

Seismic Assessment of the Washington Monument and the National Cathedral

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 ARCHITECTS
 MATERIALS SCIENTISTS
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Seismic Assessment of the Washington Monument and the National Cathedral

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Seismic Assessment of the Washington Monument and the National Cathedral

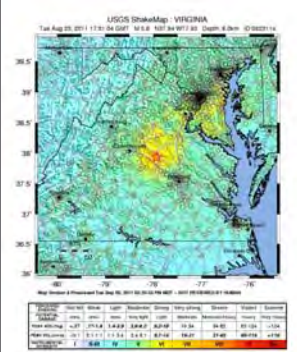
Learning Objectives

- Identify critical initial steps in the review of a monumental structure following a natural disaster
- Identify important items to review during the initial assessment
- Review considerations of various forms of access warranted for a unique and historically significant structures
- Review how to assist an Owner of an irreplaceable building with recovery from a natural disaster

Seismic Assessment of the Washington Monument and the National Cathedral

The Event...

Date: August 23, 2011
 Approximate Time: 1:51 PM EDT
 Magnitude: 5.8Mw
 Location: Mineral, VA (Approx. 4 miles southwest, 95 miles southwest of Washington, DC)
 Depth Below Surface: 3.7 miles



The USGS has reported that this event was the most widely-felt earthquake in U.S. history...

Seismic Assessment of the Washington Monument and the National Cathedral

The Event...

http://www.nps.gov/common/commonspot/customcf/audio_video/dspEmbeddedObject.cfm?vFileName=/media/ncr/avElement/conv/wamo-Emma-Out-Window-MPEG-4-480x360.mp4&vWidth=480&vHeight=360

The Washington Monument

The Numbers...



Overall Height:	555ft 5-1/8in
Height to Pyramidion:	500 ft
Width at Base:	55.6 ft
Width at Pyramidion:	34.5 ft



The Washington Monument

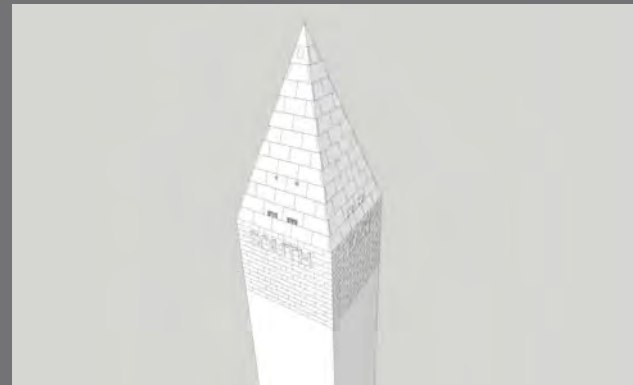
The Facts...

History

- 1833 - Washington Monument Society established
- 1845 - Design by Robert Mills selected
- 1848-1854 - Construction commenced, halted at a height of 156 ft
- 1861-65 - American Civil War
- 1876 - Nation's Centennial, ownership transfer to federal government, Army Corps study
- 1878-1880 - Structural modifications of the foundation led by Lt. Col. Thomas Lincoln Casey, Chief Engineer
- 1885 - Monument dedicated
- 1888 - Monument opened to the public
- 1897 - Magnitude 5.8 earthquake hits Virginia, approx. 300 mi. away
- 1935, 1964, and 1997-2000 - Exterior restoration projects

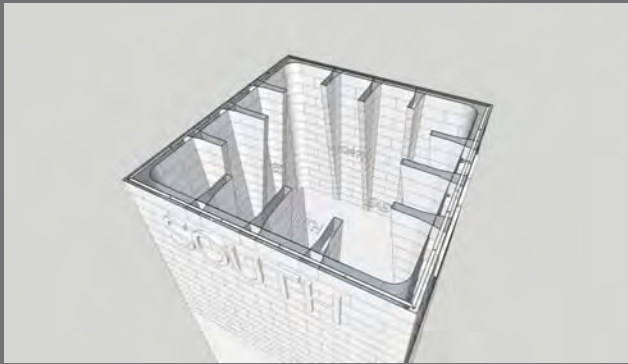
The Washington Monument

The Construction...



