exposure Category		
Basic Wind Speed	B	C	D
85-90 mph	Low	Low	Low
90-110 mph	Low	Med	Med
110-130 mph	High	High	High
130-150+ mph	High	High	High

- Demand levels for planning purposes are ranges characterized by maximum field of wall pressures and wind borne debris provisions. Future iterations will refine current wind speed and exposure demand inputs to include mean building height and component tributary area.

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Wind Benchmarks

- Benchmarks: Level of damage that will occur during a wind event ranging from major damage to minor/superficial damage.
- Metrics
  - Qualitative – Level of Damage and Continuity of Operations
  - Quantitative – Glass Hazard and Envelope Deflection

Wind Benchmarks

- ReB – Baseline (Non-Compliant)
  - Hazardous nonstructural damage is may exist.
  - Moderate glass breakage may occur.
  - Permanent deformation of cladding may exist.
  - Damage may impact operations.

- Re+ – Life Safety/Code Compliant
  - Hazardous nonstructural damage is controlled.
  - Moderate damage to building envelope cladding and components may occur. Glazing hazard is low.
  - Minor deformation and permanent set of framing members may occur at overloads.
  - There shall be no gross failure of building envelope anchorage.
  - No falling hazards should occur.
  - Minor impacts to serviceability.

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Wind Benchmarks

- Re++ – Reduced Damage
  - The building is safe to occupy. There shall be no failure or gross permanent distortion of the building envelope system anchorage and framing.
  - Minor cracking and deformation of cladding may occur, but is not expected.
  - Glazing hazard is minimal. No falling hazards allowed.
  - Negligible impacts to serviceability.

- HRe – Continued Operations
  - The building envelope system components remain in the same condition after the event as they were prior with little or no repair or replacement.
  - No glazing hazard.
  - No impacts to serviceability.

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Flood Demands

- A qualitative flood demand profile was considered to characterize building envelope flood hazard, including inputs for depth, duration and velocity.
- The flood demand was mapped in the following categories: NA, Low, Medium, High, and Extreme.

Flood Demand Profile

Floodplain *FEMA FIRM Map*	Yes
	No
Floodwater Maximum Previous Depth *FEMA FIS*	Never In Past
	Low
	Medium
	High
Duration of Previous Flooding	Never
	Short
	Medium
	Long
	Very Long
Velocity of Floodwater *ƒ(still flood depth, d_s)* *Low Bound: $V = d_s/t$* *Extreme: $V = 2(gd_s)^{(0.5)}$*	Never In Past
	Low
	Medium
	High
	Extreme

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Flood Benchmarks

- Benchmarks: Level of damage that will occur during a flooding event ranging from major damage to minor/superficial damage.
- Metric
  - Qualitative – Level of Building Envelope Damage and Continuity of Operations in Response to Floodwater Depth, Velocity, and Duration. Performance relating to flood hazard, vulnerability, consequence is measured qualitatively in the OPR tool.

Flood Benchmarks

- ReB – Baseline
  - No floodproofing is provided.
  - Severe damage and loss of operations is expected.
  - Threat to occupants may exist.

- Re+ – Life Safety
  - Building envelope damage requires major repair or reconstruction from exposure to floodwaters.
  - Threat to occupants is reduced. Water damage to the building envelope and the interior of the facility requires major cleanup, drying, repairs and replacement.
  - Damage may prevent full occupancy of the facility for several weeks to months.

Flood Benchmarks

- Re++ – Reduced Damage
  - Building envelope damage is moderate from exposure to flooding.
  - Cleanup, drying, and moderate building envelope repairs are required.
  - The facility can resume service in a short length of time.

- HRe – Continued Operations
  - The building sustains negligible damage; the envelope system is fully functional.
  - The building is immediately operational.
  - The site is not affected by erosion.
  - Minor damage from debris or staining may exist, but repairs are superficial.

