Federal Building and Fire Safety Investigation
of the World Trade Center Disaster

Project 6: WTC 7 Structural Fire Response and Collapse Analysis

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Therese McAllister, Ph.D., P.E.

Building and Fire Research Laboratory
National Institute of Standards and Technology
U.S. Department of Commerce

Therese.McAllister@nist.gov

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Objectives

To determine the structural response of WTC 7 to debris damage and internal fires and to identify the most probable structural collapse mechanism.

- Task 1: Structural Response Analysis to Identify Critical Components
- Task 2: Structural Analysis of Possible Collapse Initiation Hypotheses
- Task 3: Evaluation of Collapse Hypotheses

Task 1: Structural Response Analysis to Identify Critical Components

Develop a nonlinear global structural model of WTC 7 and evaluate its performance under design gravity loads

Identify credible failure sequences using the structural model to analyze the effect of component failures on the structural system stability

Identify dominant failure modes for critical components and subsystems for service loads and elevated structural temperatures

Conduct parametric studies of critical subsystems to identify influential parameters

Develop approaches to simplify structural analyses for global modeling and analyses

Tasks 2 and 3: Structural Analysis of Collapse Initiation Hypotheses

Refine the global model of WTC 7 to support nonlinear structural analysis for building regions affected by fire

Analyze three (3) collapse initiation sequences selected

Conduct parametric studies of the global analyses to identify influential parameters

Identify the most probable collapse initiation sequence, based upon:

- Time-sequence of events
- Mode of failure or capacity reduction for each critical member in the sequence and associated temperatures
- Load redistribution during the sequence of events
- Agreement between analysis and observed performance

Working Collapse Hypothesis

If it remains viable upon further analysis, the working collapse hypothesis suggests that it was a classic progressive collapse, including:

An Initiating Event

- An initial local failure at the lower floors (below Floor 13) of the building due to fire and/or debris induced structural damage of a critical column (the initiating event), which supported a large span floor bay with an area of about 2,000 ft^2

A Vertical Progression at the East Side of the Building

- Vertical progression of the initial local failure up to the east penthouse, as large floor bays were unable to redistribute the loads, bringing down the interior structure below the east penthouse

A Subsequent Horizontal Progression from the East to the West Side

- Horizontal progression of the failure across the lower floors (in the region of Floors 5 and 7, that were much thicker than the rest of the floors), triggered by damage due to the vertical failure

Global Collapse

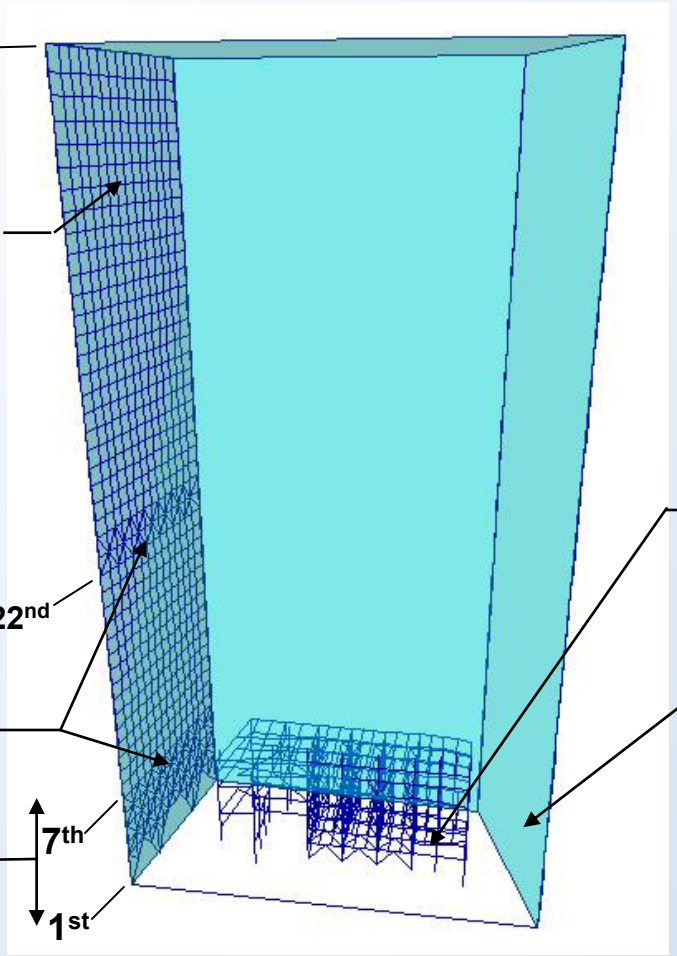
- Events resulted in a disproportionate collapse of the entire structure

Building Description

Major Features Relative to the Working Collapse Hypothesis:

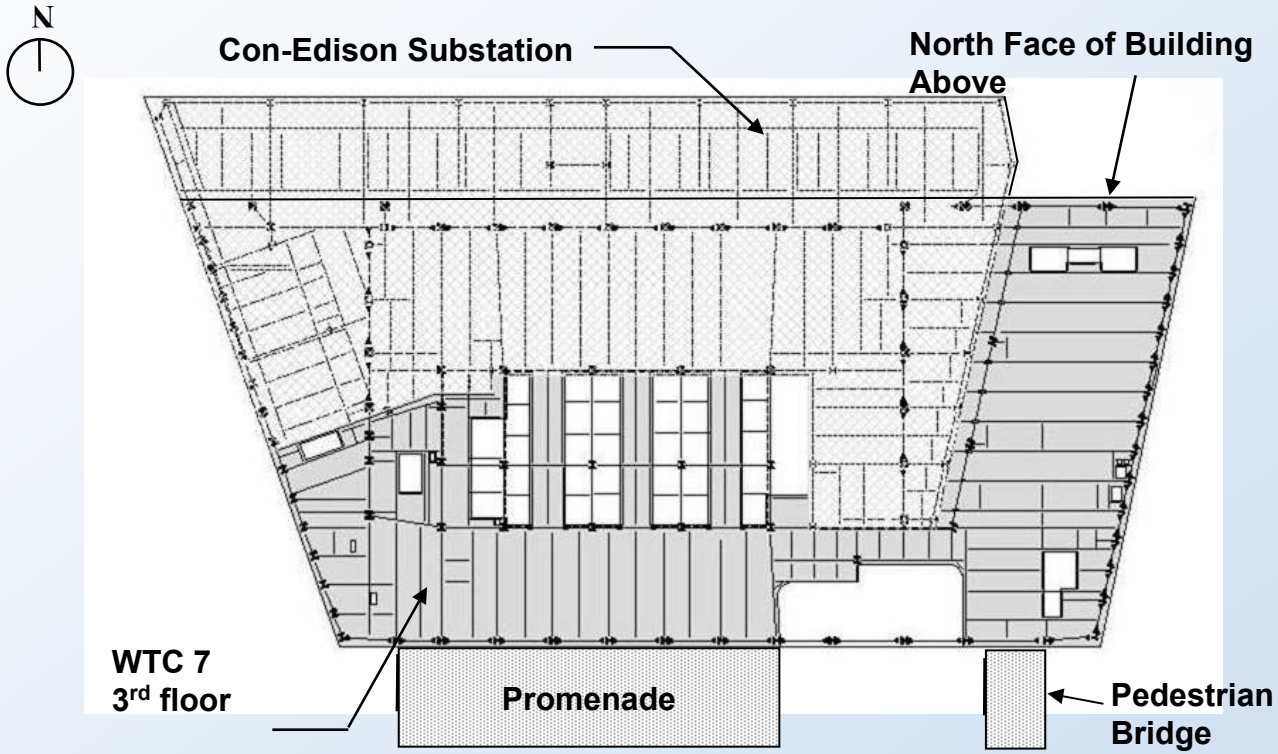
- Framing Differences Above/Below Floor 7
- Framing Relative to Con Ed Substation
- Transfer System Between Floors 5 and 7
- Floor Plan and Built Up Columns
- Roof Layout