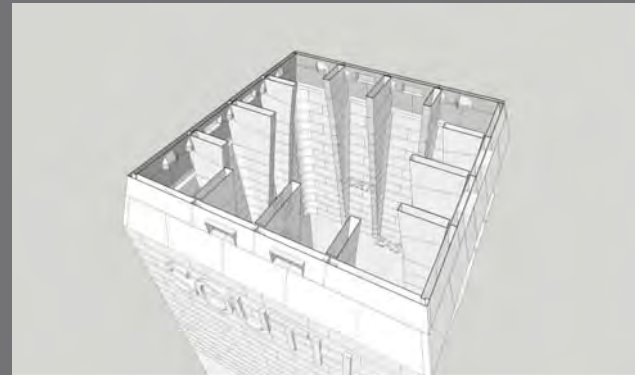
The Washington Monument

The Construction...



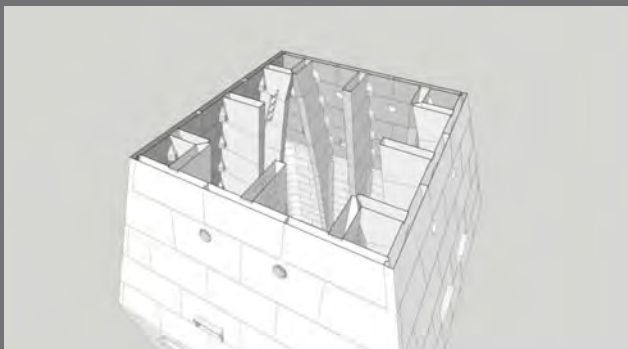
The Washington Monument

The Construction...



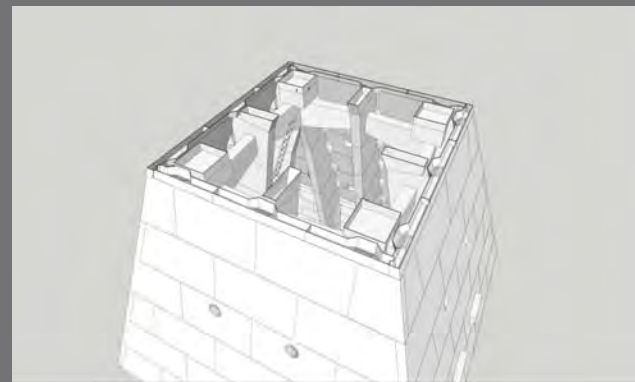
The Washington Monument

The Construction...



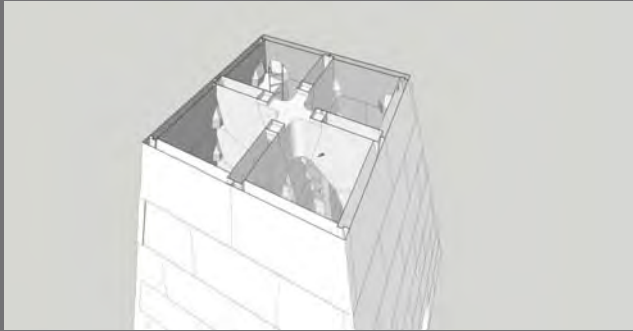
The Washington Monument

The Construction...