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Fire Demands

Fire protection demands of comparable severity may result from three distinct hazard types:

- Natural or forest fires (i.e. woodland and urban interface situations)
- Exposure fires in neighboring buildings
- Exposure fire from neighboring storage hazards

Other Fixed Hazards
(e.g. Fuel Storage Tanks)

Set back, protection provided for hazard	Low
Set back, no protection	Medium
2 sides, no protection	High

Adjacent Structures

Set back and fire resistance rating of wall, protected openings per code or neighboring building has sprinkler protection	Low
Inadequate set back or fire resistance ratings on 1 side	Medium
Inadequate set back or fire resistance rating on 2 or more sides	High

Natural /Forest Fire (WUI)

> 100’ separation to forest	Low
30’-99’ separation to forest, BI < 61	Medium
< 30’ separation to forest, BI > 61	High

(BI = Burning Index from US Forest Service)

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Fire Benchmarks

- Benchmarks: Level of damage that will occur during a fire hazard event ranging from major damage to minor/superficial damage.
- Fire protection considers structural damage to the exterior envelope and spread of fire to the interior as a result of unprotected or compromised openings.
- Metric
  - Qualitative – Level of Damage and Continuity of Operations

Fire Benchmarks

- ReB – Baseline
  - Major nonstructural damage exists.
  - Fire severely damaged exterior envelope and spread to the interior.

- Re+ – Life Safety
  - Hazardous nonstructural damage is controlled.
  - The exterior wall system anchorage may deform, but catastrophic failure cannot occur.
  - Moderate cracking, melting and charring to cladding may occur.
  - Repair possible, but may be economically impractical.
  - Ignition of significant fire inside.

Fire Benchmarks

- Re++ – Reduced Damage
  - The building remains safe to occupy; structural and nonstructural repairs are minor.
  - System with one hour fire resistance rating and unprotected openings.
  - Minor cracking, melting or charring of cladding may occur, but is not expected. No falling hazards allowed.
  - Ignition of minor item inside structure, no spread from initial item.

- HRe – Continued Operations
  - Negligible structural and nonstructural damage.
  - System with two hour fire resistance rating and protected openings.
  - The exterior wall system components remain in the same condition after the event as they were prior with little or no repair or replacement.

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Example Interactions (Glazed Facade)

- Blast
  - Beneficial: Wind, Ballistic, Acoustic
  - Detrimental: Thermal transfer
- Ballistic
  - Beneficial: Wind, Blast
  - Detrimental: Thermal Transfer
- Seismic
  - Beneficial: Acoustic, Wind
  - Detrimental: N/A

Example Interactions (Glazed Facade)

- Wind
  - Beneficial: Seismic, Acoustic, Blast
  - Detrimental: N/A
- Flood
  - Beneficial: Wind, Acoustic, Blast
  - Detrimental: N/A
- Fire
  - Beneficial: Wind, Acoustic, Thermal Transfer
  - Detrimental: N/A

Structural Committee Questions

Questions??

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Appendix/Reference

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Initial Studies

- Project began with a consideration of standards, component types and response limits that related to the structural design of a building envelope

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Overview

- The following is a list of selected structural and envelope systems that were considered:

Building Structure
Reinforced Cast-in-Place Concrete
Reinforced Precast Concrete
Metal Deck
Metal Deck, Concrete Fill
Concrete Slab
Roof Deck
Steel

Envelope Framing
Mullions (Aluminum, Steel)
Masonry (Reinforced, Unreinforced, Cavity Wall)
Cast-in-Place Concrete
Studs (Wood, Steel)
Precast
Cable
Glass

Envelope Cladding
Masonry (Brick, Natural Stone, Glass Block)
Glass (Captured, SSG, Point Supported Systems)
Metal Panel/Metal Deck
Composite Panel
Architectural Precast
Glass Fiber Reinforced Concrete (GFRC)
Sheathing with Finish (Stucco, EFIS)

Attributes – Blast/Security Loading

Attribute	Metric	Baseline Value	Benchmark Value	Future Value
Blast Resistance – Loading	Charge weight and standoff	Project Specific	Project Specific	Project Specific
Ballistic Resistance (Life Safety)	UL 752 Level	I	III	VIII
Forced Entry Resistant	ASTM F 476-84 ASTM F842-04	Grade 20	Grade 30	Grade 40