WTC 7 Framing

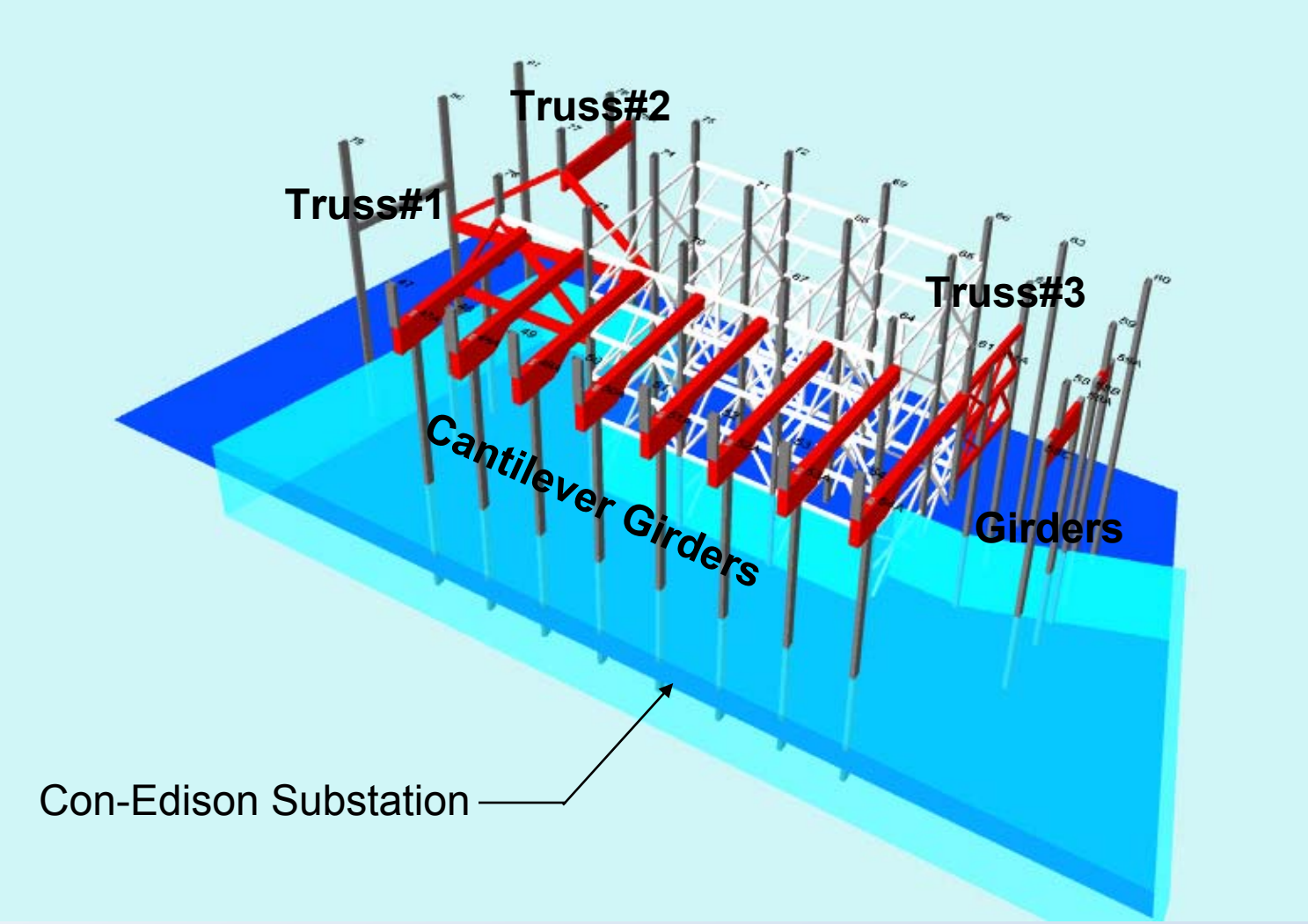


WTC 7 and Con Edison Substation

Below 7th floor, braced frame constructed over Con Ed substation



Transfer System Between Floors 5 and 7

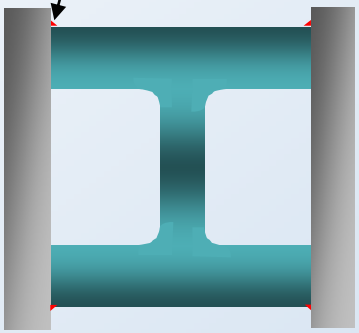


7th Floor Plan – Built-up Columns

Built-up Column

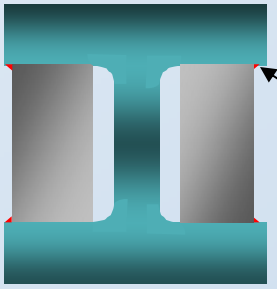
Non Built-up Column

½-in Fillet (typ)



Built-up Column with Side Plates

5/16-in Fillet (typ)



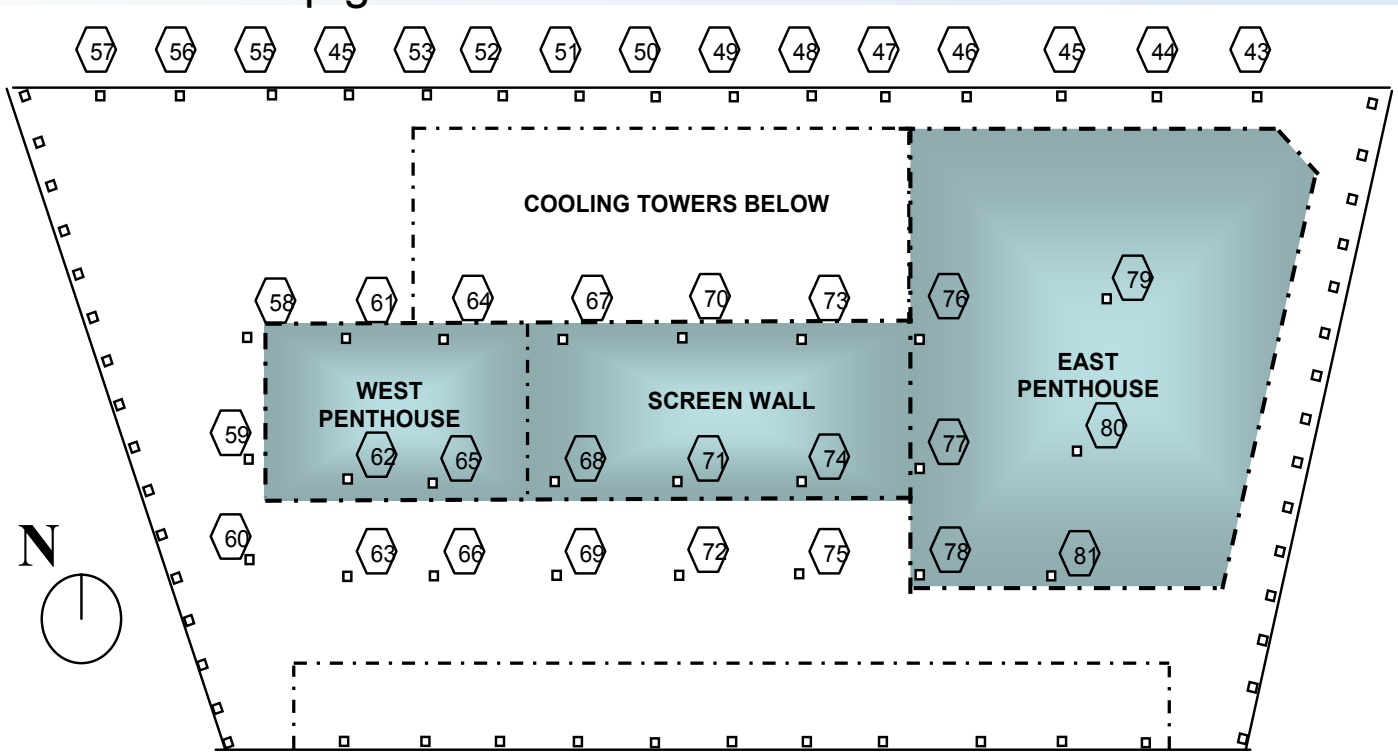
Built-up Column with Web Plates

7th Floor Plan
Built-up Column Locations

Roof Layout

WTC 7 was modified:

- Penthouse structures added to the roof
- East half of floors 41 and 43 were removed and replaced
- HVAC and communication systems were added from floor 28 to the roof
- Fuel tanks and backup generators were added



Building Conditions

Data for building conditions has been expanded and enhanced through photographs, video, and interview records:

- Debris Impact from WTC 1 and WTC 2
- Observed and Reported Fire Locations and Times
- External Signs of Collapse

Debris Damage from WTC 2

After WTC 2 collapsed:

- Some south face glass broken at lower floors
- Dust covered lobby areas at floors 1 and 3
- Power on in building, phones working
- No fires observed

Debris Damage from WTC 1

After WTC 1 collapsed:

- Heavy debris on Vesey Street and WTC 7 Promenade
- No heavy debris observed in lobby area, white dust coating
- SW Corner Damage – floors 8 to 18
- South face damage between two exterior columns - roof level down 5 to 10 floors, extent not known
- South Face Damage –
  - middle 1/4 -1/3 width south face, 10th floor to ground
  - large debris hole near center around 14th floor
  - 1/4 width south face, above 5th floor, atrium glass intact
  - 8th / 9th floor from inside, visible south wall gone with more damage to west, 2 elevator cars dislodged into elevator lobby