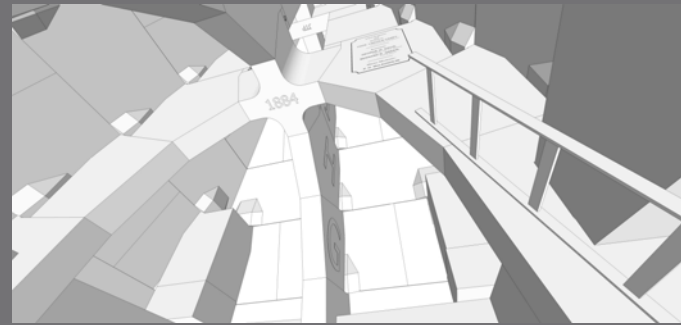
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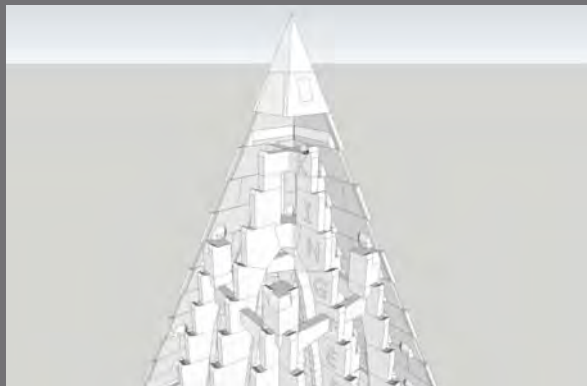
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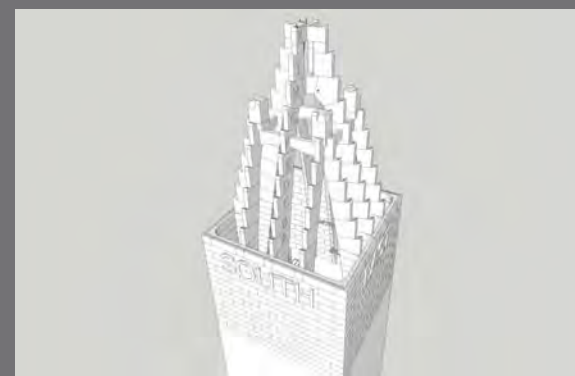
The Washington Monument

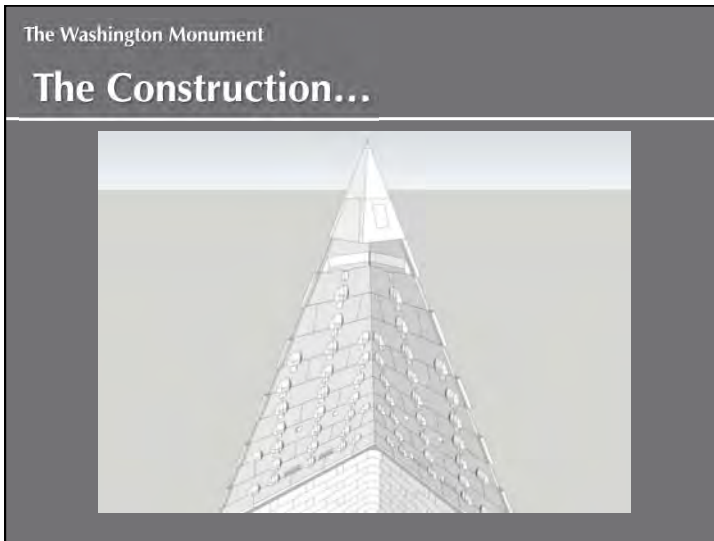
The Construction...



The Washington Monument

The Construction...





The Washington Monument

Critical Events and Activities

Make Safe Operations

Interior

- Remove Debris From Above Observation Level
- Close-Range Survey
- Certify Elevator for Limited Transport of Personnel

Exterior

- NPS Established Safe Boundary with Fence and Police/Security
- Close-Range Survey/Debris Loose Material Removal

The Washington Monument

Critical Events and Activities

Preparation for Hurricane Irene

- Application of Sealant from Interior into Large Cracks and Joints Where Daylight was Visible

The Washington Monument

Critical Events and Activities

Survey/Documentation of Seismic Damage

- Visual survey of exterior building elements
- Identifying and removing unstable elements
- Access overall extent of damage resulting from earthquake



The Washington Monument

DAT Survey

Access Considerations

- Independent anchors
- Secured ropes to tension line at night
- Accessed our ropes from small windows in pyramidion
- Personal health and safety




The Washington Monument

DAT Survey

Unique Circumstances

- Media
- Security
- Location
- Safety
- Media coverage
- Unique building elements
- Field notes – iPads
- Immortalized as a peep

The Washington Monument


Distress

Exterior and Interior

- Spalls and Incipient Spalls
- Cracks
- Displaced Stones
- Loose Mortar



- How to safely remove unstable fragments?