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Attributes – Blast Response

Attribute	Metric	Baseline Value	Benchmark Value	Future Value
Blast Resistant Glass	Debris Hazard (ASTM 1642)	Low Hazard (Level 3B/4) Glass Cracks, debris propelled into occupied space	Minimal Hazard (Level 2/3A) Glass Cracks, debris remains in frame or falls to floor	No Break (Level 1) Glass does not crack
Blast Resistant Metal Panel	Debris Hazard (based on ASTM 1642)	Low Hazard (Level 3B/4) Panel disengages, debris propelled into occupied space	Minimal Hazard (Level 2/3A) Panel damaged, debris remains in frame or falls to floor	No Damage Panel not damaged
Blast Resistant Masonry Veneer	Debris Hazard (based on ASTM 1642)	Low Hazard (Level 3B/4) Masonry disengages, debris propelled into occupied space	Minimal Hazard (Level 2/3A) Masonry damaged, debris remains in wall or falls to floor	No Damage Masonry not damaged
Blast Resistant Stone Veneer	Debris Hazard (based on ASTM 1642)	Low Hazard (Level 3B/4) Stone disengages, debris propelled into occupied space	Minimal Hazard (Level 2/3A) Stone damaged, debris remains in wall or falls to floor	No Damage Stone not damaged

Attributes – Blast Response

Attribute	Metric	Baseline Value	Benchmark Value	Future Value
Blast Resistant Mullions – quick recovery	End Rotations (θ) or ductility (μ)	θ = 3º Mullions severely distorted	θ = 1º Mullions develop permanent deformations	μ = 1 Mullions remain elastic
Blast Resistant Mullions – life safety	End Rotations (θ)	θ = 3º Mullions severely distorted	θ = 6º Mullions more severely distorted	θ = 10º Mullions most severely distorted
Blast Resistant Precast – quick recovery	End Rotations (θ) or ductility (μ)	θ = 2º Precast severely distorted	θ = 1º Precast develop permanent deformations	μ = 1 Precast remain elastic
Blast Resistant Precast – life safety	End Rotations (θ)	θ = 2º Precast severely distorted	θ = 5º Precast more severely distorted & spall+ propelled	θ = 10º Precast most severely distorted & debris propelled
Blast Resistant Masonry – quick recovery	End Rotations (θ) or ductility (μ)	θ = 2º Masonry severely distorted	θ = 1º 1º Masonry develop permanent deformations	μ = 1 Masonry remain elastic
Blast Resistant Masonry – Life Safety	End Rotations (θ)	θ = 2º Masonry severely distorted	θ = 8º Masonry more severely distorted & spall propelled	θ = 15º Masonry most severely distorted & debris propelled

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Attributes – Blast Response

Attribute	Metric	Baseline Value	Benchmark Value	Future Value
Blast Resistant C.I.P. Concrete Wall – Quick Recovery	End Rotations (θ) or ductility (μ)	θ = 2º Concrete develops large cracks	θ = 1º Concrete develop permanent deformations	μ = 1 Concrete remain elastic
Blast Resistant C.I.P. Concrete Wall – Life Safety	End Rotations (θ)	θ = 2º Concrete develops large cracks	θ = 5º Concrete develops larger cracks & spall propelled	θ = 10º Concrete develops larger cracks & debris propelled
Blast Resistant Metal Studs – Quick Recovery	Ductility (μ)	μ = 1 Studs remain elastic but may buckle	μ = 0.8 Studs remain elastic buckling less likely	μ = 0.5 Studs remain elastic
Blast Resistant Metal Studs – Life Safety	Ductility (μ)	μ = 1 Studs remain elastic but may buckle	μ = 2 Studs more severely distorted	μ = 3 Studs most severely distorted
Blast Resistant Metal Deck Roof – Quick Recovery	Rotation (θ) & (Ductility (μ)	μ = 1.8 & θ = 1.3º Deck develops permanent deformations	μ = 1.5 & θ = 1.0º Deck develops permanent deformations	μ = 1 Deck remains elastic
Blast Resistant Metal Deck Roof – Life Safety	Rotation (θ) & (Ductility (μ)	μ = 1.8 & θ = 1.3º Deck develops permanent deformations	μ = 3 & θ = 2.0º Deck develops large permanent deformations	μ = 6 & θ = 4.0º Deck may pull off of building