WTC 7 Roof After WTC 1 Collapse

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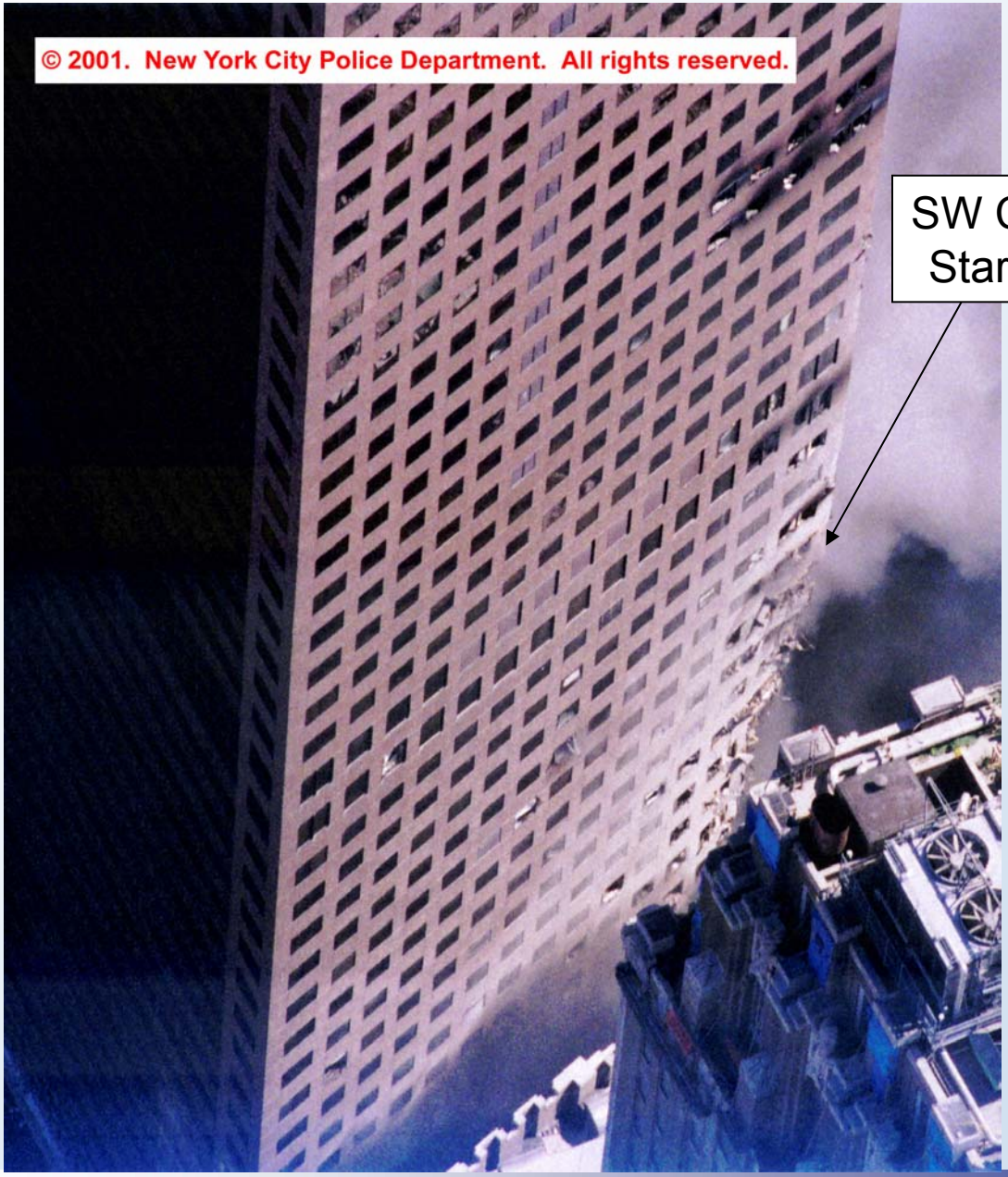
WTC 7 SW Corner After WTC 1 Collapse



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Vesey Street by Pedestrian Bridge After WTC 1 Collapse

Vesey Street by Promenade After WTC 1 Collapse

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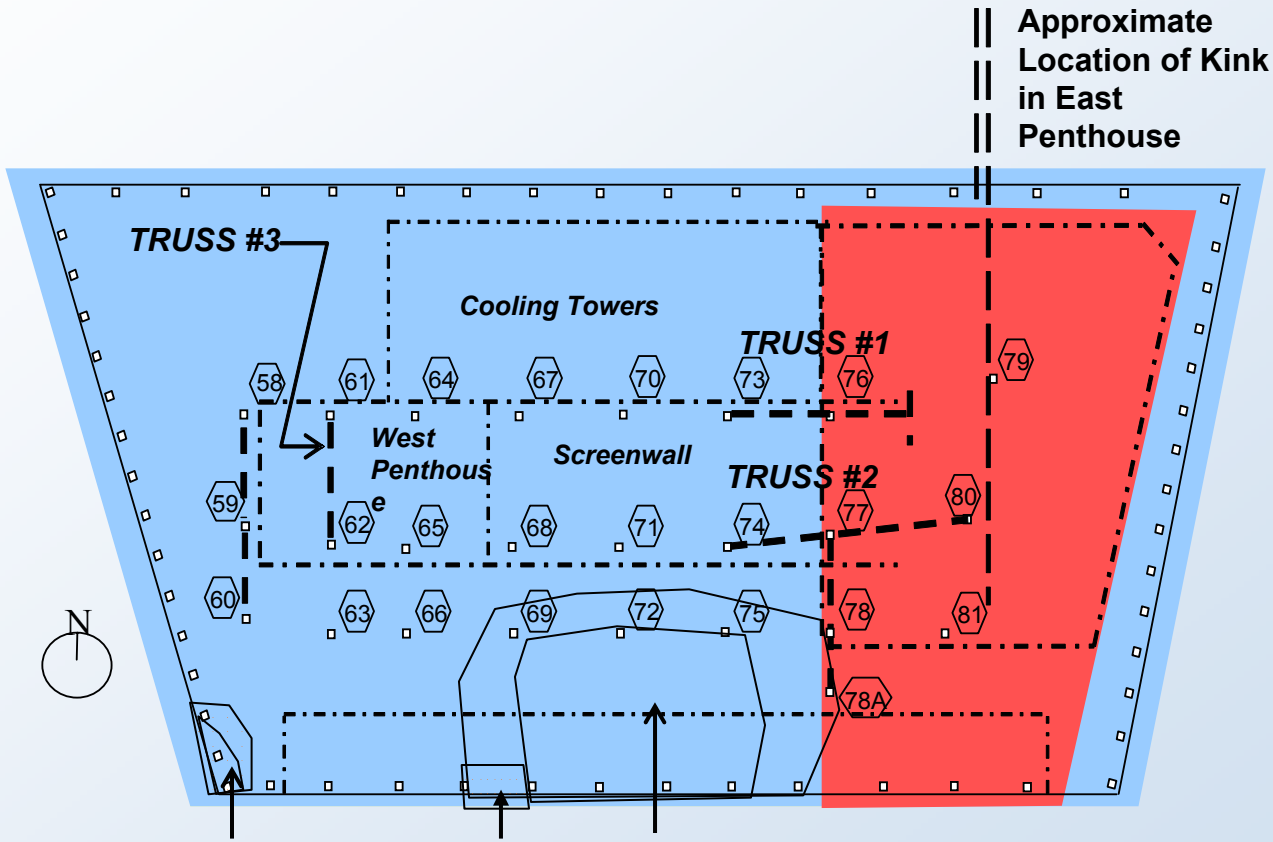
Estimated Extent of Debris Damage



Observed Fire Locations (11:30-2:30 pm)

General

- No diesel smells reported from the exterior, stairwells, or lobby
- No signs of fire or smoke below floor 6 from stairwell and lobby areas
- Fire reported at west wall of floor 7 around 12:15 pm
- In east stairwell, smoke was observed near floors 19-20;signs of a fire observed on floor 23

Looking from southwest corner to the south face

- Fire in SW corner near floors 10 or 11
- Fire on floors 6, 7, 8, 21, 30
- Multiple fires observed on floors numbered 20's and 30's
- Heavy black smoke coming out of south face gash; no fire observed

Looking from southeast corner to the south face

- Fire on floor 12;[1] area above covered with smoke
- Fire on floors 11-12[1] moved to east face and progressed to the north

[1] fires reported on floor 14, but photographs showed east face fires on floor 12