The Washington Monument

Distress



Exterior and Interior

- Cracks
 - 1/4" to 1" wide
- 6 panels
 - Through-panel cracks
 - Full height of panel





The Washington Monument

Distress



The Washington Monument

Distress



The Washington Monument

Distress

Pyramidion Shaft of Monument




The left photograph shows the pyramidion with a large, jagged crack and missing material. The right photograph shows the shaft of the monument with a deep, diagonal crack and some surface erosion.

The Washington Monument

Distress

- Interior Spalls at Panel Bearing Points



The main photograph shows a close-up of a panel bearing point with a red arrow pointing to a spall. Two smaller inset photographs show similar damage from different angles, also with red arrows pointing to the spalls.

The Washington Monument

Distress

Exterior and Interior

- Lateral Offset of Stone Units
- Exterior Corner Stones
- Interior Ribs




The left photograph is an aerial view of the exterior corner stones with a red arrow pointing to a lateral offset. The right photograph shows the interior ribs with a red arrow pointing to a similar offset.

The Washington Monument

Distress

- Loose/Missing Mortar
- Debonding/Missing Patches

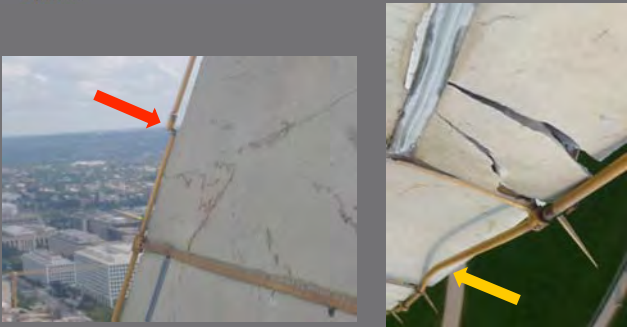


The main photograph is an aerial view of the exterior wall with a red arrow pointing to a patch of loose mortar. Two smaller inset photographs show close-ups of debonding and missing mortar patches, with red arrows pointing to the affected areas.

The Washington Monument

Distress

- Damaged Lightning Protection System



The Washington Monument


After DAT Survey...

- Installed temporary weatherization measures
- Surveyed the elevator framing for earthquake damage
- Documented earthquake damage on the interior of the monument
- Performed a seismic study
- Developed long-term repairs and construction documents that are currently out to bid

The Washington National Cathedral

The Numbers...

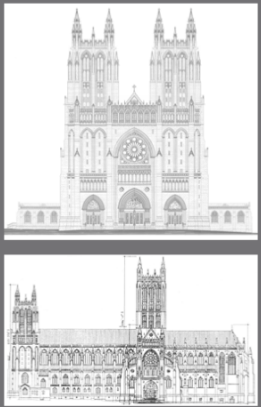
- Overall Length: 517ft
- Width of Nave: 142 ft
- Height of Nave: 102 ft
- Central Tower Height: 301 ft
- West Towers Height: 234 ft



The Washington National Cathedral

The Facts...

- Official Name: Cathedral Church of Saint Peter and Saint Paul
- The Protestant Episcopal Cathedral Foundation Operates and Funds The Cathedral
- Seat of the Presiding Bishop of the Episcopal Church
- 6th Largest Cathedral in the World (2nd largest in USA)
- 4th Tallest Structure in Washington D.C.
- Occupies the Highest Elevation in the District
- Designated as Neogothic Architectural Style
 - Pointed Arches
 - Flying Buttresses
 - Lots of Pinnacles...



The Washington National Cathedral

The Facts...

- Memorials of persons and events of national significance are present throughout the Cathedral in addition to Christian symbolism.




The Washington National Cathedral

The People...


Key Cathedral Staff

- The Very Rev. Samuel T. Lloyd III, Cathedral Dean (recently retired)
- Canon Kathleen Cox, Chief Operating Officer
- Andrew Hullinger, Senior Director of Finance and Administration



The Washington National Cathedral

The People...