Attributes – Blast Response

Attribute	Metric	Baseline Value	Benchmark Value	Future Value
Blast Resistant Metal Deck & Concrete fill Roof – Quick Recovery	End Rotations (θ) or ductility (μ)	θ = 2º Deck & fill develops permanent deformations	θ = 1º Deck & fill develops permanent deformations	μ = 1 Deck remains elastic & fill develops cracks
Blast Resistant Metal Deck & Concrete fill Roof – Life Safety	End Rotations (θ)	θ = 2º Deck & fill develops permanent deformations	θ = 5º Deck & fill develops large permanent deformations	θ = 10º Deck develops large permanent deformations & concrete debris may fall to floor below
Blast Resistant Concrete Slab – Quick Recovery	End Rotations (θ) or ductility (μ)	θ = 2º Concrete develops permanent deformations	θ = 1º Concrete develops permanent deformations	μ = 1 Concrete develops cracks
Blast Resistant Concrete Slab – Life Safety	End Rotations (θ)	θ = 2º Concrete develops permanent deformations	θ = 5º Concrete develops large permanent deformations	θ = 10º Concrete develops permanent deformations & concrete debris may fall to floor below

Attributes – Wind Loading

Attribute	Metric	Baseline Value	Benchmark Value	Future Value
Design Wind Load	ASCE 7-05 IBC-09	50-year Peak Pressures	100-year Peak Pressures	150-year Peak pressures
Hurricane Impact	TAS 201-94	Small Missile Impact	Large Missile Impact	Combined Missile Impact

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Attributes – Conventional

Attribute	Metric	Baseline Value	Benchmark Value	Future Value
Deflection – Aluminum Framing Members Supporting Glass	IBC-09 AAMA TIR A11-04 ASTM E330	For spans ≤ 13'-6" limit deflection to L/175 or 3/4", whichever is less. For spans > 13'-6" limit deflection to L/240 + 1/4". No permanent set under design load or glass breakage allowed.	Reductions in serviceability deflection and permanent set at overload conditions.	Reductions in serviceability deflection and no permanent set at overload.
Deflection – Masonry Cladding	IBC-09	L/240	L/600	Reductions in serviceability deflection at overload.
Deflection – Glazing	ASTM E1300 AAMA CW-12-84	N/A	Center of Glass Deflection shall be Limited to 1" at design load.	Reductions in serviceability deflection at overload.
Safety Glazing	ANSI Z97 IBC 2406 Breakage Characteristics	Failure of 8/1000 Lites Under Design Load; Safety Factor of 2.5.	Glass Fragments Remain in Opening	Reserve stiffness of glazing post breakage

Attributes – Fire/Thermal P

Attribute	Metric	Baseline Value	Benchmark Value	Future Value
Fire Resistance – Flame Spread/Smoke Developed	IBC-2009 ASTM E2307	Requirements Defined by IBC	Requirements Defined by IBC	Non-Combustible Construction
Fire Performance	Ignition: NFPA 259 Propagation: NFPA 285 Roof: ASTM E108 Exterior fire barrier: ASTM E2707 Insulation: ASTM E119/NFPA 251 Windows: NFPA 257	System Specific. One hour fire resistance rating.	System Specific; Two hour fire resistance rating.	System Specific. Three hour plus fire resistance rating.
Thermal Movement – Framing and Cladding	AAMA MCWM-1-89 Envelope systems shall be designed to provide for expansion and contraction of component materials resulting from an anticipated maximum range of surface temperatures.	Framing and cladding to accommodate expansion and contraction of components without detrimental effects including but not limited to noise, buckling, glass breakage, failure of joint sealants, undue stress on glass and structural elements, and reduction of performance.	Increased temperature ranges	Increased temperature ranges