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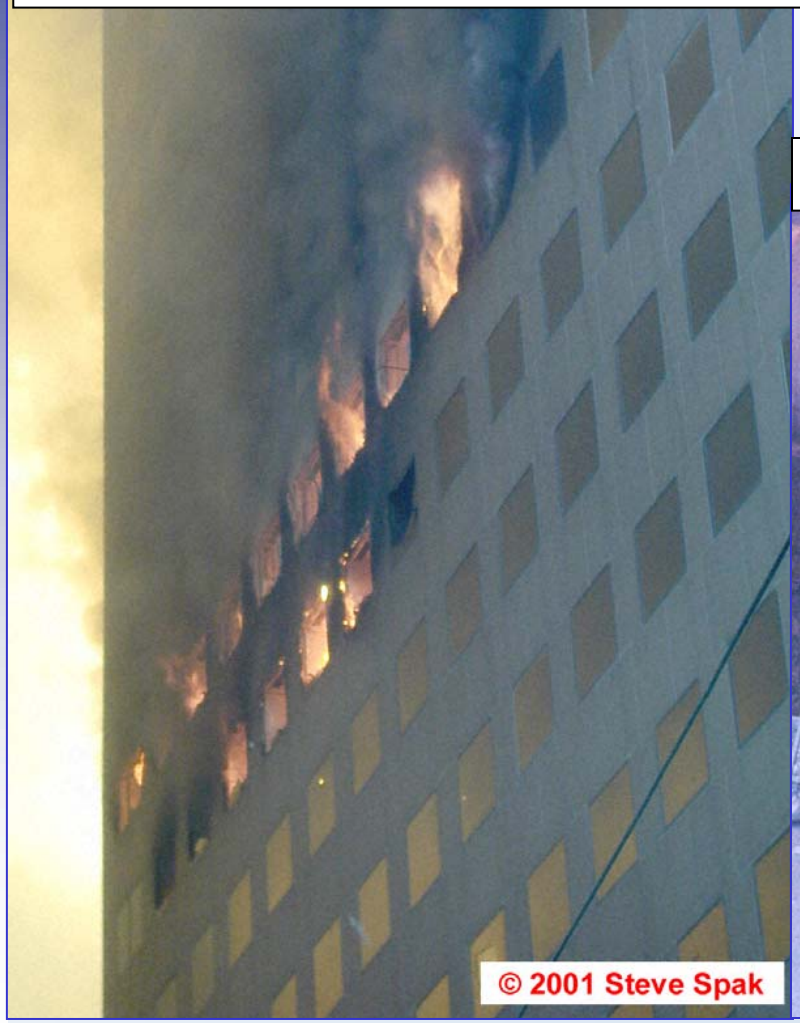
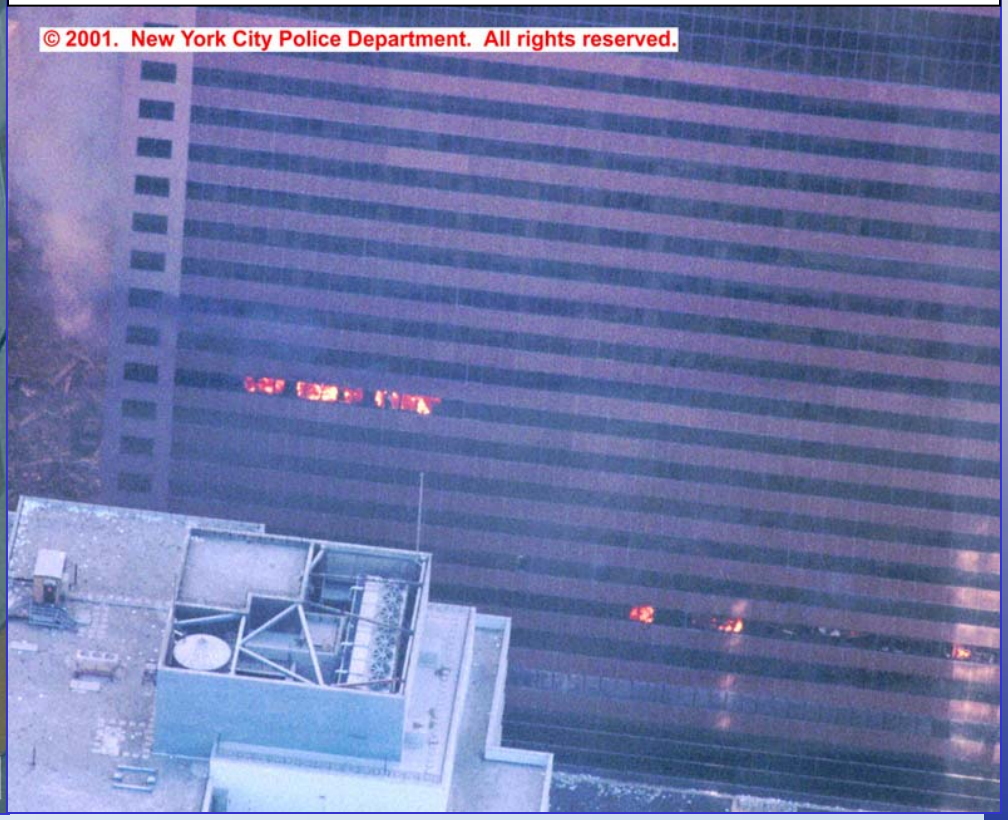
Observed Fires

East Face Fires on Floors 11-12 near 2 PM



North Face Fires on Floors 7 and 12 near 3 PM



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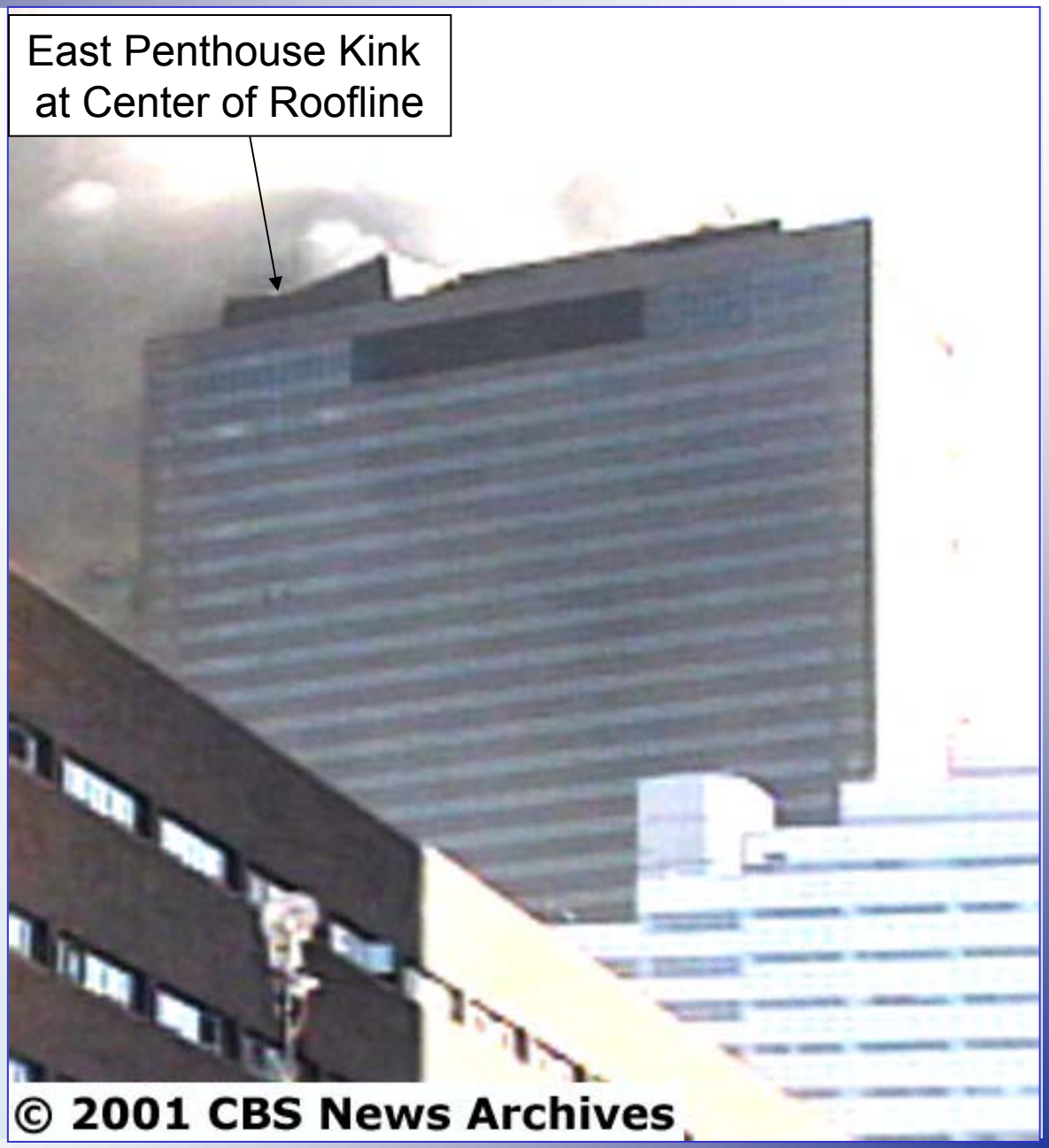
First Observation of Collapse



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2001 CBS News Archives Video Record of Collapse from the North

Insert video clip.