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graph TD
    WNC[Washington National Cathedral RESTORATION TASK FORCE  
Kathleen Cox, Andrew Hullinger, Chris Gladstone  
Richard Williams, Bob Sharb, Richard Blund, Scott Forrester]
    JA[Joe Alonso  
Dismantling and Storage of Unstable Building Elements]
    SK[Stephen Karcha  
ADVANCED PROJECT MANAGEMENT, INC.  
Owner's Representative, Project Manager]
    UBS[UBS  
Supply and Installation of Protection and Access Equipment]
    WJE1[WJE  
Earthquake Damage Assessment and Documentation  
Technical Assistance during Make-Safe and Stabilization Operations]
    WJE2[WJE  
Crane Investigation]
    WJE3[WJE  
Engineering Review of Access Systems]
    KH[K&H  
Earthquake Damage Assessment and Documentation]


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    WNC --- SK
    SK --- UBS
    SK --- WJE1
    SK --- WJE2
    SK --- WJE3
    SK --- KH
    
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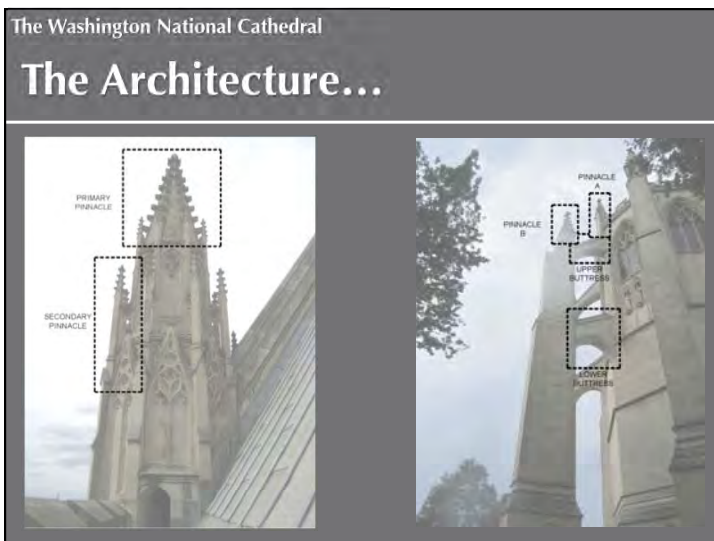
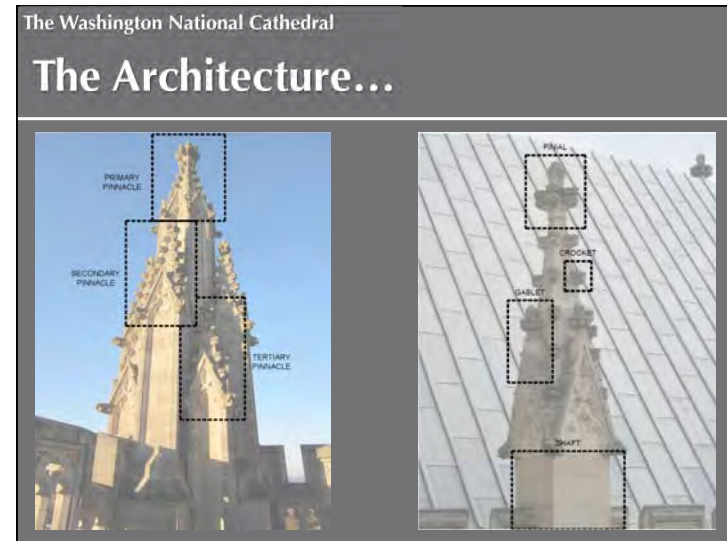
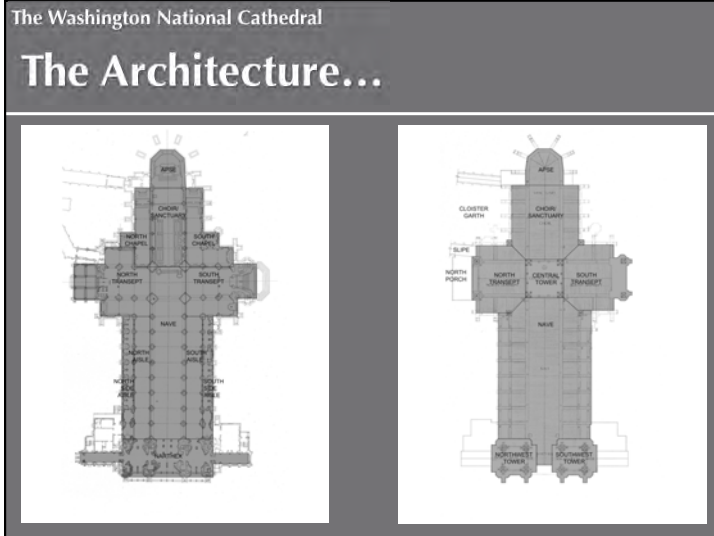
The Washington National Cathedral

The People...

Joe Alonso

- Head Mason at Cathedral Since 1985
- Helped to Put Together the Pinnacles and Finials of the West Towers in the 80's
- Helped to Remove Loose Pieces of Damaged Stone from Aerial Lift After Earthquake
- Performed Deconstruction of Pinnacles on Central Tower





The Washington National Cathedral

The Construction...

- 1893 Charter to Erect the Cathedral was Passed by the United States Congress on Jan. 6, 1893
- 1907 Construction Began on September 29, 1907
 - President Theodore Roosevelt attended laying of the foundation stone
- 1912 Bethlehem Chapel was Opened to the Public
- 1942-1948 No Construction Due to World War II
- 1948 - 1972 Construction of the Nave
- 1961-1964 Construction of the Central Tower
- 1976 Installation of the Rose Window, Interior of Nave Completed
- 1983-90 Construction of the West Towers
- 1990 Last Finial Placed, President George W. Bush Attended
- 2011 Decorative Work on the Cathedral Remained in Progress at the Time of the Earthquake

The Washington National Cathedral

The Construction...

The Washington National Cathedral

Critical Events and Activities

Make Safe Operations

Interior

- Debris Netting System
- Close-Range Survey

Exterior

- Chain Link Fence
- Roof Repairs
- Egress Protection

The Washington National Cathedral

Critical Events and Activities

Survey/Documentation of Interior Seismic Damage

- Visual Survey of Interior Building Elements from Scaffolding
- Identifying Unstable Elements
- Mapping of "Debris" Field

The Washington National Cathedral

Critical Events and Activities

Survey/Documentation of Exterior Seismic Damage

- Visual Survey of Exterior Building Elements
- Identifying Unstable Elements
- Access Overall Extent of Damage Resulting from Earthquake

The Washington National Cathedral

Critical Events and Activities

Preparation for Hurricane Irene

- Weather-in the Roof Above the Sanctuary Overcroft
- Stabilize Intermediate Pinnacles at Perimeter Walls



The Washington National Cathedral

Critical Events and Activities

Preparation for 9/11 Ceremony

- Pedestrian Tunnels
- Develop Emergency Routing Plan
- Scaffolding at Central Tower



The Washington National Cathedral

Critical Events and Activities

Central Tower Scaffolding of Grand Pinnacles

- Completion of Scaffolding and Protective Netting



The Washington National Cathedral

Critical Events and Activities

Crane Collapse/Investigation/Removal

- September 7, 2011
- 11:00 AM EDT
- Liebherr LTM1400-7.1,400 Metric Ton Crane
- Crane Services, Inc.




The Washington National Cathedral

Critical Events and Activities

Crane Collapse/Investigation/Removal

- Damage to Herb Cottage
- 9/11 Services Cancelled
- Crane Investigation/Removal



The Washington National Cathedral

Critical Events and Activities


DAT Survey of Central and West Towers



The Washington National Cathedral

Critical Events and Activities


DAT Survey of Central and West Towers



The Washington National Cathedral

Critical Events and Activities

DAT Survey of Central and West Towers



The Washington National Cathedral

Critical Events and Activities

Consecration of the Washington Diocese Ninth Bishop

- Removal of Overhead Protection at Narthex
- Bell Ringing for First Time Since 23 August 2011



The Washington National Cathedral

Critical Events and Activities

Scaffolding and Dismantling of South Transept Pinnacle

- Shoring of Colonnade



The Washington National Cathedral

Stabilization Efforts

Dismantling of Central and West Tower Turrets and Pinnacles



The Washington National Cathedral

Stabilization Efforts

Dismantling of Central and West Tower Turrets and Pinnacles



The Washington National Cathedral

Seismic Damage

Interior

- Isolated Locations of Unstable Mortar
- Limestone Spalls
- Cracks in Boss Stone, Ribs, and Ceiling Interface