Failure Sequence Timeline

Time Interval (sec)	Total Time (sec)	Observation from CNN Net Dub 7 47.avi
0.0	0.0	Movement of east penthouse roofline
0.9	0.9	East penthouse kinks between columns 44 and 45
		2 windows at floor 40 fail between columns 44 - 45
0.3	1.2	4 windows fail at floor 40
		East penthouse submerged from view (now inside building)
0.4	1.7	3 windows break at floors 41 to 44
0.5	2.2	East penthouse completely submerged
1.8	4.0	Windows break along column 46 at floors 37 and 40
3.0	7.0	North side of west penthouse moves
		Movement of entire north face of WTC7 (visible above floor 21)
0.2	7.2	West end of roof starts to move
0.5	7.7	East end of roof starts to move
		Façade kink formed along column 46-47
0.1	7.9	West penthouse submerged
0.3	8.2	Global collapse occurs as windows fail between floors 33-39 around column 55

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Structural Analysis

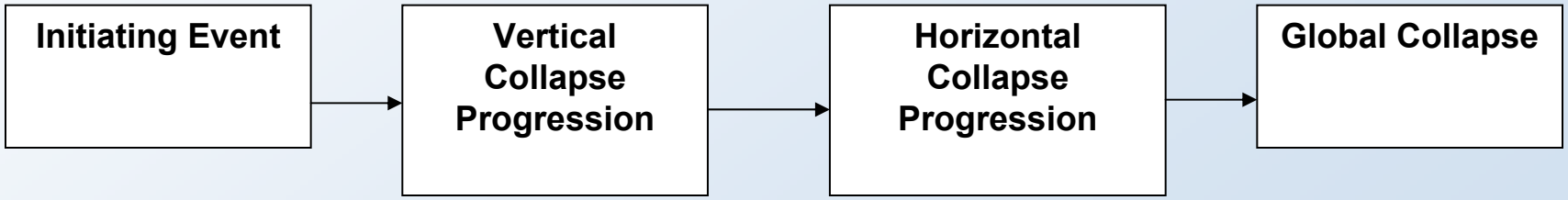
Structural Response and Collapse Hypotheses is being assessed with the following models and analyses:

- Global structural analysis
  - design gravity and wind loads
  - service loads and debris damage
- Kinematic analysis of possible failure sequences
- Composite floor system analysis of larger spans on east side
- Submodel of lowest 10 floors for analysis of failure mechanisms
- Thermal-structural analysis of critical components

Working Collapse Hypothesis

A working collapse hypothesis has been developed with four phases

- An initiating event
- Vertical progression on the east side (northeast corner)
- Horizontal progression from east to west
- Global collapse



Initiating Event & Vertical Progression

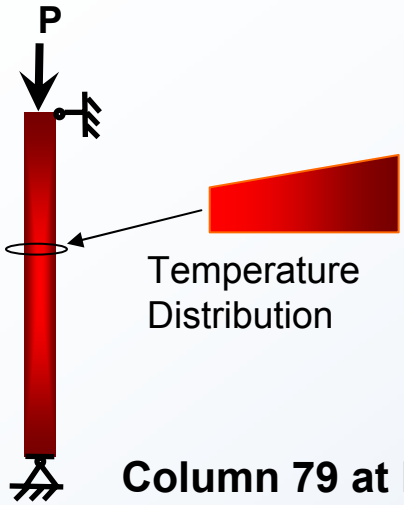
Initiating Event

- First exterior sign of failure was at the east penthouse roofline, aligned with interior columns 79, 80, and 81. Postulated initiating events include the failure of these columns.

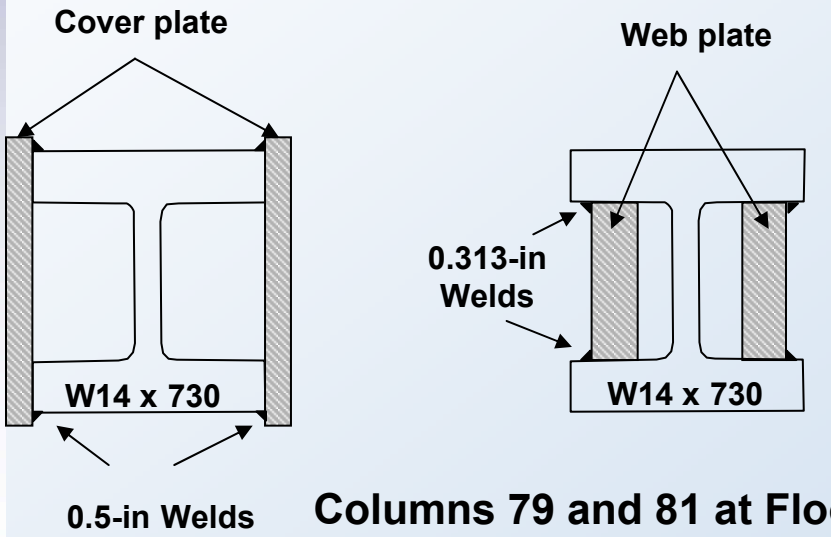
Vertical Progression

- Columns 79, 80, and 81 supported large tributary areas for floor spans of approximately 50 ft. Failure of column 79, 80, or 81 would likely result in failure at the floor-column connections and would progress vertically up to the east penthouse.

Initiating Event: Thermal-Structural Response of Critical Components



Column 79 at Floors 5-7



Columns 79 and 81 at Floors 5-7

Possible Modes of Column Failure:

- ❑ Squashing (Yielding) of Column
- ❑ Cover Plate Weld Failure
- ❑ Failure of Column Splice

Thermal Structural Analysis

- ❑ Uniform and Gradient Temperatures
- ❑ Damaged and Intact Fireproofing
- ❑ Temperature Dependent Material Properties

- ❑ Thermal Softening
- ❑ Axial Thermal Expansion
- ❑ Bowing from Thermal Gradients

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Status of Initiating Event Analysis

NIST continues to evaluate the factors that could have caused column 79, 80, or 81 to fail

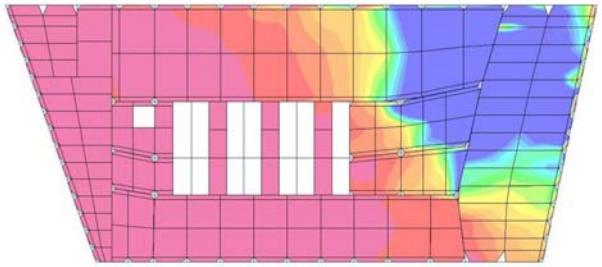
Possible contributing factors include:

- Damage to components adjacent to truss #2 from debris impact
- Damage to fireproofing from normal activities prior to event or debris damage
- Unusual fuel loads (fuel lines, high density of building contents)

Analysis to date indicates:

- Massive size of columns 79, 80, and 81 appears to require severe fires and/or damaged fireproofing to initiate thermally-related failures

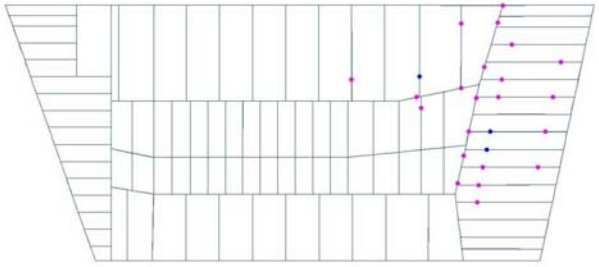
Vertical Progression: Floor Response to Loss of Column Support