The Washington National Cathedral

Seismic Damage

Interior

- Bond Line Failures
- Step Cracks
- Isolated Interior Damage




The Washington National Cathedral

Seismic Damage

Exterior – Northwest Entrance Roof

- Damage to Metal Roof and Stone Parapet from Finial

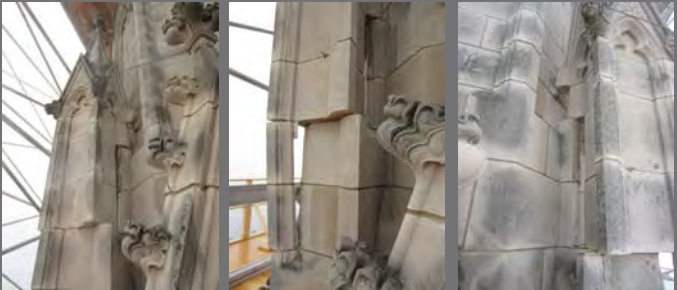


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Seismic Damage

Exterior – Central Tower Grand Pinnacles


- Pinnacle Damage



The Washington National Cathedral

Seismic Damage

Exterior – Central Tower Grand Pinnacles




The Washington National Cathedral

Seismic Damage

Exterior – Central Towers

- Roof Damage
- Pinnacle Damage




The Washington National Cathedral

Seismic Damage

Exterior - Nave

- Pinnacle Damage




The Washington National Cathedral

Seismic Damage

Exterior – North Transept

- Damage to Metal Roof From Finial and Pinnacles
- Pinnacle Damage




The Washington National Cathedral

Seismic Damage

Exterior – South Transept

- Damage to Metal Roof From Stones
- Pinnacle Damage
- Turret Damage
- Gargoyle Head Severed

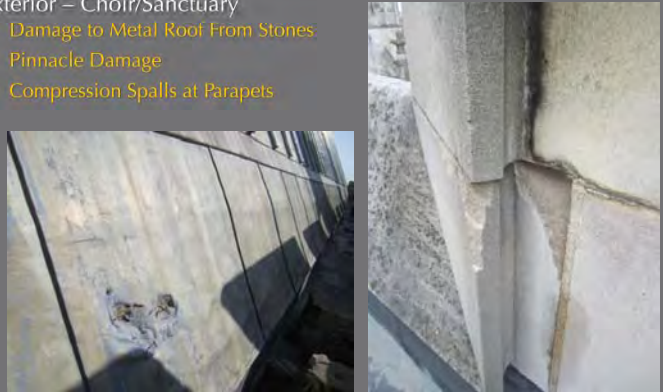


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Seismic Damage

Exterior – Choir/Sanctuary

- Damage to Metal Roof From Stones
- Pinnacle Damage
- Compression Spalls at Parapets




The Washington National Cathedral

Seismic Damage

Exterior - Apse

- Damage to Buttresses
- Pinnacle Damage
- Spalls at Parapets

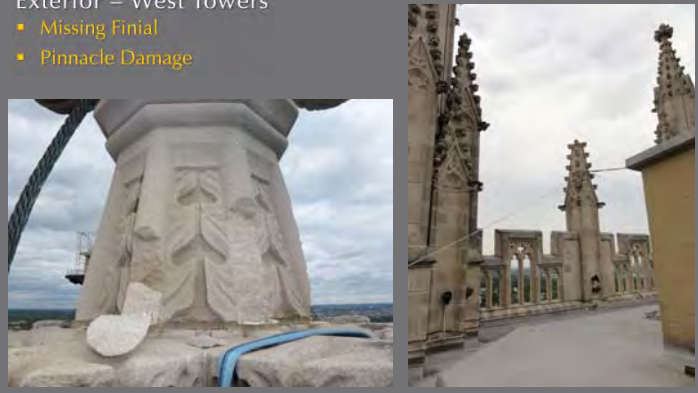


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Seismic Damage

Exterior – West Towers

- Missing Finial
- Pinnacle Damage

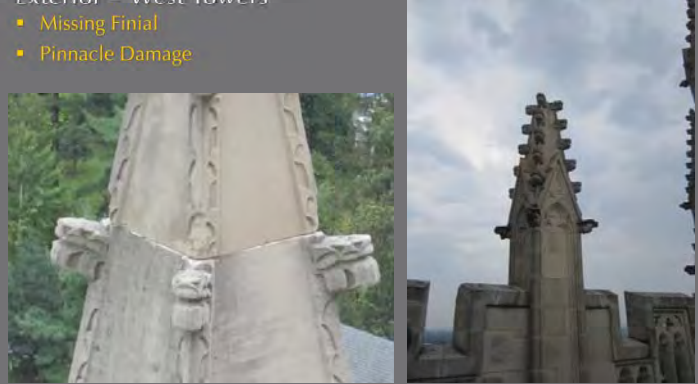


The Washington National Cathedral

Seismic Damage

Exterior – West Towers

- Missing Finial
- Pinnacle Damage



The Washington National Cathedral

Structural Response to Seismic Event


- URM Structure
- No Major Structural Damage
- Falling Hazards and Loss of Ornament
- Shaking Intensity Most Consistently Reported as an MMI V, Associated with a PGA of 0.07g (generally consistent with prior historic earthquakes such as New Madrid (1811), and Charleston (1886).
- Event was likely equivalent to the MCE¹ for shorter period structures, with a return period of 2000 to 3000 years².

1. The Maximum Considered Earthquake is defined as having a 2% chance of exceedance in 50 years, or a return period of 2,475 years. Code requires new buildings be designed for 2/3 of the MCE.
2. Based on the latest and best data available to WJE regarding the PGA and shorter period spectral acceleration produced in the Capitol Hill area.

The Washington National Cathedral

Seismic Behavioral Influences


- Multitude of Periodicity
- Longer Period Elements Suffered Most Damage
- Reduction of Shear Friction with Height



The Washington National Cathedral

Seismic Behavioral Influences

- Large Mass on Tall Slender Structures
- Soft Zones.



The Washington National Cathedral

Seismic Behavioral Influences

- Reinforcement Between Stone Elements
- Poor Bond at Mortar Interface
- Time Span of Construction

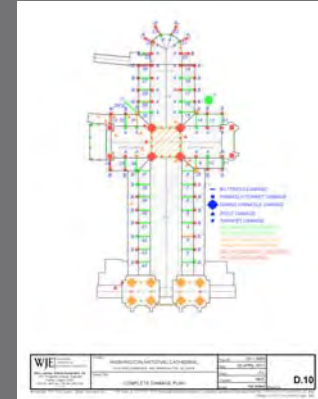


The Washington National Cathedral

Looking Ahead...

Seismic Enhancement/Repair Prioritization

- Access to Repairs
- Life Safety Risk
- Element Susceptibility to Seismic Forces
 - Aspect Ratio
 - Proximity to Damaged Elements

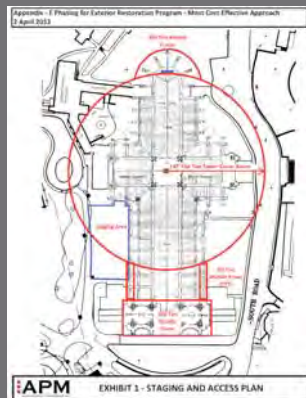


The Washington National Cathedral

Looking Ahead...

Phasing of Repairs

- Access Required
- Funding



The Washington National Cathedral

Looking Ahead...



Seismic Assessment of the Washington Monument and the National Cathedral

Questions?



The left photograph shows a worker in a white shirt and blue pants performing maintenance on the ornate Gothic architecture of the National Cathedral. The right photograph shows a worker on a rope climbing the side of the Washington Monument, with the U.S. Capitol building and two American flags visible in the background.

Seismic Assessment of the Washington Monument and the National Cathedral

Thank you.



The image shows the silhouette of the National Cathedral against a bright sunset sky. The sun is low on the horizon, creating a warm orange and yellow glow.

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