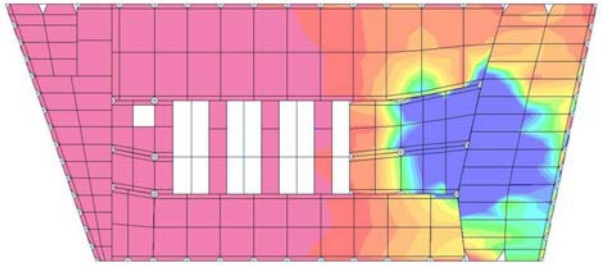


Col 79

Beam Hinges →

← Slab Force

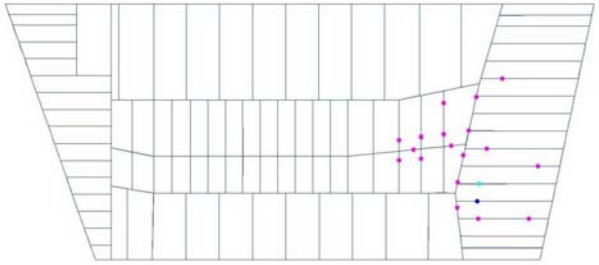


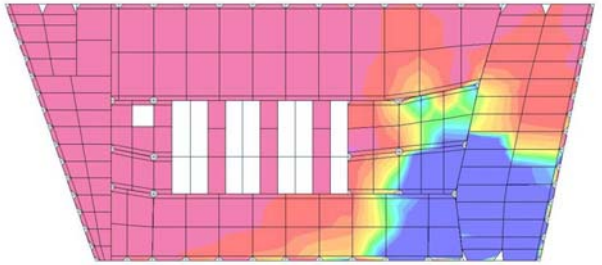


Col 80

Beam Hinges →

← Slab Force

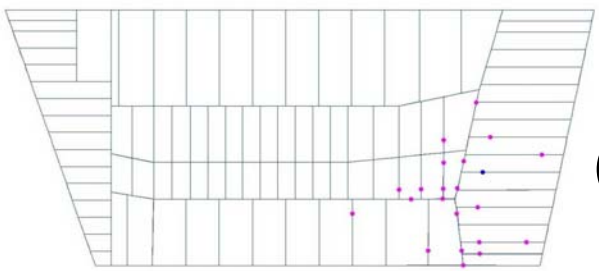




Col 81

Beam Hinges →

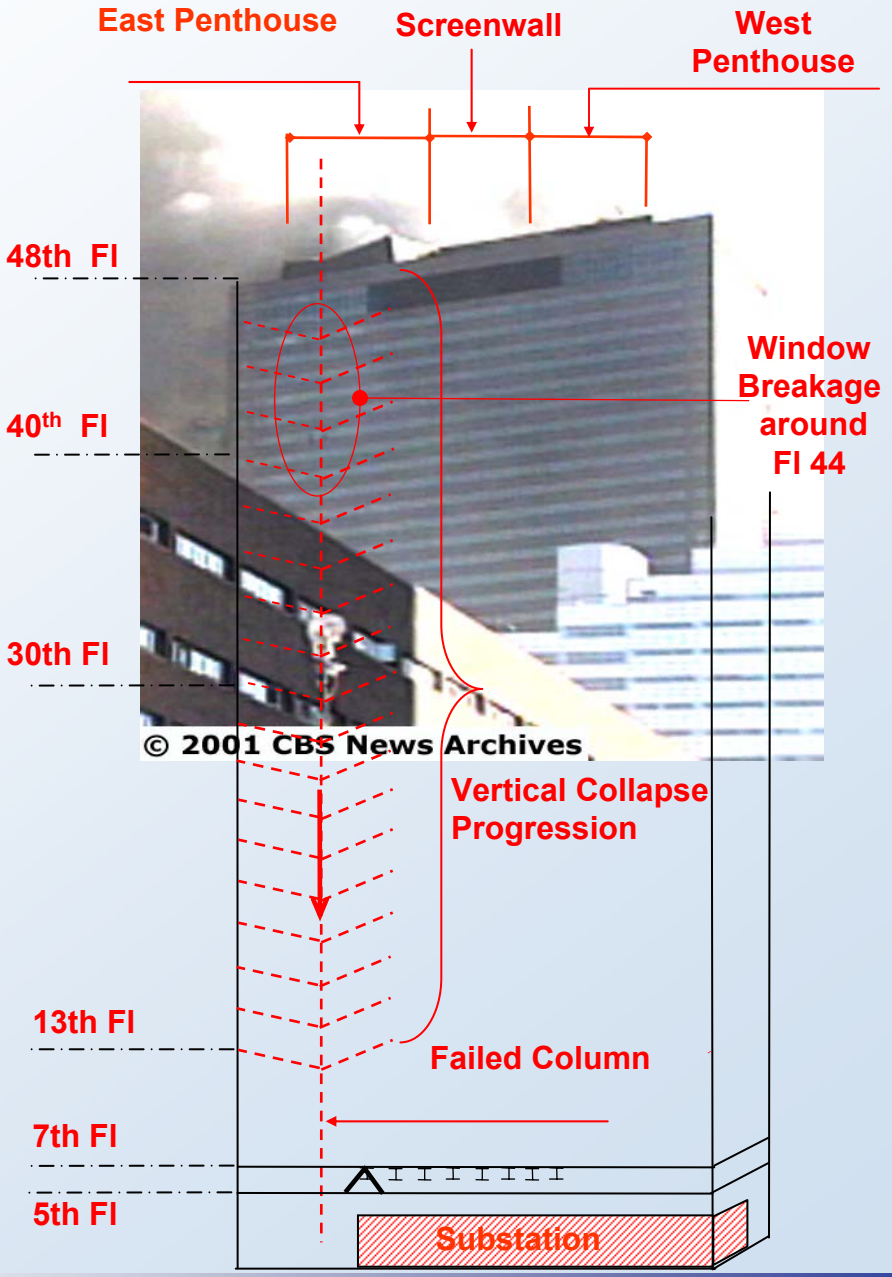
← Slab Force



Initiating Event & Vertical Progression

Exterior Observations:

- East Penthouse Kink
- Window Breakage



Horizontal Progression & Global Collapse

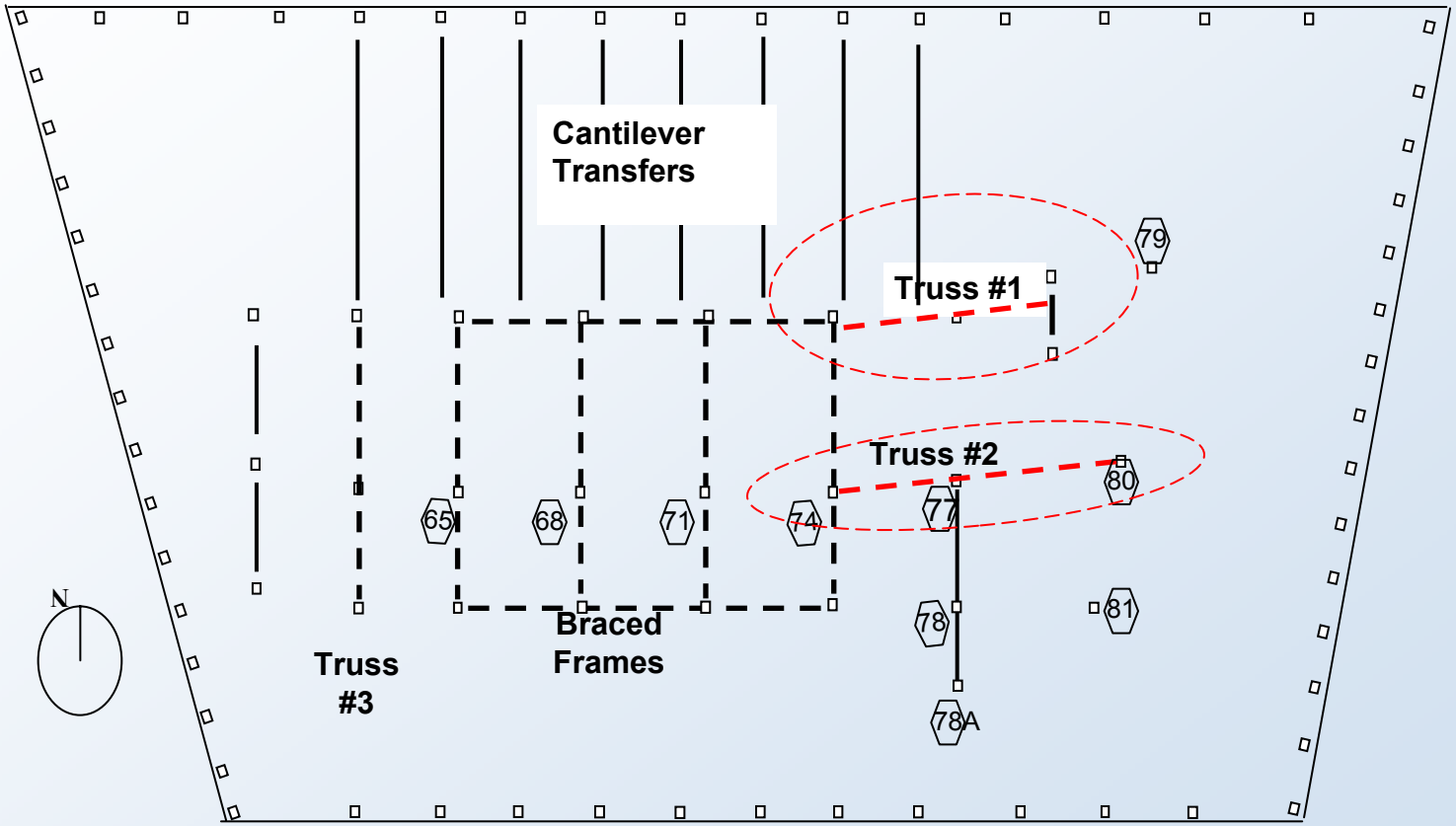
Horizontal Progression

- A vertical failure would pile debris on the east side of the building, damaging or severing transfer girders and trusses between floors 5 and 7.
- This secondary damage has been postulated to cause a horizontal progression of failure in the core columns at or near floors 5 and 7.

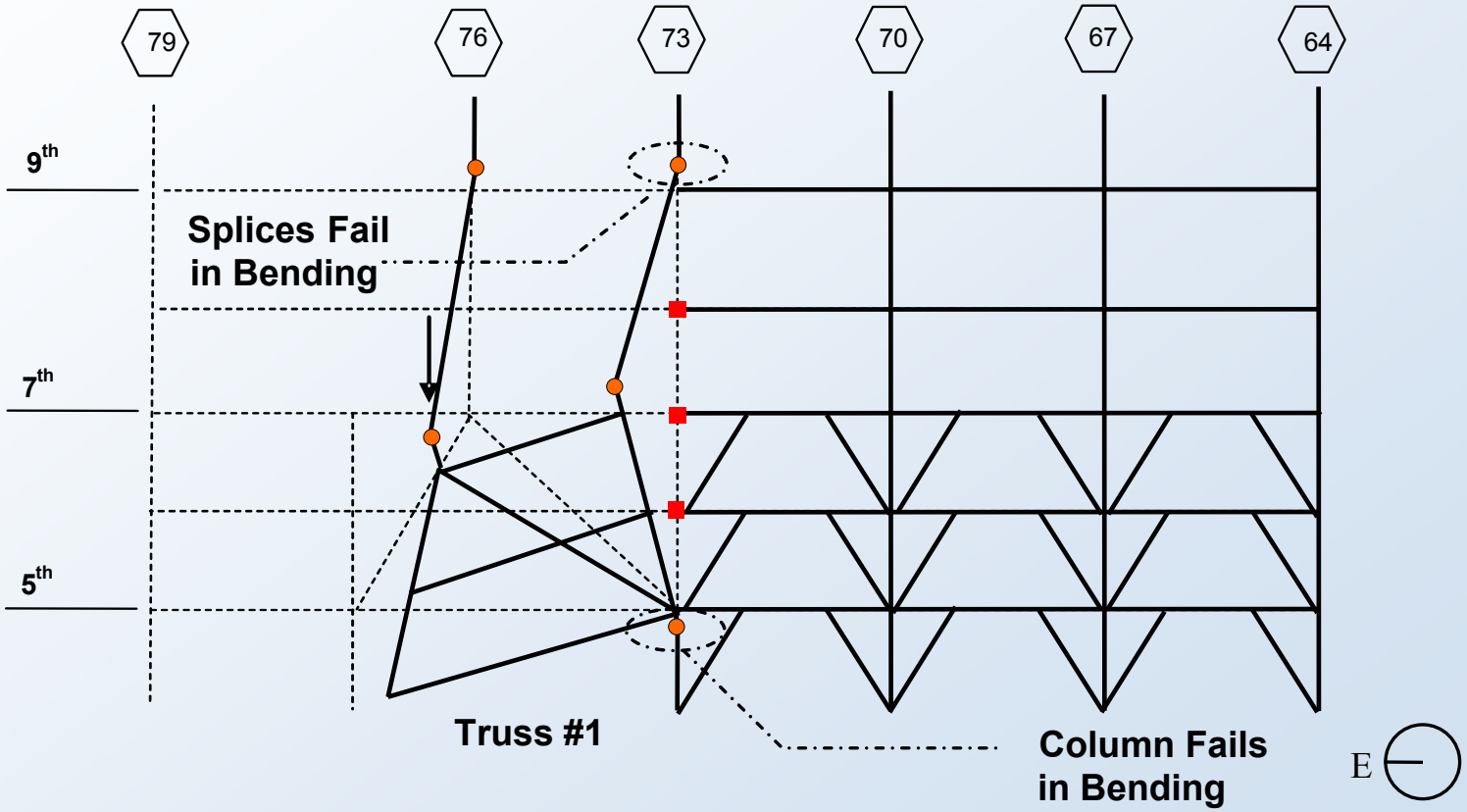
Global Collapse

- The global collapse occurred with few external signs and is postulated to have occurred with the failure of core columns

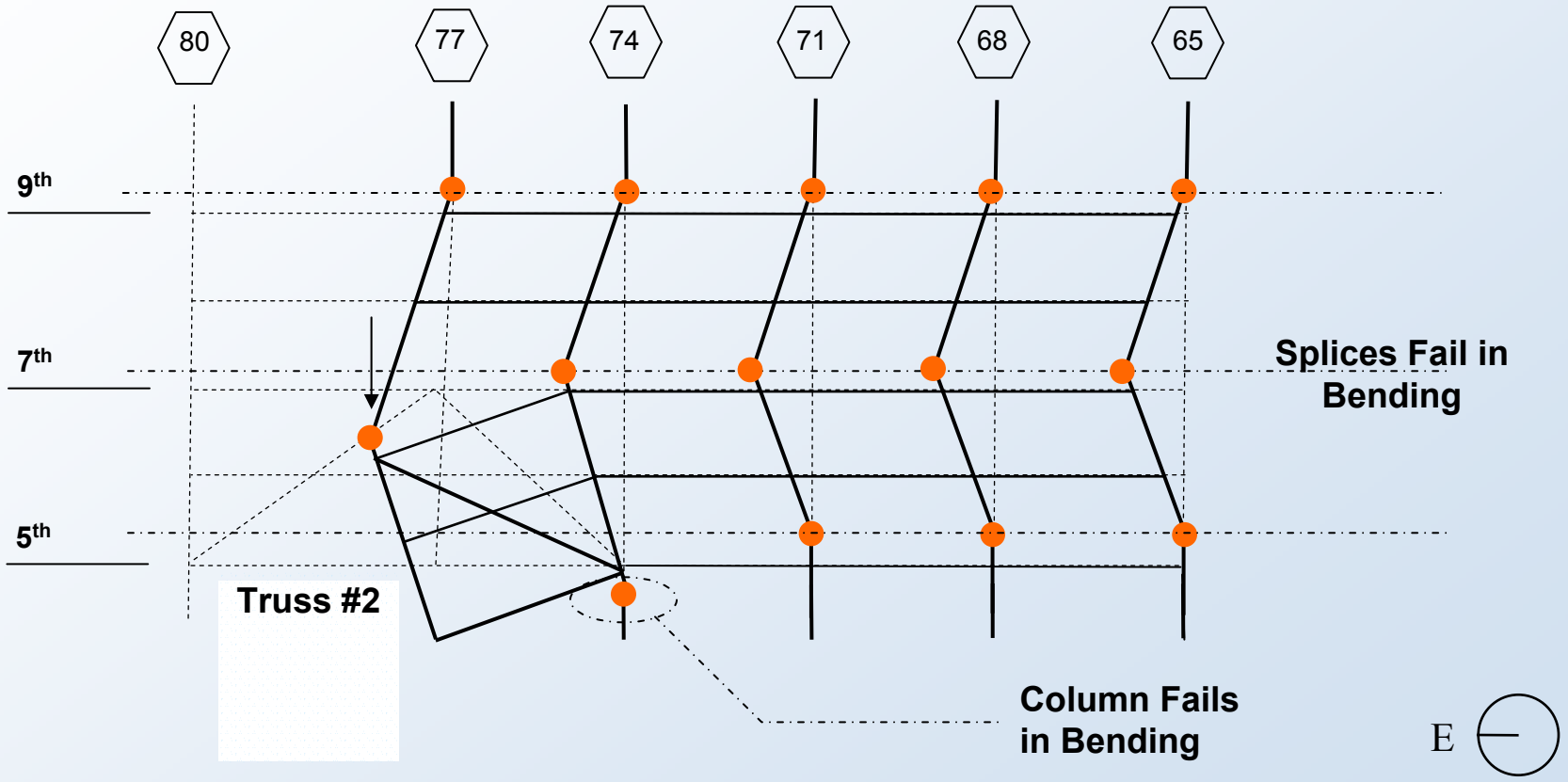
Truss #1 and Truss #2 Locations



Horizontal Progression – Truss #1



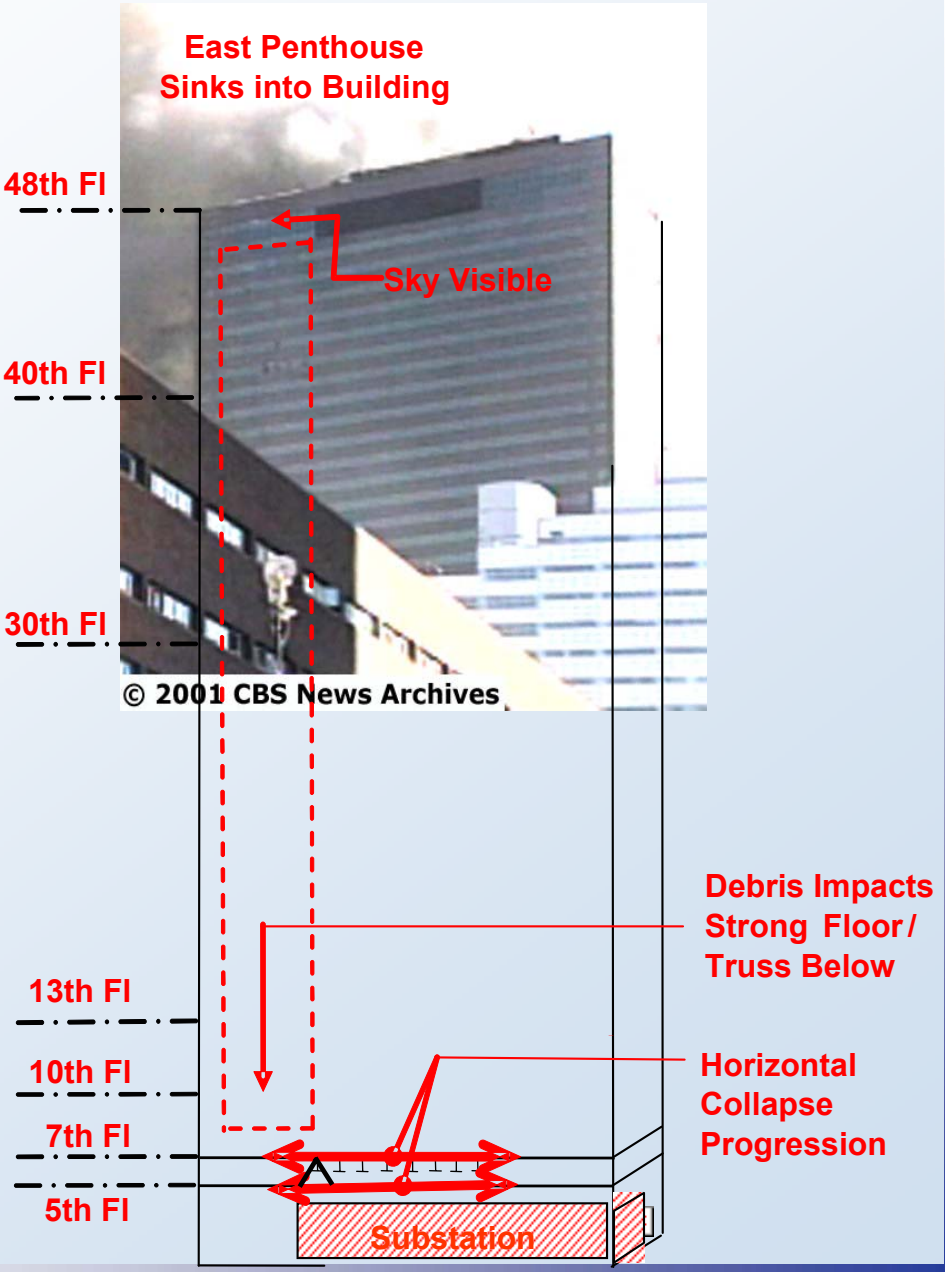
Horizontal Progression – Truss #2



Horizontal Collapse Progression

Exterior Observations:

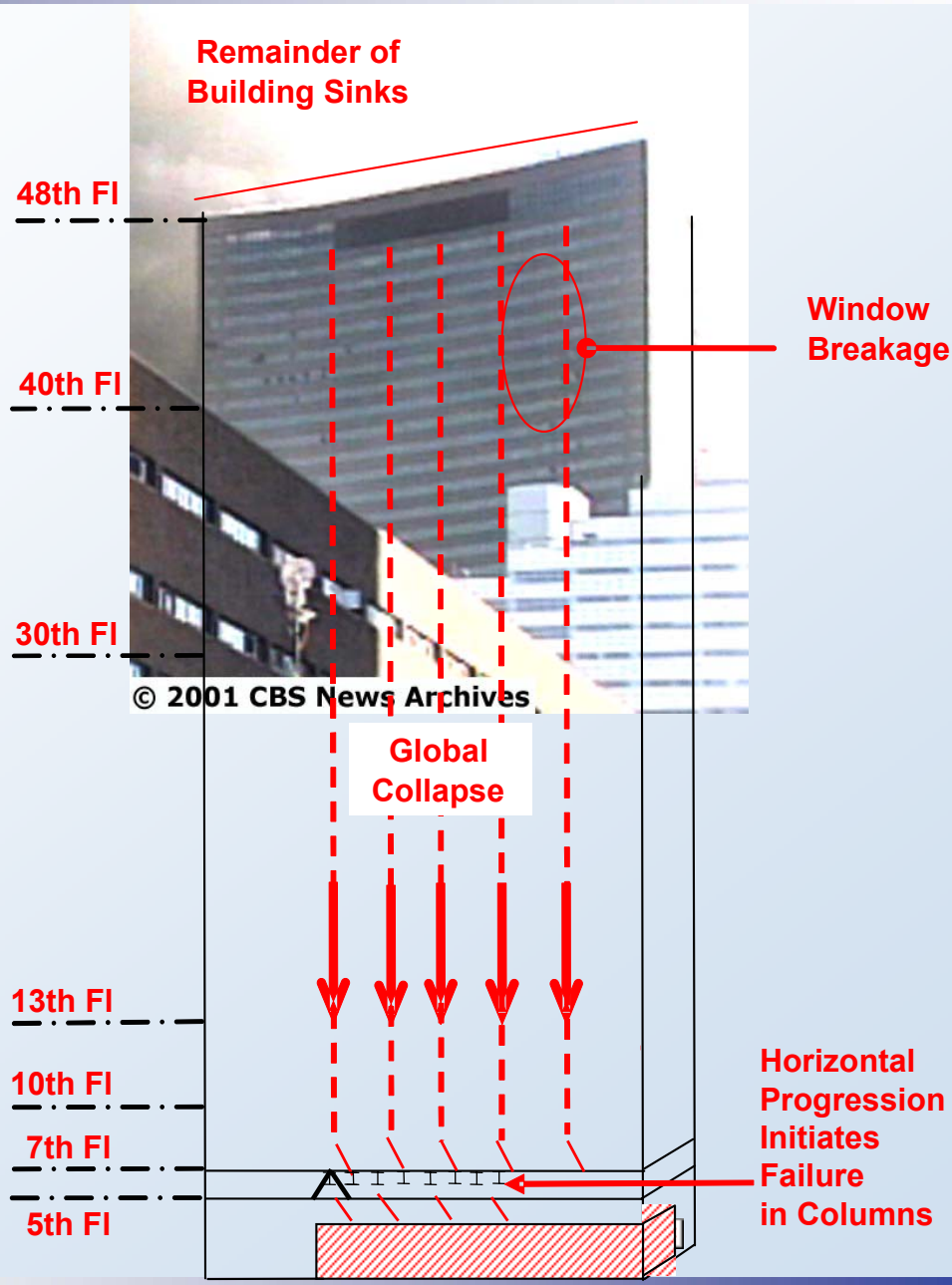
- East Penthouse Sinks
- Further Window Breakage
- No Movement for 5 sec



Global Collapse

Exterior Observations:

- Center and West Penthouses Sink
- North Façade Kink at Column 76
- Window Breakage in Front of Truss #3



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Status

- A Working Collapse Hypothesis has been developed.
- The hypothesis is consistent with visual observations.
- Comprehensive analysis is ongoing to complete the remainder of Tasks 1, 2, and 3.